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The History and Philosophy of Biosignatures

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Abstract This chapter examines the human search, understanding, and interpretation of biosignatures. It deals with four epistemological issues in the search for signs of life in outer space: (1) conceptualization, how we form concepts of life in astrobiology, how we define and categorize things, and the relation between our concepts and our knowledge of the world; (2) analogy, how we see similarities between things, and with inductive, analogical reasoning go from what we know to what we do not know, from the only example of life here on Earth, to possible extraterrestrial life; (3) perception, how we interpret what our senses convey in our search for biosignatures, how the information we get from the surrounding world is processed in our minds; and (4) the semiotics of biosignatures, how we, as interpreters, establish connections between things, between the expression (the biosignature) and the content (the living organism) in various forms of semiosis, as icons, indices, and symbols of life. In all, it is about how we get access to the world, and how we interpret and understand it, for achieving a well-grounded knowledge about the living Universe.

> ”…all this universe is perfused with signs, if it is not composed exclusively of signs.”
> C. S. Peirce, ”The Basis of Pragmaticism in the Normative Sciences” (1906; 1998, 394)

1 Introduction

In the quest for life in Universe, the most likely scenario is that we one day might find signs of life, biosignatures, that indicate certain biochemical processes that could have their origin in extraterrestrial biological activity. Probably, this is what we can hope for, insomuch as we will not in the foreseeable future find ways of exploring, in situ, foreign worlds around other stars. With current technology no manned mission will take us there. The hope of finding life on other planets or moons in our own solar system, though, has still not vanished. In some hidden corner of our solar system some microbes or unicellular organisms might hide, but some more complex forms of life would be very unlikely to find. However, it becomes more and more clear, that among the hundreds of billions of stars in our galaxy there are perhaps many millions of Earth-like planets of which many might be habitable and have the right conditions for harbouring life. Even though we will never hold these actual lifeforms in our hands, nor be able to construct an optical telescope that will let us get a glance of the planetary surface, it is fully conceivable that we in the near future will be able to refine our methods and observations in order to find signs of life.

On one hand we might come across observable and verifiable phenomena that we call "biosignatures," and on the other, we infer the existence of certain unknown instances of known biochemical processes that we call "life" that we suppose are the causes of the former. In other words, we make connections between the expression (the biosignature) and the content (the living organism). The ones who make this connection are we human beings, with our inventive minds that are a result of a particular bio-cultural coevolution of human cognition, of our species, here on Earth (Dunér and Sonesson 2016). This is what the history and philosophy of biosignatures is all about. We cannot, by no means, rule out ourselves in the inference. The data obtained, even if processed by a computer, must be comprehended and interpreted by the human mind to acquire significance. The interpreters of the "biosignatures" are and will be we. No one will help us with the interpretation. In that respect we are alone in the Universe and need to rely on our own interpretive capabilities. For us to be successful in our search for life beyond our solar system depends on, first, obviously, that it really exists life to be discovered; secondly, that we have the technology to discover it. But, that is not enough. The discovery depends on – and that is the most critical thing – the capability of the human brain, the organization and efficiency of that systematic search for knowledge that we call science, which is a product of the socio-cultural history of our species (Dunér 2016a). Our endeavour depends on human cognition and our ability to understand and interpret what we observe in our surrounding world.

Here is not the place for discussing the actual scientific research about biosignatures per se; it is dealt with elsewhere in this volume. Anyhow, biosignatures concern various things, and refer to chemical substances (elements, molecules, etc.), but also physical features (structures, shapes, morphology, etc.), and physical phenomena (electromagnetic radiation, light, temperature, etc.). They can vary in scale from atomic to planetary magnitude, or perhaps even larger. They can be searched for both by in situ investigations and through remote indirect sensing, on our nearest planets and moons as well as in other solar systems. These signatures are meant to be evidence for either living life or dead life, present or past life, distinctive from an abiogenic background. What I aim at here is to examine the human endeavour to make sense of the world around us, how we think about biosignatures, rather than explaining what they are. In the following, I will delve into the epistemic questions that the search for biosignatures provokes. The epistemology of astrobiology is a less explored philosophical territory concerning the limits of astrobiological knowledge, i.e., what is known, what is knowable in practice or in principle, and what is knowably unknown (Dunér 2013a; cf. Persson 2013). The epistemological problems of astrobiology are somewhat similar to those of other branches of science, but with the exception that the limits of our astrobiological knowledge seem to be much more uncertain. In this chapter, I will discuss four epistemological issues in the search for biosignatures: (1) conceptualization, how we form concepts of life in science, how we define and categorize things, and the relation between our concepts and our knowledge of the world; (2) analogy, how we see similarities between things, and with inductive, analogical reasoning go from what we know to what we do not know; (3) perception, how we interpret what our senses convey, how the information we get from the surrounding world is processed in our minds; and (4) the semiotics of biosignatures, how we, as interpreters, establish connections between things, between the expression and the content in various forms of semiosis, as icons, indices, and symbols of life. In all, it is about how we get access to the world, and how we interpret and understand it, for achieving a well-grounded knowledge about the living Universe.

