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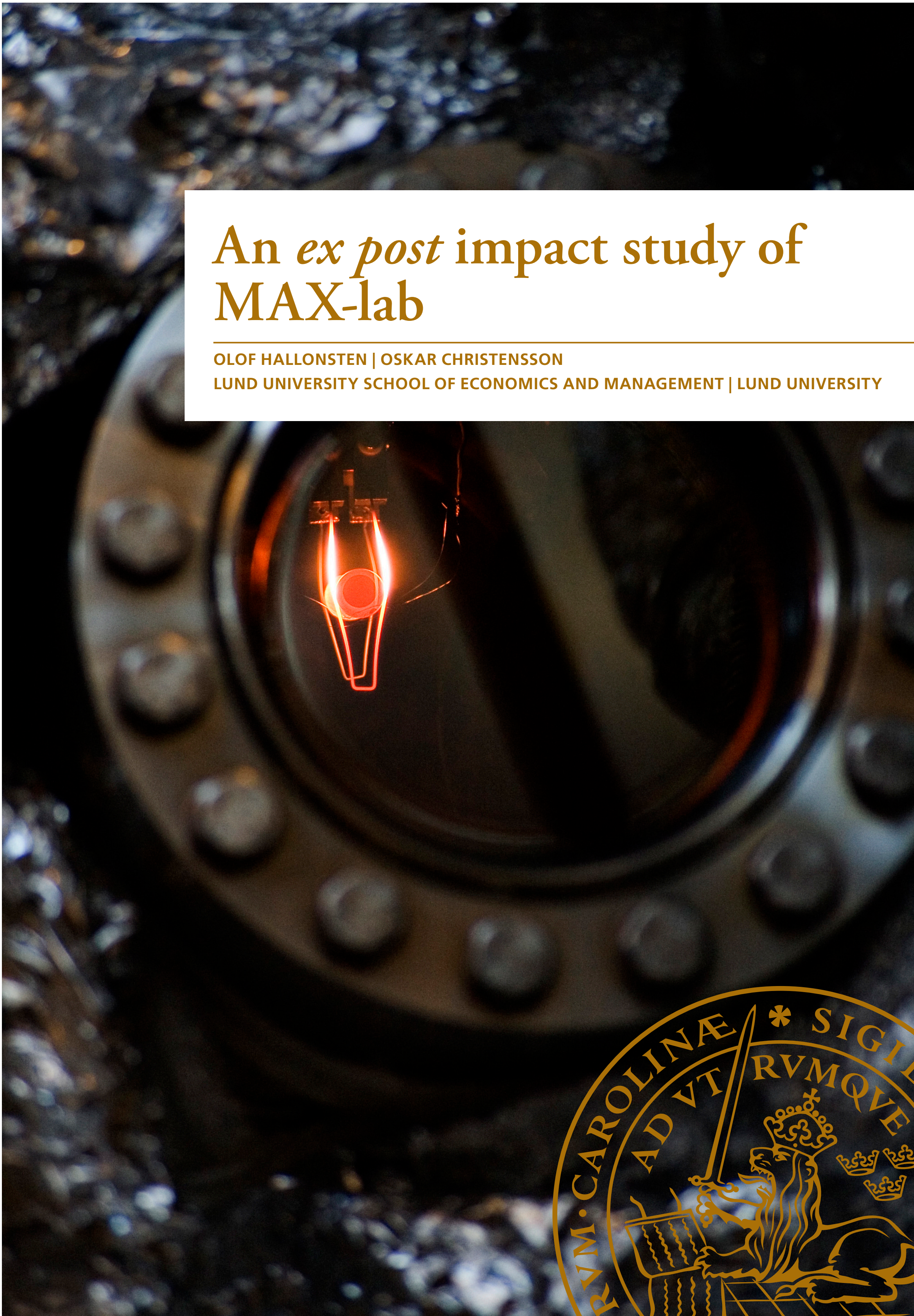

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“Is there a reasonable alternative to MAX-lab for Swedish science and technology? Not really: without it, the Swedish users could still access ESRF and other national facilities – but the experience of other countries shows that without a strong national facility the quality and quantity of synchrotron activities would degrade, confining Sweden to a second-rank role.”

(“Report from the review of the MAX laboratory, Lund, May 2009,” Swedish Research Council report 5:2010, p 24.)

“You had a certain freedom at MAX-lab, that also came with responsibilities, that you didn’t have at other labs. You learned how to inject into the ring, for example, that only happened at MAX-lab. It gives self-conficence, and decisionmaking power, but also teaches you to communicate with people. […] I have given some though to what would have happened if I wouldn’t have come to MAX-lab. I would probably have ended up at a big place and it wouldn’t have been the same. Different disciplines gathered under the same roof at MAX-lab, with the machine in common and the goal in common: to do good science for the benefit of society. This made MAX-lab special.”

(Marco Kirm, interviewed by Oskar Christensson, over Skype 6 January 2017.)

Table of Contents

Preface

This report is the result of a study undertaken in 2016-2017 on charge by the Office of the Vice-chancellor of Lund University, and the Swedish Research Council, who also jointly funded the study.

The following people have read and commented on earlier versions of this report, and contributed significantly to its quality: Ralf Nyholm, Yngve Cerenius, Ingolf Lindau, Thomas Ursby, Bent Schrøder, Derek Logan, Bengt EY Svensson, Svante Svensson, Örjan Skeppstedt, Mats Benner, and Stacey Sörensen.

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Instead of an executive summary, a condensed version of this report will be printed separately. Those interested in a short summary of the findings of this study are recommended to read the short version

List of tables

List of figures

List of abbreviations and acronyms

AFR	Atomforskningsrådet, (Swedish Atomic Sciences Research Council)
ALS	Advanced Light Source
APS	Advanced Photon Source
BESSY	Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung, (Berlin Electron Storage Ring Company for Synchrotron Radiation)
BNL	Brookhaven National Laboratory
CERN	Conseil Européen pur la Recherche Nucleaire, (European Organization of Nuclear Research)
DABIC	Danish Biotechnology Instrument Center
DESY	Deutsches Elektronen-Synchrotron, (German Electron Synchrotron)
DOE US	Department of Energy
ERA	European Research Area
ESF	European Science Foundation
ESFRI	European Strategy Forum on Research Infrastructures
ESRF	European Synchrotron Radiation Facility
ESS	European Spallation Source
FASM	Föreningen för Användare av Synkrotronljuset vid MAX-lab, (Association for Users of the Synchrotron Radiation Laboratory MAX-lab)
FRN	Forskningsrådsnämnden, (National Council for Planning and Coordination of Research)
HASYLAB	Hamburger Synchrotronstrahlungslabor, (Hamburg Synchrotron Radiation Laboratory)
ILL	Institute Laue Langevin
KAW	Knut and Alice Wallenberg Foundation
MBA	Multi Bend Acromat
NFR	Naturvetenskapliga Forskningsrådet, (Swedish Natural Sciences Research Council)
NMR	nuclear magnetic resonance
PAC	Program Advisory Committee
RJ	Riksbankens Jubileumsfond, (Bank of Sweden Tercentenary Foundation)
SciLifeLab	Science for Life Laboratory
SLAC	Stanford Linear Accelerator Center, since 2008 SLAC National Accelerator Laboratory
SPring-8	Super Photon ring 8 GeV

SRS	Synchrotron Radiation Source
SSF	Stiftelsen för Strategisk Forskning, (Swedish Foundation for Strategic Research)
SSRP	Stanford Synchrotron Radiation Project
STU	Styrelsen för Teknisk Utveckling, (Board of Technical Development)
TFR	Teknikforskningsrådet, (Swedish Technical Sciences Research Council)
UHÄ	Universitets- och Högskoleämbetet, (National Swedish Board for Universities and Colleges)
Vinnova	Verket för Innovationssystem, (Swedish Agency for Innovation Systems)
VR	Vetenskapsrådet, (Swedish Research Council)
VUV	vacuum ultraviolet
WoS	Web of Science

1. Introduction and framework

1.1 Introduction to the study

The MAX laboratory, abbreviated and commonly known as MAX-lab,[1] was a Swedish national research facility located at the Northern campus of Lund University in the town of Lund, Southern Sweden. It was originally the product of a small-scale university project in nuclear physics and grew over the years to a Swedish and international user facility for experimental research with synchrotron radiation, which is the use of extremely intense electromagnetic radiation (infrared, visible, ultraviolet and x-rays) for various studies of materials, and with vibrant and highly productive research programs in accelerator physics and nuclear physics. On March 27, 1985, the original MAX storage ring[2] was operated for the first time and in the fall of 1986, the first experiment with synchrotron radiation was conducted by external users.[3] Almost three decades later, on December 13, 2015, the then three operating MAX storage rings (MAX I, MAX II, MAX III) were closed for use and the activities of MAX-lab moved to its successor laboratory MAX IV some 2 km to the northeast, which was inaugurated on June 21, 2016.

The history of MAX-lab is remarkable: When inaugurated in 1987, the first MAX storage ring (MAX I) had been under construction for at least a decade and was largely home-made. In principle, it was an accelerator physics R&D project originally intended to be used solely for research in nuclear physics, and in the course of its completion also adapted to the function of producing synchrotron radiation for spectroscopic studies of materials. Ten years later, in 1995, the purpose-built MAX II storage ring was inaugurated and only two years later, MAX-lab had some 400 annual user visits by scientists from 20 countries and within scientific fields as disparate as surface physics and structural biology. The small Lund University project had grown to a national

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[1] The official explanation to this name is that it is an acronym for ”Microtron Accelerator for X-rays”, but there are other, more personal explanations available. See B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 35.

[2] A storage ring is a type of particle accelerator. See section 2.2.

[3] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 134. MAX-lab, “Background Material for the Evaluation of the Swedish National Facilities 2002” (Swedish Research Council, dnr 347-2001-6180, 2002), ch 2 p 4.

research facility as defined in national legislation and with the financial support and oversight of the Swedish Natural Sciences Research Council (Naturvetenskapliga Forskningsrådet, NFR). It had attracted investments by several public and private funders and strong support from local and regional authorities, and it had established itself as a vital resource for many fields of research in Sweden, which had made crucial advances with high international scientific standard in symbiosis with the experimental facilities at MAX-lab. The achievements of the lab, and of its users, had become known internationally and its innovative approach to accelerator and instrument development lauded by leading international experts. Another ten years later, MAX-lab was in the midst of a highly advanced and ambitious development project and campaign to replace its existing laboratory resources with a world-leading synchrotron radiation lab under the name MAX IV. When the activities at MAX-lab were discontinued in late 2015, this ambition had been fulfilled and the MAX-lab teams, Lund University, the Swedish scientific communities, and the various patrons of MAX-lab could proud themselves with an achievement that had put Lund University and Sweden on the map internationally, as a natural center of gravity in Northern Europe for infrastructure and instrument development, and scientific use, of synchrotron radiation, a true area of strength on the global scientific scene in the late-20th century.

As a synchrotron radiation facility, providing experimental resources for studies of materials (including biomaterials) to scientific users, MAX-lab has since the beginning of user operation in 1986 an open and user-oriented laboratory. As such, it takes place in a group of roughly 40 synchrotron radiation user facilities worldwide (beginning of the 2010s) that serve scientists in a wide range of sciences. Exact counts of the annual global number of users of synchrotron radiation are hard to produce due to differences in measuring and communicating user statistics, but according to a pan-European survey, nine synchrotron radiation facilities in Europe served no less than 30,894 individual users over a two-year period (June 2010 to May 2012).[4]

A synchrotron radiation user facility provides access to its instruments in the shape of *experimental time* (or *beamtime* as it is most often called), free of charge to anyone who applies and passes the evaluation by a peer review expert panel (the Program Advisory Committee, PAC). This peer review evaluation typically takes only scientific potential/quality and technical feasibility into account, although there have been some exceptions from this at MAX-lab and elsewhere, such as the ambition to achieve gender balance, the work to broaden the user community by giving access to new users, and the strategic direction of the lab as articulated by the board and its advisors.[5] Users are normally required to publish their results and not claim intellectual property rights, but

[4] The nine facilities in the survey are ANKA, Germany; ALBA, Spain; BESSYII, Germany; DIAMOND, UK; ELETTRA, Italy; ESRF, France (European collaboration); PETRAIII, Germany; SLS, Switzerland; SOLEIL, France. Source: http://pan-data.eu/Users2012e-Results [17 March 2017].

[5] Börje Johansson, then-chairman of the MAX-lab Program Advisory Committee (PAC), interviewed by Olof Hallonsten, Uppsala 12 October 2006.

users from the private sector can bypass the review process and procure beamtime by the hour, relieving themselves of the demand to publish so that they can use the results obtained for commercial purposes.

Organizationally and sociologically, the user orientation of MAX-lab and its sibling labs means that for the very most part, *MAX-lab itself did not produce any scientific results*. There are exceptions, because its staff made experiments and published results from these, and also participated in the experimental work of external users and thus ended up as coauthors on their publications, but generally, it was *the users of MAX-lab* that produced scientific results, drawing just as much on financial, intellectual, organizational and human resources of their home university department and lab or the organization that employed them (e.g. research institutes) and financing their work with project grants, scholarships and first-stream governmental research funding. MAX-lab was the provider of opportunities – many times absolutely vital opportunities – for this research, but for scientific results to be produced at MAX-lab, a user community had to be built, sustained and developed on basis of an effort that was in part organizationally, financially and politically separated from MAX-lab.[6] This fundamental *division of labor* or *functional differentiation* between the lab and its user community has exceptions (e.g. lab personnel conducting experiments, or external users involving themselves heavily in instrument development and maintenance) but it is crucial to grasp in order for any analysis of the output and impact of facilities like MAX-lab to make sense.

Another basic circumstance that has crucial importance for any evaluation of the activities of MAX-lab is its close ties to Lund University, which defined much of its evolution and meant both constraints and opportunities for its thriving. MAX-lab emerged as a university project in nuclear physics, and expanded to become both the natural focus for a research group in (and later university department of) accelerator physics, and an effort to produce synchrotron radiation and provide this to users in Sweden and abroad. For the whole of its history, MAX-lab remained part of Lund University, although substantial shares of both its investments and operations costs were covered by other funders such as the research councils and the private Knut and Alice Wallenberg Foundation (KAW). Lund University acted as the host of MAX-lab and integrated it into its research and education in physics, and later also chemistry and biology. Several leading positions at the lab, including not least the role as machine director and chief constructor of accelerators at MAX-lab, were occupied by people who also held academic positions at Lund University. Over the decades, Lund University has invested in many activities within its ordinary faculty structure to mobilize competence and capabilities to use MAX-lab and develop its infrastructures,

[6] For a broader and deeper discussion about the implications of this "division of labor" between facilities and their user communities, see O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), esp ch 5; O Hallonsten, "Use and productivity of contemporary, multidisciplinary Big Science," *Research Evaluation* 25 (2016), 486-495.

instrumentation, and scientific programs. Most importantly, however, the organizational integration of MAX-lab into Lund University has meant that MAX-lab has retained an essentially academic and scientific approach to its organization and development. In comparison with many synchrotron radiation user facilities abroad, where resources are pooled and utilized to the overarching end of providing users with as stable and reliable conditions for experiments as possible, MAX-lab has evolved in close collaboration with its user communities and with the articulated ambition to keep a scientific approach also to the development of infrastructure and instrumentation.

For the present effort of making a comprehensive ex post impact evaluation of MAX-lab, this brings two practical challenges: First, if MAX-lab is evaluated solely with the use of contemporarily accepted measures and indicators (such as publication and citation counts), and first- and second-hand effects for local, regional, national and international economies, it will run the risk of coming out as underperforming. Any such analysis will therefore have to be nuanced, at the very least with a thorough discussion on cost-effectiveness, and preferably also with a deep, qualitative investigation of effects that do not let themselves be captured by simple quantitative indicators but require comprehensive contextual analyses and well-informed discussion. Second, the work of drawing boundaries around the various activities at MAX-lab, and isolating events and processes in its history that can be identified as producing impact in any easily measurable sense, is severely complicated by the organizational *hybridity* that MAX-lab's integration into Lund University, its academic/scientific organizational structure, and its close relations to its users, have given rise to. Over the years, significant shares of the development and construction of MAX-lab infrastructure and instrumentation has been done by people as part of their work as holders of academic positions in Lund and elsewhere. Likewise, user support at MAX-lab has been taken care of both staff employed on the annual operations budget provided by the research councils, and by postdocs of research groups that frequently use MAX-lab but have their organizational home and funding elsewhere. These are just two examples among many: Those that set out to make a clear-cut investigation of resource flows and organizational specifics of MAX-lab over the years are bound to get lost in ad hoc arrangements and custom solutions devised and launched not to make life easier for audit services (or the undertakers of an *ex post* impact study) but to enable more and better science to be achieved, and/or to solve urgent problems as they turn up.

This report is the result of a comprehensive investigation of the 'footprint' left by MAX-lab, planned, designed, and executed with deep prior knowledge of the limitations and methodological challenges of the case as mentioned above. The key remedies to all of it has been an open and eclectic approach to the subject, to method, and not least to the definition of impact, as discussed in some more detail below.

MAX-lab has been studied and analyzed from a number of different perspectives before, not least in personal memoirs of central actors in its several-decades-long history,[7] but also in scholarly work in the history of science and science policy,[8] doctoral thesis work in research policy studies,[9] and some studies in the social sciences and humanities.[10] None of the cited works have studied the impact of MAX-lab other than indirectly, as part of other types of investigations with other purposes and research questions.

MAX-lab has, however, been evaluated several times throughout its history, with respect to scientific performance and quality, by its funder the NFR (succeeded by the Swedish Research Council, Vetenskapsrådet, VR, in 2001), and as part of other evaluations (see section 2.5). MAX-lab has also, in the recent decade, earned a greater reputation in wider circles (also internationally) because of the MAX IV project which is the largest investment in a domestic scientific infrastructure ever made by Sweden, and which would not have become reality without the preceding three to four decades of buildup of MAX-lab. No previous study has, however, taken a comprehensive grip on the issue of impact of MAX-lab as described, assessed, and evaluated ex post – that is, with evidence at hand and with a clearly limited time period to analyze.

Today's society and perhaps especially the science system, are obsessed with evaluating and measuring impact,[11] and while this obsession has been criticized for perpetuating shallow and even improper ways of understanding the true role of e.g. scientific activity in society, it has also given a much-needed impetus to take seriously the issue of evaluating the effects of investments and initiatives of various kinds. The history of MAX-lab is highly complex, and its 'footprint' very wide and varied, as this report

[7] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001). B Forkman, "Hur och varför MAX-lab kom till och växte upp," in G Broberg, B Forkman and C-M Pålsson (eds.), *Vem styr forskningen?* (Lund Studies in the History of Science and Ideas, 2003). B Forkman, A Nyberg and M Nygren (eds.), *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016). B Forkman and Per-Åke Hultberg, "Sagan om ringarna: Berättelsen om en liten MAX – hur han började gå, växte upp och blev stor," in B Forkman and K Holmin Verdozzi (eds.), Fysik i Lund – i tid och rum (Lund University, 2017).

[8] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011), 179-215. M Benner, "Big Science in a small country: constraints and possibilities of research policy," in O Hallonsten (ed.), *In pursuit of a promise: Perspectives on the political process to establish the European Spallation Source (ESS) in Lund, Sweden* (Arkiv Academic Press, 2012).

[9] O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009).

[10] S von Platen, "Reaching the inside from the outside? Member identification and auto-communication during organizational transition," B Olander, "Social media and research practices in Big Science: The example of MAX-lab," both in T Kaiserfeld and T O'Dell (eds.), *Legitimizing ESS: Big Science as a collaboration across boundaries* (Nordic Academic Press, 2013).

[11] See e.g. M Power, *The Audit Society. Rituals of Verification* (Oxford University Press, 1997). R Whitley and J Gläser (eds.), *The changing governance of the sciences. The advent of research evaluation systems* (Springer, 2007). P Weingart, "Impact of bibliometrics upon the science system: Inadvertent consequences?" *Scientometrics* 62 (2005), 117-131.

shows, and it is doubtful whether it would be possible to make enough justice to the full history of MAX-lab and all the forms of impact it has had on its surroundings – scientifically, economically, politically, and so on – without the type of both deep and wide effort that lies behind this report and is reflected in its length and level of detail. To be sure, the words "enough justice" in the previous sentence are key: The authors of this report have no illusions that all possible forms of impact of MAX-lab have been covered in these pages or that this would even be possible. The reader shall bear this in mind, but also be aware of some other key ambitions behind the work.

One of those ambitions is to go beyond simple and shallow indicators and seek to present a broader and more comprehensive picture. This ambition is based both on long professional experience that dates back to empirical studies as part of doctoral dissertation work in 2004-2005,[12] and on the conviction that labs like MAX-lab deserve performance and impact evaluation that takes seriously their role(s) and function(s) in research systems, innovation systems, and society, also in a theoretically grounded understanding of role(s) and function(s) (see below). Although this means a fairly voluminous end result – such as the present 240-page report – it is a necessary part of the effort to combat oversimplification. Here, the present study is contextually situated in the relatively new tradition of "facilitymetrics" within research policy studies and sociology of science, which is an attempt to adjust bibliometrics and other impact measures typically used in science today to the complex realities of contemporary, multidisciplinary and multifaceted "Big Science"-facilities.[13] Another strand of literature, concerned with "knowledge spillovers" from "Big Science," has focused almost entirely on very large physics labs like CERN and thus a whole other context for knowledge and technology transfer, and impact, than complex multidisciplinary user facilities like MAX-lab.[14] This literature will only be used for context in the relvant section(s), namely 4.2 and 4.3, where the collaboration between the R&D on advanced

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[12] O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009).

[13] O Hallonsten, "Introducing 'facilitymetrics': A first review and analysis of commonly used measures of scientific leadership among synchrotron radiation facilities worldwide," *Scientometrics* 96 (2013): 497-513. Olof Hallonsten, "How expensive is Big Science? Consequences of using simple publication counts in performance assessment of large scientific facilities," *Scientometrics* 100 (2014): 483-496. R Heidler and O Hallonsten, "Qualifying the performance evaluation of Big Science beyond productivity, impact and costs," *Scientometrics* 104 (2015): 295-312. O Hallonsten, "Use and productivity of contemporary, multidisciplinary Big Science," *Research Evaluation* 25 (2016): 486-495. L Qiao, R Mu and K Chen, "Scientific effects of large research infrastructures in China", *Technological Forecasting & Social Change* 112 (2016): 102-112.

[14] H Schmied, "Results of attempts to quantify the secondary economic effects generated by big research centers," *IEEE Transactions on Engineering Management* 29 (1982): 154-165. E Autio, A-P Hameri, and M Nordberg, "A framework of motivations for industry–big-science collaboration: a case study," *Journal of Engineering and Technology Management* 13 (1996): 301-314. E Autio, A-P Hameri and O Vuola, "A framework of industrial knowledge spillovers in big-science centers," *Research Policy* 33 (2004): 107-126. A-P Hameri, "Innovating from Big Science Research," *Journal of Technology Transfer* 22 (1997): 27-36.

instrumentation at MAX-lab and the development work of private companies in related industries are analyzed.

From the (yet rather small) body of literature within the “facilitymetrics” tradition comes the most spectacular example of what oversimplification and shallowness in performance and impact measures can lead to when applied to labs like MAX-lab. The exercise is the experimental calculation of the cost of the results obtained with a brand new piece of scientific infrastructure comparable with (but significantly larger than) MAX-lab, namely the

European Synchrotron Radiation Facility (ESRF) in Grenoble: When calculating the accumulated construction and operations costs for the ESRF and dividing this with the (all too commonly used) measure for scientific productivity today, namely number of journal publications that are produced on basis of experiments done at the ESRF, in its first year of operation, every journal article published in the first full year of operation of the facility (1995) cost $1.3 million. Naturally, the marginal cost is in rapid decline, so that in the third year of operation (1997), journal articles cost only $772,000 (and it is of course much lower today).[15] Still, though, if this measure is compared to an analogously calculated measure of the cost of a journal article from any scientific activity in an typical university setting where lab equipment and buildings of ordinary size and cost are used, the conclusion can be no other than the ESRF being insanely expensive.

The general lesson is of course that facilities like the ESRF are resources that are used in ways, and for purposes, that cannot be as simply measured. This has also been pointed out in follow-up studies,[16] and its true also for MAX-lab. What they have in common is the fundamental ‘division of labor’ (or *functional differentiation*) between facilities/instruments and users presented above. If this division of labor is overlooked or discarded, and the immense complexity of contemporary scientific experimental work is neglected and labs like MAX-lab are viewed as simple production units in science with no further nuance, the result will be devastating for the labs, their funders, and anyone willing to make a pitch for their existence and continued support from the public purse.

Both the ESRF and MAX-lab are/were used mostly by scientists from universities and other organizations within their ordinary research projects, that have been paid by other sources, and it is unlikely that any quantitative measure or calculation would manage to capture the full organizational and financial complexity of the science done at the

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[15] O Hallonsten, “How expensive is Big Science? Consequences of using simple publication counts in performance assessment of large scientific facilities,” *Scientometrics* 100 (2014): 483-496, on p 493.

[16] R Heidler and O Hallonsten, “Qualifying the performance evaluation of Big Science beyond productivity, impact and costs,” *Scientometrics* 104 (2015): 295-312, on p 309. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), on pp 180-184. O Hallonsten, “Use and productivity of contemporary, multidisciplinary Big Science,” Research Evaluation 25 (2016), 486-495, on 493.

facilities. The same goes, in principle, for the argument that any other scientific activity has a lower cost per publication: Such a calculation fails to take into account the complexity of research endeavors in e.g. university settings, where the full range of financial, organizational, technological, and intellectual resources used also cannot be captured by any straightforward count, if at all. Which also bolsters the argument further: It is impossible to make enough justice to scientific activities and their impact with simple quantitative indicators, and without a comprehensive source material and deep understanding of the case at hand, and its specific features.

Nonetheless, this is very common. A number of studies of impact of laboratory infrastructures like MAX-lab exist. With few exceptions, these are either *ex ante* consequence analyses that are by nature speculative,[17] or attempts to draw generalized conclusions about the impact of investments in research infrastructures.[18] Some examples of impact measures done *ex post*, and with proper attention paid to the specifics of a lab, exist. Not least can one find online several highly case-specific studies of the effects of procurement by CERN (the European Organization for Nuclear Research) in Geneva.[19] Other more recent studies that have been inspirational for the current effort are the impact study of the Synchrotron Radiation Source (SRS) at Daresbury, UK, which closed in 2008,[20] and the ongoing work to assess, describe and analyze the scientific, economic, and social impact of the DORIS accelerator facility for particle physics and synchrotron radiation at the German federal research laboratory DESY in Hamburg.

Impact studies of multidisciplinary, user-oriented research facilities that build on a wide but balanced view on the meaning of the concept of impact, and conduct a thorough and scholarly stringent analysis of a case, with high demand on source material,

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[17] M Klein, K Barker, P Stubbs and R Boden, "The Implications for Host Nations of Transnational Research Facilities: Final Report to the Economic and Social Research Council," (University of Manchester, 1994). F Valentin, M Larsen, and N Heineke, "Neutrons and innovations: What benefits will Denmark obtain for its science, technology and competitiveness by co-hosting an advanced large-scale research facility near Lund?" (Working paper 2005–2 from Research Centre on Biotech Business, Copenhagen Business School, 2005). DRI, "The economic impact of the proposed Canadian light source," (Report, DRI Canada, 416-360-8885, 1996).

[18] W Waldegrave, "Economic impacts of hosting international scientific facilities" (Crown, 1993). E Horlings, T Gurney, A Somers and P van den Besselaar, "The societal footprint of big science" (Rathenau Instituut Working paper 1206, 2011). SQW Consulting, "Review of the economic impacts relating to the location of large-scale science facilities in the UK" (report, 2008). Technopolis, "The role and added value of large-scale research facilities" (report, 2011).

[19] See e.g.: M Bianchi-Streit, N Blackburne, R Budde, H Reitz, B Sagnell, H Schmied and B Schnorr, "Economic Utility resulting from CERN Contracts" (CERN, 1984). CERN, "Report of the Finance Committee Working Group on CERN Purchasing Policy and Procedures," (CERN, 1993); P Fessia, "Trial Study of the Impact of CERN Contracts on Firms: The Development of new products and competencies" (CERN, 2001); H Schmied, "A Study of Economic utility Resulting from CERN Contracts" (CERN, 1977).

[20] "New Light on Science: The Social & Economic Impact of the Daresbury Synchrotron Radiation Source, 1981-2008" (UK Science & Technology Facilities Council, 2010).

method, theoretical awareness, are unusual. Furthermore, previous studies also have the inherent drawback of having been either commissioned or executed (or both) by the labs themselves, by their funders, or their parent organization, which raises some questions regarding impartiality and the influence of these interests on the design of the study and its outcomes. This study is also not undertaken in complete independence from such interests: It was commissioned by the Office of the Vice-Chancellor of Lund University, the parent organization of MAX-lab, and financed jointly by Lund University and the Swedish Research Council, which has shared the financial responsibility for MAX-lab with Lund University since at least the mid-1980s. The risk of bias that naturally comes from this contractual relationship is balanced by the inherent logic of the organizations that commission the study and that carries it out: The present study is done in the context of a research effort by trained scholars in the social sciences, with deep knowledge about the case as well as a well-developed professional approach to investigatory work.

1.2 Conceptual framework, notes on method, and structure of the report

Most of the institutional and technological foundations of the current science system in the industrialized world were established in the early Cold War era when a (over-) optimistic view on the role of science and technology for social and economic development spread on both sides of the Iron Curtain and led to a dramatic increase of public and private sector expenditure on R&D, in large part on the side of military applications but also on the civilian side and most importantly, in scientific activities with little or no direct demand or expectations of outcomes – these would follow automatically, the prevalent research policy doctrine said.[21]

Beginning in the 1960s, this situation changed dramatically. R&D expenditure did not decline (quite the reverse, it has been under constant increase in most industrialized countries since the end of World War II, with some minor bumps here and there), but the framework conditions were altered in a continuous process that put science under increased scrutiny from policymakers, bureaucrats, auditors and also internal scientific peer review assessment. The recent few decades have seen a flood of conceptualizations of the changing nature of science and the science-society relationship, by economists, sociologists of science, and scholars of research policy. The innovation systems

[21] D Guston, *Between politics and science: Assuring the integrity and productivity of research* (Cambridge University Press, 2000), pp 37-45. D Greenberg, *The politics of pure science*, 2nd ed. (The University of Chicago Press, 1967/1999), pp 107, 112-114. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 47ff.

perspective dominates innovation studies today and takes into account the fact that innovation (the introduction of new ideas to the market or society) is a highly complex process that typically involves many actors and subprocesses besides e.g. scientists and entrepreneurs, and governments and authorities are today involved in innovation policymaking that is not restricted to financial support and setting the basic organizational framework for R&D (as previously), but aims at trimming all parts of innovation systems, from basic science and education, over infrastructure and institutional/organizational frameworks, to incentives for inter-firm collaboration in the private sector.[22]

In principle, the innovation systems approach not only allows but also encourages attention to be paid to the specialization, differentiation, and interaction between different actors with different goals and missions, all contained in the system and all contributing to innovation. But in reality, both innovation studies and innovation policy (especially in Sweden) have placed an unnatural focus on the role and function of academic research in the innovation process, which has allowed some confusion to spread regarding two interrelated themes. The first is the idea that universities should take on more and more – perhaps all – functions and roles on the public side of the innovation system (and perhaps also some roles and functions typically assigned to the private sector, such as company startups). This one-sided view on the performing actors in innovation systems has little historical/empirical support (internationally, the roles of research institutes and non-academic government labs are significant), but is theoretically underpinned by the concepts of the "entrepreneurial university"[23] and the "triple helix" of university-industry-government relations.[24] The second is that evaluation procedures for innovation are reduced to very simple and rather shallow measures, namely the appraisal of scientific productivity and quality (or "excellence") either by simple bibliometrics, or by relative measures such as rankings of universities, or by counting patents, licenses and spinoffs, or by input measures, i.e. national or regional expenditure on R&D.

Bibliometrics of course have their merits but do not cover nearly all aspects of scientific productivity and quality, and are inadequate for capturing innovation performance. There are also significant issues connected to the evaluation of research performance that have to do with the time aspect, i.e. that not least acknowledgement of the quality or relevance of a result in the scientific community in the shape of citations often takes

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[22] See e.g. C Freeman, *Technology policy and economic performance: Lessons from Japan* (Pinter, 1987). R Nelson (ed.), *National Innovation Systems: A Comparative Analysis* (Oxford University Press, 1993). C Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations* (Pinter, 1997).

[23] B Clark, *Creating Entrepreneurial Universities: Organizational Pathways of Transformation* (IAU Press, 1998). H Etzkowitz, "Entrepreneurial scientists and entrepreneurial universities in American academic science," *Minerva* 21 (1983), pp 198-233.

[24] H Etzkowitz and L Leydesdorff (eds.) *Universities and the global knowledge economy: a triple helix of university-industry-government relations* (Pinter, 1997).

a long time to show up and therefore do not work as measures of quality or relevance of recently performed research. Patents, licenses and spinoffs suffer from a similar problem: The commercial relevance of R&D may not be possible to identify until years (or even decades) after the discovery or invention was made as part of a research project. University ranking tables are not only aggregated to a level where the utility of the measure can be doubted: Although probably the universities that are placed in the top of international ranking tables also are the homes of excellent research with far-reaching impact, the ranking position as such says very little about the innovative capacity either of these research activities or the innovation system as a whole.[25] Finally, expenditure on R&D, although commonly used to demonstrate the strength of a nation's domestic 'knowledge economy', is a measure of input and not output. To all this should also be added the recent studies that argue that the performance of national R&D efforts remains on high level, and the productivity and quality of scientific research in most industrialized countries is very high, but that if innovation systems are performing suboptimally, the deficits lie rather on the side of application and commercialization.[26]

Therefore, to give justice to the issue of impact of research activities, and provide the grounds for its assessment and evaluation, a broader view is necessary. This view should take into account impact of a greater variety than contemporary bibliometrics and patent/funding counts can capture. It should acknowledge the possibility and probability that impact shows up with a long time lag and unpredictable geographical and institutional dispersal.[27]

A highly useful and very telling example that can illustrate why this broadened view of impact is not a mere academic curiosity but a necessity, is the immensely popular consumer electronics products from Apple Inc., that arguably have made profound contributions to the reshaping of whole industries and contributed not only to the redefinition of the use of information and communication in society but also to political upheaval and radical change. In a recent book about the role of governmental R&D in complex innovation processes that are often both invisible and difficult to fully trace, the iPod, the iPhone and the iPad are analyzed with respect to the wide variety of technologies that they combine to create a revolutionary consumer electronics product.[28] As the book shows, many (or most) of these technologies emerged and were

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[25] R Münch, *Academic Capitalism. Universities in the Global Struggle for Excellence* (Routledge, 2014). E Hazelkorn, *Rankings and the reshaping of higher education. The Battle for World-class Excellence* (Palgrave Macmillan, 2011).

[26] F Erixon and B Weigel, *The Innovation Illusion* (Yale University Press, 2016).

[27] S Jacobsson and E Perez Vico, "Towards a systemic framework for capturing and explaining the effects of academic R&D," *Technology Analysis & Strategic Management* 22 (2010): 765-787. S Jacobsson, E Perez Vico and H Hellsmark, "The many ways of academic researchers: How is science made useful?" *Science and Public Policy* 41 (2014): 641-657.

[28] M Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths* (Public Affairs, 2015), pp 93-119.

developed in institutional contexts and points in time very far from both the Apple headquarters in Silicon Valley in the first decade of this millennium. Most prominent were the US Department of Defense and Atomic Energy Commission, sponsoring R&D programs in various agencies and national laboratories, and universities, in the 1950s and 60s. The lithium-ion battery, the liquid-crystal display, the embryonic internet, voice recognition software, are only some examples. But also CERN, the European Laboratory for Nuclear Research in Geneva, show up here as the inventor of the World Wide Web, which is an interesting example because this invention was the result of technology development surely important for the operation of the lab but clearly not a spinoff from its core scientific program (in particle physics). The point here is of course that hardly any of these governmentally sponsored programs would have come out favorably in performance appraisals that would have counted publications, citations and patents with the expectation to find results a mere couple of years after investments were made. A historical irony is that several of these programs (especially in the United States; the case of CERN is organizationally and politically very different) were cancelled, downsized, reshaped and bureaucratized as a result of political pressure that demanded more bang for the buck in the 1960s and on.[29] Obviously, these research policymakers of the 1960s, 70s and 80s could not have foreseen the iPhone. But just as obvious is the nearly deafening bang for those bucks that the respective technologies have delivered as vital parts of the iPhone.

But the perhaps most important lesson is that innovation never occurs in isolation. This is at the core of the innovation systems framework: An efficient and productive innovation system requires many different components, of which not all are highly productive in an immediately recognizable sense, and of which not all are possible to straightforwardly identify as vital to the system. Institutional stability has been shown to be crucial for economic efficiency and the creation of wealth, both on markets and in the public sphere.[30] Similarly, institutions that provide stability and predictability are vital for well-functioning innovation systems, although of course stable institutions may at first sight appear conservative and un-innovative. Institutional stability enables renewal in science, and it has been shown in a number of studies of innovation and technological development that imitation, standardization, and the maintenance of stable and reliable infrastructural bases of the economy, society and innovation systems

[29] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 81, 84-85, 135. C Westfall, "Surviving the squeeze: National laboratories in the 1970s and 1980s," *Historical Studies in the Natural Sciences*, 38 (2008): 475-478. C Westfall, "Institutional persistence and the material transformation of the US national labs: The curious story of the advent of the advanced photon source," *Science and Public Policy*, 39 (2012): 439-449.

[30] D North, *Institutions, Institutional Change and Economic Performance* (Cambridge University Press, 1990). B Rothstein, *Just Institutions Matter: The Moral and Political Logic of the Universal Welfare State* (Cambridge University Press, 1998).

are not only necessary for research breakthroughs and radical innovation but indeed directly conducive of the same.[31]

Several studies have similarly shown that instruments and infrastructure provide opportunity for path-breaking scientific work but must in themselves be stable and reliable.[32] To this shall be added the proven reliability of loose and informal coupling of actors in social processes,[33] including innovation and the role of tacit knowledge which is bred in stable institutional and technological settings ("protective spaces"),[34] and it becomes clear that many of the activities and organizations of contemporary science are impossible to capture by those indicators commonly used today.[35]

This is, at least in part, true for research facilities like MAX-lab. As mentioned in the introduction to this report, a fundamental feature of synchrotron radiation facilities (that they share with some other contemporary facilities for experimental scientific work) is that with few exceptions, they do not produce any scientific results themselves but function as resources that scientists employed and funded chiefly by other organizations make use of, mostly on temporary (but often recurring) basis. This *division of labor* or *functional differentiation* between facilities and users has an important implication for the study of the scientific impacts of the lab: Strictly speaking (Although with exceptions, since staff scientists at MAX-lab conduct research of their own and publish it), the contribution of MAX-lab to the science system and its

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[31] J Utterback, *Mastering the Dynamics of Innovation* (Harvard Business School Press, 1994). J Mokyr, *The Lever of Riches. Technological Creativity and Economic Progress* (Oxford University Press, 1990). W Bijker, *Of Bicycles, Bakelites, and Bulbs. Toward a Theory of Sociotechnical Change* (MIT Press, 1987).

[32] I Hacking, "The disunities of the sciences," in P Galison and D Stump (eds.), *The disunity of science: Boundaries, contexts and power* (Stanford University Press, 1996). B Joerges and T Shinn (eds.), *Instrumentation between science, state and industry* (Kluwer, 2001). C Mody, *Instrumental community. Probe microscopy and the path to nanotechnology* (MIT Press, 2011). N Rosenberg, "Scientific instrumentation and university research," *Research Policy* 21 (1992): 381-390. A van Helden and T Hankins, "Introduction: Instruments in the history of science," *Osiris* 9 (1994): 1-6.

[33] M Granovetter, "The Strength of Weak Ties," *American Journal of Sociology* 78 (1973): 1360-1380. C Phelps, R Heidl and A Wadhwa, "Knowledge, Networks, and Knowledge Networks: A Review and Research Agenda," *Journal of Management* 38 (2012): 1115-1166.

[34] S Winter, "Knowledge and competence as strategic assets," in D Teece (ed.) *The competitive challenge: Strategies for industrial innovation and renewal* (Ballinger, 1987). M Polanyi, *The Tacit Dimension* (University of Chicago Press, 1966). K Goffin and U Koners, "Tacit Knowledge, Lessons Learnt, and New Product Development," *Journal of Product Innovation Management* 28 (2011): 300-318. A Smith and R Raven, "What is protective space? Reconsidering niches in transitions to sustainability," *Research Policy* 41 (2012), 1025-1036.

[35] E Perez Vico, H Hellsmark and M Jacob, "Enacting knowledge exchange: a context dependent and 'role-based' typology for capturing utility from university research." *Prometheus* 33 (2015): 3-20, on p 3.

productivity and "excellence" is not productivity per se but contributions to this productivity by providing experimental resources not available elsewhere or otherwise.[36]

In the case of MAX-lab, it is therefore quite obvious that impact cannot be measured straightforwardly with a set of predefined indicators. This is not only because such indicators capture only parts of the full spectrum of conceivable impacts that a lab like MAX-lab can have over its several decades of existence (and long into the future, see above), but also because many of the most important forms of impact that MAX-lab has had are very complex, multifarious, and filled with feedback loops. A great example on the education and outreach side (see section 5.2) is the summer schools, which have had tremendous impact in educating a Swedish, Nordic and European user community (including not least students from Central and Eastern Europe, who got access to this school after the end of the Cold War) but which has also contributed to the cultivation of the user community, and thus in turn been an important factor for the continuous strengthening of MAX-lab as a scientific facility. Another example is the mode of collaborative work seen in the collaborations between the machine group and the accelerator component manufacturer Scanditronix in the construction of MAX II, and between the group of Nils Mårtensson in Uppsala and the company Scienta in the development of the SES-200 analyzer (see sections 4.2.1 and 4.2.2, respectively). In these two cases, the "product" or "end result" was never simply quantifiable through a count of patents or spinoff companies (patents were, as the reader will learn from the detailed descriptions of these innovation processes, out of the question right from the start) but requires deep and detailed qualitative analysis to be understood and properly assessed. The same is true for most, if not all, of the examples of impact analyzed in this report and the processes that lie behind them. The chain of events that took MAX-lab from a small university project in the late 1970s to the next very major step in the shape of MAX IV (which is the perhaps most spectacular impact of all of MAX-lab, and discussed in such terms in section 7.1.2) is a chain with feedback loops everywhere: Most evidently in how the mobilization of a user community throughout Sweden, and thus with a national base, was instrumental in taking next steps, scientifically and politically, in the development. The Uppsala connection (see section 3.4.1) is obvious in this regard; but also the relationships with groups at Linköping University, Chalmers in Gothenburg, and in Denmark, Finland and Estonia have been imporant. In a first step, these groups make great use of MAX-lab and enhance their scientific activities on basis of the experimental opportunities offered at MAX-lab, but they also contribute to the design, construction and maintenance of instrumentation. In a second step, they lend their active support to MAX-lab in its expansion plans and strengthen both the

[36] For a thorough discussion on this topic and many related issues (also including the use of bibliometrics to underpin some of the arguments), see O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 106-118, 164-184.

lab as such and, by extension, their own and others' opportunities to do experimental work at the lab.

Therefore, this holds as a general principle for the analyses in this report: The scientific impact of MAX-lab must be assessed with a broader and more varied view on the contributions it has made. The remedy is not to completely discard bibliometrics and other quantitative measures, but to use them with care and in combination with qualitatively oriented analyses of other forms of impact. Also, importantly, the organizational and technological complexity of research facilities like MAX-lab, and the disciplinary breadth of their user communities, necessitates a certain (rudimentary) level of understanding of the specifics of the lab with respect to the science it supports and enables, the technologies it utilizes for this task and how it works to maintain and refine it, the organization it has developed to run and develop the lab on short and long term and to serve the users, and also the politics that surrounds the lab and its origins. Put differently, it is necessary to have some knowledge about a technology itself before being able to fruitfully study its transfer, and also some knowledge about organizational, institutional, and political frameworks.[37]

This understanding must range from the very concrete, such as the legal framework for the organization in question – universities and corporate R&D labs obviously differ widely in this respect, but there are also many intermediaries – to the more abstract, namely the dynamics of the scientific fields concerned and the technologies used, and all the relevant organizational and cultural features of scientific fields, technological areas, and national R&D systems. In the specific case of MAX-lab, as will be evident throughout this report, the firm academic foundations of the lab and its continued organizational embeddedness in Lund University, has had a very important role in the long- and short-term development of the lab, and surely also for the question of its impacts on science, society, and the economy. Several other factors contribute in similar ways and will be discussed at various points in the report.

A key problem here is of course the question of alternatives. What about the counterfactual scenario, namely, that MAX-lab was never built at all, and the resources (financial, political, human/intellectual, technical, and so on) spent on something else? This question can be answered in two ways, and both are dissatisfying from a scientific point of view: First, it can of course be concluded that without MAX-lab, there would not be any impact of the type MAX-lab has produced. Second, in polemic with the first, it can be concluded that any investment in anything is bound to have an impact and that the complexity of the processes involved, and the very long time frames (cf.

[37] See e.g. E-J Meusel, "Einrichtungen der Großforschung und Wissenstransfer," in H Schuster (ed.), *Handbuch des Wissenschaftstransfer* (Springer, 1990). The thought was advanced in the 1970s by a pioneer in studies of the economics of technological innovation, N Rosenberg, *Pespectives on Technology* (Cambridge University Press, 1977). For a thorough discussion on this topic in the context of contemporary research facilities, see O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 195-205.

the discussion above) makes it impossible to delineate any causal relationships clear enough to render the counterfactual alternative case useful. Investments (of financial, political, human/intellectual, technical, and other resources) will have impact. The question is how.

Luckily, the glass is already half-full. It is unreasonable to assume that repeated investments in buildings and rudimentary infrastructure, and the continuous flow of hundreds of scientists annually visiting MAX-lab to do experiments, over three decades, would not have had many direct and indirect positive impacts on the local and regional economy. Likewise, it is unlikely that the continuous investment of hundreds of millions of SEK in very advanced instrumentation, and the employment of dozens of highly educated people at MAX-lab, would not have had substantial direct and indirect effects on some hi-tech industry sectors in Sweden (and abroad), through procurement, collaborations, the trading of tacit and codified knowledge, and so on. To put it differently, any such concentration of talent, skill, and technology, combined with an inflow of capital and a continuous multifaceted R&D program to both enhance technology and put it to use scientifically, and the annual visits of several hundreds of users that compete to get access to the facilities, are rather self-evidently creating wide and deep impact on the local, regional, national, and international economies, and society in general.

The issue of delimitations is not self-evident. MAX-lab is certainly a standalone organization and a very physically palpable collection of instruments and infrastructure, but it is interconnected and intertwined with so many actors, organizations, communities and institutions, in Lund, in Sweden, and abroad, that it is sometimes very difficult to draw a line between the lab and its context. MAX-lab is organizationally part of Lund University, but financed by both the university and the Swedish Research Council and predecessors (operations) and by a number of public and private funders (investments). Scientifically and technically, it is in great part a continuation of long traditions at universities and technical institutes in Uppsala, Stockholm, Linköping, Gothenburg and Lund, as well as some abroad. Large parts of the diverse and increasingly diversified user community have, ever since the 1970s, taken crucial part of instrument design and development, scientific user support, lab leadership and management, and committee work. Students and postdocs have moved freely between research and teaching in academic environments around Sweden and duties of contributing to the running and maintenance of MAX-lab. In many cases users have been listed as PIs on applications for funding for instrumentation that has later been built up at MAX-lab and fully integrated into its collected experimental resources.

This creates significant challenges of delimitation, which we have handled in two primary ways. First, by allowing the analysis to grow to encompass a broad range of topics and angles, as not least shown by the sheer volume of this report. Second, by letting the study design be guided by availability of material and the feasibility of covering a specific angle or topic. In this process, unavoidably, some aspects have most certainly therefore been overlooked or deliberately deselected. This is unfortunate but necessary in order for the study to remain (fairly) focused on MAX-lab and not grow to encompass a too large volume of activities in Swedish and foreign science and science policy. Some angles and topics have been included in the analysis although they may appear to be beside the point; a good example is the emphasis put on interaction between the lab and various people, communities, and organizations. This, we argue, is an important indicator of impact because it testifies to an interest among these actors and institutions in MAX-lab and its activities, which signals *relevance* (in a wide sense). The index of people, in appendices 3-5, is used as a source material for the analyses in chapter 3, but the lists should also be read and viewed in their own right, as testimonies to the integration of MAX-lab in all kinds of spheres.

The study is an *ex post* study, which is important given the lack of similar studies compared to speculative investigations of future impacts of research infrastructures (see the previous section). While this is in one way convenient in terms of delimitations, it does not fully prevent challenges from arising: The conceptual discussion above, pointing out that impact can show up with long delays and wide geographical dispersal, shows that in principle, this is not a good time to assess the impacts of MAX-lab even though it ceased operation over a year ago, because many forms of impact have yet not showed up. But such logic would of course prevent any impact study at any point in time. The motivation for doing this study is that an ex post analysis, at this stage, can be very useful given the relative freshness of information and the analysis' natural end point in time (2015).

A specific inconvenience related to the issue of delimitations is the overwhelming attention paid to the MAX IV facility from the time when it became a political project (in 2008-2009) and onwards, and especially after its basic funding solution was reached and construction of the lab started. One can sometimes get the impression that MAX-lab, with some 13 operational beamlines and roughly 900 annual users ceased to exist or became unimportant the minute that powerful interests on national and local level decided to launch the MAX IV project. Not only was the existing MAX-lab absorbed by the new MAX IV organization (structured to undertake a major construction project and plan a future state-of-the-art user facility), MAX IV also became the focus of another type of attention on national level and also locally in Lund. This is natural, given that the budget of MAX IV exceeded that of MAX-lab already in 2009, but it skews analysis of the last five years (2011-2015).

All along, the focus of this study has been on the MAX-lab that ceased operation in December 2015, ahead of the opening of the MAX IV facility. This means that the MAX IV project is treated as an R&D project within MAX-lab and its econsystem of users and other stakeholders, and the MAX IV facility that was inaugurated in June of

2016 is treated as an *impact* of MAX-lab, duly highlighted as one of the most spectacular and profound ones.

Regarding material and choice of material for the study, as suggested above, the trouble has rather been selecting between available topics and angles than any shortage of information. Meanwhile, the study has suffered somewhat from a shortcoming that is as common as it is annoying in qualitative mixed-methods studies, namely, that the *availability of sources* (in a very practical sense) has been allowed quite some influence over the weight given to different topics, themes and angles in the final report.

The MAX-lab activity reports, tremendously rich in information and a great source material for this study, were produced until 2010. After this, a slimmed and polished version was published in its place, more oriented to marketing the future MAX IV than to give a comprehensive and all-encompassing view of the scientific activities and technological developments at MAX-lab. Fortunately, MAX-lab staff continued to keep records of data also after 2010, and was generous enough to share this data so that the time series of e.g. publications lists and user statistics (used in chapter 3) would not be interrupted in 2010. The data and material presented in the activity reports has, however, varied over the years which means that there are some unfortunate gaps and/or lack of available data for the whole period of 1987-2015 in much of the data presented in tables and diagrams throughout the report. The only viable remedy to this unfortunate data problem has been to note very carefully in figure and table captions what years are actually covered.

Generally, the documentation on all kinds of aspects of MAX-lab is very rich. This is both due to the internal routines at the lab of collecting and compiling material, and to the principle for Swedish public authorities of disclosing and archiving material which has made it possible to retrieve most relevant printed material also going back to the 1970s. This "principle of public access to official documents" (*Offentlighetsprincipen* in Swedish), is written into the Swedish constitution and means not only that governmental documentation and the documentation of governmental authorities and agencies are openly available (and, for academic researchers, available completely free of charge), but also kept in archives and possible to retrieve. This means, for example, that the extensive self-evaluation material of MAX-lab ahead of the Swedish Research Council's evaluation of the four national facilities in 2002, has been easily accessible as part of the collection of material for this study, and it is hence extensively used as source material. By extension, the principle has also created a culture of openness in governmental agencies and universities alike, and also at MAX-lab, whose staff are generous and helpful in making available material collected and kept by them through the years, in printed form and digitally. Internally, MAX-lab began comprehensive compilation of various data in 1993, when the lab was "computerized."[38] This shows

[38] In the words of Ralf Nyholm, interviewed by Olof Hallonsten and Oskar Christensson, Lund 15 November 2016.

in many of the presentations of quantitative material throughout this report – unfortunately, some data is missing before 1993.

In addition to this voluminous documentation, whose greatest merit is to provide information on a high level of detail, we conducted a number of interviews with key figures in the history of MAX-lab. For practical reasons, we made an early choice not to conduct any survey investigation or broader collection of material beyond what is available at MAX IV, in various archives, and in the rich collection of material in our possession from previous work (including a number of interview transcripts from 2005-2007) and those analyses made then,[39] but have made the methodological choice of combining printed material and statistics with interviews to cover both detail and broader brushstrokes.

With regard to published secondary material, the book *The Marvelous Light in Lund – How MAX IV came about* (also available in Swedish) that was produced by former MAX-lab director Bengt Forkman together with a science journalist and one of the MAX IV communications officers,[40] has a limited value as source material due to its character of personal memoirs and journalistic style. Nonetheless, the book has been useful as a way to find themes or "threads" to follow up though the pursuit of other source material. In addition, the book's several interviews with key people have also been used as a source material. Another book that has been used as background material is the 2001 memoirs of the history of MAX-lab (thus far) by Bengt Forkman.[41]

Other than this, the present introductory chapter and the background chapter that comes next build heavily on secondary literature that is used to build a solid foundation in the state of the art of social sciences research on the history, politics, organization and economics of research infrastructures in general and synchrotron radiation facilities in particular, and in the contemporary knowledge and scholarly debate over impact of research and how to measure such impact. This is one of the two core features of this report that take it to an appropriate scientific level; the other one is the quality of the analysis and discussion in chapters 3 to 7, made with the use of first-hand material of the type listed above.

Finally, a note on the structure of the report. We have chosen to divide our analysis into four main sections, three of which are thematically complementary and correspond

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[39] MAX-lab was a case in the doctoral thesis work of Olof Hallonsten, which produced the thesis *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009) and the journal article "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011), 179-215. A vast amount of material was collected in the process, some of which was not used in these publications but could be conveniently recycled for the present study.

[40] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016)

[41] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001).

to three main spheres of impact of a major publicly funded research infrastructure – scientific and technological impact, economic impact, and public impact. The fourth stands out as being spatially or organizationally determined, namely impact on Lund University. The strong integration of MAX-lab into Lund University has been mentioned above and will be returned to repeatedly throughout this report. Clear is that Lund University, all the way from the start, has maintained a strong and uninterrupted support to MAX-lab, financially and organizationally, but also providing active support in negotiations and applications for funding on national level. This means that Lund University officials must have, in one way or another, expected that MAX-lab would bring certain benefits to Lund University. Chapter 6 essentially follows up on this assumption and analyzes the various forms of impact that MAX-lab has had on the university.

Throughout the report, we use short case studies to highlight especially important aspects of the history of MAX-lab in terms of impact. This way, we emphasize, for example, the symbiosis between the experimental opportunities offered at MAX-lab and the spectroscopic tradition at the department of physics at Uppsala University, the crucial procurement of magnet tripods from Olssons Mekaniska in the local village of Tollarp some 50 km outside Lund, the buildup of industrially relevant structural biology research facilities at MAX-lab with direct involvement of the pharmaceutical companies AstraZeneca and NovoNordisk, and other similar traceable forms of impact. These short case studies should be viewed partly as examples to highlight specific aspects of the topic of analysis in the report sections where they are placed, and partly as standalone vignettes that tell stories with values in their own right.

The above conceptual discussion placed strong emphasis on a solid and well-found understanding of contexts and some level of detail of the preconceptions about the topic of study. We have therefore chosen to take this issue seriously by devoting the next chapter in its entirety to background and context, which includes some historical and sociological exposés based on secondary sources, as well as some basic scientific and technical descriptions, that we judge to be useful for the reader.

2. Background and context

2.1 Science, technology and research infrastructures

Ever since the origins of modern science as a key part of the renaissance and enlightenment, and not least in the course of its development in reciprocity with the industrial revolutions of the 18th, 19th and 20th century, scientific research has been heavily dependent on *instrumentation*. The dependence has been mutual, and the relationship between scientific experimentation and technological process has been symbiotic. Classic philosophical epistemology claimed that progress in science is essentially driven by theory,[42] but recent work in the history and sociology of science has largely discarded this view and provided substantial evidence that technology very often is the driving force behind scientific advances, and also in cases when science is theory-driven, its progress is very often dependent on advanced instrumentation.[43] The 20th century saw an intensification of the dependence of especially the natural sciences on very advanced and very costly instrumentation, and a growing symbiosis between technology development and scientific experimentation and exploration.[44] In the same period, the role of political or strategic decision-making and the politically driven investment in new infrastructures, centers and program-oriented research efforts increased dramatically.[45] The most spectacular manifestations of this development was of course "Big Science" – though an ambiguous term that many stakeholders and

[42] K Popper, *The logic of scientific discovery* (Hutchinson, 1959). T Kuhn, *The structure of scientific revolutions* (The University of Chicago Press, 1962).

[43] M Merz and P Sormani (eds.), *The Local Configuration of New Research Fields* (Springer, 2016). C Mody, *Instrumental Community: Probe Microscopy and the Path to Nanotechnology* (MIT Press, 2011). S Shapin and S Schaffer, *Leviathan and the air-pump: Hobbes, Boyle, and the experimental life* (Princeton University Press, 1985). H-J Rheinberger, *Toward a history of epistemic things: Synthesizing proteins in the test tube* (Stanford University Press, 1997). T Shinn and B Joerges, "The transverse science and technology culture: Dynamics and roles of research-technology," *Social Science Information* 41 (2002): 207-251.

[44] J Ziman, *Prometheus Bound: Science in a dynamic steady state* (Cambridge University Press, 1994). O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016).

[45] D Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Brookings, 1997). D Greenberg, *Science, money and politics: Political triumph and ethical erosion* (The University of Chicago Press, 2001). P Stephan, How Economics Shape Science (Harvard University Press, 2012).

pundits have laid a claim to for a variety of purposes,[46] it is clear that the concept Big Science points at a deep embedment of scientific investigation in materially and organizationally very large and complex structures. The political and sociological consequences of Big Science have sometimes been absurd – costs have reached astronomical levels and single scientific publications have noted thousands of individual co-authors – but these megaprojects were clearly an integral part of the dominating political logic in the industrial world of the second half of the 20th century.[47]

To the extent that MAX-lab is an example of Big Science, it is probably “transformed Big Science” or “new Big Science” or at least a latter-day variety of Big Science where large and complex infrastructure is operated not for giant centrally planned and organized experiments (like the work in particle physics at e.g. CERN) but for a variety of projects that each rather qualify as ‘little’ or ‘ordinary’ science.[48] Synchrotron radiation was originally an unwanted byproduct of accelerators built for particle physics experiments, and in the first few decades of exploitation of synchrotron radiation, the activities grew in the shadows of the large particle physics programs, using their machines “parasitically”[49] (see section 2.2 below for a more thorough account on this history). The development of synchrotron radiation “from esoteric endeavor to mainstream activity” was part of a gradual but profound process that expanded the reliance of very advanced scientific instrumentation beyond the physics disciplines and deep into the ranks of chemistry, biology, and medicine. As part of this larger process, and with no small involvement of synchrotron radiation (and sibling techniques such as neutron scattering), new cross-disciplinary constellations emerged and established themselves, eventually taking the fore as the most promising and prestigious sciences of the early 21st century. Materials science (including nanotechnology) and the life sciences did not form as disciplines in a traditional sense, through specialization within existing fields, but rather by the gathering of scientists from a variety of disciplines around new problems and the use of new types of instruments and methods (such as atomic force microscopy, nuclear magnetic resonance, the new tools of molecular biology), all supported by new funding initiatives from public and private actors with

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[46] J Capshew and K Rader, “Big science: Price to the present,” *Osiris 2nd series*, 7 (1992): 3-25. C Westfall, “Rethinking big science: Modest, mezzo, grand science and the development of the Bevalac, 1971-1993,” *Isis* 94, (2003): 30-56. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 13ff, 236ff.

[47] M Riordan, L Hoddeson and A Kolb, *Tunnel visions. The rise and fall of the Superconducting Super Collider* (The University of Chicago Press, 2015). P Galison and B Hevly (eds.), *Big science – The growth of large-scale research* (Stanford University Press, 1992). D Greenberg, *The politics of pure science*, 2nd ed. (The University of Chicago Press, 1967/1999).

[48] For a thorough discussion on this, see O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), especially chapters 1, 2 and 3.

[49] O Hallonsten, “The parasites: Synchrotron radiation at SLAC, 1972-1992,” *Historical Studies in the Natural Sciences* 45 (2015): 217-272. O Hallonsten and T Heinze, “Formation and Expansion of a New Organizational Field in Experimental Science,” *Science and Public Policy* 42 (2015): 841-854.

the agenda of supporting research with long-term strategic importance for society and the economy.[50] In Sweden, the role of instrument development initiatives in Uppsala, Linköping and Chalmers, and later also Lund, and the proactive funding initiatives of the Board of Technical Development (Styrelsen för Teknisk Utveckling, STU) and the Knut and Alice Wallenberg Foundation (KAW) have been proven especially important in the process of establishing these fields in the late 20th century.[51]

As one of the most iconic types of Big Science infrastructures of the Cold War era – particle accelerators – proved useful to provide enhanced experimental opportunities in materials science and the life sciences (broadly defined), and other areas, they entered the analytical category of *generic instruments*, which means instrumentation developed for one purpose and subsequently used for others, or instrumentation designed for several, not predefined, areas of use.[52]

Today, *research infrastructures* are popular in research and innovation policy circles. They are considered vital to the EU strategies for innovation, and several countries (including Germany, France, the United Kingdom, and the United States) have launched specific initiatives to coordinate and stimulate efforts to develop and establish research infrastructures. On European level, the European Strategy Forum on Research Infrastructures (ESFRI) was launched in 2002 to help implement the goals laid out in the Lisbon Strategy of 2000, namely to build on the "central role" of research infrastructures for the future of the European "knowledge-based economy" and the so-called European Research Area (ERA).[53]

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[50] B Bensaude-Vincent, "Building Multidisciplinary Research Fields: The Cases of Materials Science, Nanotechnology and Synthetic Biology," in M Merz and P Sormani (eds.), *The Local Configuration of New Research Fields* (Springer, 2016). R Cahn, *The Coming of Materials Science* (Pergamon, 2001). H-J Rheinberger, "Recent Orientations and Reorientations in the Life Sciences," in M Carrier and A Nordmann (eds), *Science in the Context of Application* (Springer, 2011).

[51] J Gribbe and O Hallonsten, "The emergence and growth of materials science in Swedish universities," *Historical Studies in the Natural Sciences* 47 (2017), forthcoming.

[52] B Joerges and T Shinn (eds.), *Instrumentation between science, state and industry* (Kluwer, 2001). T Shinn and B Joerges, "The transverse science and technology culture: Dynamics and roles of research-technology," *Social Science Information* 41 (2002): 207-251. This is a concept not restricted to the scientific use of instrumentation; in principle, also other technologies that spread across wider spectra of utilization qualify as generic technologies, with the microchip as probably the most spectacular example, pointed out by N Rosenberg, "Scientific instrumentation and university research," *Research Policy* 21 (1992): 381-390.

[53] European Commission, "Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions: Towards a European research area," http://ec.europa.eu/research/era/pdf/towards-a-european-research-area_com_2000_en.pdf (accessed 14 December 2016). European Commission, "A vision for strengthening world-class research infrastructures in the ERA. Report of the Expert Group on Research Infrastructures," http://ec.europa.eu/research/infrastructures/pdf/era_100216.pdf (accessed 14 December 2016).

Behind the general phrases lies an acknowledgement of the important generic character of research infrastructures: In the definition used by the European Commission, research infrastructures are "facilities, resources and related services used by the scientific community to conduct top-level research *in their respective fields*" (emphasis added), and synchrotron radiation laboratories are often used as examples to prove the capability of research infrastructures to bring together a variety of scientific disciplines whose work connects to R&D and innovation in a number of fields.[54]

The first ESFRI "roadmap" for European research infrastructures was published in 2006, containing 35 projects and upgrades in a wide variety of fields, all of which were branded "key projects" by ESFRI on basis of a thorough investigatory work involving nearly 1000 experts in a peer review process that took two years.[55] Updates have since been published three times, in 2008, 2010, and 2016.[56] In Sweden, the Committee for Research Infrastructure was formed within the Swedish Research Council in 2005, and in 2010 it was transformed into a sub-council of its own. The committee/council issued its first Swedish research infrastructure roadmap in 2007, and it was followed by updates in 2012 and 2014.[57] Several other countries have issued similar roadmap documents over the past decade.[58]

In all these documents emerges a picture of research infrastructures as versatile resources for wide varieties of scientific work (including with commercial potential), very much in line with the discussion in chapter 1 on the *division of labor* or *functional differentiation* between facilities like MAX-lab and their user communities, where the facility or research infrastructure makes up a resource for scientists to use for whatever purposes they need. That this resource is many times absolutely vital for a scientific project to be possible to carry out means, on aggregated level, that research infrastructures can take a fundamentally system-bearing role in the research system or innovation system. This must be acknowledged, both in impact studies of research

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[54] European Commission, "What are RIs?" http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=what (accessed 14 December 2016).

