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Editor: Jörgen Larsson

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Introduction

The Division of Atomic Physics, Lund Institute of Technology (LTH), is responsible for basic physics teaching in all engineering disciplines and for specialised teaching in optics, atomic physics, spectroscopy, laser physics and applications of these disciplines. Research activities at the Division are mainly carried out in the fields of basic and applied spectroscopy, largely based on the use of lasers. The Division is also one of eight divisions comprising the Department of Physics, Lund University. Since 1980, biennial progress reports have been issued within the series Lund Reports on Atomic Physics (LRAP). Our latest report, covering 1995-96 was LRAP-228, preceded by the reports LRAP-20. LRAP-43, LRAP-85, LRAP-90, LRAP-119, LRAP-144 and LRAP-172. The present report describes the activities of our division during the calendar years 1997 and 1998.

Research at the Division of Atomic Physics takes place in a multi-disciplinary atmosphere, in which informal collaboration with external scientists and industry forms an important part. The Division is part of the Lund Laser Centre (LLC) which based on a long informal existence, was officially established at Lund University on March 28, 1995, directly under the Rectorate of Lund University. Other members are the Division of Combustion Physics (Prof. Marcus Aldén), the Division of Atomic Spectroscopy (Profs I. Martinson/Se. Johansson) and the Division of Chemical Dynamics at the Chemical Centre (Prof. Villy Sundström). The Lund University Medical Laser Centre is also part of the LLC, and two other umbrella organisations, the Combustion Centre and The Centre for Environmental Measurement Techniques are associated members. The Board of the LLC includes members from the Technical, Natural Sciences and Medical Faculties of Lund University. The chairman of the board, Prof. Bengt E.Y. Svensson, is appointed by the rector as the director of the LLC, S. Svanberg.

Within the Access to Large-Scale Facilities Scheme, the EC provides funding for visiting researchers to the LLC by European research groups. The Division has benefited considerably from this programme, which has resulted in many joint projects. The LLC is part of a cluster of Large-Scale Facilities, which also includes LENS - University of Florence, LOA - Ecole Polytechnique, Palaiseau, The Max-Born Institute, Berlin and ULF-Forth, Heraklion. The interaction with our sister facilities, especially within the FIRE programme for high-power laser development, where our division is a partner, has also strengthened our European links.

At the High-Power Laser Facility, which is operated by the Division of Atomic Physics, a vigorous research programme is being pursued, co-ordinated by Dr. Claes-Göran Wahlström. The facility was inaugurated at the end of 1992 and the equipment, spear-headed by a multi-terawatt chirped-pulse amplification titanium sapphire system, is successively being upgraded. A grant of SEK 10 million from the Knut and Alice Wallenberg Foundation has been instrumental during the last two years for keeping the facility at the technical frontier. The facility is the main experimental resource for our basic atomic physics research programme, and is also used for applications. High harmonics have been studied extensively. Optimisation of the generation with regard to the atomic response and phase-matching has been pursued and coherence properties have been investigated. Schemes for attosecond pulse formation are being studied. The experimental programme is accompanied by strong activities in the theoretical description of the phenomena, headed by Prof. Anne L'Huillier. She was awarded the prestigious Gustafsson Prize, carrying substantial research funding for a three-year period. We congratulate Anne on her accomplishments! The harmonic generation programme was further strengthened by the award of an NFR research associate position to Dr Mette Gaarde, won in national competition.

Another aspect of the high-power laser/matter interaction programme is the generation of broadband X-rays by focusing terawatt radiation pulses on rotating solid targets. The properties of the radiation are being studied with regard to spectral content and temporal evolution. Collaboration with the Friedrich Schiller Universtät Jena in the field of hard X-ray crystal spectroscopy, as part of an EC funded TMR Research Network, has been a valuable aspect. Radiological applications are being investigated, including gated X-ray imaging for suppression of scattered radiation. Time-gated X-ray tomography has recently been demonstrated in a generic experiment. The temporal behaviour of softer X-ray pulses has been studied with time-resolved X-ray diffraction studies in mind. Dr Jörgen Larsson returned to the group after an extended post-doc period in Berkeley after having won an NFR research associate position in National competition. This research programme also includes the use of fast synchrotron radiation pulses and is thus closely linked to the MAX-lab facility in Lund.

Extensive research activities concerning time-resolved laser spectroscopy in the VUV and XUV spectral regions have also been pursued. In a ns-pulse set-up four-wave mixing or Raman shifting are used in the generation process, while a ps system utilizes low-harmonic generation. Rydberg sequences in free atoms have been investigated, and resonance lines in atoms and ions, observed by the Hubble Space Telescope. A laser-produced plasma has been used in many experiments to produce atoms and ions, also in metastable states. XUV spectroscopy has included studies of astrophysically interesting molecular lifetimes and excited-state photo-ionisation experiments on the fundamental atom helium.

The X-ray microscopy group was transferred to the Royal Institute of Technology, Stockholm, following the appointment of Hans Hertz as professor of Physics, at KTH from January 1, 1998. We regret the loss but congratulate Hans and wish him and his group continuing success in their endeavours!

Photon echoes are being used for the investigation of relaxation processes in rare-earth-ion-doped crystals at liquid-helium temperatures and are being tested as a means of optical storage and processing. Different all-optical operations are being implemented using photon-echo techniques. This programme, headed by Dr Stefan Kröll, has recently been augmented by basic quantum optics studies including photon self-interference.

Applied molecular spectroscopy at the Division of Atomic Physics is headed by Dr Hans Edner, and includes atmospheric remote sensing using differential absorption lidar monitoring of atmospheric pollutants and fluorescence lidar studies of vegetation. Apart from monitoring of industrial effluents, the atmospheric work is focused on geophysical gas emissions from mining, geothermal and volcanic activities. In the summer of 1997, a third series of seaborne experiments to study Italian volcanic effluents was performed in collaboration with the Italian Research Council. During the last two years, techniques for IR differential absorption lidar have been implemented for hydro-carbon monitoring. Optical parametric oscillator technology is being employed and extensive control and steering systems have been constructed. Diode laser spectroscopy for applied gas monitoring is being pursued with the frequency modulation technique. Furthermore, a project on working environment studies using optical techniques, in particular diode laser particle monitoring and gas correlation passive imaging of gas leaks, is being pursued. A spectacular study of the facade of Lund Cathedral has been carried out using fluoresence Lidar techniques.

The research activities within the Lund University Medical Laser Centre have further developed during the last two years. A main part of the research deals with malignant tumour detection and treatment. A core group consisting of more than 10 physicists and physicians is now located together at the Department of Physics, ensuring close and daily interaction. The activity is headed by Dr Stefan Andersson-Engels (physics) and Dr Katarina Svanberg (medicine). Members from this group also participate in a large number of projects at other departments and clinics. Particularly active clinical departments in this collaboration are Oncology, Dermatology, ENT, Surgery, Urology, Radiology and Pathology at the Lund University Hospital. A study of colon cancer has been performed at the Endoscopy Unit of the Karolinska Hospital in Stockholm and gyneacological malignancies were studied at the Vilnius University Hospital, Lithuania. Raman- and near-IR spectroscopy are developed as alternative diagnostic techniques, in particular for cardiovascular diseases. A BIOMED-II research project in this field is co-ordinated by the Lund group. Photodynamic treatment has now been firmly established in Lund with the treatment of hundreds of tumours. The use of the haem precursor ALA, applied topically to the lesion or administered orally, has meant a breakthrough in the clinical application. A clinical study of basal cell carcinomas was successfully completed. Apart form assessing the therapeutical results, fluorescence and Doppler perfusion imaging have been used to gain insight into the processes involved. Advanced equipment for fluorescence and Raman diagnostics as well as for interactive, interstitial tumour treatment has been developed. Laser-induced hyperthermia is also being developed aimed at the treatment of benign prostatic hyperplasia. In order to detect deeper lesions we are developing techniques for tissue transillumination. The long-term goal of this research is to achieve an optical mammographic method for screening without the use of ionising radiation. Promising results have been obtained with techniques varying from terawatt laser-induced white-light illumination to diode-laser time-resolved spectroscopy.

Fluorescence and scattering spectroscopy are being employed for the characterisation of paper and pulp in an industrially oriented programme headed by Professors Willy Persson and Lennart Malmqvist. Optical and laser techniques are also being utilised in another industrial project, in which the insulating properties of air are being studied. Laser-induced breakdown in induced in order to study how space and surface charges influence the breakdown resistance of high voltage insulators. The project, which is supported by ABB, is aimed at an increased understanding of the origins of electric breakdown.

In our report series, *Lund Reports on Atomic Physics* (*LRAP*), material which is not published in international journals is presented. The reports include Master´s dissertations, doctoral theses and special investigations. So far about 240 papers have appeared in this series. At the end of the period covered by this Progress Report the staff of the Division of Atomic Physics totalled about 75. It is through the dedicated work of all the research, teaching and support staff that the accomplishments reported here have been made possible.

The Division is responsible for an extensive teaching programme ranging from the basic physics courses in the various branches of the Engineering School, to advanced elective courses, aimed mainly at Engineering Physics students, which constitute the major recruitment base for our research programme. Elective courses, given by the division include *Atomic and Molecular Spectroscopy, Advanced Optical Techniques, Laser Physics, Optical Quantum Electronics, Non-linear Optics, Tissue Optics, and Multi-spectral imaging.*

We are very grateful for the support of a large number of funding agencies, in particular the European Commission, the Swedish Natural Science Research Council (NFR), the Swedish Research Council for the Engineering Sciences (TFR), the Swedish Board for Technical and Industrial Development (NUTEK), the Swedish Space Board (RS), the Swedish Cancer Society (RmC), the Swedish Medical Research Council (MFR), the Knut and Alice Wallenberg Foundation (KAW) and the Crafoord Foundation.

Special thanks are due to Dr Jörgen Larsson, who has invested a great deal of time, patience and skill in serving as the editor of this progress report.

Sune Svanberg
Head of the Division of Atomic Physics

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Dr. Carlo Altucci (University of Naples, Italy)
Dr. P. Aruna (Anna University, India)
Dr. Philippe Balcou (CE de Saclay, France)
Dr. Marco Bellini (LENS, Florence, Italy)
Dr. Uldis Berzinsh (University of Latvia, Riga)
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Dr. Gianluca Valentini (University of Milan, Italy)
M.Sc. Alexandre Valette (CE de Saclay, France)
B.Sc. Gunnar Öhrwall (University of Uppsala, Sweden)

Ph.D. Theses

Lars Rymell	97-05-23	A new laser-plasma x-ray source for microscopy and lithography LRAP-214
Tomas Starczewski	97-09-26	Generation of coherent short-wavelength radiation – High-order harmonics and x-ray lasers LRAP-218
Mette Gaarde	97-09-30	High harmonic generation and two color mixing in strong laser fields (formally University of Copenhagen)
Annika Enejder	97-10-27	Light scattering and absorption in tissue-models and measurements LRAP-219
Baozhu Luo	98-06-10	Optical memories and processing in time- and frequency-domains LRAP-233
Christian Sturesson	98-10-24	Medical laser-induced thermotherapy models and applications LRAP-235
Matthias Grätz	98-11-06	Characterisation and application of a laser-based hard x-ray source LRAP-236

Licenciate Degree

Charlotta Lindquist	97-09-25	Development and evaluation of optical techniques for tumour detection LRAP-224

DIVISION OF ATOMIC PHYSICS
LUND INSTITUTE OF TECHNOLOGY
Head: S. Svanberg
Deputy heads: A. L'Huillier, W. Persson

Research Programme

Basic Atomic Physics	Applied Optics and Quantum Electronics	Applied Molecular Spectroscopy	Medical Applications	Industrial Applications
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C. Delfin	H. Hertz	U. Gustafsson	A. Enejder	J. Carlsson
D. Descamps	S. Kröll	Y. Saito	H. Enquist	S. Kröll
M. Gaarde	B.Z. Luo	J. Sandsten	T. Johansson	L. Malmqvist
M. Grätz	L. Malmqvist	J. Smith	C. af Klinteberg	W. Persson
P. Jönsson	K. Mohan	G. Somesfalean	S. Montán	J. Sonnerfeldt
L. Kiernan	L. Rymell	S. Wallin	S. Pålsson	A. Sunesson
J. Larsson	M. Tian	P. Weibring	Ch. Sturesson	W. Wendt
D. Lappas			K. Svanberg	
A. L'Huillier			J. Soerensen-Dam	
Z. Li			I. Wang	
H. Lundberg				
C. Lyngå				
I. Mercer				
E. Mevel				
J. Norin				
A. Persson				
L. Roos				
A. Sjögren				
T. Starczewski				
C. Tillman				
C.G. Wahlström				

A. Basic Atomic Physics

Most of our research activities in basic atomic physics have been directed towards ultra-intense laser-matter interactions, and to laser spectroscopy in the VUV and XUV spectral regions. In both these cases, the experimental work has extensively utilised the resources provided by the Lund High-Power Laser Facility, which is part of the Atomic Physics Division. This facility consists of four major laser systems. The first - *the VUV system* - is a narrow-bandwidth, tuneable system with pulse duration in the nanosecond range. It is designed to be used for pulsed laser spectroscopy in the UV and VUV spectral ranges. In 1998, this system was equipped with a pulse compressor, based on stimulated Brillouin scattering, in order to reduce the pulse length to about one nanosecond. The second system - *the XUV system* - is based on a modelocked picosecond Nd:YAG laser, pumping a short-pulse dye laser, followed by a solid-state power amplifier. In combination with high-order harmonic generation in gas jets, this system provides tuneable short-pulse radiation in the XUV spectral range. The third and largest system is *the femtosecond terawatt laser*. It is based on chirped-pulse amplification in titanium-doped sapphire, and provides 110 fs pulses of terawatt power. During the past two years, this laser has been upgraded to provide two separate laser beams. One with peak power of about two TW, propagating in air, and the other of up to about 8 TW, with pulse compression and subsequent beam propagation in vacuum. Finally, a *kilohertz laser system* has recently been added to the Facility. This laser system provides the shortest pulses, about 30 fs in duration, and operates at 1 kHz repetition rate, while the other three systems are all operating at 10 Hz.

With financial support from the Knut and Alice Wallenberg Foundation and the EC, the Facility is presently being further upgraded. The large terawatt laser is upgraded to about 20 TW and the kilohertz system to about 0.2 TW. At the same time, new user stations for advanced experiments using laser-produced X-rays or harmonic radiation are being developed.

Being a part of the Lund Laser Centre, the High-Power Laser Facility is open to European users through the European Community TMR Programme *"Access to Large-Scale Facilities"*. Over the past two-year period, several groups have visited Lund under this programme, and in a very positive and stimulating way contributed to the international atmosphere in the basic atomic physics group.

Most of our work using the femtosecond terawatt laser and part of the work with the picosecond laser is described in Sections A1 to A3 of this chapter. This work includes the generation, characterisation and applications of high-order harmonic radiation as well as laser-produced X-rays. A new research programme, directed towards investigations of super-intense - relativistic - laser matter interactions has also been initiated, while still in its initial stage. Time-resolved laser spectroscopy in the short-wavelength region (UV/VUV/XUV) is discussed in Section A4. Most of these spectroscopic investigations have been of astrophysical interest and some directly linked to observations made by the Hubble Space Telescope. The work devoted to theoretical atomic physics is presented in Section A5. However, part of our theoretical effort has been focused on the dynamics of atoms in intense laser fields and is therefore included in the discussion in Section A1.

Most of the work in the group has been presented at international conferences on atomic physics, astrophysics, spectroscopy, strong-field interactions and quantum electronics as well as discussed in review articles [A1,A2]. During the period, five MSc projects [A6-A10] and three PhD theses [A3-A5] have been completed and successfully defended ([A3] formally at the University of Copenhagen.)

A1. High-order harmonic generation

Our research on harmonic generation consists of three main areas: studies of fundamental aspects of the generation process, including optimisation of the harmonic radiation as a new source in the XUV range, development of its applications and, finally, investigation of the possibility of producing pulses of extremely short duration (attosecond pulses).

Fundamental studies of harmonic generation

Anne S. Dederichs, Christian Delfin, Mette B. Gaarde, D. G. Lappas, Anne L'Huillier, Claire Lyngå, Lena Roos, Claes-Göran Wahlström, Carlo Altucci, Philippe Balcou*, Marco Bellini*, Eric Constant*, Romain Haroutunian*, Theodor W. Hänsch*, Corrado de Lisio*, Francesca De Filippo*, Eric Mevel*, Alexandre Valette**
**Visiting scientist*

We study both experimentally and theoretically the temporal coherence of the harmonic radiation and investigated the possibility to achieve phase matching.
In a European collaboration with the LENS in Florence we characterise the temporal coherence properties of harmonic radiation [A11-A17]. Experimentally, we create two spatially separated sources of harmonics in a non-linear medium (an argon gas jet), and study the interference pattern of the generated harmonics in the far field (Fig. A1). Using a Michelson interferometer, we delay one of the laser pulses - and thereby one of the harmonic pulses - relative to the other, and determine the fringe visibility. By varying the temporal delay, we can determine experimentally the coherence time in a given spatial region. The far field profile of high order harmonics generated in Ar consists in two regions having different coherence times [A12,A14,A18]. Fig. A2 shows the far field interference pattern for the 15th harmonic generated in argon, when the two pulses are overlapped in time (a), and when one pulse is delayed relative to the other by 15 fs (b). Fringes are visible everywhere in (a), but only in the inner region in (b). A theoretical investigation shows that the presence of the two above mentioned regions has its origin in the dynamics of the ionising electron in the harmonic generation process. Indeed, the coherence time is closely related to the time spent by the electron in the

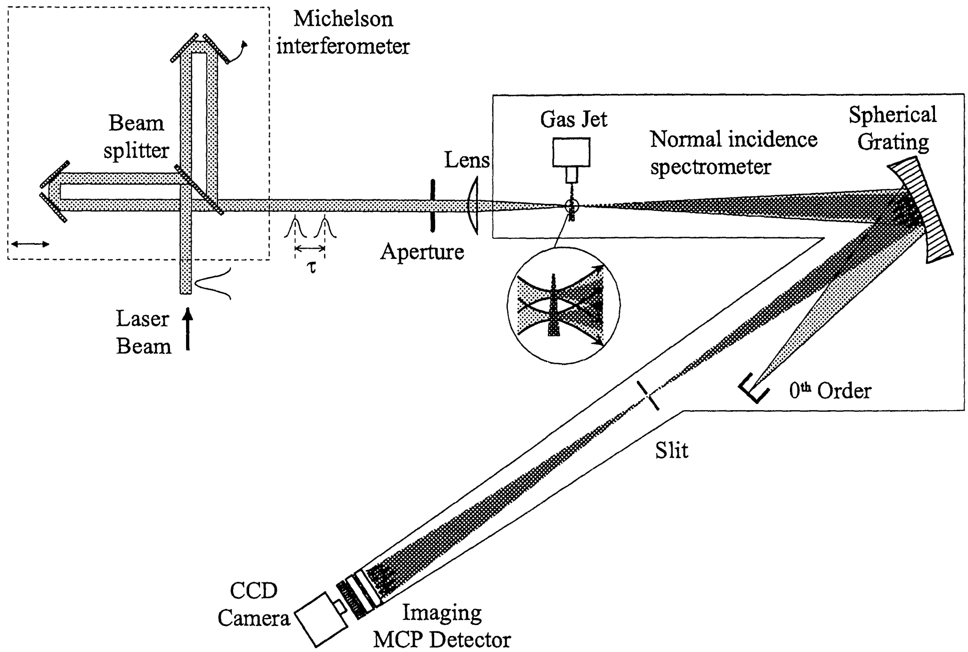

Fig. A1. *Experimental setup for studies of the temporal coherence of high-order harmonic radiation.*

continuum for the trajectory dominating the generation process in the spatial region considered. We can thus macroscopically *see* the dynamics of the electron in the strong field. By changing the focusing conditions, we can even *control* this dynamics, and thereby control the coherence properties of the harmonic radiation.