2 The Concept of Life

When searching for biosignatures, the first and foremost challenge is to determine if the sign is of a biotic or abiotic nature. Are there any ways of distinguish life from nonlife? This differentiation between biotic and abiotic leads us to the question "What is life?" If we are searching for something that we call "life," we should at least know what kind of phenomenon we have in mind. This seems perhaps obvious, but however, it is trickier than what we at first glance might expect. The definition of life is one of the most debated and discussed philosophical questions in astrobiology. No consensus has so far been established. In the course of the history of the philosophy of biology amounts of definitions have been put forward, one more inventive and clever than the other, but again, none seems to be exhaustive and indefectible (see e.g. Luisi 1998; Cleland and Chyba 2002, 2007; Ruiz et al. 2004; Oliver and Perry 2006; Robus et al. 2009; Bedau and Cleland 2010; Gayon 2010; Pross 2012; Losch 2017).

When examining Earth-like life, we find that it displays a number of characteristics inherited due to a common origin: it is carbon-based, uses a few specific organic molecules, and further more it is something that we perceive as alive, have some sort of energy consumption, metabolism, and that it to some extent grows, and transforms. One can make up a shortlist of ecological requirements for life (McKay 2007), e.g., energy, carbon, liquid water, and other elements such as nitrogen, phosphorus, and sulphur. Life is made of these and other chemical components, which are related to the surrounding environment, but in different proportions (Conrad 2007). Campbell and Reece (2002; Domagal-Goldman and Wright et al. 2016) have listed a number of traits that are common to life on Earth: ordered structure, reproduction, growth and development, energy utilization, response to the environment, homeostasis (to maintain a steady internal environment regardless of the external environment), and evolutionary adaptation. But which are the most constitutive attributes of life, reproduction, evolution, metabolism, deoxyribonucleic acid, entropy resistance… or what? Definitions of life that have been put forward commonly combine especially metabolism, reproduction, and evolution as the most decisive attributes (Palyi et al. 2002). The most popular definition, NASA's "working definition," defines life as "a self-sustaining chemical system capable of Darwinian evolution" (Joyce 1994). As has been noted (Domagal-Goldman and Wright et al. 2016), its strength is that it stresses on life as an evolutionary process, rather than its chemical composition. It pinpoints life as an evolutionary process in contrast to the individual sample of life that does not undergo Darwinian evolution itself. However, one could question how such a definition would be useful when searching and analysing biosignatures. Could the life that the biosignatures refer to be tested and proven to be capable of Darwinian evolution? Perhaps more helpful for a hunter of biosignatures is the first part of the definition. A "self-sustaining chemical system" should in one way or another differ from its surroundings. In all, a definition should tell us if the phenomenon we encounter is life or not, but also be broad enough so we will not dismiss samples of "life" that are not similar or identical to terrestrial life.

The difficulty in arriving at an acceptable definition has to do with, among other things: (1) what we mean by "definition" and what such a definition should do for us in our search for life or what it should explain (cf. Persson 2013); (2) how we categorize things and how concepts are formed and used in our minds; and (3) that we know only one living planet in Universe, our own planet, and we still do not know how life emerged here on Earth. The aim of the following is not to fully scrutinize the philosophical question of the definition of life, even less to arrive at a definite definition. But before we go into the epistemic and semiotic questions involved in the search for biosignatures, which are the main target of this chapter, we need to delve into the very concept that is in the focus for our search, life, and how it is connected to our understanding of definitions, categorization, and our own ignorance.

2.1 The Definition of Definition

Science, as well as in the case of astrobiology, concerns concepts. We need names and abstract concepts in order to be able to talk and reason about objects, structures, processes, etc., that we gather from our senses, through observations and experiments. When we are using these terms, they need to be reasonably well defined, some sort of consent needs to be established, so we can agree on what we talk about. We need definitions. One might think that these concepts are already out there, just for us to discover, but the input we get from the surrounding world has to actually be processed by our brains and depends on the cognitive abilities we possess. The scientific concepts we use are not just dependent on the particular characteristics of human cognition that is a product a biological evolution of the human brain, it is also a product of a specific cultural evolution here on Earth and many generations of natural philosophers and scientists in the history of human, terrestrial science.

Constructing concepts in order to be able to think and talk about the new phenomena encountered is a major task for astrobiological research. Astrobiologists use a wide range of concepts, besides biosignature, for example life, habitability, habitable zones (see e.g. Kane and Gelino 2012), Earth analogues, exoplanets, and other concepts and terms inherited from already well-established scientific disciplines, which together form that multidisciplinary field of research we call astrobiology. The most debated and discussed concept in astrobiology is, as said, the concept of life. However, my point here is not how we actually define life, but rather what we mean with "definition" and what it should do for us. There are a number of ingredients life needs to have in order to be life, as mentioned above, but if life is a recipe, what are the essential ingredients and which are optional ones? So far, the debate has intuitively employed an Aristotelian conception of definition (Aristotle, *Posterior Analytics*, 2.3.90b30–31), in which a "definition" is a limited list of characteristics that are necessary and/or sufficient for something to be of the type of object it is, and from which all the characteristics of the object originate. Many definitions of life tend to be a list of necessary and/or sufficient properties that something needs to have in order to be called "life," and further more, this list has the pretension to be complete. In our daily lives, however, we make relatively little use of Aristotelian definitions and depend much more on prototypes (Rosch 1975, 1978). Dogs, cats, and horses may seem to be more typical representatives for "life" than arsenic resistant microbes. In astrobiology, the prototype for life is terrestrial life, a self-sustaining chemical system capable of Darwinian evolution of that sort we find here on Earth. Another option is to comprehend concepts in Wittgensteinian terms, that there is a family resemblance among the essential features of the concept, a series of overlapping similarities, but no one common to all (Wittgenstein 1953; cf. Rosch 1987; Pennock 2012; Persson 2013), and in our case, no prototype, no typical representative of "life."