[55] European Strategy Forum on Research Infrastructures, "European Roadmap for Research Infrastructures Report 2006," https://ec.europa.eu/research/infrastructures/pdf/esfri/esfri_roadmap/roadmap_2006/esfri_roadmap_2006_en.pdf (accessed 14 December 2016).

[56] European Strategy Forum on Research Infrastructures, "Strategy Report on Research Infrastructures," http://www.esfri.eu/sites/default/files/20160309_ROADMAP_browsable.pdf (accessed 14 December 2016).

[57] Swedish Research Council, "Vetenskapsrådets guide till infrastrukturen," http://www.vr.se/forskningsinfrastruktur/vetenskapsradetsguidetillinfrastrukturen.4.61663a161121008575380002821.html (accessed 14 December 2016).

[58] See for example the "Large Facilities Roadmap," Research Councils UK, http://www.rcuk.ac.uk/documents/research/rcuklargefacilitiesroadmap2010-pdf/ (accessed 14 December 2016); the "Roadmap für Forschungsinfrastrukturen," Bundesministerium für Bildung und Forschung, https://www.bmbf.de/pub/Roadmap_Forschungsinfrastrukturen.pdf (accessed 14 December 2016).

infrastructures (like this one) and in general discussions on the role and function of various entities in innovation systems.

While the functional differentiation between infrastructure and users was probably not as articulated or marked in the case of Big Science in the Cold War era, it is clearly key to the understanding of what research infrastructures are, and what their role(s) and function(s) vis-à-vis other actors in the system are, today. Current developments in the international science system seem only to accelerate this development, and for the study at hand, its acknowledgement is a fundamental conceptual starting point: It is a mistake to discuss research infrastructures like MAX-lab in terms of performing units in science, and to compare them squarely to other organizations or organizational units in any form of assessment of productivity. Instead, the system-bearing role of MAX-lab should be assessed in a wide and deep analysis of its role(s) and function(s).

2.2 Synchrotron radiation laboratories: History, organization, science, technology

> "The most straightforward and most important conclusion of this study is that over the past 20 years in the United States synchrotron radiation research has evolved from an esoteric endeavor practiced by a small number of scientists primarily from the fields of solid state physics and surface science to a mainstream activity which provides essential information in the materials and chemical sciences, the life sciences, molecular environmental science, the geosciences, nascent technology and defense-related research among other fields."[59]

It was briefly noted in the previous section that synchrotron radiation originally was a mere (unwanted) byproduct from accelerators used for experimental particle physics. This is due to a fundamental law of physics, theoretically predicted by James Clerk Maxwell in the 1860s, namely that an accelerated elementary particle whose trajectory is bent (for example in a round-shaped accelerator) will lose energy in the form of radiation emerging in the tangential direction.[60] Particle physicists seek to achieve as high energies as possible in the particle collisions that they use to detect constituent particles and forces that emerge from such collisions, and so the energy loss was always a nuisance to those who constructed accelerators for this purpose, which led them to document and analyze the radiation carefully. The most popular and advanced

[59] B Birgeneau and Z-X Shen, "Report of the Basic Energy Sciences Advisory Committee Panel on D.O.E. synchrotron radiation sources and science," (US Department of Energy's Office of Science's Office of Basic Energy Sciences, 1997), p 7.

[60] J Blewett, "Synchrotron radiation – Early history," *Journal of Synchrotron Radiation* 5 (1998), 135-139, on p 135.

accelerator in the period from the late 1940s and until the mid-1960s was the *synchrotron*, and therefore the radiation was called *synchrotron radiation*. It was first visually detected in 1947, "as a small spot of brilliant white light by an observer looking into the vacuum tube tangent to the orbit and toward the approaching electrons" at the General Electric Research Laboratory in Schenectady, New York.[61] Further documentation and analysis of the character of the radiation revealed that it ranged from infrared over visible light to ultraviolet and also stretching into the x-ray range, and that its potential intensity was way greater than what any existing x-ray lamp could produce, which meant that on theoretical level, the prospective usefulness of the radiation – would it be possible to safely and efficiently extract, focus and tune it (with respect to wavelength), direct it at a fitting sample, and detect the effects it had on this sample – were tremendous.[62] With the advances on the side of optics and vacuum technology, prospects increased for practical utilization of synchrotron radiation for spectroscopic studies of materials in solid-state physics. Such work was undertaken at the Frascati synchrotron in Italy and the National Bureau of Standards (NBS) in Washington, DC, in the early 1960s.[63] At the newly opened Deutsches Elektronen-Synchrotron (DESY) in Hamburg, a project to use synchrotron radiation to study the contraction of frog muscles(!) was initiated in 1964.[64] The first accelerator-based facility operated with the sole to produce radiation was Tantalus in Soughton, Wisconsin (a converted nuclear physics machine), which opened to use in 1968.[65] The first purpose-built synchrotron radiation facility was the SOR machine in Tokyo, which started operation in 1974.[66]

Several technical, scientific and organizational challenges stood in the way of synchrotron radiation contributing to significant advances in the 1960s. But analyses have shown that the challenges also created favorable conditions for technical and scientific advances, and that the methodical work to overcome them also produced significant breakthroughs on technology and science. Accelerators were typically owned and operated by particle physicists, which meant that access to the radiation was restricted and the room for calibration of accelerator performance to improve the

[61] F Elder, A Gurewitsch, R Langmuir and N Pollock, "Radiation from electrons in a synchrotron," Physical Review Letters 71 (1947): 829-830.

[62] H Winick and A Bienenstock, "Synchrotron radiation research," *Annual Review of Nuclear and Particle Science* 28 (1978): 33-113, on pp 39-41.

[63] I Munro, "Synchrotron radiation," in A Michette and S Pfauntsch (eds.), *X-rays: The first hundred years* (Wiley, 1996), p 132.

[64] T Heinze, O Hallonsten and S Heinecke, "From Periphery to Center: Synchrotron Radiation at DESY, Part I: 1962–1977," *Historical Studies in the Natural Sciences* 45 (2015): 447-492, on pp 461-462.

[65] David W. Lynch, "Tantalus, a 240 MeV Dedicated Source of Synchrotron Radiation, 1968-1986," *Journal of Synchrotron Radiation* 4 (1997): 334-343.

[66] Taizo Sasaki, "A Prospect and Retrospect – the Japanese Case," *Journal of Synchrotron Radiation* 4 (1997): 359-365.

quality of the radiation was close to zero. Meanwhile, access came at a comparably very low cost: The early users of synchrotron radiation did not have to invest millions of dollars to build and operate state-of-the-art accelerator complexes but could explore the possibilities of using the radiation at a very small budget. This situation remained until the early 1980s – up until the purpose-built BESSY (Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung) in Berlin and the SRS (Synchrotron Radiation Source) in Daresbury, UK, opened to scientific use in 1981, all synchrotron radiation activities worldwide were either parasites on particle physics programs, or using accelerators that had been abandoned by nuclear or particle physicists.[67] For the development of the use of synchrotron radiation worldwide, this meant that initial expansion could occur inside preexisting organizations, tapping into the resource economies of established research labs (foremost in particle physics), and that a certain level of technical and organizational progress had been achieved when the first independent labs were launched, that these could build on. Further down the road, as synchrotron radiation was firmly established as a vital experimental resource in a wide variety of sciences, the important processes were consolidation of best practices on a number of technical, scientific and organizational matters.[68]

On the technical side, the first greatest breakthrough for synchrotron radiation came with the *storage ring* accelerator design, which was developed mainly at Stanford University in the 1960s, and implemented at several particle physics labs in the early 1970s and on.[69] A synchrotron keeps particles in acceleration a mere few milliseconds, which means that radiation is only emitted in very short flashes, whereas a storage ring keeps them *stored* (hence the name) in circulation for hours and thus can deliver continuous beams of radiation (although most are designed to produce pulses of variable length). Moreover, the available synchrotrons could not produce radiation in the x-ray range, but prospects were good that storage rings would, and therefore plans were made both at the Stanford Linear Accelerator Center (SLAC) and at DESY in Hamburg to start use the radiation emitted immediately as their respective storage ring facilities were taken into operation.[70] Results from greatly enhanced spectroscopy experiments, but also structural biology, emerged from these labs in the mid-1970s.

The second major technical breakthrough was the invention of so called *insertion devices*. Originally (and still to this day, at some facilities), synchrotron radiation was

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[67] Note, here, that also the first synchrotron radiation activities at MAX-lab were in a sense "parasitic", since the MAX ring was funded and originally designed as a facility for nuclear physics. See section 2.4.

[68] For a thorough discussion on this topic, see O Hallonsten and T Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42 (2015): 841-854.

[69] W Panofsky, *Panofsky on physics, politics, and peace: Pief remembers* (Springer, 2007), p 56.

[70] O Hallonsten, "The parasites: Synchrotron radiation at SLAC, 1972-1992," *Historical Studies in the Natural Sciences* 45 (2015): 217-272. T Heinze, O Hallonsten and S Heinecke, "From Periphery to Center: Synchrotron Radiation at DESY, Part I: 1962–1977," *Historical Studies in the Natural Sciences* 45 (2015): 447-492, on p 455.

extracted from the bending magnets where the particles in the storage ring are forced to bend their trajectory and thus naturally emit radiation. This beam is, however, emitted in a broad planar angle and this puts some restrictions on the ability to focus and extract an intense beam. An insertion device is an array of magnets that is installed (inserted, hence the name) in a straight section of a storage ring, where it makes the particles oscillate left-right or up-down (or any combination of these, i.e. in a spiral), depending on how the magnets are arrayed, and emit a far more intense beam (since every single turn of the particles produces radiation) that can also be manipulated with respect to polarization, wavelength range, and coherence (see below). Since the 1980s, insertion devices have been the preferred radiation source and since the early 1990s, all new synchrotron radiation facilities in the world are purpose-built for the optimal use of insertion devices. Two types exist – *wigglers* produce a continuous short wavelength beam, and *undulators* produce a spectrum with peaks in specific wavelengths, and the two are therefore complementary in their functions. Their technical development has followed other progress, foremost on the side of accelerators where not least the size of the electron bunches accelerated in the rings have been decreased dramatically which is an important development to increase the brightness of the radiation. Consequently, in the 1980s, 90s and 2000s, on average, the peak brightness achieved at new synchrotron radiation sources increased by one order of magnitude every 24 months(!).[71]

Almost all synchrotron radiation programs in the world remained parasitic until the mid-1980s, and synchrotron radiation remained a largely peripheral technique in global perspective, in spite of some efforts by governments and research funders to invest in purpose-built sources. The rather successful track record of European countries to collaborate on large scientific facilities made the newly created European Science Foundation (ESF) suggest a pan-European, purpose-built synchrotron radiation facility already in the mid-1970s, and similar initiatives were discussed both in Japan and the United States. Planning, design and the politics of funding and organization of these labs took the better part of the 1980s, but as the 1990s began, all three were under construction. In 1994, 1995 and 1996, respectively, the "big three" synchrotron radiation facilities – the European Synchrotron Radiation Facility (ESRF) in Grenoble, the Advanced Photon Source (APS) at Argonne National Lab in Illinois, and the Super Photon ring 8 GeV (SPring-8) in Harima northwest of Osaka – opened for scientific use. They are still the largest synchrotron radiation facilities in the world, with annual user numbers of roughly 4,000 (APS), 6,000 (ESRF) and over 10,000 (SPring-8),[72] and

[71] R Frahm and G Williams, "Twenty Years of Synchrotron Radiation," *Synchrotron Radiation News* 20 (2007): 2-3.

[72] O Hallonsten, "Introducing 'facilitymetrics': A first review and analysis of commonly used measures of scientific leadership among synchrotron radiation facilities worldwide," *Scientometrics* 96 (2013): 497-513. O Hallonsten and T Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42 (2015): 841-854, on p 845.

their start of operation in the 1990s was a major milestone in the transformation of synchrotron radiation from "esoteric endeavor" to "mainstream activity" (see the quote above). Importantly, the historical development of nuclear and particle physics, especially in Europe and the United States, opened vast opportunities: Resources were concentrated to a smaller number of sites (e.g. CERN in Europe, Fermilab in the United States), which created "mission crises" for several US National Laboratories and also freed resources on national level in some European countries (such as in Lund, see section 2.4), that the champions of synchrotron radiation could make use of.[73]

A means of categorizing synchrotron radiation facilities, convenient for the historian, is their identification as first, second, and third *generation*. In this categorization, the first generation is the parasitic programs at particle physics labs in the 1960s and 1970s (some of which continued well into the 1980s). The second generation is the group of purpose-built synchrotron radiation facilities at the end of the 1970s and beginning of the 1980s, that did not use insertion devices (until later on, as technical modifications allowed this) but were designed to produce radiation from bending magnets. The early MAX-lab was in this category (although insertion devices were used early on), together with the SRS at Daresbury and the NSLS at Brookhaven National Lab on Long Island, NY. The third generation are the purpose-built facilities of the 1990s and on, designed to make full use of insertion device technology. The third generation is still the dominant design of synchrotron radiation facilities worldwide, although there has obviously been vast technical (and scientific) progress since the early 1990s. Early on, restrictions on the technological side made it necessary to build very large storage rings with very high energy in order to access radiation in the hard x-ray range, which was part of the reason for the design and construction of the 'big three' – APS, ESRF and SPring-8 – in the 1990s. A complementary subcategory of third generation sources was the smaller rings optimized for producing radiation in the soft x-ray and ultraviolet ranges, among which MAX II was one (together with Elettra in Trieste, Italy, and the ALS at Lawrence Berkeley National Laboratory in California).[74]

The maturing insertion device technology opened dramatic new opportunities in the 1990s, especially in structural biology where the access to reliable and extremely bright hard x-rays increased the use of synchrotron radiation for structural determination of

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[73] C Westfall, "Surviving the squeeze: National laboratories in the 1970s and 1980s," *Historical Studies in the Natural Sciences* 38 (2008): 475-478. C Westfall, "Retooling for the future: Launching the Advanced Light Source at Lawrence's Laboratory, 1980-1986," *Historical Studies in the Natural Sciences*, 38 (2008): 569-609. O Hallonsten, "The Politics of European Collaboration in Big Science," in M Mayer, M Carpes and R Knoblich (eds.), *The Global Politics of Science and Technology - Vol. 2* (Springer, 2014). O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215. O Hallonsten, *Big Science Transformed. Science, Politics and Organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 80ff.

[74] O Hallonsten and T Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42 (2015): 841-854, on pp 844-845.

macromolecules (e.g. proteins) with crystallography. Especially the 'big three' took the lead in this development. Their role in the expansion of the user base in the life science was dual, as they both increased the availability of high quality radiation in a quantitative sense (increasing the global number of users possible to serve annually with close to twenty thousand over a decade), and made available beamlines and experimental stations customized for high-throughput of the comparably mundane crystallographic measurements that structural biologists in academia and industry requested, at a very high quality. Automated data taking enabled mainstream operation and a very high reliability of instruments, which these users were accustomed to in their home labs and demanded also from synchrotron radiation facilities. The eventual launch of web-based remote operation of crystallography stations and full-range services where scientists send their samples by mail and get data back without having to travel, also improved the conditions for these applications. Consequently, as seen in figure 2.1, the annual number of protein structures solved with the use of synchrotron radiation and deposited in the online Protein Data Bank multiplied in the 1990s and continued to increase dramatically in the 2000s.

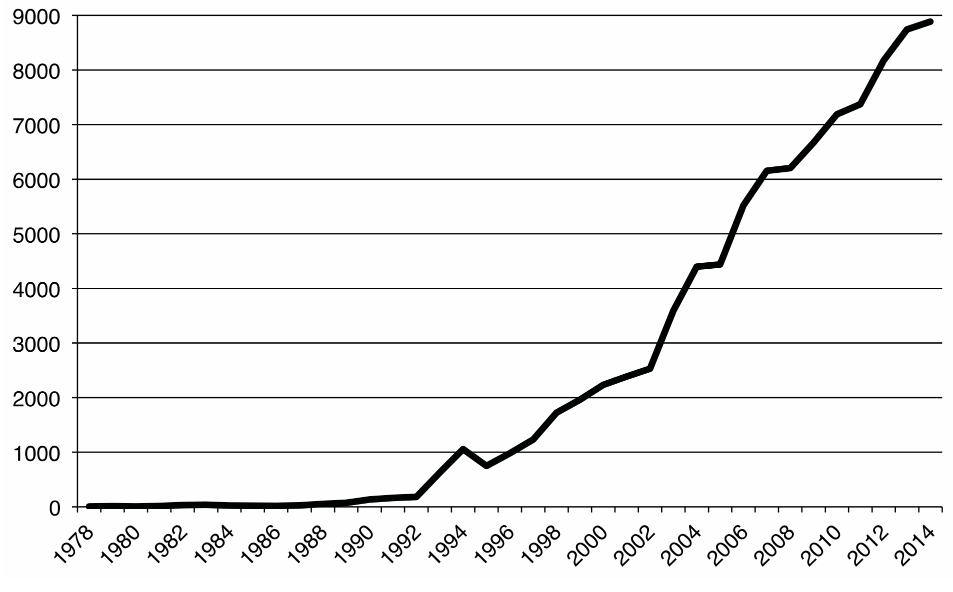

Figure 2.1:
Annual number of protein structures solved with the help of synchrotron radiation and deposited in the Protein Data Bank, 1978–2014.[75]

[75] Reprinted (with permission) from O Hallonsten, *Big Science Transformed. Science, Politics and Organization in Europe and the United States* (Palgrave Macmillan, 2016), p 252.

The broadening of the user base in the life sciences also coincided – causalities are difficult to establish here – with a kind of breakthrough for synchrotron radiation at the cutting edge of life sciences research globally. In 1997, the first Nobel Prize was awarded for a discovery that built strongly on work done with the help of synchrotron radiation, and between 2003 and 2012, another four Nobel Prizes in chemistry was awarded for achievements with a similarly strong connection to synchrotron radiation.[76]

In the late 1990s, several technical restrictions had been overcome and it became possible to build smaller rings that could produce radiation in the full range from VUV (vacuum ultraviolet) to hard x-rays. ('Soft' and 'hard' x-rays are colloquial terms for x-rays of wavelengths longer and shorter than approximately 1 Ångström. X-rays with a shorter wavelength have a greater penetrating ability, hence the label "hard".) Costs had also sunken dramatically, and demand grown, which led several countries to invest in new facilities of this new type in the early 2000s, including the UK (Diamond Light Source), France (Soleil), the United States (NSLS-II), and China (SSRC), but also countries that had previously not had any national synchrotron radiation sources, such as Switzerland (SLS), Spain (ALBA), Taiwan (NSRRC), Singapore (SSLS), Australia (AS) and Canada (CLS).[77] The MAX IV facility is a prime example of this new type of storage ring that can deliver extremely high brilliance hard x-rays in spite of its relatively modest size (in meters of circumference), although several things rather support the interpretation that the MAX IV design inaugurates a new category of light sources, since its technical design in many aspects is completely new and revolutionary (see sections 2.4 and 7.1.2). It would, however, be confusing to name MAX IV and its descendants elsewhere the "fourth generation", since this has long been the conventional label for free electron lasers.

The field of storage ring-based synchrotron radiation laboratories entered a period of consolidation around best practices on the technical and organizational side in the late-1990s, paired with a continuing expansion of the number of labs worldwide as well as user numbers. The larger labs are undergoing upgrades to match the performance of new facilities, and old and deserted particle physics accelerators are being upgraded to high-performance synchrotron radiation facilities. But the most dramatic leap in performance takes place at free electron laser labs, where linear accelerators are used to produce extremely bright and completely coherent radiation (laser) in the ultraviolet and x-ray ranges. Free electron lasers will not replace storage ring-based sources but complement them by offering some highly specialized experimental opportunities with

[76] John Walker in 1997; Roderick MacKinnon in 2003; Roger Kornberg in 2006; Ada Yonath, Tomas Steitz, and Venkatraman Ramakrishnan in 2009; and Robert Lefkowitz and Brian Kobilka in 2012. All in chemistry.

[77] O Hallonsten and T Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42 (2015): 841-854, on p 843.

extreme performance on some parameters.[78] Free electron lasers first emerged on the drawing board in the 1970s, but it was not until the 1990s and 2000s that the concept became feasible and the first free electron laser user facilities were planned and constructed. The former particle physics hotspot the Stanford Linear Accelerator Center (SLAC; nowadays renamed the SLAC National Accelerator Laboratory) is home of the world's first x-ray laser the Linear Coherent Light Source (LCLS) which opened to scientific use in 2009 and is currently undergoing a vast expansion. In Hamburg, the European X-ray Free Electron Laser (XFEL) is built adjacent to DESY through a European intergovernmental collaboration and will start operation in 2017.[79] MAX-lab developed and operated a free electron laser in the ultraviolet region in the late 1990s and early 2000s, purely as an accelerator physics R&D project (and thus never for scientific use), and plans are currently drafted for an expansion of MAX IV consisting of an x-ray free electron laser based on the linac injector, which was designed to allow this type of upgrade in the future.[80]

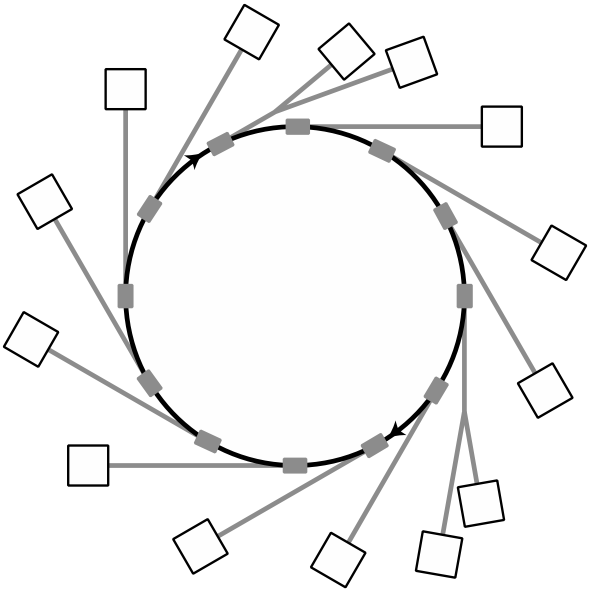

Figure 2.2:
Schematic illustration of the layout of a synchrotron radiation facility[81]

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[78] Ibid., on p 846.

[79] O Hallonsten and T Heinze, "From particle physics to photon science: Multidimensional and multilevel renewal at DESY and SLAC," *Science and Public Policy* 40 (2013): 591-603, on pp 595, 598.

[80] See e.g. *MAX IV Conceptual Design Report* (MAX-lab 2006), p 5.

[81] Reprinted (with permission) from O Hallonsten, *Big Science Transformed. Science, Politics and Organization in Europe and the United States* (Palgrave Macmillan, 2016), p 243.

Figure 2.2 shows a schematic illustration of the basic layout of a typical synchrotron radiation facility, where the black circle is the storage ring that keeps electrons at high speed/energy (black arrows) and have them pass through bending magnets in the corners of the ring and insertion devices in the straight sections – these are the smaller grey boxes. For reasons of simplicity, the figure is erroneous in more than one way (see below), one of which is the fact that storage rings are polygonal rather than circular. In the bending magnets and insertion devices, the electrons produce the radiation that is led through the tangential beamlines (grey lines) to the experimental stations (white boxes). The beamlines are all simultaneously served with radiation and can therefore operate independently and in parallel. As the figure shows, some beamlines host more than one experimental station, and in reality, there can be several (such as with the beamline I911 or "Cassiopeia" on MAX II; see chapters 3.5 and 4.3.1). The technical setup and the type of experiments supported by the stations determine whether one beamline can serve several simultaneously operating experiments or whether the radiation beam is directed to only one of them at a time.

The number of beamlines and experimental stations at a facility depends ultimately on the size of the storage ring (and of course the design of the host building) but also funding and capacity of the lab: Beamlines and experimental stations are very costly and takes great effort to build and commission, and they are normally built because there is an identified (or declared) specific demand in the user community. The maximum physical capacity of a lab needs therefore not be utilized at every point in time; quite the reverse, at a new lab, beamlines are typically built in a stepwise fashion so that the lab is overcrowded only after several years. This was true for MAX I and MAX II (see section 2.4 below) and many other labs in the world. Beamlines and experimental stations can also be modified, upgraded and even completely substituted as demand in the user community, or ambitions on behalf of the lab leadership, shifts.

Several things are missing in figure 2.2 above, and were omitted for reasons of clarity. First of all, the particles that are kept circulating in the storage ring are generated by an electron gun and pre-accelerated in a linac, and sometimes also a booster synchrotron. Second, the radiation beams also pass several technical devices on their way from the storage ring and to the experimental stations, where they are focused and polarized (by gratings and mirrors) and not least specific wavelengths of radiation are separated, by specific devices called *monochromators* (From Greek: *mono*=single, *chrom*=color). Different experiments make use of different wavelengths of radiation, and although some insertion devices can be built to achieve especially brilliant radiation in specific wavelength ranges, most of them (and bending magnets) emit radiation across the full wavelength spectrum from infrared and visible light to ultraviolet and x-rays, and monochromators are necessary to purify the radiation with respect to wavelength.[82]

[82] H Winick, *Synchrotron Radiation Sources: A Primer* (World Scientific, 1994), p 479.

When approaching the issue of scientific use of synchrotron radiation facilities, it is important to keep in mind that both the user communities and the labs are dynamic and very broad. A study of three user facilities in the United States, one of which is the synchrotron radiation facility the Advanced Light Source (ALS) which was built at the same time as MAX II and covers a similar user community (and the other two are the free electron laser LCLS and the neutron scattering facility SNS), showed that the experimental work done at the three facilities and published in 2014 appeared in journals placed in very disparate subject categories in the Web of Science (WoS) database. The total of 1,079 articles in the sample were spread over a group of 248 journals that represented 73 subject categories. Among these, 'Multidisciplinary Materials Science' and 'Biochemistry and Molecular Biology' dominate, but also 'Environmental Sciences', 'Mineralogy', and 'Physiology' are fairly common.[83] The same study pointed out that the categories used by the three facilities in their annual reports and advertisement material do not correspond to the journal categories but vary similarly. Other studies have demonstrated the same diversity and mismatch between different categorizations using other facilities as cases in point,[84] and also shown that entirely new cross-disciplinary work is likely to emerge in these highly sophisticated experimental settings.[85] Any attempt to strictly categorize or sort the scientific activities of present-day synchrotron radiation facilities with the help of traditional disciplinary labels are therefore likely to be very complicated and hard to generalize upon. The same goes for the techniques used – the variety is remarkable and although some exceptions exist (e.g. in crystallography, where standardization is a virtue), there are few examples of identical experimental stations at two different synchrotron radiation facilities in the world.

The following description of techniques and their scientific use is therefore prone to be oversimplified and miss out on some crucial details.

One very broad categorization that might be workable is to begin by establish that synchrotron radiation facilities are used to study samples of materials (including biomaterials) and that a separation can be made between the study of *geometrical structure* with x-ray diffraction, and *electronic structure* with various spectroscopic techniques. The former means studying the geometrical structure of molecules and atoms, and the object under study might then be a protein or a material of some kind. The latter means studying the electronic structure of a material, whereby energy levels,

[83] O Hallonsten, "Use and productivity of contemporary, multidisciplinary Big Science," *Research Evaluation* 25 (2016): 486-495, on p 489.

[84] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 111.

[85] R Heidler and O Hallonsten, "Qualifying the performance evaluation of Big Science beyond productivity, impact and costs," *Scientometrics* 104 (2015): 295-312, on p 309.

densities, magnetism and similar things, and the mechanisms that hold the atoms together, can be unveiled.

The study of electronic structure of materials was the first of these broad areas of use where synchrotron radiation became mainstream, within some subspecialties of condensed matter physics in the 1970s and 80s. Techniques such as photoelectron spectroscopy and absorption spectroscopy, which existed in ordinary lab settings before, were greatly enhanced by the high brightness of synchrotron radiation. Very rudimentarily explained, the technique uses the radiation to disturb the electrons in the atoms of a sample, whereby (photo)electrons or radiation is emitted, that can be detected and that reveals information about the structure of a molecule of a compound that is not possible to obtain with microscopy or crystallography (see below). The applications are wide – the information that electron spectroscopy can reveal about e.g. the structures of surfaces of materials used in electronics is crucial for the technological development in many industries today. The very large wavelength spectrum of synchrotron radiation (from infrared over visible light and ultraviolet to x-rays), and the ability to tune the wavelength, have offered new opportunities not least in the study of various materials, including not only solids but also liquids and gases.[86]

The importance of advanced materials in the contemporary society and economy, so oriented towards consumer products, is vast.[87] Likewise, the reliance on advanced materials in the technologically oriented efforts to meet current society's grand challenges associated with the ambition to achieve sustainable growth, is huge. The importance of advanced techniques for analysis and study of materials on electronic level, with respect to strength, viscosity, magnetism, conductivity, and so on, is perhaps greater than ever. Synchrotron radiation facilities have a proven track record of providing opportunities for using such techniques at the cutting edge of technology and science.[88]

As will be noted in other chapters, just as in several other places around the world, Sweden's strong tradition in electron spectroscopy formed a solid basis for the development of the first beamlines and experimental equipment at MAX I. Compared to the lab equipment available at Uppsala University, Linköping University, and Chalmers University of Technology in Göteborg, the spectroscopy beamlines at MAX I provided experiments with a much more intense beam of radiation in a wider spectrum, which both increased the possible phenomena to be studied, and allowed a greater variety of how to apply the technique.

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[86] I Munro, "Synchrotron radiation," in A Michette and S Pfauntsch (eds.), *X-rays: The first hundred years* (Wiley, 1996).

[87] See e.g. the example of going to buy a pack of milk, used by Svante Svensson in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 11.

[88] C Mody and J Martin, "Tools in Materials Research" in *WSPC Encyclopedia of the Development and History of Materials Science*. Fortcoming 2017.

Crystallography is the technique of revealing the structure of a crystallized (and thus purified) molecule by aiming an x-ray beam at the crystal and detecting the diffraction pattern, i.e. how the beam was scattered off the crystal. The use of synchrotron radiation for crystallography increases the level of detail of the structural determination, and the time it takes, because the high intensity increases the amount of information obtained per time unit. Also, the ability to make time-resolved studies and to adjust the wavelength for a specific sample make synchrotron radiation advantageous for crystallography. The technique is used both in materials science, to determine the molecular structure of advanced materials, and in the life sciences (including not least drug design), to determine the structure of proteins, which are the most common biomolecules.

According to many analysts, crystallographic techniques with high-intensity x-rays have revolutionized large parts of the life sciences and also the pharmaceutical industry. Figure 2.1 above, showing the growth in the annual number of protein structures solved with synchrotron radiation and deposited in the Protein Data Bank, is the most palpable evidence. What the figure does not show, however, is how synchrotron radiation has come to dominate in the structural determination of very large proteins. Although other techniques such as nuclear magnetic resonance (NMR) are also used alongside x-rays, it is clear that the high intensities achieved at synchrotron radiation laboratories from the 1990s and on, in combination with the lean operation, the orientation to the specific needs of this user community, and the focus on high throughput, have had enormous impact on structural biology.[89] The scientific achievements enabled were mentioned in a previous paragraph with the use of the successive Nobel Prizes in chemistry as examples. The direct impact that the development of protein crystallography with the use of synchrotron radiation has had on drug design is likewise significant: structural determination of proteins is nowadays key to drug development, since it is mostly proteins in the human body that receives the active substance of a drug.[90] Typically, hard x-rays (shorter wavelengths) are necessary for crystallography.

For objects large enough to be visible to the human eye, which means some three to four orders of magnitude larger than the biggest known proteins, x-rays of course have the advantage that they can reveal hidden structures (like in hospital or airport security checks x-rays). This use of synchrotron radiation is usually called *imaging* and is used in medicine, environmental studies, paleontology, archeology, and the history of arts, where needs appear to study objects on a very high level of detail. This category of use

[89] T Blundell and S Patel, "High-throughput X-ray crystallography for drug discovery," *Current Opinion in Pharmacology* 4 (2004): 490-496. C Murray and D Rees "The rise of fragment-based drug discovery," *Nature Chemistry* 1 (2009): 187-192.

[90] L Hardy and A Malikayil, "The impact of structure-guided drug design on clinical agents," *Current Drug Discovery*, December 2003: 15-20. N Borshell and M Congreve, "Valuation benefits of structure-enabled drug discovery" *Nature Reviews* 10 (2011): 1.

can be conceptually identified as an extension of the study of geometrical structure with synchrotron radiation (diffraction), where the quality of the x-rays means a better resolution and not least the shorter wavelengths make it possible to study smaller objects at a higher level of detail.

The user community of synchrotron radiation facilities varies a lot over time and is generally composed of ordinary researchers from universities, institutes and companies who travel to the facilities to do a couple of days' or weeks' work as part of their ordinary projects and research activities, which are normally funded by their home organization or a grant, or both. Although no two user groups are exactly alike, there are some general differences within the user communities that need some attention. Oversimplifying slightly, the categorization of experiments above, in electronic structure and geometrical structure, corresponds to a categorization of users as well: One large group of experimentalists, typically using spectroscopic techniques to study the electronic structure of materials, have a relatively high level of technical competence and a habit of modifying and adapting equipment as part of the experimentation, and are also the users that typically engage in instrument design and development. They spend several days, sometimes weeks, at the facility at a time. Early on, MAX-lab was dominated by this type of users. The other group are crystallographers, who came in later both as synchrotron radiation users globally (see above) and at MAX-lab, and who have relatively low technical expertise and expect not to have to care much at all about how the equipment work – the great challenge to a crystallographer is normally to prepare a good sample (crystal) and once present at a synchrotron radiation laboratory, the user simply expects the beam to shine through and the results to be recorded in a lean and swift manner. Crystallography beamlines are also generally much more standardized and require little intervention by the user to work, and they spend only one or a few days at the facility.[91]

As noted briefly in the very first section of this report, access to the facilities and instrumentation at MAX-lab was provided free of charge to anyone who submitted a proposal that was judged scientifically excellent and technically feasible by the proposal review panel (or Program Advisory Committee, PAC, as it was called at MAX-lab). This is the common way for most, if not all, synchrotron radiation facilities worldwide, although procedures vary slightly. At most places, including MAX-lab, the lion's share of experimental time is awarded to research groups in this procedure of organized peer review. Some time can be earmarked for staff scientists or for external groups who have made especially important contributions to the design and construction of instrumentation. The regular allocation of experimental time follows a procedure where a call for proposals is issued once or twice a year, after which the applications submitted are reviewed and graded by the panel(s) in charge of this task. All labs publish detailed

[91] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 119-120.

information regarding their beamlines and the specific experimental opportunities offered on websites and in annual reports, and users choose where to submit proposals on basis of this information and/or prior knowledge and experience from the lab in question. The popularity of instruments within the same lab can differ widely, and is reflected in oversubscription rates, which means the ratio between demand and supply of experimental time.[92]

Some sociological reflections are apt to conclude this historical and scientific/technological exposé. The long-term growth and transformation of synchrotron radiation as an experimental technique, and the formation and expansion of an organizational field of synchrotron radiation facilities in reciprocity with political, economic, social and not least scientific and technological actors and institutions, reveals several important insights with some relevance for the topic of this report, in a wide sense as well as on the level of some of its most detailed findings.

First of all, the category of organizations that we refer to as synchrotron radiation facilities emerged within preexisting organizations, either (most commonly) particle physics labs where early day synchrotron radiation enthusiasts could make parasitic use of a byproduct of the experiments that dominated, or university settings where small scale initiatives could grow and establish themselves gradually as scientific results emerged and were disseminated. (MAX-lab is an example of the latter.) Besides showing that an unwanted byproduct can become the basis for of a whole new category of scientific experiments and produce a global league of purpose-built labs to host it, this early history also shows that the parasitic use, and the small-scale exploitation of experimental opportunities with very minor resources, was a source of tremendous technological and scientific (and organizational) innovation.[93]

As some scientific and technological proofs of concept had emerged, and the great potential of synchrotron radiation became known to policymakers and funders, the formation of the organizational field of synchrotron radiation laboratories could gain momentum by the launch of several new dedicated labs (the second generation). But the real broadening of user communities occurred later, as insertion device technology became mainstream and some technological and organizational best practices were proliferated and adopted. From then on, the expansion of the fields has continued and the improvements of experimental techniques, user support, and reliability of instruments, have likewise remained in steady growth. This growth has occurred in a complex process where technology development, scientific progress, new funding programs and initiatives, expectations and demands from policymakers, institutional

[92] O Hallonsten, "Introducing 'facilitymetrics': A first review and analysis of commonly used measures of scientific leadership among synchrotron radiation facilities worldwide," *Scientometrics* 96 (2013): 497-513.

[93] O Hallonsten and T Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42 (2015): 841-854.

change of academic and industrial R&D, and broader societal developments have coproduced a transformed Big Science, where some elements of the Cold War era Big Science remain intact but several important things have changed in the process. The mode of use of synchrotron radiation facilities today, as compared to particle physics facilities in the 1960s, is perhaps the most evident change. The wide multidisciplinary character of the user communities of synchrotron radiation facilities is also spectacular in historical perspective.

The complexity of the historical development of synchrotron radiation as an experimental technique, including its impact on science and society, has been analyzed elsewhere.[94] Here, it shall be noted that MAX-lab is a rather useful example of this complex historical development; indeed, a kind of microcosmos where the multifarious interplay of political, economic, social, technological, and scientific interests is what drives development forward. Or, as put by MAX-lab itself in 2002,

> "The field is not based on one single invention or on one single breakthrough, rather it is driven by a modern and very complex buildup of know-how, scientific understanding and advanced organization."[95]

Important to note in this context is also that the global field of synchrotron radiation facilities and their users is a very open community where collaboration between laboratories is far more common and important than competition between them, although of course the latter also exists. The advisory committees and boards of labs are filled with high-profile users and not least directors and scientific staff of other labs, and when new facilities are built, it is commonplace that advisory committees are put together with experts from other labs who gather regularly during the construction and commissioning phases to give advice and help making sure that the new facility meets the expected and desired standards. The scientific and technical development of laboratories, once they are taken into operation, likewise happens with the involvement of the wider global community, through committee work, through workshops and meetings, and through informal contacts. MAX-lab is a very good example –the process through which it grew through the years was very much characterized by interaction between lab and users, and that feedback mechanisms of various sorts were immensely important for the development of the lab and its impact on science and society.

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[94] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016).

[95] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch1p1.

2.3 Sweden and 'Big Science'

It is not surprising, given the historical connection between particle physics and synchrotron radiation established in the previous section, that the political history of MAX-lab begins with CERN and a discussion about the level of the Swedish membership in CERN.

Sweden, spared from the most devastating destruction of World War II, was in a relatively good economic and social position at the end of the war and was swift in joining the international trend of mobilization in science and technology for the purpose of social and economic development.[96] But as a small country with a strong Germanic university tradition, Sweden largely retained a classic research policy where universities dominated on the performer side and were complemented by a number of relatively small industry-specific research institutes, and some largely basic science-oriented research councils were launched to complement the university block grants for research.[97] If Sweden were to have any activities in Big Science, it would have to participate in international collaborations, which it did as a founding member of CERN and of the European Southern Observatory (ESO), and as a reliable partner and participant in most European scientific collaborations formed in the 1960s, 70s and 80s.

CERN, founded in 1954 and beginning scientific operation of its first large particle accelerator the Proton Synchrotron (PS) in 1959, was originally a rather small laboratory and viewed as an urgent and keen project for the whole (Western) Europe, that would forge important peaceful alliances in the postwar era and counter European "brain drain" to the United States, and that most of its countries therefore eagerly participated in.[98] The 1960s meant a radical growth in the sizes and costs of the accelerator complexes necessary to build and operate in order to keep up with

[96] P Lundin and N Stenlås, "Technology, State Initiative and National Myths in Cold War Sweden: An Introduction," in P Lundin, N Stenlås and J Gribbe J (eds.), *Science for Welfare and Warfare: Technology and State Initiative in Cold War Sweden* (Science History Publications, 2010). D Greenberg, *The politics of pure science*, 2nd ed. (The University of Chicago Press, 1967/1999), pp 51-52. B Smith, *American science policy since World War II* (Brookings, 1990), pp 36-37.

[97] R Premfors, *Svensk forskningspolitik* (Studentlitteratur, 1986), p 13. T Nybom, *Kunskap, politik, samhälle. Essäer om kunskapssyn, universitet och forskningspolitik 1900-2000* (Arete, 1997), p 101. I Pettersson, *Handslaget. Svensk industriell forskningspolitik 1940-1980* (KTH Royal Institute of Technology, 2012).

[98] D Pestre, "Some characteristic features of CERN in the 1950s and 1960s," in A Hermann, U Mersits, D Pestre and J Krige (eds.), *History of CERN. Volume II: Building and running the laboratory, 1954-1965* (North-Holland, 1990).

international competition in the field,[99] and at CERN, a major upgrade was proposed that would multiply the financial commitments of the member states.[100]

CERN had been uncontroversial also in Sweden, but the plans for a new enlarged lab spurred an arduous debate and unveiled, for the first time, a systemic shortcoming in Swedish science policy.[101] Focused mostly on expanding the education mission of the universities, the government had established few or no mechanisms in the systems for handling large-scale and discontinuous initiatives and projects. The research councils were mostly elected assemblies where representatives of the academic community distributed comparably small sums of money on a project application and grant basis, and the governmental ministry of education was a small and lean organization with little or no capacity to investigate, prioritize or take initiatives beyond the incremental (but over time, quite dramatic) increases of student admissions to the universities. No ministry of science was ever created in Sweden, and no ministry for atomic affairs, which in other countries became the natural locus of initiative for ventures in Big Science.[102] The decision to join CERN II – as the major CERN upgrade was called – was difficult for most of CERN's member countries, but it seems the shortcomings of Swedish science policy were especially severe, as the decision process was protracted well into 1972, when all other member states had joined. Interestingly, a dual approach on behalf of the government is visible in this story: On one hand, prime minister Olof Palme referred the issue back to the scientific community (i.e. the research councils) with the comment that the scientists should take responsibility for their own priorities; on the other hand, the prime minister also spoke of an "enormous international pressure" that he had been under from colleagues in other European countries, who viewed the Swedish indecision as faithless.[103]

Scientifically, by this turn of events, experimental particle physics was no longer possible to maintain on national level in smaller countries but had to be organized through their memberships in CERN, and similar developments occurred also in e.g.

[99] L Hoddeson, A Kolb and C Westfall, *Fermilab: Physics, the frontier & megascience* (The University of Chicago Press, 2008), pp 281ff. M Riordan, L Hoddeson and A Kolb, *Tunnel visions. The rise and fall of the Superconducting Super Collider* (The University of Chicago Press, 2015), pp 77ff.

[100] Between 1964, when CERN had yet not embarked on the upgrade project, and 1974, when construction of the new accelerator complex was at its height, the total annual CERN budget sixtupled. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 88.

[101] S Widmalm, "Big science in a small country: Sweden and CERN II," in S Lindqvist (ed.), *Center on the periphery: Historical aspects of 20th-century Swedish physics* (Watson Publishing International, 1993), p 111.

[102] R Premfors, *Svensk forskningspolitik* (Studentlitteratur, 1986), pp 15-41.

[103] S Widmalm, "Big science in a small country: Sweden and CERN II," in S Lindqvist (ed.), *Center on the periphery: Historical aspects of 20th-century Swedish physics* (Watson Publishing International, 1993), p 121. O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 186.

the United States, where the transformation of particle physics to "megascience" led to the concentration of resources to a fewer number of labs, at the expense of several smaller ones.[104] Interestingly, the desertion of physical infrastructure and human capital opened a window of opportunity for the expansion of synchrotron radiation in Europe and the United States, as labs searched for new missions and technology and expertise needed new duties.[105]

Although never phrased in those specific terms either by the decision-makers involved in the process at the time or by scholars studying the process – the CERN II issue in Sweden created a precedent that could be named the "Palme doctrine" for Swedish investments in Big Science, that retains a certain influence to this day and that also played a role in the buildup of MAX-lab in the 1980s, 90s and 2000s, albeit on much smaller scale. Sweden's memberships in international scientific collaborations have been handled by the Swedish Research Council and its predecessors (and still are), and very seldom has the government made specific investments into line-items in the allocation of funding to the council(s).[106] Only recently, as Sweden sought and won the localization of the European Spallation Source (ESS) facility, has the government made specifications of this type and increased the budget of the council accordingly.[107] MAX IV remains mostly a matter for the council to fund within existing frameworks, that is, to some extent at the expense of other possible projects.[108] As will be shown in the next section and throughout the report, MAX-lab was built on funding from a large number of sponsors, issuing an even greater number of comparably small and truncated grants for specific purposes, which laboratory leadership had to put together as a jigsaw puzzle, in close collaboration with the user community, the host university, and the funders.

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[104] Hoddeson et al 2008, p 281. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 64, 80.

[105] O Hallonsten and T Heinze, "Formation and Expansion of a New Organizational Field in Experimental Science," *Science and Public Policy* 42 (2015): 841-854, on p 844.

[106] S Widmalm, "Big science in a small country: Sweden and CERN II," in S Lindqvist (ed.), *Center on the periphery: Historical aspects of 20th-century Swedish physics* (Watson Publishing International, 1993). A Granberg, "The ESS project as a generator of conflict and collaboration: an assessment of the official picture of costs and benefits and the research-community response," in O Hallonsten (ed.), *In pursuit of a promise: Perspectives on the political process to establish the European Spallation Source (ESS) in Lund, Sweden* (Arkiv Academic Press, 2012). O Edqvist, *Gränslös forskning* (Nya Doxa, 2009).

[107] O Hallonsten, "Unpreparedness and risk in Big Science policy: Sweden and the European Spallation Source," *Science and Public Policy* 42 (2015): 415-426, on pp 420-423.

[108] In 2013, the Swedish Research Council granted the MAX IV facility operations funding for the years 2015-2018, amounting to almost 1.2 billion SEK. Although the council's budget has been increased rather dramatically in recent years due to a governmental expansion of the whole public research system, it is still the case that this funding to MAX IV – whose size is probably unprecedented in council context – was made with no extra allocation from the government to the council. "Bidrag till drift aven svensk nationell infrastruktur - MAX IV-laboratoriet, för perioden 2015-2018," Swedish Research Council, dnr 827-2013-2235.

But the “Palme doctrine” of course had deeper roots in the institutional structure of Swedish science and science policy. The dominating role of universities on the performer side of the public research system has historically not meant that central university leadership has been in powerful positions; rather, the block grant funding was always distributed to scientific areas (the faculties) on basis of tradition and precedent and allocated to the rather powerful chair professors. Research management and strategy was therefore consolidated on professor or department level and any room for strategic initiative therefore largely located there, which of course meant that renewal processes had to emerge grass root or bottom-up projects.[109] The MAX project is one of the most telling examples of this, as is explicitly shown in the next section and also throughout the rest of the report, but more importantly, MAX-lab needs to be understood in this context and against this background. In light of the MAX-lab history, the claim that Swedish research policy is in lack of “aggregation mechanisms”, i.e. institutionalized methods for mobilizing resources and support for strategically important projects,[110] is in need of some moderation: Perhaps in retrospect, and with the analysis presented in this report as evidence, it can be established that some aggregation mechanisms existed and could help raising MAX-lab from small university project to international user facility. The time lag (see next section) might not have been a drawback in broader perspective and with a longer time frame.

The issue will be returned to briefly in chapter 7, where some conclusions are drawn regarding the impact of MAX-lab on the Swedish research policy system. Here, it is necessary to note a few other features of the political and funding context of MAX-lab, which have some importance for the overall presentation. First, one attempt was made in the late 1970s to make some room on national level for strategically important projects, namely the creation of the National Council for Planning and Coordination of Research (Forskningsrådsnämnden, FRN) in 1977, charged with handling “collaborative projects considered to be of special societal importance.”[111] FRN existed until 2000, when it was absorbed by the newly created Swedish Research Council (a merger of the Humanities and Social Sciences Research Council, the Medical Sciences Research Council, the Natural Sciences Research Council, and the Technical Sciences Research Council). As has been pointed out in various studies over the years, FRN was

[109] M Benner and U Sandström, “Inertia and Change in Scandinavian Public-Sector Research Systems: The Case of Biotechnology,” *Science and Public Policy* 27 (2000): 443-454, on p 444. F Melander, *Lokal forskningspolitik: Institutionell dynamik och organisatorisk omvandling vid Lunds universitet 1980-2005* (Lund University, 2006), p 133. M Benner, “Big Science in a small country: constraints and possibilities of research policy,” in O Hallonsten (ed.), *In pursuit of a promise: Perspectives on the political process to establish the European Spallation Source (ESS) in Lund, Sweden* (Arkiv Academic Press, 2012).

[110] M Benner, *Kunskapsnation i kris? Politik, pengar och makt i svensk forskning* (Nya Doxa, 2008). p 222. O Hallonsten, “Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System,” *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 186.

[111] R Premfors, *Svensk forskningspolitik* (Studentlitteratur, 1986), p 28.

a very important source of funding for MAX-lab already from the start.[112] It was FRN that provided the funding once the Natural Sciences Research Council (Naturvetenskapliga Forskningsrådet, NFR) had assessed applications for expensive equipment and recommended their approval.

Another actor with even greater importance for MAX-lab has been the private Knut and Alice Wallenberg Foundation (KAW), whose commitment to the lab has only grown over the years and has played a tremendously important role in funding its various investments.[113] Important to note is also that the decentralized Swedish research policy system created a political context for MAX-lab (and other projects of both similar and significantly smaller size) where its champions needed to actively mobilize support in a variety of settings, and when such support had been established, it was reliable and durable. Several MAX-lab "friends" at key positions in public and private research funding organizations, and in Swedish universities, have been identified in previous chronicles of the history of MAX-lab.[114]

There has been a slow but profound shift in Swedish research policy and in the funding system over the past decade or two, which has entailed the deregulation of several former structures (university organizations and funding schemes) and the increasing focus on "excellence" and strategic priorities. At first, the changes on national level appear to have been largely discursive and only marginally implemented in practical policies,[115] but in the last decade some more profound changes have been felt in the sector. Clear is that the international trend of elevated strategic importance of research infrastructures also has spread to Sweden. Not only are investments of unprecedented size made in the European Spallation Source (ESS), the MAX IV facility, and the Science for Life Laboratory (SciLifeLab) in Stockholm/Uppsala, there has also been a policy shift inside the council structure. The launch of the Committee for Research Infrastructures in 2005 and its conversion to a sub-council in 2010 was a sign that research infrastructures were given new priority. Meanwhile, the line items in the governmental appropriations to the Swedish Research Council (and some of the universities) have increased in number and it is not seldom funding for specific research

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[112] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 146ff. O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 187.

[113] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 141ff.

[114] Ibid., pp 115, 137, 161.

[115] F Melander, *Lokal forskningspolitik: Institutionell dynamik och organisatorisk omvandling vid Lunds universitet 1980-2005* (Lund University, 2006), p 138. M Benner, *Kunskapsnation i kris? Politik, pengar och makt i svensk forskning* (Nya Doxa, 2008). pp 298-299, 382.

infrastructures, domestic or abroad, that the government directly instructs its agencies the council and the universities to fund.[116]

As late as 2009, it was reasonable to conclude that Sweden's means of resolving the typical small country's dilemma in research policy, namely to decide what priorities it should make and at the expense of what, had been "to avoid taking any stand."[117] Today, this is not as evidently true, since Sweden has embarked on two infrastructural megaprojects (seen in Swedish perspective), the ESS and the MAX IV. The funding solution for MAX IV is still odd in international comparison, with money from several different sources and no obvious correlation between investments and funds for operations, but as the next section will show, this is a mere continuation of the MAX-lab funding model that produced some undisputable successes in the past. For the ESS, Swedish unpreparedness was severe and there are still signs that not enough is being made to mobilize a capable user community in Sweden in time for the start of operation of the facility in the early 2020s.[118]

In practice, the decentralized Swedish research policy system that lacked "aggregation mechanisms" but that managed to handle MAX-lab and contribute to its growth from small scale university project to international user facility had some very clear shortcomings. The Natural Sciences Research Council (NFR), and to a certain extent also the National Council for Planning and Coordination of Research (FRN) and the Knut and Alice Wallenberg Foundation (KAW), operated according to a classic research council logic which meant that proposals and applications are always received and properly assessed with respect to their scientific quality and technical feasibility, but not necessarily their relevance in a broader strategic perspective and certainly not with attention to any long-term ramifications or the need for additional resources in a later stage. In the case of MAX-lab this becomes problematic because the collected infrastructure and instrumentation was never funded in full but have been paid by a series of grants from different funders, each assessed individually and often with users as main applicants. The MAX II accelerator was funded by FRN in 1990 without there being any funding granted for beamlines and experimental stations. Once these were funded, by a number of different grants from different funders (see other sections of this report), there was no simple mechanism for increasing the operations budget from NFR.[119] In the long run, this meant that user groups involved in building beamlines

[116] The annual governmental instructions to the Swedish Research Council and other agencies, since 2003, can be found at the Swedish National Financial management Authority (Ekonomistyrningsverket), http://www.esv.se/statsliggaren/ (accessed 20 December 2016).

[117] O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009), p 70.

[118] O Hallonsten, "Unpreparedness and risk in Big Science policy: Sweden and the European Spallation Source," *Science and Public Policy* 42 (2015): 415-426.

[119] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 205.

and experimental stations (and also, in some cases, obtaining the funding for them) had to take responsibility for operation, maintenance and user support for this specific equipment. The 2002 international evaluation of the four Swedish national facilities (see section 2.5) put quite heavy emphasis on the "shadow economy" that had developed at MAX-lab as a result of the above described, acknowledging the efficiency it seemed to come with and lauding the user involvement that it necessitated, but also criticizing it strongly. Similar "shadow economies" are identified at all the four national facilities under review, which implies that the issue is general and national, but MAX-lab is also identified as especially problematic in this regard.[120]

The most profound shortcoming of this system, identified by several authors and by many of the sources used in this report,[121] is that investment in new infrastructure and instrumentation – whether made by a research council or a public or private foundation – is normally not coordinated with the securing of necessary and sufficient funds for the operation and maintenance of the infrastructure or instrumentation. This issue has turned up several times in the history of MAX-lab, sometimes rather dramatically (see below), but it is also a general challenge to science policymaking and funding in a situation where a growing number of fields of natural, technical and medical sciences (but also social sciences and the humanities) are dependent on advanced instrumentation and infrastructure.[122] A related matter is the (lack of) coordination between investments in infrastructure and advanced instrumentation and sufficient funds for domestic user groups to maintain scientific activities strong enough to be competitive in the allocation of access (experimental time) to the infrastructure and instrumentation, an issue with renewed topicality nowadays when internationalization of science has made it possible and likely for world leading scientific facilities to have truly global user communities.

While research infrastructures like synchrotron radiation sources live off international user communities and take great pride in providing access free of charge and allocate experimental time solely on basis of scientific merit (and technical feasibility), funders are most often national and want their own scientific communities to reap the greatest benefits from the investment. A synchrotron radiation facility with world-leading

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[120] "Swedish National Facilities" (Swedish Research Council 2002), pp 11, 15, 18, 40.

[121] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on pp 205-206. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 96. M Benner, "Big Science in a small country: constraints and possibilities of research policy," in O Hallonsten (ed.), *In pursuit of a promise: Perspectives on the political process to establish the European Spallation Source (ESS) in Lund, Sweden* (Arkiv Academic Press, 2012), pp 162ff. Börje Johansson, interviewed by Olof Hallonsten, Uppsala 12 October 2006. Joseph Nordgren, interviewed by Olof Hallonsten, Uppsala 13 October 2006. Leif Eriksson, interviewed by Olof Hallonsten, Stockholm 23 March 2007.

[122] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 96.

qualities will attract many of the best users from everywhere around the globe, and in order for local/domestic users to be competitive, they need support to build competitive scientific programs.[123] This is not necessarily realized by policymakers and funders in the midst of granting money to a big investment. In the history of MAX-lab, it appears the Swedish (and Nordic) user communities have been strong enough regardless of the (lack of) prudence on behalf of the funders of the facility, and remained competitive in the allocation of experimental time. A balance where roughly half of the user community have been Swedish users and roughly half have been from abroad, naturally with some variation, appears to have been maintained throughout most of its history (see next section).

2.4 A brief history of MAX-lab

When a brief history of MAX-lab is to be outlined on basis of a very rich material and as a backdrop to an evaluative analysis of the impact of the lab in various perspectives, some major generalizations are not only helpful but also necessary. One such generalization is the very workable subdivision of the chronicle of the history of MAX-lab in four main periods, each characterized by a specific process that dominated the lab during this time, as seen in table 2.1.

Table 2.1:
Periodization of the history of MAX-lab

Period	Time	Main characteristics
First	mid-1970s to 1986	• Planning, design, construction of MAX I • Organizational, financial, political buildup
Second	1986 to 1991	• Start of user operation • MAX-lab takes root as national facility • Very small-scale, very limited budget
Third	1991-2002	• Construction and start of operation of MAX II • Vast expansion, threefold increase of annual number of users • Broadening, especially to life sciences
Fourth	2002-2015	• Necessary significant budget increase (quadrupling of operations budget from the council) • Planning, design, construction of MAX IV

Some illustrative tables and figures are also useful. First, tables 2.2, 2.3 and 2.4 show the accelerators of MAX-lab in chronological order, with some basic data; the distribution of use of these over the years (for nuclear physics, synchrotron radiation, and accelerator physics); and the beamlines that were attached to the accelerators, also in chronological order and with some basic information on their use. Figure 2.3 shows a graphical timeline illustration of the beamlines operated at MAX-lab, and figures 2.4, 2.5 and 2.6 show user numbers, publication numbers (journal articles), and

[123] Ibid., p 197.

approximate numbers of MAX-lab staff over the years, for illustration. These numbers will be returned to in later chapters.

Table 2.2:
Basic data on the three MAX storage rings

	Start of planning	Start of construction	Start of operation (synchrotron radiation experiments)	Maximum number of beamlines simultaneously available to external users
MAX I	1973	1974	1987	6
MAX II	ca 1987	1992	1997	8
MAX III	ca. 1998	2001	2007	3

Table 2.3:
Scheduled use of the MAX storage rings for synchrotron radiation (SR), nuclear physics (NP), accelerator physics and maintenance (AP), 1988-2015, number of weeks (six days)[124]

	MAX I			MAX II		MAX III	
	SR	NP	AP	SR	AP	SR	AP
1988	28	12	7				
1989	28	12	7				
1990	28	12	7				
1991	28	12	7				
1992	28	12	7				
1993	28	12	7				
1994	26	11	6				
1995	27	11	6				
1996	27	11	6				
1997	27	11	6				
1998	27	11	6	38	3		
1999	26	11	6	33	5		
2000	23	10	6	33	5		
2001	24	0	6	33	3		
2002	24	0	6	32	5		
2003	24	0	4	38	4		
2004	24	5	6	30	5		
2005	20	14	6	34	6		
2006	23	14	9	37	3		
2007	18	18	2	37	1		
2008	19	18	2	37	2		
2009	22	18	1	40	1	40	1
2010	23	14	0	41	0	41	0
2011	23*	16	0	40	1	40	1
2012	14*	16	0	38	2	38	2
2013	0	16	1	38	2	38	2
2014	0	16	1	37	2	37	2
2015	0	0	1	38	1	38	1

* In mid-2011, MAX I was take out of synchrotron radiation due to a vacuum error, so in practice, it was not used for SR in late 2011 and 2012.

[124] As listed in the MAX-lab activity reports, and schedules available on the MAX-lab website, https://www.maxlab.lu.se/node/1287 (accessed 25 January 2017).

Table 2.4:
Beamlines and experimental stations at MAX-lab

Beamline	Station	Source	Available to external users	Notes
On MAX I				
22		BM	1989-1998	
31		U	1996-2009	
32		BM	1988-1997	
33		BM	1996-2007	
41		BM	1987-2011	
51		W/U	1994-1996	Moved to MAX I in 1997-1998
52		BM	1987-2008	
53		BM	1993-1999	
73		BM	1994-2011	Parts moved to D7 in 2011
On MAX II				
I311	XPS	U	1999-2015	
	PEEM		2008-2015	
I411		U	1999-2015	51 moved from MAX I in 1997-1998
I511	1	U	2000-2013	Replaced by SPECIES in 2014
	3		2001-2013	
SPECIES	HPXPS	U	2015	Replaced I511 in 2014
	RIXS		2015	
D611		BM	(2001-2015)	Not a general users beamline; no beamtime allocation in open competition
I711	MX	W	1998-2006	
	PXRD		1998-2015	
	SAXS		2006-2011	
I811		W	2004-2015	
D811		BM	1999-2003	
I911	1	W	never	Used by Copenhagen University groups for test and education
	2		2003-2015	Nearly identical, grouped in beamtime allocation as MX
	3		2003-2015	
	4		2011-2015	
	5		2003-2011	
I1011		BM	2009-2015	
D1011		BM	2000-2015	22 moved from MAX I in 1999
On MAX III				
I3		U	2009-2015	
I4		U	2009-2015	33 moved from MAX I in 2008
D7		BM	2012-2015	Parts recycled from 73

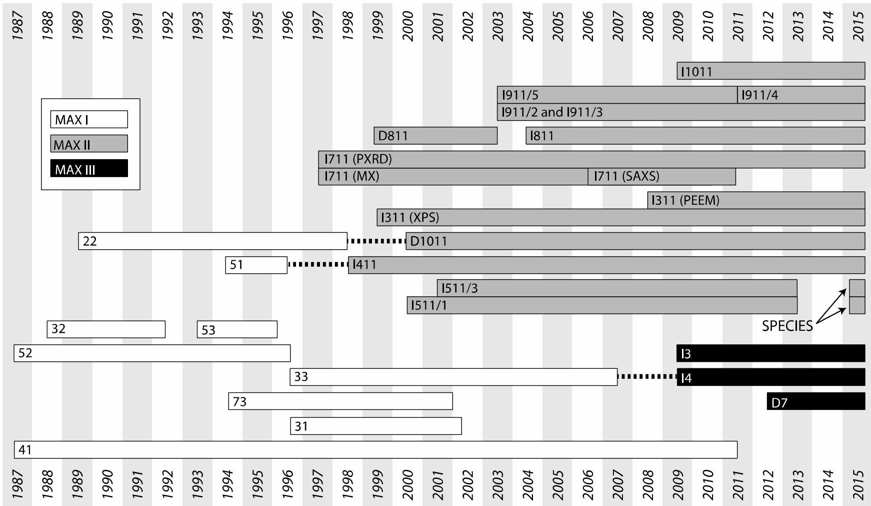

Figure 2.3:
Graphical illustration of the beamlines and experimental stations at MAX-lab and their years of operation

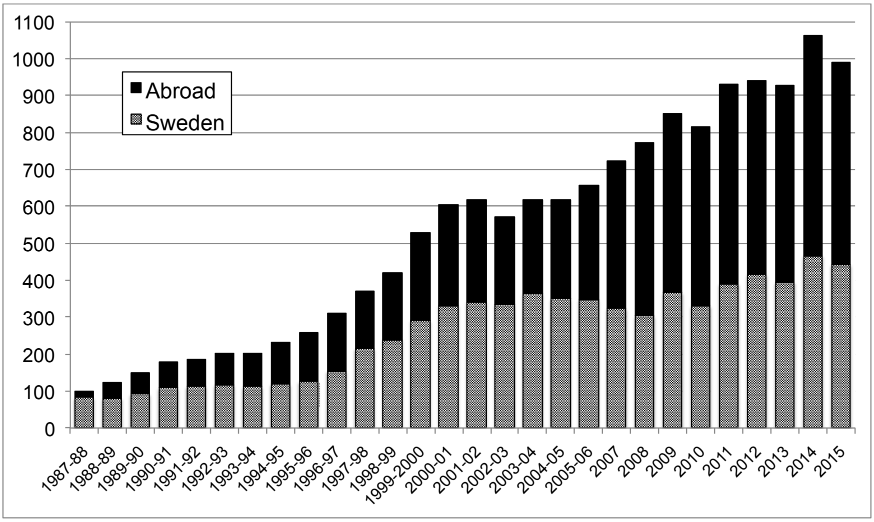

Figure 2.4:
Total number of MAX-lab users (individuals), 1987-2015[125]
Note: The data for the years 1987 to 2006 denote years from August to June; whereas from 2007 and on they denote calendar years.

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[125] As listed in the MAX-lab activity reports, and complementary data received via email from Ralf Nyholm, 2 November 2015.