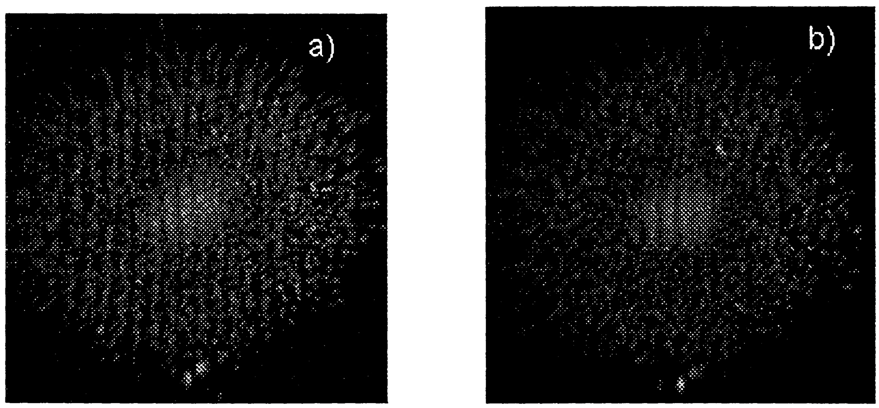

Fig. A2. *Interference patterns obtained when two pulses of the 15th harmonic interfere in the far field. In (a) the two pulses overlap in time, while in (b) there is a time delay of 15 fs between the two pulses. Fringes are visible everywhere in (a) but only in the inner region in (b), indicating a difference in coherence time.*

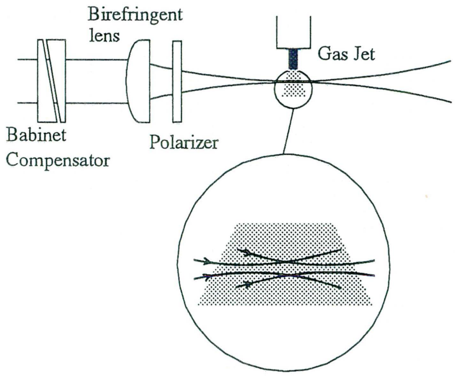

Fig. A3. *Experimental setup used to produce a long beam waist in the study of improved phase mathing.*

To optimise harmonic radiation, it is important to understand how phase matching can be realised and to experimentally investigate some ideas. In a European collaboration with the Laboratoire d'Optique Appliquée, in Palaiseau, and the University of Bordeaux, France, we have studied how the efficiency for harmonic generation in neon could be enhanced by separating the beam into two beams focused at different positions on the propagation axis [A19]. The idea is to create a "long focus" with a flat geometrical phase variation. The experimental setup is shown in Fig. A3. Enhancement up to a factor of 5 compared with harmonic generation with the usual "one focus" case could be realised. We have also, in a collaboration with the University of Naples, investigated the influence of the length of the non-linear medium on the efficiency for harmonic generation. Under our experimental conditions, in neon, the saturation of the harmonic yield as a function of the length of the medium is reached when the length of the medium becomes greater than the coherence length due to the dipole phase [A20].

All of our experimental projects involve numerical simulations and thorough theoretical interpretation. We are studying the harmonic generation process on the level of a single atom interacting with the intense laser field, and also including propagation and phase-matching of the generated radiation in the non-linear medium [A18,A21,A22]. This allows us to realistically model harmonic generation experiments. In addition, several graphical methods have been developed, one to extract the trajectories (quantum paths) responsible for harmonic generation [A18,A23], and another to visualise phase matching [A23,A24]. See Fig. A4. We have also established collaboration with Louisiana State University (K.J. Schafer) and the Lawrence Livermore National

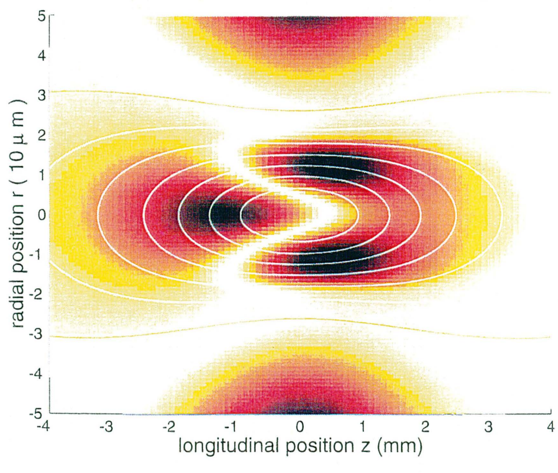

Fig. A4. *Pseudo-colour phase-matching map of the 45th harmonic, at an intensity of 6 x 10^14 W/cm^2. The laser is propagating from left to right, on an axis central in the figure. Perfect phase mathing is white, strong phase mismatch is black.*

Laboratory (K.C. Kulander), the aim of which is to provide a good theoretical description of the interaction between atoms and intense fields, by direct numerical integration of the time-dependent Schrödinger equation [A21]. By comparing these very accurate results with results of more simplified descriptions of the harmonic generation process, we can obtain deeper insight into the dynamics of the interaction process [A18]. On the single-atom level, we have studied the effect of electron correlation on harmonic generation and double ionisation. This is done in collaboration with the Department of Theoretical Physics, Lund University (U. von Barth and R. van Leeuwen) and the University of Würzburg (E. K. U. Gross), comparing results of direct numerical integration of the time-dependent Schrödinger equation with results using time-dependent density-functional theory [A25,A26].

Applications of the harmonic radiation

Carlo Altucci, Stéphanie Buil, Christian Delfin, Dominique Descamps, Anne L'Huillier, Claire Lyngå, Johan Norin, Claes-Göran Wahlström, Olle Björneholm, Patrice Caccian*, Mathieu Gisselbrecht*, Paul Hinnen*, Ingela Hjelte*, Teresa Kihlgren*, Michael Meyer*, Stacey Sörensen*, Stefan Sundin*, Wim Ubachs*, Gunnar Öhrwall**
**Visiting scientist*

The radiation generated as high-order harmonics can be used in a variety of novel applications. The applications explored so far are mainly pump-probe studies of atoms or molecules in the gas phase. In these experiments the tunability, the bandwidth and the short pulse duration of the harmonic radiation are of prime

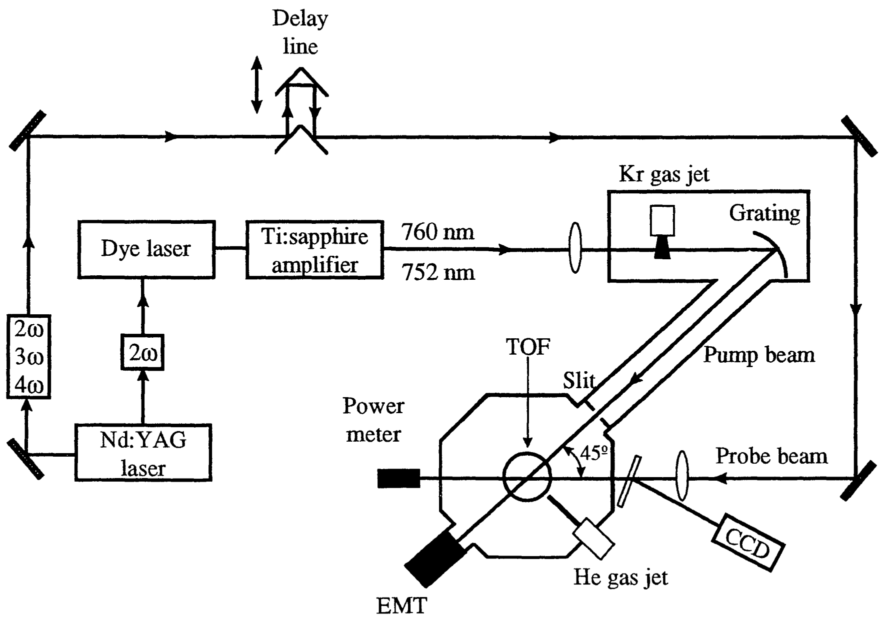

Fig. A5 : Experimental set-up for the measurement of photoionisation cross-sections from excited states in helium.

importance. A second type of potential applications takes advantage of the very high peak power of the harmonic pulses.

One experiment is devoted to the experimental determination of lifetimes of excited states of CO. The $E^1\pi$, $v=0$ and $v=1$ excited states of several isotopes of the CO molecule are excited using the seventh harmonic of our picosecond laser system (a tunable dye laser amplified in a titanium-sapphire crystal). The excited states are ionised at a later (variable) time by the third harmonic of the Nd:YAG laser pumping the dye laser. Several lifetimes have been measured between 100 ps and about 2 ns, depending on the state or the isotope. These measurements are of great interest for astrophysics [A28-A29].

A second experimental study is devoted to the measurement of the ionisation cross-sections of excited states in He. This experiment consists of exciting the $1s2p\ ^1P$ and $1s3p\ ^1P$ states of helium with the 13th or 14th harmonic of our picosecond laser system (the 14th harmonic being generated as the 7th harmonic of the 2ω radiation). (See Fig. A5). The excited states are ionised by laser pulses of different frequencies, from the infrared to the ultraviolet. The cross-sections are deduced in absolute value by recording the saturation curve of the ionisation process, and fitting the experimental data. Fig. A6 presents the measured cross-sections for the 2p and 3p states and compares them with theoretical calculations [A30, A31].

In the third, ongoing, pump-probe experiment we want to study molecular dynamics using pulses in the XUV range and on the femtosecond time scale. This project is being carried out in collaboration with the Department of Synchrotron Physics at Lund University, and the Department of Physics at Uppsala University. It involves the development of experimental techniques combining harmonics of femtosecond pulse duration and photoelectron spectroscopy [A32,A33].

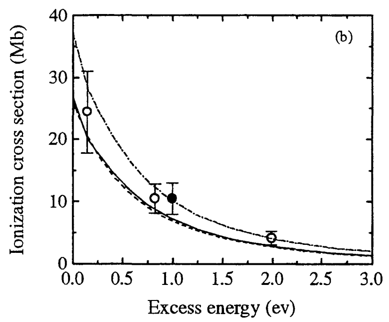

Fig. A6. Photoionisation cross-section of He 1s3p ^1P as a function the excess energy E_{exc}. The lines are different theoretical cross-sections.*

Finally, efforts are being made to explore the possibility of using harmonic radiation as a driving field for multiphoton processes in the extreme ultraviolet (XUV) region. With the high peak power and the spatial coherence of these ultra short pulses, combined with suitable high-quality XUV focusing optics, peak intensities high enough for multiphoton ionisation, or harmonic generation should be within reach. In one experiment, more than 10^6 photons per pulse of the 21st harmonic of our femtosecond terawatt laser were focused to a spot of less than 5 μm in diameter. However, further work is required to improve on these numbers in order to observe any XUV multiphoton processes.

Towards the generation of attosecond pulses of XUV radiation

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Philippe Antoine, Ian Mercer**
**Visiting scientist*

Several schemes for the generation of attosecond pulses using harmonics have been investigated theoretically. In one study [A34] we use the sensitivity of the harmonic generation process to the ellipticity of the driving field [A35]. By superposing two orthogonally polarised fields with slightly different frequencies and carefully controlling the macroscopic focusing conditions of the two fields, it is possible to generate a single attosecond pulse. In another study [A36] we compare, for a single atom, two schemes for the generation of attosecond pulses: a time-varying degree of ellipticity for the fundamental pulse and a linearly polarised pulse of intensity high enough to induce rapid ionisation.

We have also performed an experimental study [A37-A39], in which we use two orthogonally polarised chirped laser pulses to modulate the time-dependent ellipticity, and thereby *control* the harmonic emission in time. We create pulses which are linearly polarised during a short "gate", estimated to be about 5 fs. Fig. A7. We can also create two gates, one on either side of the maximum of the pulse. By analysing the spectral content of the harmonic emission generated in this way, we showed experimentally that the harmonic pulses are intrinsically frequency chirped (i.e. have a time-dependent frequency modulation). We estimate that the radiation generated in the "one gate" case has a duration of a few femtoseconds.

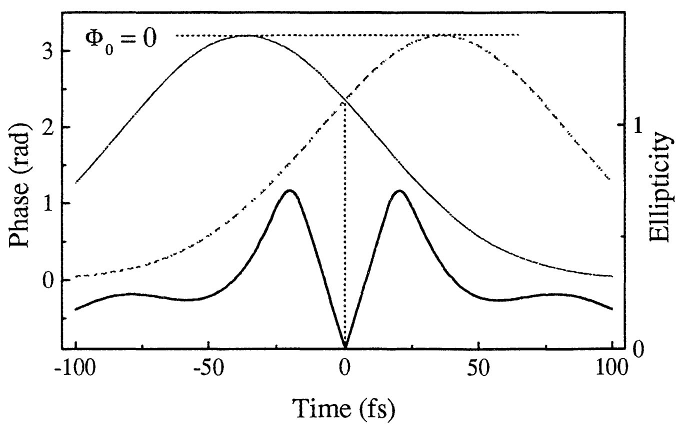

Fig A7. *The figure shows the phase variation in time for two orthogonally polarised laser pulses. The corresponding combined laser ellipticity is the thick line at the bottom. At t = 0 the phase difference between the two pulses is zero and close to t=0 we produce a time gate of nearly linearly polarised light. In this case harmonic radiation is emitted during approximately 5 fs.*

A2. Generation of hard X-rays from laser-produced plasmas

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* *Visiting scientist*

Hard X-rays are routinely produced in an experimental setup based on a laser-produced plasma. Light pulses from the terawatt laser system are focussed onto a solid metal target thereby creating a plasma. Electrons are accelerated in the plasma and generate X-rays upon their interaction with the target material. Hard X-rays with photon energies up to the MeV region can be generated due to the ultrashort duration and the ultrahigh intensities of the laser pulses. The experiments have been mainly focussed on spectral source characterisation and potential applications of this unique X-ray source.

Spectroscopic investigations have been performed using both diffractive crystal spectrometers [A40,A41], and conventional single-photon counting detectors [A42]. In both cases, absolute photon numbers and conversion efficiencies have been determined for different target materials, thus allowing for comparison with theoretical plasma simulations. Recent results obtained with a bent-crystal spectrometer are shown in Fig. A8. The spectrum consists of a continuous Bremsstrahlung part and line emission characteristic for the target material. In addition, various studies on X-ray flux fluctuations from the source were performed.

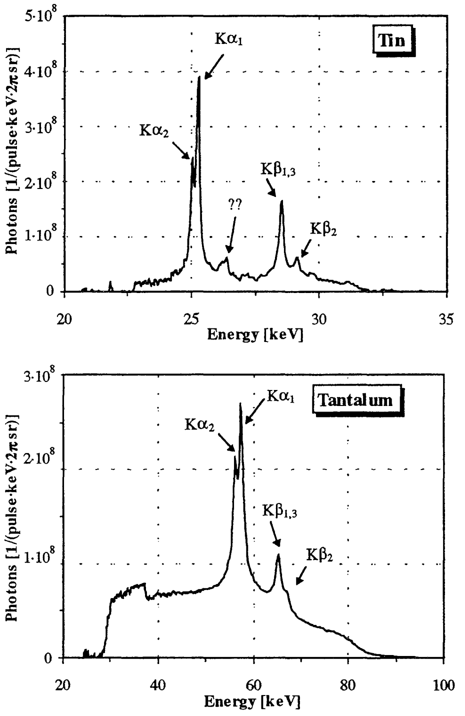

Fig. A8. *X-ray spectrum from a tantalum and a tin target, obtained with a bent-crystal spectrometer in Laue geometry, with absolutely calibrated photon numbers.*

The spectral properties of the X-ray source were used in investigations of differential imaging, a technique for selective imaging of certain contrast agents [A43].

Time-gated imaging is another potential application of the laser-produced plasma X-ray source, essentially due to the very short time duration of the X-ray pulses. Time-gated imaging, based on an ultrafast detector capable of separating the scattered from the ballistic (non-

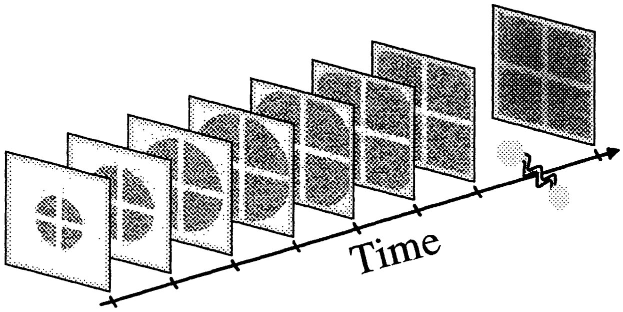

Fig. A9. *Example of output from the Monte Carlo simulation in spatially resolved geometry, for illumination of an 18 cm soft tissue layer, at a photon energy of 80 keV. The images are 1 ps apart, the image to the right shows the time-integrated image.*

scattered) photons and a short-pulse X-ray source, improves the radiological image quality, at constant dose, by means of scatter reduction. Alternatively, the dose necessary to obtain an image can be reduced by a factor of up to 10, for a given image quality, depending on the tissue thickness and photon energy.