The search for life in the universe has to a great extent highlighted how strongly the evolution of life and environment are intertwined (Golding and Glikson 2011; Schulze-Makuch et al. 2015; Cabrol 2016), that the coevolution of life and environment determines the uniqueness of an extraterrestrial life form (Watson 1999; Irwin and Schulze-Makuch 2001; Kooijman 2004; Dietrich et al. 2006). A definition of life should not only encompass all the life we know, it should also be anticipatory and be prepared for putting future phenomena in one of the categories "life" and "nonlife." Future discoveries in astrobiology will most likely challenge our categorizations and definitions, that is to say, our preconception of what the world is and not is. So, we should be prepared to re-categorize and redefine our concepts. Future exobiological systematics and taxonomy will face problems for how we identify, describe, and categorize what we encounter. And in that respect, the taxonomy of future extraterrestrial life will be a product of the human mind.

2.2 The Categorization of Our Categories

A definition of life aims to delineate life and nonlife, and be able to deal with the intermediate evolutionary stages between nonlife and life. Our understanding of the origin of life as a bio-chemical evolutionary process supposes that there are intermediate stages from "dead" chemical elements to increasingly more complex forms of life. But where can we draw the line and say to each other that after this point the existing chemical congregations must be called life. Other entities appear as conceptual intermediaries, such as viruses, that possess many characteristics similar to organisms; they evolve, have an ordered structure, and go through maturation. But for most biologists, they could not be regarded as life in a proper sense, due to their lack of homeostasis, energy utilization, response to the environment, and perhaps most critically, they cannot reproduce independently of the metabolism of their infected hosts. Other biological entities, such as transposons, are also close to the blurred borderline between life and nonlife. The evolution of life seems to suggest that there is a continuum between life and nonlife, or grades of life, a series of increasing possession of "liveability." Could something be less or more alive? My tentative answer is yes.

It is our human way of understanding the world, by using categories, that makes problems for us when we are dealing with phenomena far beyond the well-known of our daily lives. As said, the problem of defining life has to do with how we categorize things (Lakoff 1990; Taylor 2003). All living creatures seem to categorize the environment in terms of edible versus inedible, benign versus harmful, and so forth. Categorization becomes more complex in human cognition. The human mind tends to categorize, to see hierarchies and similarities between things, such as species and genera in taxonomy (Berlin 1992; Dunér 2013b). When encountering new unfamiliar things, the old categories, systems, and beliefs are challenged and sometimes will fall short. Our thinking, science, and belief systems will have to be revised, which will lead to adjustments, adaptations, and compromises. But anyhow, we need these categories and invent new ones in order to handle the world around us; otherwise we would fall into a chaotic abyss of unsorted impressions.

2.3 Empirical Ignorance

Rather than defining “life,” one might aim for understanding “life.” In astrobiology there is an endeavour to achieve an objective concept of “life” that can guide scientific research. The question is, if such objectivity is reachable. The way towards an objective, scientific concept of life is not, by no means, straightforward. A major question concerns how to distinguish those general characteristics of “life” in Universe from those that are specific to our own life here on Earth (Gayon 2010). Without additional examples of life, as Cleland and Chyba (2002) argues, it would be impossible to know if our concept of life refers to a universal, objective natural phenomenon or is just a subjective category. Some characteristics of life might be universal in its proper sense, that there are certain necessary features that life needs to have in order to be alive. The lack of a second instance of life makes it hard to distinguish those characteristics that are universal of life from those that are inherited due to a common origin. This empirical ignorance prevents us from arriving at a definite definition. If future search for life will be successful, it will fundamentally change or concept of life.

Searching for biosignatures is to a large extent a hypothetico-deductive endeavour. We formulate a hypothesis, that certain signatures indicate biological activity, and then we search for these “biosignatures,” make observations, and deduce that they indicate that life exists on that particular planet. However, only when all other hypotheses have been disproved, and only the habitation-hypothesis remains, then we can consider it to be established scientific knowledge. But in most cases biosignatures are not unambiguous. Both biological and abiotic processes can produce them. The question is how to distinguish true biogenic signatures from abiotic mimics. On one hand we need to avoid “false positives” that mimic life, and on the other hand we need to avoid “false negatives,” that real signatures of life are overlooked (Tarter et al. 2007; Horneck et al. 2016). Researchers have faced this ambiguity of biosignatures in the search for the earliest traces of life on Earth (Pilcher 2003; Golding and Glikson 2011; Westall and Cavalazzi 2011) as well as in the analysis of Martian rocks (Westall et al. 2015). A famous example of ambiguous experimental results is the controversy of the Viking mission results (Klein et al. 1976; Levin and Straat 1976, 1979, 2016). Viking 1 landed in Chryse Planitia and Viking 2 in Utopia Planitia. Both had instruments, such as gas chromatograph-mass spectrometers, for performing experiments in situ to detect traces of life, to search for organic molecules that Earth-based organisms have, and gases that are consumed or produced in the metabolism of terrestrial organisms. Despite a well-equipped mission, the results became ambiguous. Partly, this ambiguity of biosignatures lies within the human mind, in our definitions, categories, and lack of empirical knowledge. Next, I will go on to another cognitive peculiarity of human reasoning that plays tricks on us in our endeavours: analogical arguments.