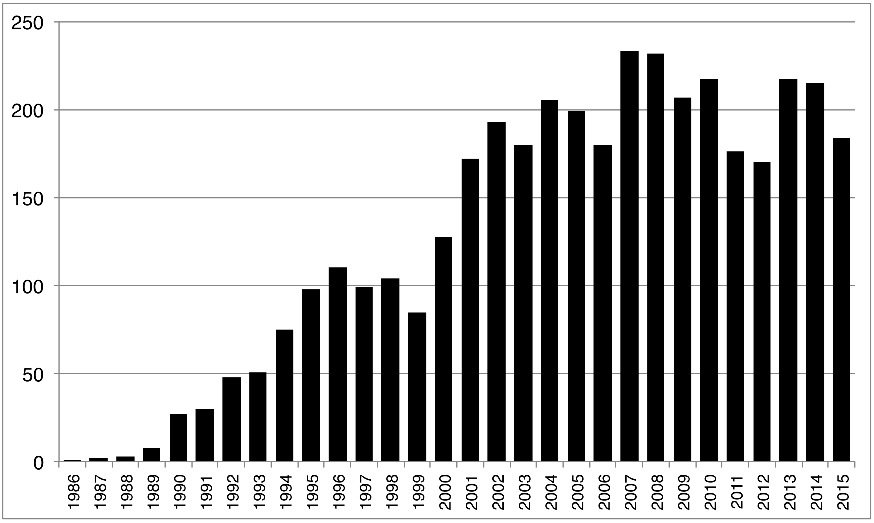

Figure 2.5:
Number of journal articles based on work done at MAX-lab, 1986-2015[126]

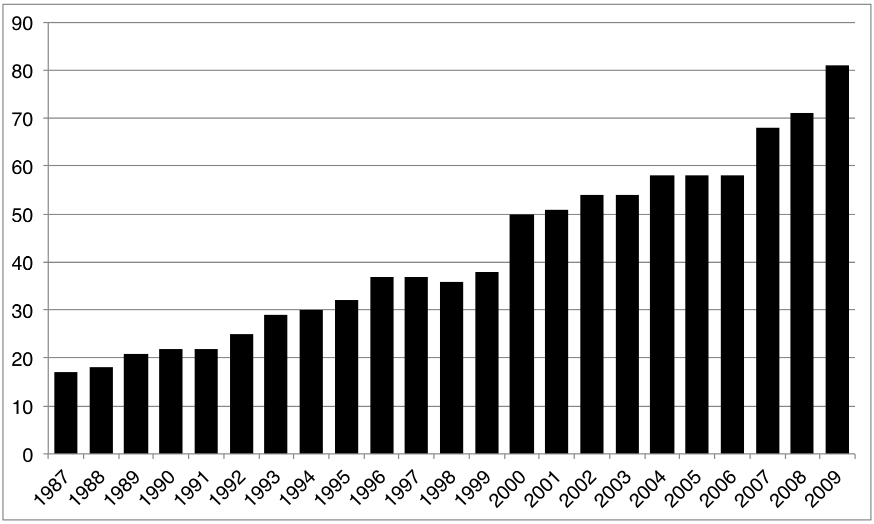

Figure 2.6:
Total number of MAX-lab staff, 1987-2009 (gross count)[127]

[126] As listed in the MAX-lab activity reports. Only *published* articles are counted, not *submitted* or *forthcoming*.

[127] As listed in the MAX-lab activity reports.

The investments in MAX-lab over the years are a trickier affair to account for, and will be returned to in chapter 4. Here, it suffices to note the estimation that the total direct financial investment in MAX-lab over the years amounts to between one half and one billion SEK (see section 4.2 for calculations/estimations). The development of the annual operations budget provided by the Swedish Natural Science Research Council (before 2001) and the Swedish Research Council (from 2001) is seen in table 2.5. Important to note is that this operations budget did not cover rent, electricity or cooling water – these costs were covered by Lund University under a separate agreement.

Table 2.5:
Annual MAX-lab operations budget from the Swedish Research Council and predecessors, 1994-2014[128]

Year	million SEK
1994/95	14.03
1995/96	14.67
1997	13.85
1998	17.72
1999	18.4
2000	18.6
2001	18.7
2002	19
2003	24.8
2004	29
2005	31.2
2006	36.7
2007	48.9
2008	55.4
2009	63.1
2010	75
2011	80
2012	85
2013	91.6
2014	116.6

The first period in the history of MAX-lab have only a vague starting point, because the birth of the MAX project was intertwined with a number of initiatives and circumstances locally in Lund and in Swedish national research policy, and indeed also on international level (see sections 2.2 and 2.3 above). Bengt Forkman has done an excellent job of untangling these rather delicately interlaced processes and singled out the most important ones for the origins and realization of MAX I and MAX-lab, citing a few crucial factors behind it. First, the need for a new experimental program in nuclear physics in Lund in the early- to mid-1970s; second, the decision to employ Mikael

[128] "International Evaluation of Swedish National Facilities" (Swedish Natural Science Research Council, 1997), p 3. "Swedish National Facilities" (Swedish Research Council, 2002), p 9. MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p21. Swedish Research Council Annual Reports 2003-2014.

Eriksson on half time for the development of the accelerator system; and third, the initiative on behalf of some young physicists in Linköping and Gothenburg to go ahead and seek funding for the expansion of the MAX project to also include a synchrotron radiation program.[129]

The LUSY (Lund University Synchrotron) had been in operation at the Department of Physics at Lund University since 1962 but had to be closed as the Swedish Atomic Sciences Research Council (Atomforskningsrådet, AFR) decided to withdraw its support for the program in the process of resource prioritization in favor of the Swedish membership in CERN II in the early 1970s (see section 2.3 above).[130] The nuclear physicists in Lund saw to a new type of machine, a so called *pulse stretcher*, to fulfill their needs for a specialized infrastructure of reasonable size that could keep them busy for some years to come, and Mikael Eriksson had arrived from Stockholm and started working with accelerator development as part of doctoral studies in nuclear physics, and as funding was obtained for MAX in 1974, a half-time position for him was created. A few years later, as Mikael Eriksson had published the first MAX design as his doctoral thesis and other necessary preparatory work had been done, the AFR granted some funding for construction of MAX. The Knut and Alice Wallenberg Foundation (KAW), the Bank of Sweden Tercentenary Foundation (Riksbankens Jubileumsfond, RJ) and Lund University covered the remaining part, and construction could start.[131]

Several Swedish physicists brought up in the instrumentation-intensive spectroscopy traditions of Kai Siegbahn in Uppsala, and Einar Lindholm in Stockholm, spent time as post-docs abroad in the early- to mid-1970s and made valuable contacts with the early breakthroughs with synchrotron radiation at Stanford, California, in Madison, Wisconsin, and in Hamburg.[132] Among them were Anders Flodström, who later became the first coordinator for synchrotron radiation at MAX-lab (until 1985) and who is regarded one of the authors of the original idea to make MAX a synchrotron radiation facility. The other is Per-Olof Nilsson, physicist at Chalmers University of Technology in Gothenburg, who had done some exploratory work with synchrotron radiation from the LUSY accelerator in Lund already in the early 1970s, and who took the initiative to start a discussion among Swedish and Nordic physicists over the possibilities of a Swedish synchrotron radiation facility.[133] Together, Flodström and

[129] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 74ff, 99ff.

[130] Ibid., pp 70-71.

[131] Ibid., pp 79-81.

[132] J Gribbe, "Omvandling och fasta tillstånd: Materialvetenskapens etablering vid svenska universitet," (Vinnova Analys VA 2016:06, 2016), pp 30-31.

[133] The initiative led, among other things, to a 1975 workshop in Gothenburg with several prominent international guests, where these plans were discussed. The workshop came to no clear conclusion and had no practical consequences other than bringing together those with an interest in the plans and the

Nilsson made contact with the nuclear physics group in Lund, including Mikael Eriksson, launching the idea to make MAX into a synchrotron radiation source. In January of 1978, the two of them submitted an application to the Swedish Natural Sciences Research Council (NFR) for 444 kSEK for “the construction of a Swedish national synchrotron radiation source.”[134] The application was granted 390 kSEK of funding in 1980. By then, MAX construction had already started and the untidy local university-political process of finding a home for the combined storage ring/pulse stretcher and future experimental equipment was at its height. In 1983, the move from the physics department to a new location on the north campus of Lund University (where MAX-lab remained until the end of 2015) was made, and two years later, on March 27, 1985, the MAX accelerator stored its first electrons.[135]

MAX-lab had received its first statutes through decision by the Lund University board in 1981, and in 1982, the Swedish government acknowledged the status of the laboratory as a (future) national facility, which was laid down in an official regulation in February of 1986, largely echoing the content of the university’s statutes of 1981.[136]

Bengt Forkman’s detailed description of how the small but ingenious group of MAX physicists and engineers built the first MAX ring in 1976-1986 is a truly amazing read that also gives important clues to understanding how MAX-lab came into being – the creative and inventive spirit in this group.[137] This aspect of the history, which is very important for the overall and has great relevance for the conceptualization and identification of impact of MAX-lab, will be discussed in chapter 4. Here, it is apt to make an international comparison to benchmark the MAX I development, which has previously mostly been accounted for in anecdotal fashion.

In the United States, the successes of the parasitic Stanford Synchrotron Radiation Project (SSRP) at SLAC (Stanford Linear Accelerator Center) in the mid-1970s had prompted an effort on behalf of the main funder of federal large-scale research infrastructure, the Department of Energy (DOE), to support the effort to build a dedicated synchrotron radiation facility within its system of National Laboratories.[138] Initiatives had been taken earlier, at Brookhaven National Lab (BNL) on Long Island whose tradition in accelerator construction was strong but whose role was a little bit

technique. The documentation of the workshop, carefully compiled by Per-Olof Nilsson, is available at his website: http://www.ponilssonshomepage.se/NordicMeeting.pdf (accessed 29 December 2016).

[134] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 100, 111-112, 116.

[135] Ibid., p 134.

[136] Ibid., pp 112-114.

[137] Ibid., pp 116-128.

[138] O Hallonsten, “The parasites: Synchrotron radiation at SLAC, 1972-1992,” *Historical Studies in the Natural Sciences* 45 (2015): 217-272. B Crease, “The national synchrotron light source, part I: Bright idea,” *Physics in Perspective* 10 (2008): 438-467.

unclear after the grandiose launch of the two single-purpose flagship particle physics facilities SLAC in the 1960s and Fermilab in the 1970s. The National Synchrotron Light Source (NSLS) was constructed at BNL starting in 1978 and consisted of two storage rings, one for ultraviolet and soft x-rays and one for hard x-rays, which opened to users in 1982 and 1984, respectively.[139]

Technically, the MAX storage ring was similar to the ultraviolet/soft x-rays ring of the NSLS, and in part also modeled after it.[140] In their respective official histories, the two projects also appear similar, but their differences are in reality huge and very telling. BNL lab historian Robert Crease has described the process of constructing and commissioning the NSLS as "arduous" and "traumatic," achieved only by heroic efforts of a team working after-hours, with allegedly very insecure funding conditions, delays, and constant threats to the survival of the project.[141] The work to build MAX is very similarly described not least by Bengt Forkman but also by others who took active part, including Mikael Eriksson and Anders Flodström (although they rarely use such strong words as "traumatic").[142] Both had relatively stable organizational conditions, the BNL and Lund University, and were thus able to make use of some local organizational and technical support when needed. But while the NSLS had been granted $24 million from the DOE in 1978, MAX was funded through (at least) fourteen different grants from six different funders, issued continuously over the whole construction period and with little or no coherence between them, or predictability. A rough count puts the total sum of these grants at close to 10 million SEK (which would converse to between $1.5 and 2.5 million, depending on the year). The institutional contexts probably also differed a lot: BNL is described by Crease as an "ideal place" for a synchrotron radiation laboratory, "given its interdisciplinary resources, superb accelerator building, and history of supporting facilities for outside users,"[143] whereas MAX was little more than a university project built in a refurbished warehouse by the use of the tools and equipment available at the mechanical workshop of the university and otherwise scavenged where available – including a mangle previously used to press clothes by the

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[139] B Crease, "The national synchrotron light source, part II: The bake-out," *Physics in Perspective* 11 (2009): 15-45.

[140] Mikael Eriksson, "The Accelerator System MAX," *Nuclear Instruments and Methods* 196 (1982), 331-340, on p 335.

[141] Robert P. Crease, "The National Synchrotron Light Source, Part II: The Bakeout," *Physics in Perspective* 11 (2009), 15-45.

[142] Mikael Eriksson, interviewed by Olof Hallonsten, Lund 17 March 2006. Anders Flodström, interviewed by Olof Hallonsten, Stockholm 22 March 2007. Mikael Eriksson, "The history of the MAX-lab accelerators: from microtron to MAX IV," in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 160-168.

[143] Robert P. Crease, "The National Synchrotron Light Source, Part I: Bright Idea," Physics in Perspective 10 (2008), 438–67, on p 444

mother of one of the project members.[144] Taken together, the comparison of the two projects shows that MAX I came about not only against all odds but in a spirit and mode of work that most likely left some marks – positive and negative – on the MAX-lab organization that remained in place until 2010.

Mikael Eriksson had been appointed professor of accelerator physics in 1984 (see chapter 6), and built a research group that took the overall responsibility for the construction and trimming in of MAX I, and later oversaw its operation together with the accelerator operations group. The two groups were "operating closely to each other" with a "somewhat diffuse" border between their activities, which meant that MAX-lab had an operations division partly run by an academic research group, and an academic research group with extra resources in the shape of professional operating staff.[145]

The second period of the MAX-lab history as outlined in table 2.1 above starts with the start of operation of the first MAX accelerator (it was not called MAX I until MAX II was proposed some years later). It stored its first electrons on 27 March 1985,[146] and the first scheduled beamtime for external users was in the fall of 1986, on beamline 41, built for photoemission spectroscopy. Several years later, this was described by MAX-lab as "a natural start of synchrotron radiation activities in Sweden" given the strong tradition in photoelectron spectroscopy (see section 3.4).[147]

MAX-lab became a "national facility" by decision in the governmental research bill of 1987. In practice this meant little, since MAX-lab was already oriented to a national user community, but with respect to organizational status and structure the reform was important as it formalized the arrangement that Lund University as the host of the facility takes the responsibility for operations and personnel, and agrees to supply conventional facilities, and that the government (through its agency the NFR) agreed to finance operations with an annual allocation of funding.[148] In 1988, county commissioner Lennart Linder-Aronson became chairman of the MAX-lab board,[149] which meant a formidable strengthening on the side of political skill and competence of the MAX-lab organization. Especially during the political campaign to launch the

[144] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 121. Mikael Eriksson, interviewed by Olof Hallonsten, Lund 17 March 2006.

[145] MAX-lab Activity Report 1987, p 17.

[146] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 134.

[147] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch 2 p 4

[148] Swedish Governmental Research Bill of 1987 (Prop. 1986/87:80), Bilaga 6 Utbildningsdep., pp 53-54, 98.

[149] MAX-lab Activity Report 1988, p 1.

MAX II project, Linder-Aronson proved enormously important with his extensive personal network in local, regional and national politics.[150]

Locally at MAX-lab, the organization was still very small in the 1980s, with the number of staff (approximate counts) exceeding 20 only in 1989-90 (see figure 2.6 above). In these years, all personnel either belonged to the operations group or the research group in accelerator physics, both under the leadership of Mikael Eriksson. All other manpower at MAX-lab was either affiliated and employed with other parts of Lund University (foremost the Department of Physics) or other universities in Sweden (especially Uppsala, Linköping, Chalmers).[151] The latter was of course a blessing for this very small laboratory in the early days, and continued to be for a long time, as will be returned to repeatedly in this chapter and throughout the whole report: The symbiosis with a vibrant and capable user community, whose experiences in designing, building and operating instrumentation were often world-leading in the concerned fields, made the whole difference for MAX-lab. In 1989, the foreword to the annual report notes deep involvement in MAX-lab instrumentation building and operations by groups from several universities in Sweden but also Estonia, Finland, Germany, the Netherlands and Switzerland. Major commitments at this time include the Uppsala involvement in beamlines 22, 41, 51 and 53, the Linköping involvement in beamline 33 and 41, the Chalmers involvement in beamline 41, and the "Finnish consortium" (Universities of Oulu and Turku, and the Finish Academy of Sciences), which made a substantial investment of both money and manpower/competence in beamline 51.[152]

The nuclear physics activities had a similarly international flavor, and groups from Glasgow and Tübingen contributed directly with equipment in the late 1980s. Several international groups frequently carried out experiments in nuclear physics at MAX-lab in collaboration with the local group which was tied to the nuclear physics division of Lund University's Department of Physics and counted some ten people.[153] Funding for the nuclear physics program in the early years was received from a diverse set of sources, including NFR, KAW, the Foundation of Magnus Bergvall, and the Bank of Sweden Tercentenary Foundation.[154]

In 1988, it seems operations at MAX-lab had stabilized significantly, and MAX I was routinely operated 24 hours a day, six days a week (with Mondays reserved for maintenance), and 48 weeks a year. 60% of the total time was devoted to synchrotron

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150 See e.g. statements by Ingolf Lindau during the panel discussion "Looking Back" at the MAX IV annual users meeting, Lund 21 September 2015, available at https://vimeo.com/140290252 (accessed 4 January 2017).

151 MAX-lab Activity Report 1989, p 6; 1991, p 7.

152 MAX-lab Activity Report 1989, p 1.

153 "Södra Högskoleregionen Person- och Adresskatalog 1987-1988," p 49. MAX-lab Activity Report 1988, p 95. MAX-lab Activity Report 1989, p 1.

154 MAX-lab Activity Report 1987, p 83; 1988, p 95.

radiation, 25% to nuclear physics, and 15% to accelerator physics and maintenance (a distribution that remained in place for MAX I until 2001). Three beamlines (32, 41, 52) were used for experiments, and the oversubscription rate (ratio between applied-for and granted beamtime) was estimated to 2:1.[155] A year later, increased interest from user groups across Sweden and the Nordic countries was noted and the need for more beamlines to be readied for operation urgently felt by the user community and MAX-lab staff.[156]

MAX-lab was early on very much characterized by an academic-style organization which, among other things, meant that the R&D and training within accelerator physics group had a strong role at the lab, and the design and development of new accelerator concepts and solutions was always an integrated part of MAX-lab. Thus already before MAX I had been taken into routine operation, plans were drafted for a new, larger and better, storage ring.[157] The first concept was the "Super-MAX", drafted and proposed to NFR in 1985 as a Nordic synchrotron radiation facility covering both soft and hard x-rays (see section 2.2 above).[158] At this time, the discussion over Swedish participation in the European Synchrotron Radiation Facility (ESRF) was at its height, and in light of this, SuperMAX was regarded as too ambitious, and the plans shelved.[159] MAX-lab returned with a second proposal in 1987, with somewhat lowered ambitions on the side of technical performance but still encompassing plans to go beyond spectroscopy applications and build beamlines for crystallography and x-ray lithography.[160]

The council had twice made clear that focus for future developments at MAX-lab should be in the VUV region. Therefore, it was not until the third proposal, drafted in 1988 and 1989, that MAX II finally made it to a serious discussion in the council and on the level of the national (potential) user community. In 1988, an ad hoc group had been appointed by the MAX-lab board, "with the mission to investigate the future users demands and to propose suitable solutions," and chaired by Per-Olof Nilsson of Chalmers. The ad hoc group organized two workshops in Lund in the spring of 1989 under the chairmanship of Ingolf Lindau, each attracting about a hundred scientists, which worked out a scientific case for the MAX II facility. The ad hoc group emphasized that full exploitation of MAX I should be given highest priority, and that MAX II should be built as a 1.5 GeV ring optimized to produce radiation in the VUV

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155 MAX-lab Activity Report 1988, p 1.

156 MAX-lab Activity Report 1989, p 47.

157 B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 130.

158 "Rådsrapport 1986, del II, Nationellt tillgängliga forskningsanläggningar – en utredning ur NFR-perspektiv" (Swedish Natural Science Research Council, 1986), pp 3, 6.

159 "Minnesanteckningar från överläggning i Stockholm 1986-12-03 om nordisk samverkan rörande deltagande i ESRF" (Swedish Natural Science Research Council, 1986).

160 "Proposal for a 1 GeV Synchrotron Light Source," dated 871103, MAX-lab.

region. In August of 1989, a proposal was submitted to the council.[161] The proposal was reviewed by an international committee, on charge by NFR (see next section).

The big issue for the council to settle on was whether the future use of MAX II by Swedish scientists would be big enough to motivate the investment. At this time, synchrotron radiation had yet not had its real breakthrough in the life sciences (see section 2.2 above), and MAX II was viewed almost exclusively as a physics project which caused resentment in the council whose delegates and committee members had the CERN II debate and the resource drainage it produced in fresh memory (see section 2.3), and argued that Sweden already had three physics-oriented national facilities (apart from MAX-lab, the The Svedberg Lab in Uppsala and the Manne Siegbahn Lab in Stockholm).[162] MAX-lab director Ingolf Lindau, who had succeeded Bengt Forkman in 1989, was "laughed down" at a council hearing when suggesting that the lab would have a thousand annual users by the beginning of the 2000s.[163] Chemists and biologists from Uppsala suggested that a hard x-ray synchrotron radiation source should be constructed at Uppsala University, while other council delegates argued that membership in ESRF was sufficient for Sweden. A resolution was reached in May 1990, when the council united in its support for the MAX II project but refused to pledge any money and recommended that the bill be paid by others: FRN was asked to provide the funds for the accelerator (estimated to 40 MSEK); Lund University was expected to cover the building and the "conventional facilities" (office space and similar); beamlines and experimental equipment was supposed to be financed by KAW, future user groups, and the Technical Sciences Research Council (Teknikforskningsrådet, TFR). The operations budget for the expanded MAX-lab was apparently also the responsibility of Lund University, in the view of the council.[164]

In 1991, the government stepped in and pledged 62 MSEK for the building for MAX II. FRN had already made a promise to grant 40 MSEK for the accelerator, in 1990, which was now effectuated. In 1992-1995, a series of grants from KAW and FRN paid for those beamlines and experimental stations that had been agreed upon in workshops and meetings in 1991-1992.[165] Construction of MAX II could begin, and on 21 February 1992, a groundbreaking ceremony took place.[166]

[161] MAX-lab Activity Report 1988, p 1; 1989, p 38.

[162] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on pp 196-197.

[163] Ingolf Lindau, interviewed by Olof Hallonsten, Lund 29 January 2007.

[164] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 170-172. O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on pp 196-197.

[165] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 199. MAX-lab Activity Report 1992, p 14.

[166] MAX-lab Activity Report 1991, p 1.

The third period in the history of MAX-lab is characterized by the construction and commissioning of MAX II, and the ensuing growth of the laboratory and broadening of its scientific constituency. The "general design philosophy" behind MAX II was "to build a low cost, high performance workhorse to be operated at fixed parameter values,"[167] and to achieve a world-leading synchrotron radiation user facility in the wavelength range of VUV and soft x-rays: The ambition was to achieve an "internationally competitive" facility, "second to none".[168] The international competition was put up foremost by the Advanced Light Source (ALS) at Lawrence Berkeley National Lab in California and the Elettra facility in Trieste, Italy, both somewhat larger but with similar ambitions with respect to wavelength range and thus scope of scientific use.[169] A similar comparison as between MAX I and the NSLS at Brookhaven (see above) shows a less spectacular result, but it is clear that MAX II cost less than half than the ALS (whose budget covered accelerator, beamlines and experimental stations, and conventional facilities but no building as it was housed in an old accelerator building at Berkeley Lab) – exact comparisons are difficult to make given the patchwork funding of MAX II.[170]

The 1994 MAX-lab activity report reported on progress on construction of the MAX II accelerator and the beamlines: In June of 1995, three beamlines with experimental stations, funded by FRN and KAW, were under construction. Two of these were undulator beamlines for spectroscopy and microscopy designed and constructed by Lund/Linköping and Uppsala groups (eventually the I311 and I511), and the third was to be connected to a wiggler that would allow the production of radiation in the hard x-ray regime – the beamline (eventually I711) was, hence, a crystallography beamline.[171] This beamline had been proposed by a group of chemistry professors at Lund University and Chalmers University of Technology in Gothenburg (Anders Liljas, Åke Oskarsson, Kenny Ståhl and Jörgen Albertsson, see also chapters 3 and 6) and planned to become operative as swiftly as possible, which led the group to go for the unconventional solution of purchasing the blueprints of an existing beamline (at the SRS in Daresbury) and build an exact copy (see section 3.5).[172] Decisions had also been taken to move the very successful beamlines 22 and 51 from MAX I to MAX II (these

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167 MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p2.

168 Ingolf Lindau, interviewed by Olof Hallonsten, Lund 29 January 2007.

169 Ingolf Lindau, "MAX II – a personal perspective," in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), 83-95, on p 84. O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 199.

170 C Westfall, "Retooling for the future: Launching the Advanced Light Source at Lawrence's Laboratory, 1980-1986," *Historical Studies in the Natural Sciences*, 38 (2008): 569-609, p 607.

171 MAX-lab Activity Report 1994, p 1.

172 R Nyholm, "Building beamlines," in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), 229-248, on p 233.

became D1011 and I411), and a grant had also been issued by the Technical Sciences Research Council (Teknikvetenskapliga Forskningsrådet, TFR) for a micro-/nanofabrication and x-ray lithography beamline (eventually the D811).[173]

On 15 September 1995, the King of Sweden Carl XVI Gustav inaugurated MAX II in the presence of the Rector of Lund University, the County Governor, and several hundred invited guests.[174] Less than two years later, MAX-lab director Ingolf Lindau commented that the MAX II ring performed "beyond the most optimistic expectations, achieving or superseding all the original design specifications,"[175] and an international evaluation of the Swedish national facilities (see next section) concluded that the MAX II project had been finalized "on time and on budget" through "a heroic effort of a small team" and now met "key specifications, such as operating energy, stored current, and emittance."[176] Several beamlines were under planning, including not least a hard x-rays beamline for materials science applications of crystallography and x-ray absorption spectroscopy (eventually the I811).[177]

At the beginning of the third period, although MAX-lab was gearing up for a major expansion in the shape of the MAX II project, the organization of the lab was still very much overlapping and intertwined with Lund University. In March of 1993, the lab had 19.5 employees (full time equivalents, FTEs), of which four (one professor, one associate professor, one assistant professor, and one doctoral student) belonged to the division of accelerator physics, led by Mikael Eriksson who had the responsibility for this group as well as operations manager and deputy director of MAX-lab. The remaining 15.5 FTEs (9 research engineers, 2 engineers, 3 instrument makers, and 1.5 administrators) were part of the national facility and under the leadership of MAX-lab director Ingolf Lindau, who held the professorship in synchrotron radiation physics at Lund University and whose position as MAX-lab director was not funded by the lab. The two positions as coordinators for synchrotron radiation and nuclear physics were held by researchers employed by the university on funds separate from the MAX-lab budget. A review of the resource needs of the four Swedish National facilities in 1993 concluded that given this situation, "the scientific competence among the staff of the laboratory in nuclear physics and synchrotron radiation physics" was "close to inexistent" but very strong in the two divisions of nuclear physics and synchrotron radiation physics within the Department of Physics at Lund University. The

173 MAX-lab Activity Report 1994, p 1.

174 B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 218.

175 MAX-lab Activity Report 1996, p 1.

176 "International Evaluation of Swedish National Facilities, April 1997." Swedish Natural Science Research Council, p 7.

177 MAX-lab Activity Report 1995, p 1.

competence in accelerator physics within the lab was, however, judged “extraordinarily strong”.[178]

In 1994, the situation changed dramatically, as the Swedish parliament adopted new legislation for the national laboratories, including MAX-lab.[179] From 1 July 1994, Lund University operated MAX-lab under a contractual agreement with NFR, stipulating that NFR provide the main operating budget and take chief responsibility for the scientific programs and for undertaking periodic reviews of the activities, and Lund University acts as employer of all MAX-lab staff and provides conventional facilities (buildings, office space, electricity, etc.).[180]

In 1994, the first MAX-lab website (http://www.maxlab.lu.se/) was launched.[181]

The most visible or physically palpable change to MAX-lab in the third period of its history was of course the construction and start of operation of MAX II, but the changes that it produced are also spectacular and seen not least in figures 2.4, 2.5 and 2.6 above: between 1991 and 2002 the number of staff more than doubled, the number of users tripled, and the number of publications more than sextupled. The operating budget also grew, not least after the 1997 international review of the Swedish National Facilities (see next section) but also before it.[182]

MAX II of course meant a significant increase in the capacity for the core scientific applications of MAX-lab in spectroscopic studies in the physics of materials, but it also led to a broadening of the user community to new areas where also the sheer volumes of users were very big. Already from the start of design of MAX II, plans had been drafted to insert a wiggler that would enable the production of high-intensity x-rays of wavelengths useful for crystallography, in spite of the core design of the ring as an ultraviolet and soft x-ray facility. As it happened, it was a crystallography beamline (eventually I711) that first got funded (by NFR and KAW) and first began user operation, in 1997.[183] The beamline was an exact copy of the beamline 9.6 at the Synchrotron Radiation Source (SRS) in Daresbury, UK, built to come on track as fast as possible to begin building a user base for structural biology as well as powder diffraction and small molecule crystallography at MAX-lab.[184]

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[178] “Resursbehov m m för nationella forskningsanläggningar och nationella forskningsresurser,” Swedish Natural Science Research Council 1993, p 16.

[179] “Förordning (1994:946) om den nationella forskningsanläggningen i elektronacceleratorlaboratoriet (MAX IV-laboratoriet) i Lund,” Swedish Code of Statutes 1994:946, issued 9 June 1994.

[180] MAX-lab Activity Report 1994, p 9.

[181] Ibid., p 7.

[182] MAX-lab Activity Report 1996, pp 1-2.

[183] Anders Liljas, interviewed by Olof Hallonsten, Lund 10 November 2006.

[184] Yngve Cerenius, interviewed by Olof Hallonsten, Lund 10 October 2006.

The superconducting wiggler got an offspring, or in fact two that were inserted into the MAX II ring in the early 2000s to support the beamlines I811 for various applications in materials science that requires x-rays (including both crystallography and spectroscopy) and I911 which became the second protein crystallography beamline at MAX-lab and eventually supported five experimental stations (see below).[185] It is quite clear that this broadening of the scientific program of MAX-lab to chemistry and biology was key to the mobilization of support in the broader scientific communities in Sweden and throughout its academic system, as well as locally at Lund University, where previous turf wars over MAX-lab seem to have been replaced by both support and pride across most of the university's faculties.[186]

In 1998, the two spectroscopy beamlines I311 and I511 opened to external users, and in the same year, the move of beamlines 22 and 51 to MAX II was completed. 22 got the new name D1011 and opened to external users in 2000, and 51 became I411 and opened to external users in 1999. Meanwhile, new beamlines had also been completed on MAX I, through collaborations with university groups from Lund, Linköping and Uppsala. Beamlines 53 and 73 had started external user operation in 1994, and beamlines 33 and 31 opened for external use in 1999 and 1997, respectively.

Thus at the turn of the millenium, MAX-lab had a total of ten beamlines in operation, and a user community that had grown to over 600 annual users (individuals). The organization was likewise growing, with the number of staff surpassing 50 (see figure 2.6 above). Meanwhile, new plans had emerged – most of all, the great new synchrotron radiation facility that would eventually become MAX IV was on the drawing boards of the accelerator physics group, and planning for a new injector had also begun – already in 1995 the old microtron, used to inject to MAX I and eventually also MAX II, had been named "the most vulnerable link"in the accelerator system, and a workshop was held to discuss alternatives for injector upgrades.[187] In 1997, FRN granted SEK 25 million for a new injector system, which also included funds for a third storage ring to be built between MAX I and MAX II, and the injector would also be designed so that in the future, it would be capable of supporting a free electron laser in the infrared and ultraviolet wavelength range.[188] The upgrades and installations of the new injector and the MAX III ring took place in 2000-2004, with the consequence that no nuclear physics experiments were done during this period.[189] However, an upgrade to the nuclear physics facilities in the same period enabled an enhancement of this program

[185] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[186] Peter Honeth, interviewed by Olof Hallonsten, Lund 9 June 2006.

[187] MAX-lab Activity Report 1995, p 1.

[188] MAX-lab Activity Report 1998, p 1.

[189] MAX-lab Activity Report 2001, p 1.

when it restarted in 2005.[190] The free electron laser was eventually built as a test facility in collaboration with the Lund Laser Center (a multi-department unit within Lund University) and the synchrotron radiation facility BESSY in Berlin, and partly funded by a EU project for free electron lasers, named EUROFEL.[191] Later, it also joined the European IRUVX collaboration, and it produced its first laser light in 2009.[192]

But while user numbers continued to grow and new exciting projects on both the accelerator and beamlines sides turned up and got investment funding, the organization and the operations budget showed signs of unsustainability. In 1997, a disparity or asymmetry in the expansion of MAX-lab showed up for real, namely, that the investments made had produced a situation where the operations budget for the lab was simply too small. The systemic shortcoming identified and discussed at the end of section 2.3 above – that investments are not typically synchronized with operations budgets in the pluralist Swedish research funding system – was part of the reason. But NFR did not increase the operations budget. Instead, a temporary grant from the Swedish Foundation for Strategic Research (Stiftelsen för Strategisk Forskning, SSF, a public research foundation launched in 1993) resolved the immediate cash flow issue. The reason for not adjusting the budget might be found in the 1997 evaluation of Swedish national facilities, which identified the MAX-lab operations budget as "rather low, if not too low" but simultaneously praised the MAX-lab organization for being "lean" and "efficient".[193]

Thus as MAX-lab entered the fourth period in its history, it did so with a persistent funding shortage. The 2002 evaluation of the four Swedish national facilities was clearer in its critique of the insufficient operations budget for MAX-lab, noting at several points in its report the existence of an advanced "shadow economy" at the lab and urging the funders to increase the budget.[194] Consequently, in the fall of 2002, the Swedish Research Council (which had been formed in 2001 as a merger of four disciplinary councils and FRN) decided to withdraw its support to two of the national facilities – the The Svedberg Lab in Uppsala and the Manne Siegbahn Lab in Stockholm – and concentrate support to MAX-lab and the Onsala Space Observatory in Gothenburg.[195] Consequently, as seen in table 2.5 above, the MAX-lab operating budget almost doubled in five years, between 2002 and 2007, and continued to increase dramatically also after that. Though never articulated thus, the council had made a firm

[190] "Report from the review of the MAX laboratory, Lund, May 2009". Swedish Research Council report 5:2010, p 12-13.

[191] MAX-lab Activity Report 2003, p 1; 2004, p 1; 2005-06, p 1.

[192] MAX-lab Activity Report 2007, p 1; 2010, p 42.

[193] "International Evaluation of Swedish National Facilities, April 1997," Swedish Natural Science Research Council, pp 7-8.

[194] "Swedish National Facilities", review report, Swedish Research Council 2002.

[195] Swedish Research Council Annual Report 2003, p 21.

stand after the 2002 review that MAX-lab was a national research infrastructure of highest priority.

The first few years of the 2000s was very much characterized by the upgrade and partial replacement of the injector (see above) and the design and construction of the MAX III ring, but also by the further expansion of the protein crystallography activities by the opening of a third hard x-ray beamline on MAX II, the I911 or "Cassiopeia" as it was also called. A consortium of researchers from Lund University and Copenhagen University developed and built the I911 beamline in collaboration with MAX-lab, with funding from KAW, the Danish Research Council, the Danish Biotechnology Instrument Center (DABIC), and the two pharmaceutical companies AstraZeneca and Novo Nordisk.[196] The beamline was equipped with five experimental stations, slightly differently optimized: the I911/2, I911/3 and I911/5 were the "work horses" for macromolecular crystallography, supporting most of the users in this area; I911/1 was mainly used by the groups from Copenhagen University for testing and education; and I911/4 was eventually equipped with an experimental station for so called small angle x-ray scattering (SAXS). At first, as I911 took over all protein crystallography in 2006, an experimental station for SAXS was added to beamline I711, but this station was short-lived and the I711 returned to serving mostly powder diffraction measurements as I911/4 was completed in 2011.[197] The investments from AstraZeneca and NovoNordisk guaranteed these firms some earmarked beamtime (see section 4.3.1) and meant the first and only large-scale industrial commitment to MAX-lab. The opening of Cassiopeia meant a further expansion of the scientific program of MAX-lab to the life sciences, which meant a fortification of the support and anchoring of MAX-lab in Swedish scientific communities.[198] The broadening is also seen in the growth of overall user numbers between 2002 and 2008 (figure 2.4) above, although curve shows a small temporary decline in 2003/04 and 2004/05. This interruption of the user growth is likely due to some serious problems with the superconducting wiggler experienced in 2004, when beam interruptions were common and many users – especially in crystallography where patience with technical malfunctioning is generally smaller than among other users – were scared off.[199]

The growth in user numbers neccesitated an expansion of the staff (see figure 2.6 above) which was enabled by the steep growth in the operations budget. Especially on the side of user support, where the needs were the greatest, necessary increases in staff were made

[196] MAX-lab Activity Report 2000, p 1; 2002, p 1.

[197] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[198] "Swedish National Facilities", review report, Swedish Research Council, 2002. p 36

[199] Thomas Ursby, interviewed by Olof Hallonsten, Lund 20 October 2006.

in 2007 and onward.[200] The overall expansion in this period was accompanied by increasing international collaboration as well as acclaim for innovative technical solutions and high scientific quality, which had begun for real already as MAX II started operation in the late 1990s.[201] In 2009, an international review of MAX-lab commissioned by the council concluded that the laboratory was very cost-efficient and had achieved a high scientific quality in spite of some underfunding.[202] As a result, the council increased the operations budget further.[203]

At that point, however, the council had already entered into an agreement with Lund University, the Swedish Agency for Innovation Systems (Vinnova), and the County Council of Scania (Region Skåne), to provide the initial funds for the construction of MAX IV, the next generation MAX-lab. MAX IV had emerged on the drawing board already in the late 1990s, and grown gradually through a series of workshops and not least the development work of the accelerator physics group at MAX-lab, who had also used the opportunity offered by the construction of MAX III to try some core new technologies for the future facility. In 2004, a major workshop took place that launched the work on a scientific case for the facility, and in 2006 a Conceptual Design Report (CDR) was published.[204] The coming years saw several modifications to the plans, a series of evaluations of both the technical concept and the scientific case (see next section), and a tiresome political process to get the project funded.

After the decision in April of 2009 to launch MAX IV, work ensued to secure the remaining shares of the funding and to establish an adequate orgaanizational structure for building the new facility while maintaining operations of the existing MAX-lab on an acceptable level. In 2010, MAX-lab changed names to MAX IV and a new organizational structure was adopted,[205] but the budgets for the two purposes – building MAX IV and operating MAX I, II and III – were kept separeate, with the council's share of the latter reaching 80 MSEK in 2011.[206] In reality, however, it is doubtful whether such a separation can be made – there was a steep growth in the number of staff in 2010-2015 and most of them appear to have been engaged in both the operation of MAX-lab and the various parts of the buildup of MAX IV.[207]

[200] Swedish Research Council, "Report from the review of the MAX laboratory, Lund, May 2009" (Swedish Research Council Report 5:2010), p 12.

[201] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p15-16.

[202] "Report from the review of the MAX laboratory, Lund, May 2009," Swedish Research Council report 5:2010.

[203] Swedish Research Council Annual Report 2009, p 36.

[204] MAX IV Conceptual Design Report, 2006.

[205] MAX IV Highlights and Activities 2011-2012, p 6.

[206] Ibid., p 57.

[207] MAX IV Highlights and Activities 2013, p 47.

In the shadow of the enormous task of building MAX IV – a project with a total cost of several times the collected investments in MAX-lab up until 2009 – the lab continued to thrive and develop to meet the needs of its user communities. MAX III began routine operation in 2007 and had its first two beamlines taken into operation for external users in 2008-2009. One of them was the beamline 33 on MAX I, moved and upgraded to make use of the better performance of the MAX III ring. On MAX II, the crystallography activities continued to grow (see above), and a second station was added to the I311 beamline in 2008. In early 2011, the experimental station on I511/3 was replaced. Parts of beamline 73 was moved to the beamline D7 on MAX III in September of 2011.[208]

In 2012, the last synchrotron radiation experiments with light from MAX I were undertaken. The nuclear physics activities continued, as did the synchrotron radiation activities on MAX II and MAX III, until MAX-lab closed in December of 2015, six months ahead of the inauguration of MAX IV.[209]

Summarizing this brief history of MAX-lab, it can be concluded that on a very general level, the lab is a local incarnation of the transformation of Big Science as conceptualized in recent work:[210] Originally a nuclear physics machine, it underwent a gradual but profound transformation from nuclear physics to synchrotron radiation, over some decades. While nuclear physics was still part of the scientific program of the lab right before its closing in 2015, it was small and still more or less on the level of where it was in 1987. Synchrotron radiation research, however, had grown manifold in the near-three decades of the history of the lab, either one counts annual number of users or output in the form of publications. This development is itself interesting, and testifies to the capability of synchrotron radiation as an experimental technique to make an impact on science and surrounding society – should such an impact not have been made, the lab would hardly have developed in the way it did. The remainder of this report will analyze in great detail *how* MAX-lab had an impact.

Importantly, as has been pointed out by analysts of the history of MAX-lab, the gradual and organic growth of the lab from a small university project to an international user facility over thirty years is both typical to how Swedish science and science policy works (or "symptomatically Swedish"[211]) and probably the only way in which MAX-lab could have come into being. Key people in the history of the lab confirm the view:

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[208] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[209] MAX IV Highlights and Activities 2013, p 14.

[210] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016).

[211] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011): 179-215, on p 214.

> "MAX I was never Big Science. Perhaps in the visionary thoughts of a few of the individuals, it was viewed as the start of something big, but for the most part, it was a continuation of a Swedish spectroscopy tradition, with new opportunities and perhaps somewhat more expensive."[212]

> "If one would start all over again with MAX-lab and the conditions would have been the same and the financial constraints the same, one would have done it all the same way. I can't see any other way of doing it."[213]

2.5 Short summaries of previous evaluations of MAX-lab and similar documentation

The earliest available external evaluation of the MAX ring as a combined nuclear physics and synchrotron radiation facility is a report from 1978 by theoretical physicist Karl-Fredrik Berggren of Linköping University, called "Ang. Möjligheten att utnyttja MAX som synkrotronljuskälla" ("On the possibilities of using MAX as a synchrotron light source"). The evaluation was made as part of the work of NFR to assess the application filed by Anders Flodström and Per-Olof Nilsson in 1978 to start a synchrotron radiation program at MAX (see previous section). The report concludes that there is a demand for synchrotron radiation in "biology, atomic and molecular physics, photoemission and surface physics" in Sweden. An expansion of MAX won't however cover for the whole national demand for synchrotron radiation, and the report judges it unreasonable to place that sort of demands on the MAX-facility. The report also acknowledges the international development of a differentiation of light sources between the ones for VUV and soft x-rays and the ones for hard x-rays, and recognizes that the hard x-ray rings are significantly more expensive. The conclusion in the report is that it would be reasonable for Sweden to commit to the VUV and soft x-rays through the proposed modification of the MAX ring and underlines the fact that this modification is considerably cheap and cost effective. The total amount requested in the application is judged to be "very moderate" compared to corresponding facilities abroad, even though this amount only accounts for the 'naked' ring and no beamlines or experimental stations. In the opinion of the panel, the commitment to MAX in Lund does not rule out but rather complement a Swedish commitment to foreign facilities for hard x-rays.[214]

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[212] Anders Flodström, interviewed by Olof Hallonsten, Stockholm 22 March 2007.

[213] Nils Mårtensson, interviewed by Olof Hallonsten, Lund 7 November 2006.

[214] K-F Berggren, "Ang. Möjligheten att utnyttja MAX som synkrotronljuskälla," report to the Swedish Natural Science Research Council dated 1978-09-20, p 10-11.

A very brief and summative report on the technical feasibility of turning the MAX ring into a combined nuclear physics and synchrotron radiation facility by Dirk Husmann at the University in Bonn, Germany, is mainly focused on advice on how to proceed with this project, should the funding requested (of SEK 444,000) commence. The report states laconically that "it is principally possible to use the converted MAX as a beam stretcher and a radiation source" but that more technical studies are needed on the details of how this should be achieved. The report places great trust in Mikael Eriksson to lead this work. It makes no comments whatsoever regarding the scientific potential of using the MAX ring to produce synchrotron radiation, but remains exclusively concerned with the technical parameters of the design and what these will lead to in terms of performance and radiation quality. The report sets off a long tradition in evaluations of MAX-lab and its successive accelerator projects that continues to this day (see below) – namely, to raise concerns over limited budgets. In this case, the evaluator considers the budget "moderate compared with the proposed work."[215]

In 1987, a comprehensive evaluation of Swedish research in nuclear physics was undertaken by an international panel on charge by NFR. Naturally, MAX-lab received special attention in the report, which viewed the MAX ring as a "masterpiece of engineering" and its chief designer and constructor Mikael Eriksson as a "first rate accelerator physicist" with "remarkable qualities of leadership". The technical preconditions for a high-quality nuclear physics activity are judged of "high quality" but the scientific achievements of the nuclear physics program is criticized for lack of productivity. Althoiugh preparations had been underway since 1980, "little has been achieved" at the time of the evaluation (1987). In comparison with the synchrotron radiation program, with which the evaluation panel was "impressed" although it had no task of evaluating this side of the lab, the nuclear physics activities are "disappointing" and the group are encouraged to seek to develop international collaborations to improve the quality of the program and thus "demonstrate the scientific potential of the tagged photon beam at the MAX-lab in a convincing way."[216]

The report recommended a new evaluation three years later, which was undertaken on a special charge from NFR. This time, the evaluation panel was "favourably impressed" by the nuclear physics program, noting a "very different" situation from what was seen three years earlier, including a "remarkable change" in the breadth of international collaboration, which has also led to improvements on the side of instrumentation. In sum, this evaluation "convinced the committee that the experimental programme in photonuclear research is now in a good shape," and in light of the "high quality of the

[215] D Husmann, "Comments on the Proposal to use MAX as a Beam Stretcher and a Synchrotron Radiation Source," Swedish Natural Sciences Research Council dnr. 2928-100:3, 1978.

[216] "International Evaluation of Swedish Research in Nuclear Physics," Swedish Natural Science Research Council 1987, pp 15-16, 43.

programme" the committee unanimously recommended continued funding from the council.[217]

The first evaluation of the operating and scientifically productive MAX-lab was undertaken when the application for funding for MAX II was appraised, in 1989. The proposed MAX II project was evaluated by an international team of four experts, and while the evaluation report naturally focused on the technical reliability and feasibility, and scientific potential, of MAX II, it also contained evaluative statements of the MAX-lab activities thus far (up to 1989), mostly as a background. The report calls the buildup and operation of MAX I thus far "successful" and notes that the machine group is "small but very competent" machine group in Sweden, which is capable of carrying through a new project." The committee is "favourably impressed by the scientific and technological performance" of MAX-lab.[218] While the report states that "the rate of development of the MAX Laboratory has been slower than we consider ideal", the science produced so far is regarded as "important" and showing very promising signs for the future, when more beamlines are taken into operation.[219]

The panel sees a clear demand in Sweden for a domestic synchrotron radiation source of the MAX II type, noting that its design is world-leading in terms of brightness for the production of radiation in some spectral regions and that there will be a demand in Swedish scientific communities for synchrotron radiation that will likely not be possible to fulfill only with MAX I and with participation in international projects, also if counting the ESRF which is planned to open to users in 1994. The evaluation also notes the considerable competitive advantages that will be brought to Swedish research groups from having a domestic synchrotron radiation facility of the quality of the proposed MAX II, where tighter collaborations with permanent staff can be established and maintained, to the benefit for the scientific progress of the concerned fields in Sweden.[220] Specifically on the side of macromolecular crystallography, in a response letter to the evaluators' questionnaire appended to the evaluation report, Anders Liljas states that "Availablity is essential for routine data collection and training. Without a home base, ESRF cannot be properly used for the most demanding experiments."[221] Importantly, however, MAX I is also judged to be good enough not to be replaced by MAX II, and the panel argues that some experiments are in fact better performed on MAX I than on MAX II. Therefore, "MAX II should not be thought of as the successor

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[217] "Report of the NFR Evaluation Committee for the Nuclear Research Programme at the MAX Laboratory at Lund, November 1990," Swedish Natural Science Research Council 1990, pp 1-3.

[218] "International Evaluation of the MAX II Project," Swedish Natural Science Research Council 1989, p 12.

[219] Ibid.. p 5.

[220] Ibid.. p 8.

[221] Ibid.. appendix.

to MAX I, but rather as a complementary activity."[222] As the first in a long sequence of evaluations of MAX-lab through the years, the panel also notes the strong commitment to MAX-lab and its future development by Lund University.[223]

In 1992, a comprehensive international evaluation of Swedish research in physics was carried out on charge by NFR, and the report paid specific attention also to MAX-lab in its chapter on "Large Scale Facilities." No explicit assessment of productivity or quality is made, but the recommendations – that MAX-lab be better funded and receives the status of a facility of national importance (also reflected in its funding and organization model) – is testimony to a positive stance on behalf of the evaluation committee, towards MAX-lab. Otherwise, the report makes a rather thorough inventory of the present capacity of MAX-lab and the user community, noting that six beamlines are in operation and two under construction, and that an approximate count shows that ten "major user groups (including one from Finland)" are active at MAX-lab, using approximately six weeks of beamtime each per year, and that an additional approximataly ten groups are "regular users but require less beam time."[224]

The nuclear physics activities at MAX-lab are favorably evaluated; A "unique activity in medium energy nuclear physics" is carried out at MAX-lab "with excellent instrumentation that is unique", and MAX-lab is considered "very well equipped" for the nuclear physics program it serves.[225]

The chapter of the evaluation report concerned with surface physics also mentions MAX-lab in very favorable terms, considering it a natural next step in a long and strong Swedish tradition that allows already excellent activities elsewhere in Sweden to take quantum leaps in their development. The groups in Gothenburg, Linköping, Lund, Stockholm and Uppsala active in this area "all make very effective use of the synchrotron radiation source MAX." [226]

In 1992 and 1993, two reports were published by NFR and the National Swedish Board for Universities and Colleges (Universitets- och Högskoleämbetet, UHÄ), as part of the investigatory work to provide improved organizational and financial frameworks for Swedish national research facilities. The reports wer mainly concerned with the legal frameworks and how these should be reformed to better meet the needs of the concerned facilities, their users, their parent organizations (universities), and their funders, and many of the suggestions of the reports were also implemented in the bill of 1994 (see previous section) and the contracts between NFR and the respective host

[222] Ibid., p 11.

[223] Ibid., p 12.

[224] "International Evaluation of Swedish Research in Physics". Swedish Natural Science Research Council 1992. pp 39-40.

[225] Ibid.. pp 14-15.

[226] Ibid.. pp 20-21.

universities later the same year. The 1992 report notes a considerable "confusion" around the issue of how the increased operations costs for MAX-lab shall be financed once MAX II is taken into operation, and urges the responsible agencies to take greater notice of this issue.[227] The 1993 investigation was completely focused on funding issues and concluded that there is a shortage of funds at MAX-lab (and at the other national facilities) and suggest a number of improvements of the funding model including increases of the operating costs.[228]

A follow-up report on the resource needs of the national facilities was published by the Natural Sciences Research Council in 1996. Specifically regarding MAX-lab it notes that when MAX II is fully built out, "Sweden will have an internationally competitive synchrotron radiation source in the soft x-ray range with advanced instrumentation." The need for an increase of the MAX-lab operations budget is repeated here, but in terms of solutions to this need, the report restricts itself to a recommendation that the lab tries the possibility to fund parts of its activities by selling beamtime to industry.[229]

A self-evaluation by MAX-lab, submitted in advance, was appended to this report. There, MAX-lab praises itself for a scientific program of "highest international standard" in acceleratopr physics, nuclear physics, and a number of disciplines based on synchrotron radiation. Through the "unique and first class instrumentation" at MAX I, the lab has "achieved a leading position in the world in high-resolution electron spectroscopy".[230]

In 1997, the first comprehensive evaluation of the four Swedish national facilities (MAX-lab, The Svedberg Lab, Manne Siegbahn Lab, and Onsala Space Observator) was made on charge by NFR. It was conducted by a steering group of council officials from Sweden and Denmark, and with the direct involvement of a comparably large group of experts from various fields, who were brought in to conduct different specific tasks. The synchrotron radiation activities and nuclear physics activities at MAX-lab were, for example, evaluated with the help of two different expert groups.[231] In its general evaluation of MAX-lab, the report notes that the lab "has accumulated a record of outstanding scientific accomplishments in the area of synchrotron radiation science", with several users "among the world leaders, particularly in the areas of surface science and atomic and molecular science." With a steadily growing output of publications,

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[227] Ingvar Lindgren, "Nationella forskingsanläggningar och nationella forskningsresurser," Swedish Natural Sciences Research Council and the National Swedish Board for Universities and Colleges 1992, pp 20-21.

[228] "Resursbehov mm för nationella forskingsanläggningar och nationella forskningsresurser," Swedish Natural Sciences Research Council 1993, pp 16-18.

[229] "Fördjupad anslagsframställning 1997-99, Nationella forskningsanläggningar," Swedish Natural Sciences Research Council 1996, p 5.

[230] Ibid., appendix 1, p 2.

[231] "International Evaluation of Swedish National Facilities, April 1997," Swedish Natural Science Research Council, p 4.

also in high quality journals (such as *Physical Review Letters*, *Surface Science*, *Physical Review*), the current scientific program is "well motivated and highly productive." The accelerator physics program at MAX-lab is also acknowledged as "internationally recognized" and the nuclear physics program identified as filling "a unique niche in the world". [232]

While the scientific program at MAX-lab is multidisciplinary, the report notes that its "major impact has been in two areas, i.e. surface science and atomic/molecular science, where the scientific results have been outstanding and have attracted visiting scientists from all over the world". Nonetheless, the evaluation panel recommend "that the MAX-lab management and user community vigorously seek out new directions" and endorses the medium- and long-term strategic plan of the laboratory and its ambitions to expand the user community to new areas, not least the life sciences through structural biology, and x-ray lithography for microfabrication.[233]

The role of MAX-lab in the Swedish science system is described as both a service facility for a large user community and as a locus of spearhead developments in some areas. MAX-lab "is the only one of the four facilities which is a national facility in the sense of offering a platform or service for various research groups from different Swedish universities and abroad" and thus it has "not a scientific mission by itself" but "rather a service mission." But the role of the lab "to initiate experimental developments which open new possibilities and offer services to users" is also identified as "extremely important".[234] The report ends its recommendations with a note that the lab, given the "present economic circumstances" will have to "make clear priorities."[235]

A 1999 council evaluation of Swedish research in structural biology notes, very briefly, that MAX-lab can make a strong contribution to the field's development, emphasizing the importance of high-quality synchrotron radiation for the field and thus identifying MAX II as a vital resource for structural biology in Sweden and not least highlighting the positive impact of the crystallography facilities at MAX-lab on research in structural biology at Lund University.[236]

The main result of the 2002 international review of the four national facilities organized by the Swedish Research Council (Vetenskapsrådet, VR) was that MAX-lab and Onsala Space Observatory got much-needed budget increases at the expense of the The Svedberg and Manne Siegbahn labs (see previous section), but the report also contains

[232] Ibid., pp 7, 9.

[233] Ibid., pp 8-9

[234] Ibid., p 27.

[235] Ibid.. p 28.

[236] "International Evaluation of Structural Biology, December 1999," Swedish Natural Science Research Council, pp 5, 41.

a very thorough evaluation of the scientific productivity and quality of MAX-lab in 2002.

All four of the national facilities are praised by this review, which finds their scientific output "remarkable … in proportion to their operating budgets" which are "about 2 to 3 times lower than for comparable facilities abroad". Although they are successful, the budget situation of the labs is unsustainable, says the report, and there is a "mismatch between program aspirations and operating budgets" that has to do with the habit of the funders to make investments without securing operations costs (see sections 2.3 and 2.4 above) and that has resulted in rather well-developer "shadow economies" at the labs, where students and researchers affiliated with other institutes and universities "routinely carry out tasks of general user support."[237]

MAX-lab is considered "thriving, healthy, but underfunded", with a "clear mission as the Swedish national synchrotron radiation light source, serving a large, dynamic, and growing community in the fields of physics, materials science, chemistry, and biology." It "stands out among the four national laboratories as a source of basic infrastructure support for swedish science and technology broadly defined," and has "gained a very high reputation worldwide for its foresight in carefully planning the radiation sources, the beamlines and the instrumentation together with highly competent user groups, so that the laboratory could offer novel instrumentation for cutting edge research in emerging fields of science in due time." In addition, the report states, the laboratory is "blessed with truly imaginative accelerator physicists who should be planning strategically to stay at the forefront of synchrotron radiation research."[238]

The MAX-lab organization is adequately structured to join together the managerial level with user groups and scientific advisory commitees, and both the user community and the MAX-lab staff include many prominet scientists active in their respective fields. The lab management is praised by the review panel for its ability to balance the needs of different user groups. In this work, especially the flexibility of the organization has been important, argues the panel, because this has enabled the lab to appropriately react to new scientific developments and adapt the goals of the lab.[239]

In 2004, VR undertook a comprehensive review of Swedish research in condensed matter physics, where MAX-lab quite naturally got some attention. This evaluation is covered and discussed more thoroughly in section 3.3, and here follows only a brief summary. Swedish research in condensed matter physics, especially surface and interface science and electronic structure, has benefited enormously from access to synchrotron radiation, the report states, and MAX-lab has a major part in this, having been "an exceptionally successful and competitive facility" built and operated "for a

[237] "Swedish National Facilities", review report, Swedish Research Council 2002, p 11.

[238] Ibid., pp 11-13, 36.

[239] Ibid., p 39.

small fraction of the cost of facilities delivering similar performance elsewhere."[240] The work of prominent Swedish surface scientists, in Stockholm, Lund, Gothenburg, Linköping and Uppsala, has also reciprocally benefited MAX-lab and its broader user community; most of all through the active involvement of these groups in the design, construction and operation of beamlines and experimental stations, but also their pioneering role of "demonstrated the capability of this facility to perform experiments not readily performed elsewhere." MAX-lab is therefore a "manifestation of the visibility of Swedish condensed matter physics", seen in the large share of use of its facilities for experiments in condensed matter physics by scientists from Europe, Japan, and the USA.[241] Several of the long-time users of MAX-lab, who have also served on committees, built equipment and held staff positions at the lab, are mentioned by name in the review report as especially good examples of the prominence of condensed matter physics in Sweden.[242]

In 2005 and 2006, as the MAX IV project had reached the state of conceptual design, VR decided to have the technical concept and the scientific case for MAX IV evaluated by separate international panels. The review panel for the technical concept "congratulates MAX-lab on the innovative design" and "appreciated the strong interest and support by Lund University, which is identified as crucial for the success of the laboratory and the MAX IV proposal." It also commented that the preliminary budget for MAX IV was "on the low side" in international comparison, but noted that "the laboratory has demonstrated its capacity to build accelerator components in a cost-effective way" which is an indirect positive appraisal of the technical achievements of MAX-lab thus far.[243] The panel that evaluated the scientific case was similarly positive, concluding that the scientific case for a MAX IV facility is very strong, and recommending VR to fund the project "to the level requested … as soon as possible."[244] In 2009, as the MAX IV facility design had been significantly modified, the council made a new evaluation, in whose overall assessment there is also an indirect assessment of at least one very important aspect of the performance of MAX-lab as a national and international user facility, namely, a highligt of the "very good contact and interactions between the MAX-lab and its user community".[245] The same year, former MAX-lab pioneering user and the coordinator for synchrotron radiation research at the lab between 1982 and 1985 Anders Flodström got an assignment from the Swedish government to investigate the preconditions for the realization of MAX IV, and suggest

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[240] "International Evaluation of Swedish Condensed Matter Physics", Swedish Research Council report 12:2005, pp 27-28.

[241] Ibid., p 25.

[242] Ibid., pp 39-41, 64, 120, 159-160, 164, 171, 178, 184, 192, 194.

[243] "An international evaluation of the MAX IV technical concept 2005", Swedish Research Council report 5:2006, p 6.

[244] "Scientific evaluation of the MAX IV proposal 2006", Swedish Research Council report 20:2006, p 6.

[245] "Evaluation of the modified MAX IV proposal 2009", p 24

a funding model. In his report, Flodström made a historical exposé, highlighting how MAX-lab enabled "a remarkable renewal of the research that gave Kai Siegbahn the Nobel Prize in physics and in the involvement of Swedish researchers at synchrotron light facilities in other countries". His position is clear: "If Sweden may be considered to head any area of research at the international level, this is it."[246]

In 2007-2008, Lund University undertook a comprehensive evaluation of all its research activities. The evaluation report praised the accelerator physics department, acknowledging its "wide international recognition" and giving it the overall assessment "outstanding". The education and training in accelerator physics at MAX-lab is rare also internationally, and is considered "a unique asset for Lund University" and "recognized internationally as such". The collaborations between the Lund Laser Center and MAX-lab, in accelerator physics and synchrotron radiation instrumentation, is named "a union blessed in heaven", with the "potential to become a model internationally of how to approach the future light source development." Here, the evaluation states, "Lund University has the unique potential to become a world leading center for development of the laser-based new techniques and methods into the X-ray domain".[247]

Uppsala University had undertaken a similar evaluation of its collected research activities a year earlier, and its evaluation report put some emphasis on the important symbiosis between the Uppsala physics department and MAX-lab, noting that the former is a "key and crucial participant" in the use and development of MAX-lab with a "strong, ongoing commitment", building on the "particular strength and tradition in developing new instruments and associated spectroscopic techniques and application areas".[248]

In 2009, it was once again time for regular evaluations of the performance and quality of the Swedish national facilities, of which now remained two. MAX-lab and Onsala Space Observatory were evaluated separately, and both evaluations also specifically looked at the effects of the dramatic increase in their operations budgets as a result of the 2002 evaluation (see above).[249]

The evaluation concluded that MAX-lab "is a very successful enterprise in science and technology" and compares very well with "the top synchrotron facilities in Europe and in the world". The achievements in experimental methods with soft x-rays are specifically mentioned, and the lab is considered "an extremely valuable resource for

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[246] Anders Flodström, "Arguments for and financing of MAX IV," Swedish Government dnr U2009/4845/F, p 6.

[247] "RQ08 – a Quality Review of Research at Lund University 2007/08," Lund University 2008, p 368.

[248] "Quality and Renewal 2007: An overall evaluation of research at Uppsala University 2006/2007", pp 74, 280, 285.

[249] "Report from the review of the MAX laboratory, Lund, May 2009," Swedish Research Council report 5:2010, p 4.

many Swedish scientists, a facility of reference for the entire Nordic region and the laboratory of choice for many scientists from other regions of Europe and the world". MAX-lab furthermore has a "factual, unmatched record of cost effectiveness both for the construction and operation of facilities" which is "a striking point considering the very high quality of its sources and beamline instrumentation as well as the continuing attention to the user needs."[250]

Interestingly, the evaluation does not criticize the funding model for MAX-lab, but instead praises its organization and strategy for expansion over the years, arguing that this is a model example of "the optimal exploitation of synchrotron light techniques" whereby national sources like MAX-lab complement the larger international ones (like ESRF) by achieving high standard research in specialized areas and also preparing its domestic user communities for exploitation of the international sources. In this regard, the evaluation report says, MAX-lab "places Sweden in a small elite club of nations as far as synchrotron light research is concerned", and thanks to it, "Sweden is the unchallenged leader of the Nordic and Baltic countries."[251] Following the example of the series of previous similar evaluations, the report also praises the strong and healthy relationship between the lab and its host univetsity.[252]

In 2012, VR undertook an "interim" evaluation of 11 national research infrastructures, among which MAX-lab was considered one. The lab is there viewed as an "impressive research infrastructure with a well-defined set up." The great availability to users – "if a researcher is doing good science and beam time is available; it is likely they will be able to do work there" – is highlighted as an important quality of the lab, as is the high degree of collaboration with Swedish university research activities and labs and research environments abroad, and the firm position within Lund University.[253]

Before concluding this section, a report that stands out in the collection of material reviewed above and used in the analyses in the remainder of the report deserves some notice. In 2010, the management consultancy division of Ramböll was asked by Vinnova to undertake an evaluation of the "expected benefits of MAX IV to industry", and since there was little else than MAX-lab to focus empirically on, the report contains quite extensive analyses of the interactions between MAX-lab and local and national industrial firms. The report is explicit on the point that there are significant organizational and cognitive distances between on one hand MAX-lab and the research opportunities it offers, and on the other hand the industrial firms with potential to use it. Representatives of firms interviewed as part of the investigation report on difficulties to know exactly how MAX-lab and its experimental resources can be used in their

[250] Ibid., p 7.

[251] Ibid., p 11.

[252] Ibid., p 7.

[253] "Interim Evaluation of 11 National Research Infrastructures 2012," Swedish Research Council, pp 37-39.

activities, and call for better support functions as well as mechanisms for rapid access in the future to enable their use.[254] Specific relationships established and cultivated between MAX-lab and firms are analyzed in the report, such as the acclerator technology developer and manufacturer Scanditronix and the spinoff service company SARomics Biostructures. These analyses are returned to in chapter 4.