Monte Carlo simulations were performed in order to investigate the influence of various parameters, for example, photon energy, tissue composition and temporal resolution, on the performance of time-gated imaging [A44-A46] and to predict achievable contrast improvement. In the simulations, photons are propagated in a modelled scattering medium containing imbedded objects. As an example of the simulation output, the images of a small cross imbedded in a water slice at different times are shown in Fig. A9.
One-dimensional, time-resolved imaging using a streak camera was used to demnstrate the effectiveness of this imaging technique [A45] The possibility of time-gated computed tomography imaging was also demonstrated , as seen in Fig. A10 [A46,A47]. This technique could potentially allow for scatter-reduced volumetric computed tomography imaging.

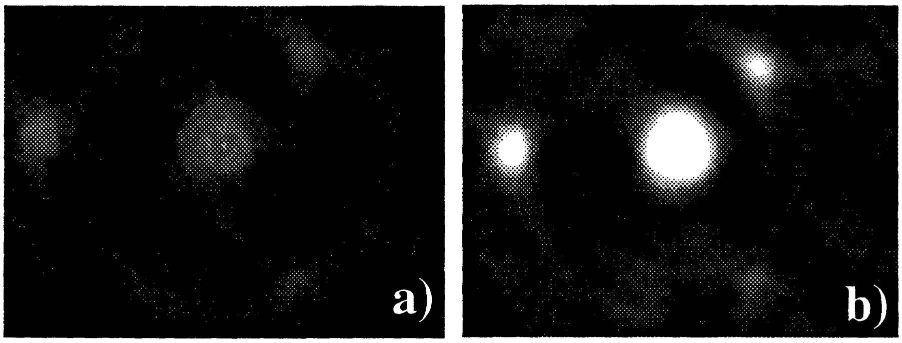

Fig. A10. *Reconstructed images of a small object imaged through a 9 cm thick water layer, time-integrated (a) and time-gated (b). The gray level is proportional to the attenuation, with lighter shades corresponding to high attenuation.*

A3. Time-Resolved X-ray studies

In 1998 a research programme in the field of time-resolved studies of the structure of matter was initiated at the Division of Atomic Physics. The project has two immediate goals in order to facilitate such studies. One is to determine whether laser-based X-ray sources (such as laser-produced plasmas) are suitable sources for this type of study. This will be achieved by investigating the temporal and spectral properties in the 3 keV - 10 keV photon energy range. The other goal is to develop methods that can be employed at synchrotron radiation facilities.

Investigation of the temporal structure of the X-ray emission from cluster and solid targets

Jörgen Larsson and Anders Sjögren

Van der Waals clusters, such as Ar clusters, irradiated by short-pulse lasers (100 fs) emit a substantial amount of X-rays. The time structure of the X-ray emission has been a topic of discussion for the last 5 years. Short-duration emission (< 1 ps) would be of particular interest for ultrafast visible pump / X-ray probe experiments. Compared with synchrotrons and electron beam devices, laser-based sources are

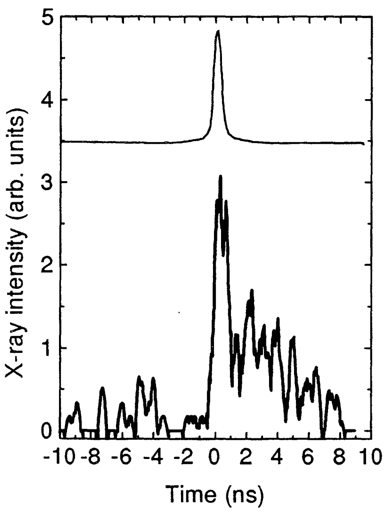

Fig. A11. *Time-resolved emission from clusters as detected by a streak camera. The time response from a series of 100 fs UV pulses is also shown. The data for both the X-ray and UV radiation consist of 100 averaged pulses.*

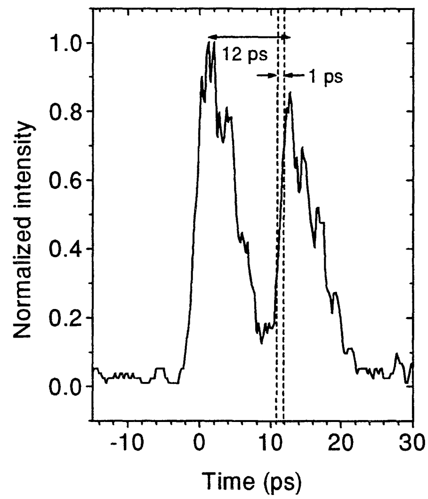

Fig. A12. *The emission from a stainless steel target which was irradiated by two intense laser pulses of 100 fs duration, separated by 12 ps. The emission was detected by an averaging X-ray streak camera. Allthough 2000 shots were averaged, ta rise time faster than 1 ps is observed. The slower decay is believed to represent the actual emission. characteristics of the plasma.*

cheap and compact. Compared with solid target X-ray sources, rare gas clusters produce little debris, are easily renewable and is less sensitive to alignment. All the factors are important when designing an X-ray source.

We have recently measured the absolute average photon flux, the spectral characteristics and the time structure of X-rays emitted from Ar clusters which were irradiated by a 100 fs laser with an intensity of 10^{17} W/cm^2 [A48]. The measured photon flux was 10^7 photons per shot in the K_a (at 3 keV) line in a 4π sr solid angle. The temporal structure was measured using a streak camera with a 10 ps time resolution. It was found that less than 1 % of the photons were emitted within the 10 ps time-response function of the streak camera. The emission profile was found to be roughly exponential with a time constant of 3 ns, as seen in Fig. A11.

We have developed a novel readout technique for streak cameras analogous to single photon counting, which is a standard technique in atomic spectroscopy. Using this technique we can operate a commercial streak camera in averaging mode and obtain a temporal resolution of about 1 ps, as can be seen from the rise-time in Fig. A12.

Ultrafast studies of disordering and reordering in laser-irradiated InSb

Jörgen Larsson

The use of time-resolved X-ray diffraction for studies of disordering of crystals has recently recieved a great deal of attention. In collaboration with research groups at UC Berkeley, Oxford University and the Lawrence Berkeley Laboratory, we have carried out pump-probe experiments in which a sample interacts with a short (100 fs) laser pulse and subsequently the structure is probed by X-rays from a synchrotron [A49,A50]. By using a two-crystal set-up we can obtain a temporal resolution which, in principle, is limited only by the laser pulse duration.

This type of laser-pump/X-ray probe experiment has been used to investigate the timescale for the disordering (melting) of laser-irradiated InSb. We concluded that this occurred on a time scale shorter than 2 ps,

We have studied the regrowth of the material following disordering and we observed two time scales. A fast recovery occurring on a time scale of about 15 ps was seen followed by a slower regrowth which takes about 50 ns.

A4. Time-resolved laser spectroscopic lifetime measurements of atomic and ionic excited states

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** Visiting scientist*

Time-resolved laser spectroscopy has proved to be an accurate method for the determination of excited-state radiative lifetimes. Radiative lifetimes, together with branching ratio measurements, can be used to deduce oscillator strengths. The oscillator strengths of spectral lines are used in astronomy to compute atomic and ionic abundances in the sun, as well as in stars, comets and other celestial objects. The radiative properties of free atoms depend sensitively on the atomic wavefunctions and thus experimentally determined natural lifetimes are useful for testing theoretical calculations.

In the last decade, the Rydberg states of alkali and alkaline-earth elements, which have s^1 and s^2 outer-shell electron configurations, respectively, have been extensively investigated and their spectra have been successfully analysed. Lead is one of the heaviest stable elements with a p^2 outer-shell electron configuration, and its Rydberg states are expected to have some new physical properties. Natural lifetimes and g_J factors of the Rydberg series corresponding to odd-parity [A51] and even-parity [A52] have been measured with time-resolved laser spectroscopy.

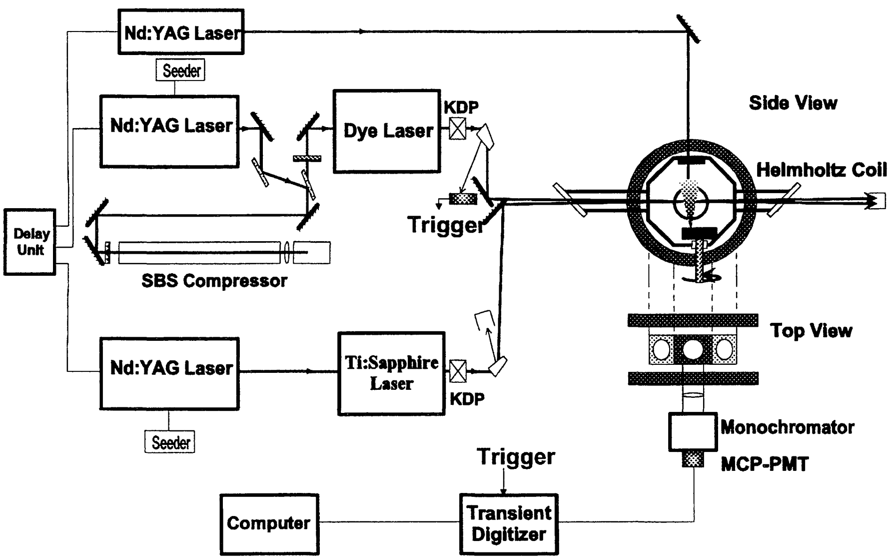

Fig. A13. Experimental set-up for lifetime measurement of Yb II levels.

Comparisons of the experimental results with relativistic Hartree-Fock (HFR) calculations have been made and an analysis based on Multichannel Quantum Defect Theory (MQDT) is in progress.

With the strong development of techniques for astrophysical observation, more and more accurate atomic radiative data are needed for the analysis. The activities of the Lund laser spectroscopy group have been focused on the study of some of the problems where experimental difficulties have previously prevented a solution.

The radiative lifetimes of 6d and 8s levels of neutral sulphur have been measured with time-resolved laser spectroscopy, by employing a two-colour, three-photon excitation scheme [A53]. The measured lifetimes combined with HFR-derived branching ratios have provided accurate oscillator strength data [A54] of high value to astrophysicists.

For refractory elements and elements which are evaporated as molecules, a laser-produced plasma technique has been developed. In this plasma, not only free atoms but also free singly and doubly charged ions [A55] can be obtain.

Most of the astrophysically interesting lines involve short-lived upper levels. In order to measure these short lifetimes accurately, a fast detection system and a short excitation laser pulse are required. In order to fulfill these requirements, a pulsed compressor based on Stimulated Brillouin Scattering (SBS) has been build in Lund [A10], which enables the generation of tunable laser pulses as short as 1 ns. The experimental set-up for lifetime measurements of the Yb II levels is shown

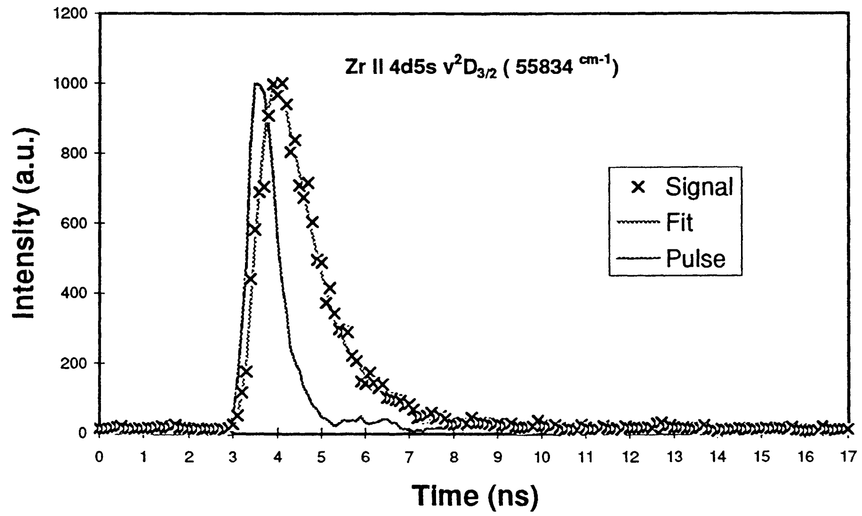

Fig. A14. Typical recorded time-resolved laser-induced fluorescence signal with fit.

in Fig. A13 [A57]. A similar set-up has been used to study the lifetimes of the astrophysically interesting upper levels of La II,III [A55] and Ge [A56].

For states with even shorter lifetimes, less than 1 ns, a Distributed Feedback Dye Laser (DFDL) system, which can provide a 100 ps laser pulse, is used. The lifetimes of the levels of the 4d5s5p configuration of Zr II [A58] were measured with this laser system. A typical fluorescence signal from the $v^2D_{3/2}$ level recorded in this experiment is shown in Fig. A14. Combined with branching ratio measurements, the produced oscillator strengths have been used in the Zr^+ abundance analysis of the HgMn star χ Lupi with the spectrum recorded by the Hubble Space Telescope. The lifetimes of the 4p5s configuration of Ge I [A59] have also been measured, and these data have direct solar implications.

With the development of these techniques, the FERRUM Project [A60,A61], which is aimed at obtaining a large amount of reliable experimental data on Fe II, is currently progressing well in the Lund laser spectroscopy group.

At the end of this section, we would also like to announce the publication of some work [A62-A65] discussed in our previous Progress Report. A number of conference contributions covering our works have also been presented [A66-A69].

A5. Theoretical Atomic Physics

Per Jönsson, Demetris Lappas, Anne L'Huillier, Mette Gaarde

The work on atomic theory has been done in collaboration with several international research groups. It has been focused, in the first part, on transitions and spectral properties of astrophysical interest, and in the second part on atoms in intense laser fields.

Boron is the key element in the understanding of the cosmic production of the light elements. Of special interest is the $^{11}B/^{10}B$ isotope ratio, which is relatively sensitive to the different models proposed for the production processes. Together with the group at the Department of Atomic Spectroscopy at Lund studies of isotope shifts in astrophysically important transitions in B II have been performed [A70-A72]. Following a theoretical study of the isotope shift in the resonance transition in B III, measurements of the $^{11}B/^{10}B$ isotope ratio in early B stars has been done with the Hubble Space Telescope (HST) as part of the HST-GO program 6644 [A73].

Much work has been done on improving the fully relativistic multiconfiguration Dirac-Fock (MCDF) method. Combined with a new technique for computing transition matrix elements [A74], this method has been used to predict transition rates over wide ranges of ions in isoelectronic sequences [A75,A76].

The development of new computer programs for predicting different properties is an important part of the theoretical work at the department. Programs to describe the interaction of isolated atoms with external magnetic and electric fields are currently being developed.

In the second part of our theory programme, we mainly study the interaction of free atoms and molecules in intense laser fields. Single atom effects, as well as macroscopic effects like phase matching and beam propagation in an ionising medium is being investigated. Most of these were discussed in Section A1, in connection to the experiments. A few additional investigations are reported in Reference [A77-A80].

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B. Quantum electronics, quantum optics and solid state spectroscopy

In this chapter it is described how coherent transient techniques are used to 1) explore all-optical techniques for data storage and data processing, 2) to test fundamental concepts in physics, and 3) to obtain spectroscopic information on interactions in rare-earth-ion-doped inorganic crystals. One PhD thesis covering several aspects of this has been presented during this two-year period [B1] and in January 1999 an additional PhD thesis, covering especially the first topic mentioned above, was defended [B2].

B1. Time-domain optical data storage and processing

Ulf Elman, Stefan Kröll, Baozhu Luo, R. Krishna Mohan, René Nilsson and Mingzhen Tian

The time-domain optical data storage and processing project is concerned with the physics and the concepts of photon-echo-based techniques for optical storage and processing of information. Optical fibres are replacing electronic transmission lines at increasingly shorter distances and the application of optical switches is continuously increasing. It is clear that the replacement of electronics with optical solutions and devices will continue. Thus, the demand for optical solutions in storage, processing and communication applications will increase.

Data storage densities above Gbits/cm^2, data rates above THz and density bandwidth products of 10,000 Tbits/(cm^{2}s) have been achieved using photon-echo-based techniques, and storage densities >Tbits/cm^2 have been predicted. The projected and demonstrated performance makes photon-echo techniques highly interesting for future optical storage and processing concepts.

Nevertheless, many problems must be addressed and solved in order to make time-domain optical storage and processing competitive with existing technology. Our major long-term objective is to demonstrate 1) bit-selective data erasure or random access rewriteable memories, and 2) all-optical data-rate conversion using photon-echo techniques.

Time-domain or photon-echo storage is one of the techniques by which many bits of information can be stored and addressed within a single diffraction-limited point (area) because atoms within this small area absorb at different frequencies. In some rare-earth-ion-doped materials, more than 10^7 different spectral intervals can be addressed within any such single spatial point. This is the basis for the high storage densities that have been achieved and predicted in these materials. In the time-domain or photon-echo approach to data storage and processing in these materials it is the frequency Fourier spectra of temporal wave forms (data streams) that are stored. This makes it possible to perform a variety of all-optical operations on temporal data. For example, temporal pattern recognition, header/address decoding, optical time domain encryption, bit rate conversion, serial-to-parallel and parallel-to-serial conversion.

Erasure of photon echo data

Continuing from our previous work on data erasure (J. Opt. Soc. Am. **B13**, 1905 (1996)) the decrease in erasure efficiency was modelled as a function of data writing and data storage time in terms of random phase and frequency fluctuations in our laser sources [B3]. The linewidth of the dye laser used in the initial erasure experiments was 1 MHz. By using a 200 kHz linewidth Ti:S laser we demonstrated an order of magnitude better data erasure efficiency [B4] in agreement with our models. Yet another order of magnitude improvement in erasure efficiency was obtained during a visit by two of the group members to Neil Manson's laboratory at the Australian National University in Canberra [B5]. Here, a ring dye laser system equipped with an intra-cavity phase modulator was used. The laser was locked to an external Fabry-Perot cavity, in which the mirrors were mounted on a ceramic Zero-dur tube. The short-time-duration linewidth of this system was in the kHz range. In this work [B5] it was also shown that by using phase-sensitive detection of the photon-echo output, the laser phase that is required for the erasure process can readily be determined.