3 The Analogy of the Earth-Twins

Above, I have put forward some of the reasons why the scientific community has failed, and probably will fail, to come up with a consistent definition of life as a limited list of necessary or sufficient conditions. Such a definition might, though, be of heuristic value, i.e. as a practical, useful aid by analogy from the known. To begin with, we assume that there is only one physics, one chemistry in the Universe, and accordingly all phenomena will follow the same natural laws. We know just one inhabited planet, and everything that live on that planet is related, have one common origin. In astrobiology it is assumed that this particular planet, except that it is a living planet, has no exceptional characteristics. There are billions of stars of the same type as our Sun in the Universe, with presumably millions, billions of Earth-like planets that possess similar physical characteristics as our planet. Earth is a rather mediocre place in the Universe. This so-called mediocrity principle states that there is nothing remarkable with Earth. If this is true, it opens up for the quest for Earth-twins.

A common form of argumentation in astrobiology is analogical reasoning from what we know to what we do not know (Dunér 2013c). An analogical argument could be explained as a search for similarities, i.e., a way of selecting features in the source domain that are to be mapped onto the target domain, and of transferring relevant properties from the source to the target. If x has the properties P_1, P_2, P_3, P_4 … P_n, and there is a y that has P_1, P_2, P_3, we may conclude that it also has P_4. If we know there is an x that has these qualities, and we discover a y that also has some of these qualities, then we conclude that all y also have the quality that we are seeking, P_4, or formulated in first-order logic: $\exists x(P_1x \wedge P_2x \wedge P_3x \wedge P_4x \ldots P_nx) \wedge \exists y(P_1y \wedge P_2y \wedge P_3y) \Rightarrow \forall y(P_4y)$. The challenge is then to select the correct and relevant salient features from an infinite number of possible ones in the source domain, features that then will be transferred to and mapped onto the target domain. In some sense, astrobiology as a whole is one single, great analogy. Starting from the one particular type of life we happen to know something about, namely life on Earth, we proceed to search for life on other planets. We predominantly look for life as we know it: something needing liquid water, being based mainly on carbon, inhabiting a planet of a certain magnitude, gravitation, atmosphere, chemistry, temperature, etc., that revolves within the habitable zone, at a certain distance, period, eccentricity, inclination, etc., of a solar-type star (a G2 main sequence star of 4.5 Gyr of age), which in turn has to be of a certain size and temperature, and so on. There are a number of problems with such an analogical argument: first of all, do we know all the necessary and sufficient conditions for life? Another problem is that we restrict ourselves to one particular sort of life we happen to know, life as we know it, and might overlook other forms of "weird life," life as we do not know (Davies et al. 2009). The third problem lies in the unpredictability of evolution, that there are some stochastic events involved in the evolutionary process. The question is if all ingredients of life are in place, will that inevitably, by necessity lead to the emergence of life? Is life a natural manifestation of matter? (cf. Duve 1995)

Logically speaking, analogical arguments are invalid. The historian of science Michael Crowe (1986) points out that one of the most pervasive logical and/or methodological fallacies in the plurality debate is mistaking necessary conditions for sufficient conditions. If liquid water is a necessary condition for life as we know it, it is just one among numerous other necessary conditions, which all need to be present if a planet is habitable. Just an evidence of an atmosphere, even if it contains the right chemical components including water vapour, is not enough to prove that life exists on its surface. All too often, Crowe states, finding some few necessary conditions among a larger set of necessary conditions, has been taken as a proof of life. If all necessary conditions need to be in place, the question arises if we know the complete set of conditions, or are there unknown conditions still to be discovered? The conclusion is that, not until we know all necessary and sufficient conditions for life, we will only be able to infer that the planet is habitable, but not that it is actually inhabited.

The fallacious use of analogical arguments were also discussed by the philosopher and logician Charles Sanders Peirce, stating that "There is no greater nor more frequent mistake in practical logic than to suppose that things that resemble one another strongly in some respects are any more likely for that to be alike in others" (Peirce 1957, 134; Crowe 1986, 552). However, Peirce admitted, analogical argumentation could be accepted as a method of discovery, but not a method of proof. In providing us with some point of departure, analogical arguments still might hold some heuristic advantage in the search for life. Astrobiology as a great analogy is an inductive argument that cannot logically prove anything, just propose that life in Universe is a theoretical probability, but not an inductive probability. Just one sample of life, our own here on Earth, is a rather poor, to say the least, start of an empirical-inductive argument. Nor are large numbers, for example of stars, exoplanets, Earth-twins, any conclusive ground for an argument, just a theoretical probability.

What we are actually looking for is something that reminds us of ourselves, something similar to us, to earthly life, whether microbes or more complex life. In fact, to stretch it a bit, we are searching for "ourselves." Though, life might be very different from what we imagine. The history of science is actually a history of surprises. The world we are living in turned out to be very different from what we first thought: richer, more complex, more peculiar and more astonishing than what we could dream of. This will also be true for astrobiology. Future discoveries in astrobiology will surprise us completely.