[254] "Näringslivets förväntade nytta av MAX IV," Ramböll Management 2010, p 7.

3. Scientific and technological impact

3.1 Science at MAX-lab

As noted in the introductory chapters, synchrotron radiation is a *generic* experimental technique and has had a strong impact of several fields of science, including atomic and molecular physics, surface and interface physics, nanoscience and nanotechnology, the physics and chemistry of materials, structural biology, and several other areas in the borderlands between these disciplines. In the most recent two decades, especially the expansion of the use of synchrotron radiation in the life sciences has been spectacular (see e.g. figure 2.1 in section 2.2), but the applications on the side of physics and chemistry have also undergone dramatic improvements of performance, reliability, and user friendliness.

Therefore, on a very rudimental level, it is possible to establish that in terms of scientific impact, MAX-lab has been a tremendous resource for Swedish, Nordic and international scientists from the mentioned fields. Many times crucial, as this chapter will show, and many times with a role as a core asset in the resource economy that surrounds any scientific undertaking in this day and age.

Leaving the most rudimentary level, it is important to establish that an evaluation of the scientific impact of MAX-lab must take into account, and use as a framework and fundament for the analysis, some specific and key features of the lab. Ultimately, this goes back to what was stated in sections 1.2 and 2.1, that in order to document, measure and analyze the activities of any science, it must first be understood at least on some rudimentary level what the science is about, what resources it requires, how it is organized, and how results are achieved and disseminated.[255] Some of the features that distinguish MAX-lab from other organizations and resources in the scientific landscape are features that the lab shares with most or all synchrotron radiation laboratories worldwide (see section 2.2 above), while some are highly specific, or even unique, for MAX-lab.

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[255] E-J Meusel, “Einrichtungen der Großforschung und Wissenstransfer,” in H Schuster (ed.), *Handbuch des Wissenschaftstransfer* (Springer, 1990), p 365. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 195.

First of all, MAX-lab is an example of what has been called “small science on big machines”[256] from a sociological/organizational viewpoint, or Big Science that has been “transformed” into a state of serving a large user community of great disciplinary breadth and composed of research groups from academia or industry no size bigger than other groups in these scientific contexts.[257] The central piece of infrastructure is physically big and requires a team of skilled engineers and several auxiliary functions (radiation safety, vacuum maintenance, and so on) to be operated. The lab as such requires a heterogeneous organization to be operated successfully and provide the expected resources and services to users. But the science done by the user groups in e.g. surface physics, metalorganic chemistry or structural biology does not typically, nowadays, require technical expertise beyond what groups in these areas need to do work in their home labs.

Second, somewhat contradictory to this, what characterizes MAX-lab just like many or most synchrotron radiation facilities that were built up and started operation before synchrotron radaiation became “mainstream” (see section 2.2) is the high degree of *user involvement* in design and construction of instruments and in the operation of equipment and experimentation. The early MAX-lab activity reports (up until at least the mid-1990s) all instruct users to “take full responsibility for carrying out their research projects and […] become familiar with the experimental equipment and data-taking systems which are available at the laboratory before they begin the experiments”[258] which, in comparison with many other labs (especially nowadays) means that MAX-lab put a lot of responsibility on the users. Part of the reason for this is the historically small-scale organization of MAX-lab, and its tight budget, which effectively prevented the buildup of a full-fledged user support organization. But part of the reason is also the tradition that MAX-lab was built within, namely, Swedish research in condensed matter physics which was especially strong on instrument development and which meant that leading users, early on, quite naturally took a great part of the responsibility for instrumentation at MAX-lab and also set a standard for the user community; most, if not all, early MAX-lab users belonged to groups with a high degree of technical expertise. The early MAX-lab activity reports also contained instructions to users that they “are also welcome to contribute to design, construction and development of new equipment at MAX-lab” and note that “a great part of the existing facility has been developed in a close collaboration with enthusiastic and skillful users.”[259] Later evaluations of MAX-lab credited the scientific successes of MAX-lab in the early years in large part to this strong involvement of users, that enabled scientific

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[256] O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009).

[257] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 16-21.

[258] MAX-lab Activity Report 1995: 13

[259] MAX-lab Activity Report 1987, p 8

work on high quality with relatively small financial investments.[260] Also in the nuclear physics activities, a significant involvement of external users in instrument development can be noted.[261]

But the user involvement in MAX-lab was also *organized* early on – according to sources, the first version of the Association for Users of the Synchrotron Radiation Laboratory MAX-lab (Föreningen för Användare av Synkrotronljuset vid MAX-lab, FASM) was founded by pioneer synchrotron radiation and MAX-lab user Per-Olof Nilsson of Gothenburg already in 1978.[262] Later, it evolved into a natural part of the MAX-lab ecosystem, almost integrated with the lab organization and with permanent representation in the MAX-lab board, which ensured a tight collaboration between the lab and its users in long- as well as short-term strategic planning and development (see section 3.7.1 below).

There are clear exceptions to this heavy user involvement: structural biologists and other scientists doing work on the crystallography beamlines (I711 and I911) have a wholly different attitude towards the lab and typically expect to be spared from duties of caring for the experimental equipment (see section 2.2 above and 3.5 below). But MAX-lab was, for the better part of its several-decade history, very much characterized by the deep integration of users into the lab organization, the scientific program, and the development and maintenance of technical equipment and instruments. Prominent users chaired committees, held leadership positions at the lab, lobbied for MAX-lab in the research council(s), and not least spent enormous amounts of time and energy on building and maintaining equipment and enabling themselves and other users to do experimentation at the lab.

The user involvement is one key reason for the horizontal and rather informal organizational structure at MAX-lab, which many informants bear witness of. The distances between different parts of the organization have historically been short, and this informal organizational culture has been actively maintained by lab leadership. According to some, this is a main reason for the ability of MAX-lab to achieve scientific successes in spite of funding shortage, since it has enabled the lab to work as one, to reach technical solutions that optimizes the system as a whole, from accelerator to beamline to experimental station.[263] This is also related to the flip side of the coin that has been discussed repeatedly in evaluations of MAX-lab (see section 2.5 in the previous

[260] "International Evaluation of the MAX II Project", Swedish Natural Science Research Council 1989. p 12-13. "Swedish National Facilities", review report, Swedish Research Council, 2002. p 37

[261] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002),

[262] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 102.

[263] Jesper Andersen, interviewed by Olof Hallonsten, Lund 11 October 2006. Nils Mårtensson, interviewed by Olof Hallonsten, 7 November 2006.

chapter), namely the very advanced "shadow economy" that evolved to cover for the funding shortages. It is important to note that this feature of the MAX-lab organization is truly dual: While in one sense unsustainable and opaque on the verge of the murky, it should also be noted that MAX-lab was built on it and probably could not have survived, let alone succeeded, without it. Funding shortages, informal organizational structure, and heavy user involvement are three very much interrelated features of the organizational history of MAX-lab that are difficult to analytically separate.

Another main feature, somewhat easier to pinpoint and discuss separately, is the other reason for the horizontal and informal organization of MAX-lab, namely the academic culture of the lab. This is just as much key to understanding how the lab works and what it produced over the years in terms of impact. MAX-lab sprung out of a small-scale university project and grew organically from there to become a national and international user facility. It therefore bore traces of its original organization as a university project, with its management holding academic positions at Lund University and its operations and maintenance carried out chiefly by academics. Until 1994, there was no funded director position at MAX-lab – this post was filled by two consecutive professors of Lund University on basis of their academic positions. But also beyond the organizational reforms of the 1990s, when MAX-lab got upgraded from a university department structure to national facility under the stewardship of the NFR, MAX-lab remained part of Lund University and key leadership positions at the lab remained essentially academic posts. The essentially academic culture of MAX-lab never left the lab, or if it did, it was only in 2011 and forward when it was transformed to the MAX IV organization and the staff increased dramatically.

Two things are extremely important to note in this context. First, the academic culture at MAX-lab and the academically structured organization of the lab (also in a formal sense) made it possible for the lab to seek solutions and development paths that it probably could not have done otherwise. This included the accelerator development, which was part of the division of accelerator physics at Lund University and included doctoral training, and the development of beamlines and experimental stations which was made with deep involvement of user groups but overseen by the coordinator for synchrotron radiation who had an academic position in synchrotron radiation instrumentation (a standalone professorship from 1998). In both realms, the development of technical solutions for the lab was to a significant degree academic work in itself; i.e. it was not mere work to prepare infrastructure and instrumentation for the external user community to utilize.

In the long run, this was probably instrumental to MAX-lab's successes. In the short run, obviously, it created some hurdles for the lab and its users to cope with: A good example is when in 2003/04 the radiofrequency cavities in MAX II were upgraded to meet the requirements (in terms of power) of a new type of insertion devices (the superconducting wigglers, see section 3.3), which created some troubles that led to occasional losses of beamtime that tried the patience of the users and ultimately resulted in a small decline in user numbers the following year (see figure 2.4 in section 2.4 above). The idea of implementing the superconducting wiggler in the ring in the first place would probably not have crossed the minds of the lab leadership at a synchrotron radiation facility with less of an academic culture – indeed the superconducting wiggler itself would perhaps not have been invented at all at a lab where technical reliability and the meeting of design specifications is front and center.[264] The consequences on long term were therefore really on the positive side – enabling a broadening and true solidification of the lab's user community in biology and chemistry – but on short term, quite evidently, the troubles were challenging for the lab and its users in 2003/2004.[265]

A second, very important, feature of MAX-lab that stems from the strong academic culture at the lab is the *evolutionary* mode by which it has developed over the years. It has been repeated in previous sections that throughout its history, MAX-lab has developed gradually, through a series of incremental steps.

A certain *adaptability* is built into synchrotron radiation laboratories, as noted in chapter 2 – although accelerators are big monoliths that can only be modified with some rather major interventions, the modular character of the whole lab is one of the most striking features of synchrotron radiation labs and current "transformed" Big Science.[266] Individual beamlines and experimental stations can be substituted and modified mostly without disturbing each other, and as long as there is funding available in some form (and space available at the lab floor!), new beamlines and experimental stations can be built and attached to the ring and thus expand the scientific program to new areas.

In one sense, MAX-lab was a case of perfection of this adaptability: During its thirty-year history, the lab was almost in constant change. Some new instrument was always under construction. During times, a new accelerator (MAX I, MAX II, MAX III, the injector system, the free electron laser) was being built and commissioned, or upgraded. In addition, many unconventional but highly inventive technical solutions were implemented in the MAX accelerator system (see section 3.3). This situation is in part due to the funding situation: MAX-lab was not, as is common for counterparts abroad (like the ALS in California, the BESSY in Berlin, or Elettra in Trieste, Italy), built in full on one major grant or investment, but through a series of grants from different

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264 As a telling but somewhat unfair example can be used the European Synchrotron Radiation Facility (ESRF) in Grenoble where, according to sources, the machine group is "like an army" and never gambles even the slightest with the ability to deliver the beam to users, and prides itselfs with average uptimes of 98-99%. See O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009), p 258.

265 Mikael Eriksson, interviewed by Olof Hallonsten, Lund 28 March 2007.

266 O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 100.

sources, each funding some part.[267] But the reason for the evolutionary development lies also in the academic culture, which bred a constant curiosity and interest in trying new things, improving existing instrumentation, and breaking boundaries – the essence of classic academic science. Though it was sometimes noted by evaluators that MAX-lab was constrained in its ability to exploit the inherent flexibility and adaptability of the lab, due to budgetary limits,[268] it must also be concluded that the lab was very successful in exploiting its inherent academic culture and turn the constraints of the funding situation into a mode of work and development of the lab that, in the long run, was what enabled its growth to a multidisciplinary, international user facility with very strong anchoring in the local university environment and the Swedish and Nordic scientific communities and science policy and funding systems.

As noted by MAX-lab leadership itself, in a document from 2002,

> "The formation of the scientific visions of a user dense facility deserves a more sophisticated discussion than can be normally found in reviews o f the present kind. Normally the management and the Board try to give the impression that they create the visions, which are subsequently imposed on the organization by traditional management methods. A strong management and a strong Board are certainly needed, but at a user dense facility the process of forming the visions is much more advanced. The user community - the core of the laboratory - is certainly characterized by strong scientific visions. First of all the relevance of the scientific projects is evaluated by MAX-lab and its expert committees in the beamtime allocation process. The projects are also in different ways evaluated by several other actors in the funding system (such as VR, SSF, KAW, EU, etc). The direction of the laboratory is manifested also in the development of the scientific equipment and the underlying setting of priorities."[269]

Although when measuring things like uptime (the share of time of uninterrupted beam of radiation delivered to the experimental stations) it is likely that MAX-lab would compare poorly with counterparts abroad, it must be underscored that the academic culture is not detrimental to scientific productivity, success or excellence, but perhaps contributed to achieve this in an alternative way. This alternative way was probably more time-consuming and more taxing on the patience of users, but it might have been the only pursuable road for a lab like MAX-lab, with its specific circumstances. Whether it was forced by limited funding or a product of a lively academic culture, or both, is a discussion that will not reach a conclusion in this report. It is clear that MAX-

[267] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p1.

[268] "International Evaluation of Swedish National Facilities, April 1997." Swedish Natural Science Research Council. p 8.

[269] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch4p1.

lab was highly cost-efficient, given that it evidently achieved remarkable scientific results on a very limited budget, as several evaluations have noted (section 2.5).

In the remainder of this chapter, the scientific and technological impact of MAX-lab will be analyzed in greater detail.

3.2 General assessment of the impact of the scientific program of MAX-lab

To begin with, an overall quantitative assessment of the scientific use of MAX-lab is useful. This is a rather simple affair to convey in tables and diagrams, given the amount of data available in the activity reports. First, we may consider the use of the lab – and here, it is not possible to obtain a figure of the total number of individuals who have done scientific work as users of MAX-lab, but it can be estimated at several thousand. Individual users have been counted, but only on a yearly basis. Figure 3.1 shows that the annual number of users that visited MAX-lab rose from roughly a hundred in 1987/88 to over 600 in 2000/01, and reached 1000 in 2014.

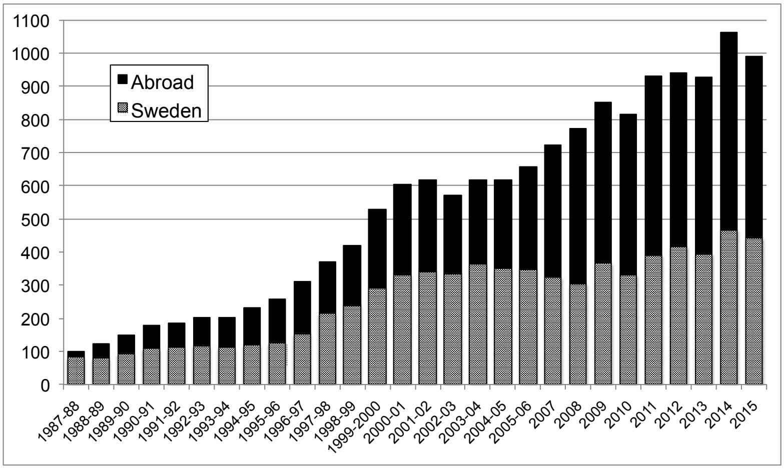

Figure 3.1:
Total number of MAX-lab users (individuals), 1987-2015 (identical with figure 2.4)[270]

[270] As listed in the MAX-lab activity reports, and complementary data received via email from Ralf Nyholm, 2 November 2015. Note: The data for the years 1987 to 2006 denote years from August to June; whereas from 2007 and on they denote calendar years.

Key to the analysis of impact of a user facility like MAX-lab is its reach, institutionally and geographically. MAX-lab was dominated by academic users, but their geographical distribution inside and outside Sweden is astonishing, as figures 3.2, 3.3 and 3.4 illustrate: At most, fifteen different universities and university colleges in Sweden were represented by the MAX-lab users, and over 35 countries.

Moving on to output, publications and doctoral theses are listed in the activity reports for 1987-2010, and complementary lists for 2011-2015 are also available. Figures 3.5 and 3.6 show the overall scientific output of experimental work done at MAX-lab (both synchrotron radiation and nuclear physics, these are not separated in the lists and not separated in this analysis) over the years, in journal articles and conference contributions. In turn, the total numbers for these two categories of output are 3,849 (journal publications, 1986-2015) and 3,158 (conference contributions, 1982-2010; the activity report for 1987 contains items back to 1982, but no lists are available for the years 2011 and on). The journal publications have covered a set of 588 different journals over the years, which in itself is testimony to the disciplinary breadth of the scientific program of MAX-lab.

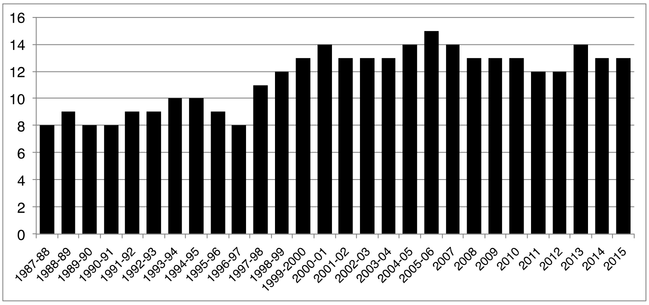

Figure 3.2:
Number of Swedish universities and university colleges represented among MAX-lab users, 1987-2015

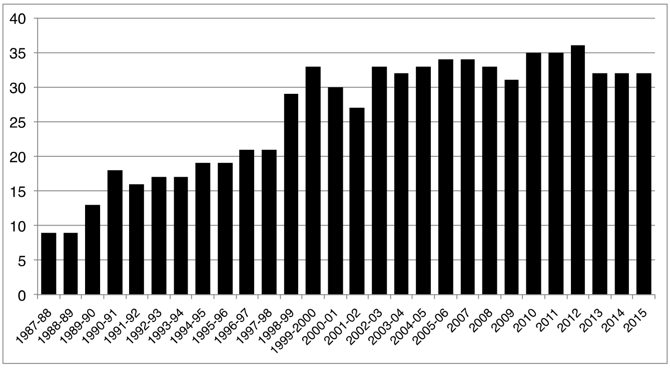

Figure 3.3:
Number of countries represented among MAX-lab users, 1987-2015

Figure 3.4:
World map showing the geographical distribution of MAX-lab users, 1987-2015

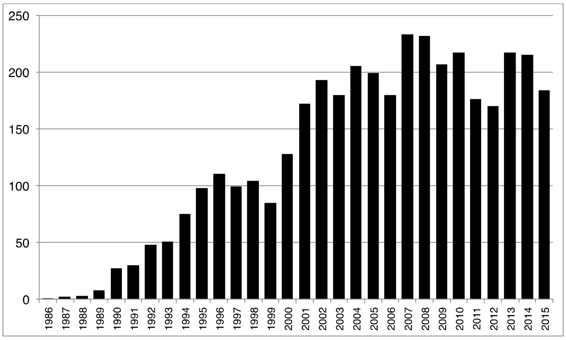

Figure 3.5:
Number of journal articles based on work done at MAX-lab, 1986-2015 (identical with figure 2.5)[271]

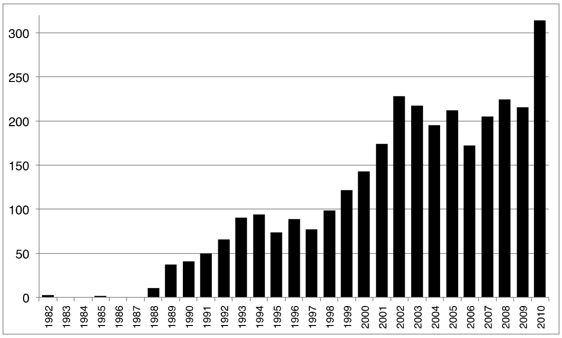

Figure 3.6:
Number of conference contributions based on work done at MAX-lab, 1982-2010[272]

[271] As listed in the MAX-lab activity reports. Only *published* articles are counted, not *submitted* or *forthcoming*.

[272] As listed in the MAX-lab activity reports.

Table 3.1 shows the most common journals in which publications based on experimental work done at MAX-lab have appeared in, over the years, and information on their subject classifications and impact factors (from the database Web of Science). Two things are noteworthy here: First, the variation among the journals listed, as seen in the column with subject categories, once more speaks to the disciplinary variation of MAX-lab. So does also the fact that no journal, as table 3.1 also conveys, covers more than 10% of the total journal article output from the lab over the years, and the tenth most common journal (among the total of 588) has been the outlet for only 2.2% of the total number of articles, which is a sign of variation and distribution over the wide disciplinary breadth already identified.

Table 3.1:
Ten most common journals of articles based on work done at MAX-lab, 1987-2015

Journal	No of Articles	% of total	Impact factor (WoS)		WoS subject categories
			2015	5-year (2015)	
Physical Review B	362	9.4%	3.718	3.513	Condensed matter physics
Surface Science	252	6.5%	1.931	1.745	Physical chemistry; Condensed matter physics
Journal of Electron Spectroscopy and Related Phenomena	131	3.4%	1.516	1.679	Spectroscopy
Journal of Physical Chemistry C	122	3.2%	4.509	4.919	Physical chemistry; nanoscience and nanotechnology; multidisciplinary materials science
Journal of Chemical Physics	116	3.0%	2.894	2.950	Physical Chemistry; Atomic, molecular and chemical physics
Physical Review A	115	3.0%	2.765	2.598	Optics; Atomic, molecular and chemical physics
Acta Crystallographica D	91	2.4%	2.512	8.751	Biochemical research methods; Biochemistry and molecular biology; Biophysics; Crystallography
Journal of Molecular Biology	90	2.3%	4.517	3.621	Biochemistry and molecular biology
Journal of Biological Chemistry	88	2.3%	4.258	4.403	Biochemistry and molecular biology
Physical Review Letters	84	2.2%	7.645	7.346	Physics, multidisciplinary

In the context of a study like this one, it is tempting to make citation analyses of the available publication lists with the help of the Web of Science (WoS) database. This, however, is a venture with some serious built-in methodological flaws and should not be part of serious reporting of productivity and impact. Sure, citation scores is an accepted and widespread method for illustrating impact of published research, or at least demonstrate whether at all a publication or a set of publications (and thus, by extension, the research behind) are relevant. But citation analyses do not account for negative citations (which include works that question or discard the value of the work cited), which have sometimes been estimated to constitute as much as one tenth of all journal articles.[273] Moreover, the issue of time frames is challenging but too often overlooked: At any point in time when a citation analysis is made, it can only account for those citations that have been made so far (and reported to WoS or other database used), which renders imbalances in the material. In the case of MAX-lab, articles published in 2015 and 1987 would be assessed side by side, and so an analysis made today (2017) would then judge the 2015 articles on basis of only two years and the 1987 articles on basis of thirty. But the troubles do not stop there – other, deeper methodological issues embed citation analyses. Many articles are not cited until several years after their publication, and also those that belong to the category of "Non Cited Literature (NCL)" which has stirred interest in some bibliometric studies and been shown to make up roughly 20% of all published scientific articles,[274] may end up being "sleeping beauties"[275] that can have enormous impact several years or decades down the road.

For individual articles, or for a smaller set of publications, citation analyses can be very helpful as a way to analyze impact in the scientific communities, not least when the time dimension can be constructively used to analyze when and how results are taken up by other scientists and thus incorporated into the scientific commons or canon.[276] Also analyses where subject categories of journals are used to analyze how results (represented by articles) spread across disciplinary boundaries. We use such an analysis in a later part of this report (section 4.2.1) to show the impact of an article that describes the Scienta SES-200 analyzer. But for the body of 3,849 journal articles produced in

[273] W R Shadish, D Tolliver, M Gray and S K Sengupta, "Author judgements about works they cite: three studies from psychology journals," *Social Studies of Science*, 25 (1995), 477-499. H F Moed, *Citation analysis in research evaluation* (Springer, 2005).

[274] H P van Dalen and K Henkens, "Demographers and their journals: who remains uncited after ten years?" *Population and Development Review*, 30 (2004), 489-506. W Glänzel, B Schlemmer and B Thijs, "Better late than never? On the chance to become highly cited only beyond the standard bibliometric time horizon," *Scientometrics*, 58 (2003), 571-586. I Sengupta and R G Henzler, "Citedness and uncitedness of cancer articles." *Scientometrics*, 22 (1991), 283-296. R E Stern, "Uncitedness in the biomedical literature," *American Society for Information Science Journal*, 41 (1990), 193-196.

[275] A F J Van Raan, "Sleeping beauties in science," *Scientometrics*, 59 (2004), 467-472.

[276] T Heinze, R Heidler, R H Heiberger and J Riebling, "New Patterns of Scientific Growth: How Research Expanded After the Invention of Scanning Tunneling Microscopy and the Discovery of Buckminsterfullerenes," *Journal of the American Society for Information Science and Technology*, 64 (2013), 829–843. T Heinze,

"Creative accomplishments in science: definition, theoretical considerations, examples from science history, and bibliometric findings," *Scientometrics* 95 (2013): 927-940.

1987-2015 on basis of work done at MAX-lab, which means an average of over 200 articles per year, such an analysis – studying the time dimension and analyzing citations in journals classified in subject categories – is not possible, as it would require a major effort and take hundreds of report pages, but still not evade the methodological problems of citation time lags, as discussed above.

The Annual Report of the MAX IV Laboratory to the Swedish Research Council from 2012 makes a half-hearted effort of using citation analysis to demonstrate scientific excellence on behalf of the scientific program at MAX-lab, calculating the average number of citations (listed in WoS) per publication to "more than 13," which it claims "is better than or similar to many other synchrotron facilities such as those at ESRF, HZB and DESY."[277] There is no information given on the time frame either of the list of publications analyzed or the years in which citations have been counted. The comparison perhaps filled a purpose as part of advertisement material, but will not be repeated here.

Instead, to make some kind of assessment of the quality of the publication output from MAX-lab we will follow the lead of a recent contribution to the "facilitymetrics" literature (see section 1.2) where the body of journal articles that build on work done at MAX-lab is differentiated by identifying a number of high profile journals, whose impact factor (in WoS) is high but whose informal reputation in the scientific communities is especially high. Repeating the selection of a previous study of a synchrotron radiation facility (the ESRF), a neutron scattering facility (the Institute Laue Langevin, ILL, in Grenoble), and a free electron laser facility (the LCLS at SLAC in California), nine journals were selected, namely: *Nature*, *Science*, *Cell*, *Physical Review Letters*, *Advanced Materials*, *Nano Letters*, the *Journal of the American Chemical Society (JACS)*, *Proceedings of the National Academy of Sciences (PNAS)*, and the *Journal of Applied Crystallography*.

The ESRF is commonly named one of the most successful synchrotron radiation facilities in the world, and out of the 1,782 articles published in 2014 and based on work done at the ESRF (as listed in its official publications database), 125 appeared in these nine high-profile journals, or 7%. Taking the whole list of articles based on work done at MAX-lab (1986-2015), 180 of these, or 4.7%, appeared in the nine listed high-profile journals. The comparison is not completely fair (and very unbalanced given that one year of ESRF publication is here compared to 28 years of MAX-lab publications), but MAX-lab nonetheless comes out rather strongly. Especially the high number of appearing in the very prestigious journal *Physical Review Letters* stands out at MAX-lab: Over the years, no less than 84 articles, or three each year on average, appeared in this rather prestigious physics journal.

[277] The Annual Report of the MAX IV Laboratory to the Swedish Research Council 2012, p 8.

Leaving this methodologically slightly equivocal analysis, we may instead put some focus on the substantial scientific output of the use of MAX-lab in the shape of doctoral theses. Figure 3.7 shows the total number of doctoral theses listed in the MAX-lab activity reports for the years 1988-2015.

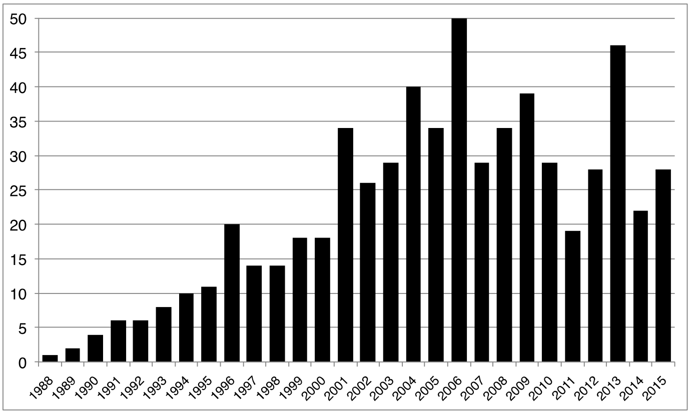

Figure 3.7:
Numbers of published doctoral theses that build on work done at MAX-lab, 1988-2015[278]

618 total doctoral theses are listed in the MAX-lab activity reports (and complementary lists that cover the years 2012-2015) as building on work done at MAX lab. They were published and defended at 83 different universities and institutes in 26 countries, and 259 of them outside Sweden. Most common among universities are Uppsala University (103 theses), Lund University (95), Copenhagen University (37), KTH Royal Institute of Technology in Stockholm (36), Oulu University in Finland (35), Karolinska Institute in Stockholm (22), Chalmers University of Technology in Gothenburg (20 + 5 jointly with Gothenburg University), Linköping University (20), the Swedish University of Agricultural Sciences in Uppsala (19), and Aarhus University in Denmark (17).

Besides scientific output, doctoral thesis work constitutes a foundation of the academic scientific system. It is also a key merit in the contemporary knowledge economy, given that doctoral training, especially in very technically advanced areas, typically entails both highly specialized skills and a set of generic competences and knowledges. A key impact of any scientific activity, in any context, is therefore (the contribution to) the production of doctorates. In the case of MAX-lab, this effect is likely enhanced since the lab makes up a resource and a system of technologies not available elsewhere, or at least not in the close vicinity. This human capital dimension is important. We have

[278] As listed in the annual reports and online: https://www.maxlab.lu.se/node/1157 and https://www.maxlab.lu.se/node/2061 (accessed 21 December 2016)

little or no means of tracing the careers of these doctoral students who have done work at MAX-lab and whose these are listed in the activity reports and noted above, except for noting that several of them emerge in the lists of employees at MAX-lab and MAX IV after completion of their thesis work. Apart from that, the conclusion of this analysis will have to stop at the realization that over 600 people have visited MAX-lab as part of their doctoral training, and possibly or likely earned skills that are hard to replace. Most of them have come from universities outside Lund (523), and close to half of them outside Sweden (259), which also makes it highly likely that they have brought back important knowledge, experiences and skills from their visits at MAX-lab to the rest of Sweden and the rest of the world. (See also section 5.2.1, on the summer schools in synchrotron radiation.)

A similar argument can, quite naturally, be made regarding the many postdocs and visiting scientists that have spent longer time than the typical user in the lab, and who also are highly likely to have gained very valuable experiences and knowledge that they have brough with them to coming positions and assignments in their careers.

Postdocs and visiting scientists are listed in the MAX-lab activity reports (not all years). Searches on the LinkedIn online career network showed that a significant share of these have gone on to staff positions at MAX IV, to similar positions at other synchrotron radiation and free electron laser facilities abroad (including SOLARIS in France, the Australian Synchrotron, the Stanford Synchrotron Radiation Lightsource, the European X-ray Free Electron Laser in Hamburg, and the Canadian Light Source), and other prominent positions, including not least affiliations in academia (professorships), in the public and private sectors (research administrators and corporate R&D staff), in Europe and the United States. Among the companies that have hired scientists that previously worked at MAX-lab are found Novo Nordisk A/S, SonyEricsson, Vattenfall, Scienta, ABB, Axis Communications, and Sandvik.[279]

As a means of assessing scientific impact, this human capital dimension is the one where the perhaps most profound impact lies. Although we have not been able to map this impact in detail, the above analysis clearly shows MAX-lab's broad and deep contribution, over a long period of time, to science and industry in Sweden and abroad.

Finally, before moving on to qualitative analyses of different broad subject areas, we may pay some briaf attention to the matter of funding. The habit of using investments in R&D as a measure of scientific productivity or relevance (this is common not least on the international stage, where national strength in R&D is usually demonstrated with the help of measures of the percentage of GDP annually spent on R&D) is methodically flawed, since input generally is a very inefficient measure of output. Nonetheless, extending the argument slightly and putting it into proper context,

[279] A list of postdocs and visiting scientists at MAX-lab between 1998 and 2010 is found in appendix 5. This list was used in a search on the LinkedIn site (www.linkedin.com).

continuous investments in a project or facility like MAX-lab over several decades, and the continuous increase of these investments, is of course a sign of willingness of funders and politicians to pay, and this willingness must be based on some kind of assessment of quality and/or relevance. Given that MAX-lab, for all of its history, has been positioned in a science policy and funding system very much characterized and ruled by universities and research councils, an expansion of the sort seen in the case of MAX-lab could not have been done unless the universities and the council(s) – and, by extension, the government – would have thought it worthwhile, and based this assessment on careful analysis and evaluation. The repeated performance evaluations reviewed in section 2.5 also show this: MAX-lab has been evaluated repeatedly and always come out favorably. From the side of the funder(s), a quote from the Swedish Research Council's recommendation to the government ahead of the latter's 2004 research bill is tellling: "The operations budget of MAX-lab must be more than doubled in order for the lab to maintain its currently strong international position."[280]

3.3 Machine and instrumentation

A quote from then-director of MAX-lab Nils Mårtensson in 2006 is a good illustration of the importance that the accelerator physics group has had for the lab over several decades, that was noted in the previous section and will be the topic of the first part of this section. Mårtensson says,

> "If we would only have our operations budget we wouldn't be able to motivate that some people work on long term projects, accelerator development projects, and sit around calculating and finding new solutions for the ring while the ring itself has a somewhat unstable performance. It wouldn't be justifiable, because operations must be prioritized. […] But simultaneously, we can have these activities, with doctoral students who do work on future projects and such. And that is not something all labs have. For us, being able to work on these odd solutions alongside, is something that has been a tremendous strength in the long run."[281]

The repeated evaluations of MAX-lab have noted this, albeit not in the exact same terms, commenting that the accelerator physics research activities and the inventions and new solutions that have been produced there "are the bases for the success of the laboratory." The accelerator physics group has been "truly imaginative" and

[280] "Underlag till forskningspropositionen 2005–2008 från Ämnesrådet för naturvetenskap och teknikvetenskap," Swedish Research Council 2003, p 31.

[281] Nils Mårtensson, interviewed by Olof Hallonsten, Lund 10 November 2006.

“impress[ed] the world by their far-sighted planning of new components of the facility and the cost efficient realisation of these projects.”[282]

The scientific impact of MAX-lab in the field of accelerator physics can be measured by conventional metrics: At least fifteen students have completed doctoral education in the accelerator physics group over the years, and the group in total has continuously had five to six members since the mid-1980s.[283] The group has published extensively, and thus performed excellently over the years, earning a worldwide reputation matched by few. The evaluation of all research at Lund University in 2008 consequently mentioned the accelerator physics activities specifically when naming (some parts of) physics in Lund “one of the crown jewels” of the university, and noted that this is “a unique asset for Lund University and is recognized internationally as such”.[284]

But the development of the MAX accelerator system, the successive storage ring projects (including MAX IV, see section 7.1.2), and how these have been conceived and developed, is of course a measure of impact of greater importance, which not least also the report from the evaluation of research at Lund University in 2008 noted as one of its key markers of quality: “Pioneering concepts developed here have for years enjoyed that highest degree of flattery – being copied and implemented in other facilities around the world.”[285]

MAX I was, as noted in sections 1.1 and 2.4, a “home made” accelerator. Small scale and funded not by a large prestigious investment but through small-scale efforts, and built in the context of a university project, MAX I was clearly a machine project that enabled the accelerator group to learn tremendously and also experiment a lot with innovative solutions. Contacts were taken early on with people on the commercial side, and crucial interpersonal relations were established that would prove extremely valuable in later projects (see also section 4.2). To a great degree, this was necessary: There were not many synchrotron radiation facilities around at the time, but those very few that existed (in Wisconsin, Hamburg, and at Stanford) were soon integrated in the personal networks of Mikael Eriksson and his accelerator physics group. Many ideas were imported from these places, but many were also conceived locally, within the group.[286]

There is no doubt that it worked, and worked well – as noted in the 1989 review of the MAX II proposal, the accelerator team at MAX-lab did “an excellent job on MAX I, on a very limited budget” and managed to draft a design for MAX II that the evaluators

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[282] ”Swedish National Facilities”, Swedish Research Council report 2002, pp 38-41.

[283] List compiled from the activity reports. For a full list of finalized doctoral theses that build on work done at MAX-lab, see appendix 2.

[284] “RQ08 – a Quality Review of Research at Lund University 2007/08,” Lund University 2008, pp 21, 351, 368.

[285] Ibid., p 368.

[286] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 117.

considered “a very interesting step in the development of compact, inexpensive third generation light sources.”[287] Needless to say, the experience that the group gained from constructing MAX I was extremely valuable, or indeed necessary, when MAX II was designed and built. In this sense, the MAX II design can be dubbed the first major impact of MAX-lab on the accelerator physics side, since it was a key outcome of the accelerator physics group that enabled new steps to be taken on several fronts (see coming sections on scientific impact).

MAX III was a standalone facility, optimized for ultraviolet radiation and some of the types of experimental work that formed the core of the scientific program at MAX-lab in the early days and throughout its history (see next section). But it was also a project that formed part of the R&D within the MAX IV project, as a ring where technical solutions could be tried and developed.[288] Magnet designs for MAX III were later used in MAX IV.

The MAX IV design is absolutely world leading in many respects and should be considered one of the most significant and spectacular impacts of MAX-lab, not only from the accelerator physics group but indeed the whole laboratory and its ecosystem of users, funders, and other supporters and stakeholders, given how these cooperatied symbiotically to make MAX IV reality. This argument is developed further in section 7.1.2. But remaining on the accelerator/machine side, there are several other important and very concrete outputs that have made great impact locally and globally, and many of them have originated in academic research in accelerator physics, only to be identified as viable (yet often times innovative and somewhat risky).

The use of so called *Landau cavities* was implemented at MAX-lab as a result of development work that started with a doctoral thesis project in accelerator physics.[289] In the early 2000s, Landau cavities were routinely used in the MAX II ring as a means to improve the beam lifetime (the time that the electrons are possible to keep in circulation in the ring and be made to produced radiation of acceptable quality). Their use was initially considered high-risk but was proven to work well with MAX II and the experiences were carried over to other labs, including ALS in California and BESSY in Berlin, with whom MAX-lab had extensive collaborations in this area and where now Landau cavities are also used in routine operation of storage rings for synchrotron radiation.[290]

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[287] ”International Evaluation of the MAX II Project”, Swedish Natural Science Research Council 1989. p 9.

[288] MAX-lab, “Background Material for the Evaluation of the Swedish National Facilities 2002” (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p3

[289] M Georgsson, *Higher harmonic cavities at 3rd generation synchrotron light sources*, Doctoral thesis, Lund University, 2001.

[290] MAX-lab, “Background Material for the Evaluation of the Swedish National Facilities 2002” (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p2, ch3p2.

The most significant invention of the accelerator physics group, besides the magnet technology that went into the MAX IV design, is probably the *superconducting wiggler*. Starting as a research project in the accelerator physics group in the 1980s, the MAX wiggler was optimized for the performance parameters of the MAX II ring and enabled it to produce hard x-rays with no significant loss in intensity. This had, so far, been impossible with storage rings of lower energy, which was also one key reason for why the ESRF and counterparts in Japan and the United States were build in the late 1980s and early 1990s. With the MAX wiggler, developed as part of both postdoctoral and doctoral thesis work in the accelerator physics group,[291] was what solidified and the expansion of the MAX-lab scientific program to protein crystallography (beamline I911) and those areas of materials science that require hard x-rays (beamline I811), by enabling a higher and more reliable capacity in these areas. The two MAX wigglers implemented were built inhouse.[292]

The use of solid magnets for MAX III (and later, MAX IV) is another major innovation in accelerator technology made at MAX-lab. For fundamental technological reasons that have to do with the ability of magnets to swiftly deliver a powerful magnetic field, magnets for accelerators and storage rings have traditionally consisted of thin plates laminated together. The use of solid magnets was seen as a bold and risky venture in the community but meanwhile, its technical advantages were severe. While not a technological breakthrough in itself, this is a good example of the ability of the MAX-lab accelerator group to make use of existing technologies in the most clever way.[293]

Similar, but more innovative also in a purely technical sense, is the concept of the Multi Bend Acromat (MBA), probably invented in the early 1990s but refined and implemented as part of a storage ring design at MAX-lab. The MBA allows a dramatic reduction of the cross-sectional size of the electron bunch stored in the ring, which in turn means a remarkable increase in the quality of the radiation produced. Implemented in MAX IV, the concept has now won worldwide acclaim and has been taken up by “ten different labs” including the ESRF, the Advanced Photon Source (APS) at Argonne National Lab in Illinois, and the Spring-8 in Japan.[294] The impact that this concept has had is truly remarkable, leading some to compare it with the impact of Nobel Prize-winning work.[295]

These are some examples of how the accelerator physics group has worked to develop technical solutions that have come to great use elsewhere and rendered the group and MAX-lab a worldwide reputation. Similar examples of technology development have

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[291] Ibid., ch3p2.

[292] MAX-lab Activity Report 2001, p 32. Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

[293] Bengt Anderberg, interviewed by Oskar Christensson, Uppsala 13 December 2016.

[294] Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

[295] Oscar Tjernberg, interviewed by Oskar Christensson, 13 December 2016.

occurred also on the instrumentation side, with involvement of users, and will be discussed below. But before moving on, some additional things are worth mentioning in terms of output and impact of the accelerator physics activities at MAX-lab.

Throughout the years, the accelerator physicists at MAX-lab have taken part of many important accelerator development projects worldwide, as consultants, committee members, and collaborators on technical solutions with mutual benefit for MAX-lab and the collaborating labs. Collaborations with the private sector will be discussed separately, in section 4.2. Here, we note that over the years, the MAX-lab accelerator physics group has been involved in projects and collaborations with the ESRF, the Brazilian Synchrotron Light Source, the ASTRID synchrotron radiation facility in Aarhus, Denmark, the National Synchrotron Radiation Research Center (NSRRC) in Taiwan.[296] Its members have had appointments on machine advisory committees of BESSY in Berlin, the Swiss Light Source (SLS) in Villigen, the Canadian Light Source in Saskatchewan, the DELTA synchrotron radiation source in Dortmund, the SESAME synchrotron radiation facility in Jordan, the Diamond synchrotron radiation facility in Oxford, UK, the DESY facilities in Hamburg, the Elettra in Trieste, the ESRF, and several others.[297]

Collaborations with the ALS and BESSY on Landau cavities were mentioned above. Several other similar collaborations have been undertaken by the accelerator physics group. These include collaborations on insertion device development with the Karlsruhe Institute of Technology, and not least the free electron laser development efforts together with DESY, SLAC, BESSY, the Budker Institute in Novosibirsk, and the APS, in the 2000s.[298] Locally at Lund University, the collaborations with the Lund Laser Center are noteworthy and will be returned to in section 6.1.

On the side of instrumentation, it is important to note that the developments at MAX-lab from the mid-1980s and forward places itself very well in a long tradition of instrumentation development at Swedish universities. In Uppsala, Stockholm, Linköping and at Chalmers in Gothenburg, vast improvements were made in the second half of the 20th century on many key technologies in the area of materials science, that contributed greatly to the renewal in this field, its growth to preeminence and a Swedish scientific area of strength, with both fundamental scientific advancements (including in nanotechnology) and the development of important

[296] MAX-lab Activity Report 1987: 21. MAX-lab Activity Report 1989: 21.

[297] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p15. Herman Winick, interviewed in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 211. Mikael Eriksson CV, appended to the application for funding for MAX IV beamlines to the Knut and Alice Wallenberg Foundation 2010 (Swedish Research Council, dnr 827-2010-189).

[298] MAX-lab Activity Report 2000, p 32. MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch4p4

applications of great interest for Swedish industry.[299] These developments in Uppsala, Linköping, Stockholm and Gothenburg were, in turn, continuations and augmentations of a strong Swedish tradition that goes back to the 1920s and 1930s and the pioneering work of Manne Siegbahn in x-ray spectroscopy that gave him the Nobel Prize in physics in 1924. Kai Siegbahn, son of Manne, continued in the tradition and made significant contributions to the development of photoelectron spectroscopy, including instrument development, and won his own Nobel Prize in physics in 1981. Several of the doctoral students of Kai Siegbahn took active part in the renewal of Swedish materials science in the 1970s and on, through their international experiences gained as postdocs abroad, and formed the core of the professoriate in Sweden in surface and interface science and other similar branches of physics and chemistry that formed the emerging cross-disciplinary field of materials science.[300] Several also did early work at MAX-lab and took part in instrument development in the 1980s and 1990s.

A pointed way of expressing how groups from Uppsala, Linköping and Gothenburg made core contributions to instrument development at MAX-lab is to say that "the univerity in Sweden that contributed the least to MAX-lab is Lund University."[301] This is of course not true in any general sense (quite the reverse, as will be discussed in chapter 6), but in the case of instrument development, it is quite clear that it took some time before the required competence was built up locally in Lund. Users from other academic environments took part in most of the development of experimental stations early on.

This way, know-how was brought to MAX-lab from groups with long experience and strong tradiations in their home labs, and the lab was also tied very closely to its user community by their involvement in design, construction and maintenance of instrumentation.[302] But importantly, the interactions also made MAX-lab available to groups at universities in Sweden, who got experience and developed skills and knowledge in symbiosis with the lab and its instrumental setup that had significant impact on their local academic environments and Swedish physics as a whole.

The nine beamlines on MAX I were built in two main 'chunks', with the 22, 32, 41 and 52 built and taken into operation in the 1980s, and the 31, 33, 51, 53 and 73 built in the late 1980s and early 1990s and taken into operation in parallel with MAX II construction and commissioning, in 1994-1996. In the first chunk, beamline 22 was built with involvement from Uppsala physicists[303] and used the first Scienta S-200

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[299] J Gribbe, "Omvandling och fasta tillstånd: Materialvetenskapens etablering vid svenska universitet," (Vinnova Analys VA 2016:06, 2016).

[300] J Gribbe and O Hallonsten, "The emergence and growth of materials science in Swedish universities," *Historical Studies in the Natural Sciences* 47 (2017), forthcoming.

[301] Anders Flodström, interviewed by Olof Hallonsten, Stockholm 22 March 2007.

[302] MAX-lab Activity Report 1988: 5; 1990: 8.

[303] MAX-lab Activity Report 1990: 35-36

analyzer that is the topic of a case study of its own (section 4.2.1). Beamline 22 was in operation until 1998, when it was moved to MAX II and became D1011. The 32 was a collaboration with a group from Karolinska Institute, and was dismantled in 1997-1998. Beamline 41 was a collaboration with groups from Uppsala, Linköping and Gothenburg, and it was in operation until 2010, and beamline 52 was a collaborative project with groups from Lund University (and later also KTH in Stockholm) and ran until 2008. In the second chunk, the mostly internally developed beamlines 31 and 73 were in operation until 2009 and 2011, respectively. Beamline 33, a collaboration with groups from Linköping University, was in operation until 2007, when it was moved to MAX III and renamed I4. Beamline 53 was a collaboration with Uppsala groups, and was in operation until 1999.[304] The beamline 51 was designed and built with strong involvement from users in Uppsala as well as the universities of Turku and Oulu in Finland, and was also partly funded by these universities and the Academy of Finland. It was later moved to MAX II (and became I411) in 1997-1998.[305]

The MAX II was also equipped with beamlines in a step-by-step fashion, with the spectroscopy beamlines I311 (a Linköping and Lund collaboration) and I511 (essentially an Uppsala project) built first, and taken into user operation in 1998. I311 got an upgrade in 2008 (a second experimental station) and was operated until 2015. I511 had two experimental stations, one of which was taken into operation in 1998 and the other one in 2001. In 2013, the beamline was completely upgraded and renamed SPECIES. It was in operation until 2015, and was later moved in its entirety to the MAX IV facility.[306]

The first beamline to come into operation at MAX II was the I711 for crystallography and powder diffraction, built as an exact copy of a beamline and experimental station at the Synchrotron Radiation Source (SRS) in Daresbury, by a team of people foremost from Lund University.[307] It started operation in 1997 and ran until 2015. In 2006, as I911 took over all protein crystallography, a new experimental station was added to I711. The moved beamline 51, that became I411 on MAX II, also began operation in 1998 and remained operational until 2015. Just as when it was once built, groups from Uppsala and Finland took responsibility for the moving and the installation. The

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[304] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[305] MAX-lab Activity Report 1992, p 35. MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p15.

[306] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[307] R Nyholm, "Building beamlines," in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), 229-248, on p 233.

D1011, which was the beamline 22 from MAX I moved to MAX II, began operation in 1999 and remained so until 2015.[308]

In the early 2000s, a consortium was formed between Lund University and Copenhagen University to build the Cassiopeia beamline (or I911), with some involvement of AstraZeneca and NovoNordisk.[309] The beamline was equipped with five experimental stations that were taken into opertion successively over the years 2003-2011. They remained operational until 2015. Another hard x-ray beamline for materials science, the I811, was built in collaboration with a group from Chalmers University of Technology in Gothenburg and was in operation between 2003 and 2015.

The D811, built for x-ray litography and funded mainly through an EU project, was in operation only for five years, between 1998 and 2002, and the D611, an internal LU project, was never open to external users but ran as an internal R&D project between 2001 and 2013. The I1011, a collaboration between MAX-lab and an Uppsala group, opened for experiments in 2008 and ran until 2015, and the D1011 which was the beamline 22 moved from MAX I was in user operation between 1999 and 2015.

At MAX III, beamline I3 which ran between 2009 and 2015 was in part funded by Estonian and Finnish groups, and I4 which was the moved beamline 33 from MAX I retained a strong involvement of groups from Linköping University. The D7 beamline was a collaboration with a group from the Lund University chemistry department.

Some relationships between MAX-lab and devoted users have lasted from the very first buildup of experimental equipment on MAX I to the design of beamlines for MAX IV in 2010 and on. The Uppsala connection stands out, where users built instrumentation for beamlines 22, 41, 51 and 53 and obtained the first results, moved on to the I411, I511 and D1011 on MAX II, and developed these beamlines with upgrades and kept a close collaboration with the lab. But also groups from Linköping and Chalmers have had similar long-lasting relationships with the lab and built and maintained instrumentation: The beamline 33 was built by involvement from Linköping and moved to MAX III (beamline I4), and the same users were also involved in I311 on MAX II, together with colleagues from Karlstad University and the Royal Institute of Technology in Stockholm. Early enthusiasts from Chalmers were involved in beamline 41 in early days and later the I811 on MAX II. And it was mostly the same group of chemists from Lund and biologists from Copenhagen that took the initiative for I711, and later I911. The impact in terms of knowledge and skills developed and obtained by these groups as part of beamlines design, construction, maintenance, and upgrades,

[308] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[309] MAX-lab Activity Report 2000, p 1; 2002, p 1.

and the broader impact his has had on Swedish (and Nordic) research in the related fields, shall not be underestimated although it is hard or impossible to quantify.

When MAX-lab closed, in 2015, a number of components from the existing beamlines and experimental stations were moved to the new MAX IV facility where they are used to build up new beamlines. Only one beamline, SPECIES, was moved in its entirety. In addition, a lot of components that were not useful to move to MAX IV have come to use in labs at Swedish universities, for example vacuum equipment. The beamline I1011 was moved in its entirety to Krakow, where it serves at the synchrotron radiation facility SOLARIS.[310]

3.4 Materials science

As has been noted in previous sections, MAX-lab places itself neatly in a strong Swedish tradition in condensed matter physics, and has functioned as a locus for some developments that have been key to the emergence and strengthening of materials science as a key area for Swedish science today. The general development of Swedish materials science from the 1960s and on has been described in great detail elsewhere, and we will not dwell in the details of this history here but only note that the symbiosis between the strong Swedish nationwide development in the fields that form the cross-disciplinary area materials science in the second half of the 20th century and on, and MAX-lab, has been key to the success of the lab and probably also a fundamental prerequisite for its existence.[311]

The 1986 international evaluation of condensed matter physics activities with NFR support gives a good impression about the latent demand for synchrotron radiation in the Swedishh physics community at the eve of start of operation of MAX I. The evaluation was not concerned with MAX-lab per se, but notes that the "very large number of highly qualified and highly regarded scientists using various forms of spectroscopy as a major research tool" in Sweden will be needing access to synchrotron radiation, preferably within the Swedish borders, in order to "remain at the forefront of research on an international scale."[312] Specific groups mentioned in this regard are those of Nils Mårtensson at Uppsala University, Leif Johansson at Linköping University, and Per-Olof Nilsson at Chalmers University of Technology in Göteborg.

[310] Ralf Nyholm, interviewed by Olof Hallonsten and Oskar Christensson, Lund 15 November 2016.

[311] J Gribbe, "Omvandling och fasta tillstånd: Materialvetenskapens etablering vid svenska universitet," (Vinnova Analys VA 2016:06, 2016). J Gribbe and O Hallonsten, "The emergence and growth of materials science in Swedish universities," *Historical Studies in the Natural Sciences* 47 (2017), forthcoming.

[312] "International Evaluation of Condensed Matter Physics November 1986," Swedish Natural Science Research Council, p 9.

These groups, whose use of synchrotron radiation at facilities abroad is considered vital for their research, are expected to benefit especially from the availability of beamtime at MAX-lab after its opening.[313]

Throughout its whole history, materials science research with the use of photoelectron spectroscopy has been a cornerstone of the scientific program at MAX-lab. In 1992, an international evaluation of Swedish research in physics concluded that all the Swedish groups strong in surface physics research with spectroscopy – in Gothenburg, Linköping, Lund, Stockholm and Uppsala – "make very effective use of the synchrotron radiation source MAX".[314] In the report, MAX-lab is presented as having given condensed matter physics in Lund a real boost, and enabling already excellent activities elsewhere in Sweden to take quantum leaps in their development.[315] The 2004 international evaluation of Swedish research in condensed matter physics noted that MAX-lab, from the point of view of this scientific area, "has been, and continues to be, an extremely successful and highly competitive facility," which has "shaped a significant fraction of high-quality condensed matter physics research in Sweden" and "placed several [...] groups in a world-leading position."[316]

There is, in other words, little doubt that also from a scientific perspective, in spite of being "home made" and built with very limited resources, MAX I was internationally competitive and a great resource for Swedish (and Nordic) condensed matter physics. It provided a natural and very useful platform for a number of researchers to use to establish themselves in the field and to build on for future developments (including both research on MAX II and competitiveness to get experimental time at facilities abroad), and it helped establishing Sweden as a strong player in synchrotron radiation instrumentation, and excellent use of it.[317] But MAX I also produced standalone results that were of remarkable quality. Although MAX I was never the best machine available, and the lab suffered from a comparably small budget for user services, the whole experimental setups from machine to beamlines, experimental stations, and not least competent users, was world-leading in some areas.[318] Beamline 22 stands out. Witnesses

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[313] Ibid., pp 18, 31, 47.

[314] "International Evaluation of Swedish Research in Physics". Swedish Natural Science Research Council 1992. p 21

[315] Ibid., p 20

[316] "International Evaluation of Swedish Condensed Matter Physics", Swedish Research Council report 12:2005, p27-28

[317] Nils Mårtensson, "MAX IV: The long process of refinement," in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), 97-112, on p 97.

[318] Jesper Andersen, interviewed by Olof Hallonsten, Lund 11 October 2006. Nils Mårtensson, interviewed by Olof Hallonsten, Lund 10 November 2006.

call beamline 22 “a revolution”[319] and claims that it placed MAX-lab “on the world map”.[320]

With the performance increases offered by MAX II, and the continuing tight relationships between MAX-lab and the core user groups in Uppsala, Linköping, and Gothenburg, the importance of MAX-lab for Swedish condensed matter physics was only intensified in the 1990s and 2000s.

Surface science remained a cornerstone: the 2004 evaluation of condensed matter physics in Sweden noted that “some Swedish groups continue to play a leading role on the world stage in developing new and existing electron and related spectroscopies.”[321] The 1992 evaluation of Swedish research in physics had complained that surface science perhaps was “over-represented” in Swedish condensed matter physics and blamed the strong spectroscopy tradition in Uppsala (in combination with “inbreeding”) for this.[322] From the natural viewpoint of such a broad and comprehensive evaluation in 1992, as MAX-lab was still a very small user facility and the real expansion with MAX II had only barely been initiated, this is a reasonable point. Considering the continued development of MAX-lab, and how it grew further into a national resource extending far beyond Uppsala, Linköping, Lund and Gothenburg (but also clearly contributing to the expansion and enhancement of these scientific environments), the fear of a too dominant surface physics is petty: A small country like Sweden can hardly be criticized for strategic prioritization, especially if there is evidence of strength and tradition in particular areas, and resources (material and human) available to develop it further. Consequently, the 2004 evaluation of condensed matter physics turns the argument around, noting how the buildup of MAX II “has created such a favourable environment” for surface physics “that it would be unreasonable if Swedish scientists did not exploit this remarkable advantage.” Moreover, the report observes, the groups involved in the area have clearly “broadened their base in terms of methods and applications,” which the advantages provided by MAX-lab, including the connection of Swedish condensed matter physics to a vibrant international community (see section 3.7) has no small role in.[323] The same evaluation report notes how the active

[319] Jesper Andersen, interviewed by Olof Hallonsten, Lund 11 October 2006.

[320] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 196.

[321] ”International Evaluation of Swedish Condensed Matter Physics”, Swedish Research Council report 12:2005, p37

[322] ”International Evaluation of Swedish Research in Physics”. Swedish Natural Science Research Council 1992. p 23

[323] ”International Evaluation of Swedish Condensed Matter Physics”, Swedish Research Council report 12:2005, p37

involvement of Swedish scientists in beamline and instrument development at MAX-lab has been key to their scientific successes in symbiosis with the lab.[324]

The buildup of MAX II and MAX III, and their beamlines and experimental stations, were important for the broadening of the materials science activities at MAX-lab. The I711 and I811 beamline, using hard x-rays produced by wigglers, allowed new applications of both crystallography and spectroscopy in materials science, including absorption spectroscopy. But also extensions to nanoscience and nanotechnology were possible with the I311 beamline on MAX II and the I3 and I4 beamlines on MAX III, where collaborations with the Nanometer Structure Consortium at Lund University, a center with funding from various national strategic programs, and other groups at universities in Sweden, were cultivated.[325] Other further developments extended to environmental science applications in collaboration with several new user groups.[326]

Obviously, the facilities at MAX-lab have been used by a large group of users from outside Sweden throughout the years, as figure 3.3 and 3.4 in section 3.1 above showed. Already in the mid-1990s, foreign use of MAX-lab approached half of the total (see figure 3.1). International users were attracted to MAX-lab not least because of the ability of the domestic user community to produce excellent results at the lab, which has functioned as an advertisement.[327]

But while the international user community of MAX-lab in materials science is difficult to get a simple overview of, the domestic user community in condensed matter physics is slightly more manageable. It can serve as a good overview of its composition in the first two decades of operation of MAX-lab to summarize the rather exhaustive inventory of all research groups with strong involvement in MAX-lab provided by the 2004 review of Swedish Research in Condensed Matter Physics. This is done in table 3.2.

The most accurate way of describing the impact of MAX-lab in materials science in Sweden and abroad is probably that it has been profound, broad and deep, and helped transforming the field and renew it intellectually and technologically. This means that it is hard to point at specific examples of scientific impact; instead, it is the wider and deeper role that MAX-lab had for Swedish materials science, as a *resource* and therefore *enabler*, that shall be highlighted.

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[324] Ibid., p38-39

[325] "Swedish National Facilities", review report, Swedish Research Council, 2002. p 36. "Report from the review of the MAX laboratory, Lund, May 2009". Swedish Research Council report 5:2010. p 14-15. "International Evaluation of Swedish Condensed Matter Physics", Swedish Research Council report 12:2005, p64

[326] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 200.

[327] "International Evaluation of Swedish Condensed Matter Physics", Swedish Research Council report 12:2005, p25

Table 3.2:
Research groups in condensed matter physics in Sweden with strong involvement in MAX-lab, as listed by the 2004 VR evaluation of Swedish research in condensed matter physics.[328]

Group	Head	University
Materials Physics	Ulf Karlsson	KTH Royal Institute of Technology, Stockholm
Electronic Structure of Condensed Matter	Per-Olof Nilsson	Chalmers University of Technology, Gothenburg
Solid State Physics	Lars Walldén	Gothenburg University and Chalmers University of Technology, Gothenburg
Surface and Semiconductor Physics	Roger Uhrberg	Linköping University
Surface Physics and Chemistry	William Salaneck	Linköping University
Synchrotron Radiation Physics	Jesper N. Andersen	Lund University
Materials Physics	Lars Johansson	Karlstad University
Soft X-ray Physics	Joseph Nordgren	Uppsala University
Surface Physics	Nils Mårtensson	Uppsala University

Looking from the side of the facilities, it is quite clear that MAX I enabled physicists from Uppsala, Linköping, Gothenburg and other places enhanced preconditions for spectroscopic studies that they were already involved in, and thus was a national resoiurce for Swedish materials science already at the start. With MAX II, the performance level of experiments was further improved and users could take active part in designing and building beamlines that suited the existing user community but improved their experiments dramatically. With MAX III, a very niched machine, new opportunities opened for some parts of Swedish condensed matter physics, and some almost unique scientific achievements were made.[329]

Some specific groups and departments, including Uppsala, Linköping and Estonia, will be discussed under separate headlines below. Besides these, MAX-lab has had a profound impact also on Karlstad University, KTH Royal Institute of Technology in Stockholm, Chalmers University of Technology in Gothenburg, and the universities in Turku and Oulu in Finland. In Karlstad, where the local university college was upgraded to university in 1999, the physics activities were built up largely in symbiosis with MAX-lab, since the newly created department had little or no lab resources of its own but could do high-class experimental work at MAX-lab.[330] The KTH Royal Institute of Technology in Stockholm has been an important place for Swedish research in materials physics for a century, and in its ranks are several prominent users of MAX-lab, including former MAX-lab employees Anders Flodström and Ulf Karlsson who both are professors at KTH, and in more recent times Oscar Tjernberg whose research activities are very much tied to MAX-lab.[331] Pioneer MAX-lab user Per-Olof Nilsson

[328] Ibid., pp 120, 159-160, 164, 178, 184, 186, 192, 194

[329] Oscar Tjernberg, interviewed by Oskar Christensson, Stockholm 13 December 2016.

[330] Lars Johansson, interviewed by Oskar Christensson, Karlstad 12 January 2017. "Forsknings- och utbildningsstrategi foӧr Karlstads universitet 2009- 2012," KaU dnr C2007/127.

[331] Oscar Tjernberg, interviewed by Oskar Christensson, Stockholm 13 December 2016.

of Chalmers University of Technology in Gothenburg has been mentioned several times in previous sections, and is a good representative of the local MAX-lab user community in Gothenburg. Nilsson was appointed professor in 1986 on the urging of NFR who saw the creation of this academic position as key to the buildup of use of MAX-lab,[332] but several other people at Chalmers have also been loyal users of the lab over the years. The Finnish involvement in beamline 51 was mentioned in previous sections and is a good example of the long-term involvement of physicists from the universities of Oulu and Turku as users of MAX-lab for almost three decades.[333]

3.4.1 Uppsala University's Department of Physics

It was mentioned in previous sections, and it has been a key theme of historical studies of the history of MAX-lab, that the close collaboration between the lab and the users at the Department of Physics at Uppsala University is perhaps the key alliance that built MAX-lab as we know it today.[334] Several other user groups obviously contributed greatly over the years (see above), but the Uppsala connection deserves special attention.

The physics department of Uppsala University was the locus for the late-20th century strong instrument development tradition in Sweden in photoelectron spectroscopy, with Kai Siegbahn's 1981 Nobel Prize in physics as a culmination. Many prominent users of varieties of this technique were trained there in the 1960s and 1970s, and went on to seek international experience as postdocs in the 1970s and 1980s, which connected them to the early efforts of using synchrotron radiation for spectroscopy at e.g. Stanford, Hamburg, Wisconsin and Paris, which they brought back and turned into hands-on development of instrumentation and experimental use of the instrumentation, in Uppsala and at MAX-lab.

Uppsala physicists have been directly involved in the design and construction of six or eight beamlines at MAX-lab, depending on the count, namely 22, 41, 51, 53 on MAX I and I411 (51 moved), I511, I1011 and D1011 (22 moved) on MAX II. While users from Gothenburg, Linköping, Stockholm, Copenhagen, Lund, Oulu, Turku and Tartu (Estonia) also have been involved in beamline and instrument development, Uppsala physicists indeed stand out in terms of their long-lasting and deep relationship with MAX-lab.

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332 "Rådsrapport 1986, bilaga till del II, Nationellt tillgängliga forskningsanläggningar – en utredning ur NFR-perspektiv," appendix 1, p 1

333 B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 170.

334 O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009). O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011), 179-215.