Amplification of photon echo signals

We have previously suggested a self-compensating approach to eliminate laser phase and frequency fluctuations in the erasure process (J. Opt. Soc. Am. **B13**, 1905 (1996)). The idea is to first read out the photon-echo data which are to be erased, to send the photon-echo output signal through an amplifier and then direct them into the sample with a 180 degree phase shift. Possible laser phase and frequency fluctuations are now completely irrelevant as we have generated a true replica of the data and this itself is used for the erasure process. Since the output from a photon-echo process is normally only 0.1-1% of the input it is, however, necessary to amplify the output before it is sent in for the erasure process. The same problem occurs in bit-rate conversion. Bit-rate conversion can be of interest because there is a mismatch between the bandwidth of the optical fibres that transmit signals and the electronics used to generate the signals. By compressing the data generated from opto-electronic devices in time, the data rate can be increased to better match the communication channel, and before the data are read by the electronics at the other end, it can be de-compressed (expanded). One photon-echo process can be used to compress the data and another photon-echo process can be used to expand it. However, again the output signal from the compression process must be amplified to make it strong enough to be used as input in the de-compression process. Together with Anne Tropper at the University of Southampton, we developed a fibre amplifier that could be operated at the same wavelength (606 nm) as the photon-echo material, Pr^{3+}-doped Y_2SiO_5 [B6-B8]. By improving the amplifier design we have obtained a gain of 300. At high gain we have demonstrated that when the amplified photon-echo output signals were sent back into the crystal, these could themselves generate new photon echoes [B9-

have demonstrated that when the amplified photon-echo output signals were sent back into the crystal, these could themselves generate new photon echoes [B9-B12]. These results indicate that we are well on the way to reaching our objectives, mentioned above. The experimental arrangement used for this last experiment is shown in Fig B1. AOM stands for acousto-optic modulator. The two AOM's after the fibre amplifier were only used in some of the measurements.

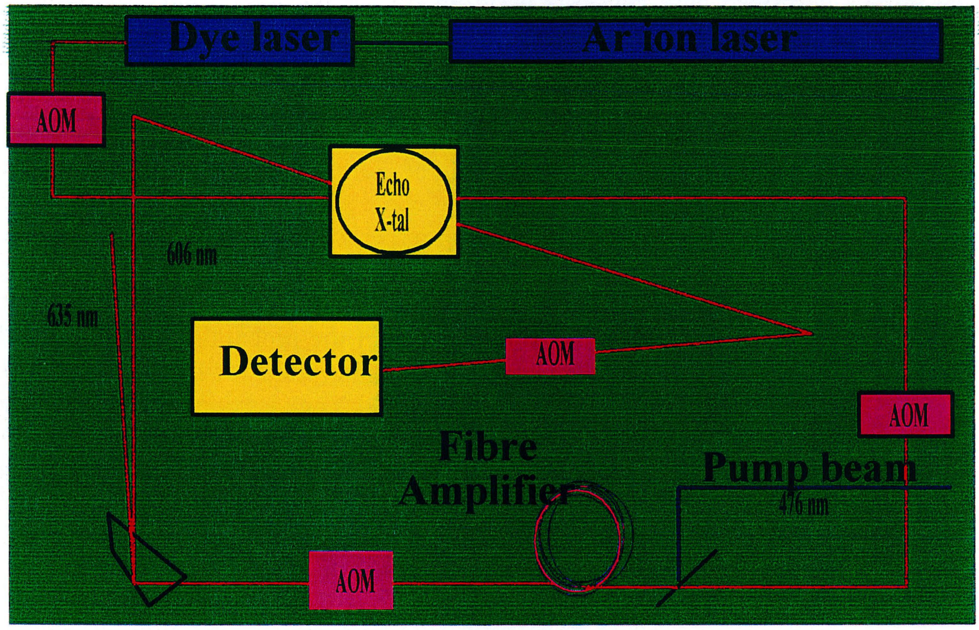

Fig. B1. *Experimental arrangement for generating secondary echo signals from amplified echo output signals*

Experiments related to photon-echo data processing

As indicated earlier, one of the interesting properties of photon echoes is that they can be used for all-optical, bit-rate conversion. To do this, it is necessary to chirp the laser frequency when the echoes are generated. To convert data to high rates the frequency must be chirped over large frequency intervals. An external-cavity diode laser capable of chirping the frequency over several GHz in a few microseconds has been constructed in a Master´s project [B13]. There are several interesting aspects of using chirped pulses to generate photon echoes. For example, it is possible to perform a spectral analysis of the stored input signal. Since it is the Fourier spectra of the input sequence which are stored, they can be read out with a chirped input pulse, presenting the stored Fourier components one after the other. Depending on the chirping rate of the read-out pulse, the recalled Fourier spectra will be more or less distorted. In fact, it can be shown [B14] that such a Fourier analysis can be the temporal counterpart to a diffraction process in space, and by changing the chirping rate, a transition for the diffraction in time can occur, which is exactly analogous to the transition from Fraunhofer to Fresnel diffraction for diffraction in space. The existence of a temporal Talbot effect was also predicted for this type of experiment [B14]. Additional aspects of our work have been presented at various conferences using a method similar to the approach used for word-by-word logical operations (Opt. Lett. **18**, 1834 (1993)). A patent for rapid image recording using spectral hole-burning materials has also been submitted [B20].

B2. Delayed single-photon interference

Stefan Kröll, Baozhu Luo and R. Krishna Mohan

The project described here concerns basic aspects of the interference of light, as well as basic aspects of the absorption of photons.

The aim is to perform an experiment in which a single-photon wavepacket is split into two. The two wavepackets take two different routes and are then subsequently made to interact with an atom (or an ensemble of atoms) with a time delay between the two interactions much longer than the wave-packet coherence time. This experiment is similar to a Young's double slit experiment in which an interference pattern due to single-photon self-interference occurs when the photon probability amplitudes for both paths are simultaneously nonzero at some crossing point. However, in the experiment proposed in this project the probability amplitudes do **not** need to be nonzero simultaneously at the crossing point for interference to be observed. This is distinctly different from the normal Young's double-slit case. The reason why an interference pattern still can be formed is attributed to the fact that the phase of an atomic wavefunction excited by an electromagnetic field is open to interference with a later field, as long as the time of zero amplitude between the interactions is shorter than the homogeneous dephasing time of the transition. This is generally utilised in photon-echo experiments.

We have analysed an experimental realisation of this idea of delayed single-photon self-interference based on photon echoes using materials with long homogeneous dephasing times [B21, B22]. We have calculated the expected photon-echo signal strength using different semiclassical and quantum approaches, and pointed out that such a phenomenon has several unique features *e.g.*, single photons are used to carry out what is generally regarded as a multiphoton process and it presents a novel single-photon absorption experiment in the sense that the absorption of a single photon, in this case, can be seen as being separated into two distinctly different moments in time. This in itself raises a number of intriguing questions, *e.g.*, when does absorption actually take place? If the first part of the split single-photon wave packet were to be absorbed by an atom, by what mechanism is this information communicated so that the next packet is also seen only by the same atom, and when? Do single photons have a well-defined phase? and many more.

Our detailed calculations show that the single-photon experiment should be feasible in terms of obtaining a detectable signal strength if many single-photon events can be accumulated before the resulting signal is read out. In [B21] we demonstrated the validity of our calculations by extending them to a multiphoton case, and we compared the results with those of a photon-echo generation experiment performed with a multiphoton source using a rare-earth-ion-doped inorganic crystal as the frequency-selective material.

B3. Dephasing in rare-earth-ion-doped inorganic crystals

Stefan Kröll and Baozhu Luo

Optical transitions of rare earth ions doped into inorganic crystals can have sub-kHz homogeneous linewidths at liquid helium temperatures. As optical transition frequencies are about 10^{15} Hz, these optical resonances have Q-values of the order of 10^{12}. They are therefore exceptionally sensitive probes for studying perturbations and interactions in the material. This also means that interactions which would normally be masked by other effects can be revealed. This occurred, for example, for Pr-doped $YAlO_3$, where a resonance was observed in the dephasing time as a function of magnetic field. This resonance was masked by excitation-dependent dephasing processes at higher excitation energies and could only be seen at low excitation energies. We are only aware of one similar observation. At that time, the resonance was caused by Zeeman crossings between hyperfine levels. However, in our case no such crossing could be identified based on existing data for this crystal. The origin of the resonance is therefore still unknown [B23].

The properties of these transitions in rare-earth-ion-doped crystals at low temperatures are generally investigated by coherent transient techniques, e.g., photon echoes. Like some other coherent techniques, for example, quantum-beat spectroscopy, echo techniques allow the scientist to observe features which are much more narrow-band than the light source, by looking at the time-domain signal. In the experiments described here, interactions between the excited ions could still be observed when the average distance between the excited ions (assuming randomly distributed dopant atoms in the crystal) was greater than 100 nm. This is especially remarkable considering that the 4f electrons participating in the transitions are not outer-shell electrons. In fact the 4f electrons should be quite well shielded from the surroundings. Such long-range interactions have been attributed to electric or magnetic dipole-dipole interactions between excited atoms, or to non-equilibrium phonons generated in the excited atom decay process, e.g. [B23]. This has been further studied in Pr-doped Y_2SiO_5 crystals [B24, B25]. Specifically, we investigated how dopant ions in the excited state effected the homogeneous line-width. Based on the results, it appears that the mechanisms affecting the linewidths differ strongly for different materials. The mechanism seems to depend mainly on the active ion, as could possibly be anticipated from earlier measurements, but site-dependent differences in the intensity-dependent dephasing is also observed here for the active ion. It was found that within the range of laser pulse energies and laser beam focal areas studied, only one of the two Pr sites showed an excitation-area-dependent dephasing, as would be expected for a dephasing mechanism based on non-equilibrium phonons. However, it appears that this observation can be understood in terms of different Pr concentrations at the two sites [B25].

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B4. Soft X-ray sources and applications

Magnus Berglund, Hans M. Hertz, Lars Malmqvist, Lars Rymell and Thomas Wilhein

High-brightness soft X-ray sources have applications in may fields, e.g., microscopy, lithography and surface sciences. Many applications would benefit from table-top sources having high peak power and reasonable repetition rates. This is particularly true for X-ray microscopy. The soft-X-ray research group, particularly focusing on microscopy and lithography applications, pursued its work within theAtomic Physics Division up till December 31, 1997 [B26-B29]. With the appointment of Hans Hertz as Professor of Physics at the Royal Institute of Technology (KTH), the group moved to Stockholm, where its Internet coordinates are http://www.biox.kth.se.

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C. Applied Molecular Spectroscopy

Research projects in the field of applied molecular spectroscopy are directed towards the development and application of optical techniques, both laser and non-laser, to measure mainly gases and particles in various environmental studies. Several of the techniques are used for remote sensing over long distances. The method most used in studies of air pollutants is the differential absorption lidar (DIAL) technique, where a mobile DIAL system has been employed in several field campaigns. The lidar system has also been used in the remote monitoring of environmental effects on historical stone buildings and monuments using laser-induced fluorescence techniques (LIF), and special multi-colour imaging methods have been developed for this purpose. The method for imaging of gas flows using an IR camera and gas correlation techniques has been further pursued. The aim here is to develop a method that can produce images of a certain gas at a certain location using only the thermal background radiation. Finally, ultrasensitive gas measurement methods are being developed in a project utilising diode laser spectroscopy and frequency modulation (FM) techniques. This metod was recently applied to the detection and identification of aerosol particles. Some of the projects are run through the Centre for Environmental Measurement Technology (CENTEC), which co-ordinates research and teaching in environmental sensing technology within different departments of the Lund Institute of Technology.

C1. Lidar measurements of atmospheric gases

Hans Edner, Yasunori Saito, Sune Svanberg and Petter Weibring

The results from previous field campaigns with the mobile DIAL system in the Mediterranean area have now been published. The Mediterranean basin is characterised by the presence of a geological anomaly of large cinnabar deposits which are part of a mercury-containing belt that encircles the earth. The lidar technique, complemented by point monitoring methods, has been used to measure concentrations and fluxes of atmospheric mercury from these sources. Mercury degassing rates from different mineralised areas in Italy and Spain have been studied, including seasonal and daily variations, for a better understanding of mercury geochemistry [C1]. Special measurements have been performed in mineralised areas in the Mt. Amiata region in Italy, which contain several remains and deposits from earlier cinnabar mining activities [C2]. The abandoned mining complexes as a whole emit amounts of mercury comparable to the fluxes from the geothermal power plants in the same area during the warmest months, but are much less during the winter [C3]. Similar measurements have been performed in Almadén, Spain, where the most important mercury mines in the world are located, with uninterrupted mining activity over the past 2000 years [C4, C5]. The area is highly affected by elevated concentrations of mercury in air, soil and vegetation. The use of the lidar remote sensing technique allowed rapid coverage of large areas, both horizontally and vertically, with good temporal resolution. Vertical lidar scans were combined with wind data to measure the total mercury flux into the atmosphere from all sources. The deduced flux values, close to 1 kg/h, demonstrated that this is one of the largest mercury emission sources in Europe.

The earlier construction and application of a dedicated ozone DIAL system, based on a KrF excimer laser, within the EUROTRAC project has now been published, including intercomparison measurements with a Nd:YAG/dye-laser-based lidar system and a long-path differential optical absorption spectroscopy (DOAS) system [C6]. A special study on the efficiency and quality of Raman-shifted wavelengths under different operating conditions was also performed within this project [C7].

A new method for remote monitoring of industrial gas emissions, which is a combination of DIAL and plume velocity measurements, has been developed and tested [C8]. The wind speed is measured by an imaging technique that calculates the horizontal displacement of the plume with cross-correlation techniques using an ordinary video or CCD camera. The camera is aimed at the most visible part of the plume, taking snapshots of the irregular structure, while the laser repeatedly scans the plume cross-section for concentration measurements at an optimal position along the plume. An illustration of the measurement arrangement is shown in Fig. C1. The wind speed is estimated by taking the horizontal cross-correlation between two sequential images, given their time separation and the distance to the plume. The wind direction is calculated by measuring the distance to the source and the plume centre at the lidar scanning position and the angle between these directions. The method was validated in comparisons with data from different

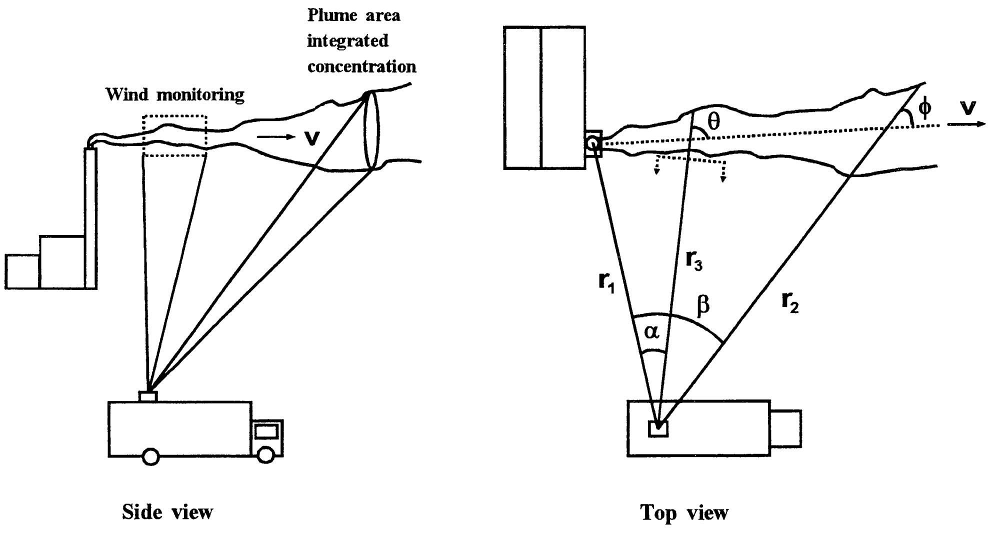

Fig. C1. Illustration of the arrangement for gas flux measurements.

anemometers during longer runs, which showed that the lidar/camera method shows high accuracy in determining the wind field near the concentration measurement position. The advantages of the new method, compared with other wind instruments, are the remote measurement of the plume speed at the correct height and location, and the volume integration, which eliminates the influence of fast, local variations in the wind field. The time resolution can be matched to the time resolution of the concentration measurements and a more accurate estimate of the flux is achieved with estimates of the variances for both the area-integrated concentration and the wind field.

The sulphur dioxide emissions from the Italian volcanoes Etna, Stromboli and Vulcano have been studied by optical remote sensing techniques during three measurement campaigns onboard the research ship Urania [C9-C12]. Total flux values were derived with the DIAL system operating in a vertical measuring mode and the ship performing repeated traverses under the volcanic plumes. Typical emission values were 1300, 180 and 25 tonnes/day for the three volcanoes mentioned. These are the first measurements of volcanic gas fluxes using an active remote sensing technique. During the last campaign, during August 1997, new photon-counting electronics increased the effective range of the lidar system and additional wavelengths were used for better mapping of particles in the plume. In particular, the DIAL data were compared with results obtained with a COSPEC (Correlation Spectroscopy) instrument, using the sky radiation as the light source. Several measurements of volcanic plumes were made at different heights, and the data were used to investigate the scattering effects on COSPEC values at various

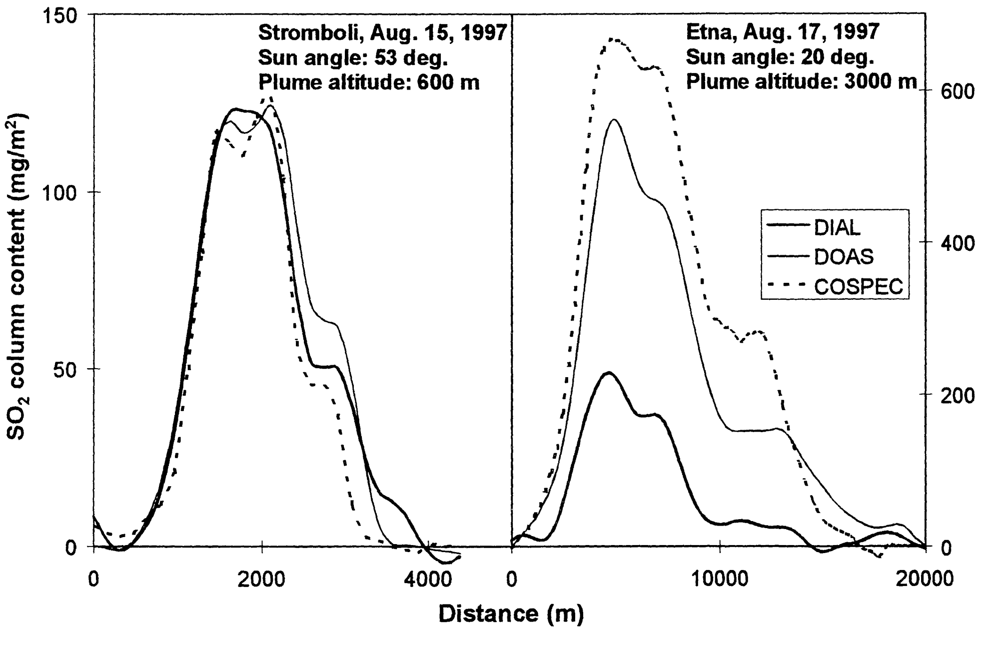

Fig. C2. Comparison of data from three remote sensing systems during traverses under volcanic gas plumes.

sun angles. Most volcanic gas flux monitoring performed during the last 20 years has been carried out with COSPEC techniques. The comparison underlined inherent problems with passive optical measurements due to scattering effects and difficulties in establishing the effective optical path through the plume, which can cause large errors under certain conditions. Fig. C2 shows some examples of good and bad correlation of data from active DIAL and passive DOAS and COSPEC measurements during traverses under the volcanic plumes of Stromboli and Etna. The altitude of the plume and the sun angle clearly affect the reliability of the data from the passive instruments. The influence of scattering in the plume will be modelled to enable correction of the COSPEC data, enabling a more correct assessment of the volcanic contribution to the global sulphur budget.