3.1 The Mountains of the Moon

Analogical reasoning is very common in the history of astrobiology and in the search for biosignatures. Many works have discussed the history of the extraterrestrial life debate and the emergence of the science of astrobiology (see e.g. Dick 1982, 1996; Guthke 1983; Crowe 1986, 2008; Sullivan and Carney 2007; Briot 2013; Dunér 2012, 2016b; Crowe and Dowd 2013; Dunér et al. 2016), but the concept of biosignature has not got particular attention. In the extraterrestrial life debate of the seventeenth and eighteenth centuries our closest celestial body, the Moon, was the prime candidate for life on other worlds. A number of scientists and scholars also speculated about life on Venus, Mars and on other planets, both within our solar system and beyond its frontiers.

In the autumn of 1609, Galileo Galilei made the first closer observations of extraterrestrial bodies through a telescope. In the *Sidereus nuncius* from 1610, he shows, based on his telescopic observations and analogical reasoning, that the Moon has mountains and therefore has the same solid, opaque and rugged nature as the Earth. The irregular border between its dark and illuminated parts is incompatible with the idea that it is a perfect spherical solid. Galileo wrote: "Anyone will then understand with the certainty of the senses that the Moon is by no means endowed with a smooth and polished surface, but is rough and uneven and, just as the face of the Earth itself, crowded everywhere with vast prominences, deeps chasms and convolutions" (Galileo 1610; Spranzi 2004, 459). The Moon had a smooth appearance, though, in its contour, which he explained was because it might have an atmosphere. Galileo never stretched his analogical reasoning so far as he could by clearly claiming the existence of life on other planets. However, he did not consider it impossible that there were inhabitants on these spheres. And further more, we could not take it for granted that life elsewhere in the Universe must resemble our own. In 1612 Galileo wrote: "I agree with Apelles [the astronomer Christoph Scheiner] in regarding as false and damnable the view of those who put inhabitants on Jupiter, Venus, Saturn and the Moon, meaning by inhabitants, animals like ours, and men in particular" (Galileo 1957, 137; Dick 1982, 86). Later in the *Dialogo … sopra i due massimi sistemi del mondo* (1632), he stated that there is no water, no humidity, no seas on the Moon, and therefore no life (Galileo 1632, 1953; Spranzi 2004).

In his *Cosmotheoros*, the Dutch scientist Christiaan Huygens (1698) expressed the view that it was highly probable that there was life on other planets. He noted that liquid water is necessary for life, and he saw darker and lighter spots on the surfaces of Mars and Jupiter that he interpreted as water and ice. Beyond our solar system there are stars similar to our sun, and he asked why these stars could not have their own planets with their own moons. As for Venus, he empirically stated that a thick atmosphere surrounds it. He could not clearly detect any patches on the surface that might be signs of seas and mountains. Perhaps, he said, there are no seas on Venus, or, as he believed more probable, the air and clouds around Venus reflect nearly all the light from the Sun.

The first more certain telescopic observations of Venus, after Galileo's discovery of its phases, were made during the 1761 transit of Venus. Many observers reported certain phenomena during the transit that they believed to have been caused by an atmosphere surrounding Venus (Proctor 1874; Woolf 1959; Maor 2000; Sellers 2001; Sheehan and Westfall 2004; Wulf 2012; Aspaas 2012; Sterken and Aspaas 2013). Certain astrodynamic facts relating to Venus were well known to the astronomical community, for example, its orbit around the Sun, magnitude, and phases, etc. However, the question of the atmosphere and topography of Venus was still unresolved. New observations of Venus against the solar disc changed the situation. The analogy argument started from the general supposition that there were no actual differences between Earth and Venus. They were both planets that orbited the Sun, were of similar size, solid, and, as some astronomers claimed, Venus also possessed mountains and an atmosphere. If there is life on Earth, then one may ponder why it could not also exist on Venus. If we can estimate the axial rotation and detect an atmosphere and mountains on that planet, it might also be true that it harbours life. These questions were in fact those that were investigated during the seventeenth and eighteenth centuries, and they included the length of its period of rotation and whether it had mountains, an atmosphere and life. The Russian polymath Mikhail Lomonosov argued that his observations of the transit of Venus in 1761 supported the idea of a Venusian atmosphere: "Based on these observations I conclude that the planet Venus is surrounded by a distinguished air atmosphere similar (or even possibly larger) than that is poured over our Earth" (Marov 2005, 214 f.). Because an existing atmosphere had been proved, then it could be concluded that Venus is also inhabited.

Later Johann Elert Bode (1801) at the Berlin Observatory accepted astronomer Johann Hieronymus Schröter's (1793, 1796) claims about the existence of mountains and valleys on Venus (Crowe 1986). Bode applied an apparently analogical reasoning. He concluded that if Venus had land and sea, mountains and valleys, clearings and condensations occurred in its atmosphere, and it had a companion moon, then it was entirely similar to our Earth and consequently also habitable. The French populariser of astronomy Camille Flammarion (1862) considered in *La pluralité des mondes habités* that it was absurd that the Sun was employed solely to illuminate and heat our small world. This absurdity became even more striking when Venus was found to be a planet of the same dimensions as the Earth, with mountains and plains, seasons and years, and days and nights analogous to our own. That analogy was expanded to the conclusion, that, since they are alike in their physical characteristics, they must be alike also in their role in the Universe: "if Venus were without population, then the Earth must be similarly lacking, and reciprocally, if the Earth were populated, Venus must be populated also" (Flammarion 1862; Crowe 2008, 417 f.). Flammarion demonstrates here a characteristic analogical thinking, typical of the astrobiological search for an Earth analogue. In a later work on popular astronomy he says of the inhabitants of Venus: "this world differs little from ours in volume, in weight, in density, and in the duration of its days and nights. […] It should, then, be inhabited by vegetable, human, and animal races but little different from those of our planet" (Flammarion 1880; 1907, 371; Sheehan and Westfall 2004, 214).