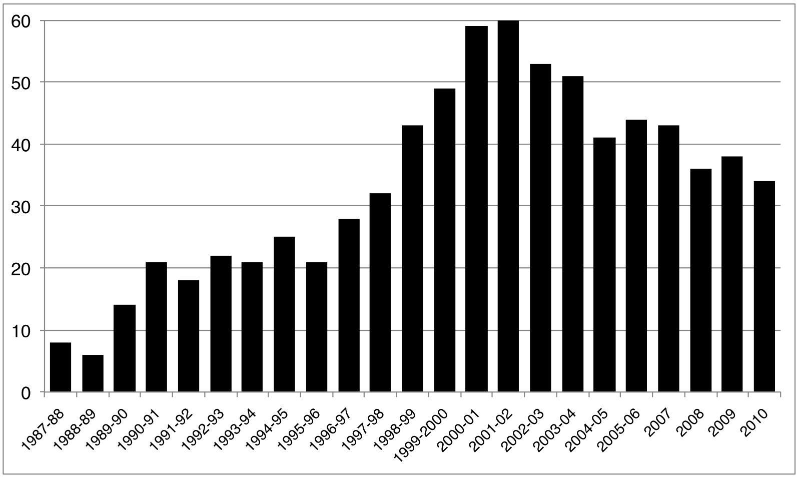

Figure 3.8:
Number of MAX-lab users affiliated with the Department of Physics, Uppsala University, 1987-2010[335]

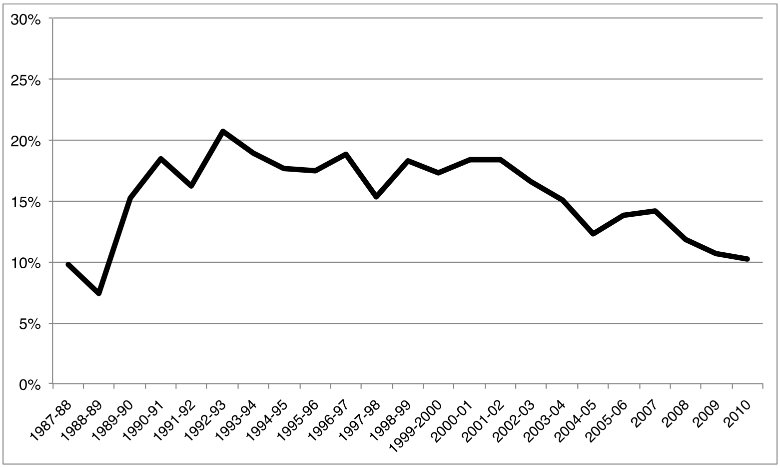

Figure 3.9:
Share of total number of MAX-lab users affiliated with the Department of Physics, Uppsala University, 1987-2010[336]

The Uppsala physicists probably earned a significant competitive advantage from their investment of money, time and effort in building instruments at MAX-lab, although this is hard or impossible to quantify. This investment is also key to the symbiosis between this user group and the lab: Immediately when MAX I was opened to scientific use in 1987, the Uppsala physics department became a very natural and very strong

[335] As listed in the MAX-lab activity reports.

[336] As listed in the MAX-lab activity reports.

base for the Swedish user community around MAX-lab. Figure 3.8 shows how the number of users of MAX-lab from the Uppsala University Department of Physics (from 2008 the Department of Physics and Materials Science, and from 2010 the Department of Physics and Astronomy) grew in the first years of use of MAX I, saturated on a rather high level in the first half of the 1990s (making up between 1/5 and 1/6 of the total annual user numbers), and then grew significantly when the spectroscopy beamlines at MAX II started user operation in the late-1990s. As seen in figure 3.9, the share of users of MAX-lab from the department in the years 1989-2010 was never lower than 10%.

The slight peak in use by Uppsala University physicists in 2000-2002 seen in figure 3.x is most likely due to the competitive advantage these users had due to their efforts of designing and building instruments for the I411 and I511 beamlines on MAX II, and starting their use for experimentation. That the increase did not continue but was turned into a decline in 2002 and on (also relatively, as seen in figure 3.9) is probably due to the expansion of the user community in general, and its broadening across Sweden also within physics, in the 2000s. It cannot be ruled out that the Uppsala physicists also used the experience accumulated in the process of building and using instruments on MAX I and MAX II to establish themselves as strong and recurrent users of labs abroad, which could brandish beamlines of higher performance than MAX II, and thus decreased their overall use of MAX-lab.

The composition of the user community from the Uppsala physics department deserves a note as part of the analysis of the symbiotic relationship between the lab and the department. In total, 213 individuals from the department are listed in the MAX-lab activity reports as having visited the lab as users in the years 1987-2010. More than half of these have been returning (i.e. are listed in more than one activity report), and no less than 57 of them (26.7%) are listed five times or more. Four individuals stand out as users of MAX-lab: Joseph Nordgren, 22 consecutive years (1987-2009), Svante Svensson, 22 years with a gap of one year (1987, 1989-2010), Olle Björneholm, 21 years with a gap of two years (1987-1993, 1995-2010), and Nils Mårtensson, 20 consecutive years (1987-2007). But importantly, there are also 82 individuals listed in only one activity report each, and another 34 listed only twice. Together, this means that the physics department of Uppsala University makes up *a very varied community* of users of MAX-lab – a number of faithfuls distinguish themselves in the material but there is also a large group of temporary users.

Qualitatively, these figures are matched by quite unequivocal personal statements by the users themselves: For some parts of the physics research in Uppsala, synchrotron radiation is absolutely vital,[337] and the department is described as very much

[337] Joseph Nordgren, interviewed by Olof Hallonsten, Uppsala 13 October 2006.

characterized by the culture and lifestyle of synchrotron radiation use (including traveling and spending weeks at MAX-lab).[338]

The 2006-07 comprehensive evaluation of all research at Uppsala University is a great source document to make a qualitative evaluation of what MAX-lab has meant for the Uppsala physics department. Noting that the department "has a particular strength and tradition in developing new instruments and associated spectroscopic techniques and application areas," the evaluation panel identifies the "key role" of synchrotron radiation generally, and MAX-lab specifically, for the scientific excellence of the department.[339] The evaluation also places MAX-lab and the Uppsala physics user community in the tradition where it belongs: the Nobel Prize-winning work of the department in previous times is said to "be continuing into the next generation," much through MAX-lab, where "Uppsala is a key and crucial participant."[340]

The symbiosis between MAX-lab and the Department of Physics at Uppsala University is an evident feature of the whole history of the lab, and one should not underestimate the contributions of Uppsala physics to the development of MAX-lab, in nearly every aspect – technically, scientifically, financially, politically, organizationally (note for example that an Uppsala physics professor, Nils Mårtensson, was the MAX-lab director for fourteen years, in 1997-2011, and several Uppsala physicists have also served on the MAX-lab board, the various committees, and the board of FASM, see appendix 4) – it is of course necessary in the context of this report to highlight the reverse relation, namely the impact of MAX-lab on physics at Uppsala University. Here, the evidence and hard facts are not as unequivocal, since the Uppsala physics department existed for a long long time before MAX-lab even emerged on the drawing board. MAX-lab can therefore not be simply or linearly identified as the source of the scientific excellence at the Department of Physics of Uppsala University, but it can quite accurately be viewed as a key factor for the renewal of the department's activities beyond its achievements in the mid- to late-20th century. In this respect, the assessment of the impact of MAX-lab on physics in Uppsala is a kind of micro version of the argument that will be developed further in section 3.7 below – MAX-lab has functioned as a vessel or vehicle for renewal (and internationalization) of large parts of Swedish science. In Uppsala, at the Department of Physics, this is perhaps particularly evident.

A special type of indication of the importance of MAX-lab for physics in Uppsala is found in the fact that in 2005, MAX-lab chief accelerator designer and constructor Mikael Eriksson received a honorary doctorate at Uppsala University.[341]

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[338] Maria Novella Piancastelli, interviewed by Olof Hallonsten, Uppsala 12 October 2006.

[339] Quality and Renewal 2007. An overall evaluation of research at Uppsala University 2006/2007, p 74

[340] Ibid., p 280-283

[341] Hedersdoktorer, Uppsala University, http://www.uu.se/om-uu/akademiska-traditioner/priser-utmarkelser/hedersdoktorer (accessed 30 Nov 2016)

3.4.2 Physics in Linköping

Linköping University's Departmetn of Physics and Measurement Technology is another strong research environment in Sweden in materials science, especially surface science, and the use of spectroscopic techniques for various studies in these areas. Linköping University had, since its early founding as an engineering school in the 1960s, a strong research and teaching environment in surface science around Stig Hagström (who had his training in Uppsala and moved to Linköping in 1969) and later Jan-Eric Sundgren, Ingemar Lundström, Birgit Jacobsson, William Salaneck and Anders Flodström.[342] The latter two both became heavily involved in MAX-lab – Flodström as the first coordinator for synchrotron radiation research (until 1986), and Salaneck as long-time user all the way until his retirement in 2006.

Roger Uhrberg, user of MAX-lab from the very start (first beamtime in September 1987), early member of the MAX-lab board (1987-1990) and long-time member of the board of FASM (1994-2003), says Anders Flodström was the "driving force behind Linköping's involvement with MAX-lab". Many people at Linköping University performed experiments with synchrotron radiation at HASYLAB (Hamburger Synchrotronstrahlungslabor) at DESY in Hamburg and at SSRL at Stanford already in the late 1970s, including Leif Johansson, Anders Flodström, and Göran Hansson, which meant that many doctoral students got involved in experiments with synchrotron radiation at an early stage, and were therefore well positioned to take an active part in the buildup of MAX and its beamlines. Linköping thus became a natural part of the national community of users that developed around MAX-lab.[343]

The lists of users in the MAX-lab activity reports reveal a local user community in Linköping not very unlike that of the Department of Physics in Uppsala, only smaller. A group of six people are the most recurrent users and are listed in ten or more activity reports, and among them especially Roger Uhrberg and Leif I Johansson stand out, with mentionings in 23 and 22 (out of 23) activity reports, respectively. Also William Salaneck and Mats Fahlman distinguish themselves by being mentioned as users in 18 and 14 reports, respectively.[344] Until 2003/04, the only MAX-lab users from Linköping University were from the Department of Physics and Measurement Technology, and as seen in figure 3.11, for roughly the first decade of MAX-lab operation (which coincides with the period of time when beamlines on MAX I were the only available instruments at MAX-lab), the department's share of the total number of users oscillated around 10%.

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[342] J Gribbe, "Omvandling och fasta tillstånd: Materialvetenskapens etablering vid svenska universitet," (Vinnova Analys VA 2016:06, 2016).

[343] Roger Uhrberg, interviewed in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 207-208.

[344] As listed in the MAX-lab activity reports.

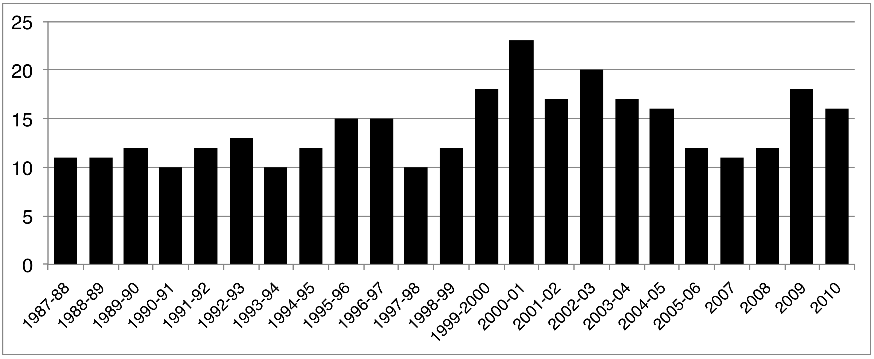

Figure 3.10:
Number of MAX-lab users affiliated with the Department of Physics and Measurement Technology, Linköping University, 1987-2010[345]

Figure 3.11:
Share of total number of MAX-lab users affiliated with the Department of Physics and Measurement Technology, Linköping University, 1987-2010[346]

Especially Uhrberg and Johansson have been involved in instrument development at MAX-lab over the years, and developed a symbiosis between their research activities and the lab. The beamlines 33 and 41 had strong involvement of physicists from Linköping in their design and construction, but also I311 on MAX II and I4 on MAX III (which was 33 moved from MAX I), which has most likely given the physicists in Linköping a competitive advantage in using these instruments over the years.[347]

A symbiosis with MAX-lab on departmental level, like in the case of Uppsala, is hard to find in Linköping – here, it is clearly more a matter of a few individuals whose groups

[345] From 2009 the Department of Physics, Chemistry and Biology (IFM). MAX-lab Activity Reports.

[346] From 2009 the Department of Physics, Chemistry and Biology (IFM). MAX-lab Activity Reports.

[347] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017. Roger Uhrberg, interviewed by Olof Hallonsten, Linköping 25 August 2006.

have made tremendous use of MAX-lab in their work and who have had great benefit from the lab, not least given its proximity. Research activities in surface physics are typically dependent on synchrotron radiation and the users in Linköping could probably have made their experimental work on synchrotron radiation facilities abroad (which they also have done), but the geographical proximity to MAX-lab and the interdependences it has bred have been very beneficial to them.[348] The development over the years, with MAX I, MAX II, and MAX III, has meant constant improvements that the Linköping physicists have been part of.[349] For some, especially in surface physics, access to MAX-lab is said to have been "crucial for the ability to stay in research."[350]

3.4.3 Physics in Tartu, Estonia

A peculiar yet evident case of how MAX-lab has had a direct impact on the buildup and development of specific research activities is the user community from Tartu, Estonia, which consists of a rather small and persistent group of users of MAX-lab.

Already in the early 1980s, physicists of the University of Tartu had began to use synchrotron radiation at the Budker Institute in Novosibirsk. Towards the end of the 1980s, Lund University physicist (and MAX-lab board member until 1993) Indrek Martinson, who was of Estonian descent, made contacts with the Tartu physicists and arranged for them to come and use MAX-lab, and the first group visited MAX-lab in 1989. Ergo Nömmiste, who was one of the first MAX-lab users from Tartu in 1989, moved to Lund in 1993 to start working with beamline 51, after which he was affiliated with Oulu University in Finland (from which he also vistsed MAX-lab as a user) between 1994 and 1997. According to Nömmiste himself, the quality of the synchrotron radiation available in Novosibirsk in the 1980s was subcritical, especially compared to what he and colleagues got access to at MAX-lab in the early 1990s. Therefore, it was only after starting to use MAX-lab that the group "obtained real results".[351]

Importantly, the link between Tartu and MAX-lab was established in the late 1980s and early 1990s, at the time of independence of Estonia.[352] At MAX-lab, Estonian physicists could use synchrotron radiation to do research of high international quality "despite being in the midst of the difficult transition from Soviet rule," and formed a

[348] Roger Uhrberg, interviewed by Olof Hallonsten, Linköping 25 August 2006.

[349] Roger Uhrberg, interviewed by Oskar Christensson, Linköping 28 November 2016.

[350] Leif Johansson, interviewed by Oskar Christensson, Linköping 28 November 2016.

[351] Ergo Nömmiste, interviewed by Oskar Christensson, over Skype, 5 January 2017.

[352] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 170.

durable local user community across the Baltic Sea that remained important throughout the whole history of MAX-lab and also on to MAX IV.[353]

The Swedish Natural Science Research Council was enrolled in 1991 to coordinate and evaluation of all research performed at academic institutions in Estonia. In the evaluation reports section on condensed matter physics, the laboratory of x-ray spectroscopy at the Institute of Physics of the Estonian Academy of Sciences in Tartu is described as very much involved in synchrotron radiation activities. An ”active co-operation” has recently been established with MAX-lab, says the report, and the overall evaluation of the group is that its future continuation of an excellent research program depends strongly on this cooperation with MAX-lab.[354]

Marco Kirm, who came to MAX-lab in 1991 from Tartu and started doing research as a doctoral student, on the initiative of Indrek Martinson, has since made a career largely in synchrotron radiation and physics that uses it. “Indrek opened many doors, and when I came to MAX-lab, for the first time I was free to do the research that I wanted, which was completely new for me.” After completing his doctorate in Lund in 1995, Kirm spent time at DESY and is now (since 2012) vice rector for research of Tartu University. For him, MAX-lab was “where it all started.”[355]

The number of users from these institutes listed in the Activity Reports never superseded 15 (this was the peak year, in 2001-02), but it is clear that a rather small group of devoted users have remained loyal to MAX-lab over the whole time period studied. Ergo Nömmiste (see below), was among the six users that visited MAX-lab in 1989-90, and with an interruption of five years (1993/94-1997/98), he remained a MAX-lab user until 2015. Though the group of users has been comparably small and intact, the affiliations have changed: Estonian Academy of Sciences, Tartu (1989/90-1994/95), Tartu University (1993/94, 1996/97), Institute of Physics, Tartu, Estonia (1995/96-1996/97), Institute of Physics, Tartu University, Estonia (1997/98-2010).

Ergo Nömmiste and Marco Kirm agree that MAX-lab has had an enormous importance for the buildup of physics research at Tartu University post-1991, not only as an experimental resource that has contributed a lot to resutls per se, but also as a node in a network that they have been able to connect to, and a place with a concentration of knowledge and competence to tap into. The physicists at Tartu University (and the Estonian Academy of Sciences in Tartu; organizational divisions and affiliations have changed through the years, see above) have also, in large part through the experiences gained at MAX-lab, established themselves as frequent users of

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[353] N Mårtensson, “MAX IV: The long process of refinement,” in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 97-112, on p 97.

[354] ”Evaluation of Estonian Research in Natural Science, Report to the Estonian Science Fund Council 1992,” Swedish Natural Science Research Council, p 133

[355] Marco Kirm, interviewed by Oskar Christensson, over Skype, 6 January 2017.

other synchrotron radiation facilities abroad, including DESY, BESSY, SOLEIL and Elettra.[356]

3.5 Life science

The deep and profound impact of synchrotron radiation on the sciences since its first use in the 1960s has come gradually, and while the applications in materials science have been evolving rather closely together with the developments in technology (see section 2.2), the use of synchrotron radiation for applications in the life sciences came comparably suddenly and grew rapidly once their true potential had been shown.

This potential has shown especially in medicine and health, including the pharmaceutical industry, where the importance of synchrotron radiation for structural determination of macromolecules has opened new worlds for medical treatment and new drugs. Structure-guided drug design has grown dramatically as technologies have matured and allowed the obtaining of increasingly detailed structural information of potential drug targets, i.e. biomolecules inside human cells that may be activated or inhibited by a particlular drug's active substance.[357]

This is probably a major reason behind the rather common claim that the most profound and most spectacular impact of synchrotron radiation on the sciences has been in the area of the life sciences. Such statements must always be made with caution, and for the specific case of MAX-lab and its user community dominated by Swedish and Nordic scientists it would probably not be true. But the sudden emergence of life science applications in the scientific program of MAX-lab is quite evident – when in 1997 beamline I711 started user operation, it was the first time that instrumentation was made available that was specifically designed and built for applications in the life sciences. When in 2003 the first branches of beamline I911 opened to scientific use, this meant a broadening of the base in the life sciences, and the entering of MAX-lab into a completely new realm where direct impact could be made in areas different from the applications of materials science. Specific examples of work done at MAX-lab that has contributed directly to the progress in biomedical research include the mapping of

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[356] Marco Kirm, interviewed by Oskar Christensson, over Skype, 6 January 2017. Ergo Nömmiste, interviewed by Oskar Christensson, over Skype, 5 January 2017.

[357] R C Stevens, "The cost and value of three-dimensional protein structure," *Drug Discovery World* Summer 2003, pp 35-48, on p 35. T L Blundell and S Patel, "High-throughput X-ray crystallography for drug discovery." *Current Opinion in Pharmacology* 4 (2004), pp 490-496. N Borshell and M Congreve, "Valuation benefits of structure-enabled drug discovery," *Nature Reviews* 10 (2011), p 1. K Wilson, "Illuminating crystallography," *Nature Structural Biology* August 1998, pp 627-630, on p 627. L W Hardy and A Malikayil, "The impact of structure-guided drug design on clinical agents," *Current Drug Discovery*, December 2003, pp 15-20, on pp 15-16.

a protein common in myelin, a substance that insulates nerves and thus has a crucial role in the nervous system, and whose malfunctioning is throught to be a factor in Multiple Sclerosis.[358]

Pharmaceutical industry had been using I711 already from the start, and with I911 their engagement was intensified, with AstraZeneca and NovoNordisk investing directly in equipment and signing agreements with MAX-lab that gave them access to a certain amount of beamtime every year (see section 4.3.1). University groups involved in similar activities, i.e. structural determination of macromolecules with strong relevance for drug development, also came along, most evidently the users from Copenhagen University. The first users from the Center for Crystallographic Studies at the Department of Chemistry of Copenhagen University visited MAX-lab in 1997/98,[359] and from then on, the representation of the department in the user lists of the activity reports only grows – from four individuals in 1997/98, to fifteen in 2000/01. Several other life sciences users, from other institutes and universities in the Nordic countries and elsewhere, also emerged and increased their presence at MAX-lab in this period.

It has been noted in previous sections (2.4 and 3.3) that MAX II was not originally designed to produce the hard x-rays necessary for macromolecular crystallography, and MAX-lab therefore remained essentially a "soft x-rays lab," with the hard x-ray activities colloquially referred to as an "island" at the lab as late as 2006.[360] But the invention of the superconducting wiggler that made it possible to extract hard x-rays from MAX II sparked an important development where local Lund University groups (in molecular biophysics and inorganic chemistry) and Chalmers University of Technology in Gothenburg acted swiftly to get a crystallography beamline online as soon as possible. The exact copy of a beamline at Daresbury (9.6) was built up in 1996-1997 and became I711. It "worked instantly"[361] and delivered its first results in late 1997, when the structure of the protein L22 was mapped. This particular structural determination was in fact also an important early step in a progression that, several years later, produced a detailed image of the ribosome, which in turn was awarded with the Nobel Prize in chemistry of 2009.[362]

The potential demand for hard x-rays from MAX II, used wisely at experimental stations for macromolecular crystallography, was great. A 1999 evaluation of Swedish research in structural biology by the Swedish Natural Sciences Research Council

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358 B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 199.

359 MAX-lab Activity Report 1997, p 18

360 Yngve Cerenius, interviewed by Olof Hallonsten, Lund 10 October 2006.

361 Anders Liljas, interviewed by Olof Hallonsten, Lund 10 November 2006.

362 B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 225.

emphasized the high and growing importance of synchrotron radiation for the field. The evaluation identifies several macromolecular crystallography groups in Sweden that are "world leaders" and "prominent users of synchrotron radiation." In only two years of operation, I711 at MAX-lab had apparently grown into "a vital resource for the Swedish structural biology community," and was, the report noted, fully booked. The plans to build another crystallography beamline (what would become I911) was described as very much anticipated by the community.[363]

The global importance of synchrotron radiation for structural biology specifically, and the life sciences generally, was seen also in the Swedish national context, and here MAX-lab played a crucial role. The 1999 evaluation was clear in pointing this out and placed the two hard x-ray beamlines at MAX-lab in historical perspective as well as foresight into the future: Synchrotron radiation constituted a continuation and enhancement of the techniques available in smaller labs at e.g. universities, and "will continue to be essential" to macromolecular crystallography.[364]

Sweden and the Nordic countries have been historically strong in the area of structural biology. While perhaps not on the level of materials science and the spectroscopy tradition as described in the previous section, biologists in Uppsala and Stockholm have distinguished themselves internationally in crystallography, and became early users of synchrotron radiation first at the NSLS at Brookhaven, then the SRS in Daresbury, and later at the ESRF in Grenoble, where also Uppsala biologist Carl-Ivar Brändén was one of two scientific directors in 1992-97 (a position that later MAX-lab director Sine Larsen had in 2003-08). MAX-lab was therefore part of a renewal of biology that had many fronts but where the development of technologies for structural determination and analysis of biomolecules was essential.[365] Beginning in the late 1990s, the Swedish and Nordic structural biology communities became very tightly connected to MAX-lab.[366] In 2010, rougly ten departments of molecular biology, systems biology, medicinal chemistry, structural biology, etc. in Sweden, Denmark and Norway were represented among MAX-lab users, and the total individuals affiliated with these departments (rough count) approached 100. In addition, another at least hundred users from chemistry departments and other organizational units inside and outside academia in these countries and abroad used MAX-lab for "life science" or "chemistry" as defined

363 "International Evaluation of Structural Biology, December 1999," Swedish Natural Science Research Council, pp 5, 67.

364 Ibid., p 68

365 Letter from the MAX Association for Synchrotron Radiation Users (FASM), appended to MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002). Anders Liljas, interviewed by Olof Hallonsten, Lund 10 November 2006.

366 Astrid Gräslund, interviewed in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 207.

by themselves when registering as users at MAX-lab in the beginning of an experimental period.[367]

A major driving force behind the crucial expansion of the MAX-lab scientific program to biology by the buildup of I711 and I911 was the relationship established with the groups of Åke Oskarsson, Kenny Ståhl and Anders Liljas in Lund, and Jörgen Albertsson at Chalmers in Gothenburg. Anders Liljas had become professor at the Division of Molecular Biophysics at the Lund University Department of Chemistry in 1988, a position he had sought much because of the potential he saw in MAX-lab.[368] The division had been founded in 1985 and was initially small but grew significantly from 1998 and on, with MAX-lab as a key reason for the growth.[369] Liljas, the primus motor of the I711 project and a key person also in I911/Cassiopeia (see below) was member of the board of MAX-lab (1998-2007) and of the PAC for synchrotron radiation (1991-97). He notes that MAX-lab has been ”crucial” for his research, and while he himself ceased using MAX-lab in 2005, upon his retirement, his colleagues at Lund University and elsewhere remained active part of the user community and also in the buildup of beamlines and instrumentation at MAX IV. He is also involved in the company SARomics Biostructures (see section 4.3).[370]

3.5.1 “Low throughput”

The I711 had been a success, as noted in the previous section, and demand for hard x-rays for macromolecular crystallography continued to be high. Ideas were drafted and presented to MAX-lab for a new beamline, foremost among Danish long-time users of synchrotron radiation for these purposes at other labs in Europe, and the design settled upon became a beamline with five stations, slightly differently optimized but with macromolecular crystallography as the overall purpose. Anders Liljas got a grant of 25 million SEK from KAW in 1999 to build the beamline I911, which was complemented by one grant from the Danish Biotechnology Instrument Center (DABIC) and investments from AstraZeneca and NovoNordisk.[371] The equipment paid by Danish sources was built in Copenhagen and brought to MAX-lab for mounting on the beamline.[372] The Danish involvement in I911, from both physicists and chemists at

[367] MAX-lab Activity Report 2010, pp 21-37.

[368] Anders Liljas, interviewed by Olof Hallonsten, Lund 10 November 2006.

[369] Jesper Sjöström, *Kemicentrum vid Lunds Universitet: Perspektiv på organization och forskning vid Sveriges första storinstitution*, Lund University 2007, pp 342-343.

[370] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 208.

[371] Extracted from a list compiled by MAX-lab staff, presented in its entirety in appendix 1, received (personal communication) from Ildikó Toth of MAX IV on 15 November 2016.

[372] Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

Copenhagen University, and then later also Aarhus and Lyngby, suggests that the expansion of the scientific program to structural biology had especially great importance on the other side of Øresund.

While the MAX wiggler (see section 3.3) surely could deliver hard x-rays to the I911, it was quite clear that quality of the radiation never was on the level of what state-of-the-art beamlines for macromolecular crystallography at e.g. ESRF achieved, in a technical sense but also in terms of reliability and the user support infrastructures around them. The idea was therefore to build up experimental equipment ready to use when demand arouse, and the five experimental stations at I911 were used very differently.[373] I911/2 and I911/3 were the "work horses" for macromolecular crystallography, with some use also of I911/5 for the same purpose; I911/4 was a testing station and rebuilt for small angle x-ray scattering (SAXS) in 2011, which made further use of I911/5 impossible for technical reasons; and I911/1 was used for tests and education by the group from the physics department (Niels Bohr Institute) at Copenhagen University that participated in the design and construction of the beamline.[374] The flexibility of planning and the availability of time (compared to the often heavily oversubscribed crystallography beamlines at ESRF and other facilities abroad) was made a competitive advantage of MAX-lab that contributed to cultivating the user community. "Low throughput" – as a contrast to the ideal of "high throughput" (see section 2.2) – was made an ideal and a means for MAX-lab to find a niche in the structural biology community as a lab where a local user community could train students and explore method and new solutions.[375]

The fact that the I911 beamline was seldom or never overbooked, which is often the case of state-of-the-art beamlines for macromolecular crystallography abroad, became a special type of resource for MAX-lab, for the user groups involved in the beamline, and to some extent also for the general user community. Students could get easy access and come with short notice, and use time to measure without the overwhelming pressure that short beamtime slots obtained in harsh competition at other labs ususally means for the individual.[376] Interestingly, the somewhat lower overall quality of the hard x-rays from MAX II meant that data taking times were generally longer, which gave users the option of modifying samples and experimenting during beamtime to an extent that

[373] Thomas Ursby, interviewed by Olof Hallonsten, Lund 20 October 2006.

[374] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017.

[375] Yngve Cerenius, interviewed by Olof Hallonsten, Lund 10 October 2006. Anders Liljas, interviewed by Olof Hallonsten, Lund 10 November 2006. Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

[376] Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

also is not typically possible at other labs, where all preparation must be done in advance to allow maximum utilization of the short beamtime slot one has managed to get.[377]

3.6 Nuclear physics

The nuclear physics activities at MAX-lab built on a rather long tradition in Lund, where first accelerators at the Department of Physics, including the LUSY synchrotron, had been used (see section 2.2). With MAX-lab, the activities got a new home and an infrastructure that gave them opportunities to pursue a research program with world-leading performance in its specific niche. Scientifically, the activities were separate from the synchrotron radiation program, and much smaller, comparable to the volume of research of a beamline on MAX I. The MAX I ring was also the only of the three MAX storage rings that was used for nuclear physics activities; for the better part of the history of MAX-lab on 25% of its total time of operation.

The first experiments in nuclear physics at MAX-lab began in early 1987 and were conducted in collaboration between the local nuclear physics research group and users from Gent and Glasgow.[378] For several years to come, all experiments were undertaken in similar collaborations,[379] and the number of foreign collaborators grew steadily until the end of the 1990s, as seen in table 3.3. Collaborators in the 1990s came from a diverse but stable set of research environments, foremost abroad and including Lund, Gent, Amsterdam, Edinburgh, Melbourne, Glasgow, Tübingen, Göttingen, and Moscow.

Qualitatively, it is important to remember that the nuclear physics activities cannot be evaluated in the same way as the synchrotron radiation activities. While the latter can be said to have had an impact as soon as an external user successfully undertakes an experiment and brings data back home to her lab, the former were more directly tied to the scientific productivity and excellence of the local group and their (international) collaborations. Noteworthy in this context is also that the nuclear physics activities at MAX-lab never had a national user base like the synchrotron radiation program, but was a concern for a local group at Lund University and some groups in other countries (see tables 3.3 and 3.4).

A number of evaluations were made of the nuclear physics activities at MAX-lab, both separate and as part of the regular evaluations of the lab as a whole (see section 2.5), and among them, the 1987 and 1990 evaluations were arguably the most important,

[377] Derek Logan, interviewed by Oskar Christensson, Lund 17 January 2016.

[378] MAX-lab Activity Report 1987: 83

[379] MAX-lab Activity Report 1988: 95; 1993: 185; 1994: 231; 1995: 243; 1997: 219; 1998: 265; 1999: 305; 2000: 337.

as these two acknowledged first a dramatic need for improvement of the program (1987), and then reported that the lab quite evidently had fulfilled this need (1990). The outcome of the latter was also that the program could expand slightly, since the evaluation effectively ave go-ahead to an increase in the operations costs from NFR and Lund University, and some grants for instrumentation from FRN and KAW.[380] The expansion seems to have born fruit as well, given the statement in the 1992 international evaluation of Swedish research in physics by the Natural Sciences Research Council, that judged the nuclear physics activities at MAX-lab to be a "unique activity" in its specific area, and considers MAX-lab "very well equipped" for the nuclear physics program it serves.[381]

In the 1990s, although it did not expand nealy as swift and far as the synchrotron radiation activities, the nuclear physics program at MAX-lab continued to be a vital part of the lab. On a smaller scale, it was also an international user facility: As table 3.3 shows, in the years 1993 to 2001, between 60 and 75 per cent of the users were external. Since no other Swedish academic organizations were ever represented as users of the nuclear physics facilities at MAX-lab, all the external users in table 3.3 are foreign.

Table 3.3:
Numbers of projects and users of the experimental facilities for nuclear physics at MAX-lab, not counting users from and projects by the local core group, 1993-2001[382]

Year	Projects	Members of the local group	External users
1993/94	19	11	22
1994/95	21	14	24
1995/96	22	12	25
1996/97	25	10	29
1997/98	24	9	28
1998/99	25	12	29
1999/2000	26	11	30
2000/01	26	11	30

In terms of output, it is difficult to single out the nuclear physics publications from the synchrotron radiation publications in the lists provided in the activity reports, and therefore the tables and figures of scientific productrivity in section 3.2 above combines the two programs (and accelerator physics). But the doctoral theses can be identified by using the lists in the activity reports for a number of years of doctoral students, from several countries, who performed experimental work in nuclear physics at MAX-lab. Table 3.4 is not complete but gives an impression about the productivity and the

[380] Activity Report 1990: 141

[381] "International Evaluation of Swedish Research in Physics," Swedish Natural Science Research Council 1992, p 14-15.

[382] MAX-lab Activity Report 1994: 231-232; 1995: 244; 1996: 215-216; 1997: 219-220; 1998: 266; 1999: 305-306; 2000: 337-338.

impact of the MAX-lab nuclear physics program in terms of doctoral studies and thesis work at several universities abroad.

The 1997 evaluation of the national facilities (see section 2.5) repeated earlier evaluation reports in claiming that the nuclear physics facilities at MAX-lab "fills a unique niche in the world" which the local group and their international collaborators have used effectively, making "outstanding" contributions to the field through publications and training of students. The group is "well positioned to move their program into the future."[383]

Table 3.4:
Doctoral thesis work in nuclear physics at MAX-lab, 1990-2005[384]

	Affiliation	Year of completion
Akkurt, Iskender	Glasgow	1998
Andersson, Bengt-Erik	Lund	1994
Bobeldijk, Irene	Amsterdam	1995
Boland, Mark	Melbourne	2001
de Bever, Laurens	Amsterdam	1993
Dias, Johny	Gent	1994
Fuhrberg, Kai	Göttingen	1992
Glebe, Thorsten	Göttingen	1996
Häger, Dirk	Göttingen	1995
Ireland, David	Edinburgh	1991
Isaksson, Lennart	Lund	1996
Karlsson, Martin	Lund	2005
Kuzin, Alexander	Melbourne	1997
Lilja, Per	Lund	2004
Ludwig, Michael	Göttingen	1991
Lundin, Magnus	Lund	2002
Mauser, Gernot	Tübingen	1992
Mondry, Andre	Tübingen	1997
Morrow, Steve	Edinburgh	2000
Nilsson, Björn	Lund	2003
Nilsson, Dahn	Lund	1990
Pöch, Christoph	Göttingen	1996
Proff, Stephan	Göttingen	1998
Rauf, Amir	Edinburgh	1996
Reiter, Andreas	Glasgow	2004
Ruijter, Hendrik	Lund	1995
Sims, David	Melbourne	1995
Van den Abeele, Caroline	Gent	1994
Van Hoorebeke, Luc	Gent	1991

[383] "International Evaluation of Swedish National Facilities, April 1997." Swedish Natural Science Research Council. pp 9-10

[384] Compiled from the MAX-lab activity reports and with the help of Bent Schrøder, via email 27 February 2017.

But this future was nonetheless a bit unsure in the mid- to late-1990s – the ageing injector (see section 2.4) was a core part of the nuclear physics facilities at MAX-lab and when it was to be replaced in order to increase the operations reliability of MAX I and II for synchrotron radiation, it was not obvious that the upgrade to the nuclear physics facilities necessary to keep the program alive would be possible to fund. Nuclear physics at MAX-lab had been identified in the 1997 evaluation as "of less importance in a national context" and of lower priority should it come to "a situation of stiff competition for economic resources and beamtime."[385] The cheaper option when upgrading the injection system was certainly to terminate the nuclear physics program,[386] and some also claim that on its own, the nuclear physics activities were not strong enough to motivate the costs,[387] but the upgrade, as one part in a threefold application to the council (for a new injector, MAX III, and the nuclear physics upgrade), was nonetheless granted funding in 1999.[388] Perhaps the comparable favorable review in 1997 contributed to the decision not to cancel the program but instead enhance it with an upgrade. But it can doubtlessly be considered a marker of quality that the council decided to fund also the nuclear physics upgrade and not cancel the program when it had the opportunity.

The upgrade began in 1999, and included an enlargement of the experimental area to make room for new instrumentation.[389] Meanwhile, interest in the facilities continued and was intensified: In 2001, 17 letters of intent, representing 55 scientists from all over the world, were submitted and reviewed by the Program Advisory Committee for nuclear physics,[390] and in the same year new instrument developments were also planned and reviewed by the committee.[391] A 2001 workshop that gathered interested researchers reportedly demonstrated "the strength of this sub-field of nuclear physics" and the "vitality" of the local group.[392]

The 2002 evaluation of Swedish national facilities, and the background material provided to the evaluators by MAX-lab ahead of the evaluation, gives a very good snapshot of the state of the nuclear physics activities at the lab in the early 2000s. The background material describes these as "very productive and cost-effective" and uses the apt comparison with a typical synchrotron radiation beamline at MAX-lab as a

385 Ibid., p 28

386 Nils Mårtensson, interviewed by Olof Hallonsten, Lund 10 November 2006.

387 Bent Schröder, interviewed by Oskar Christensson, 22 November 2016.

388 Kurt Hansen, interviewed by Oskar Christensson, Lund 22 November 2016.

389 MAX-lab Activity Report 1999: 307

390 MAX-lab Activity Report 2001: 10

391 MAX-lab Activity Report 2002: 388

392 MAX-lab Activity Report 2001: 379

means to describe the current resource needs of the activities.[393] The Scientific Advisory Committee of MAX-lab agrees with this assessment in its letter submitted as part of the background material, noting that the nuclear physics activities are "at the forefront of physics" although investments in the facilities have been "rather moderate" due to the willingness and ability of external users to contribute with detectors.[394] Consequently, the 2002 report from the review of the four national facilities is mostly positive in its assessment of the nuclear physics program, noting that the specific instrument setup at MAX-lab gives the lab "a niche within the international nuclear physics program" but simultaneously questioning whether the activities are really "at the forefront of nuclear physics" given the topics studied, which in the view of the review panel "would not justify a stand-alone program or commitment of significant new resources" but should be continued given the relatively modest costs.[395]

The upgrade meant that the program was put on a halt in 2003-2005. In 2005, the upgrade was completed and the new facilities commissioned with the help of external users.[396]

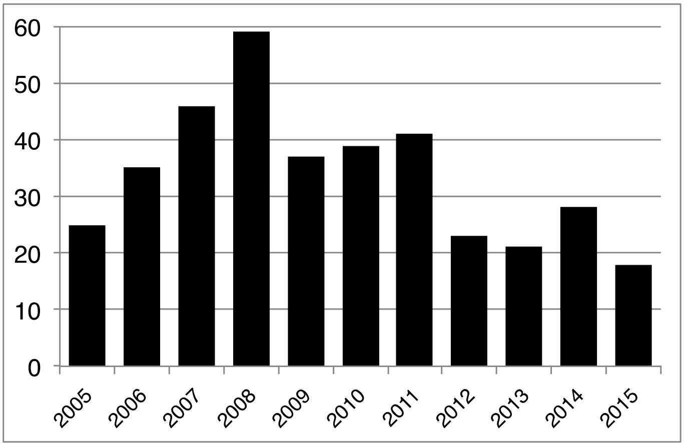

Fig 3.12:
User visits, nuclear physics, 2005-2015[397]

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[393] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), summary, ch2p4.

[394] Report of the Scientific Advisory Committee of MAX-lab November 27 2001, appended to MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002).

[395] "Swedish National Facilities", review report, Swedish Research Council, 2002. p 38

[396] MAX-lab Activity Report 2005-06: 441.

[397] Received directly from Ralf Nyholm on November 18, 2016 and February 24, 2017.

In the comprehensive and detailed data on user visits available, where every visit of an externally affiliated scientist to MAX-lab between 2003 and 2011 is listed along with some basic information,[398] 283 entries concern nuclear physics, and are listed between 2005 and 2011. These 283 visits over nine years were made by 93 individual scientists from 27 universities in nine countries, with Sweden, the United States, the United Kingdom, Germany, Australia, Israel and Ukraine as the most represented countries. Figure 3.12 shows the numbers per year in this period.

Although figure 3.12 stops in 2011 and we have no data for the years after, it is reasonable to conclude that the nuclear physics activities remained a small but healthy part of the scientific program of MAX-lab until the lab was closed in 2015. The 2009 evaluation of MAX-lab by the council declares the nuclear physics activities "small but of high quality" and recommends its continued support "until the phasing out of the present accelerator structure when the MAX IV facility will take over."[399]

On the side of technology, it deserves to be highlighted that the so called "tagging system" that formed a core part of the nuclear physics facilities at MAX-lab was built by the local group under the leadership of Bent Schröder and Jan-Olof Adler, and it "quickly became one of the most advanced in the world" and was a key reason for the rather extensive network of foreign scientists that visited MAX-lab regularly to do nuclear physics experiments; from Australia, Belgium, Canada, Germany, the Netherlands, Scotland, and the USA.[400] Otherwise, a lot of instrumentation was also brought to MAX-lab by nuclear physics users over the years, and made available to other users as well. Some instrumentation also remained part of the permanent experimental setup once the users had left.[401]

Given the special status of the nuclear physics activities at MAX-lab, it is apt to make two concluding reflections in this section. The first is that the nuclear physics activities, because of its organization and character, was of little or no national interest outside Lund and therefore fitted rather poorly with the developing image of MAX-lab as a truly national research infrastructure in the late 1980s and on. The quality of the activities was never doubted, quite the reverse (as the evaluations cited above show), but in comparison with the synchrotron radiation program it was clearly of less national

[398] A "visit" here means that a user has registered arrival and departure at MAX-lab. Days of a visit means the number of days that passed between the arrival and departure and says nothing about the extent to which the scientist used instrumentation at MAX-lab, let alone for what. The data comes from a document that details user names, affiliation, country, email address, arrival and departure dates, project leader, and beamline for all user visits in the years 2003-2011. Received directly from Ralf Nyholm on November 18, 2016.

[399] "Report from the review of the MAX laboratory, Lund, May 2009". Swedish Research Council report 5:2010. p 12-13

[400] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 202.

[401] Bent Schröder, interviewed by Oskar Christensson, Lund 22 November 2016.

interest. Nonetheless, it survived in some part on its own merits, but it shall be added here that politically and organizationally, the nuclear physics activities would never have survived without the synchrotron radiation program at MAX-lab and its expansion, which provided the rationale for continued investment in the lab. In this sense, a clear but somewhat auxiliary impact of the synchrotron radiation program of MAX-lab is the continued existence and well-being of the nuclear physics program.

3.7 A motor for progress, renewal and internationalization of Swedish science

The above analysis of the scientific impact of MAX-lab over the years was naturally focused on three thematic areas – materials science, the life sciences, and nuclear physics. The expansion of the user base and of the disciplinary breadth of the scientific program has been a key theme in this report so far, and while the most spectacular expansion was the one whereby large segments of chemistry and biology became part of the user community of the lab, there are also other disciplines and areas of use that have become users of MAX-lab but do not neatly sort themselves into the two categories materials science and life sciences.

Paleonthology is one. Although the techniques used are in principle the same as for materials science (or surface physics) and life science (or structuiral biology), the study of e.g. the composition of fossils have other scientific relevance. The work done at MAX-lab, of proving right the hypothesis that fossilized materials contain intact biomolecules, is a clear example of this broadening of the use of e.g. spectroscopic methods with synchrotron radiation.[402] Other similar examples exist.

Another area where great hopes were once put on synchrotron radiation to provide leaps in the performance of certain application areas of x-rays is lithography, and MAX-lab also had a brief encounter with this. The application area is separate from both spectroscopy (electronic structure) and crystallography (geometrical structure) (see section 2.2); the principle is that synchrotron radiation x-rays are used to draw something on a material or make an imprint in it, for example for circuit manufacturing in the electronics industry.[403] In the late 1980s, hopes were high that optimized synchrotron radiation facilities for chip production would be built all over the world,

[402] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 201.

[403] I Munro, "Synchrotron Radiation." In A Michette and S Ptauntsch (eds), X-rays: The First Hundred Years (John Wiley & Sons, 1996), p 152-153; A Smith, "X-Ray Lithography." In A Michette and S Ptauntsch (eds), X-rays: The First Hundred Years (John Wiley & Sons, 1996), pp 158, 161-163.

but the comparably unreliable operations of the storage rings made this impossible.[404] At MAX-lab, a beamline and experimental station for x-ray lithography was built in the mid- to late-1990s, funded by the Technical Sciences Research Council (Teknikvetenskapliga Forskningsrådet, TFR) and with primarily two groups at the Nanometer Laboratory at Lund University as users involved in the design and construction.[405] The activities were mostly geared towards testing of methods and materials, but had to be shelved when key people involved in the project left for other employments. The beamline was dismantled when its space on the laboratory floor was needed for other equipment.[406]

The tables and figures used in section 3.2 above to illustrate the scientific use and productivity of MAX-lab in various aspects have their clear purpose, as they give impressions of how the lab has impacted science in multiple dimensions: Across disciplinary borders, with great geographical distribution, and not least with a steadily growing user community that has expanded in both realms over the years.

What statistics of this type cannot convey, however, are the qualitative aspects of scientific impact of research infrastructures; pointed out by most interviewees in this study in one form or another and also by the many evaluations over the years (section 2.5). MAX-lab was, as will be discussed in the coming pages, a locus for developments in several fields that Swedish scientific communities made great use of, beyond what numbers can convey. As a resource for skilled and driven researchers obtaining access in open competition, it enhanced experiments and pushed developments that would not have been possible otherwise. Physicists, chemists and biologists involved in progressions of various sorts could make use of MAX-lab to further enhance experimental work already very promising. The occasional identification of MAX-lab as a continuation of the very strong spectroscopy-dominated tradition in surface physics in Uppsala, Linköping and Gothenburg is the perhaps most evident example of this, but as section 3.5 above showed, also Swedish (and Nordic) research in structural biology developed a similar relation to the opportunities opened at MAX-lab. For some research environments in Sweden and abroad, it seems MAX-lab was absolutely crucial: physics at Karlstad University and in Tartu, Estonia are especially visible examples. Other university groups have also reaped enormous benefits, such as in Copenhagen and Aarhus; at the KTH Royal Institute of Technology in Stockholm; and Oulu and Turku in Finland. The impact on Lund University will be discussed under a separate headline later in this report (chapter 6).

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404 I Goodwin, "Compact X-Ray Lithography Machines Generate Hope for Semiconductors." *Physics Today* 41 (1988), pp 49-52, on p 52. A Smith, "X-Ray Lithography." In A Michette and S Ptauntsch (eds), X-rays: The First Hundred Years (John Wiley & Sons, 1996), p 164.

405 MAX-lab Activity Report 1994, p 48.

406 Ralf Nyholm, email 24 January 2017.

The 2006 scientific evaluation of the MAX IV proposal summarized this qualitatively oriented argument thus:

> "In the event that MAX IV will not be built, it is inevitable that the Nordic research community will be negatively affected. The market for excellent professionals for accelerator and beamline science and technology is highly competitive and the most competent staff will migrate to more modern sources. This will have serious consequences for research and education in Sweden and the Nordic countries."[407]

The evaluation report argues – implicitly but unequivocally – that MAX-lab thus far (2006) had achieved a remarkable buildup of talent, competence, and technology to the benefit of a Swedish and Nordic community that had been able to make use of the lab in the most efficient ways to produce excellent research. Given the development since, with MAX IV as a kind of crown achievement, we can only conclude that the buildup of talent, competence, and technology has continued further, and continued to benefit Swedish and Nordic science deeply and profoundly.

Specifically on the side of Swedish mobilization in areas judged to be of key strategic importance nationally, it can be noted that several of the national Materials Consortia established in the late 1980s by the Board of Technical Development (Styrelsen för Teknisk Utveckling, STU) and NFR had key involvement of prominent MAX-lab users,[408] as did their sequel excellence centers, sponsored by the Swedish Foundation for Strategic Research (Stiftelsen för Strategisk Forskning, SSF). At the end of the 1990s, the same foundation funded strategic programs in structural biology, where many of the sponsored environments also had great involvement in MAX-lab, and the genomics programs of KAW have also benefited from connections to the lab.[409] The Linnaeus Grants and the Strategic Research Areas grants, both key parts of the Swedish governmental excellence funding programs of the 2000s and 2010s,[410] financed a number of research environments that clearly have increased their performance over the years through access to MAX-lab.[411] Similar importance of MAX-lab on Nordic

[407] "Scientific evaluation of the MAX IV proposal 2006", Swedish Research Council report 20:2006, p 20.

[408] J Gribbe, "Omvandling och fasta tillstånd: Materialvetenskapens etablering vid svenska universitet," (Vinnova Analys VA 2016:06, 2016), pp 43ff.

[409] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p17

[410] O Hallonsten and C Silander, "Commissioning the university of excellence: Swedish research policy and new public research funding programs," *Quality in Higher Education* 18 (2012), pp 367-381.

[411] Mid-term evaluation report of the 2006 Linnaeus environments and doctoral programmes, commissioned by the Swedish Research Council and Formas. Swedish Research Council 2012. p 93-96

level has been discussed in previous sections, and has been highlighted by evaluations and other documentation.[412]

A key matter in the qualitative analysis of how MAX-lab grew to become this vital resource for Swedish and Nordic scientists in a variety of fields is of course *proximity*. Not only does this provide an explanation to how potential users become actual users, it also explains how research groups could develop deep and long-lasting relationships to the lab – relationships that in many cases proved truly synergistic – and how the impact of the lab for these groups and for the scientific communities concerned went beyond the availability of experimental resources, to becoming a key node in networks and, in the long run, functioning as a vehicle for internationalization of Swedish science.

Several interviewees have witnessed that access to comparable experimental resources abroad was restricted and highly competitive in the 1980s and 1990s, and that the availability of MAX-lab to Swedish and Nordic researchers in this formative period of time gave them the opportunity to develop competences that, in turn, made them competitive on the global scale later on. Although synchrotron radiation sources abroad brandished beamlines and experimental stations with world leading performance, it was not necessarily so that users in solid state physics were able exploit this performance, since it normally took time and effort to learn how to operate an experimental setup of this kind. Access to instrumentation closer to home, where one can also take part in design and construction, means a better platform to develop the necessary skills. To this shall of course be added comparably mundane aspects of proximity: Travel times are always a nusiance, especially for early career researchers with a family at home. In the 1980s and early 1990s, these aspects seem to have been very important for those research groups in solid state physics that recurrently used MAX-lab and built their activities and reputations in symbiosis with the lab.[413] Later, when structural biology had made its entrance both at MAX-lab and synchrotron radiation laboratories abroad, the proximity and the somewhat lower level of competition at MAX-lab seems to have worked in favor of the Swedish and Nordic user communities in similar ways: Users could travel for one day instead of three, and still had more time and less stress to obtain the data they needed (cf. the discussion on "low throughput" in section 3.5.1).[414]

The proximity aspect is very valuable, not least when combined with the level of performance achieved at MAX-lab, which attracted some attention globally and spilled over to its user community, making the lab into a contact point for Swedish science to

[412] "Swedish National Facilities", review report, Swedish Research Council, 2002. p 36-37. B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 170.

[413] Roger Uhrberg, interviewed by Olof Hallonsten, Linköping 25 August 2006.

[414] Thomas Ursby, interviewed by Olof Hallonsten, Lund 20 October 2006. Yngve Cerenius, interviewed by Olof Hallonsten, Lund 10 October 2006.Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

the international stage. This feature of the lab was acknowledged already in the 1989 evaluation of the MAX II proposal,[415] and not least also in the 2002 evaluation, which notes that MAX-lab "has become the centre of a very effective network, stimulating communication and exchange between swedish scientists from many different disciplines in an international context."[416] MAX-lab connected Swedish and Nordic scientists to pioneers of synchrotron radiation abroad, including Bernt Sonntag and Christof Kunz of DESY in Hamburg, Steve Milton of APS, Giorgio Margaritondo of Elettra, and Keith Hodgson, Britt Hedman and Arthur Bienenstock of SLAC/Stanford.[417] Bienenstock's services to MAX-lab in critical phases of its development also made him honorary doctor at Lund University in 2006. The international contacts were established early on: When in 1978 Karl-Fredrik Berggren was charged with evaluating the first funding application by Anders Flodström and Per-Olof Nilsson (see section 2.5), he spent considerable time at Stanford to familiarize himself with synchrotron radiation, and established crucial contacts between MAX-lab/Sweden and the pioneers of synchrotron radiation in California.[418]

MAX-lab formed an important basis for Swedish and Nordic researchers to forge international collaborative ties, also on a personal level, between themselves (Nordic collaboration) and with international partners. The growing number of Swedish *and* international users (see figure 3.1 in section 3.2) is a testimony that this function of the lab only intensified over time. The forming of a user community, durable and prominent in many scientific areas and experimental techniques that use synchrotron radiation, is among the most profound forms of impact of MAX-lab over the decades. There are several examples of individuals that embody this development (see not least the preceding three sections), but the very large community of people who remain more or less anonymous but are behind the hundreds of publications that make up the tangible impact of MAX-lab (see figure 3.5 in section 3.2) are likewise very important. Several of these have of course only visited MAX-lab once or twice over the years, conducted some research, and gone home with data and published it. Many have interacted with the lab in various ways and contributed to its survival and success on long term. People who have participated in the summer schools (see section 5.2.1) as doctoral students and gone on to become postdocs abroad, in groups and institutes run by MAX-lab "friends" have later established themselves in Sweden and built their own researcb groups, remaining reliable users of MAX-lab and also traveling abroad, to other synchrotron radiation facilities, to do complementary experimental work. Some of these have eventually emerged in MAX-lab's committees, advisory groups and the

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[415] "International Evaluation of the MAX II Project", Swedish Natural Science Research Council 1989. p 5

[416] "Swedish National Facilities", review report, Swedish Research Council, 2002. p 36

[417] Ingolf Lindau, "MAX II – a personal perspective," in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), 83-95, on p 93. See also the list of board and committee members in appendix 4.

[418] Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

board (see appendix 4). Users with this type of resumé are often quick to emphasize how MAX-lab, in the early days, provided opportunities for young researchers to learn and build experience in a way that appears unique.[419]

A key part of this, noted briefly above, is the apparent ability of MAX-lab to prepare Swedish and Nordic scientists for using synchrotron radiation at facilities abroad. The 1992 international evaluation of Swedish research in physics expressed fears that Swedish physicists "particularly in condensed matter and materials science, will not be taking advantage of the unique opportunities provided by the ESRF" to the same degree as German, French and British physicists.[420] We know now that Swedish (and Nordic) scientists make use of beamtime at ESRF at a rate that continue to exceed the financial contributions, which is a testimony to their competitiveness.[421] Similarly, Swedish and Nordic users are present and visible at many other synchrotron radiation facilities around the world. While the argument that MAX-lab contributed to this situation in the late 1980s and 1990s by building and cultivating a strong Swedish and Nordic synchrotron radiation community cannot be proven, it can also not logically be discarded. A 1997 governmental investigation of the worth of Sweden's various memberships in international collaborative scientific facilities concludes that MAX-lab has given Swedish reserachers "good training" and an "entry ticket to the international arena."[422]

Generally for science, the environment that MAX-lab provides for young researchers shall also not be underestimated; apart from the results obtained and the knowledge and skills learned, it is important for young scientists to meet other scientists and interact with them within the context of a lab environment like MAX-lab. As expressed by a long time user of Linköping University: "To have a national infrastructure like MAX-lab has been tremendous for us, in terms of education and training, and I think that is very hard to measure quantitatively."[423] The same is essentially true also for scientists in later career stages – MAX-lab has been a meeting point and a basis for the forming of collaborations and networks that go beyond the scientific activities at the lab.[424]

Human capital, as an output or impact, shall not be underestimated – this is many times what drives scientific progress, as people move around, exchange ideas, start

[419] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 206.

[420] "International Evaluation of Swedish Research in Physics". Swedish Natural Science Research Council 1992. p 35

[421] O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009), p 245.

[422] "Besparingar i stort och smått", Swedish Governmental Investigation (SOU 1997:69), p 50.

[423] Kajsa Uvdal, interviewed by Oskar Christensson, Linköping 28 November 2016.

[424] Lars Johansson, interviewed by Oskar Christensson, Karlstad 12 January 2017.

collaborations, and use their networks to pursue new plans. MAX-lab has been part of several national and international networks of more or less formal nature that illustrate this feature of a multidisciplinary user facility quite well. The Swedish national infrastructure for structural biology (Swedstruct) is a national infrastructure network with three nodes; the protein production facility at Karolinska Institute, the Swedish NMR (nuclear magnetic resonance) center at Gothenburg University, and the crystallography beamlines at MAX-lab (now at MAX IV). These three nodes together provide the complete chain from protein production, via sample preparation, to measurement with the technique most suitable.[425] Since the late 1990s, MAX-lab was a member in the European "Access to Large-Scale Facilities" program, providing EU funding for travel and lodging to European scientists coming to do experimental work at the lab.[426] In the 2000s, similar programs were initiated with MAX-lab as a member, among them the "Integrating Activity on Synchrotron and Free Electron Laser Science" and the "European Light Sources Activity."[427] The opportunities for foreign researchers to come and use MAX-lab, and thus contribute to the intellectual fertilization and internationalization of the lab, were thereby enhanced. It should be mentioned in this context that the program was open to Swedish scientists going to labs in other European countries to do experimental work, but not MAX-lab, as costs were not covered for domestic travels, a side-effect of less positive character that might have caused some Swedes to choose to go abroad instead of going to MAX-lab.[428]

When it comes to the profound, long-term impacts on Sweden and the scientific community, the process of internationalization is important. MAX-lab was built up and expanded during a time when internationalization of science, and globalization, took new speed. In the midst of these transformations, MAX-lab provided the concerned Swedish scientific communities with a platform and a forum for development that indeed meant an "entry ticket" to international arenas, where important collaborations and networks formed.[429] The rise of new interdisciplinary collaborations and strategic research programs that run across previous categories is another important trend of the past few decades, and also here MAX-lab helped Swedish science to renew and revitalize itself.

Early on, physicists identified the potential value of synchrotron radiation generally, and MAX-lab specifically, for chemistry and biology and began broadening their networks to include also representatives of these fields. In a next step, in the late 1990s

[425] Forskningens Framtid! Översikt 2014 Forskningsinfrastruktur. Swedish Research Council 2015. appendix p 62.

[426] MAX-lab Activity Report 1997: 1

[427] MAX-lab Activity Report 2009: 8

[428] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 209.

[429] Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

and 2000s not least laser physics and its importance for chemistry and biology, followed. Through MAX-lab and the broader national and international developments that it is part of, chemists and biologists in Sweden realized how infrastructures and bigger collaborative projects can benefit also their disciplines, and they have also become involved in crucial instrument development that has been brought back to their respective labs, and followed physics in the development towards a situation where their own small-scale research is combined with larger collaborative initiatives, using big equipment.[430]

In this sense, MAX-lab was a means to open up Swedish science to the outer world. It built on core areas with strong tradition in Sweden, like structural biology, surface science, and condensed matter physics, and meant a revitalization and simultaneous prioritization of these fields.[431]

3.7.1 The user association(s)

The forming of networks and a MAX-lab user community happened over time, through informal and spontaneous interaction at the lab floor, but also some formalized structures were very important in the process. Among these, the user associations – most of all the Association for Users of the Synchrotron Light at MAX-lab (Föreningen för Användare av Synkrotronljuset vid MAX-lab, FASM) but also the user association in nuclear physics – played crucial roles.

FASM was formed already in 1978 by pioneer synchrotron radiation and MAX-lab user Per-Olof Nilsson of Gothenburg,[432] and it became a natural part of the MAX-lab ecosystem, with permanent representation in the MAX-lab board (see also appendix 4) that enabled tight collaboration between lab leadership and users, and the involvement of the user community in most lab affairs. This has been mentioned a key factor for the long-term development of the lab and its successes, because it mobilized a strong support throughout Sweden, strengthening its cause and its prospects for continued and expanded support from funders, politicians and university leaders.[433] It also contributed greatly to the forming and sustaining of networks among not least Swedish and Nordic users, which proved important for the lab's development and in the process of finding Nordic collaboration models around MAX IV.[434]

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[430] Örjan Skeppstedt, interviewed by Olof Hallonsten, Gothenburg 25 January 2017.

[431] Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

[432] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 102.

[433] Svante Svensson, interviewed by Oskar Christensson, Uppsala 2 December 2016

[434] Lars Johansson, interviewed by Oskar Christensson, Karlstad 12 January 2017. Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

Table 3.5 shows a list of the MAX-lab user meetings/annual meetings of FASM over the years, with notes on number of participants (when available) and special events held in connection to the meetings. In addition to what is noted in the table, all meetings have had oral and poster presentations of results obtained at MAX-lab, and a few international guests invited to talk about recent developments in synchrotron radiation and related topics. The importance of these meetings, as a forum for the exchange of all kinds of knowledge and experience among MAX-lab users, and thus in the long run as a recurrent event that fortified and developed the user community, should not be underestimated.

FASM was also a role model for other, later, user associations abroad and how these interacted with the labs whose users they represented. FASM chairman (1994-1999) Svante Svensson was occasionally invited to other labs in Europe in the 1990s to speak about FASM and give advice on how to form similar organizations: "They couldn't do it exactly like we did, because traditions are different, but today there are users associations at all labs, that can be mobilized when necessary, to gather around initaitives and lend them support."[435]

In 1994, a MAX Association for Nuclear Physics Users was formed. Long time external nuclear physics users of MAX-lab John Annand and Cameron McGeorge, both from the Department of Physics and Astronomy at the University of Glasgow, became the first contact persons for the association. For several years, the association was referred to as "rather informal" in the MAX-lab activity reports, and it held occasional meetings in connection with workshops and conferences (both at MAX-lab and elsewhere in the world), and the annual meetings of the PAC for nuclear physics.[436] In 2007, the user association is mentioned as a somewhat more stable entity, with a board composed of four members (John Annand, University of Glasgow, UK, chairman; William Briscoe, The George Washington University, Washington DC, USA; Lennart Isaksson, Lund University, Sweden; and Peter Grabmayr, University of Tübingen, Germany), a board composition that remained intact at least through 2010.[437] However, it seems the board did not meet for some years until in 2009, when it convened in connection with the regular MAX-lab users meeting.[438]

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[435] Svante Svensson, interviewed by Oskar Christensson, Uppsala 2 December 2016

[436] MAX-lab Activity Report 1994: 16; 1996: 14; 2000: 10.

[437] MAX-lab Activity Report 2007: 12; 2008: 12; 2009: 12; 2010: 14.

[438] MAX-lab Activity Report 2009: 12.

Table 3.5:
The Annual Meetings of the Association for Users of the Synchrotron Light at MAX-lab, 1988-2015[439]

Dates	No of participants	Events
September 20-21, 1988	> 80	
September 19-20, 1989	~ 70	
September 18-19, 1990	~ 100	Minisymposium on Microspectroscopy
September 17-18, 1991	~ 120	Nordic information meeting on the European Synchrotron Radiation Facility, ESRF, in Grenoble.
September 15-16, 1992	~ 130	Special half-day meeting on insertion devices
September 14-15, 1993	> 100	
September 13-14, 1994	120	Special session on the use of international synchrotron radiation facilities. Several satellite meetings including one concerning the board of the ESRF.
September 14-15, 1995	> 100	Held in connection with the inauguration of MAX II facility. Special popular science poster session.
September 24-25, 1996	80	
September 9-10, 1997	~ 100	Special miniconference on "Synchrotron Radiation applied to Microtechnology"
September 24-25, 1998	112	Meeting program organized to welcome the new big user community from biology. Special miniconference on "Crystallography at MAX II"
September 27-28, 1999	118	Special miniconference on "Infrared Spectroscopy at MAX"
September 28-29, 2000	109	Special miniconference on EXAFS and the 1811 beamline
September 20-21, 2001	135	
September 19-20, 2002	111	
October 8-9, 2003	108	Panel discussion about the MAX IV project
September 27-28, 2004	~ 400*	Held in connection with the MAX IV workshop "Our Future Light Source"
September 28-29, 2005	128	
September 25-27, 2006	153	Expansion of the user meeting, including the introduction of new beamline-specific sessions. New was also student awards for poster and oral presentations.
October 29-31, 2007	> 400*	Coordinated with the workshop "Science at MAX IV"
October 20-22, 2008	280*	Coordinated with the workshop "New Directions for MAX IV". Two additional meetings: CoLuAa, the 17th annual meeting for macromolecular crystallographers in Copenhagen, Lund and Aarhus and a workshop on Time Dependent Density Functional Theory in Sweden
November 2-4, 2009	> 300	Coordinated with a number of small workshops devoted to beamlines at the planned MAX IV facility
November 8, 2010	342	Dominated by the MAX IV project.
November 14, 2011	280	A new organization, Swedish Synchrotron Radiation Users Organisation (SSUO) was formed at this meeting, with the purpose of promoting the interests of Swedish synchrotron light users in general, and to become the Swedish representative in the European Synchrotron Radiation Users Organization (ESUO).
September 24-26, 2012	230	
November 23, 2013	250	
September 29-October 1, 2014	247	
September 21, 2015	275	

* Held in connection with bigger meetings which increased the number of participants

[439] As noted in the MAX-lab Activity Reports. Complementary data received from Ralf Nyholm, via email, 27 February 2017.