The DIAL system has been upgraded with an all-solid-state OPO (Optical Parametric Oscillator) laser system. An OPO system has several advantages compared with the presently used dye laser system, such as greater and more rapid tunability for the detection of several different species. The tuning range has been further extended in the IR region with frequency mixing and optical parametric amplification techniques. The region around 3 μm is now covered which enables the detection of various hydrocarbon compounds. Laboratory work on absorption cross-section determinations as well as atmospheric studies have been performed on some species, including a biogenic compound, alpha-pinene. The development of an OPO-based DIAL system for hydrocarbon detection has also been benefited by our work on rapid tuning with piezo-translators. A complete system with piezo-controlled wavelength tuning mirror in the OPO master oscillator cavity, OPO and frequency-mixing crystals, has been developed and successfully tested [C13]. This enables the generation of alternating on- and off-resonance wavelengths from a single OPO system, which is important from a practical point of view for mounting in the mobile lidar system. The rapid scanning will also be used in a multi-wavelength DIAL scheme with more than two wavelengths. This is often necessary for accurate determination of the concentration of different hydrocarbons in a mixture of several compounds. In certain IR regions there is also interference due to H_2O and CO_2 bands, which make the normal two-wavelength DIAL method difficult to apply.

C2. Fluorescence lidar applications

Petter Weibring, Thomas Johansson, Hans Edner and Sune Svanberg

Remote fluorescence monitoring of the stone facades of historical monuments provides valuable information in connection with damage assessment and restoration planning. No scaffolding is needed and large areas can be covered in comparatively short times. We have reported our first imaging measurements of this kind using a scanning fluorescence lidar system placed at a distance of about 50 m from Lund Cathedral [C14-C18]. The fluorescence lidar system used a frequencytripled Nd:YAG laser as the transmitter and a 40 cm diameter Newtonian receiving telescope. Two simultaneous detection channels based on filters and photomultipliers, or a gated optical multi-channel analyser (OMA) system, were used in the measurements where an 8 cm diameter laser spot was scanned row by row over the facade by a computer-controlled mirror on the roof of the lidar system.

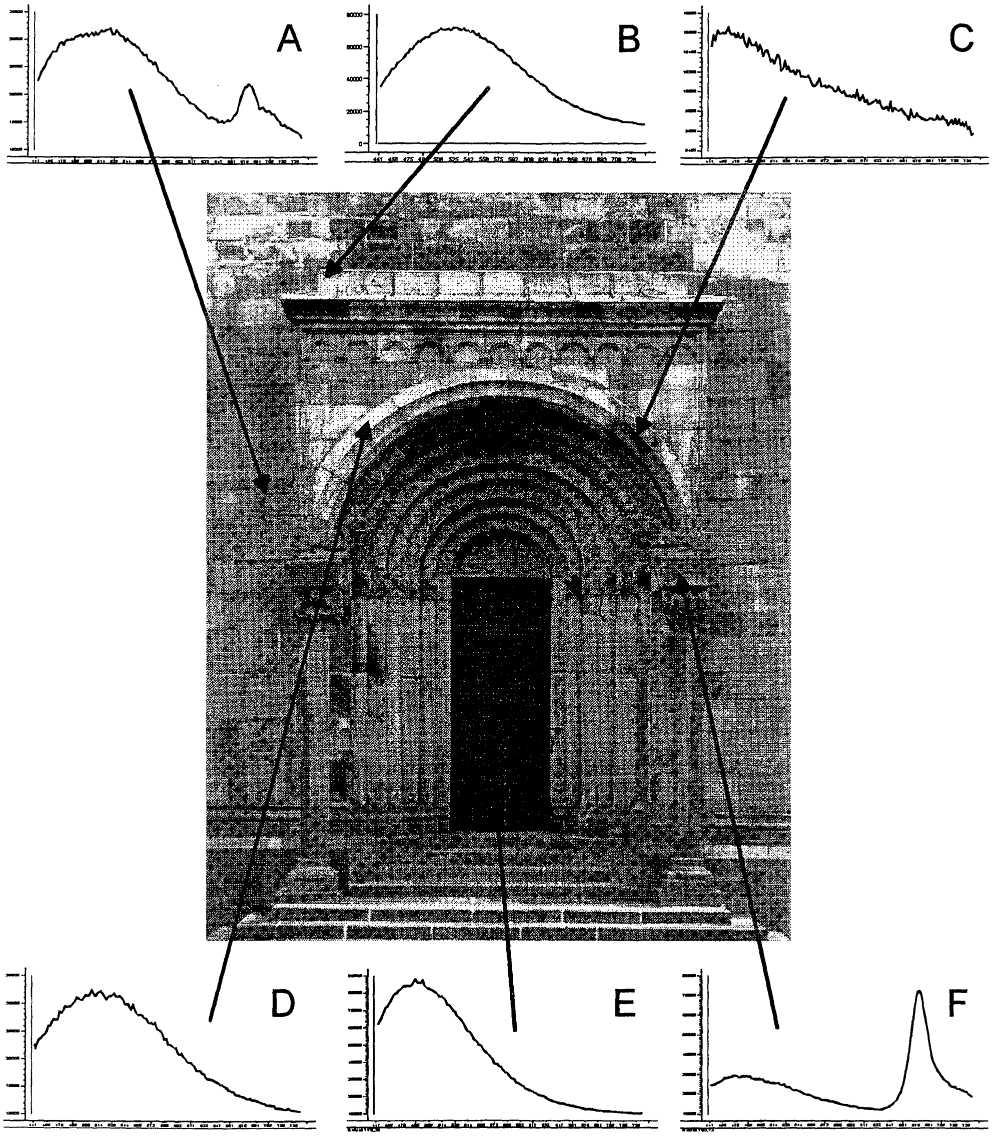

Fig. C3. Point monitoring spectra from the northern portal of Lund Cathedral. The figures show LIF signatures in the region 440-740 nm from: A. Algaea signal not seen by eye. B. Metal roof. C. Quenching from iron. D. Clean sandstone. E. Door. F. Strong signal from algae.

Computer routines were developed enabling full fluorescence spectral recording from 400 - 800 nm, covering one of the church portals, as can be seen in Fig. C3. Algal growth is evident on the shadow side of the portal and on the ornamental sculptures, as well as strong fluorescence quenching from iron ions related to decaying supporting metal bands. The averaging recording of 10 laser shots, the storage of the data and the mirror advancement to the next measurement point took less than 1 second. An area of approximately 8x8 m^2 was covered and about 7200 full spectra were recorded and stored during a 2 h run for the area shown in the figures. Multivariate analysis of the data revealed many details, based on known spectra from well-characterized areas of the facade.

C3. Gas imaging using gas-correlation spectroscopy

Jonas Sandsten, Hans Edner, Sune Svanberg and Petter Weibring

A new method for remote visualisation of gas flows, based on infrared absorption and gas-correlation techniques, has been further developed. Two images of flowing gases are formed simultaneously on an IR-sensitive detector with a split-mirror Cassegrainian telescope. A suitable bandpass filter is used to isolate a small region containing absorption features of the gas to be studied. One of the images is further filtered by a short cell filled with a high concentration of the gas. After image processing the two images can be used to eliminate differences in background illumination as well as the interference by other gases and particles. The end result is a grey-scale or false colour-coded image showing the distribution of a specific gas in the area studied. We have recently demonstrated gas correlation spectroscopy of flowing gases in real time with natural thermal background radiation as the only radiative source. The applications we have been working on are remote methane (CH_4) visualisation of leakages from pipelines, other hydrocarbon emissions such as ethene (C_2H_4), visualisation of hazardous gases, for example ammonia (NH_3) after a transportation accident, and working environment studies using nitrous oxide (N_2O) flowing turbulently in air.

The experiments on methane, ethene and ammonia were performed with simulated gas leakages from a gas tanker at the gas exercise site at Malmö Fire Department. The tanker itself was radiating the thermal background used in this passive gas-correlation technique. A new infrared camera with a set of optimised filters was used in combination with fast capture of images, and the whole set-up was placed 20 metres from the truck.

We have also explored the possibilities of using a quantum-well infrared-photodetector-based camera which has narrow responsivity and very high quantum efficiency, both advantageous features in passive gas correlation spectroscopy, at the R&D department of the infrared camera manufacturer, Agema.

C4. Diode laser spectroscopy

During the past two years, we have pursued a number of different applications based on inexpensive, room-temperature-operated and readily available near-infrared diode lasers. The main focus of the project is absorption spectroscopy, which is a powerful method of performing quantitative measurements with high sensitivity, especially when using frequency-modulation (FM) techniques. Common to a variety of FM techniques is the shifting of the detection band to higher frequencies to avoid laser source (1/f) noise. We have specialised in an approach called two-tone frequency-modulation spectroscopy (TTFMS), which provides high dynamic range, favourable detection bandwidth and shot-noise-limited detection, i.e. ultra sensitive absorption measurements. Although shot-noise-limited detection is possible at 10^{-7} - 10^{-8} fractional absorption, our experimental arrangements normally have a detection sensitivity of about 10^{-6}. This high sensitivity is suitable for work on small volumes of absorbing gas and for measuring weak molecular transitions in the near-infrared region. We are also pursuing sum- and difference-frequency generation, which enables access to strong fundamental transitions in the UV/visible and middle infrared region. Another new application in the project is the use of an external-cavity diode laser for detection and identification of aerosol particles in real time. A cavity loss signal from the aerosol particles entering the external cavity is combined with near-forward scattered light to reduce the size distribution interval of ordinary optical particle counting (OPC) instruments and to capture a Fourier transformed shaped image of the aerosol particle. The instrument sensitivity is an intrinsic function of the measurement volume and the external-cavity mirror reflectance.

Tomographic reconstruction of temperature and concentration in a methane-oxygen flame

Ulf Gustafsson

Spatially resolved measurements of temperature and concentration are important in fluid flow, combustion and heat transfer research. Laser absorption spectroscopy is a fast, sensitive and nonintrusive method for quantitative measurement of temperature and concentration, but it does not yield spatial information since it is a line-of-sight method. By combining multi-angular TTFMS and tomography spatially resolved measurements can be performed on weakly absorbing objects. Presently, we are mapping the temperature and concentration in a methane-oxygen flame by simultaneously recording the whole absorption lineshape of four weak transitions in the oxygen A-band at 760 nm.

Vapour pressure measurements, a tool for water activity determinations in solutions

Ulf Gustafsson, Jonas Sandsten and Gabriel Somesfalean

The equilibrium partial pressure of water vapour in a gas over an aqueous solution is dependent upon the water activity of the solution. The water activity of a system is, in turn, a function of the nature and concentration of the solute or solute mixture, and is intrinsically dependent upon the interactions between the molecular species present. Accordingly, the nature of the solute(s) and the interactions between the species present in a sample can be investigated by monitoring the water vapour pressure in the headspace above the solution using laser absorption spectroscopy. We have obtained a minimum detectable pressure change of 0.3% by measuring the peak-to-peak value of the TTFMS lineshape of a water absorption line at 819 nm. At the moment, we are working on enhancing the detection sensitivity by using a diode laser at 1.39 μm and increasing the measurement accuracy by analysing the whole absorption lineshape. This will allow us to study very small pressure changes. The technique will be applied to the study of solution structures of biologically significant molecules, including the thermodynamic factors affecting association in solutions, e.g. the hydrophobic effect.

External-cavity diode laser using optical feedback for sensitive measurements of aerosols

Jonas Sandsten, Ulf Gustafsson and Gabriel Somesfalean

Allergy and asthma are known to increase as a result of indoor environment exposure to, for example, fungus spores and outdoor environment exposure to pollution and pollen. Rapid changes in working life concerning production technology and the development of materials lead to the rapid introduction of new potential risks. We would like to be able to monitor and identify aerosol particles of hazardous materials, such as respirable fibres in real time at places of work. We are therfore working on a new principle for the detection and identification of aerosol particles *in situ* using an external-cavity diode laser with optical feedback from an aerosol particle, and a CCD camera sampling near-forward scattered light from the same aerosol particle [C19,C20]. Fig. C1 shows the experimental arrangement. Using the discriminator circuit it is possible to set the instrument to sample aerosol particles of the same shape and size distribution. The optical feedback signal induced by the aerosol particle entering the external-cavity diode laser is detected with the diode laser's built-in photodiode and gives information about the size distribution of the aerosol particles. The orientation and shape of an aerosol particle cross-section are obtained from the Fourier-transformed diffraction image. The experimental setup is simulated with software for optics design and extended scalar diffraction theory is used to compare the simulated diffraction images with the experimental data. The simulated point-spread functions agree well with the experimental cross-section of the images. We have presented results from experiments with fibres of occupational exposure interest, for example glass, carbon and nylon. The present measurable diameter range is 1.5 μm - 150 μm.

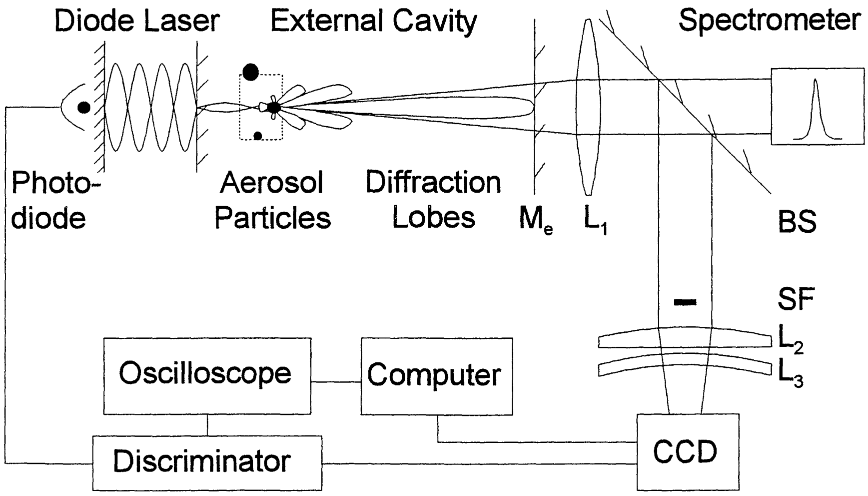

Fig. C4. Experimental arrangement for aerosol particle measurements.

Sum- and difference frequency generation using diode lasers

Ulf Gustafsson, Janis Alnis, Gabriel Somesfalean and Sune Svanberg

An experimental facility for sum- and difference frequency generation using diode lasers is being set up for assessing UV and blue wavelengths as well as infra-red wavelengths. The possibility to combine the techniques with frequency modulation schemes will be explored. Species of particular interest are atomic mercury and hydrocarbons. A single-mode ring dye laser for red wavelength generation and an Alexandrite pulsed amplifier are being employed for facilitating initial demonstration experiments.

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D. Laser Applications in Medicine and Biology

The Division of Atomic Physics has continued to play a central role in research at the Lund University Medical Laser Centre. The aim of this organisation is to support interdisciplinary projects using lasers in medical research involving the Faculties of Medicine, Natural Sciences and Engineering within the University, to run courses and seminar series in related subjects, to act as a base for grant applications, and to act as a partner for other groups in multicentre research studies. The activities within the Centre cover a wide field of interdisciplinary research, involving clinicians from various clinical specialities, physicists and chemists. In our presentations of the personnel involved in the different projects, only people located at the Division of Atomic Physics are listed. A large number of collaborators, within and outside the Medical Laser Centre, also contribute to our work.

The research activities at the Division of Atomic Physics involve tissue characterisation using laser spectroscopic techniques and laser treatment of malignant tumours. Tissue diagnostic research has mainly been directed towards two fields: the early detection and identification of premalignant and malignant lesions, and the characterisation of cardiovascular tissue to identify degenerated areas causing decreased circulatory function. In the cardiovascular field we initiated a European project which we now co-ordinate. The project is supported by the BIOMED II programme of the European Commission.

The first technique for tissue characterisation investigated in this project was laser-induced fluorescence, to identify diseased tissue. This project started in 1982. The native tissue autofluorescence, originating from endogenous fluorophores, as well as fluorescence from administered tumour markers, mostly porphyrins, was included in the studies. Research in this field during the past two years has partly been directed towards clinical evaluation of the techniques and of the systems developed in various clinical specialities; and partly to gaining knowledge regarding the pharmacokinetics and biodistribution of various fluorescent tumour-marking agents. Photodynamic therapy (PDT) of malignant tumours using a photochemical reaction involving externally administered photosensitising agents and tissue-bound molecular oxygen, has been examined in clinical trials. A large comparative study between PDT, following topical application of δ-amino levulinic acid (ALA) for photosensitisation, and cryosurgery in the treatment of non-melanoma malignant skin tumours has been completed. It is interesting to note that the PDT project has passed the pure clinical research stage. Hundreds of patients have now been treated. A potentially interesting technique under development for early breast tumour detection is based on temporally resolved tissue transillumination measurements. At present we aim to fully explore the spectroscopic basis of the technique with *in vivo* and *in vitro* tissue studies. Furthermore, we aim to improve our basic understanding of light transport in tissue. This work includes tissue-simulating phantom studies and theoretical and numerical modelling of light distribution. Other alternative laser-based diagnostic techniques under investigation include elastic- and Raman-scattered light as well as IR tissue spectroscopy. We have also initiated two new projects for laboratory studies: spectroscopy at the microscopic level in two-photon fluorescence microscopy and in a confocal microscope. The concept of fluorescence imaging detection in chemical separation using electrophoresis is also being explored.