Such analogical arguments could be summarized as a search for similarities in an inductive manner, in order to pinpoint as many as possible, especially those of a significant nature, i.e., those critical features that were believed to indicate a habitable environment. It was known that both Earth and Venus were planets of a similar size, both orbited the Sun, and were exposed to its light and heat, and that both globes were opaque and had a solid ground. These similarities could be extended, as some astronomers maintained, to both of them having nearly exactly the same period of axial rotation, as well as a companion moon, an atmosphere, mountains and seas. If Earth and Venus seemed to be perfect twins, then there must be life on Venus too.

The last decades, analogy reasoning lies behind a number of experiments on terrestrial life as preparation for in situ investigation on extraterrestrial bodies. Terrestrial biosignatures have been treated as analogical models for possible extraterrestrial biosignatures. If we turn to ourselves, are we detectable; is it possible to discover life on Earth from outer space? Based on observations made with the Galileo probe, Carl Sagan et al. (1993) proposed what biosignatures might be possible to observe in the reflective light of Earth. According to the spectroscopic results, water, oxygen, ozone, carbon dioxide, carbon monoxide, nitrous oxide and methane were detected in the atmosphere of the Earth. The Very Large Telescope (VLT) of the European Southern Observatory (ESO) in the Atacama Desert, Chile, was used by Michael F. Sterzik et al. (2012) for studying the Earthshine, the light from Earth that reflects on the surface of the Moon, seen as a greyish light on the lunar surface which is not lighten by the sun. The colour and polarization of the Earthshine showed that Earth's atmosphere contains clouds, that its surface is partially covered by a sea, and that it has vegetation. The idea was that by studying how Earth look like from space, one could get a reference for future analyses of exoplanet atmospheres. Analogy reasoning, helpful or not, rests on another cognitive process. In order to make an analogy between observations, one needs to interpret the perceptual information.

4 Epistemic Perception

The philosopher in Bernard de Fontenelle's *Entretiens sur la pluralité des mondes* (1686) states that all philosophy (understood as the natural sciences) is based on two things: curiosity and poor eyesight. We want to know more than what we can see. In contemporary astrobiology life seems always be beyond the fields we know. What the senses convey have to be interpreted through means of specific cognitive processes, and the interpretation of what has been observed is based on a preconceived understanding, concepts, and prior knowledge. Observations are not separate from theory. In contrary to the tendency to place excessive trust in "objective" observations, many philosophers of science, such as N.R. Hanson, Thomas Kuhn, and Michael Polanyi, have emphasized that observations are theory-laden, that there are no sharp dichotomy between observation and theory in scientific research (Crowe 1986). We need theories to understand what we see, and our preconceptions and expectations lead us in one or another direction, sometimes the wrong course. Not seldom we see what we expect to find.

In the optical observations of distant worlds, preconceived understanding often shapes the interpretation of what the observers see. Through their senses, the observers receive impressions from outer space, and they collect and collate information using their sight. What their senses convey have to be interpreted by means of specific cognitive processes before becoming reality. As observers, we do not just passively receive images and input from the world around us. Instead, the brain actively searches out patterns in what is conveyed to it through the senses, and interprets them through a process that is determined by both biological and cultural factors. Perception is not a neutral, objective, and realistic recording of reality. This conceptual or epistemic perception implies an identification of what is seen, and takes place by applying our concepts to visual perceptions, that is, concepts affect what we see, and, should we lack any concept of a specific phenomenon, then it will be difficult to distinguish it among all our impressions. The world distorts our concepts, and the concepts distort our world.

4.1. The Atmosphere of Venus

Astronomer William Herschel's lunar observations from 28 May 1776 highlight the difficulty to see and arrive at a conclusive interpretation of the seen. He saw growing substances: "My attention was chiefly directed to Mare humorum, and this I now believe to be a forest, this word being also taken in its proper extended signification as consisting of such large *growing* *substances*" (Crowe 1986, 63). This forest would require, he said, trees at least 4–6 times the height of ours. In 1778 he even suspected that lunar craters could be towns of the Lunarians. He saw circular buildings on the Moon: "I am almost convinced that those numberless small Circuses we see on the Moon are the works of the Lunarians and may be called their Towns" (Crowe 1986, 65). Those certain luminous spots that occasionally could be seen on the dark side of the Moon, Herschel explained as volcanoes in eruption. Church minister and science teacher Thomas Dick later wrote that a more pleasing idea would be that they were "some occasional splendid illuminations, produced by the lunar inhabitants, during their long nights" (Crowe 2008, 262 f.).