3.7.2 Workshops and conferences

Besides the annual user meetings listed in the previous section, MAX-lab was the host and/or organizer of many conferences and workshops over the years, that functioned as gathering events and platforms for network building and maintenance among users. Conferences and workshops are key features of the social (self)organization of science, and a part of international scientific communities that is as natural as it is crucial for the exchange of information and maintenance of contacts between researchers at the scientific forefront of specialisms as well as broader areas.

The organization of conferences and workshops at and around MAX-lab therefore served as a way to maintain networks in specialized areas (in contrast to the user meetings whose scope was more general), to communicate results and advances at the lab, and not least to mobilize the capabilities of the user communities in the conceptualization, design and development of new instrumentation and new areas of use.[440] The meetings contribute to the shaping of interpersonal and inter-organizational networks and offer rare opportunities for scientists with common interests to share experiences and knowledge. They are also important as places for meetings between users and representatives of industrial firms, the latter both in the capacity of exhibitors and as participants. Tables 3.6 and 3.7 contain lists of workshops noted in the activity reports; these lists are most likely not complete but offers glimpses into the rich and varied conference and workshop activities at and around MAX-lab over the decades.

[440] For a longer discussion on this, see O Hallonsten, *Small science on big machines: Politics and practices of synchrotron radiation laboratories* (Lund University, 2009), pp 272-274.

Table 3.6:
Workshops and conferences (synchrotron radiation and related) listed and described in the MAX-lab activity reports, 1989-2010

Dates	Theme	Notes
April 11-12 and 14, 1989	Synchrotron Radiation Research at MAX-lab	Workshop as part of the long-term strategic work that led to MAX II.
September 19, 1990	Minisimposium on Microspectroscopy	Held in connection with the FASM annual meeting.
May 25-27, 1992	Symposium on new research opportunities and developments of beamlines at MAX II	Fifteen invited speakers.
January, 1996	Workshop on the feasibility of an X-ray beamline for material science at MAX II	
March, 1996	Workshop on the scientific case for an infrared free-electron laser at MAX-lab	
September, 1996	Workshop on high-resolution spectroscopy	
September, 1997	Annual Workshop on European Light Sources	The fifth in a series of meetings among the light sources in operation, construction or design in Europe. Over 50 participants from 14 labs.
October 14-15, 1997	Annual Nordic Ring Meeting	Almost 50 participants from 6 Nordic labs.
August 30-31, 1999	3:rd European Light Source Radio Frequency Meeting	About 20 participants from the European synchrotron radiation sources and from ALS in the US.
November 30, 1999	MAD MAX Workshop	Workshop on the design of the new protein crystallography beamline (I911). 23 attendees.
March 29, 2000	Workshop to establish infrared microspectroscopy at MAX-lab (IMAM2000)	58 attendees from both universities and companies.
August 18, 2000	MAD MAX 2nd Symposium	Symposium on the coming MAD beamline at MAX-lab.
June 13-16, 2001	Fifth Workshop on Electromagnetically Induced Two-Hadron Emission	Nuclear physics workshop.
July 17-20, 2001	Workshop on the Generation and Uses of VUV and Soft X-ray Coherent Pulses	Workshop with the purpose to bring together designers/constructors and users of free-electron lasers.
June 28-29, 2002	XAFS workshop: Introduction to XAFS theory and data treatment, including practical exercises	28 participants.
June 22-27, 2003	12th International Conference on X-ray Absorption Fine Structure (XAFS-12)	More than 450 participants from 30 countries.
March 1-2, 2004	Workshop on Research at I811	About 20 participants.
March 5-6, 2004	2nd MAX-INF Integration Workshop	Workshop within a network that promotes cooperation within the macromolecular crystallography community to facilitate access to and exploitation of synchrotron radiation sources. 40 participants.
March 10-12, 2004	Workshop on Low Emittance Lattices	Joint MAX-lab/ALBA (Barcelona) workshop. 15 invited guests and the local MAX-lab staff.

September 27-29, 2004	'Our Future Light Source'	Workshop as part of the preparation of the scientific case for the MAX IV proposal. Close to 400 participants.
January 19-20, 2005	Frontier Conference on Synchrotron Radiation and Related Methods in Advanced Materials Science	26 invited talks.
February 1-2, 2007	Fourth Scandinavian Workshop on Scattering from Soft Matter	2 days' workshop with some 80 participants.
June 11-13, 2007	New and emerging sources of intense beams of particles and short-wavelength radiation	102 participants from 13 countries.
June 11-20, 2007	XAFS for beginners	22 participants from Sweden, Finland, Denmark, Germany and the UK.
September 1-10, 2008	XAFS for Beginners	20 participants from Sweden, Finland, Denmark, Germany, Hungary, Latvia, Norway, Turkey, Poland, Switzerland and the UK.
October 21-22, 2008	CoLuAa – 17th annual meeting for macromolecular crystallographers in Copenhagen, Lund and Aarhus	Held in connection with the MAX-lab 21st Annual User Meeting.
October 21-22, 2008	Time Dependent Density Functional Theory in Sweden	Held in connection with the MAX-lab 21st Annual User Meeting.
February 3-4, 2009	High Resolution Electron Spectroscopy – Future and Perspectives	25 participants.
October 5-4, 2009	XAFS for beginners	21 participants from Sweden, Denmark, Germany, Hungary, Spain and Brazil.
February 22-23, 2010	Beamlines at MAX IV	Over 170 users of Synchrotron Radiation from Sweden, the Nordic/Baltic countries, Poland and Europe.
May 5-7, 2010	Second Workshop on High Harmonic Seeding for Present and Future Short Wavelength Free-Electron Lasers (FELs)	Hosted by MAX-lab, the Lund Laser Centre, Sincrotrone Trieste, ENEA, INFN-LNF and University of Rome. Over 50 participants.
August 23-27, 2010	FEL 2010 – 32nd International Free Electron Laser conference	Over 300 participants. 63 presentations.
November 9-10, 2010	IDMAX2010, Insertion Devices for Rings and Linacs	Held in connection with the MAX-lab Annual User Meeting. 23 speakers. Presentations from 5 different companies manufacturing insertion devices.

Table 3.7:
Workshops and conferences (nuclear physics) listed and described in the MAX-lab activity reports, 1997-2006, including nulcear physics users' meetings

Dates	Theme	Notes
March 10-12, 1997	First MAX-lab Workshop on the Nuclear Physics Program with Real Photons below 250 MeV	Workshop on the upgraded nuclear physics facility at MAX-lab.
June 13-16, 2001	Fifth Workshop on "Electromagnetically Induced Two-hadron Emission"	About 70 scientists from all over the world.
May 30-31, 2002	Second MAX-lab Workshop on the Nuclear Physics Program with Real Photons below 250 MeV	40 attendees from 20 institutes. Workshop on the upgraded nuclear physics facility at MAX-lab.
November 20-21, 2003	Users Meeting for Nuclear Physics Users at MAX-lab	28 participants representing 14 international research groups.
December 6-8, 2004	Users Meeting for Nuclear Physics Users at MAX-lab	
October 6, 2006	Users Meeting for Nuclear Physics Users at MAX-lab	

4. Economic impact

4.1 How facilities like MAX-lab can and cannot have economic impact

No matter where one looks, there is a ubiquity of expectations, from policymakers and the general public, that academic research environments and resources for the scientific community that are geared towards academic or fundamental research shall have impacts on the economy, preferably in very tangible and measurable ways. In the case of research infrastructures, it seems the demands and expectations of "technology transfer" and "spinoffs" showed up before they took root in the academic world; the huge investments in e.g. particle accelerators and telescopes in the 1960s and 70s seem to have made "arguments drawn from the cultural value of research and other intangibles" unconvincing for policymakers who experienced a simultaneous economic downturn. As a result, "secondary effects 'falling out' from basic research, the so-called 'spin-offs'" became a motivation for investments – only to become the source of some controversy since these "are not as easy to prove and quantify as was first believed."[441] In the 1980s, the expectations and demands that large scientific infrastructure labs engage in "technology transfer", and thus contribute directly to the economy, became part of the frameworks for their governance and funding.[442]

Today, these expectations and demands are obvious parts of the marketing campaigns for many new research facilities – also those comparable to MAX-lab in their scientific activities and scope.[443] The neutron scattering facility European Spallation Source (ESS), being built outside Lund as a collaborative project between a handful of European governments and Sweden and Denmark as co-hosts, is the perhaps most evident example of this;[444] the Swedish bid to host the ESS was made a priority of the

[441] H Schmied, "Results of attempts to quantify the secondary economic effects generated by big research centers," IEEE Transactions on Engineering Management 29 (1982): 154-165, on p 154.

[442] O Hallonsten and T Heinze, "Institutional persistence through gradual adaptation: Analysis of national laboratories in the USA and Germany," *Science and Public Policy*, 39 (2012), 450-463.

[443] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), ch 6.

[444] W Agrell, "Framing prospects and risk in the public promotion of ESS-Scandinavia," *Science and Public Policy* 39 (2012), 429-438.

government on basis of arguments of industrial importance and economic growth, rather than scientific ones.[445]

Facilities like MAX-lab has the capability of creating economic impact in a number of quite different ways, but that some of these are rather opaque and very difficult to measure or demonstrate. On the other hand, they will logically appear and should hence be expected: It is unlikely that investments in advanced technology and conventional facilities (buildings etc.), the employment of high-skill labor, the continuous inflow of likewise high-skill users making temporary visits, and the ongoing use of the facilities for rather advanced experimental scientific research *would not* render any economic output.[446]

It is possible to make a classification of economic impacts from labs like MAX-lab as threefold; stemming from procurement, from technology/knowledge transfer, and from industrial use of facilities and their instrumentation.[447] Parts of technology/knowledge transfer, and the industrial use of facilities, are "primary economic effects", i.e. they stem from the scientific use of the facility; procurement and some other parts of technology/knowledge transfer are instead "secondary economic effects" that do not come from the core activities of a facility but are produced as part of its work to enable this scientific use; i.e. its direct procurement of goods and services and its development of technology and organizational practices that can be of value also outside the labs.[448]

As noted repeatedly in previous chapters, the knowledge production of MAX-lab and similar facilities is for the most part undertaken by external users with the activities of their home university (or institute) as basis, and the same goes for industrial use, which means that the framework set for the technology transfer that has to do with scientific use of the facility is no different from other university and industry R&D activities. Instead, it is the organizational and institutional (and political) logic of the university research environments and other organizations where users have their employment and main scientific activities that set the frameworks for knowledge and technology transfer from the scientific use of MAX-lab and similar labs.

More importantly, the scientific and technological (and organizational) development that happens inside the lab and/or because of the lab's ambitions to provide resources for scientific work leads to technology and knowledge transfer that is *specific* for the lab

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[445] A Larsson, "Svenskt värdskap för ESS," Swedish Government Ds 2005:20.

[446] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), p 200

[447] E-J Meusel, "Einrichtungen der Großforschung und Wissenstransfer," in H Schuster (ed.), *Handbuch des Wissenschaftstransfer* (Springer, 1990). ERID watch report 2009: 14; Technopolis, "The role and added value of large-scale research facilities" (report, 2011), p 18-29.

[448] H Schmied, "Results of attempts to quantify the secondary economic effects generated by big research centers," *IEEE Transactions on Engineering Management* 29 (1982): 154-165, on p 154.

and its technological and organizational (and political) characteristics. Three case studies – of the magnet technology for the MAX storage rings, of the procurement of tripods for the magnets, and of the development of an analyzer for experimental stations for spectroscopy at MAX-lab – are found later in this chapter and are great examples of this. In all three, there are elements of what is popularly called "spinoffs" since the technological development has had commercially relevant features, but interestingly, no patents have been sought or granted in the processes.

Technology and knowledge transfer is typically studied by the identification of spinoffs, patents and licenses. None of these are very present in the history of MAX-lab, but other channels through which technology and knowledge transfer occur are all the more common, especially the training of personnel that go on to enrich industrial sectors with their specialist knowledge and skills, and the temporary mobility of scientists and technicians between the lab and other sectors of the economy.

Here it is important to remind the reader of the discussion in chapter 2 on the necessity to apply a holistic view on impact. The easily distinguishable impacts of spinoffs and patents (although these seem not to be found at all in the case of MAX-lab) are always complemented with other impacts later on, at other places, and in other contexts. Whether or not these can be traced and demonstrated is as much a methodological question as a matter of patience: The example of the iPhone[449] used in chapter 2 makes quite clear that in principle, there is nothing to suggest that technology developments done at MAX-lab, say, in the 1990s, could not appear in refined form in some innovation put together by a business and marketing genius somewhere in the world several decades from now. We won't speculate about that now, only reiterate the crucial insight that no matter how hard we look, all forms of impact from technology and knowledge transfer will not appear before our eyes. There is also much to suggest that especially in the case of labs like MAX-lab, which most of all have the function of serving users the most optimal technical and organizational preconditions for experimental work they need to undertake as part of their research projects (planned and for the absolute most part executed elsewhere), the most important impacts are hard to trace and hard to get a good grip on.[450] The same goes for the technology development that labs undertake, as the examples of the case studies of Scienta, Scanditronix, and Olssons Mekaniska (see below) show quite clearly.

When it comes to procurement, however, the issue is much simpler. Labs like MAX-lab procure many goods and services, both what could be categorized as "high tech"

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[449] M Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths* (PublicAffairs, 2015).

[450] H Schmied, "Results of attempts to quantify the secondary economic effects generated by big research centers," *IEEE Transactions on Engineering Management* 29 (1982): 154-165, on p 154. E-J Meusel, "Einrichtungen der Großforschung und Wissenstransfer," in H Schuster (ed.), *Handbuch des Wissenschaftstransfer* (Springer, 1990).

(e.g. advanced instrumentation, and associated services) and what could be categorized as "low tech" or "conventional facilities" (e.g. buildings, furniture). The latter follows somewhat more predictable patterns than the former, since "high tech" procurement often involved highly specialized and detailed orders and collaborations between procurer and vendor, whereas conventional facilities more often concern "off the shelf" goods. It is, of course, in the "high tech" category that the potential for long and unpredictable sequences of impact, involving technology and knowledge transfer and further innovation down the road, are most likely to occur.

What "low tech" and "high tech" procurement have in common is that all large (public) investments have significant positive effects on the economy; locally, regionally, nationally, internationally; and in the various sectors where procurement is made. Over time, the series of investments made in a facility like MAX-lab will have an accumulated positive effect, and studies have shown that a majority of the investment in a large research infrastructure stays in the local or regional economy and gives rise to several dynamic effects, direct and indirect.[451] One proof of this, or at least a proof that policymakers generally believe that there are significant local and regional benefits from the localization of a large scientific facility, is the "site premium" often paid by the host country of European collaborative research facilities (like the ESS, or the ESRF in Grenoble), and the various schemes and procedures put in place to secure that also other, non-hosting, member countries get their fair share of the benefits.[452]

It is of course very logical that a very large proportion of the procurement contracts of large scientific facilities and labs go to firms in the close geographical vicinity, since this is at least nominally most efficient, and also coheres with conventional wisdom in studies of knowledge transfer, spillovers and the geography of innovation: there is an added value of geographical proximity in any business transaction and collaboration.[453] The tax revenue from the large number of people employed at the facility is of course a gain for the region and nation, but taxes are supposedly paying for public services that

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[451] For example, statistics from the research facilities ESRF and ILL in Grenoble show that as much as 80% of the procurement contracts from these two facilities combined stay in France, and 44% in the Isère region; W Stirling, "GIANT Innovation Campus: Grenoble Innovation for Advanced New Technologies." Presentation, http://essmax4tita.skane.com/files/w-g-stirling_tita_20110401.pdf (2011). See also W Waldegrave, "Economic impacts of hosting international scientific facilities" (Crown, 1993). SQW Consulting, "Review of the economic impacts relating to the location of large-scale science facilities in the UK" (report, 2008).

[452] O Hallonsten, "The Politics of European Collaboration in Big Science," in M Mayer, M Carpes and R Knoblich (eds.), *The Global Politics of Science and Technology - Vol. 2* (Springer, 2014), pp 43-44. O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 93-94, 202.

[453] Z J Acs, D B Audretsch and M P Feldman, "R & D spillovers and recipient firm size," *The Review of Economics and Statistics*, 76(1994), 336-340. A B Jaffe, M Trajtenberg and R Henderson, "Geographic localization of knowledge spillovers as evidenced by patent citations," *The Quarterly Journal of Economics*, 108 (1993), 577-598.The line of argument goes far back to studies of geographical limits to the transmission of "tacit knowledge", e.g. A Marshall, *Principles of economics* (Macmillan, 1890).

the same people utilize, which means that the argument is not as solid as some of these studies make them appear.

Studies of the economic impact of large facilities, especially those made ex ante in order to supply a political campaign with arguments, highlight these things in order to prove that there will be an economic benefit for the host country and region that can be easily quantifiable and does not need to take into account the possible future scientific productivity of the facility in question, which is an uncertain basis for a business case compared to the irrefutable logic that huge foreign investments made in a facility whose procurement of goods and services is predominantly made locally means an inflow of capital to the region and nation.[454] Today, many things complicate this – the extensive use of in-kind contributions, the increasingly international labor market for researchers, and the use of tax reliefs to attract talent from abroad puts the business case largely out of play.[455] But fortunately, in the case of MAX-lab, these things are on a more manageable level. The lab was always a national facility, and organizationally tied to Lund University, and had only relatively minor amounts of foreign investments over the years. Moreover, procurement was predominantly done locally and nationally, with some exceptions (the Finnish research institute VTT built most of the insertion devices, see section 4.2). The gradual but vast increase in number of employees at MAX-lab (see figure 2.6 in chapter 2) obviously meant that new jobs were continuously created for comparably high-skill, high-educated people who furthermore paid taxes in Lund and Sweden. There are available estimations of accumulated local and regional employment effects from existing and planned large facilities, but these are mostly based on extrapolations and the use of multiplier effects whose stringency duly can be questioned.[456]

Importantly, however, there are provable secondary effects: Suppliers of goods and services on the high tech side tend to undergo significant learning as part of the processes, enhancing in-house knowledge, and the effect is also, to some extent, visible on the level of whole regions. Similar effects concern employment, where a learning effect takes place also in the form of an increase in skills and know-how of those employed at a facility, that may later migrate to other parts of the economy. In-depth studies of the procurement of high tech goods and services at CERN show how the development of long-term relationships between the lab and its contractors led to mutual learning, the transfer of knowledge and technologies in both directions, and an accumulation of knowledge, skills and experience that can open the doors to whole new

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[454] A Larsson, "Svenskt värdskap för ESS," Swedish Government Ds 2005:20. W Waldegrave, "Economic impacts of hosting international scientific facilities" (Crown, 1993). Kamer PM, "The Economic Impact of Brookhaven National Laboratory On the New York State Economy," 2005

[455] O Hallonsten, "Unpreparedness and risk in Big Science policy: Sweden and the European Spallation Source," *Science and Public Policy* 42 (2015): 415-426.

[456] Technopolis, "The role and added value of large-scale research facilities" (report, 2011), p 32-33. A Larsson, "Svenskt värdskap för ESS," Swedish Government Ds 2005:20.

markets.[457] The generalizeable learning, that also applies to the case here (in spite of the huge differences between CERN and MAX-lab) is that scientific facilities that routinely push the boundaries of technology in their development of new instrumentation can act as important first customers for firms that invest in the development of emerging technologies, and function as test beds for advanced R&D projects.[458] The labs are complex technical setups, often at the forefront of scientific development of instrumentation, and place “unusually high demands on the technological and managerial skills on contracting industry,” which this industry benefits from in terms of skills and competence enhancement.[459] Evaluation reports have noted the increase in “technical competitiveness” that appear to have happened as a result of delivering components to MAX-lab.[460] The involvement of “social capital built into the relationship” between the supplier and the lab is emphasized as conducive of especially important and visible spinoff effects for the companies.[461]

Long-term secondary effects inside firms may therefore even outweigh the purely financial gains, and lead to further spillovers to the greater economy and society. But they are typically difficult to prove, seldom quantifiable and usually delayed, amounting to “behavioral additionalities” that require in-depth qualitative analysis to be traced.[462]

The perhaps currently most vivid expectations on research infrastructures that predominantly serve materials science and life sciences is that industrial firms shall become significant users and turn the investments into innovation-based economic growth.[463] Of course, the use of cutting-edge instrumentation by industrial R&D units would in principle give them same or similar competitive advantage that an academic research group would get. Speculation holds that direct industrial use of synchrotron

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[457] Autio E, Bianchi-Streit M and Hameri A-P, ”Technology Transfer and TEchnologial Learning Through CERN’s Procurement Activity,” CERN Education and Technology Transfer Division 2003, CERN–2003–005. E Autio, A-P Hameri and O Vuola, “A framework of industrial knowledge spillovers in big-science centers,” *Research Policy* 33 (2004): 107-126.

[458] E Autio, A-P Hameri and O Vuola, “A framework of industrial knowledge spillovers in big-science centers,” *Research Policy* 33 (2004): 107-126, on pp 108, 118.

[459] H Schmied, “Results of attempts to quantify the secondary economic effects generated by big research centers,” *IEEE Transactions on Engineering Management* 29 (1982): 154-165, on p 154.

[460] Swedish Research Council Evaluation of 11 national research infrastructures 2012: MAX IV project and MAX lab, 8

[461] Autio E, Bianchi-Streit M and Hameri A-P, ”Technology Transfer and TEchnologial Learning Through CERN’s Procurement Activity,” CERN Education and Technology Transfer Division 2003, CERN–2003–005.

[462] See e.g. L Georghiou, “Impact and additionality in innovation policy.” In P Boekholt (ed.), *Innovation Policy and Sustainable Development: Can Public Innovation Incentives Make a Difference?* (IWT-Vlaanderen, 2002).

[463] W Agrell, ”Framing prospects and risk in the public promotion of ESS-Scandinavia,” *Science and Public Policy* 39 (2012), 429-438. J Rekers, ”The ESS and the geography of innovation,” In T Kaiserfeld and T O’Dell (eds.), *Legitimizing ESS. Big science as a collaboration across boundaries*. (Nordic Academic Press, 2013).

radiation facilities is increasing on global level, due to determined strategies of many (or most) labs to achieve such a development, but it is also quite clear that it remains on rather low levels, i.e. a few per cent or in the best cases ten to fifteen per cent of the total use. The four synchrotron radiation facilities in the United States National Laboratory System had between 4.5 and 6.5 per cent *direct industrial use* in fiscal year 2014 (October 2013-September 2014; counting individual users); but many research projects undertaken with academic scientists as principal investigators also involve industrial partners, which makes the grey area potentially significant.[464]

At MAX-lab, direct industrial use never exceeded a few per cent – roughy 5% if counting number of users, all years; about 3.5% if counting days of beamtime allocated, 2003-2011. The latter figure should be treated with some care given that most direct industrial use was on the crystallography beamlines (I711 and I911) where beamtime slots are generally much shorter than on the spectroscopy beamlines (roughly two thirds of the beamtime scheduled to industrial users in 2003-2011 was on these two beamlines, see table 4.4 in section 4.3). We have no knowledge of the share of beamtime allocated to collaborative projects between academic and industrial users, but there are indications that several such projects have utilized beamtime at MAX-lab over the years.[465]

4.2 Procurement and technology transfer

As noted in the previous section, the procurement of goods and services at a facility like MAX-lab has what can be called a low tech side and a high tech side. The development and construction of instrumentation at MAX-lab is a complicated affair, and even more so is the task to identify and quantify the impact of such development and construction work on the economy through the procurement of components from industrial firms. An accelerator-based user-oriented synchrotron radiation laboratory is an extremely complex collection of technological gadgets and systems that are, to varying degrees, designed and built by its staff and its users, specially ordered from firms on basis of detailed specifications, or off-the-shelf equipment procured from the same or other companies specialized in these areas. Investments in instrumentation and equipment, and in conventional facilities, means a clear economic impact, because instruments and/or components are procured from manufacturers. Running costs are more difficult to evaluate from this point of view; employment and the payment of salaries also typically mean that money is spent in the economy, as does operating costs such as

[464] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 203.

[465] MAX-lab, “Background Material for the Evaluation of the Swedish National Facilities 2002” (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p12.

electricity, although this can also be counted on the side of negative effects if weighing in sustainability/environmental factors.

The larger pieces of infrastructure components, like magnets, insertion devices, vacuum tubes, radiofrequency cavities, electric installations, and so on, or the major parts of a beamline and experimental stations, like monochromators, vacuum chambers, analyzers and so on, constitute investments in the range of hundreds of thousands, or millions, of SEK. Also the very many comparably minor instruments and components like vacuum pumps, computers, mirrors and gratings (not to mention the continuous supply of tin foil), amount to large amounts of money together, although they are comparably inexpensive individually.

This means, with a rough calculation, that a storage ring like MAX II, equipped with a handful of beamlines and experiment stations, has a replacement cost of hundreds of millions of SEK, not counting low-tech (like floor tiles, concrete shielding, wallpaper and window glass) and the conventional facilities that surrounds the lab and is likewise necessary for its operation (like office equipment and coffee machines).

A “reconstruction cost” of MAX-lab was calculated by its directors in 2003, amounting to roughly half a billion SEK (in 2003 prices), and another calculation was made in 2013, when another almost 200 million SEK had been invested.[466] Adjusting for inflation, and rounding off slightly to cover for the final two years of operation (and investment), the total sum approaches 800 million SEK. Closer than that is hard to come.

Beginning with the low tech side, or conventional facilities, we can note that for MAX I, the building was already in place but probably needed some adjustment. We have no access to tenders or contracts from this time. The big investment on the side of conventional facilities came with MAX II, whose building cost 62 million SEK (in 1991 prices), and whose main contractor was Byggproduktion Aktiebolag (BPA), now part of Bravida.[467]

MAX-lab kept a digital archive of contracts on procurement (and other contracts) from 1993 and on, where records can be found of some purchasing over the years. That MAX-lab was part of Lund University probably means that a lot of procurement of goods and services was handled by centralized units of the university and that hence, it is neither possible to retrieve the documentation regarding this purchasing nor use it to single out MAX-lab’s shares. In the files available, contracts with AGA and Air Liquide on the delivery of gas containers (Helium and Nitrogen) are recurrent, together with service contracts with Minolta, Xerox and Canon on photocopiers, and a firm called

[466] Compilation and calculation of investments and procurement by Ralf Nyholm, received through personal communication, 18 November 2016.

[467] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 176, 203.

SAQ besiktning AB that took care of controls of hydraulic equipment and high pressure containers. Other than that, the material is scarce.

If the low tech side is difficult to get a grasp on due to a lack of available material, the high tech side is likewise complex and elusive, not for this reason but because the topic itself has more depth and complexity built in. As noted in the previous section, the literature on spinoffs from Big Science makes a convincing agrument that it is most of all in the processes of procurement of high tech goods (and services) that effects can be expected. Relationships that involve trust and short cognitive distance are of course beneficial for both parts, and the case studies presented later in this chapter are prime examples. The main point here is that procurement on the high tech side, and "technology transfer", need to be analyzed together in the case of MAX-lab. With a few notable exceptions (see the analysis of innovations on the technology side in section 3.3), "technology transfer" in the classic sense has occurred as a result of development of MAX-lab only within the context of procurement of high tech products, or better defined, within the context of collaborative projects between MAX-lab staff and commercial firms.

Table 4.1:
Yearly collected investments at MAX-lab, 1997-2012, kSEK

	Accelerator systems	Beamlines	Experimental equipment	Nuclear physics	Total
1997		18,000			18,000
1998		18,900	2,600		21,500
1999	25,000	29,200	5,000	430	59,630
2000		29,900	2,700	400	33,000
2001		6,950	5,252		12,202
2002	14.000	35,366		900	50,266
2003		7,200	15,600		22,800
2004	11,800		5,480		17,280
2005			15,000		15,000
2006			2,700		2,700
2007			25,380		25,380
2008			8,470	2,700	11,170
2009		22,935			22,935
2010			8,295		8,295
2011					0
2012			10,415		10,415
Sum	*50,800*	*168,451*	*106,892*	*4,430*	*330,573*

Appendix 1 shows a table, compiled by MAX-lab staff over the years, of all investments in equipment between 1997 and 2012, the sums of money, the source of the funds, and other relevant information. Table 4.1 shows a condensed version, where the investments are summed up for every year and divided on category.

The accelerators – or storage rings, to be correct – at MAX-lab were built at rather different periods in the lab's development and growth, and hence with rather different framework conditions and logics. MAX I was, as noted in previous chapters, "home made," with materials bought from local suppliers: Already in 1973, when the first proposal for what eventually would become MAX I was submitted to the Atomic Sciences Research Council (Atomforskningsrådet, AFR), custom forged iron was ordered from Hellefors Jernverk, to be used when building two bending magnets.[468] The iron and the steel used in MAX I had been refined by Plannja, a subsidiary of the Swedish state-owned company Svenska Stål (Swedish Steel), for use in consumer products like refridgerators and kitchen stoves, and MAX-lab allegedly got to buy the needed quantities cheaply, which later led CERN to want to order iron from the same manufacturer. The thin iron sheets were delivered to Lomma Metalltryckeri AB nearby Lund, where they were punched out and transported to the mechanical workshop at the Department of Physics at Lund University, where they were laminated with a mangle previously used to press clothes.[469] Also the power supply system was home made, and had to be replaced by more stable devices built by Danfysik, a Danish company specialized in particle accelerator technology and other high tech equipment for scientific use, some years later.[470]

The importance of the personal networks built up around the accelerator constructors at MAX-lab during this time seems to have been instrumental in later work, with MAX II and MAX III. Chief accelerator constructor at MAX-lab Mikael Eriksson emphasizes how knowing people and knowing their competences and their character, their track record and ability to deliver, was far more important than the formalities of a tender and procurement process. Such personale networks were built and developed with the ambition to create win-win situations for the lab and the external partners.[471] The experiences from building MAX I was translated into a competence that also proved very valuable when procuring commercial products that were cheap but of high quality, for the MAX II and III machines.

For MAX II, the strategy to keep costs down seems to have been to procure complete sections of the ring, including magnets, tripods and vacuum chambers from single vendors, in order to cut down on the very expensive and time-consuming element of

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[468] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 27.

[469] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 121.

[470] MAX-lab Activity Report 1992: 27.

[471] Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

accelerator construction that usually goes under the name "assembly".[472] After the ususal bidding process, the Uppsala-based accelerator construction company Scanditronix emerged as the winner.[473] The relationship between MAX-lab and Scanditronix will be analyzed in greater detail under a separate headline below. Here, we can note that whole ring sections, including vacuum system, magnets, power supplies, were delivered by Scanditronix on a single contract, but with subcontractors for magnets (Goudsmit), power supplies (Danfysik) and other details, whereas some additional parts of the system were manufactured locally at MAX-lab.[474]

The superconducting wiggler was analyzed in section 3.3 and is a good example of a technology that has been invented at MAX-lab and then "transferred," both elsewhere and to new contexts, so to speak, within the lab; when enabling new scientific areas to be explored. Another major innovation of MAX-lab is of course the Multi Bend Acromat, discussed in the same section.

The mechanical equipment for the MAX II project was purchased at a number of mechanical workshops, locally and nationally, where Ohlssons Mekaniska stand out (see section 4.2.3 below), but where all were well-known by Scanditronix for their reliability. For the radiofrequency system, the radio station in nearby village Hörby was used, who could deliver these components at a much lower price than what systems custom-built for accelerators typically cost.[475] Generally, it seems, most of the procurement contracts for both MAX I and MAX II stayed in the region and within Sweden.

Insertion devices are manufactured separately from the storage rings where they are used. MAX I had two insertion device beamlines, both built by the Finnish governmental research institute VTT in Espoo. Four insertion devices were ordered and built in parallel with the construction of MAX II, three undulators and one wiggler, all built by VTT. Two MAX wigglers were built inhouse (see section 3.3), and three undulators, one from ADC (in Ithaca, New York, United States; not to be confused with ADC Telecommunications in Minnesota) and one built inhouse, were also inserted into the ring. At MAX III, two insertion devices were used, both of which were manufactured by ADC. The main suppliers of equipment to the beamlines and experimental stations at MAX-lab have been Danfysik, Zeiss, Elmitec, Newport,

[472] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 213-214. Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

[473] MAX-lab Activity Report 1991: 39.

[474] MAX-lab Activity Report 1992: 29.

[475] Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

Oxford Instruments, MARresearch, BESTEC, Bruker, and of course Scienta (see next section).[476]

4.2.1 The Scienta SES-200

The history of the three-party collaboration between the Uppsala-based company Scienta, the physics department at Uppsala University, and MAX-lab is an intriguing episode with many important lessons to be learned about innovation and technological development in the context of forefront instrument-intensive natural science research. The analyzer that was the result of this collaboration, the *Scienta SES-200*, has become standard in the world of synchrotron radiation – "all labs that have a soft x-ray beamline has the Scienta SES-200 analyzer."[477] In terms of impact of MAX-lab, it is likely one of the most tangible examples, where also clear commercial relevance can be seen.

In the mid-1980s the Uppsala-based instrumentation manufacturer Scienta had developed an analyzer (the device necessary to record data from spectroscopic experimentation) in collaboration with the group around physics professor and Nobel laureate Kai Siegbahn at Uppsala University. The device bore the name ESKA-300 and was a "monster," a very big piece of equipment that was optimized to the limits and extremely advanced, but way too big to be practical in lab settings – to try to fit it onto a beamline of MAX I would be practically impossible – and also very expensive.[478]

In the late phases of MAX I construction, when beamlines were under planning and design, the idea came up to try to build a downscaled version of the analyzer that would be possible to mount on the future beamline 22 at MAX-lab. The idea, pushed by Uppsala physicists and pioneer MAX-lab users and instrument builders Nils Mårtensson and Svante Svensson, was taken to Scienta and led to an agreement where instrument maker of the Uppsala physics department Jan-Olov Forsell would get the blueprints of the ESCA-300 and design a smaller version, optimized for use at synchrotron radiation labs. Scienta would get the new blueprints back in return for giving the first copy of the instrument to the university. "This way, we [Scienta] avoided the costs for developing the instrument by providing the original blueprints, and we got back a new design."[479]

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[476] Ralf Nyholm, compilation of material regarding beamlines at MAX-lab, received by email on 24 January 2017. Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

[477] Ralf Nyholm, interviewed by Olof Hallonsten and Oskar Christensson, Lund 15 November 2016.

[478] Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016. Anders Stenborg, interviewed by Oskar Christensson, on telephone 9 January 2017. Björn Wannberg interviewed by Oskar Christensson, on telephone 10 January 2017.

[479] Anders Stenborg, interviewed by Oskar Christensson, on telephone 9 January 2017.

Meanwhile, beamline 22 at MAX-lab was being planned, and the monochromator used for the beamline was specially designed to fit with the performance of the downscaled Scienta analyzer, and as part of the beamline construction, a kind of prototype to the SES-200 was custom-built to fit beamline 22.[480]

Scienta was able to manufacture several copies of the SES-200 and sell to synchrotron radiation facilities all over the world,[481] and continued to be a successful supplier of instrumentation for synchrotron radiation facilities as well as other lab equipment. Mergers with firms called Generators, Omicron and VG ensured its long-term renewal and successes,[482] and the company is identified as having had "a leading role in commercial synchrotron instrumentation for more than two decades."[483] The SES-200 became a kind of industry standard and other companies made their own similar devices;[484] at MAX II, all spectroscopy beamlines have varieties of the SES-200, and also at MAX III, Scienta analyzers were present.[485]

Three things are especially noteworthy in the story. First, it seems the symbiotic relationship between MAX-lab and the Uppsala physics department (described in section 3.4.1) was what made the difference for Scienta in this process; this axis between the instrument tradition in Uppsala and the buildup of MAX I in Lund was "decisive" for the success of the SES-200, and indeed also for the whole company – "With the monster they had before [the ESKA-300], Scienta would never have survived."[486] The symbiosis has continued: many people who work at VG-Scienta today are former doctoral students and postdocs of the Uppsala physics department who have done experimental work at MAX-lab.[487]

Second, the marketing of the SES-200 seems to have been taken care of most of all by the publication that described the device, published in 1994,[488] and to date (as of December 2016, as recorded in WoS) have been cited 168 times, spread rather evenly over the years but with some peaks in 2001 and 2015,[489] and by the results produced at beamline 22 on MAX I (a "truly revolutionary" beamline, see section 3.4), and later

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480 Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

481 Anders Stenborg, interviewed by Oskar Christensson, on telephone 9 January 2017.

482 Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

483 "Report from the review of the MAX laboratory, Lund, May 2009". Swedish Research Council report 5:2010. p 18

484 Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

485 Oscar Tjernberg, interviewed by Oskar Christensson, 13 December 2016.

486 Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

487 Näringslivets förväntade nytta av MAX IV. Report, Ramböll Management, 2010, p 12

488 Mårtensson N, Baltzer P, Brühwiler PA, Forsell J-O, Nilsson A, Stenborg A, and Wannberg B, "A very high resolution electron spectrometer," *Journal of Electron Spectroscopy and Related Phenomena* 70 (1994) 117-128.

489 Web of Science database search (apps.webofknowledge.com) on 21 December 2016.

results from research done at MAX-lab. Also here, the developing symbiosis is obvious: When Scienta marketed the SES-200, they also promoted the results of the Uppsala physics department and MAX-lab, and when these results were published, they helped in promoting the SES-200.[490]

Third, and most interesting of all, is the fact that no patents were ever sought for the SES-200. This was a deliberate choice:

> "We decided that we would not patent it, because that would only mean a lot of work to describe every detail, and then a lot of work to fight infringements. Instead, we published as much as we could, so that no one else could patent it either, and we trusted that the knowhow we had would continue to give us and Scienta competitive advantage. Plus, the publication gave us an edge. This is important: In terms of academic qualifications, patents are important today and I have no patents at all, but I have contributed to something with great impact. In the long run, others have entered and built their varieties, but this has gained the whole field and also Scienta, who have been able to sell even more of their products due to an elevated interest. Our role is to push science forward, so we should not lock things in by patenting."[491]

4.2.2 Scanditronix

Another company that developed a symbiotic relationship with MAX-lab, and where the complete absence of patents in favor of competence building and inhouse knowhow was as vivid, was Scanditronix, a commercial manufacturer of particle accelerators based in Uppsala. The company was formed in 1965 and went bankrupt in 1995. Its main products were accelerators for the national accelerator-based facilities, and for healthcare applications.[492]

The accelerator physics group at MAX-lab came in contact with Scanditronix already in the 1970s, and a collaboration was formed that remained an essential part of the activities of Scanditronix for two decades and produced the MAX II ring, among many other things. The accelerator physicists at MAX-lab did consultancy work for Scanditronix with raised crucial funds for the lab[493] and added crucial competence to

[490] Anders Stenborg, interviewed by Oskar Christensson, on telephone 9 January 2017. Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

[491] Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016.

[492] Bengt Anderberg, "Scanditronix och MAX," document received by email from Bengt Anderberg on 22 December 2016.

[493] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p16. Mikael Eriksson interviewed 2016

the company's R&D – "We realized, early on, that Mikael [Eriksson] was very skilled, and we trusted him."[494]

The first collaborative project was to deliver an injector to the synchrotron radiation facility BESSY in Berlin in the late 1970s, a project where the involvement of Mikael Eriksson and Lars-Johan Lindgren of MAX-lab proved crucial. Later projects in the 1980s involved an accelerator for hospital use in Umeå and a synchrotron radiation facility in Taiwan.[495]

In these early days, it seems the collaboration was truly symbiotic: People involved in Scanditronix at the time claim that neither the Berlin or the Taiwan projects would have been possible without the involvement of the MAX-lab group,[496] and Mikael Eriksson speaks of crucial personal contacts established during this time, that enabled him and MAX-lab to procure high-end components for MAX II, at a relatively low price, in the 1990s.[497]

The 1989 international evaluation of the MAX II proposal notes the relationship between MAX-lab and Scanditronix and highlights their "close collaboration" with "great advantages for both sides" as very promising for the completion of the project.[498] Consequently, unsurprisingly, it was Scanditronix that got the order to deliver the MAX II ring – quite simply, the procurement process followed all regulations and the order went to the best bidder, which was Scanditronix because of the competitive edge it had developed on basis of a long relationship with MAX-lab.

At the end of the collaboration on MAX II, Scanditronix went bankrupt, however with no damage incurred for MAX-lab.[499] Key people at Scanditronix formed the company AMACC, "a very small firm but with an extraordinary level of competence,"[500] which was involved in both the construction of the new injector system at MAX-lab in the early 2000s, and the MAX III ring, and later the construction of MAX IV. Key people from Scanditronix and AMACC have also later been employed at MAX-lab/MAX IV as part of the lab's expansion.[501]

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494 Bengt Anderberg, interviewed by Oskar Christensson, Uppsala 13 December 2016.

495 B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 116n92.

496 Jonas Modéer, interviewed by Oskar Christensson, Uppsala 13 December 2016.

497 Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

498 "International Evaluation of the MAX II Project", Swedish Natural Science Research Council 1989. p 12

499 Bengt Anderberg, "Scanditronix och MAX," document received by email from Bengt Anderberg on 22 December 2016.

500 Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

501 Bengt Anderberg, "Scanditronix och MAX," document received by email from Bengt Anderberg on 22 December 2016.

Already in the 1970s, Scanditronix benefited greatly from the collaboration with MAX-lab, since their core competence lied in the manufacturing of the advanced technological components of accelerators but not in the visionary scientific work to renew accelerator designs. “When building accelerators at the forefront of scientific and technological development, there are no reference facilities, and therefore Scanditronix became completely dependent on the physics we provided. It has to be edgy, realizable, and not too expensive. That’s where we made the biggest impact.”[502] The picture is confirmed by former Scanditronix employees: “There was a lot of competence input from MAX-lab to Scanditronics.”[503] “Without MAX-lab, we would not have been able to stay in the business.”[504]

Interestingly, like in the case of the Scienta SES-200 analyzer, there were no patents but a complete reliance on the buildup of knowhow and competence, which ultimately goes back to an academic attitude towards science and technology development: “We publish, we keep things open. If we didn’t have this attitude I think technology development in this field would be slowed down dramatically.”[505] And Scanditronix seems, at least in the long run, have benefited from this – although it went bankrupt, the competence survived and has been very competitive. AMACC is still in business. Scanditronix Magnet, a subsidiary formed in 1980, survived the bankruptcy of 1995 and is still in business, delivering magnet technology for particle accelerators on a global scale.

4.2.3 Erik Olssons Mekaniska

The magnet technology of the MAX accelerators is an important example of technological development at the lab, undertaken in collaboration with Scanditronix. But the tripods for the magnets of the MAX II ring is an innovation process of a different type, where the precision and need to keep costs down led to the development of an unusual partnership between MAX-lab and local mechanical engineering manufacturer Erik Olssons Mekaniska in the small village of Tollarp, some 50 km north-east of Lund.

It was the precision of the equipment in the mechanical engineering technology industry that attracted the interest of MAX-lab. The established method for building tripods for magnets in accelerators abroad was very costly, as it allowed continuous adjustments of the magnet blocks, and the accelerator group at MAX-lab toyed with the idea of instead constructing magnet tripods with a precision high enough from the

[502] Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

[503] Bengt Anderberg, interviewed by Oskar Christensson, Uppsala 13 December 2016.

[504] Jonas Modéer, interviewed by Oskar Christensson, Uppsala 13 December 2016.

[505] Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

beginning, which would dramatically reduce costs. Highly unconventional, the method would require the use of numerically steered machines of the type typically available in the mechanical engineering technology industry, and through Scanditronix, MAX-lab got in touch with Erik Olssons Mekaniska. Quite evidently, the plan entailed great risk, but the group trusted its competence and went ahead. MAX-lab agreed to fund half of the equipment necessary to manufacture the tripods this way, and Erik Olssons Mekaniska got to keep it afterwards.[506]

Once the design and construction proved to work, when MAX II was successfully taken into operation, Erik Olssons Mekaniska got several new customers around the world. The exchange of competence and knowledge between MAX-lab and the firm is evident and has led to a long-term competitive advantage that the firm has exploited in several other customer relations.[507]

The magnet tripods for MAX IV, but also the Swiss Light Source (SLS) at Paul Scherrer Institute (PSI) in Villigen and the Diamond Light Source in Oxford, UK, have been manufactured by Olssons Mekaniska.[508]

4.3 Industrial use of MAX-lab

As noted in a previous section, the use of synchrotron radiation labs by industrial R&D units is one of the most important potential sources of industrial impact, but while there seems to be a general global growth trend in industrial use of the facilities, it remains at low levels. The potential competitive advantages of using synchrotron radiation should, in principle, be the same for commercial users as for academic ones, but it must also be borne in mind that industrial firms generally have other demands of operations reliability and also, naturally, do less of the fundamental research work that a large share of the application areas of synchrotron radiation supports.

At MAX-lab, as noted, direct commercial use never exceeded a few per cent of the total beamtime, but MAX-lab does probably also, just like all synchrotron radiation facilities, have a certain amount of unrecorded use by commercial firms, as part of collaborations with non-commercial users from e.g. academia and research institutes. Furthermore, as noted above, the data on commercial use should be used with care: a scheduled (and paid) shift of beamtime for a commercial firm does not guarantee any (economic) output, and commercialization of research results (in part) obtained at MAX-lab or a

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[506] Leif Thånell, interviewed by Oskar Christensson, Lund 18 January 2016. Mikael Eriksson, interviewed by Oskar Christensson, Lund 21 November 2016.

[507] "Näringslivets förväntade nytta av MAX IV." Report, Ramböll Management, 2010, p 12

[508] Erik Olssons Mekaniska, http://eomek.se (accessed 6 January 2017)

comparable laboratory elsewhere can just as well occur when the result was produced as part of non-commercial use.

The buildup of MAX II and the expansion that it brought included work to involve commercial partners in the lab. MAX-lab director (1991-1997) Ingolf Lindau was in contact with local pharmaceutical company Draco (eventually part of Astra and AstraZeneca) already in the early 1990s, when the first plans to extract hard x-rays from MAX II emerged.[509] In 1996, Astra and the Danish pharmaceutical company NovoNordisk both signed collaborative agreements with MAX-lab,[510] and in the same year the company MAX-lab Service AB was formed as a subsidiary of the Lund University holding company LUAB, with the purpose of facilitating contacts with industry and enabling an increase in the commercial use of the lab.[511] The company never really took off, although it reportedly facilitated some procurement of beamtime by industrial firms, and it was dismantled in the early 2000s.[512]

The background material for the 2002 evaluation of the Swedish national facilities gives a snapshot of the status of commercial use of MAX-lab in the early 2000s, reporting that synchrotron radiation "has become an important cornerstone for the research and development in modern industry, notably in biomedical and pharmaceutical industry" and that "a strong interest from industrial researchers to use MAX-lab" is seen. The material reports that "about 10% of the beamtime at beamline I711 is sold to commercial users," and communicates earnest expectations that both the I811 (the hard x-rays beamline for materials science) and the I911 (the crystallography beamline) will "attract new industrial users". Many industrially relevant projects were reportedly carried out in collaborations with academic user groups, among them projects with involvement from AGFA, Thin Film Electronics AB and Granges Aluminium AB.[513] The two pharmaceutical companies AstraZeneca and NovoNordisk stand out among commercial users of MAX-lab, and their involvement will be analyzed separately below.

Figure 4.1 shows the annual number of users of MAX-lab, as listed in the activity reports, with noted affiliation with a private company, divided on Swedish and foreign companies, and figure 4.2 shows the overall share of commercially affiliated users.

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509 Ingolf Lindau, interviewed by Olof Hallonsten, Lund 29 January 2007.

510 MAX-lab Activity Report 1996: 1.

511 MAX-lab Activity Report 1997: 15.

512 MAX-lab Activity Report 2000: 11. Peter Honeth, interviewed by Olof Hallonsten, Lund 9 June 2006. Nils Mårtensson, interviewed by Olof Hallonsten, Lund 29 March 2006.

513 MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p12

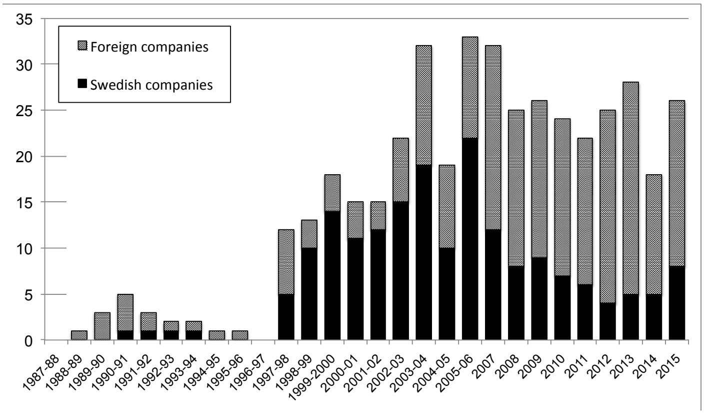

Figure 4.1:
Annual number of users of MAX-lab with noted affiliation with a private company, 1987-2015

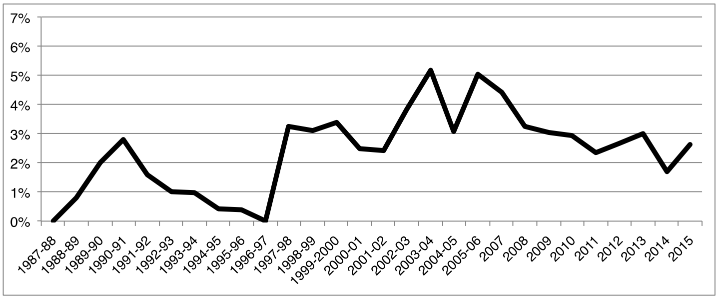

Figure 4.2:
Annual share of the total number of users of MAX-lab with noted affiliation with a private company, 1987-2015

In the years 2003-2011, for which detailed data is available, a total of 32 commercial firms were registered as using MAX-lab directly. For natural reasons, companies from Sweden and Denmark dominate in this group, but also South Africa, Germany, the Netherlands and the United Kingdom are represented. Most of all, commercial firms used the macromolecular crystallography facilities at beamline I711 and the experimental stations 2, 3 and 5 on beamline I911, but also the materials science beamline I811, the spectroscopy beamline I511, and the infrared spectroscopy beamline 73 are represented in the data, along with some minor use of beamlines I311, D1011, and the SAXS facility on station 4 of beamline I911. Table 4.2 shows a list of the firms, with number of visits and number of days of beamtime.[514]

[514] A "visit" here means that a user has registered arrival and departure at MAX-lab. Days of a visit means the number of days that passed between the arrival and departure and says nothing about the beamtime (in hours or eight-hour shifts) used, let alone the actual time spent doing experiments. The data was extracted from a document with all utilized beamtime 2003-2011, where user names, affiliation, country,

Table 4.2:
Commercial firms that used MAX-lab in 2003-2015

	Days	Visits
Novo Nordisk	795	444
Saromics Biostructures	295	224
Haldor Topsoe	232	47
Astra Zeneca	167	84
VG Scienta	153	18
Carlsberg	148	76
Sasol	67	12
EKA Chemicals	41	10
Biovitrum	18	8
LEO Pharma	12	5
Formox	11	2
Colloidal Resource Competence	10	9
Hagedorn Institute	9	5
IHP Microelectronics	9	1
Obducat	7	1
Johnson Matthey PLC	6	1
Active Biotech	4	1
Camurus	4	1
Novaled	4	1
Crystal Research	3	3
Novozymes	3	3
Spago Imaging	3	3
PSF biotech	3	2
Karo Bio	3	2
AAK	3	2
ABB	3	2
Arexis	3	1
Colloidal Resource	2	2
Bruker Optics	2	1
Medivir	2	1
NeuroSearch	2	1
Sandvik	2	1
Accenture	1	1
Bonesupport	1	1
Dannalab	1	1
Gambro	1	1
Tetra Pak	1	1
Speximo	1	1

Table 4.3 shows another measure of the share of *direct* industrial use of MAX-lab, namely visits (number of days) by users with industrial affiliation. The table shall be treated with some care, since roughly two-thirds of the total of 1406 days of visits by commercial users in the concerned years are at the I711 and I911 beamlines, where

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email address, arrival and departure dates, project leader, and beamline are detailed. Received directly from Ralf Nyholm on November 18, 2016.

beamtime slots are generally much shorter than at other beamlines. In table 4.4, individual beamlines are listed with the total number of days they were used by commercial users in the concerned years, and a percentage share.

Table 4.3:
Visits (number of days) by users, 2003-2015

	Total days	Of which commercial	%
2003	7989	177	2.22%
2004	5900	180	3.05%
2005	6276	197	3.14%
2006	6285	149	2.37%
2007	6503	162	2.49%
2008	6974	137	1.96%
2009	7778	168	2.16%
2010	8090	113	1.40%
2011	9093	123	1.35%
2012	8889	179	2.01%
2013	8458	262	3.09%
2014	8892	164	1.84%
2015	8855	131	1.48%
Total		2142	
Average			2.13%

Table 4.4:
Visits (number of days) by users affiliated with commercial firms, 2003-2015, divided on beamlines

Beamline	Days	Share
73	26	1.21%
D1011	13	0.61%
I311	9	0.42%
I511	142	6.63%
I711	327	15.27%
I811	503	23.48%
I911	1110	51.82%
D7	3	0.14%
I3	9	0.42%
Sum	2142	

In the final half a decade of operation of MAX-lab, the lab made an effort to improve its service to commercial users, probably in part in anticipation of the transition to MAX IV in 2016. This work refining the process by which companies get access, and also producing a "standardized commercial user agreement" and "an industry website" on them lab homepage, and engaging in deeper direct discussions with companies, "e.g. by visiting several major industrial fairs and conferences throughout the year including

Scanpack, the Packaging Materials Day, NextNano12 and AIMday," and inviting companies to the lab to discuss matters of industrial use with staff scientists.[515]

A service company called SARomics Biostructures was founded in 2006 to make use of the newly-built crystallization facility at MAX-lab to assist commercial users in structural determination of macromolecules.[516] The company made use of this facility, and the beamline I911, to deliver a full-scale service from crystallization over data taking to analysis.[517] While the company would clearly not have existed without MAX-lab, and it benefited greatly from the proximity to MAX-lab and the flexibility of access and scheduling atb MAX-lab (see the discussion on "low throughput" in section 3.5.1 and similar importance for other companies in the next section), it is also not a spinoff company in the classic sense, since it was formed not on basis of a research result or technology developed at MAX-lab but instead as a service company to increase the industrial use of MAX-lab in structural biology. The idea was formed on basis of the work done to build the crystallization facility, by former employees of the local biotech firm Active Biotech, which also became one of the company's first customers. The local biotech industry was otherwise not very interested, and it took some years before the company took off, through customer relations developed with companies abroad.[518]

4.3.1 AstraZeneca and NovoNordisk at Cassiopeia

The involvement of the pharmaceutival companies AstraZeneca and NovoNordisk at MAX-lab has been mentioned several times in this report. The expansion of the scientific program at MAX-lab in the 1990s, to structural biology, naturally arouse some interest also in the private sector, and when academic groups in Sweden and Denmark started using the crystallography beamline I711, word quite naturally spread in the community, also to the private sector. Discussions ensued on possible commercial investments in a new crystallographic beamline, and a number of people, with Anders Liljas and Sine Larsen as key figures, entered into concrete discussions. Anders Svensson, who had been involved in the construction of I711 had taken up a new position at NovoNordisk and became a natural discussant, and at AstraZeneca, future MAX IV life science director Tomas Lundqvist acted as contact person in the planning.[519]

515 The Annual Report of the MAX IV Laboratory to the Swedish Research Council 2012: 10-11.

516 Derek Logan, interviewed by Oskar Christensson, Lund 17 January 2016.

517 "Näringslivets förväntade nytta av MAX IV," report, Ramböll Management, 2010, p 14. "Swedish Research Council Evaluation of 11 national research infrastructures 2012: MAX IV project and MAX lab," p 8.

518 Derek Logan, interviewed by Oskar Christensson, Lund 17 January 2016.

519 Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

The proximity to MAX-lab became a key factor; AstraZeneca had (and has) a large structural chemistry department in Mölndal south of Gothenburg (a mere 300 km north of Lund) and NovoNordisk was even closer, with its headquarters in the Greater Copenhagen area right across Øresund. [520]

The investments of the two companies, amounting to SEK 6 million each, contributed to the construction of I911, and both of them got a special arrangement through which they had access to one full day of beamtime each on the beamline. Some of the investment was counted as advance payment for beamtime, but otherwise a (slightly subsidized) fee was charged also for this earmarked time. For NovoNordisk, the I911 became an important resource – "they used it all the time" – whereas AstraZeneca apparently never made full use of their investment but rather chose to utilize the mail order crystallography service of ESRF and other sources abroad, and their home lab equipment in Mölndal.[521] Interestingly, while the direct use of MAX-lab by NovoNordisk must have had scientific results with great relevance for the company, the fact that AstraZeneca did not use their share had another type of impact, which was discussed in a previous section (3.5.1) – the vacated beamtime contributed to the "low throughput" principle that had became important for competence building and the long-term development of the structural biology community at and around MAX-lab.

[520] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch3p12

[521] Thomas Ursby, interviewed by Oskar Christensson, Lund 22 November 2016.

5. Educational and public impact

5.1 When science and society meet at MAX-lab

Science and technology have, at least since the Enlightenment, been able to capture people's imagination and has taken an important role also in public debate and popular culture. When in the 20th century the role of science and technology in the advancement of societies and the improvement of life was intensified, it was also reflected in a growing public awareness and interest in science and technology.

The *promises* that scientific and technological progress give to the public has become increasingly important, and it has been argued that these promises and the expectations they carry have taken a key role also in political reform agendas and political decisionmaking, not least perhaps when it comes to investments in science and technology.[522] The European Spallation Source (ESS) facility is once again a telling example – not only did promises and expectations of economic benefits for the region blossom in the political rhetoric surrounding the Swedish campaign to win the hosting of the ESS, the facility was also presented as a core future resource for the solving of many, if not most, of society's grand challenges.[523]

Science captures the imagination of people, and research infrastructures such as MAX-lab, with their delicate and complex assemblages of high tech instrumentation, often become the focus of attention for those with a fascination and interest in scientific progress, as symbols for this progress and for the extreme technical and intellectual sophistication of later day scientific achievements. Therefore, although it did not exhibit a visitor's center in the traditional meaning, MAX-lab partly functioned as a science center where school classes and the interested general public could get a glimpse into the exciting world of materials science and life science and its use of synchrotron radiation.

The impact of science centers can be personal and individual, resulting in learning and changed attitudes on individual level as well as inspiration for future career choices,

[522] O Hallonsten, *Big Science Transformed: Science, politics and organization in Europe and the United States* (Palgrave Macmillan, 2016), pp 185ff.

[523] W Agrell, "Framing prospects and risk in the public promotion of ESS-Scandinavia," *Science and Public Policy* 39 (2012), 429-438.

besides personal enjoyment and satisfaction of curiosity. On aggregated level, the same type of impact can lead to increased awareness of scientific issues across broader layers of society, with major secondary and tertiary effects.[524]

Synchrotron radiation connects to a broad range of features of the everyday life of people, that also involve very specialized scientific and technological advancement, such as drug development and the development of new materials that enhance the performance of gadgets and gears like batteries, digital storage media and transport vehicles. Other areas of use of synchrotron radiation that doubtlessly appeal to the imagination and interest of the general public are the reading of the handwriting of Archimedes, hidden behind a medieval painting,[525] the analysis of wood pieces from the Vasa shipwreck that can help in the preservation and continuous exhibition of the ship,[526] and the uncovering of a previously unknown van Gogh painting.[527] These are examples of uses of synchrotron radiation that are clearly not part of the mainstream activities of labs like MAX-lab, but their potential is great for raising the awareness of how x-rays from synchrotron radiation sources can be used for new and unforeseen purposes. The many Nobel Prizes in chemistry awarded to breakthroughs done in part by the use of synchrotron radiation are clearly more in the mainstream column of scientific areas that benefit from the labs, and can similarly demonstrate the potential of scientific work with the use of exclusive lab resources (see section 2.2).

Synchrotron radiation has a potential “hands-on” quality, able to connect both to areas of science with relevance in people’s lives, and to the absolute forefront of many disciplines (physics, chemistry, biology) and cross-disciplinary fields (materials science, life science). They are physically tangible and manifestly real, and they serve primarily as resources for science of a wide array of disciplines of which the general public often has some prior awareness. The breadth is also fascinating in itself. Therefore, synchrotron radiation laboratories are excellent potential “gateways” to science for the interested general public.

MAX-lab has taken on this role in various ways though the years, providing a range of services to the general public and to students of different levels in order to help in the raising of their awareness about science and the stimulation of their interest. A 2012 evaluation noted that over the years, MAX-lab has made a tangible contribution to the awareness of science and education in the region, and that its international character,

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524 P-E Persson, “Community Impact of Science Centers: Is there Any?” Curator: The Museum Journal 43 (2002): 9-18.

525 R Netz and W Noel, *The Archimedes Codex. Revealing the Secrets of the World's Greatest Palimpsest* (Da Capo Press, 2007), pp 273-280.

526 M Sandström, F Jalilehvand, I Persson, U Gelius, P Frank and I Hall-Roth, ”Deterioration of the 17th century warship Vasa by internal formation of sulfuric acid,” *Nature* 415 (2002), 893-897.

527 J Dik, K Janssens, G Van Der Snickt, L van der Loeff, K Rickers and M Cotte, ”Visualization of a Lost Painting by Vincent van Gogh Using Synchrotron Radiation Based X-ray Fluorescence Elemental Mapping,” Analytical Chemistry, 80 (2008), 6436–6442.

with users from all continents, has helped promoting the view of Sweden as a knowledge-intensive country.[528]

In terms of science communication, the MAX-lab activity reports stand out for their detail and comprehensiveness, but also for their rather technical style and straightforward layout. The reports are clearly not written for the general public but mostly for the user community and other stakeholders. From 1987-2010, as noted in the introduction to this report, the annual activity reports contained rather detailed and specialized reports on the scientific work done with the help of MAX-lab's facilities. From 2011 and on, the activity report was replaced by a MAX IV highlights and activities report which contained more popular science-oriented descriptions of the science done at the lab. While this means that results and achievements are presented in a more accessible manner, which is good for the general reader (and the policymakers and administrators in charge of funding and organization of MAX IV), it also means that the detailed descriptions of the full range of scientific achievements at MAX-lab are lost to the interested layman, which represents an oversimplification and reduction. Besides the activity reports, the lab produced a number of different brochures, pamphlets and reports over the years, as well as specific information on the website oriented to the general public.[529]

A typical public outreach activity is the Open House Day, recurrently organized at and by MAX-lab as a means to interact with surrounding society, with guided tours and public seminars. A number of special tours of the laboratory have also been organized through the years, for example for Lund University board members, delegations from parliament and government, funding agencies, local and regional authorities, companies and associations, private charities, and labor unions.[530]

The *Teacher's Days* was a recurrent popular event, when teachers from high schools in Lund and surrounding towns visited the lab to learn about its scientific program. In 2010, the Teacher's Day spurred a follow-up three-day workshop for physics teachers, in collaboration with the National Centre for Education in Physics.[531] School classes regularly made study visits to the lab, mostly from high schools (since safety regulations prohibit visits on the laboratory floor by children under the age of 16), and high school students were also admitted to the lab within the programs for professional orientation (PRAO) in Swedish schools.[532]

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[528] "Swedish Research Council Evaluation of 11 national research infrastructures 2012: MAX IV project and MAX lab," p 8.

[529] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p17-18.

[530] Ibid., ch2p17-18.

[531] MAX-lab Activity Report 2009: 15

[532] MAX-lab, "Background Material for the Evaluation of the Swedish National Facilities 2002" (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p17-18.

Regarding press coverage, the general tendency is that there is very little attention in national and local press given to MAX-lab until in the early 2000s when the plans to localize the ESS to Lund brings MAX-lab into a spotlight of sorts,[533] and of course somewhat later, when the MAX IV plans emerge and slowly become reality.[534] Also the more typical kinds of local news coverage, where journalists visit the lab and make a feature of it, emerges only when MAX-lab gets attention as the prequel to, or birthplace of, the much more spectacular MAX IV. In the 1980s and 90s, press coverage of MAX-lab is scarce and only the most obvious aspects of the lab and its history makes it to the press – the inauguration of MAX I in 1987,[535] the inauguration of MAX II in 1995 which also attracted some nationwide attention,[536] the MAX II plans,[537] the 2002 decision to dramatically increase the MAX-lab operating budget,[538] and some events of local news character and of limited or no wider interest.[539] The brief encounter with x-ray lithography at MAX-lab, which followed an international trend that disappeared almost as fast as it came, got some sparse attention in a national news story in 1988.[540] Also the Cassiopeia project got some attention in 2001 for its unusual combination of academic and commercial investment.[541]

An important source of information for the interested layperson is of course the books by Bengt Forkman (cited throughout this report) from 2011 and 2016.