Collaboration has taken place with more than 10 other research groups during the past two years. Annika Enejder and Christian Sturesson defended their PhD theses and Charlotta Lindquist her Licenciate thesis during the period [D1-3]. A number of Master's students have also presented their projects [D4-10]. Our recent work has also been presented in a large number of invited talks and review papers [D11-17].

D1. Tissue characterisation using laser-induced fluorescence

The potential of laser-induced fluorescence (LIF) as a tool in tissue diagnostics has been evaluated in a number of studies; pre-clinical as well as clinical. Both the endogenous fluorescence from the tissue and the fluorescence from externally administered agents have been used. A new compact fluorosensor, adapted for clinical use, has been developed. This system allows us to record time-integrated, as well as time-gated, fluorescence emission spectra for two different excitation wavelengths. Studies to compare the capabilities of the multi-colour fluorescence imaging system developed within the group and a time-resolved imaging system developed by the group of Prof. Rinaldo Cubeddu in Milan have also been conducted.

Experimental studies

Stefan Andersson-Engels, Annika Enejder, Katarina Svanberg, Sune Svanberg, Ingrid Wang

Three experimental studies have been completed. They were all designed to optimise the parameters for tumour identification using laser-induced fluorescence. In the first study, the potential of various carotenoporphyrins as fluorescent tumour markers was addressed [D18]. One of the interesting features of carotenoporphyrins as fluorescent tumour markers is that the substances do not induce phototoxicity. This means that they cannot be used for photodynamic therapy (see below), but have no photo-toxicity as a side-effect of the fluorescence examination. The other two studies addressed the distribution of protoporphyrin IX as well as its pharmacokinetics in the body following intravenous injection of ALA [D19-20]. These results are important in optimising the technique for the detection of malignant tumours.

We have also involved ourselves in the development of better numerical models for light transport in tissue in order to gain a better understanding of the fluorescence signals recorded from tissue. The Monte Carlo model developed is presented in Ref. [D21].

Clinical studies

Stefan Andersson-Engels, Markus Andreasson, Charlotta Eker, Annika Enejder, Claes af Klinteberg, Ola Sandström, Katarina Svanberg, Sune Svanberg, Ingrid Wang

A number of clinical studies have been conducted during the period. The instrumentation used has also been refined based on the experience gained through many years of clinical fluorescence studies. Thus, a new compact fluorosensor has been developed. The system has a number of new features as compared with the older systems used, and is also very compact. Figure D1 shows the system in use at the Karolinska Hospital in Stockholm. Also, the performance of the multi-colour imaging system has been improved by changing some components of the collection and splitting optics.

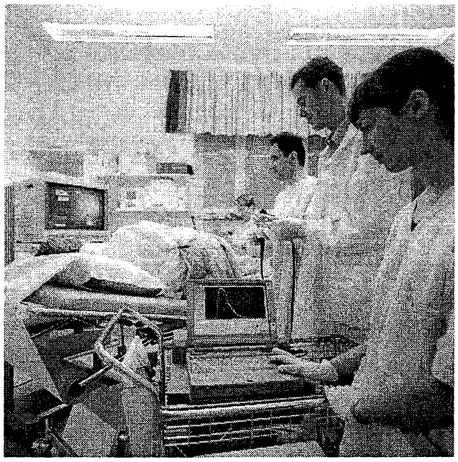

Fig. D1. *The new compact fluorosensor used during coloscopy at the Karolinska Hospital in Stockholm.*

Several fluorescence studies have been conducted to investigate the PpIX fluorescence in skin lesions following topical ALA application. These studies have been performed in connection with the clinical PDT study described below. Both the selectivity to malignant skin lesions and the kinetics of the fluorescence have been investigated in detail [D22-23]. Also, fluorescence images visualising the protoporphyrin distribution were recorded from this type of lesion. An example of a multicolour image and a fluorescence lifetime image of the same lesion is shown in Fig. D2. The detailed results from these imaging studies can be found in Refs [D24-26].

Fluorescence studies have also been performed to identify malignant tumours at other locations in the body. Laser-induced fluorescence was used to evaluate its potential in discriminating between premalignant and benign lesions in the female genital tract [D27]. Clinical spectral characterisation of colonic mucosal lesions has also been performed [D28]. Several studies in the ENT region have also been conducted, of which one has been completed and is presented in Ref. [D29]. All these studies show that fluorescence can give information of value to an examining physician.

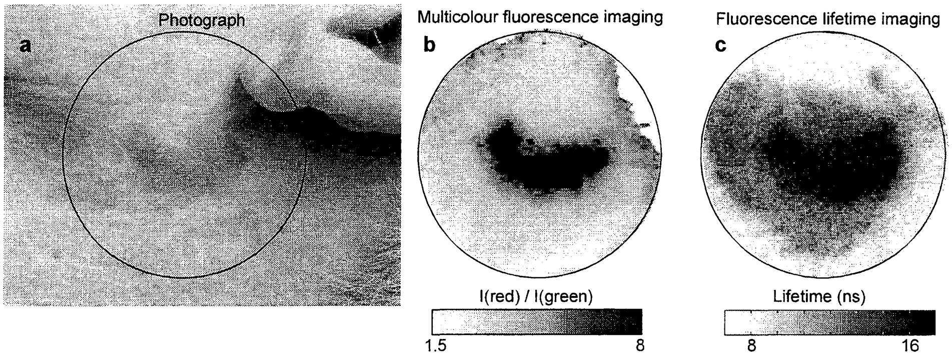

Fig. D2. *Fluorescence images of a superficial basal cell carcinoma below the ear of a patient. a) photograph of the lesion. b) processed multicolour image indicating the tumour in dark (high red/green ratio). c) fluorescence lifetime image illustrating the image in dark (long lifetime).*

D2. Tissue optical properties

Peter Alsholm, Stefan Andersson-Engels, Annika Enejder, Christian Sturesson, Johannes Swartling

Knowledge of the optical properties of tissue is important in most applications in medical optics. On the therapeutic side, there are PDT and laser-induced thermotherapy, where the optical properties in combination with models for light propagation are necessary for dosimetry and prediction of the effects of the treatment. In laser-induced fluorescence diagnostics, they provide help in understanding the nature of the response signal of the fluorescence. Knowledge of the optical properties is also essential for tissue transillumination diagnostics. Annika Enejder has been working on the development of methods to measure these properties. She defended her doctoral thesis "Light Scattering and Absorption in Tissue – Models and Measurements" in November, 1997 [D1].

The optically integrating sphere provides a convenient way of accurately determining the optical properties of tissue *in vitro,* and in some cases also *in vivo*. The optical properties of interest are most often the absorption, described by the absorption coefficient μ_a, the scattering (analogously described by μ_s), and the amount of forward scattering, described by the mean cosine of the scattering angle, denoted g.

The problem of determining the optical properties of tissue is non-linear, which usually calls for some iterative solution algorithm. In general, most approaches employ a scheme in which the measured signals from a sample are compared with computations from a numerical model, which are repeated until convergence is reached. In our case, we make use of a pre-computed database of Monte Carlo simulations, in order to reduce the computation time needed in the iterations.

The experimental set-up used (see Fig. D3) consists of a broad-band light source (a xenon or halogen filament lamp), an integrating sphere which is covered on the inside with highly reflective barium sulphate, and a collimated beam. The light from the sample is transmitted to a spectrometer and detected using a cryo-cooled CCD. This set-up allows us to perform three independent measurements: the total amount of transmitted light (the sample in position A), the backscattered light (position B) and the collimated transmitted light (position C). A specially developed computer program then calculates the three parameters μ_a, μ_s, and g by interpolation in the Monte Carlo database. The broad-band light source and spectrometer also allow us to view the spectral variation of these parameters.

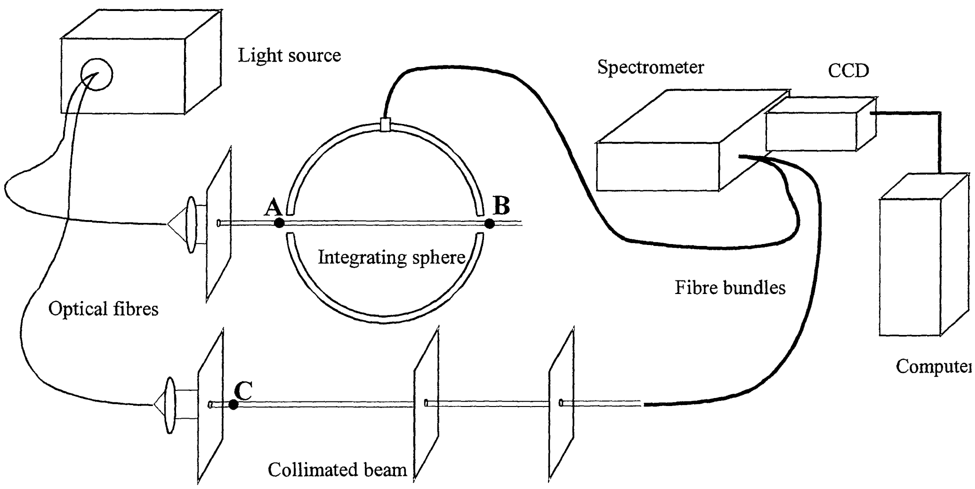

Fig. D3. *The experimental arrangement for the optically integrating sphere and the collimated beam.*

The collimated-beam measurement, which gives the total attenuation coefficient $\mu_t = \mu_s + \mu_a$, sets the limit of the range of optical properties that can be measured. The signal decreases exponentially with μ_t. Recently, we have studied the effects of the optical properties of various tissues due to heating [D30-32], both tumour tissue and blood. Pure blood is a typical example of a tissue type for which it is difficult to measure the properties. It is characterized by a very high value of μ_s and a value of g close to unity. In co-operation with Gambro AB, we are running a project with the aim of gaining a better understanding of the optical properties of blood. It is possible to reduce the number of measurements by excluding the collimated beam, at the expense of only being able to extract two parameters, μ_a and the reduced scattering coefficient $\mu_s' = \mu_s(1-g)$.

Knowledge of the optical properties is also important in order to understand how the microstructure of the tissue influences light propagation. For example, comparing the measured values of the scattering properties with Mie theory calculations gives an estimate of the size of the scatterers in the tissue. The results indicate that the average scatterer size in typical tissue is of the order of less than 0.5 μm, which is the same size as the internal structures in the cell, such as mitochondria. Blood cells, on the other hand, have no nucleus, and the whole cell therefore acts as the scattering object. Since blood cells are 5 - 15 μm in diameter, the scattering properties are very different from those of other tissue. Moreover, the shape of the blood cells is also important. T-matrix theory calculations of scattering from disc-shaped spheroids, which resemble the biconcave appearance of red blood cells, show that especially the forward scattering differs from that from spherical objects [D33].

The disc shape of the blood cells may also influence the macroscopic scattering of blood in other ways. In flowing blood, the cells tend to line up in certain more or less regular patterns, giving rise to detectable differences in the measured signals from different modes of flow.

D3. Scattering spectroscopy for medical diagnostics

As can be understood from the above, scattering is a very prominent mechanism in light interaction with tissue. Thus a precise knowledge of the scattering properties is very important in developing various medical laser techniques into useful clinical tools. Below, some diagnostic techniques are discussed for which the scattering properties of the tissue examined are essential.

Time-resolved diffuse reflectance

Stefan Andersson-Engels, Charlotta Eker, Claes af Klinteberg, Sune Svanberg

The time-resolved diffuse reflectance method of characterizing tissue has been further evaluated at our laboratory. As one of the pioneering groups in this field, the experience gained from various types of instruments and experiments is very valuable. The potential usefulness of the technique for breast tumour identification and localisation is discussed in Ref. [D34]. The technique is probably not realistic for whole population screening, but may develop into a candidate for the screening of selected risk groups. Such groups may include women from families with many cases of breast cancer, or women suspected to have breast cancer after positive blood sample tests.

Four laboratory and two computer exercises have been developed especially for the combined undergraduate and graduate course in tissue optics. The instructions for both the laboratory and computer exercises have been published on the Internet [D35] and the instructions for the laboratory exercise on time-resolved measurements have also been published as a separate report [D36].

The optical properties of tissue can be extracted from time-resolved measurements of the diffuse reflectance. To extract the parameters, a theoretical model must be fitted to the recorded data. Usually, an analytical model based on the diffusion equation is used for this purpose. This model has proven to accurately describe light propagation in tissue, provided that the absorption coefficient is much smaller than the scattering coefficient and that the separation between the detector and source fibres is much greater than the photon diffusion length in the tissue probed. This is typically the case for red light with a fibre separation of at least 10 mm. In other cases, this approach is not as accurate, and other models should be considered. Under these circumstances, Monte Carlo simulations are frequently used. This model is, however, slow and not well suited for solving the inverse problem. We have thus developed an accelerated Monte Carlo model for this purpose [D37].

It is very interesting to be able to obtain the spectral variations of the optical properties of tissue. Such spectroscopic data make possible the evaluation of the wavelength to be use for optimal identification of breast tumours, as well as measurements of the true *in vivo* absorption spectra of various photosensitisers used for PDT. By using the non-linear properties of water, short white pulses have been generated by focusing femtosecond pulses from the high-power laser at the Lund Laser Centre into a cuvette of water. The diffusely reflected, or transmitted, white light from various tissues can thus be recorded using a spectrometer and a streak camera. A schematic representation of the experimental set-up is shown in Fig. D4.

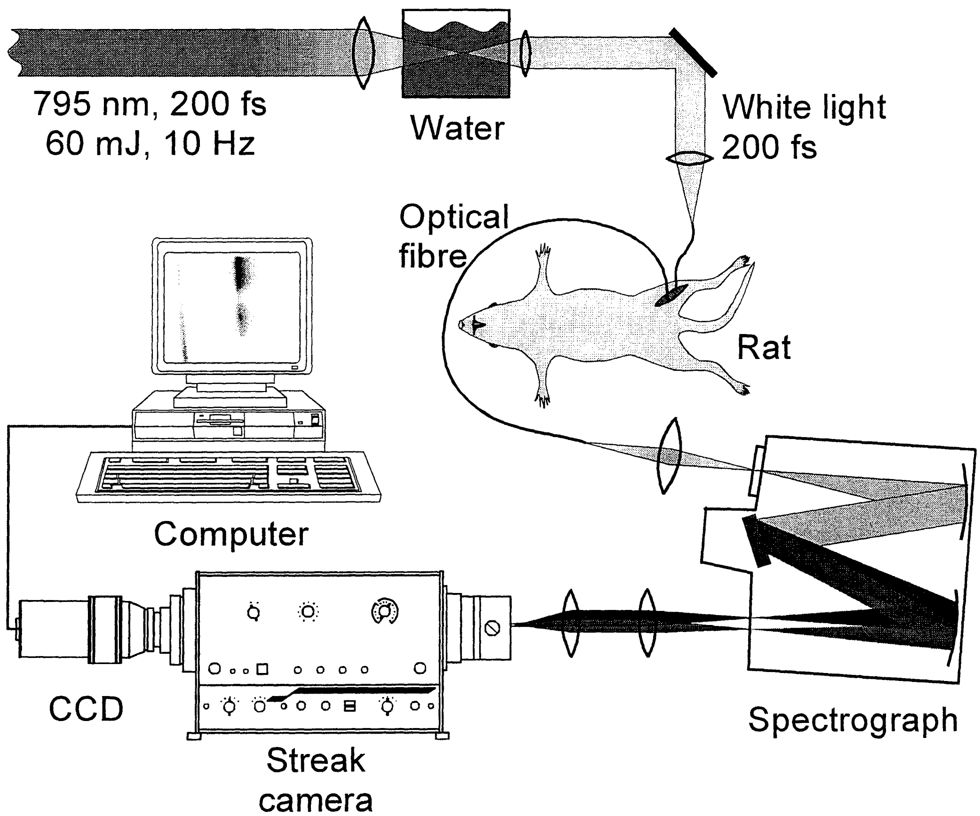

Fig. D4. Optical arrangement for time-resolved white light measurements.

The optical properties of tissues can, in this way, be extracted for the wavelengths of interest (in the visible and NIR regions) [D38]. The absorption spectrum of one photosensitiser for PDT, di-sulphonated aluminium phthalocyanine (AlS_2Pc), has been recorded *in vivo* in rats using this method [D39].

Frequency domain diffuse reflectance

Charlotta Eker

An alternative to time-resolved diffuse reflectance is to measure in the frequency domain using harmonically modulated light sources instead of short pulses. An advantage of the frequency domain technique is the relatively simple instrumentation required. The similarity to equipment used for radio communication means that this field is well developed. Charlotta Eker has spent some time during two periods at the University of California, Irvine, in the group of Prof. Bruce Tromberg, performing measurements using their equipment. This equipment allows diffuse reflection measurements at several different wavelengths and at many modulation frequencies up to 1 GHz. The optical properties of the tissue under examination can be obtained by fitting the recorded data to a diffusion model. Charlotta has mainly focused on measuring the physiological properties of breast tissue using the technique. This means that the contents of water oxyhaemoglobin, deoxyhaemoglobin and fat have been measured using the technique. Several publications are under preparation describing the results of those measurements [D40-42].

Laser Doppler perfusion imaging

Stefan Andersson-Engels, Annika Enejder, Claes af Klinteberg, Katarina Svanberg, Sune Svanberg, Ingrid Wang

Doppler shifts generated by blood cells moving inside the tissue can be measured by analysing the frequency components of diffusely scattered laser light with high resolution. A laser Doppler perfusion imaging system developed by the group of Prof. Gert Nilsson in Linköping has been used to measure the vascular damage due to photodynamic therapy. Interestingly, the results clearly show that the vascular damage depends critically on the route of administration of the photosensitiser. If the agent used to sensitise the tissue is administered systemically, the drug is present at a high concentration in the blood vessels. In such cases the vessels will be damaged due to the treatment, causing decreased blood supply to the treated tissue volume [D43]. This might result in a secondary treatment effect, due to the decreased oxygen tension in the treatment volume lasting for a long period after treatment. The results from laser Doppler perfusion measurements suggest, however, that PDT following topical application does not cause sever damage to the blood vessels. Instead, the local blood perfusion increases due to the treatment in the same way as for an inflammatory response [D44-45]. As the treatment response is also very efficient for topical application, we have drawn the interesting conclusion that the PDT effect is not only limited to the secondary effects due to lack of oxygen in the treated tissue following the radiation. Thus, there seems to be an efficient direct treatment effect damaging the tissue.