Other striking examples of this epistemic perception are the maps of Venus that delineated the surface of the planet, which shown mountains and other geological features. Even a dim light, faint spots and lines, and a companion moon seemed to appear when Venus was viewed through a telescope. The astronomers interpreted their obscure observations in line with their prior knowledge and their ideas of the nature of the world, and they often found what they sought. If they believed in the existence of mountains and an atmosphere on Venus, then they duly found them. In 1645 the Neapolitan astronomer Francesco Fontana recorded "a dark patch in the centre of the disk" of Venus, which can be said to be the first attempt to note surface details there (Fontana 1646; Moore 1956; Cattermole and Moore 1997). In 1667 the astronomer Giovanni Domenico Cassini saw "various bright and dusky patches" from which he deduced the first estimated period of rotation of 23 hours and 21 minutes (Cassini 1667). Another Italian astronomer, Francesco Bianchini, drew the first "map" in 1726 recording oceans and continents (Bianchini 1728; Sheehan and Westfall 2004). On mist-free days, at twilight, he saw rounded patches similar to lunar craters, and from their movements, he deduced that the period of rotation of Venus was 24 days and 8 hours. There is no doubt that these records of the surface features of Venus were purely optical. Beside the fact that the optical quality of the telescopes was not always reliable, and that weather conditions could considerably influence the quality of the observations, there is obviously also an epistemic perception that changes the interpretations of the seen. The uncertain observations by Fontana, Cassini, Bianchini and others were interpreted in a particular way. If they believed in the existence of oceans and continents on Venus, they searched for them and found them, because their prior knowledge and beliefs directed their attention towards certain interpretations. The illusion or fallacy in their perception did not lie primarily and only in the flaws in their optical equipment, but in their imaginative minds, the cognitive apparatus that processed their sensory impressions.

During the transit of Venus of 6 June 1761, two surprising phenomena were observed: a bright ring around Venus and the "black drop" during the contacts. The ring was re-observed on

3 June 1769, and its causes were still being debated even then, but it was unanimously taken as proof of the existence of an atmosphere on Venus. Concerning the black drop, the astronomer Daniel Melanderhjelm explained it as caused by an atmosphere. The secretary of the Royal Swedish Academy of Sciences, Pehr Wilhelm Wargentin, on the other hand, saw it as a mere diffraction phenomenon (Dunér 2013c). Melanderhjelm's observations were, as he said, just "fallaciæ visus," optical fallacies. The physician Johan Carl Wilcke performed a number of experiments during the summer of 1769 showing that the same phenomenon arises with a black body seen against a luminous body without any need to assume an atmosphere. Wargentin and Wilcke, however, did not disbelieve in the existence of an atmosphere, but the black drop could not provide proof of it.

Whether Venus has mountains and a surface similar to the Earth with valleys and seas had been debated ever since the first Venus maps appeared in the seventeenth century. Here, again, the conclusions were often a result of analogical reasoning and epistemic perception. The great observational astronomers Herschel and Schröter engaged in a heated argument as to the presence or absence of mountains on Venus. However, they both agreed that Venus has an atmosphere. It was well known in the era of Schröter and Herschel that Venus and the Earth, with regard to their size and mass, were almost perfect twins. It then became also reasonable to assume that their atmospheres were similar too, with regard to their extent and composition. In February 1788 Schröter perceived the ordinarily uniform brightness of the disk as being marbled by a filmy streak, and he concluded that what he was seeing was the outmost part of a dense, cloudy atmosphere (Cattermole & Moore 1997). Moreover, the horns of the crescent were seen to extend beyond the semi-circle, which could not be the case in the absence of an atmospheric mantle. On 28 December 1789 Schröter saw that the southern cusp of Venus was blunted, and that there was a small luminous speck beyond it (Baum 1973). He saw the same thing again in 1790 and 1791 and concluded from these observations that it must be a very lofty "enlightened mountain" that was catching rays of the Sun. Herschel re-observed Venus in 1793, and he questioned Schröter's findings. He agreed that Venus has an atmosphere, but he never found those high mountains that Schröter mentioned (Herschel 1912). In the *Philosophical Transactions* he states: "As to the mountains in Venus, I may venture to say that no eye, which is not considerably better than mine, or assisted by much better instruments, will ever get a sight of them" (Herschel 1793, 216; Moore 1956; Baum 1973).

The observers of Venus saw things that needed explanations and interpretations. They seemed to detect vague spots, streaks, lines, drops, a dim light, and a vague companion. Such optical misinterpretations, or rather what could be explained as an epistemic perception, were involved in the claims of a habitable Venus. The Ashen light, the dim visibility of the non-sunlit side of Venus, when it is in the crescent stage, was first reported in 1643 by the Italian Jesuit and astronomer Giovanni Battista Riccioli. This phenomenon was also the object of an epistemic perception leading to certain interpretations of the seen. The German astronomer Franz von Paula Gruithuisen in Munich declared that the light had been seen in 1759 and again in 1806, an interval of seventy-six Venusian years, and he wrote: "The observed appearance is evidently the result of general festival illumination in honour of the ascension of a new emperor to the throne of the planet" (Cattermole & Moore 1997, 17). However, Gruithuisen later modified his explanation and instead of a Venusian coronation, he suggested that the light might be caused by the burning of large areas of jungle to create new farmland. In a paper from 1824, "Discovery of Many Distinct Traces of Lunar Inhabitants, Especially of One of Their Colossal Buildings", Gruithuisen even reports that he had observed cities, forts, a temple, and animal trails on the Moon (Crowe 1986; Sheehan and Dobbins 2001). Later in the nineteenth century, the invent of spectroscopic analysis brought hope that lines for oxygen and water vapour in the atmosphere of Venus could be detected, and some preliminary results seemed to support that. It was only in 1966 and 1967 that the Russian space probes Venera 3 and Venera 4 dived into the cloud shield, and a very hostile Venusian environment was discovered (Harvey 2007).