5.2 Education

Specifically on the side of education, MAX-lab's integration with Lund University has meant that its potential for rasing awareness and provoking the interest of students has been quite extensively utilized.

One of the high schools in Lund, Polhemsskolan, had a built-out collaboration with MAX-lab for several years, as part of the school's so-called "cutting edge education program" in physics. The collaboration was built through personal contacts but

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533 See e.g. "ESS ödesfråga för Öresundsregionen", Skånska Dagbladet 7 September 2004.

534 See e.g. "Anläggning för dryg miljard planeras i Lund", Sydsvenskan 12 May 2005.

535 "Synkrotronljus", TidningarnasTelegrambyrå 29 January 1987.

536 "Forskning i ljusets hastighet", Göteborgs-Posten 15 September 1995. "Kunglig glans vid invigningar i Skåne", Tidningarnas Telegrambyrå 15 September 1995.

537 "Andra MAX-labbet i Lund", TidningarnasTelegrambyrå 21 February 1992

538 "MAX-lab i Lund räddas i förslag", Sydsvenskan 3 October 2002

539 "Elfel vållade rökutveckling", Sydsvenskan 18 April 2005

540 "Gränsen för information på mikrochips ännu inte nådd", Tidningarnas Telegrambyrå 21 September 1988

541 "Labb i Lund får 12 miljoner till strålrör", Sydsvenskan 1 February 2001

developed into a fruitful project where MAX-lab contributed to the education in physics at the school by making its facilities available (mostly old and worn-out equipment) and engaging its staff in teaching.[542]

But the main impact on the education side has of course been achieved through the full integration of the lab in Lund University. Until 1994, MAX-lab was part of the Department of Physics within the Faculty of Mathematics and Natural Sciences at Lund University, and after 1994, it remained part of Lund University as a standalone organization separate from the ordinary faculty structure and divisions. Key staff, including not least the accelerator physics group and the coordinators for synchrotron radiation and nuclear physics, remained part of the faculty of Lund University and retained duties in teaching and supervision throughout their tenures at MAX-lab.

In 1996, as MAX II was about to start user operation, an undergraduate level course in fundamental accelerator technology was launched at MAX-lab but within the cycle of undergraduate education at the faculty of natural sciences at Lund University, made possible by the several joint positions between the faculty and MAX-lab. Later, courses on advanced level were launched, that still exist today. Several synchrotron radiation labs worldwide have allegedly followed suit and give basic and advanced level courses in accelerator technology in collaboration with neighboring universities. In the last few years of operation, students of physics and other fields at Lund University could take courses in accelerator physics, synchrotron radiation instrumentation, and many of the areas of application where instrumentation at MAX-lab was used in practical elements of the teaching. The hands-on experience and knowledge possible to convey through this arrangement, completely dependent on the close and productive relationship between MAX-lab and its host university, should not be underestimated. In addition to this, many students from other universities in Sweden and the Nordic countries have made study visits at MAX-lab over the years.[543]

A specific course offered part time and with teaching in the evening, was the "Frontline of science" course which was open to all undergraduate students at the faculty of science and where scientists from many different fields were invited to give lectures about their research, partly with focus on the science done at MAX-lab and with the articulated ambition of raising the awareness and interest around the lab, and partly with a general natural sciences focus.[544] Several undergraduate programs in a variety of fields at other

[542] Kurt Hansen, interviewed by Oskar Christensson, 22 November 2016

[543] S Werin, "Teaching at MAX-lab" in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 315-316, on p 315

[544] Bent Schröder, interviewed by Oskar Christensson, Lund 22 November 2016

Swedish universities have also used MAX-lab for visits and thematic lectures and course modules on synchrotron radiation and its use in various disciplines.[545]

The role of MAX-lab in doctoral education has been discussed in other parts of the report, and appendix 2 contains a list of all doctoral theses listed in the activity reports as building on research done at MAX-lab. Several courses on graduate/doctoral level have been offered throughout the years to students from all over Sweden, in accelerator technology and synchrotron radiation instrumentation, and in advanced instrument handling.[546]

5.2.1 The Summer School in Synchrotron Radiation Research

An educational activity in and around MAX-lab with particular strong impact is the Summer School in synchrotron radiation research, organized every year from 1985 and until 2014. The initiative was taken by pioneer MAX-lab user Per-Olof Nilsson, who saw an opportunity to establish and cultivate a user community on long term through the summer school, by having it focus mostly on different uses of synchrotron radiation, with very practical hands-on elements, but also involving teaching on the lab as a whole, including basic accelerator technology, which was thought to increase awareness and devotion in the user community. The school was soon taken over by Svante Svensson of Uppsala University, and throughout the whole time, Sverker Werin acted as the contact person at MAX-lab.[547]

The school was funded by the Nordic Research Academy every year and admitted 30-40 students from all over the Nordic countries each time, mostly students one or two years into their doctoral education, from departments with recurrent MAX-lab users. But also groups planning to start using MAX-lab sent students to the school in order to learn more about the potentials of the techniques.[548] In the early 2000s, the school was expanded to cover larger parts of Europe.[549]

The extensive international network of people around MAX-lab, discussed in section 3.7, was often used to invite distinguished scientists as lecturers on the school, which

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545 MAX-lab, “Background Material for the Evaluation of the Swedish National Facilities 2002” (Swedish Research Council, dnr 347-2001-6180, 2002), ch2p14

546 Ibid., ch2p13-14.

547 Svante Svensson, interviewed by Oskar Christensson, Uppsala 2 December 2016. Sverker Werin, interviewed by Oskar Christensson, Lund 21 November 2016.

548 S Svensson, ”Nordic Research Schools in Synchrotron Radiation Science” in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 317-318, on p 317. Sverker Werin, interviewed by Oskar Christensson, Lund 21 November 2016.

549 Svante Svensson, interviewed by Oskar Christensson, Uppsala 2 December 2016

meant that a high quality was maintained over the years.[550] A unique feature of the school was the direct access to MAX-lab; when the school was once started, the lab was small enough to allow the summer school to do experimental laboratory work directly on the beamlines. Another thing that distinguished the school in international perspective was the holistic view of the lab that the school embodied; elements of accelerator technology and operation was included, and theoretical class-room teaching was combined with practical hands-on experience on the laboratory floor. As the MAX-lab scientific program expanded its disciplinary range, more and more fields were represented among the students but the school retained its inclusive and holistic grip on synchrotron radiation, involving teaching on all fields of application as well as instrument development and maintenance.[551]

In the example of the summer school is found a feedback loop that is typical for MAX-lab, and that is found repeatedly in the material and the analysis of impact, and discussed especially in section 3.7: While itself a great example of impact of MAX-lab in the area of education and competence building, the summer school also had an important function in building the user community and the whole ecosystem around the lab. The networks that were formed among and between students of the summer school have been identified as "very important" for the lab and its user community on long term, and a high proportion of the participants in the summer school have gone on to take up important academic positions in their respective countries, and remained close to MAX-lab in various capacities, including committee work and as devoted users. The lab has also, to some extent, been able to use the school as a talent pool for recruitments.[552] Many people identified by name in this report, including Ergo Nömmiste, Marco Kirm, Kajsa Uvdal, and Oscar Tjernberg are former participants.[553]

The summer school has had a few offsprings, especially at the ASTRID facility in Denmark, "with slightly different focus,"[554] but also specialized equivalents of the school locally, for example in crystallography in 2007 and 2009, also with distinguished international guests as teachers, and funding from companies AstraZeneca and NovoNordisk,[555] and a summer course on new methods of using synchrotron radiation

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[550] S Svensson, "Nordic Research Schools in Synchrotron Radiation Science" in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 317-318, on p 317.

[551] Svante Svensson, interviewed by Oskar Christensson, Uppsala 2 December 2016

[552] Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016. S Svensson, "Nordic Research Schools in Synchrotron Radiation Science" in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 317-318, on p 317.

[553] Svante Svensson, interviewed by Oskar Christensson, Uppsala 2 December 2016. Sverker Werin, intervieweded by Oskar Christensson, Lund 21 November 2016

[554] S Svensson, "Nordic Research Schools in Synchrotron Radiation Science" in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), pp 317-318, on p 317.

[555] MAX-lab Activity Report 2007, p 15; 2009, p 15

for surface physics, open to Nordic and Baltic doctoral students and held in Pühajärve, Estonia and at MAX-lab in 2009.[556]

[556] MAX-lab Activity Report 2009, p 14

6. Lund University and MAX-lab

6.1 A well integrated lab

A striking feature of almost all evaluations that have been made of the scientific program at MAX-lab, and the lab's expansion projects, is the strong support that the lab seems to always have enjoyed from its host, Lund University. The support "was, is, and will be vital for the success of MAX-lab"[557] – "one could hardly ask for a more positive relationship between a laboratory and its host university."[558]

MAX-lab has had the blessing of the university rectors from the very beginning; already Nils Stjernqvist, rector 1980-1983, is acknowledged for his support to the lab in its early buildup phase.[559] Also rector Håkan Westling (in office 1983-1992) was very supportive of the lab, and all his successors have remained so: The committee of the 2002 evaluation of the Swedish national facilities was reportedly very impressed by the fact that then-vice chancellor Boel Flodgren actively participated in the meeting between the committee and representatives of the lab that was held as part of the evaluation.[560] Göran Bexell (in office 2003-2008), and the university's administrative director between 1990 and 2006, Peter Honeth, also deserve mentioning for their active support of MAX-lab.[561]

The relationship between MAX-lab and Lund University is probably most accurately described as a *symbiosis*, and in this sense it is a kind of microcosmos of the symbiosis between on one hand research infrastructures and instrumentation, and on the other hand their use by scientists and students, as described especially in section 2.1. Ideally, the relationship between a facility like MAX-lab and its host university is a win-win relationship where world class instruments are developed and made available to university researchers (benefiting not least from the geographical proximity of the lab) and the whole capacity and talent pool, not least of students, is made available to the

[557] "International Evaluation of Swedish National Facilities, April 1997." Swedish Natural Science Research Council. p 8

[558] "Swedish National Facilities," review report, Swedish Research Council, 2002, p 41

[559] Nils Stjernqvist obituary, Sydsvenska Dagbladet 22 September 2000.

[560] Gunnar Öquist, interviewed by Olof Hallonsten, Umeå 11 January 2017.

[561] Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

lab. The continuous throughput of students and the intellectual renewal that it secures in the academic setting is at the core of the role of universities in society, and universities are therefore unique loci for scientific progress. Research infrastructures, with the potential of providing unique opportunities for experimental work in a wide range of sciences, fills a different role on basis of which symbiotic relationships with academic environments can be established and developed. It is quite clear that MAX-lab has obtained exactly this type of position in Swedish and Nordic science, but also locally in Lund.[562]

While it is simple to point out this symbiosis, it is much more difficult to identify impacts from MAX-lab on the university. The key purpose of this chapter is to describe the symbiosis rather than trying to prove how exactly the existence of MAX-lab has produced favorable outcomes for Lund University, although attempts at the latter is also done, in the next section. Clearly, MAX-lab has contributed to putting Lund University "on the map" and meant a concentration of talent and competence in some specific areas, including of course accelerator development, instrumentation for synchrotron radiation, and it use.[563]

In the general discussion on scientific impact in chapter 3, it was mentioned that MAX-lab provided a locus for internationalization of Swedish research during a time when processes of internationalization and globalization took off for real. The same can be said about Lund University, where some argue MAX-lab opened up core areas of the university to international influences which strengthened their competitiveness in the long run.[564]

6.2 Research activities at Lund University directly related to MAX-lab

The importance of MAX-lab for Lund University can of course be illustrated straightforwardly, with some numbers. In figure 6.1, the annual number of users of MAX-lab affiliated with Lund University over the years is displayed, with the internal MAX-lab users as well as the nuclear physics and accelerator physics groups singled out. The grey parts of the stacks show the users from the synchrotron radiation group (after 1989 the Division of Synchrotron Radiation Physics at the Department of Physics) and

562 "International Evaluation of Swedish National Facilities, April 1997." Swedish Natural Science Research Council. p 8. "Swedish National Facilities," review report, Swedish Research Council, 2002, p 41.

563 Peter Honeth, interviewed by Olof Hallonsten, Lund 9 June 2006. Sture Forsén, interviewed by Olof Hallonsten, Lund 30 November 2016.

564 Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

the black parts of the stacks show the number of users from other departments at Lund University, giving an overall image of the growth in use at the university. In the same period, the number of Lund University departments represented in the local user community doubled, from 10 to 21, although this is a figure with more caveats given the many reorganizations of department and faculty structures at the university in this 22-year period.[565]

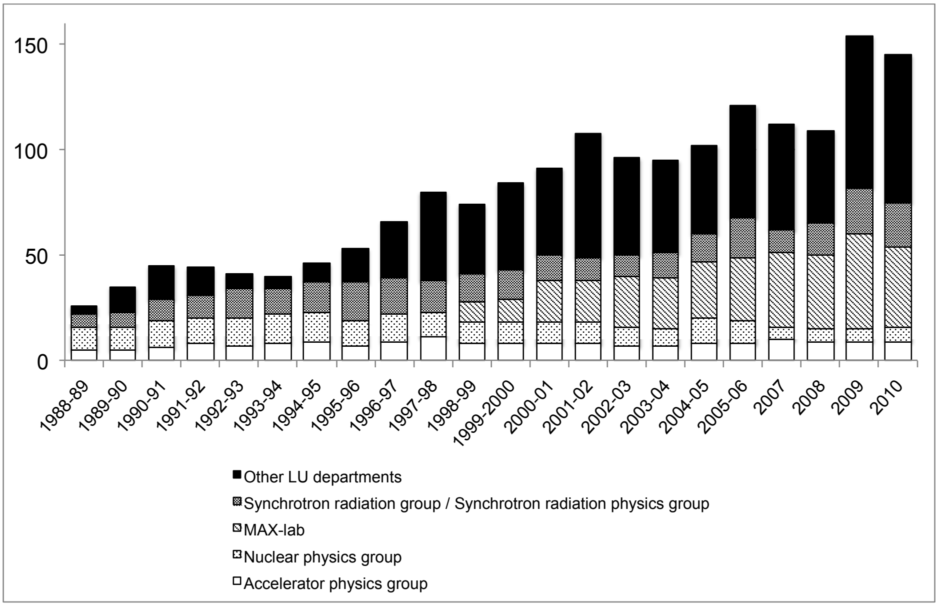

Figure 6.1:
Annual number of MAX-lab users affiliated with Lund University, 1988-2010[566]

The 1997 evaluation of MAX-lab by NFR judged the share of Lund University scientists among the users as "substantial but not dominating."[567] Figure 6.2 shows the share of users affiliated with Lund University and the share of users affiliated with Lund University but not MAX-lab, over the years. Clearly, MAX-lab's own share of the user community decreased over time, and while the increase in users from Lund University in 2008-10 is rather dramatic (figure 6.1) it was apparently matched by a similar increase in the overall number of users.

[565] As listed in the MAX-lab activity reports

[566] As listed in the MAX-lab activity reports

[567] "International Evaluation of Swedish National Facilities, April 1997." Swedish Natural Science Research Council. p 8

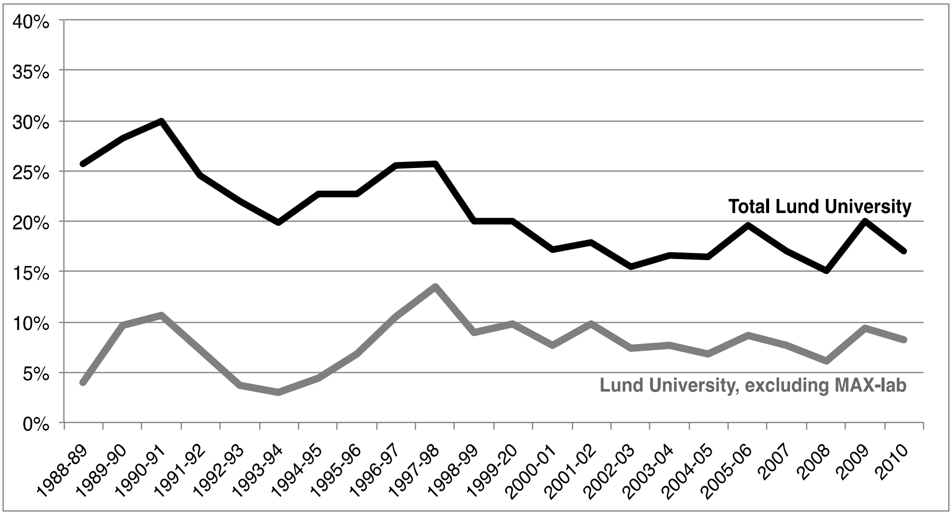

Figure 6.1:
Annual share of the number of MAX-lab users affiliated with Lund University, and with Lund University but not MAX-lab, 1988-2010[568]

The nuclear physics activities at MAX-lab was a continuation of one branch of nuclear physics at the Department of Physics at Lund University, that built and operated synchrotrons already in the 1950s and whose knowledge and competence in accelerator-based nuclear physics was the breeding ground for the whole MAX project (see section 2.4).[569] In 1976, a nuclear physics group existed as a separate unit within the Department of Physics (alongside solid state physics, atomic physics, electronics, and particle physics) which was a department shared by the faculties of engineering and science.[570] Bengt Forkman had become assistant professor of physics 1970, and became full professor of physics 1979 (and emeritus 1995),[571] and several of the future MAX-lab personnel had appointments at various parts of the Department of Physics at this time, including Leif Thånell, Bent Schrøder, Mikael Eriksson, Lillemor Persson, Bengt-Erik Wingren, and Werner Stiefler.[572] The nuclear physics group that had started to build the MAX machine and that would become its users was part of the Faculty of Science, separate from the Faculty of Engineering, and it was not until 1985 that this group was listed as affiliated with MAX-lab, rather than part of the Department of Physics, and singled out as distinct from the nuclear physics group of the Faculty of

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568 As listed in the MAX-lab activity reports

569 B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 56ff.

570 Lunds Universitets katalog 1976, pp 112, 114-115.

571 Data from the Swedish Government Register (Sveriges Statskalender) for the respective years

572 Södra Högskoleregionen Person- och Adresskatalog 1979, pp 233-238.

Engineering.[573] As noted in section 3.6, the local nuclear physics group at MAX-lab thrived throughout the whole history of the lab and remained separate from the nuclear physics activities at the Faculty of Engineering.[574]

The accelerator physics group (and later department) was always part of MAX-lab and inseparable from the construction and operation of the MAX machines, and it was originally born out of the nuclear physics activities, with Mikael Eriksson originally employed as research engineer at the Department of Physics and receiving his doctorate of technology (*Teknologie Doktor*) in 1976, formally at the KTH Royal Institute of Technology.[575] When in 1982 the chair of accelerator physics at KTH was vacated, Eriksson applied for the position. Ranked highest among the applicants, Eriksson got the appointment and was set to leave Lund and the MAX project.[576] Faced with this, the MAX-lab board and the Faculty of Science at Lund University acted quickly to create a chair position in accelerator physics in Lund, and appoint Mikael Eriksson to it. "This was one of the best decisions I have ever made in a university leadership position. […] We realized that if Mikael would disappear to Stockholm, the MAX project would be dead. We believed in MAX, and there was a national interest in it, that could help putting Lund on the map."[577] The creation of the professorship in accelerator physics was, quite simply, the means at the disposal of the university when it needed top secure the future of MAX-lab.

As noted in section 3.3, the accelerator physics group has led a healthy life at MAX-lab, producing excellent results and at least fifteen doctoral students over the years. The worldwide reputation of the group is remarkable and MAX IV is certainly a kind of crown of its achievements. From the perspective of the university, the accelerator physics group is clearly both a great asset and one of its most excellent research environments.[578]

When it comes to physics generally, it seems MAX-lab was not as integrated into the faculties of engineering and science, and its joint department of physics, in the early days. There are signs that the champions of other physics activities in Lund viewed MAX-lab with suspicion[579] (while of course also acknowledging its successes and its importance), but as noted repeatedly throughout this report, the user community had

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573 Södra Högskoleregionen Person- och Adresskatalog 1985-86, pp 41-42.

574 Lunds Universitet Person- och Adresskatalog 1999, pp 76, 79.

575 M Eriksson, *Studies on a 100 MeV Race-track Microtron/Pulse Stretcher System* (Diss., KTH Royal Institute of Technology Stockholm, 1976).

576 B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), p 119.

577 Bengt EY Svensson, interviewed by Olof Hallonsten, Lund 22 November 2016.

578 "RQ08 – a Quality Review of Research at Lund University 2007/08," Lund University 2008, pp 21, 351, 368.

579 Bengt EY Svensson, interviewed by Olof Hallonsten, Lund 22 November 2016.

little basis in Lund until roughly a decade into MAX-lab operation. In later years, collaborations with the Nanometer structure consortium and Lund Laser Center have created vital and highly productive alliances at the Department of Physics, whose full potential seems to be possible to exploit in the future, with MAX IV.[580]

The fact that MAX-lab had little or no user community at Lund University early on led university leadership to act, in the late 1980s, to build up a capacity in the realm. Anders Flodström had been appointed senior lecturer (docent) in synchrotron radiation research in 1981, a position he held until 1985 when replaced by Ralf Nyholm, but this position most of all entailed a coordinating role at MAX-lab, in the buildup of beamlines for MAX I and the mobilization of a user community.[581] In 1988, a professorship in synchrotron radiation physics was created at the university,[582] and in 1989, Ingolf Lindau was appointed professor of physics, especially synchrotron radiation research.[583] The division was founded simultaneously. In its first ten years, it was relatively small, probably in part due to the fact that its academic staff (and not least its professor and head, Ingolf Lindau), was heavily involved in the buildup of MAX II, but it is estimated that the division consisted of 17 people when Ingolf Lindau returned to Stanford University, in 1997.[584] In 2016, the division has 45 listed staff members, of which six are professors and 19 are doctoral students.[585] The collaborations across the university are many; with the Nanometer Structure Consortium, the Lund Laser Centre, Chemical Physics, and Combustion Physics.[586] For Lund University, the division of synchrotron radiation physics at the Department of Physics is one of the most visible impacts of MAX-lab, but also other activities at the Faculty of Science have clearly drawn major benefits from the existence of the lab in Lund.

A separate professorship of synchrotron radiation instrumentation, located to MAX-lab, was created in 1999, with Ralf Nyholm as first holder. The professorship was a way to complement the accelerator physics group and securte the long-term health and vigor of the development of instrumentation at MAX-lab.[587]

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[580] Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

[581] B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 29. MAX-lab Activity Report 1987, p 42.

[582] MAX-lab Activity Report 1988, p 1

[583] Data from the Swedish Government Register (Sveriges Statskalender) for the respective years

[584] I Lindau and S Ristinmaa Sörensen, "Synkrotronljuset från Lund: Hur lundafysiker lärde sig använda synkrotronljus på olika sätt," in B Forkman and K Holmin Verdozzi (eds.), Fysik i Lund – i tid och rum (Lund University, 2017), p 402.

[585] "Synchrotron Radiation Research, Staff," http://www.sljus.lu.se/staff-and-contact-information/ (accessed 8 February 2017)

[586] Stacey Sörensen, interviewed in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), p 210.

[587] Ralf Nyholm, interviewed by Olof Hallonsten, Lund 9 March 2006. MAX-lab Activity Report 1997, p 1.

Moving on to chemistry, it seems the groups involved in macromolecular crystallography at the Department of Chemistry of Lund University were swift in identifying the potential of having a synchrotron radiation facility as neighbor.[588] Anders Liljas had become professor of molecular biophysics in 1988, and mentions MAX-lab as a key reason for moving to Lund,[589] and the symbiosis developed between his group and the crystallography activities at MAX-lab have been emphasized in earlier sections (3.5 and 4.3.1).[590] In 1991, a division of "MAX-chemistry" ("MAX-kemi") was formed in order to make use of the experimental opportunities at MAX-lab, and while the division changed names to "chemical physics" in 1995, its activities have continued to focus on use of MAX-lab.[591]

A general but concrete assessment of the importance and impact of MAX-lab for Lund University can be made on basis of the 2008 comprehensive evaluation of all research at the university. The evaluation report has been cited in previous sections (2.5 and 3.3), especially its remarkable identification of physics as one of the "crown jewels" of the university, with MAX-lab explicitly mentioned as a key factor for this.[592] MAX-lab is mentioned at several instances, in connection with the highlighting of excellent research environments in physics which have MAX-lab in part to thank for their high performance and international acclaim, including the Lund Laser Centre, the Nanoscience Consortium, the Division of Atomic Physics, the Division of Solid State Physics, and the surface science group.[593] The same can be said about chemistry; the 2008 evaluation points out how "excellent" research is done in several groups not least in fields relating to the structure, function and dynamics of macromolecules with great use of the facilities at MAX-lab.[594]

The role of MAX-lab as a motor for progress, renewal and internationalization of science was discussed in section 3.7, and it is quite clear that a similar argument can be made with attention to the local context of Lund University, which MAX-lab clearly has fertilized by its constantly developing international orientation and participation at the forefront of several of the technologies and sciences of synchrotron radiation. MAX-lab has been identified as an

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588 Sture Forsén, interviewed by Olof Hallonsten, Lund 30 November 2016. Ingolf Lindau, interviewed by Olof Hallonsten, Lund 30 November 2016.

589 Anders Liljas, interviewed by Olof Hallonsten, Lund 10 November 2006.

590 "International Evaluation of Structural Biology, December 1999," Swedish Natural Science Research Council, p 41

591 Jesper Sjöström, *Kemicentrum vid Lunds Universitet: Perspektiv på organization och forskning vid Sveriges första storinstitution*, Lund University 2007, pp 163, 332.

592 "RQ08 – a Quality Review of Research at Lund University 2007/08," Lund University 2008, p 21

593 Ibid., p 351, 355, 365, 367.

594 Ibid., p 391

early example of a cross-disciplinary "meeting point" at the university, that also served as inspiration for future similar intersectional projects. At Lund University, MAX-lab has clearly been a source of inspiration in the work to break the old departmental/faculties structures and cultivate new cross-border initiatives with the potential of hosting and developing boundarybreaking research efforts across traditional disciplinary boundaries.[595]

Finally, an odd but relevant assessment of the value of MAX-lab to Lund University can be made by looking through the list of honorary doctors appointed at the Faculty of Science over the years. Several of these have had connections to MAX-lab and its buildup: Lennart Linder-Aronson (2002), Sine Larsen (2002), Arthur Bienenstock (2004), and Nils Mårtensson (2014).[596]

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595 Fredrik Melander, *Lokal forskningspolitik: Institutionell dynamik och organisatorisk omvandling vid Lunds universitet 1980-2005* (Lund University, 2006), pp 205, 213, 220.

596 Lund University Faculty of Science, Honorary Doctors, http://www.science.lu.se/research/honorary-doctors (accessed 26 November 2016).

7. The broader picture: Lessons from the history of MAX-lab

7.1 Growing Big Science in a small country

The gradual, evolutionary buildup of MAX-lab was highlighted already in the introduction to this study, and has been returned to repeatedly. From small-scale university project in the 1970s and 80s, over a great expansion of scientific breadth and size and scope of the user community, and to an internationally renowned user facility in the 2000s that closed in 2015 in order to move into the large, and in many respects world-leading, MAX IV in 2016, the history of MAX-lab is a truly remarkable slice of late modern history of science.

There are at least two complementary ways of viewing this history from an impact perspective: One is characterized by fascination and astonishement that this was at all possible, and the other is characterized by an itching feeling that suboptimality and inefficiency has plagued the lab and prevented many remarkable achievements. Previous studies have indeed communicated both views: MAX-lab is called “the marvelous light in Lund”, “the laboratory that was never intended to be”, and also “symptomatically Swedish”.

The ubiquity of the notes of funding shortage at MAX-lab in the 2002 facilities review poses the question to any critical reader if the tight budget and low level of funding perhaps inhibited MAX-lab and prevented it from realizing its full potential in terms of technological, scientific and human resources capabilities. This is a tricky question and there is likely no clear answer. A reasonable assessment of the topic will require counterfactual history-writing and analysis, and also bring in arguments and evidence from the economics of technological change and innovation, that discuss fundamental issues of whether necessity is the mother of invention; whether ingenuity stems from poverty; and so on.[597] Clear is that MAX-lab did not follow the typical pattern of buildup of a synchrotron radiation facility internationally – it was not funded in full by

[597] E.g. J Schumpeter, *Business cycles,* Vol. I (McGraw-Hill, 1939), esp p 85. C M Cipolla, *Before the industrial revolution: European society and economy, 1000-1700* (Routledge, 1980), p 181. J Mokyr, *The lever of riches. Technological creativity and economic progress* (Oxford University Press, 1990), p 85.

a governmental agency on basis of thorough scientific and technical reviews and political decision-making (including regional politics and interdepartmental bargaining, as is normally the case in e.g. the United States or the Federal Republic of Germany), but came into being in an evolutionary fashion that has led analysts and commentators to conclude that MAX-lab was never intended to be, let alone grow and become as successful as it did. Meanwhile, there is much to suggest that it was exactly the way in which it grew that provided for its success, since it meant an almost full freedom for the accelerator physics group to unleash its creativity and ingenuity; a scientific approach to infrastructure and instrument development that enabled an optimization of components and the lab as a whole in several steps, as work proceeded; and the deep involvement of users, which secured national and international legitimacy and also broadened the user base in a timely fashion.

An analysis of the history of MAX-lab from a science policy perspective has concluded that while MAX-lab was unique in Sweden, it embodied some core features of the Swedish science policy system, namely decentralization, indecision, and a notorious lack of ability to make strategic priorities. The argument is that exactly because MAX-lab was the result of its champions' clever manuevering through a science policy system that was not directly hostile but also not very favorable to initiatives of the kind, rather than a result of deliberate and coherent policymaking and planning, successes were achieved at MAX-lab that lack counterparts abroad.[598]

On the one hand, the amount of money spent is astonishingly small. In section 4.2, the replacement cost of MAX-lab, at the end of its operation in 2015, was estimated at some 800 million SEK. Adding an estimation of the accumulated operations costs of the facility until its closing in 2015, the total cost of MAX-lab in the years covered by this report (1987-2015) would amount to something in tbe vicinity of 2 billion SEK, which for comparison, is less than half than the total cost of the Swedish membership in CERN in the same period.[599]

On the other hand, large chunks of this sum were invested by public and private funders throughout the years with little or no coordination; for example, the government granted 62 million SEK for the building for MAX II in 1991 without any guarantee that the building would have a tenant, and the FRN granted 40 million SEK the year after for the MAX II storage ring without any guarantee that it would be equipped with any beamlines. Several times during the buildup of MAX II, and after, has the lab been

[598] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011), 179-215, on p 181.

[599] Sweden's membership in CERN was around 100 million SEK in the late 1980s, but grew gradually to exceed 200 million SEK in 2015. An average of 150 million SEK annually yields a total cost over the concerned years of more than 4 billion SEK.

threatened by lack of funds that stem, in part, from this incoherence in the financing model.[600]

The interesting lesson of this is of course that the money invested in MAX-lab, with little or no central coordination of the efforts, did amount to a rather significant strategic commitment of Swedish science and science policy to synchrotron radiation. Although MAX-lab cost significantly less than e.g. the CERN membership, a domestic commitment is arguably a strategic choice of greater magnitude: MAX-lab was entirely designed, constructed, and built domestically (though with great involvement of international expertise, through the extensive networks built and maintained by MAX-lab staff and users), which produced a significant mobilization of competence. In addition, not to forget, a national scientific user base was built, maintained and cultivated by priorities in the science policy and funding system; although never a coherent policy or strategy, this is what the investments in MAX-lab brought to Swedish science.[601] Today, materials science is an area of strength of Swedish science, and the study of materials (including biomaterials) by the use of synchrotron radiation and neutrons is quite evidently a strategic priority of Swedish science policy. How else should the current scenery in the north east of Lund, with MAX IV opening its doors to scientific use, and the ESS construction process entering the phase of installation of accelerator components and instrumentation, at the time of writing this report?

On basis of all this, it is tempting to suggest not only that the pursued path of MAX-lab was the only way in which it could have been built at all, and that once it was built, it paved the way for another regime of science policy and funding, where pooling of resources around strategically important projects and areas is more accepted and a common ingredient. There are some things to suggest that this is what happened: While Sweden had some large projects also before MAX-lab, and certainly participated in most international scientific collaborations, the situation is quite different today. Not only have both MAX IV and ESS come into being in Lund; the Science for Life Laboratory (SciLifeLab) in Stockholm/Uppsala is another major venture that builds on strategic priorities and resource mobilization. Three consecutive governmental research bills have redirected (in relative terms) large sums of money from unfettered funding to the universities and research councils to specific "excellence" programs.[602] The growing importance of "research infrastructures," not least in policy language (see

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[600] B Forkman, *Och det blev ljus: Hur MAX-lab kom till, växte upp och blev stort* (Lund University, 2001), pp 176, 180, 183, 217. O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011), 179-215, on p 197.

[601] O Hallonsten, "Growing Big Science in a Small Country: MAX-lab and the Swedish Research Policy System," *Historical Studies in the Natural Sciences* 41 (2011), 179-215, on p 195.

[602] U Sandström, A Wold, B Jordansson, B Ohlsson and Å Smedberg, "Hans Excellens: om miljardsatsningarna på starka forskningsmiljöer," report, Delegationen för jämställdhet i högskolan 2010. O Hallonsten and C Silander, "Commissioning the university of excellence: Swedish research policy and new public research funding programs," *Quality in Higher Education* 18 (2012), pp 367-381.

section 2.1) has been felt in Sweden as well, where a special infrastructure sub-council within the VR structure was formed a decade ago.

It is difficult to fully assess the importance of MAX-lab as a pioneer project for the reshaping of Swedish science policy, but some weight must probably be given to the considerable success it achieved with relatively minor resources. "A certain amount of national self-assertion is certainly part of it."[603]

What is interesting, to once again use a reversed argument, is the seeming unity that quite swiftly was mobilized around MAX-lab. Traditionally, Swedish universities have always competed over everything, but MAX-lab is an exception from this.[604] In this way, MAX-lab can perhaps be identified as a kind of role model for later initiatives.

7.1.2 MAX IV

The introduction to this report established its focus quite clearly; it is the MAX-lab that closed on December 13th, 2015, that is analyzed from the perspective of the impact it has had on various institutions in its surroundings. MAX IV, its successor, is currently taken into operation but is not part of the ambitions of the report to cover, other than in an indirect sense, as a form of impact of MAX-lab.

Viewing MAX IV this way, it can probably be identified as the single most spectacular impact of MAX-lab. Beyond doubt, MAX IV would not have existed if it wouldn't have been for the more than three decades of buildup of MAX-lab that preceded it.[605] MAX-lab paved the way for MAX IV, not only technically and scientifically, but also organizationally and politically.

The first idea for MAX IV came already before MAX II was taken into user operation, and grew as an accelerator physics R&D project over the years, with the injector upgrade and MAX III facility as pilot projects that tested some concepts and technologies.[606] In 2002, the work began for real to define basic performance parameters and ambition, and funding was granted by KAW for a design study that would produce a Conceptual Design Report.[607] In 2004, the workshop "Our Future Light Source" was organized in Lund in conjunctuion with the annual MAX-lab users meeting, with close to 400 participants and several parallel sessions that made a major effort on the scientific case for MAX IV as presented in the conceptual design report,

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603 Bengt EY Svensson, interviewed by Olof Hallonsten, Lund 22 November 2016

604 Gunnar Öquist, interviewed by Olof Hallonsten, Umeå 11 January 2017

605 Nils Mårtensson, interviewed by Oskar Christensson, Uppsala 2 December 2016

606 Mikael Eriksson, interviewed by Olof Hallonsten, Lund 28 March 2007.

607 MAX-lab Activity Report 2002, p 1.

issued in 2006.[608] The design was revised a few times before construction started, in 2011. The funding for the facility was collected from several sources; VR, Vinnova, Lund University and the Regional Council of Skåne agreed in 2009 to fund the storage ring, and a consortium of Swedish universities and KAW funded the first set of beamlines.

Without doubt, MAX IV is a world-leading synchrotron radiation facility. The storage ring design, with the MBA concept (see section 3.3), is state-of-the-art, and the beamlines and experimental stations, designed to make optimal use of the extremely high-quality x-rays produced by the ring, are similarly cutting-edge. In great part, this quality of the design and conceptualization of instrumentation at MAX IV made possible because of the networks and national and international support for MAX-lab.[609]

When it comes to MAX IV defined as impact from MAX-lab, this is twofold: First, the MAX IV facility is the most obvious and (using a very fitting metaphor) the most brightly shining example of what the several decades long evolutionary scientific and technological developments in accelerator physics and synchrotron radiation instrumentation have produced in terms of impact. Second, the design concept as such, a product of R&D at MAX-lab in the first decade of the 20th century, has been enormously impactful on a global level. The statement by Nils Mårtensson on this topic is probably no exaggeration: “The MAX IV project has changed the field of synchrotron radiation research internationally.”[610]

7.2 Impact revisited

Concluding this extensive report of the *ex post* impact study of MAX-lab, some things deserve to be reiterated. Important for the overall message is that MAX-lab most of all was an *enabler*, and in this role it had a system-bearing function, both as a platform for research of various kinds (first in nuclear physics, accelerator physics and materials physics, then in biology, and also in several other fields along the way) and as a vehicle for renewal and internationalization of Swedish science in the concerned fields. MAX-lab’s impact on Swedish and Nordic science, on local and regional society, on Lund University, and so on, was enormously complex and multifarious. The report has managed to convey some broad brushstrokes and the details of some specific forms of

[608] MAX-lab Activity Report 2004, p 1. MAX IV Conceptual Design Report, 2006.

[609] MAX-lab Activity Report 2010, p 1. MAX IV Highlights and Activities 2011-2012, p 6.

[610] Nils Mårtensson, “MAX IV: The long process of refinement,” in B Forkman, A Nyberg and M Nygren, *The Marvelous light in Lund: how MAX IV came about* (Lund University, 2016), 97-112, on p 111.

impact, but surely missed out on some. There are several secondary, tertiary (and further down the road) effects that cannot be assessed today but are very likely to happen.

Albert Einstein is credited with the line "not everything that can be counted counts; not everything that counts can be counted," although the phrase was likely minted years after Einstein's death by sociologist William Bruce Cameron.[611] The point is that a similar maxim should be considered as key to the present attempt to evaluate the impact of MAX-lab in a variety of realms. There are severe methodological problems of any ex post impact study, most of all the issue of time lag, in this case that most significant impacts of MAX-lab may show up several years after this report is written, and method problems that have to do with (in)availability of data and material. As has been pointed out repeatedly in this report, the material has unfortunate gaps and the study has also been unsuccessful in tracking down some informants and information. No study can cover everything. The scope and depth of the analysis on the preceding 150+ pages marks an honest attempt to cover as much as possible. But the acknowledgement of this limitation can also be turned into an argument of potential: Although the report has demonstrated quite substantial impact of MAX-lab in a variety of realms, all that has not been captured (and probably never will) means that the reader will have to use her imagination to cover the rest.

A key message of the analysis in the preceding pages has been that MAX-lab grew *gradually*, *incrementally* and *organically* from a small-scale university project in nuclear physics to a national and international user facility for synchrotron radiation. It managed to do so, to the benefit of its user communities – locally, nationally and internationally – by its built-in continuous *technological adaptability* and *organizational responsiveness* to the user communities. This, in turn, was enabled by MAX-lab's essential academic mode of organization, which made possible a creative and scientific approach to short- and long-term developments. It also put MAX-lab and its staff and leadership in touch with the user communities (these were, in fact, partially overlapping) which secured the vitality of the *crucial alliance* between the synchrotron radiation facility and its user community. This alliance was near-perfected at MAX-lab, with some inadvertent side-effects ("shadow economies") but with the main result that the lab and its users drove the development *in reciprocity*, to mutual benefit. The same is true for some of the key collaborative efforts with involvement by industrial firms (section 4.2).

Long time MAX-lab user, professor and academic leader Anders Flodström is quoted in section 4.3 having said that "the univerity in Sweden that contributed the least to MAX-lab is Lund University."[612] While this is not true, taking into account the full

[611] W B Cameron, *Informal Sociology, a casual introduction to sociological thinking* (Random House, 1963), p 13.

[612] Anders Flodström, interviewed by Olof Hallonsten, Stockholm 22 March 2007.

history of the lab as accounted for here, there is an important argument to be made there: It has been pointed out by several sources that the relative lack of interest (and competence) in Lund was an advantage for MAX-lab in the long run, because it had to attract devoted users from all over Sweden (and the other Nordic countries) right from the start, and thus built a strong national (and Nordic) base for its activities.[613] This base was politically opportune, when support was to be drummed up for MAX II in the early 1990s, and when the MAX IV plans emerged for real some fifteen years later, but it also secured the vital inflow of expertise from all over Sweden to MAX-lab and solidified both the user community as such and the vital axis between lab and user community that, this report concludes, was absolutely crucial for the successes that MAX-lab managed to produce. While not a form of *impact* of MAX-lab *per se* (rather, a form of impact *on* MAX-lab), this is one of the absolute key conclusions of this report: A facility like MAX-lab makes its most substantial and positive impact on science (and, by extension, society) by integrating itself in the scientific communities that it serves, cultivating this crucial alliance to the benefit of all.

In this respect, the *broadening of the user base*, from solid state physics to chemistry and biology, from local/national and to Nordic/global, from a smaller group of Swedish physicists to a broader set of academic environments throughout Sweden, is itself a testimony to great (and increasing) scientific impact: MAX-lab became a vital resource for a wide range of excellent Swedish and Nordic research activities. On a related note, in terms of growth, it is quite clear that MAX-lab managed to put Lund and Sweden *on the map* in the global synchrotron radiation community, and in wider circles, and therefore also functioned as a *vehicle for the internationalization* of research activities in parts of physics, chemistry and biology at Lund University and Sweden/Scandinavia as a whole. This is especially true for surface physics and structural biology.

In the latter regard, MAX-lab plucked into, and catalyzed, some core developments in Swedish science at the end of the 20th century and contributed to the *renewal* of several fields in materials science and life science, which among other things is seen in the Linnaeus Grants, strategic research areas, and similar excellence centers. Thus MAX-lab *paved the way* for strategic mobilization around areas of strength in the 2000s, by showing what collaborative efforts between Swedish (and Nordic) universities and research policy and funding agencies can achieve. However, policymakers should be aware of the risks of funding infrastructure without properly securing funding for its use.

Was MAX-lab unique? Scientifically and technically it was not, other than in the strictest sense of the word, but historically/politically it was: The decades when MAX-

613 I Lindau and S Ristinmaa Sörensen, "Synkrotronljuset från Lund: Hur lundafysiker lärde sig använda synkrotronljus på olika sätt," in B Forkman and K Holmin Verdozzi (eds.), Fysik i Lund – i tid och rum (Lund University, 2017), p 398. Gunnar Öquist, interviewed by Olof Hallonsten, Umeå 11 January 2017.

lab was built and grew to a position as international user facility was a time when Swedish science in the related fields was renewed, and a similar renewal also occurred on international stage. This means that MAX-lab was placed in a unique historical context that also made the facility as such unique.

Appendices

Appendix 1: Investments in MAX-lab, 1997-2012[614]

Year	Name	Category	Funder	kSEK
1997	Additional funding for undulator beamlines at MAX II	Beamlines	KAW	6500
1997	Material science beamline I811	Beamlines	KAW	11500
1998	Multipole wiggler for the material science beamline I811.	Beamlines	FRN	6000
1998	Diffractometer for the material science beamline I811.	Beamlines	FRN	5000
1998	Low energy (NIM) beamline for MAX III	Beamlines	FRN	3700
1998	Cluster source and electron-ion coincidence spectrometer	Experimental equipment	KAW	2600
1998	Low energy (NIM) beamline for MAX III	Beamlines	NFR	4200
1999	Detection system for protons.	Nuclear physics	Crafoord	430
1999	LINAC injector and MAX III	Accelerator systems	FRN	25000
1999	CCD detector for beamline I711.	Experimental equipment	KAW	5000
1999	Protein crystallography beamline I911 at MAX II	Beamlines	KAW	25000
1999	Low energy (NIM) beamline for MAX III	Beamlines	NFR	4200
2000	Side station for the protein crystallography beamline I911.	Beamlines	Astra/Novo	10000
2000	Spectrometer for neutral pions.	Nuclear physics	Crafoord	400
2000	Equipment for the protein crystallography beamline I911.	Beamlines	DABIC	14000
2000	Soft X-ray spectrometer and experimental chamber for beamline I511.	Experimental equipment	FRN	2700
2000	High resolution photoelectron spectrometer for the NIM at MAX III.	Beamlines	KAW	5900
2001	Experimental station for time resolved X-ray studies at MAX II.	Beamlines	FRN	6950
2001	Laser equipment and manipulator for beamline I411	Experimental equipment	FRN	5252
2002	Framtagning av en nästa synkrotronljuskälla i Sverige.	Accelerator systems	KAW	14000

614 List compiled by MAX-lab staff. Received (personal communication) from Ildikó Toth of MAX IV on 15 November 2016.

2002	Move of beamline 33 at MAX I to MAX III and a multi-detection system for the electron analyzer.	Beamlines	VR	7500
2002	A new high-brilliance source for circularly polarized X-rays at MAX-lab.	Beamlines	VR	27866
2002	Spectrometer for neutral pions.	Nuclear physics	VR	900
2003	Molecular photoexcitation, photoionization and photofragmentation by a new multicoincidence apparatus.	Experimental equipment	KAW	3800
2003	Beamllne for infrared microspectroscopy at MAX III.	Beamlines	KAW	7200
2003	SPELEEM: Structural, chemical and magnetic surface imaging with high spatial resolution.	Experimental equipment	VR	11800
2004	Ultrafast x-ray studies of transient structural distortions from laser generated phonon-polaritons	Experimental equipment	Crafoord	300
2004	Cryostat and furnace for beamline I811	Experimental equipment	Crafoord	180
2004	Pipetting robot for protein crystallography.	Experimental equipment	SweGene	1400
2004	100 MHz accelerator equipment for MAX II.	Accelerator systems	VR	6200
2004	Equipment for beam technology preparing for UV Free Electron Laser and femto second radiation at MAX-lab.	Accelerator systems	VR	5600
2004	Molecular photoexcitation, photoionization and photofragmentation by a new multicoincidence apparatus.	Experimental equipment	VR	3600
2005	Equipment for in-situ x-ray diffraction and EXAFS experiments at beamline I811	Experimental equipment	KAW	8000
2005	Equipment for in-situ x-ray diffraction and EXAFS experiments at beamline I811	Experimental equipment	VR	7000
2006	Advanced laser equipment and x-ray optics for laser and synchrotron radiation studies of atoms, molecules and clusters.	Experimental equipment	VR	2700
2007	Combined ambient pressure and ultrahigh vacuum electron spectroscopy instrument for research in synchrotron radiation-based catalysis, surface reaction, corrosion, and liquids science.	Experimental equipment	KAW	9500
2007	Developing femtosecond x-ray capabilities at MAX II.	Experimental equipment	KAW	6500
2007	Equipment for MBE preparation of magnetic semiconductor structures at MAX III	Experimental equipment	VR	3900
2007	Equipment for making Cassiopeia's I911 (1) a facility for humidity control experiments on protein crystals.	Experimental equipment	VR	5000
2007	Sample environment for SAXS at I711.	Experimental equipment	VR	480

2008	Equipment for research with monoenergetic photons	Nuclear physics	KAW	2700
2008	Instrumentation for High Resolution X-ray Diffraction and High Sensitivity Small Angle X-ray Scattering at MAX-lab.	Experimental equipment	VR	8470
2009	A circular polarized soft X-ray spectroscopy beamline for research in surface science and reactions, catalysis and corrosion, functional materials, and molecular science in condensed and liquid phase.	Beamlines	KAW	20000
2009	A circular polarized soft X-ray spectroscopy beamline for research in surface science and reactions, catalysis and corrosion, functional materials, and molecular science in condensed and liquid phase.	Beamlines	VR	2935
2010	Polarimeter to MAX-lab.	Experimental equipment	VR	4895
2010	Upgrade of the macromolecular crystallization facility at MAX-lab to meet increased demand.	Experimental equipment	VR	3400
2012	Detector	Experimental equipment	Carl Tryggers	450
2012	New opportunities in nano-science: a shared STM facility at MAX-IV.	Experimental equipment	VR	2765
2012	Aberration corrected spectroscopic photoemission and low energy electron microscope: structural, chemical, and magnetic surface imaging with spatial resolution of a few nanometers.	Experimental equipment	VR	7200

Appendix 2: List of all published doctoral theses that build on work done at MAX-lab, alphabetical order of authors, 1988-2015[615]

Abu-samha, M., Bergen University, Norway, 2006

Achour, A., Karolinska Institute, Stockholm, Sweden, 2001

Adell, J., Chalmers University of Technology, Gothenburg, Sweden, 2009

Adell, M., Chalmers University of Technology, Gothenburg, Sweden, 2006

Adlkofer, K., Technische Universität München, Germany, 2003

Agåker, M., Uppsala University, Sweden, 2006

Ahire, J.H., East Anglia University, UK, 2014

Ahmadi, S., KTH Royal Institute of Technology, Stockholm, Sweden, 2013

Ahola-Tuomi, M., Turku University, Finland, 2013

Al Jebali, R., Glasgow University, UK, 2013

Alfredsson, Y., Uppsala University, Sweden, 2005

Ali-Löytty, H., Tampere University, Finland, 2013

Almkvist, G., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2008

Álvarez Ruiz, J., KTH Royal Institute of Technology, Stockholm, Sweden, 2004

Andersen, J., Technical University of Denmark, Lyngby, Denmark, 2015

Andersson, A., Uppsala University, Sweden, 2003

Andersson, B.-E., Lund University, Sweden, 1994

Andersson, C., KTH Royal Institute of Technology, Stockholm, Sweden, 1996

Andersson, C., Uppsala University, Sweden, 2006

Andersson, H.O., Uppsala University, Sweden, 1999

Andersson, K., Stockholm University, Sweden, 2006

Andersson, L., Uppsala University, Sweden, 2004

Andersson, M.E., Stockholm University, Sweden, 2000

Andersson, S., Uppsala University, Sweden, 1998

Andersson, S.C., Stockholm University, Sweden, 2012

Andersson, Å., Lund University, Sweden, 1997

Andreasen, K.P., Aarhus University, Denmark, 2015

[615] Extracted and compiled from the MAX-lab Activity Reports, 1987-2010, plus lists online for the years 2011-2015; https://www.maxlab.lu.se/node/1218 (accessed 9 January 2017) and https://www.maxlab.lu.se/node/2062 (accessed 9 January 2017).

Anselmo, A.S., Karlstad University, Sweden, 2013
Arent, S., Copenhagen University, Denmark, 2004
Arp, U., Hamburg University, Germany, 1993
Ataman, E., Lund University, Sweden, 2011
Aurelius, O., Lund University, Sweden, 2015
Ausmees, A., Tartu University, Estonia, 1991
Awad, W., Lund University, Sweden, 2015
Baev, A., KTH Royal Institute of Technology, Stockholm, Sweden, 2003
Baken, S., Catholic University Leuven, Belgium, 2015
Bao, Z., Uppsala University, Sweden, 2008
Bariseviciute, R., Vilnius University, Lithuania, 2006
Barkhordarian, G., Technische Universität Hamburg-Harburg, Germany, 2007
Beck, M., Lund University, Sweden, 2003
Becker, J., Aarhus University, Denmark, 2010
Benach-Andreu, J., Karolinska Institute, Stockholm, Sweden, 1999
Bender, J., Chalmers University of Technology, Gothenburg, Sweden, 2007
Bengtsson, J., Lund University, Sweden, 1988
Bennig, P., Uppsala University, Sweden, 1996
Berg, C., Trondheim University, Norway, 1994
Bergersen, H., Uppsala University, Sweden, 2008
Berglund, J., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2004
Bergmann, J., Karl-Franzens-Universität Graz, Austria, 2001
Berthold, C.L., Karolinska Institute, Stockholm, Sweden, 2008
Besnard, C., Lund University, Sweden, 2004
Beutler, A., Lund University, Sweden, 1998
Bhaumik, R., Oulu University, Finland, 2006
Biedron, S.G., Lund University, Sweden, 2001
Birgerson, J., Linköping University, Sweden, 2001
Birgersson, M., Lund University, Sweden, 2002
Bjork, A., Oslo University, Norway, 2004
Björklund, S., Lund University, Sweden, 2013
Björkqvist, M., KTH Royal Institute of Technology, Stockholm, Sweden, 1997
Björneholm, O., Uppsala University, Sweden, 1992
Björström Svanström, C., Karlstad University, Sweden, 2007
Blomfeldt, T., KTH Royal Institute of Technology, Stockholm, Sweden, 2012

Blomquist, J., Lund University, Sweden, 2007
Bobeldijk, I., Utrecht University, The Netherlands, 1995
Boland, M., Melbourne University, Australia, 2002
Borek, D., A. Mickiewicz University, Poznan, Poland, 2001
Borg, M., Lund University, Sweden, 2003
Boye Jensen, L., Copenhagen University, Denmark, 2011
Brangulis, K., Latvian Biomedical Research and Study Centre, Riga, Latvia, 2014
Brauer, H., Chalmers University of Technology, Gothenburg, Sweden, 1996
Breitholtz, M., Chalmers University of Technology, Gothenburg and Gothenburg University, Sweden, 2004
Bremholm, M., Aarhus University, Denmark, 2009
Bring, T., KTH Royal Institute of Technology, Stockholm, Sweden, 2006
Brink, B.K., Technical University of Denmark, Lyngby, Denmark, 2015
Brix Ley, M., Technical University of Denmark, Lyngby, Denmark, 2014
Bruce, R., Lund University, Sweden, 2009
Brunnbauer, M., Hamburg University, Germany, 2003
Bryngelsson, H., Uppsala University, Sweden, 2008
Brzezinski, K., A. Mickiewicz University, Poznan, Poland, 2006
Bugris, V., Szeged University, Hungary, 2014
Bunk, R., Lund University, Sweden, 2005
Burmeister, F., Uppsala University, Sweden, 2003
Bösenberg, U., Technische Universität Hamburg-Harburg, Germany, 2009
Böth, B., Karolinska Institute, Stockholm, Sweden, 2014
Caló, A., Oulu University, Finland, 2007
Cant, D.J.H., Manchester University, UK, 2013
Carlegrim, E., Linköping University, Sweden, 2010
Carlsson, G., Uppsala University, Sweden, 2004
Carlstedt, J, , Lund University, Sweden, 2012
Castell, A., Uppsala University, Sweden, 2008
Céolin, D., Paris Sud University, France, 2003
Ceponkus, J., Vilnius University, Lithuania, 2006
Chao, Y.-C., Linköping University, Sweden, 1996
Chen, W., KTH Royal Institute of Technology, Stockholm, Sweden, 1994
Chen, Y., Uppsala University, Sweden, 2013
Chesneau, F., Heidelberg University, Germany, 2011

Choudhury, D., Indian Institute of Science, Bangalore, India, 2010
Christensen, C.E., Copenhagen University, Denmark, 2010
Christensen, K.E., Stockholm University, Sweden, 2008
Claesson, D., Chalmers University of Technology, Gothenburg and Gothenburg University, Sweden, 1998
Claesson, M., Karolinska Institute, Stockholm, Sweden, 2013
Clemens, A., Chalmers University of Technology, Gothenburg, Sweden, 2015
Cockburn, D., Dublin University, Trinity College, Ireland, 2012
Conradsson, T., Stockholm University, Sweden, 2002
Cordara, G., Oslo University, Norway, 2013
Cornish, A., Reading University, UK, 2011
Cramer, J.F., Aarhus University, Denmark, 2009
Crihan, D., Justus-Liebig University Gießen, Germany, 2008
Csendes, Z., Szeged University, Hungary, 2014
Cunniffe, J.P., Dublin University, Trinity College, Ireland, 2011
Cutic, N., Lund University, Sweden, 2011
Dahl, J., Turku University, Finland, 2015
de Bever, L., Utrecht University, The , 1993
Dias, J.F., Gent University, The Netherlands, 1994
Dithmer, L., University of Southern Denmark, Odense, Denmark, 2015
Djukic, U., Cergy-Pontoise University, France, 2015
dos Santos, S., Lund University, Sweden, 2010
Dowiercial, A., Nencki Institute of Experimental Biology, Warsaw, Poland, 2011
Doyle, C., Dublin City University, Ireland, 2013
Drath Bøjesen, E., Aarhus University, Denmark, 2015
Duda, L., Dortmund University, Germany, 1999
Duda, L., Uppsala University, Sweden, 1996
Ekegren, J., Uppsala University, Sweden, 2006
Ekvall, I., Chalmers University of Technology, Gothenburg and Gothenburg University, Sweden, 1999
Elfstrand, L., Lund University, Sweden, 2006
Emanuelson, A., Lund University, Sweden, 2001
Eneqvist, T., Umeå University, Sweden, 2000
Enquist, H., Lund University, Sweden, 2009
Ericsson, L.K.-E., Karlstad University, Sweden, 2013

Ericsson, U., Stockholm University, Sweden, 2006
Eriksson, J., Linköping University, Sweden, 2010
Ernst, H.A., Copenhagen University, Denmark, 2008
Evju, C., Lund University, Sweden, 2002
Feifel, R., Uppsala University, Sweden, 2003
Feilberg, K.L., Copenhagen University, Denmark, 2005
Ferguson, A., McGill University, Montreal, Canada, 1999
Fernandes, V.R., Norwegian University of Science and Technology (NTNU), Norway, 2014
Fodje, M.N, Lund University, Sweden, 2003
Folsted Andersen, C.B., Aarhus University, Denmark, 2006
Forsberg, J., Uppsala University, Sweden, 2009
Forsgren, N., Umeå University, Sweden, 2010
Forti, S., University Erlangen-Nürnberg, Germany, 2013
Friemann, R., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2004
Fuhrberg, K., Göttingen University, Germany, 1992
Furukawa, M., Osaka University, Japan, 2002
Färnbäck, M., Lund University, Sweden, 2003
Föhlisch, A., Uppsala University, Sweden, 1999
Galberg, P., Copenhagen University, Denmark, 2013
Gavrilyuk, S., KTH Royal Institute of Technology, Stockholm, Sweden, 2009
Georgsson, M., Lund University, Sweden, 2001
Gerber, T., Köln University, Germany, 2013
Giovanelli, L., University de Provence, Marseille, France, 2000
Glans, P-A., Linköping University, Sweden, 2001
Glebe, T., Göttingen University, Germany, 1996
Goshtasbi Rad, M., KTH Royal Institute of Technology, Stockholm, Sweden, 2000
Grahn, E., Uppsala University, Sweden, 2001
Greczynski, G., Linköping University, Sweden, 2001
Grehk, T.M., KTH Royal Institute of Technology, Stockholm, Sweden, 1994
Grizolli, W., Lund University, Sweden, 2015
Grundahl Frankær, C., Technical University of Denmark, Lyngby, Denmark, 2012
Grånäs, E., Lund University, Sweden, 2014
Gudmundsson, M., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2014
Gundersen Zahl, M., Bergen University, Norway, 2015
Gurnett, M., Karlstad University, Sweden, 2005

Gustafson, J., Karlstad University, Sweden, 2006
Gustafsson, J., Karlstad University, Sweden, 2005
Gustavsson, C., Lund University, Sweden, 2015
Gålnander, B., Uppsala University, Sweden, 2001
Göthelid, M., KTH Royal Institute of Technology, Stockholm, Sweden, 1994
Haahr Jepsen, L., Aarhus University, Denmark, 2015
Haddad Momeni, M., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2014
Hahlin, A., Uppsala University, Sweden, 2003
Hald, H., Copenhagen University, Denmark, 2009
Hamming, O.J., Aarhus University, Denmark, 2010
Handrup, K., Nottingham University, UK, 2014
Hansen, M., Aarhus University, Denmark, 2010
Hansson, A., Lund University, Sweden, 2012
Hansson, M.D., Lund University, Sweden, 2009
Hansson, S., Lund University, Sweden, 2005
Harbst, M., Lund University, Sweden, 2005
Harkoma, M., Oulu University, Finland, 2002
Harnes, J., Bergen University, Norway, 2012
Hasan, M., Lund University, Sweden, 2014
Hasselström, J, Uppsala University, Sweden, 1999
He, Z., Chalmers University of Technology, Gothenburg, Sweden, 1996
Heister, K., Heidelberg University, Germany, 2001
Helgstrand, C., Uppsala University, Sweden, 2002
Helt, S.S., Technical University of Denmark, Lyngby, Denmark, 2008
Hemmen, H., Norwegian University of Science and Technology (NTNU), Norway, 2012
Hennies, F., Hamburg University, Germany, 2006
Henningsson, A., Uppsala University, Sweden, 2002
Hernnäs, B., Uppsala University, Sweden, 1995
Herstedt, M., Uppsala University, Sweden, 2003
Hilner, E., Lund University, Sweden, 2009
Hiltunen, A., Oulu University, Finland, 2000
Hirsch, T., Regensburg University, Germany, 2008
Hirschauer, B., KTH Royal Institute of Technology, Stockholm, Sweden, 1998
Hirvonen Grytzelius, J., Karlstad University, Sweden, 2012
Hjelte, I., Uppsala University, Sweden, 2002

Hjort, M., Lund University, Sweden, 2014
Hogner, A., Royal Danish School of Pharmacy, Copenhagen, Denmark, 2002
Holappa, M., Oulu University, Finland, 2011
Holland, B.N., Dublin University, Trinity College, Ireland, 2008
Holme, A., Bergen University, Norway, 2013
Holmner-Rocklöv, A., Chalmers University of Technology, Gothenburg, Sweden, 2005
Hua Qu, Chalmers University of Technology, Gothenburg, Sweden, 1991
Hudl, M., Uppsala University, Sweden, 2012
Huen, P., Aarhus University, Sweden, 2015
Huner Dunn, J., Uppsala University, Sweden, 1998
Huttula, M., Oulu University, Finland, 2004
Huttula, S.-M., Oulu University, Finland, 2003
Hütt, M-Th., Göttingen University, Germany, 1997
Håkansson, C., Lund University, Sweden, 1995
Håkansson, L., Linköping University, Sweden, 1993
Håkansson, M., Lund University, Sweden, 2001
Häger, D., Göttingen University, Germany, 1995
Häggblad, R., Lund University, Sweden, 2010
Hällberg, M., Uppsala University, Sweden, 2002
Høiberg-Nielsen, R., Copenhagen University, Denmark, 2009
Hörnberg, A., Umeå University, Sweden, 2004
Höwing, J., Uppsala University, Sweden, 2004
Iablonskyi, D., Oulu University, Finland, 2013
Ingvarsson, H., Uppsala University, Sweden, 2010
Ireland, D., Edinburgh University, Scotland, 1991
Iskasson, L., Lund University, Sweden, 1996
Isvoranu, C., Lund University, Sweden, 2010
Jackman, M.J., Manchester University, UK, 2015
Jacobson, F., Chalmers University of Technology, Gothenburg, Sweden, 2006
Janiak, J., Lund University, Sweden, 2012
Janin, E., KTH Royal Institute of Technology, Stockholm, Sweden, 2001
Janowski, R., A. Mickiewicz University, Poznan, Poland, 2002
Jansson, A., Karolinska Institute, Stockholm, Sweden, 2004
Jansson, A.M., Uppsala University, Sweden, 2013
Jansson, H., Gothenburg University, Sweden, 2007

Jauhiainen, J., Oulu University, Finland, 1996
Jaworowski, JA., Lund University, Sweden, 2001
Jegou Saint-Jean, S., Lund University, Sweden, 2004
Jenner, J.B., Aarhus University, Denmark, 2000
Jeppersen, S., Technical University of Denmark, Lyngby, Denmark, 2003
Johansson, E., Karolinska Institute, Stockholm, Sweden, 2000
Johansson, E., Uppsala University, Sweden, 2006
Johansson, K., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2000
Johansson, L.S.O, Linköping University, Sweden, 1990
Johansson, M., Lund University, Sweden, 1997
Johansson, M., Lund University, Sweden, 2001
Johansson, P., Uppsala University, Sweden, 2006
Johansson, U., Lund University, Sweden, 1997
Johnsen Venvik, H., Norwegian University of Science and Technology (NTNU), Trondheim, Norway, 1998
Johnson, M.T., Lund University, Sweden, 2013
Jónsson, S., Lund University, Sweden, 2005
Juknaite, L., Copenhagen University, Denmark, 2013
Jurgilaitis, A., Lund University, Sweden, 2012
Jurvansuu, M., Oulu University, Finland, 2001
Jussila, R., Tampere University, Finland, 2009
Jönsson, S.K.M, Linköping University, Sweden, 2004
Kaiser, L., Karolinska Institute, Stockholm, Sweden, 2004
Kantia, T., Oulu University, Finland, 2011
Kapetaniou, E., Turku University, Finland, 2005
Karawajczyk, A., KTH Royal Institute of Technology, Stockholm, Sweden, 1995
Karis, O., Uppsala University, Sweden, 1997
Karkehabadi, S., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2005
Karlberg, T., Lund University, Sweden, 2006
Karlsen, T., Bergen University, Norway, 2001
Karlsson, A., Umeå University, Sweden, 2008
Karlsson, C., Linköping University, Sweden, 1994
Karlsson, R., Uppsala University, Sweden, 2006
Karlsson, T., Swedish University of Agricultural Sciences, Umeå, Sweden, 2005
Karvonen, J., Oulu University, Finland, 1999