Vibrational spectroscopy

Stefan Andersson-Engels, Annika Enejder, Markus Gustafsson, Mårten Pålsson, Sara Pålsson

We have, during the last 2 years developed instruments and evaluated vibrational spectroscopic techniques for tissue characterisation. Vibrational spectroscopy probes the molecular bonds, and signals specific to various bonds can be recorded. This makes vibrational techniques interesting candidates for tissue characterisation. Two vibrational spectroscopic techniques have been investigated within the group – NIR and Raman spectroscopy. NIR spectroscopy measures the overtones and combination bands of vibrational absorption. In order to achieve signals that are not totally dominated by water absorption, wavelength regions with only small absorption in water are of interest. This limits the regions to below 1.4 μm and in small windows around 2.5 μm. We have performed a study to characterise cardiovascular tissue using NIR spectroscopy [D46]. The results show that it was possible to distinguish between all tissue types examined using this technique. We have also devoted considerable effort in developing a system for *in vivo* Raman spectroscopy. The main limitation of Raman spectroscopy is the weak signals generated. Very sensitive detectors must thus be used, and the optics must be of high quality to avoid background signals generated by the system itself. Systems for two measurement geometries are now available at the Division. One employs a direct laser beam irradiation, while the other uses a fibre-optic probe from Visionex. The first system (shown in Fig. D5) has a very high light collection efficiency with only a few lenses in the beam path, while the other system is much more flexible and allows examination of most lesions accessible with the fibre-optic probe. We are presently conducting several studies to evaluate how well this method can identify various tissue lesions. None of these studies has yet been completed or published.

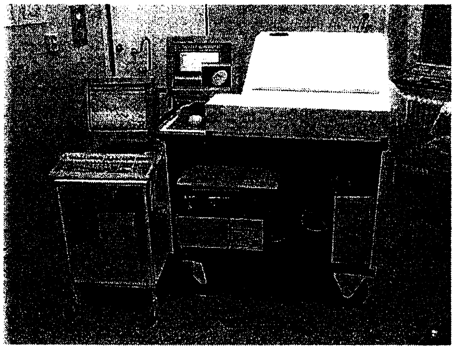

Fig. D5. *Photograph of the newly developed Raman spectroscopy system*

D4. Photodynamic therapy

Stefan Andersson-Engels, Annika Enejder, Thomas Johansson, Inga Karu, Claes af Klinteberg, Nichlas Ohlsson, Sara Pålsson, Ola Rylow, Katarina Svanberg, Sune Svanberg, Ingrid Wang

Photodynamic therapy (PDT) is a tumour treatment modality employing light in combination with photosensitisers administered to the patient. The lesion is illuminated with red light, exciting the photosensitiser molecules accumulated in the tissue. The excitation energy is transferred to the surrounding oxygen molecules, eventually causing tissue oxidation. This treatment procedure takes place mainly in the malignant tissue, due to its selective uptake of the photosensitiser. We have performed a number of clinical PDT studies during the period [D47-51]. To achieve routine clinical use of PDT when treating basal cell carcinomas in the skin, a clinical trial has been performed, comparing cryo-therapy – the conventional treatment modality of today – with PDT using topically applied ALA-induced protoporphyrin IX as a photosensitiser. A great deal of experience has been gained in Lund as well as in several other clinics concerning ALA-PDT as a treatment modality for non-melanoma malignant skin lesions [D47]. The results show that ALA-PDT can lead to results that are comparable to those of conventional modalities. Certain lesions require repeated PDT sessions. The treatment spares normal tissue and leads to very little scar formation (see Fig. D6). There appears to be many, easily implemented, small improvements to ALA-PDT which can increase the efficacy, and simplify the treatment regimen. Each of these suggested improvements, must to be studied separately and in combination, to find the optimal treatment protocol. One of the major issues is how to deliver the light optimally. We have examined two small diode lasers for this purpose (see Fig. D7) [D49-50]. We have also monitored one of the side-effects of the treatment in detail – the pain during treatment [D51]. This investigation showed that some patients feel itching and/or prickling during irradiation, but in almost all cases the pain has been tolerated by the patients.

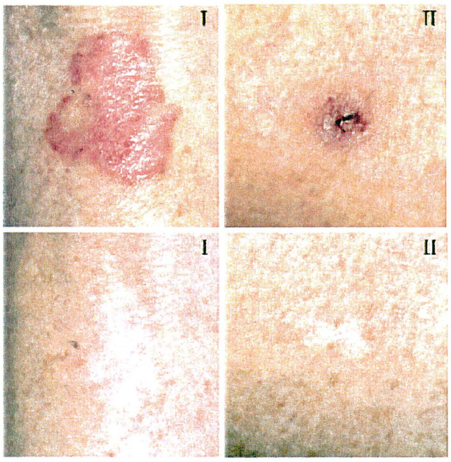

Fig. D6. *Superficial (I) and nodular (II) BCC prior to (upper) and one year after (lower) PDT.*

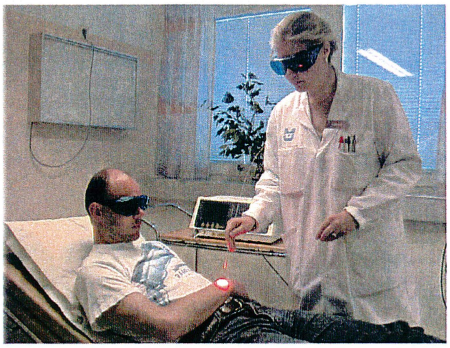

Fig. D7. *Diode laser PDT treatment.*

Based on these considerations, it is clear that there is at least one clear niche where PDT plays a very important role as a treatment modality. This is in the treatment of superficial tumour growth when it covers large areas, or is situated in areas where function or cosmetics is important [D48]. PDT can also be performed when other modalities are excluded, for instance, when a full dose of ionizing radiation has been given, surgery cannot be performed, or the patient is in poor general condition. A good example of a lesion in which ALA-PDT is an ideal treatment modality, can be seen in Ref. 47 (Figure 1b). This is a large superficial BCC, situated in the pre-tibial area, in which both surgery and ionizing radiation are modalities that can be difficult to perform, due to the proximity to the underlying bone, tight skin covering and generally poor blood perfusion.

D5. Laser-induced thermo-therapy

Stefan Andersson-Engels, Annika Enejder, Christian Sturesson

Heat has, for a long time, been utilised as a therapeutic tool in medicine. Laser-induced heat treatment relies on the conversion of light absorbed in the tissue into heat, enabling treatment of various tumour diseases and vascular malformation. It is important to have knowledge of the entire temperature distribution in the tissue since the cellular response to the treatment is highly dependent on the local treatment temperature.

Our research within this field has been directed partly towards modelling heat transport in tissue and partly towards the study of damage caused by heating of the tissue in experimental studies. In the animal model we have mainly studied rat liver tissue. The temperature rise due laser radiation is highly dependent on the blood perfusion through the organ. We have thus studied the blood flow during heating and also what effect inflow occlusion has on the treatment effect [D52-54]. Other parameters of importance for the therapeutic results, such as how carbonisation effects the size of the photo-inactivated lesion, have also been studied [D55-56]. To improve the possibility of performing well-controlled and reproducible treatment, we have also developed a feed-back controlled laser system and studied whether MRI can be used to measure the temperature distribution within the tissue during treatment [D57-58].

The other main application of thermo-therapy on which we have focused during the period covered by this report is the treatment of benign prostatic hyperplasia (BPH). We have followed two directions in the development of treatment modalities for such a condition. Regarding laser-induced therapy, we have developed a specially designed catheter probe for this type of treatment [D59]. An improvement of this probe allows irradiation along two lines, see Fig. D8. A new technique is employed to develop such a probe, using a highly scattering plastic bulk material instead of reflective optics. In this way, very efficient redirection of the light in the required geometry could be achieved. The probe was designed to direct the light in such a

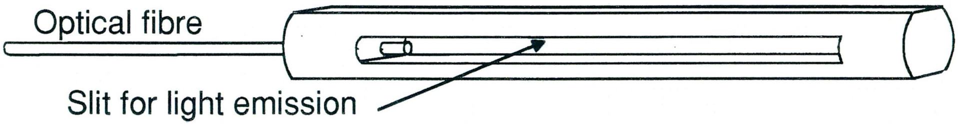

Fig. D8. Schematic illustration of the side-firing laser probe. A clear cut optical fibre is placed inside a highly scattering plastic material formed with an internal slit of air. The light exits the probe through the two slits.

way that it matched the geometry of the tissue to be treated optimally. It enables both lobes of the prostatic gland to be heated, while sparing other tissues. The light fluence in a plane perpendicular to the fibre probe is shown in Fig. D9. The temperature distribution resulting from irradiation of bovine muscle *ex vivo* was measured to estimate the *in vivo* heating characteristics of the catheter. An example of the results of these measurements is shown in Fig. D10. We have submitted a patent application to protect the commercial rights to this probe design [D60].

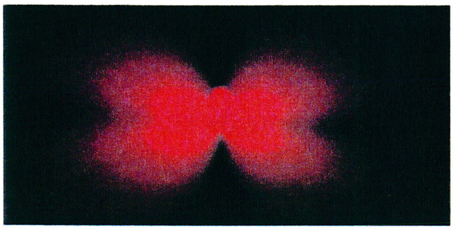

Fig. D9. Light radiation in a plane perpendicular to the probe in Fig. D8.

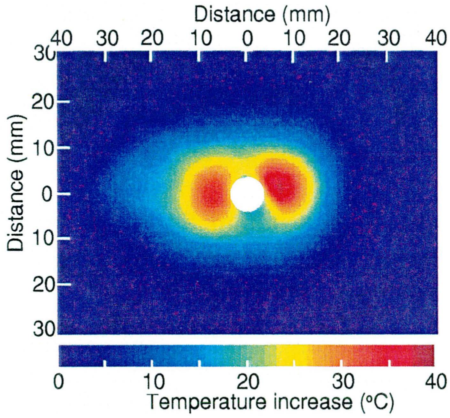

Fig. D10. Temperature distribution perpendicular to the fibre probe after laser irradiation.

The mathematical model developed for laser-induced thermotherapy has also been adapted to microwave-induced thermotherapy. The new model is now implemented and used to control transurethral microwave treatment (TUMT) of the prostatic gland [D61]. The results obtained with the ProstaLund instrument from Lund Instruments shows as much as a 100% improvement in the clinical results using an intraprostatic temperature sensor with this model (to be published).

During the past year Christian Sturesson has completed a comprehensive PhD thesis in the field of laser-induced thermotherapy entitled "Medical Laser-Induced thermotherapy – Models and Applications" [D2].

D6. Analytical chemistry

Jonas Johansson, Thomas Johansson

The different detection techniques used in analytical chemistry constitute an interesting area of research. UV absorption and laser-induced fluorescence are the two main techniques used for detection in liquid samples. Collaboration between the Divisions of Atomic Physics and Technical Analytical Chemistry at Lund Institute of Technology was initiated few years ago and several projects are now in progress.

Capillary electrophoresis (CE) is a valuable analytical tool owing to its high separation efficiency, its flexibility, and the ease of introducing new modes of operation. CE still presents a challenge to detector technology due to the constraints of nanolitre analyte volumes and micrometre detection path lengths. Laser-induced fluorescence (LIF) is today the most sensitive optical detection scheme available for CE. The excitation light is usually focused near the end of the capillary and a light detector measures the emitted fluorescence. LIF imaging of a capillary through a camera lens system onto a charge-coupled device (CCD) camera, giving

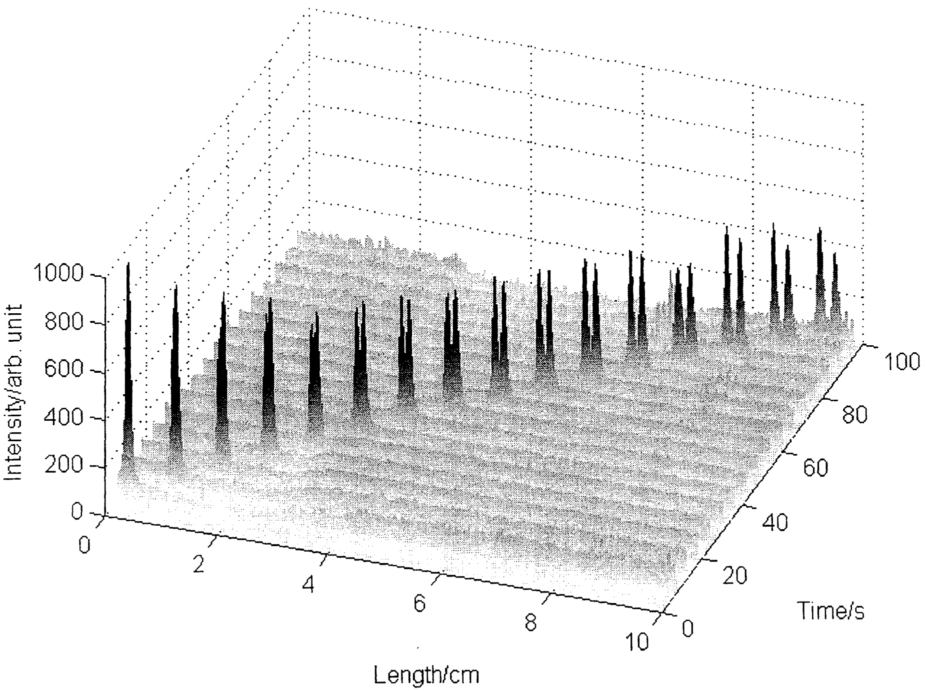

Fig. D11. *3-D image of 10 μM DNS-Asp (dissolved in methanol and diluted in water) using l_{ex} 405 nm. After 10 cm the two enantiomers are separated. A 50 μm i.d., 375 μm o.d., 28 cm total length capillary imaged between 1.5–11.5 cm was used. Injection at the anode was done for 10 s at 10 cm, and the separation potential was 10 kV generating a current of 11 μA.*

consecutive images of the capillary, has been developed. The collection efficiency was increased by placing a fibre array perpendicular to the capillary for the collection and transport of the fluorescence to the CCD camera,. A 10 cm wide fibre array was constructed and used to visualise enantiomer separation of dansyl-DL-amino acids [D62]. The large amount of data generated with an imaging system can be used to extract additional information about the separation and the analytes' electrophoretic behaviour. A custom-designed computer program was therefore developed to process and display the data. Analyte position and velocity, band broadening and separation efficiencies are parameters that can be extracted as a function of time from the electropherograms. Various digital signal processing techniques were used to increase the signal-to-noise ratio. Another approach is to visualise absorption for axial-beam geometry [D63]. Here, the excitation light is introduced at one end of the capillary and the absorption along the capillary is visualised. A new type of micro-chemistry project eliminating the need of a sample cuvette is also initiated. The sample is instead kept as a levitated droplet in an ultrasonic field. Different chemicals can be added with a piezo-electric drop injector and the fluorescence can be easily detected because of the non existing cuvette, or the sample can be transferred to a capillary for further analysis [D64].

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E. Industrial Applications

In this chapter, the two projects "Optical and Spectroscopic Investigations of the Physics of Electric Breakdown" and "Optical Spectroscopy of Paper" are described.

E1. Optical and spectroscopic investigations of the physics of electric breakdown

Stefan Kröll, Jonas Sonnerfeldt and Anders Sunesson

This project has been carried out in cooperation with ABB Corporate Research. Anders Sunesson has been employed by ABB Corporate Research but has been placed at the Department of Physics, LTH. In June 1998 Anders Sunesson left the project and it is currently being reorganised. The project is supported by the Strategic Research Foundation and Elforsk AB. It is expected that the project will be recommenced during 1999. However, a preliminary investigation has been carried out and this is described below.

The influence of space and surface charges in air gaps with barriers

A good understanding of the influence of space and surface charges in air gaps with barriers will lead to improved design and a reduction in the cost of air insulation systems. In the future, air insulation systems will become more important. The size (and thus the cost) of these insulation systems depends on the air gap clearance required to avoid breakdown. Apart from the voltage which must be withstood, the required clearance also depends on electrode and barrier geometry. Space and surface charges are expected to strongly influence the performance of the insulation system. If it can be understood exactly how the surface and space charges are formed and the influence they have on the insulation performance significant design improvements may be possible.

The overall objective of the project is to obtain a detailed description of how space and surface charges affect the breakdown resistance in covered electrode systems with an air gap. This should be obtained by quantitatively determining the space and surface charge concentration between, on and around the electrodes. The effect of the space and surface charges on breakdown resistance and other insulation properties could then be deduced by altering the space and surface charge concentration and observing the effects on the insulation properties.

Laser-plasma-induced electric breakdown studies were performed with and without barriers to learn basic facts about electric break-down in air-gaps with barriers. Laser pulses with a duration of 10 nanoseconds were focused creating a laser-induced plasma at various positions relative to the electrodes and barriers. Such a plasma can be regarded as representing (or acting as) a partial discharge which could trigger an electric breakdown process in the gap. This triggering process could lower the breakdown voltage in the gap. The most significant lowering of the breakdown threshold occurred for smaller gaps with partially covered electrodes where the laser-induced plasma was positioned somewhere along the shortest path between two bare electrode surfaces. But for large barriers, which can be regarded as analogous to the case of completely covered electrodes, the breakdown voltage was not lowered by the laser-induced plasma. This seems to indicate that an insulation system consisting of an air gap between covered electrodes is quite robust against partial discharge in the air gap. This is significantly different from our previous experience of studies of bare electrodes in dielectric liquids (transformer oil) where there was a clear separation between breakdown voltage and propagation voltage.

From investigations performed by Li Ming at ABB Corporate Research in Västerås it has also been possible to conclude that surface charges on the barriers may have as strong an impact on the insulation performance as space charges in the air gap between the electrodes. Initial steps to asses the possibility of remotely and non-intrusively measuring surface charges by surface-enhanced laser frequency doubling were therefore taken. The technique of surface-enhanced frequency doubling was used on the surface of a mirror coated with aluminium. From the experimental data it was possible to specify which laser sources would be required to detect surface-enhanced frequency doubling. The work will be continued by improving the detection limit and then investigating frequency doubling at electrode surfaces. Following this the project will be extended to the study of barriers. For a 10 Hz laser system transmitting 150 fs pulses, frequency doubling on an aluminium surface could be demonstrated at pulse energies down to 80 μJ. From this it can be estimated that a 10 Hz repetition rate picosecond system (10 ps pulse duration) delivering 800 μJ pulses or an 80 MHz system delivering an average power of 100 mW (150 fs pulses) could be used for these studies. Thus, in short, a range of standard systems is feasible for the investigation

E2. Optical spectroscopy of paper

Jörgen Carlsson, Lennart Malmqvist, Carl Magnus Nilsson and Willy Persson

Optically based methods for studying paper during production at the mill or in the laboratory are being developed within a network called the Paper-Print-Physics Group. This group consists of scientists from the Divisions of Atomic and Nuclear Physics at LTH and the Centre for Imaging Science and Technologies at Halmstad University. The group is working in co-operation with the four newsprint-producing paper mills within Stora and MoDo/Holmen.

Optical properties of paper and print

The optical properties of paper, particularly of uncoated paper such as newsprint, are determined not as much by direct reflection at the paper surface as by scattering and absorption inside the paper. This must also be considered when studying paper with print. Both the penetration of ink into the paper and the scattering and absorption of light inside the paper are then of importance. One effect of this is optical dot gain, which appears when light impinging on a paper sheet near a printed screen dot is scattered into the dot and absorbed by it, making the dot appear larger than it is. Another effect is print-through, which means that print on one side of the paper is more or less visible from the back of the paper due to ink and light penetration.

Three-dimensional models have been developed for the structure of paper and for the interaction of light with paper. These models are used in Monte Carlo simulations of the propagation of light in paper. The models are applied to paper with print to study effects such as optical dot gain and print-through and to elucidate how these effects depend on the paper properties and the ink penetration [E1].

Optical dot gain is being studied experimentally by determining the physical distribution of ink pigment in printed screen dots using a nuclear microprobe and particle-induced X-ray emission (PIXE), and by recording the optical image of the same screen dots [E2, E3, E4]. Figure E1 shows two images of the same 200 μm diameter screen dot. On the left is shown the amount of pigment in each 2 μm×2 μm pixel, on the right the saturation of the corresponding pixels in the optical image. The optical image of the dot is much smoother and has a larger diameter than the dot actually printed. This is due to the scattering of light inside the paper.

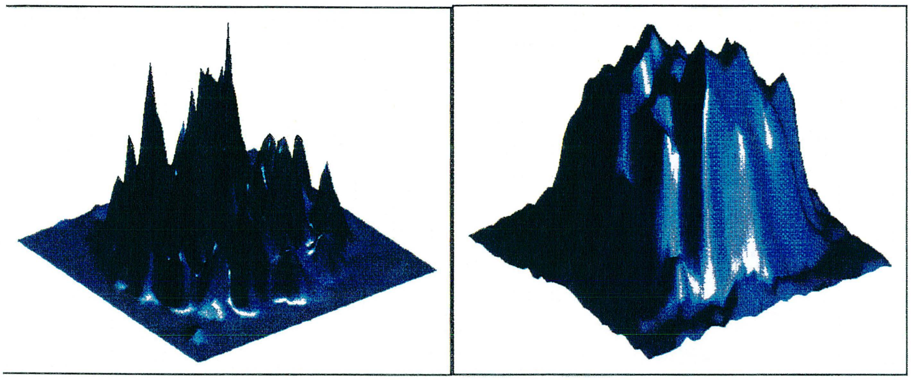

Fig. E1. The distribution of pigment in a printed screen dot (left) and the optical image of the same dot (right).

Fluorescence spectroscopy in paper manufacturing

One important demand on graphical paper is that it should be as homogeneous as possible. Variations over the surface of either the mechanical or chemical properties will affect both the strength and appearance of the paper. The printing properties will also be affected. In trying to control and minimise such variations, measurements of local paper properties during production are highly desirable.

Equipment for performing high-resolution, non-intrusive on-line measurements on paper during production is being developed. Reflectance and fluorescence measurements are performed with submillimetre resolution on paper webs moving at 25 m/s. Depending on the choice of wavelengths for illumination and detection, information concerning different aspects of the paper is obtained. Fluorescence measurements can be made using a HeNe-laser, a semiconductor laser or a Hg-lamp for excitation. The fluorescence light is detected in a photomultiplier tube. The light can be transported by an optical fibre to a small probe which can be conveniently set up at different locations along the production line.

Fig. E2. *Fluorescence-based measurements at a paper mill.*

Fluorescence measurements are particularly valuable since they can give information on the local chemical composition of the paper. Lignin in paper can be identified by fluorescence measurements at sampling rates well exceeding 100 kHz. For paper manufactured using recycled fibre, fluorescent material brought into the pulp by the recycled fibre can be identified in a similar way. Figure E2 shows one of the fluorescence meters installed at a rewinding machine at a paper mill. Figure E3 shows a recording of the lignin signal. For newsprint, fluorescence measurements can also give information on the local basis weight of the paper. It is most important to control the variation in the local basis weight, also known as the formation of the paper. The sensitivity to the local basis weight also makes these measurements useful in observing changes and defects in the paper. [E5]

Together with these systems an optical speedometer for paper is being used in order to accurately convert the time scale of the measurements to the length scale of the paper. This instrument is based on a correlation technique using reflectance measurements in two points on the moving web with a well known separation. The speed measurements are performed with the same high resolution and sampling rate as the fluorescence measurements. The speedometer can be seen next to the lignin meter in Figure E2.

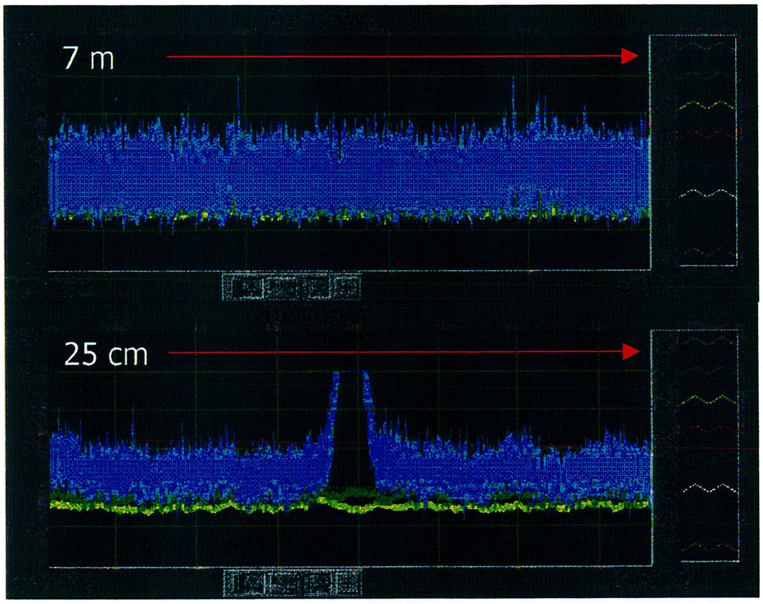

Fig. E3. *Example of an on-line lignin measurement on newsprint. The lower graph is an enlargement of the area around one of the peaks in the upper graph.*

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F. Teaching Programme

Professors and lecturers: *Stefan Andersson-Engels, Lars Engström, Maria Gerling, Günter Grossmann, Gilbert Jönsson, Göran Jönsson, Gabriele Kalus, Stefan Kröll, Rune Kullberg, Anne L'Huillier, Hans Lundberg, Elisabeth Nilsson, Willy Persson, Rolf Petersson, Sven-Göran Pettersson, Nina Reistad, Stacey Ristinmaa-Sörensen, Ingela Simonsson, Tomas Starczewski, Kristina Stenström, Sune Svanberg, Claes-Göran Wahlström.*
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F1 Undergraduate teaching

The Department of Atomic Physics gives basic physics courses for the Schools of Engineering Physics (F), Electrical Engineering (E), Computer Science and Technology (D), Mechanical Engineering (M), Civil Engineering (V), Fire Protection Engineering (BI), Environmental Engineering (W) and Chemical Engineering (K). Furthermore, specialized courses in *Atomic Physics*, *Laser Physics*, *Laser Technology*, *Advanced Optics*, *Non-linear Optics*, *Optical Quantum Electronics Atomic and Molecular Spectroscopy*, *Multispectral Imaging* and *Medical Optics* are given, primarily for students from F, E and D. Courses not included in the regular programs are *Color Holography*, *Radon* and *Technical Foundation Year* (a preparatory physics course on a level in-between high school and collage physics).

The main purpose of the undergraduate courses is to provide a solid base for a "life-long learning", a concept that is becoming increasingly important in the rapidly changing world of science and technology. Basic components in this strategy include stressing the interplay between theory and experiments, emphasizing that there are no absolute truths and that any model is only as accurate as it can be verified experimentally. Another important aspect is the construction and critical evaluation of models based on physical principles and experimental observations translated and analyzed using the language of mathematics. Finally our courses should develop the students experimental skill and their ability to plan, execute and critically analyse experimental results. The specialized courses should also provide a clear insight into current research projects in Lund.

The courses in physics contain both theory and laboratory practicals, and are based on lectures, problem-solving sessions and laboratory work. Lectures and problem-solving sessions stress the learning of the fundamental physical principles and their applications. Whenever possible the detailed contents of the courses are closely related the large variety of basic and applied research projects within the physics department. The laboratory work provide experience in the design of experiments and illustrate the validity and limitations of the theoretical models. During experimental sessions in the basic courses the students work in groups of two, and each supervisor teaches 8 students at a time. For the specialized courses the number of students per supervisor is reduced to 4 or 6. In the courses on atomic and molecular spectroscopy and advanced optics, research equipment is used by the students in their experimental work.

A survey of the courses given by the department of atomic physics is given in Table 1.

F2 Basic courses

Students in the School of Engineering Physics take three compulsory courses. *Introductory Physics, Optics, and Atomic Physics*. *Introductory Physics* comprises experimental methods, general physics and thermodynamics. An introduction to the research activities at the department of physics is also included. *Optics* is a fairly advanced course given at the end of the second year, which makes the students well acquainted with physical optics in general and different optical materials and their properties and spectroscopic techniques utilizing interferometers and gratings in particular. The Optics course thus lay the experimental foundation for the study of atomic and molecular spectra, and for specialized laser-physics courses. *Atomic Physics* provides the students with basic knowledge of the structure and dynamics of atoms and molecules. It also illustrates quantum mechanics as the basis for modern physics.

For students in the School of Electrical Engineering the basic course *Physics course for E* is given. This comprises general physics, thermodynamics, optics, waves and modern physics combined with laboratory work.

For students in the School of Computer Science and Technology and the School of Environmental Engineering the basic course *Physics course for D and W* is given. This course has been completely renewed in the year 98/99, with our energy supply and our environment as a consistent theme. The course covers traditional areas of physics such as experimental methods, mechanics, thermodynamics, heat transfer, optics, atomic, molecular, atmospheric and nuclear physics. The fundamental aspects of these subjects are treated in some detail, but the selection of subtopics and their presentation is focussed on an understanding of problems related to our energy supply and environmental concern.

For students in the School of Mechanical Engineering one basic course is given. It consist of general physics, optics, waves and atomic physics combined with laboratory practices.

For students in the School of Civil Engineering (course V2) and Fire Protection Engineering (course BI1) the basic courses *Physics basic course for V* and B*asic course for BI* are given. These consist of general physics with thermodynamics and fundamental electricity combined with laboratory practices. For students in their fourth year, V4, the *Specialised course* in physics is given, which is directed towards physical measuring techniques.

For students in the School of Chemical Engineering the basic course *Physics course for K* is given. This consists of electricity, wave physics, geometrical optics and nuclear physics combined with laboratory work.

F3 Specialised courses

The specialized courses *Laser Physics* and *Laser Technology* deals with the physical principles of lasers, the most common types of lasers and their applications in research and industry. In laboratory practicals the students learn to study the fundamental properties of different lasers and to use the laser as a powerful tool in optical measurements.

The specialized course *Atomic and Molecular Spectroscopy* provides knowledge about modern atomic and molecular spectroscopy with special emphasis on technical applications. About 40 students follow this course. Together with the laser physics course, this course forms the natural introduction to graduate studies at the department of atomic physics.

The course in *Multispectral Imaging* deals with the extraction of physical and chemical information from images. The course covers imaging using radiation ranging from X-rays to microwaves and applications from astronomy to microscopy. Four advanced laboratory exercises are included in the course.

A specialized course in *Advanced Optics* has been established at the department. This course emphasizes Fourier optics, interferometry, fiber optics, holography and phase-conjugation techniques In 1996 we introduced a new course in *Medical Optics*, emphasizing light transportation in strongly scattering media (such as living tissue) and laser-based therapeutic methods.

The graduate/undergraduate courses in *Non-linear Optics* and *Optical Quantum Electronics* are given in alternating years. These are mainly theoretical courses that provide the background for the non-linear interaction between light and matter and for lasers and laser amplifiers, respectively

Courses in *Holography* are also available to those interested in photography, imaging techniques and optical measurements. The course starts with lectures on geometrical optics and wave optics and, together with laboratory sessions, the fundamentals of holography and related topics are discussed and different types of holograms are made.

The courses *Radon* and *Radon and Indoor Air Quality* involve measuring techniques, economical, geological and environmental aspects of this radioactive gas, which is found in many common building materials.

Course	***School/year***	***No. of students***	***Credit points***	***Student hours***
Physics course, E	*E1*	165	9	154
Physics course, D	*D1*	148	9	142
Physics course , M	*M3*	147	6	100
Physics, basic course, V	*V2*	91	5	92
Physics, Measuring Practice, V	*V3*	9	3	42
Physics course, K	*K1*	131	5	92
Physics course, BI	*BI1*	34	5	84
Physics course, W	*W1*	31	7	122
Physics, basic course	*F1*	113	5	86
Optics	*F2*	92	4	66
Project based course in Optics	*F2*	29	2	2
Atomic Physics	*F3*	78	5	72
Laser Physics	*F4*	22	5	60
Laser Technology	*F4,E4,D4,M4*	32	3	49
Non-linear Optics	*F4*	9	5	42
Optical Quantum Electronics	*F4*	16	5	40
Advanced Optics	*F4,E4*	8	4	56
Atomic and Molecular Spectroscopy	*F3*	33	5	66
Multi-Spectral Imaging	*F4,D4,E4*	29	4	48
Medical Optics	*F4,D4,E4*	14	5	54
Radon and Indoor Air Quality	*V4*	8	5	50
Holography		5	3	34
Holography with project		5	5	34
Radon		6	5	32
Technical Foundation year		142	13	280

Table 1. *Courses given by the Department of Atomic Physics, 98/99*

F4 Graduate teaching

The course in Super Intense Laser Atomic Physics, which was given for the first time in 1995, was given again during 1997-98. It is a course which is followed by most graduate students in the Basic atomic physics group.

A graduate course "Quantum Mechanics oriented towards Atomic Physics and Quantum Optics" based on the book "Modern Quantum Mechanics" by Sakurai was given in 1998.

The graduate/undergraduate 5 credit points course in Optical Quantum Electronics, based on the book "Lasers" by A.E. Siegman, was given in 1997.

A new 3 credit points seminar-based course in multidisciplinary laser spectroscopy was given 1997 jointly with the Lund Laser Centre(LLC).

The graduate/undergraduate 5 credit points course in Non-linear Optics based on R. W. Boyd's book "Nonlinear optics" was given in 1998.

F5 Master's Projects

Several undergraduate students are performing their Master's projects within the Atomic Physics Division. Below, those who completed their projects during the present period are listed, together with the title of their dissertations.

Markus Andreasson **Ola Sandström**	*The design and implementation of a compact fluorosensor for medical diagnostics, LRAP-239*
Anders Bergkvist	*Biospeckle-based study of the line profile of light scattered in strawberries, LRAP-220*
Tobias Elmhäll **Martin Wiklund**	*Evaluation of an optical technique to measure blood volume changes during hemodialysis, LRAP-237*
Henrik Enquist **Rickard Larne**	*Early detection of bladder cancer using autofluorescence, ALA-induced P_pIX fluorescence and diffuse reflectance, LRAP-215*
Lars-Johan Hardell	*High-speed radiography using laser-produced x-rays; Characteristics and applications, LRAP-217*
Jens Ingemansson	*Optical properties and ablation of ophtalmic media and biocompatible materials in view of phototherapeutic keratectomy (PTK), LRAP-225*

Allan Johansson	*Defocusing and spectral blueshifting of an intense laser pulse propagating in a gas, LRAP-227*
Emma Johansson	*Measurements of tissue optical properties using an integrating sphere set up, LRAP-216*
Dan Liungman	*The impact of surface structure on laser triggered electrical breakdown, LRAP-222*
Cecilia Nilsson	*Femtosecond optical bit multiplication by photon echoes excited with spectrally modulated laser pulses, LRAP-213*
René Nilsson	*Konstruktion och test av en externkavitetsdiodlaser med snabb frekvensavstämning, LRAP-241*
Johan Norin	*Development of a laser-pulse compression device based on stimulated brillouin scattering, LRAP-230*
Arne Nykänen	*Spatial characterisation of a laser-produced x-ray source, LRAP-210*
Nicklas Ohlsson **Ola Rylow**	*Development of a multifibre system for interstitial photodynamic therapy of malignant tumours, LRAP-240*
Per Petersson	*Two-photon excited laser scanning confocal microscopy, LRAP-226*
Sara Pålsson	*Development of a fiber-optical probe for near-infrared Raman spectroscopy in tissue, LRAP-221*
Magnus Rimskog	*New receiver optics for wireless communication with IR-technique, LRAP- 212*
Anders Sjögren	*Diagnostics for single ultrashort laser pulses using transient grating frequency resolved optical gating (FROG), LRAP-229*
Gabriel Somesfalean	*Development and experimental evaluation of an optical sensor for aerosol partical characterization, LRAP-231*
Johannes Swartling	*Mathematical modeling of light distribution in turbid media in terms of photon hitting densities, LRAP-211*