Kaurila, T., Turku University, Finland, 1997

Kennedy, B., Dublin University, Trinity College, Ireland, 2011

Khan, M.N., Heidelberg University, Germany, 2014

Khazmi, Y., Chalmers University of Technology, Gothenburg, Sweden, 1997

Kihlgren, T., Gothenburg University and Chalmers University of Technology, Gothenburg, Sweden, 2004

Kivilompolo, M., Oulu University, Finland, 2000

Kivimäki, A., Oulu University, Finland, 1994

Knapp, M., Justus-Liebig University Gießen, Germany, 2005

Knut, R., Uppsala University, Sweden, 2012

Koivusaari, J., Oulu University, Finland, 2000

Kooser, K., Tartu University, Estonia, 2008

Kosinska, U., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2007

Koskiniemi, H., Karolinska Institute, Stockholm, Sweden, 2009

Kotlov, A., Tartu University, Estonia, 2004

Kowalik, I.A., Polish Academy of Sciences, Warsaw, Poland, 2006

Kozlov, A.A., Melbourne University, Australia, 1999

Kraft, L., Karolinska Institute, Stockholm, Sweden, 2001

Krighaar Rasmussen, K., Copenhagen University, Denmark, 2013

Kirm, M., Lund University, Sweden, 1995

Krishnamurthy, S., Newcastle upon Tyne University, UK, 2006

Kristensen, E., Uppsala University, Sweden, 2006

Kristensen, L.H., Copenhagen University, Denmark, 2012

Kudryavtseva, I., Tartu University, Estonia, 1997

Kukk, E., Oulu University, Finland, 1996

Kull, F., Karolinska Institute, Stockholm, Sweden, 2001

Kursula, I., Oulu University, Finland, 2003

Kuzin, A., Melbourne University, Australia, 1997

Kvashnina, K., Uppsala University, Sweden, 2006

Küller, A., Heidelberg University, Germany, 2006

Käämbre, T., Uppsala University, Sweden, 2002

Lampimäki, M., Tampere University, Finland, 2007

Landemark, E., Linköping University, Sweden, 1993

Langholm Jensen, J., Copenhagen University, Denmark, 2013

Langkilde, A., Copenhagen University, Denmark, 2008

Larsson, A.M., Uppsala University, Sweden, 2006
Larsson, C., KTH Royal Institute of Technology, Stockholm, Sweden, 1990
Larsson, J., Lund University, Sweden, 2012
Larsson, K., Chalmers University of Technology, Gothenburg, Sweden, 2003
Larsson, K.M., Stockholm University, Sweden, 2004
Laukkanen, R., Turku University, Finland, 2005
Laurberg, M., Lund University, Sweden, 2002
Le Nours, J., Copenhagen University, Denmark, 2005
Leandersson, M., Lund University, Sweden, 2000
Lecerof, D., Lund University, Sweden, 2002
Leenders, R., Agricultural University Wageningen, The Netherlands, 1993
Leisenberger, F.P., Graz University, Austria, 1999
Lejon, S., Uppsala University, Sweden, 2008
Li, F., Karl-Franzens-Universität Graz, Austria, 2010
Libuda, J., Ruhr-University Bochum, Germany, 1996
Lilja, P., Lund University, Sweden, 2004
Lindberg, J., Uppsala University, Sweden, 2004
Lindblad, A., Uppsala University, Sweden, 2008
Linde, V., Royal Danish School of Pharmacy, Copenhagen, Denmark, 2000
Lindgren, A., Lund University, Sweden, 2006
Lindsjö, M., KTH Royal Institute of Technology, Stockholm, Sweden, 2005
Ling Lee, H., Dublin City University, Ireland, 2012
Lint, P.J.B., Manchester University, UK, 2013
Liu, J.-C., KTH Royal Institute of Technology, Stockholm, Sweden, 2009
Ljunggren, A., Lund University, Sweden, 2009
Lock, N., Aarhus University, Denmark, 2009
Loosvelt, H., Katholieke University, Leuven, Belgium, 2005
Lu, H., Heidelberg University, Germany, 2013
Lu, H., KTH Royal Institute of Technology, Stockholm, Sweden, 1998
Lundberg, D., SUL Uppsala, Sweden, 2006
Lundgren, E., Lund University, Sweden, 1996
Lundin, M., Lund University, Sweden, 2002
Lundwall, M., Uppsala University, Sweden, 2007
Lunn, M-L., Royal Danish School of Pharmacy, Denmark, 2002
Maeda, K., Technical University of Denmark, Lyngby, Denmark, 2007

Magnano, G., Nottingham University, UK, 2010
Mahrov, B., Uppsala University, Sweden, 2004
Malecki, P., Adam Mickiewicz University, Poznan, Poland, 2013
Malmgren, S., Uppsala University, Sweden, 2013
Mammen, C.B., Copenhagen University, Denmark, 2005
Mancini, D.C., Uppsala University, Sweden, 1994
Mankefors, S., Chalmers University of Technology, Gothenburg, Sweden, 1999
Mathieu, C., University Pierre & Marie Curie, Paris, France, 2009
Matila, T., Oulu University, Finland, 2002
Mattila, S., Turku University, Finland, 2006
Mauser, G., Tübingen University, Germany, 1992
Maxwell, A.J., Uppsala University, Sweden, 1996
Mayor, L.C., Nottingham University, UK, 2009
McGuinnes, C., Pennsylvania State University, USA, 2006
Melero García, E., KTH Royal Institute of Technology, Stockholm, Sweden, 2006
Meno, K., Copenhagen University, Denmark, 2002
Meyerbröker, N., Heidelberg University, Germany, 2012
Michaelsson, J., Karolinska Institute, Stockholm, Sweden, 2002
Michalska, K., A. Mickiewicz University, Poznan, Poland, 2007
Mikkelsen, A., Aarhus University, Denmark, 2001
Mikkelsen, N.M., SUL Uppsala, Sweden, 2007
Mikkelä, M.-H., Oulu University, Finland, 2013
Minkov, I., KTH Royal Institute of Technology, Stockholm, Sweden, 2006
Mirza, O., Copenhagen University, Denmark, 2003
Moche, M., Karolinska Institute, Stockholm, Sweden, 2003
Modin, A., Uppsala University, Sweden, 2009
Mondry, A., Tübingen University, Germany, 1997
Morrow, S.A., Edinburgh University, UK, 2000
Munack, S., Oulu University, Finland, 2013
Mursu, J., Oulu University, Finland, 1998
Mursula, A., Oulu University, Finland, 2002
Myers, L.S., University Illinois at Urbana Champain, USA, 2010
Myllykoski, M., Oulu University, Finland, 2013
Mähler, J., SUL Uppsala, Sweden, 2013
Mäkinen, A., Oulu University, Finland, 2013

Møller, A. M., Copenhagen University, Denmark, 2013
Nasertorabi, F., Uppsala University, Sweden, 2005
Naur, P., Copenhagen University, Denmark, 2006
Naves de Brito, A., Uppsala University, Sweden, 1991
Navirian, H.A., Lund University, Sweden, 2009
Neubauer, R., Erlangen-Nürnberg University, Germany, 2006
Ng, M.L., Uppsala University, Sweden, 2010
Nielsen, E.R., Technical University of Denmark, Lyngby, Denmark, 2001
Nielsen, S.S., Copenhagen University, Denmark, 2010
Nikkinen, J., Oulu University, Finland, 2005
Nilsson, A., Uppsala University, Sweden, 1989
Nilsson, B., Lund University, Sweden, 2003
Nilsson, D., Chalmers University of Technology, Gothenburg, Sweden, 2007
Nilsson, D., Lund University, Sweden, 1990
Nilsson, K., Uppsala University, Sweden, 2007
Niño Orti, M.A., University Autónoma de Madrid, Spain, 2006
Niskanen, J., Oulu University, Finland, 2010
Nordlinder, S., Uppsala University, Sweden, 2005
Nordlund, D., Stockholm University, Sweden, 2004
Norrman, M., Lund University, Sweden, 2007
Nygaard, F.B., Copenhagen University, Denmark, 2001
Nylén, H., Lund University, Sweden, 1997
Nüske, R., Lund University, Sweden, 2011
Nytén, A., Uppsala University, Sweden, 2006
Nömmiste, E., Tartu University, Estonia, 1991
Nørby, P., Aarhus University, Denmark, 2015
Nørgaard, A., Technical University of Denmark, Lyngby, Denmark, 2003
Nørholm, A.-B., Copenhagen University, Denmark, 2014
Oddershede, J., Technical University of Denmark, Lyngby, Denmark, 2008
Odille, F., Lund University, Sweden, 2006
Ollongvist, T., Turku University, Finland, 2001
Olse, J.G., Copenhagen University, Denmark, 2000
Olsen, J., Copenhagen University, Denmark, 2014
Olsson, L.Ö., Chalmers University of Technology, Gothenburg, Sweden, 1995
Oltedal, V.M., Bergen University, Norway, 2007

Osborne, S.J., Uppsala University, Sweden, 1997
Osikowicz, W., Linköping University, Sweden, 2004
Otten, H., Copenhagen University, Denmark, 2011
Palmgren, R., KTH Royal Institute of Technology, Stockholm, Sweden, 2007
Partanen, L., Oulu University, Finland, 2007
Parteder, G., Karl-Franzens-Universität Graz, Austria, 2009
Patanen, M., Oulu University, Finland, 2010
Patthey, L., Lausanne University, Switzerland, 1995
Paul, A., Heidelberg University, Germany, 2005
Pedersen, A.K., Royal Danish School of Pharmacy, Denmark, 2003
Pedersen, L., Copenhagen University, Denmark, 2004
Peltekis, N., Dublin University, Trinity College, Ireland, 2010
Peredkov, S., Lund University, Sweden, 2007
Persson, A., Uppsala University, Sweden, 2010
Persson, K., Swedish University of Agricultural Sciences, Uppsala, Sweden, 1999
Persson, P., Uppsala University, Sweden, 2000
Perälä, R.E., Turku University, Finland, 2008
Peterman, N., Lübeck University, Germany, 2009
Petersson, B., Royal Danish School of Pharmacy, Copenhagen, Denmark, 2004
Petersson, K., Lund University, Sweden, 2003
Petoral Jr, R., Linköping University, Sweden, 2005
Philippe, B., Uppsala University, Sweden, 2013
Pietrzyk, M., Polish Academy of Sciences, Warsaw, Poland, 2010
Pietzsch, A., Hamburg University, Germany, 2009
Piotrowski, Y., Lübeck Univ, Germany, 2009
Plogmaker, S., Uppsala University, Sweden, 2012
Pramhed, A., Lund University, Sweden, 2008
Proff, S., Göttingen University, Germany, 1998
Pugila, C., Uppsala University, Sweden, 1997
Punekar, A.S., Uppsala University, Sweden, 2014
Pärna, R., Tartu University, Estonia, 2012
Pöch, C., Göttingen University, Germany, 1996
Qian, L., Uppsala University, Sweden, 2001
Qvarford, M., Lund University, Sweden, 1996
Ragazzon, D., Uppsala University, Sweden, 2014

Ramachandran, A., Norwegian University of Science and Technology (NTNU), Norway, 2009

Ramstad, A., Norwegian University of Science and Technology (NTNU), Norway, 1999

Rander, T., Uppsala University, Sweden, 2007

Rauf, A., Edinburgh University, Scotland, 1996

Razado-Colambo, I., Linköping University, Sweden, 2009

Redzynia, I., Lodz Technical University, Poland, 2009

Reiter, A.J.H., Glasgow University, UK, 2004

Ren, H., Peking University, China, 2005

Rensmo, H., Uppsala University, Sweden, 1998

Resta, A., Lund University, Sweden, 2008

Ricagno, S., Karolinska Institute, Stockholm, Sweden, 2004

Richter, J.H., Uppsala University, Sweden, 2006

Riedl, C., Friedrich-Alexander-University Erlangen-Nürnberg, Germany, 2010

Rinaldo-Matthis, A., Stockholm University, Sweden, 2004

Rius i Riu, J., KTH Royal Institute of Technology, Stockholm, Sweden, 2002

Rode Mosbæk, C., Copenhagen University, Denmark, 2011

Roedern, E., Aarhus University, Denmark, 2015

Rohde, L.A.H., Copenhagen University, Denmark, 2012

Ross, B., Copenhagen University, Denmark, 2007

Rosso, A., Uppsala University, Sweden, 2008

Ruijter, H., Lund University, Sweden, 1995

Rumnieks, J., Latvian Biomedical Research and Study Centre, Riga, Latvia, 2015

Rusanova-Naydenova, D., Luleå University of Technology, Sweden, 2006

Ruszkowski, M., Adam Mickiewicz University, Poznan, Poland, 2013

Ruus, R., Tartu University, Estonia, 1999

Rüter, H.-H., Hamburg University, Germany, 1991

Ryttersgaard, C., Copenhagen University, Denmark, 2001

Ryynänen, M., Helsinki University, Finland, 2004

Røjkjær Andersen, K., Aarhus University, Denmark, 2009

Sahlberg, M., Uppsala University, Sweden, 2009

Sairanen, O.-P., Oulu University, Finland, 1992

Salek, P., KTH Royal Institute of Technology, Stockholm, Sweden, 2001

Salomon, E., University de Provence, Marseiile, France, 2005

Sandell, A., Uppsala University, Sweden, 1993

Sander, F., Basel University, Switzerland, 2013
Sandmark, J., Karolinska Institute, Stockholm, Sweden, 2001
Sankari, A., Oulu University, Finland, 2008
Sankari, R., Oulu University, Finland, 2003
Schaefer, A., Bremen University, Germany, 2010
Schiessling, J., Uppsala University, Sweden, 2003
Schmitt, T., Uppsala University, Sweden, 2004
Schnadt, J., Uppsala University, Sweden, 2002
Schoiswohl, J., Karl-Franzens-Universität Graz, Austria, 2006
Schuster, S., Heidelberg University, Germany, 2015
Schwenke, J., Lund University, Sweden, 2012
Schütz, C., Stockholm University, Sweden, 2015
Segad Meehdi, M., Lund University, Sweden, 2014
Selegård, L., Linköping University, Sweden, 2013
Selmer, M., Lund University, Sweden, 2002
Shahsavar, A., Copenhagen University, Denmark, 2014
Shao, Y., KTH Royal Institute of Technology, Stockholm, Sweden, 1993
Sigrell, J.A., Uppsala University, Sweden, 1998
Sims, D. A., Melbourne University, Australia, 1995
Sipiczki, M., Szeged University, Hungary, 2013
Sjögren, T., Uppsala University, Sweden, 2001
Sjöstedt, C., KTH Royal Institute of Technology, Stockholm, Sweden, 2012
Sjöström, M., Lund University, Sweden, 2009
Skaar, K., Stockholm University, Sweden, 2015
Skripka, G., Lund University, Sweden, 2015
Smatanová, I., Masaryk University Brno, Czech Republic, 1999
Smed, M., Lund University, Sweden, 2001
Sock, M., Karl-Franzens-Universität Graz, Austria, 2004
Sohail, H.M., Linköping University, Sweden, 2014
Soroka, I., Uppsala University, Sweden, 2005
Sranko, D.F., Szeged University, Hungary, 2012
Stanciu, V., Uppsala University, Sweden, 2005
Stenborg, A., Uppsala University, Sweden, 1989
Stenmark, P., Stockholm University, Sweden, 2005
Stjerndahl, M., Uppsala University, Sweden, 2008

Stoltz, S., Gothenburg University and Chalmers University of Technology, Gothenburg, Sweden, 2004

Strisland, F., Norwegian University of Science and Technology (NTNU), Norway, 1998

Suarez Covarrubias, A., Uppsala University, Sweden, 2008

Suchodolskis, A., Semiconductor Physics Institute, Vilnius, Lithuania, 2005

Sultana, A., Karolinska Institute, Stockholm, Sweden, 2006

Sundin, S., Uppsala University, Sweden, 1998

Svensson, G., Lund University, Sweden, 2011

Svensson, S., Karolinska Institute, Stockholm, Sweden, 1999

Svenum, I.-H., Norwegian University of Science and Technology (NTNU), Norway, 2009

Swarbrick, J.C., Nottingham University, UK, 2006

Synnergren, O., Lund University, Sweden, 2005

Syres, K.L., Manchester University, UK, 2010

Szamota-Leandersson, K., KTH Royal Institute of Technology, Stockholm, Sweden, 2010

Söderberg, C., Lund University, Sweden, 2013

Södergren, S., Uppsala University, Sweden, 1996

Söderström, J., Uppsala University, Sweden, 2007

Tai, Y., Heidelberg University, Germany, 2005

Tamu-Dufe, V., Lund University, Sweden, 2007

Tang, L.Q., Stockholm University, Sweden, 2005

Tarawneh, H., Lund University, Sweden, 2006

Tars, K., Uppsala University, Sweden, 1999

Taskinen, J., Oulu University, Finland, 2006

Taylor, J.B., Nottingham University, UK, 2007

Tengelin-Nilsson, M., Chalmers University of Technology, Gothenburg, Sweden, 2006

Thapper, A., Lund University, Sweden, 2001

Tholander, F., Karolinska Institute, Stockholm, Sweden, 2006

Thorell, S., Karolinska Institute, Stockholm, Sweden, 2001

Thorin, S., Lund University, Sweden, 2009

Thymark, M., Copenhagen University, Denmark, 2008

Tigerström, A., Gothenburg University, Sweden, 2004

Tillborg, H., Uppsala University, Sweden, 1993

Tjernberg, O., KTH Royal Institute of Technology, Stockholm, Sweden, 1996

Toller, S., KTH Royal Institute of Technology, Stockholm, Sweden, 2008

Torapava, N., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2011

Torpenholt, S., Copenhagen University, Denmark, 2012
Travnikova, O., Uppsala University, Sweden, 2008
Tvedebrink Haahr, L., Technical University of Denmark, Lyngby, Denmark, 2012
Ulfat, I., Chalmers University of Technology, Gothenburg, Sweden, 2012
Unge, J., Chalmers University of Technology, Gothenburg, Sweden, 2008
Unge, J., Lund University, Sweden, 2003
Uppsten, M., SUL Uppsala, Sweden, 2004
Urpelainen, S., Oulu University, Finland, 2009
Ussing, C.A., Copenhagen University, Denmark, 2013
Uysal, H., Lund University, Sweden, 2008
Vahlberg, C., Linköping University, Sweden, 2011
Vall-Ilosera, G., KTH Royal Institute of Technology, Stockholm, Sweden, 2008
Vallenhag, L., Lund University, Sweden, 2014
Van de Abeele, C., Gent University, The Netherlands, 1994
van Schaik, J.W.J., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2008
Varekamp, P. R., KTH Royal Institute of Technology, Stockholm, Sweden, 1995
Vasur, J., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2009
Velloso, L.M., Karolinska Institute, Stockholm, Sweden, 2004
Vester-Christensen, M.B., Technical University of Denmark, Lyngby, Denmark, 2009
Vévodová, J., Masaryk University, Brno, Czech Republic, 2002
Vijayalakshmi, S., Hamburg University, Germany, 2006
Vinogradov, N., Uppsala University, Sweden, 2013
Virojanadara, C., Linköping University, Sweden, 2004
Vognsen, T., Copenhagen University, Denmark, 2015
von Schenk, H., KTH Royal Institute of Technology, Stockholm, Sweden, 2002
von Würtemberg, K.M., Stockholm University, Sweden, 2013
Wadsten-Hindrichsen, R., Chalmers University of Technology, Gothenburg, Sweden, 2007
Wahlström, E., Chalmers University of Technology, Gothenburg, Sweden, 2000
Walle, L.E., Norwegian University of Science and Technology (NTNU), Norway, 2009
Wang, H., Stockholm University, Sweden, 2009
Watcharinyanon, S., Karlstad University, Sweden, 2008
Weidner, T., Kassel University, Germany, 2006
Weirum, G., Karl-Franzens-Universität Graz, Austria, 2010
Weissenrieder, J., KTH Royal Institute of Technology, Stockholm, Sweden, 2003
Welin, M., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2007

Welner, D.H., Copenhagen University, Denmark, 2011
Werin, S., Lund University, Sweden, 1990
Werner, J., Uppsala University, Sweden, 2015
Weser, M., Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany, 2013
Wessely, O., Uppsala University, Sweden, 2006
Westermark, K., Uppsala University, Sweden, 2001
Westerström, R., Lund University, Sweden, 2010
Widstrand, S., Karlstad University, Sweden, 2004
Wiell, T., Uppsala University, Sweden, 1996
Wiesner, K., Uppsala University, Sweden, 2003
Wigren, C., Lund University, Sweden, 1992
Wigren, E., Karolinska Institute, Stockholm, Sweden, 2012
Wikberg, M., Uppsala University, Sweden, 2010
Wiklund, S., Lund University, Sweden, 1992
Winkler, M., Bergen University, Norway, 2015
Winther, A.-M. L., Aarhus University, Denmark, 2008
Wojtkowiak, A., Adam Mickiewicz University, Poznan, Poland, 2013
Wu, M., SUL Uppsala, Sweden, 2013
Wugt Larsen, R., Lund University, Sweden, 2004
Xing, K., Linköping University, Sweden, 1996
Xu, Y., Stockholm University, Sweden, 2000
Yengo, R.K., Lund University, Sweden, 2011
Ylianttila, M., Oulu University, Finland, 2005
Yoshiki Franzén, K., KTH Royal Institute of Technology, Stockholm, Sweden, 1998
Younsei, R., Uppsala University, Sweden, 2012
Yu, S., KTH Royal Institute of Technology, Stockholm, Sweden, 2011
Zhang, C., Uppsala University, Sweden, 2013
Zhang, H., Linköping University, Sweden, 2003
Zhong, L., Karolinska Institute, Stockholm, Sweden, 2000
Znamenskaya, Y., Malmö University, Sweden, 2013
Ågren, D., Karolinska Institute, Stockholm, Sweden, 2009
Åhlund, J., Uppsala University, Sweden, 2007
Åsklund, H., Chalmers University of Technology, Gothenburg, Sweden, 2001
Öhrwall, G., Uppsala University, Sweden, 1999
Ökvist, M., Gothenburg University, Sweden, 2004

Önsten, A., KTH Royal Institute of Technology, Stockholm, Sweden, 2011
Öster, L., Swedish University of Agricultural Sciences, Uppsala, Sweden, 2005

Appendix 3: List of MAX-lab staff and faculty, 1987-2010[616]

Adell, Johan. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline I4, 2009-2010*

Adler, Jan-Olof. Coordinator for nuclear physics research, 1998-2004.

Ahlbäck, Jonny. MAX-lab staff member: vacuum system design, MAX IV, 2009-2010*

Andersson, Pontus. PhD student at the Department of Synchrotron Radiation Instrumentation, 2003-2008.

Andersson, Robert. MAX-lab staff member: workshop, mechanics, 2008-2010*

Andersson, Åke. Member of the accelerator physics group, *1987-1996. MAX-lab staff member: operations, 1991; electronics for the accelerator system, 1992-1999; radiation protection and safety, 1994-2006; development and maintenance of the accelerator system, 2000-2006; maintenance and development of accelerators, 2008-2009; deputy machine director, 2010*

Balasubramanian, Thigaraian. MAX-lab staff member: design, installation and maintenance of beamlines, 2000-2006; design, installation and maintenance of beamlines, especially I3 and I4, 2007-2009; coordinator for low energy beamlines (73, I3, I4), 2010*

Barthel, Ann. MAX-lab staff member: reception, office work, 1993-2006; office work, 2006; office work and invoiving, 2007-2010*

Bauhn, Jim. MAX-lab staff member: service, 2007-2008.

Berglund, Magnus. MAX-lab staff member: design, installation and maintenance of vacuum systems, 2003; deputy manager of design and installations, 2004; manager of design and installations, 2005-2009; head of engineering group, 2010*

Bergqvist, Marlene. MAX-lab staff member: micro-wave electronics for the accelerator system, 2001-2006; operation of MAX II, 2004-2006.

Biedron, Sandra. PhD student at the Department of Accelerator Physics, 1997-2000.

Bjermo, Anders. MAX-lab staff member: design and construction, 2010*

Björck, Matts. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline D1011, 2009-2010*

[616] Extracted and compiled from the MAX-lab Activity Reports, 1987-2010. Note that the time interval is 1987-2010 although in some cases tenure, functions, and periods of service may extend backwards in time, before 1987, and forwards in time, beyond 2010. MAX-lab (MAX IV) staff is not listed in the "Highlights and Activities" reports of 2011-2015. An asterisk (*) is found with every instance of a tenure that begins with 1987 and/or ends with 2010, as a reminder that these time periods likely (but not necessarily) extend forwards or backwards in time. MAX-lab expanded its staff considerably in the year 2010 as the organization was transformed into MAX IV; for reasons of clarity and space, we have chosen not to include in this list those staff members etc. that only appear in the 2010 activity report.

Brandin, Mathias. PhD student at the Department of Accelerator Physics, 2002-2007.

Broberg, Magnus. MAX-lab staff member: electrical installations, 1996-2003.

Bruce, Roderik. PhD student at the Department of Accelerator Physics, 2005-2009.

Canton, Sophie. Research associate at the Department of Synchrotron Radiation Instrumentation, 2009-2010*

Carlson, Stefan. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I811, 2000-2010*

Cederholm, O. MAX-lab staff member: electronics, *1987-1991; micro-wave electronics for the accelerator system, 1992-2001. *See also list of board and committee members*.

Cerenius, Yngve. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline I711, 1997-2006; research coordinator for hard x-ray activities, 2007-2009; coordinator for beamline projects, MAX IV, 2010*

Christensen, Jeppe. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I711, 2009-2010*

Čutić, Nino. PhD student at the Department of Accelerator Physics, 2007-2010*.

Dahlström, Elisabeth. MAX-lab staff member: reception, office work, 2003-2010*

Demirkan, Medine. PhD student at the Department of Accelerator Physics, 1999-2003.

Edvardsson, Evelina. MAX-lab staff member: cleaning, 2000.

Ekstedt, Lillemor (f Persson). MAX-lab staff member: secretary, *1987-1991; administration, 1992-1999; personnel and executive support, 2000-2003. *See also list of board and committee members*.

El Afifi, El Sayed. MAX-lab staff member: design and construction, 2008-2010*

Engdahl, Anders. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline 73, 2004-2010*

Enquist, Henrik. MAX-lab staff member: design of the short-pulse facility for MAX IV, 2009-2010*

Eriksson, Mikael. Head of the accelerator physics group/department, *1987-2015. Deputy director of MAX-lab, 1992-2009. Manager of the machine group, 2002-2009. Machine director, 2010*

Forkman, Bengt. Director of MAX-lab, *1987-1990.

Forsberg, Johan. MAX-lab staff member: design of the new beamline I511, 2009-2010*

Friedrich, Thilo. PhD student at the Department of Accelerator Physics, 2007-2009.

Gaponov, Yury. MAX-lab staff member: software development of hard x-ray beamlines, 2009-2010*

Georgsson, Mattias. PhD student at the Department of Accelerator Physics, 1996-2001.

Gullberg, Anna-Lisa. MAX-lab staff member: cleaning, 1995-2000.

Hagman, Monica. MAX-lab staff member: cleaning, 1995-2003; office work, 2003.

Hansen, Kurt. MAX-lab staff member: maintenance of beamlines and experiment stations, 1992-1994; head of the user support group 1994-2010*, responsible for installation and maintenance of beamlines and experimental stations, 1994-1999.

Hansson, Anders. PhD student at the Department of Accelerator Physics, 2007-2010*

Haase, Dörthe. MAX-lab staff member: maintenance of hard x-ray beamlines and experimental stations, 2008-2010*

Hennies, Franz. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I511, 2008-2010*

Hunter Dunn, Jonathan. MAX-lab staff member: design, installation and maintenance of beamlines, 2000-2006.

Hägneryd, Fredrik. MAX-lab staff member: installations, 2000; electrical installations, 2001-2010*

Isaksson, Lennart. MAX-lab staff member: nuclear physics and radiation safety, 2004-2009; coordinator for nuclear physics and radiation safety, 2010*

Jensen, Brian N. MAX-lab staff member: design, installation and maintenance of beamlines, 1992-2009; stability, tolerances and vibrations and stability group manager, 2010*

Johannesson, Markus. MAX-lab staff member: IRUVX-PP project, 2009-2010*

Johansson, Lars-Gösta. MAX-lab staff member: electronics, *1987-1991; high-tension current systems for the accelerators, 1992-2010*; electrical installations, 2004-2010* *See also list of board and committee members*.

Johansson, Mikael. MAX-lab staff member: electronics for the experiments, 1995-2010*

Johansson, Per-Olof. MAX-lab staff member: economy, 2000-2001.

Johansson, Ulf. MAX-lab staff member: design, installation and maintenance of beamlines, 1997-1999; deputy manager of beamlines, 2000-2010*

Kendrup, Axel. MAX-lab staff member: maintenance, service, 2007-2010*

Key, W. MAX-lab staff member: electronics, *1987-1988.

Kumbaro, Dionis. MAX-lab staff member: injector system, 2004-2006; maintenance and operation of accelerators, 2007-2010*

Kvick, Åke. Guest professor and senior advisor, 2007-2010* *See also list of board and committee members*.

Larsson, Krister. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I911 and chemical safety, 2005-2008; head of computing services and control systems, 2009-2010*

Leandersson, Mats. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline D1011, 2000-2003; maintenance of beamlines and experimental stations, especially on beamline I3, 2010*

LeBlanc, Greg. PhD student at the Department of Accelerator Physics, 1994-2002. MAX-lab staff member: development and maintenance of the accelerator system, 2000-2002.

Leemann, Simon. Postdoc at the Department of Accelerator Physics, 2007-2009.

Lenngren, Claes. MAX-lab staff member: electrical installations, 2003-2010*

Lilja, Per. MAX-lab staff member: maintenance and operation of accelerators, 2007-2010*

Lindau, Filip. MAX-lab staff member: FEL test experiments and lasers, 2007-2008; FEL test experiments and laser safety, 2009-2010*

Lindau, Ingolf. Director of MAX-lab 1991-1997. Senior advisor, 2010*

Lindgren, Lars-Johan. Member of the accelerator physics group, *1987-2010*. Member of the MAX-lab staff: deputy manager of the machine group, 2008-2010*. Coordinator for accelerator physics research 1992-2010*.

Lundin, L. MAX-lab staff member: service, *1987-1991; maintenance and service, 1992-1998.

Lundin, Magnus. MAX-lab staff member: computers for the experiments, 1999-2010*; radiation safety, 2002-2010*

Malmgren, Lars. MAX-lab staff member: micro-wave electronics for the accelerator system, 1999-2010*

Milton, Steve. Adjunct professor at the Department of Accelerator Physics, 2002-2007.

Månsson, Anders. MAX-lab staff member: construction and vacuum, 1991; mechanical construction and vacuum for accelerators and beamlines, 1992-1998; maintenance of vacuum and cryo systems, 1999-2010*

Mårtensson, Nils. Director of MAX-lab, 1997-2010* *See also list of board and committee members*.

Mårtensson, S., deputy member of the MAX-lab board (representative of Lund University) *1987-1990.

Nilsson, Björn. MAX-lab staff member: nuclear physics, 2009-2010*

Nilsson, Catarina. MAX-lab staff member: cleaning, 2002-2010*

Nilsson, Dahn, MAX-lab staff member, computers for the experiments, 1995-1998.

Nilsson, Jens. MAX-lab staff member: programming, 2000.

Nilsson, Martin, MAX-lab staff member: workshop and mechanics, 1993-2010*

Nilsson, Mats. MAX-lab staff member: computers for the accelerator system, *1987-2010*

Nilsson, Robert. RF and diagnostics, 2007-2010*

Norén, Katarina. MAX-lab staff member: design, installation and maintenance of beamlines and experimental stations, especially beamline I811 and chemical safety, 2009; coordinator for hard x-ray (I711, I811, and I911) and chemical safety, 2010*

Nyberg, Annika. MAX-lab staff member: information officer, 2006-2010*

Nyholm, Ralf. Coordinator for synchrotron radiation research, *1987-2010*. Professor and head of the department of synchrotron radiaiton instrumentation, 1998-2010*.

Olofsson, Monica. MAX-lab staff member: reception, office work, 1996-1998.

Olsson, Lisbeth. MAX-lab staff member: cleaning, 2001-2010*

Persson, Bo. MAX-lab staff member: mechanics, *1987-1991; workshop and mechanics, 1992-2010*

Persson, Lillemor. See Ekstedt, Lillemor

Persson, Nils-Erik. MAX-lab staff member: mechanics, *1987-1991; workshop, especially weldings, 1992-2008.

Preobrajenski, Alexei. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline D1011, 2007-2010*

Roslund, Johnny. MAX-lab staff member: maintenance and operation of beamline 32, 1992-1995.

Roxendal, Mats. MAX-lab staff member: financial manager, 2002-2010*

Röjsel, Peter. Member of the accelerator physics group, *1987-1991, 1993-1996. MAX-lab staff member: electronics, 1991-1995; diagnostics and control systems for the accelerators, 1992-1995. PhD student at the Department of Accelerator Physics, 1992-1998.

Sankari, Rami. Lecturer at the Department of Synchrotron Radiation Instrumentation, 2009-2010*

Schmidt, Jerry. MAX-lab staff member: development and maintenance of the accelerator system, 2002-2003; development and maintenance of the accelerator system, especially insertion devices, 2004-2010*

Schrøder, Bent. Coordinator for nuclear physics research, *1987-1998, 2004-2010*. Deputy member of the MAX-lab board (representative of Lund University) *1986-1993. Senior advisor, 2010*

Schwenke, Jörg. PhD student at the Department of Synchrotron Radiation Instrumentation, 2007-2010*

Sjöström, Magnus. PhD student at the Department of Accelerator Physics, 2004-2009.

Sommarin, Bengt. MAX-lab staff member: installations, 2000-2009; alignment and installations, 2010*

Sondhauss, Peter. Research associate, Department of Synchrotron Radiation Instrumentation, 2002-2006. MAX-lab staff member: maintenance of beamlines and experimental stations, especially beamline D611, 2007-2008; design and simulation of x-ray optics, 2009-2010*

Stiefler, Werner. MAX-lab staff member, beamlines, *1987-1991; radiation safety, 1991-1995; installation and maintenance of beamlines, 1992-1995.

Svensson, Bertil. MAX-lab staff member: maintenance of hard x-ray beamlines and experimental stations, 2008-2010*

Svensson, Christer. MAX-lab staff member: programming, 2001-2008; software development for hard x-ray beamlines, 2009-2010*

Svensson, Håkan. MAX-lab staff member: mechanical construction and vacuum for accelerators and beamlines, 1999; manager of design and installations, 2000-2004; deputy manager of design and installations, 2005-2009; design and construction, 2010*

Svensson, Svante. Deputy director of MAX-lab, 2010*. *See also list of board and committee members.*

Tagger, Juri. Member of the accelerator physics group, 1989-1990. MAX-lab staff member: electronics, 1988-1991; electronics for the accelerator system, 1992-2009; accelerator control system developer 2010*

Tarawneh, Hamed. PhD student at the Department of Accelerator Physics, 2001-2006.

Tchaplyguine, Maxim. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I411, 2008-2010*

Thorin, Sara. PhD student at the Department of Accelerator Physics, 2004-2009.

Thånell, Johan. MAX-lab staff member: mechanics/vacuum for the construction of MAX II, 1993; maintenance of beamlines and experiment stations, 1994-2010*; automation/PLC, 2010*

Thånell, Leif. MAX-lab staff member: construction and vacuum, *1987-1991; head of the mechanical workshop and responsible for mechanical construction and vacuum for accelerators and beamlines, 1992-1999; deputy manager of design and installations, 2000-2004.

Törmänen, Markus. MAX-lab staff member: RF and diagnostics, 2004-2006.

Ullman, Helena. MAX-lab staff member: reception, office work, 1998-2002; personnel and executive support, 2003-2009; executive support, meetings coordinator, 2010*

Ursby, Thomas. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I911, 1999-2010*

Váncsa, András. MAX-lab staff member: installation and maintenance of computer systems, 2001-2009; computer support, 2010*

Väyrynen, J., Turku, Finland. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1997-1999.

Wallén, Erik. Research engineer at the Department of Accelerator Physics, 1996-1998. Research associate at the Department of Accelerator Physics, 2001-2010*

Werin, Sverker. Research associate at the Department of Accelerator Physics, 1992-1997. Lecturer at the Department of Accelerator Physics, 1998-2009. Professor at the Department of Accelerator Physics, 2010*

Wiklund, Stefan. MAX-lab staff member: maintenance of beamlines and experiment stations, 1993-2010*; safety manager, 2000-2010*

Wingren, Bengt-Erik. MAX-lab staff member: service, *1987-1991; maintenance and service, 1992-2010*

Zakharov, Alex. MAX-lab staff member: maintenance of beamlines and experiment stations, 2001-2008; maintenance of beamlines and experiment stations, especially the SPELEEM at beamline I311, 2009-2010*

Öhrwall, Gunnar. MAX-lab staff member: design, installation and maintenance of beamlines, especially beamline I1011, 2007-2010*

Appendix 4: List of MAX-lab Committee members, board members, etc, 1986-2010[617]

Abela, Rafael. Member of the MAX IV Scientific Advisory Committee, 2011-2015.

Åberg, S., Lund. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1995-2000.

Åberg, T. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1995-1997.

Ahrens, J. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 2001-2010.

Aksela, Helena. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2005-2010. Member of the MAX IV Scientific Advisory Committee, 2011-2012.

Aksela, Seppo. Member of the research board of MAX-lab for synchrotron radiation, 1988-1989. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1990.

Andersson, B. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1997-1998.

Annand, J.R.M. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1997-1998.

Arleth, Lise. Member of the FASM board, 2007-2009. Member of the MAX IV Scientific Advisory Committee, 2013-2015.

Asensio, M. C., Madrid, Spain. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1999-2010.

Åstrand, Maria. Member of the MAX IV Laboratory Board, 2011-2012.

Balewski, K., Hamburg, Germany. Member of the MAX IV Laboratory Machine Advisory Committee, 2010-2015.

Balewski, Klaus. Member of the MAX IV Laboratory Machine Advisory Committee, 2011-2015.

Bargholz, C., Stockholm. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1995-2006.

Bengtsson, P. Member of the MAX-lab board (student representative), 1991-1993.

[617] Extracted and compiled from the MAX-lab Activity Reports, 1987-2010, and the MAX IV "Highlights and Activities" Reports 2011-2015. Note that the time interval is 1986-2015 although in some cases tenure, functions, and periods of service may extend backwards in time, before 1986. An asterisk (*) is found with every instance of a tenure that begins with 1986, as a reminder that the time period likely (but not necessarily) extends backwards in time.

Berggren, T. Member of the research board of MAX-lab for energetic electrons, *1987-1989.

Blomqvist, J., Stockholm. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1990. Chairman of the Program Advisory Committee of MAX-lab for energetic electrons, 1991-1995.

Borg, Anne. Member of the MAX-lab board (representative of VR), 2007-2010.Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Börjesson, Lars. Chairperson of the MAX IV Laboratory Board, 2011-2012.

Børve, Knut, Bergen. Member of the FASM board, 2007-2013.

Braicovich, L., Milano, Italy. Member of the MAX-lab Scientific Advisory Committee (SAC), 2005-2010.

Brändén, Carl-Ivar, Stockholm. Member of the MAX-lab Scientific Advisory Committee (SAC), 1996-2002

Brookes, N., Grenoble, France. Member of the MAX IV Laboratory Programme Advisory Committee for Soft X-ray and IR science, 2011-2012

Brookes, Nicholas. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2012.

Carrondo, M. A., Lisbon, Portugal. Member of the MAX IV laboratory Scientific Advisory Committee (SAC), 2011.

Cederholm, O. Deputy member of the MAX-lab board (employee representative) 1989-1990. *See also list of staff and faculty*.

Chandesris, D., Paris, France. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2002-2010.

Daillant, Jean. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2011-2015.

Debevec, P., Urbana, Il, USA. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1998-2000. Chairman of the Program Advisory Committee of MAX-lab for energetic electrons, 2001-2006.

Djinovic-Carugo, Kristina. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2013-2015.

Dosch, Helmut. Member of the MAX IV Laboratory Board, 2011-2015.

Eberhardt, Wolfgang. Member of the MAX IV Scientific Advisory Committee, 2011-2012.

Eberson, Lennart, member of the MAX-lab board (representative of Lund University) 1994-1997.

Edström, K., Uppsala University, Sweden. Member of the board of the MAX IV laboratory, 2010-2015.

Edström, Kristina. Member of the MAX IV Laboratory Board, 2011-2015.

Ekedahl, L. G., member of the MAX-lab board (representative of NFR) 1996-1999.

Ekstedt, Lillemor (f Persson). Member of the MAX-lab board (employee representative) *1987-1993. *See also list of staff and faculty*.

Erman, P., deputy member of the MAX-lab board (scientists/users representative) 1991-1993.

Fahlman, Anders. Chairman of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1990-1995.

Fahlman, Mats, Linköping. Member of the MAX-lab board (representative of VR), 2000-2007. Member of the MAX-lab board (representative of the users), 2007-2010.Chairman of FASM, 2004-2006. Member of the board of the Swedish Synchrotron Radiation Users Organisation (SSUO), 2011-2015.

Fäldt, G., Uppsala. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 2001-2006.

Feidenhans'l, R., Roskilde, Danmark. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1997-2010.

Fitch, Andrew N. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2011-2015.

Flavell, Wendy. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Flodström, Anders, member of the MAX-lab board (representative of STU) 1988-1990.

Forsén, Sture, member of the MAX-lab board (representative of Lund University) 19xx-1993, member of the MAX-lab board (representative of NFR) 1994-1997.

Fourme, R., Orsay, France. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1999-2010.

Friborg, Göran, deputy member of the MAX-lab board (representative of STU) 19xx-1990,

Friis Poulsen, Henning. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2011-2015.

Gajhede, Mikael. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2003-2010. Member of the MAX IV Laboratory Programme Advisory Committee for X-ray science, 2011-2015.

Gidefeldt, Lars, member of the MAX-lab board (representative of NFR) 19xx-1993.

Gräslund, A., Deputy member of the MAX-lab board (scientists/users representative) 1992-1993. Member of the research board of MAX-lab for synchrotron radiation, *1987-1989.

Grenthe, I., member of the MAX-lab board (representative of NFR) 1991, deputy member of the MAX-lab board (representative of TFR) 1992-1993.

Hämäläinen, Keijo. Member of the MAX IV Scientific Advisory Committee, 2013-2015.

Hedin, L. Member of the research board of MAX-lab for synchrotron radiation, *1987-1989.

Hertz, Hans. Chairman of the MAX IV Laboratory Board, 2013-2015.

Hettel, Bob. Member of the MAX IV Laboratory Machine Advisory Committee, 2011-2015.

Hirschmugl, Carol. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Hofmann, Philip. Member of the MAX IV Scientific Advisory Committee, 2013.

Höistad, B., Uppsala. Chairman of the Program Advisory Committee of MAX-lab for energetic electrons, 2007-2010.

Horn, Karsten. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Hultman, Lars. Member of the MAX IV Laboratory Board, 2011-2012.

Hunter, Bill. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2011-2012.

Huttula, Marko. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2013-2015.

Isaksson, L. Member of the MAX-lab board (student representative) 1990-1993.

Johansson, Börje, Uppsala. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1990-2004. Chairman of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2005-2010. Chairman of the MAX IV laboratory Scientific Advisory Committee (SAC), 2011-2012.

Johansson, Lars-Gösta. Deputy member of the MAX-lab board (employee representative) 1991-1993. *See also list of staff and faculty*.

Johansson, Lars. Chairperson of the MAX IV Laboratory Program Advisory Committee (PAC), 2011-2015.

Johansson, Leif I., member of the MAX-lab board (scientists/users representative) 1997-1999. Secretary of FASM, 1992-1993.

Källne, Elisabeth, see Rachlew-Källne, Elisabeth.

Kanski, Janusz. Member of the MAX-lab board (representative of the users), 2000-2007.

Karlsson, B., deputy member of the MAX-lab board (representative of NFR) 19xx-1993,

Karlsson, Ulf. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1995-1997. Chairman of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1997-2005. Chairman of FASM, 1991-1993. Member of the FASM board, 1994-1996.

Kasemo, B., deputy member of the MAX-lab board (representative of NFR) 1991.

Kiskinova, Maya. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Kloo, Lars, Member of the MAX-lab board (representative of VR), 2007-2010

Knight, S., Uppsala. Member of the FASM board, 2003-2006.

Koch, E. E., Berlin. Member of the research board of MAX-lab for synchrotron radiation, *1987.

Köllerström, B., member of the MAX-lab board (employee representative) 19xx-1993.

Korsunsky, Alexander. Member of the MAX IV Scientific Advisory Committee, 2013-2015.

Kukk, Edwin, Oulu, Finland. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2000-2004. Member of the MAX IV Laboratory Programme Advisory Committee for Soft X-ray and IR science, 2011-2012. Member of the FASM board, 2007-2009.

Kunz, Christof. Member of the research board of MAX-lab for synchrotron radiation, 1988-1989. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1990. Member of the International Reference Group for the MAX II Project, 1992-1996. Member of the MAX-lab Scientific Advisory Committee (SAC), 1996-2004

Kuske, Peter. Member of the MAX IV Laboratory Machine Advisory Committee, 2011-2015.

Kvick, Åke. Member of the MAX-lab board (representative of NFR/VR) 1998-2007. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1997-2010. Member of the MAX IV Laboratory Programme Advisory Committee for Synchrotron Radiation, 2011. *See also list of staff and faculty.*

l'Huillier, Anne. Member of the MAX IV Laboratory Board, 2011-2015.

Larsen, Sine. Member of the MAX IV Laboratory Board, 2011.

Lidin, Sven. Chairman of the MAX-lab Scientific Advisory Committee (SAC), 2005-2010.

Liljas, Anders. Member of the MAX-lab board (representative of Lund University) 1998-2007. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1991-1997.

Linder-Aronson, Lennart, Chairman of the MAX-lab board 1988-2001.

Logan, Derek, LU. Member of the board of the Swedish Synchrotron Radiation Users Organisation (SSUO), 2011-.

Magnusson, T., deputy member of the MAX-lab board (employee representative) 1988-1993

Malmqvist, Helena. Member of the MAX IV Laboratory Board, 2013-2015.

Margaritondo, Giorgio. Member of the MAX IV Scientific Advisory Committee, 2011-2012.

Mårtensson, Nils. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1990-1994. Chairman of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1995-1997. *See also list of staff and faculty.*

Martinson, Indrek, Vice-chairman of the MAX-lab board (representative of Lund University), *1987-1990, member of the MAX-lab board (representative of Lund University), 1991-1993.

Mathiesen, Ragnvald. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2011-2015.

McCusker, Lynne. Member of the MAX IV Scientific Advisory Committee, 2011-2012.

Miron, Catalin. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Molenbroek, Alfons. Member of the MAX IV Scientific Advisory Committee, 2011-2015.

Morin, P., Paris, France. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2002-2007

Mülhaupt, G., Grenoble. Member of the International Reference Group for the MAX II Project, 1992-1996. of the MAX-lab Scientific Advisory Committee (SAC), 1996.

Nave, C., Daresbury, UK. Member of the MAX-lab Scientific Advisory Committee (SAC), 2005-2010.

Neutze, Richard. Member of the FASM board, 2007-2013.Member of the MAX IV Laboratory Board, 2013-2015.

Nilsson, D., deputy member of the MAX-lab board (student representative) 1988-1989.

Nilsson, L. Member of the research board of MAX-lab for energetic electrons, *1987-1989. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1990-1995. Deputy member of the MAX-lab board (representative of STU) *1987-1990, member of the MAX-lab board (scientists/users representative) 1991-1993.

Nilsson, Per-Olof, member of the MAX-lab board (scientists/users representative) 1991-1996. Contact person for FASM, *1987-1991. Member of the FASM board, 1992-1996.

Nordén, B. Member of the research board of MAX-lab for synchrotron radiation, *1987-1989. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1990.

Nordgren, Joseph, member of the MAX-lab board (scientists/users representative) 19xx-1990. Member of the FASM board, 1992-1993. Chairman of the International Reference Group for the MAX II Project, 1992-1996. Chairman of the MAX-lab Scientific Advisory Committee (SAC), 1996-2004. Chairman of the MAX IV laboratory Scientific Advisory Committee (SAC), 2013-2015.

Odeskog, C., member of the MAX-lab board (representative of Lund University) 1998-2007.

Olsson, G., deputy member of the MAX-lab board (representative of Lund University) 1991-1993.

Olsson, Ulf. Member of the MAX IV Laboratory Board, 2013-2015.

Owens, R., Glasgow. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1995-1996. Chairman of the Program Advisory Committee of MAX-lab for energetic electrons, 1997-2000.

Pape Møller, Søren. Member of the MAX IV Laboratory Machine Advisory Committee, 2011-2015.

Patthey, Luc. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Persson, Ingmar, SLU, Uppsala. Member of the FASM board, 2004-2006. Chairman of FASM, 2007-2013.

Petersson, L. G., member of the MAX-lab board (representative of NFR) 1994-1995.

Phillips, D., Ohio, USA. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 2007-2010.

Piamonteze, Cinthia. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2013-2015.

Pilotti, A.-M., member of the MAX-lab board (representative of TFR) 1992-1993.

Rachlew (formerly Källne), Elisabeth. Deputy member of the MAX-lab board (scientists/users representative) *1987-1990. Member of the FASM board, 1997-1999.

Reichert, Harald. Member of the MAX IV Scientific Advisory Committee, 2011-2015.

Reineck, Ingrid. Member of the MAX IV Laboratory Board, 2011.

Rigler, R., Stockholm. Member of the FASM board, 1992-1993.

Rivkin, Lenny. Chairperson of the MAX IV Laboratory Machine Advisory Committee, 2011-2015.

Robinson, Ian. Member of the MAX IV Scientific Advisory Committee, 2011-2012.

Rubensson, Jan-Erik, Uppsala. Chairman of FASM, 2000-2003. Member of the FASM board, 2003-2006.

Salaneck, William, Member of the research board of MAX-lab for synchrotron radiation, *1987-1989.

Sandell, A., member of the MAX-lab board (student representative) *1987-1989,

Schertler, Gebhard. Member of the MAX IV Scientific Advisory Committee, 2011-2015.

Schoch, B. Member of the research board of MAX-lab for energetic electrons, *1987-1989. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1990. Member of the MAX-lab Scientific Advisory Committee (SAC), 1996-2010.

Skogö, Ingemar. Chairman of the MAX-lab board, 2002-2010.

Skopik, D., Saskatchewan, Canada. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 1991-1995. Chairman of the Program Advisory Committee of MAX-lab for energetic electrons, 1995-1997.

Söderström, B. Member of the MAX-lab board (representative of Lund University), 2007-2010.

Sommarin, Marianne.Member of the MAX IV Laboratory Board, 2013-2015.

Sonntag, Bernt. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1991-2004.

Sörensen, Stacey. Member of the MAX-lab board (representative of Lund University), 2007-2010. Member of the board of the MAX IV laboratory, 2010-2012.

Ståhl, Kenny. Member of the FASM board, 1994.

Streijffert, Bengt, member of the MAX-lab board (representative of Lund University) 1994-1997.

Sundström, V., Umeå. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1992-1997.

Suoninen, E., Turku, Finland. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1991-1994.

Svensson, Anders. Member of the FASM board, 1995-2002.

Svensson, Svante. Member of the MAX-lab board (scientists/users representative) 1994-2010. Chairman of FASM, 1994-1999. Member of the FASM board, 2000-2006. *See also list of staff and faculty*.

Tazzari, S. Rome. Member of the International Reference Group for the MAX II Project, 1992-1996. of the MAX-lab Scientific Advisory Committee (SAC), 1996-2004

Tjeng, L. H., Köln, Germany. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 2002-2010.

Tromp, Moniek. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for X-ray science, 2013-2015.

Uhrberg, Roger, member of the MAX-lab board (scientists/users representative) *1987-1990. Secretary of FASM, 1994-2003.

van der Rest, Michel. Member of the MAX IV Laboratory Board, 2011-2015.

Vartaniants, Ivan. Member of the MAX IV Scientific Advisory Committee, 2013-2015.

Walker, Richard. Member of the MAX IV Laboratory Machine Advisory Committee, 2011-2015.

Walldén, L., Gothenburg. Member of the FASM board, 1997-2003.

Watts, D., Edinburgh, UK. Member of the Program Advisory Committee of MAX-lab for energetic electrons, 2007-2010.

Wilson, K., York, England. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1998-2010.

Woodruff, Phil. Member of the Program Advisory Committee of MAX-lab for synchrotron radiation, 1991-2010. Member of the MAX IV Scientific Advisory Committee, 2011-2015.

Wrulich, A. Villigen, Switzerland. Member of the MAX-lab Scientific Advisory Committee (SAC), 2005-2010.

Wurth, Wilfried. Member of the MAX IV Laboratory Program Advisory Committee (PAC) for Soft X-ray and IR science, 2011-2015.

Appendix 5: Postdoctors and visiting scientists listed in the MAX-lab Activity Reports, 1998-2010[618]

Adell, Johan. Postdoctor, beamline 41, 2007-2008, affiliated with Chalmers University of Technology, Gothenburg.

Adell, Martin. PhD student, beamline 41, 2001-2004, affiliated with Chalmers University of Technology, Gothenburg and MAX-lab. Postdoctor, beamline 33 and 41, 2005-2007, affiliated with MAX-lab.

Agåker, Marcus. Researcher, beamline I511, 2010*, affiliated with Uppsala University.

Andersson, Tomas. PhD student, beamline I411, 2009-2010*, affiliated with Uppsala University.

Arvanitis, Dimitri. Researcher, beamline I1011, 2002-2008, affiliated with MAX-lab. and Uppsala University.

Attal, Maher. PhD student, accelerator physics, 2007, affiliated with MAX-lab., MAXLAS Marie Curie fellowship.

Balasubramanian, Thigaraian. Postdoctor, beamline 33, *1998-1999, affiliated with MAX-lab.

Bergersen, Henrik. PhD student, 2005-2008, affiliated with Uppsala University and MAX-lab.

Björneholm, Olle. Researcher, beamline I411, 2010*, affiliated with Uppsala University.

Bogdanov, Alex. Guest researcher, beamline D811, *1998-2002, affiliated with MAX-lab.

Boland, Mark. Postdoctor, nuclear physics, 2001-2003, affiliated with MAX-lab.

Bovet, Nicolas. Postdoctor, beamline I811, 2005-2008, affiliated with MAX-lab.

Brudvik, Jason. Postdoctor, nuclear physics, 2008-2009, affiliated with MAX-lab.

Bässler, Margit. Research associate, beamline I411, *1998-2000, affiliated with Uppsala University.

Céolin, Denis. Postdoctor, beamline I411, 2002-2006, affiliated with MAX-lab.

Chatbi, Hassan. Guest researcher, beamline D811, 1999, affiliated with MAX-lab.

Clausén, Maria. Postdoctor, beamline I811, 2004-2007, affiliated with MAX-lab.

Curbis, Francesca. PhD student, FEL test experiments, 2008, affiliated with MAX-lab, MAXLAS Marie Curie fellowship.

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[618] Extracted and compiled from the MAX-lab Activity Reports, 1998-2010. Postdocs and visiting scientists are listed neither in the activity reports prior to 1998, nor in the MAX IV "Highlights and Activities" reports of 2011-2015. Note that the time interval is 1998-2015 although in some cases tenure, functions, and periods of service may extend backwards in time, before 1998, and forwards in time, beyond 2010. An asterisk (*) is found with every instance of a tenure that begins with 1998 and/or ends with 2010, as a reminder that these time periods likely (but not necessarily) extend forwards or backwards in time.

Denecke, Reinhard. Postdoctor, beamline I511, *1998-1999, affiliated with MAX-lab.

Dulancic, Samir. Student, 2005-2007, affiliated with the University of Applied Sciences, Berlin, Germany.

Dünnermann, Jens. Student, beamline I511, 2007, affiliated with the University of Applied Sciences Lippe, Höxter, Germany.

Fissum, Kevin. Researcher, nuclear physics, 2010*, affiliated with Lund University.

Flatken, Markus. Student, beamline I511, 2007, affiliated with the University of Applied Sciences Lippe, Höxter, Germany.

Fodje, Michel. Researcher, beamline I911, 2002-2006, affiliated with Novo Nordisk A/S and MAX-lab.

Friedrich, Thilo. Student, beamline I1011 and accelerator physics, 2005-2006, affiliated with MAX-lab.

Garnier, Michael Gunnar. Postdoctor, beamline I511, *1998-2000, Swiss funding.

Gerull, Kerstin. Student, 2008, affiliated with the University of Applied Sciences, Berlin, Germany.

Gisselbrecht, Mathieu. Postdoctor, beamline I411, 2000-2002, affiliated with MAX-lab.

Glover, Chris. Postdoctor, beamline I511, 1999-2001, affiliated with MAX-lab.

Gorovikov, Sergey. Postdoctor, beamline I311, 1999-2003, affiliated with MAX-lab.

Goryl, Pjotr. Visiting scientist, accelerators, 2009-2010*, affiliated with MAX-lab.

Graham, Stephen. PhD student, beamline I911, 2003-2004, affiliated with University of Sydney, Australia.

Grehk, Mikael. Reasearch associate, beamline I811, *1998-1999, affiliated with Chalmers University of Technology, Gothenburg.

Gridneva, Lidia. Postdoctor, beamline I511/3, 2000-2002, affiliated with MAX-lab. Postdoctor, beamline I811, 2003-2008, affiliated with MAX-lab. Researcher, beamlines D1011 and I1011, 2007-2008, affiliated with Uppsala University and MAX-lab.

Gundlach, Carsten. Postdoctor, beamline I1811, 2009, affiliated with MAX-lab.

Hansen, Tue N. Postdoctor, beamline D611 and accelerator physics 2003-2006, affiliated with MAX-lab.

Harb, Maher. Postdoctor, beamline D611, 2010*, affiliated with Lund University.

Hennies, Franz. Postdoctor, beamline I511, 2005-2007, affiliated with MAX-lab.

Håkansson, Maria. Research engineer, protein crystallization facility, 2005-2010*, affiliated with SARomics Biostructures AB.

Jurgilaitis, Andrius. PhD student, beamline D611, 2010*, affiliated with Lund University, Faculty of Technology.

Kennedy, Brian. Postdoctor, beamline I511, 2010*, affiliated with MAX-lab.

Kjeldgaard, Lisbeth. Postdoctor, beamline I511, 2001-2005, affiliated with MAX-lab.

Knaapila, Matti. Postdoctor, beamline I711, 2005-2008, affiliated with MAX-lab.

Kowalik, Iwona. Postdoctor, beamline I1011, 2007-2010*, affiliated with MAX-lab.

Käämbre, Tanel. Postdoctor, beamline I511, 2002-2008, affiliated with University of Tartu, Estonia and MAX-lab.

Labrador, Ana. Researcher, beamline I911-4, 2010*, affiliated with MAX-lab.

Larsson, Jörgen. Researcher, beamline D611, 2010*, affiliated with Lund University.

Larsson, Krister. Postdoctor, beamline I911, 2003-2004, affiliated with Lund University and MAX-lab.

Le Cann, Xavier. Postdoctor, beamline D1011, *1998-1999, affiliated with MAX-lab.

Leandersson, Mats. Research engineer, beamline I3, 2009, affiliated with Chalmers University of Technology, Gothenburg.

Lindblad, Andreas. Researcher, IRUVX-PP, 2010*, affiliated with Uppsala University.

Ling Ng, May. PhD student, beamline D1011, 2007-2010*, affiliated with Uppsala University.

Ljungbertz, Erik. Research engineer, nuclear physics, 2003, affiliated with MAX-lab.

Logan, Derek. Researcher, beamline I911, 2010*, affiliated with Lund University and MAX-lab.

Miron, Catalin. Postdoctor, beamline I411, *1998-2000, affiliated with Uppsala University.

Nagasono, Mitsuru. Postdoctor, beamline I511, *1998-2000, affiliated with MAX-lab.

Nelander, Bengt. Researcher, beamline 73, 2007-2010*, affiliated with MAX-lab.

Nilsson, Björn. Research engineer, nuclear physics, 2007, affiliated with MAX-lab.

Nordlund, Dennis. PhD student, beamline I511, 1999-2000, affiliated with Uppsala University.

Norén, Katarina. Postdoctor, beamline I811, 2007-2008, affiliated with MAX-lab.

Nygaard, Jesper. PhD student, beamlines I711 and I911, 2009-2010*, affiliated with the University of Copenhagen and MAX-lab.

Nüske, Ralf. PhD student, beamline D611, 2010*, affiliated with Lund University.

Ottosson, Niklas. PhD student, 2008, affiliated with Uppsala University and MAX-lab.

Pal, Prabir. Postdoctor, beamline I3, 2009-2010*, affiliated with Uppsala University.

Palaudoux, Jérôme. Postdoctor, beamline I411, 2007-2008, affiliated with Uppsala University and MAX-lab.

Palmgren, Pål. Researcher, beamline I3, 2008, affiliated with MAX-lab.

Peredkov, Sergey. Scholarship, beamline D811, *1998-2007, affiliated with MAX-lab and Lund University.

Persson, Andreas. PhD student, beamline I1011, 2007-2009, affiliated with Uppsala University.

Pietsch, Annette. Postdoctor, beamline I511, 2008-2009, affiliated with MAX-lab.

Plivelic, Tomás. Postdoctor, beamlines I711 and I911, 2008-2009, affiliated with MAX-lab.

Preobrajenski, Alexei. Postdoctor, beamline D1011, 2001-2006, affiliated with MAX-lab.

Pugachov, Dmytro. Postdoctor, nuclear physics, 2004-2007, affiliated with MAX-lab.

Rosso, Aldana. PhD student, beamline D1011, 2004-2008, affiliated with Uppsala University and MAX-lab.

Rubensson, Jan-Erik. Researcher, beamline I511, 2007-2008, affiliated with Uppsala University and MAX-lab.

Sadowski, Janusz. Postdoctor, beamline 41, *1998-2003, affiliated with MAX-lab, Lund University, the University of Copenhagen, Chalmers University of Technology, and the Polish Academy of Sciences, Krakow. Researcher, beamlines 41 and I3, 2008-2009, affiliated with MAX-lab.

Sanyal, Biplab. Postdoctor, theory, 2000-2001, affiliated with MAX-lab.

Schiessling, Joachim. Researcher, beamline I411, 2005-2006, affiliated with Uppsala University and MAX-lab.

Schmitt, Thorsten. Postdoctor, beamline I511, 2003-2005, affiliated with the Royal Institute of Technology, Stockholm and MAX-lab.

Schulte, Karina. Postdoctor, beamline I311, 2008-2009, affiliated with MAX-lab.

Schulz, Joachim. Postdoctor, beamline I411, 2002-2006, affiliated with Uppsala University, Oulu University, Finland, and MAX-lab.

Srivastava, Abk. Researcher, beamline D611 and I411, 2007, affiliated with MAX-lab, Lund University and Oulu University, Finland.

Steven, Mary. Postdoctor, beamline I911, 2004-2006, affiliated with MAX-lab.

Stoltz, Sven. Postdoctor, beamline I311, 2004-2007, affiliated with MAX-lab.

Szamota-Sadowska, Karoline. PhD student, beamline 41, 1999-2000, affiliated with the Royal Institute of Technology, Stockholm

Såthe, Conny. Research Engineer, beamline I511, 2010*, affiliated with Uppsala University.

Tarawneh, Hamed. Guest researcher, accelerators, 2000, affiliated with MAX-lab.

Taylor, Wendy. Research engineer, protein crystallization facility, 2004-2006, affiliated with MAX-lab.

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An ex post impact study of MAX-lab

MAX-lab was a Swedish national research facility for synchrotron radiation, nuclear physics, and accelerator physics, in operation between 1986 and 2015 and located on the northern campus of Lund University. This report is the result of a comprehensive analysis of the impact of MAX-lab on science, economy, and society, and on local, national and international level. The report is based on official documentation, statistics, interviews, and previous studies of the history of MAX-lab. Its analysis and conclusions contribute to a broader and deeper understanding of the role of research infrastructures in science and society.

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