4.2 The Canals of Mars

Perhaps the most famous example in the history of astrobiology of such epistemic perception is the debate concerning the canals of Mars. In 1877 Giovanni Schiaparelli at Brera Observatory in Milan recorded in detail the Martian network of canals for the first time. In the beginning other astronomers had problem to confirm these observations, but during the next decades many succeeded. Schiaparelli's findings were confirmed by the American astronomer Percival Lowell who detected hundreds of Martian canals that he interpreted as an artificial irrigation system (Hoyt 1976; Strauss 2001). In his book *Mars* (1895) he claimed that he now had conclusive evidence of an intelligent civilization on the dying planet of Mars. A change of Martian coloration was also observed, as evidence for seasons and vegetation. A darkening of the surface spread when the spring came on.

But there were sceptics. Edward Walter Maunder of Greenwich Observatory questioned the canal observations as mere optical illusions. The eye tends to integrate details, he explained, that are below the limits of vision. Eugène Antoniadi used the high quality telescope at Meudon Observatory, and made a drawing of a specific region of Mars, which he compared with Schiaparelli's drawing from the same area. Where Schiaparelli's drawing showed canals, Antoniadi's saw just diffuse details, no canals. Schiaparelli's canals had been, according to

Antoniadi, created by connecting dots on the surface or on the border between darker and lighter regions. In the American magazine *Popular Science* 1912, the reader could by himself experience this optical illusion with a simple, practical test consisting of random dots (Hennessey 1999). By then most astronomers had abandoned this imaginative idea.

Mapping the planets involves great patience, to monitor the shimmering images of the planets disturbed by the atmospheric conditions on Earth. The blurred images seen in the telescope were faint sensory impressions that needed interpretations by applying prior knowledge and conceptions to what the eyes perceived. The active mind searched for regularities, order, and comprehensibility in the observations. The story of human observations of the Moon, Venus, and Mars, tells us about the imprecision of the human eye-brain-hand system under difficult conditions (Sheehan 1988; Sullivan and Carney 2007). When searching for biosignatures, we are looking for regularities, order, and connections, based on previous knowledge, expectations, and theories. Next, I will turn to the question how we connect the expression (the sign of life) with its content (life).

5 Semiotics of Biosignatures

The semiotics of biosignatures is about the meaning-making processes of the human mind and its ability to make meaningful connections between things. The problem of biosignatures is very much a semiotic problem: how meaning can be discovered, invented, deciphered, and interpreted. One might say that the science of astrobiology "invents" connections between the signifier and the signified, expression and object, "signs of life" and "life." The first problem that arises in a situation of interpreting a biosignature is realising that it really is a sign at all. Some regularity and order, or finding a repetition in the pattern is not enough. The sign should be recognized as such by the interpreter, i.e., that it contains an expression that refers to a content, leading to an interpretive process by the interpreter. In other words, the interpreter needs to identify the physical phenomenon as containing semiotic meaning, something that can be a sign of life, a biosignature, that has a particular meaning by referring to its content "life." In our everyday lives as well as in well-established science, the expression of a phenomenon can easily be connected to its content. Seeing the footprints of an animal, we can infer – based on previous knowledge – what kind of animal it is, its weight and its direction. However, this semiotic confidence becomes much more uncertain when we turn to biosignatures of unknown forms of life. We are compelled to a number of assumptions that underlie the connection we try to establish between the expression and the content. Our assumptions might be mistaken, which leads to wrong interpretations, or even worse, we fail to make any assumptions at all, in other words, the phenomenon encountered, "the signature," would not be recognized as a meaningful sign whatsoever. Even though we have good reasons to believe that the connection we infer between the expression and the content, between the biosignature and the living organism, is scientifically correct, we need to rule out other explanations of the signrelation. The "biosignature" might not be a true biosignature at all, but instead is caused by an unknown or known abiotic process.

Before we go further into the semiotics of biosignatures, it would be in place to explain some fundamental semiotic concepts. As a study of signs, modern semiotics has a long prehistory that could be traced back to the philosophy of Plato and Aristotle, to John Locke and early modern medicine where semiotics was the interpretation of bodily signs, to draw conclusion from symptoms, to arrive at appropriate treatment of the patient. Particularly Peirce and Ferdinand de Saussure in the turn of the last century formed semiotics (or in the latter's case, semiology) of today. A certain sub-field of research, biosemiotics, has focused on the production and interpretation of signs in the biological realm (Wheeler 2006; Hoffmeyer and Favareau 2008; Romanini and Fernández 2014). Cognitive semiotics, on the other hand, studies the meaning-making structured by the use of different sign vehicles, and the properties of meaningful interactions with the surrounding environment, both with the physical and the social environment (Sonesson 2007, 2009; Zlatev 2012, 2015; Dunér and Sonesson 2016). Following attempt to uncover the meaning-making strategies in the search for biosignatures takes its departure from cognitive semiotics and related fields of research.

Semiotics is the study of meaning-making. It concerns *signs*, which can be said to be something that we interpret as having meaning. According to Peirce, one of the main figures in semiotics, "A sign, or *representamen*, is something that stands to somebody for something in some respect or capacity" (Peirce 1932, 135; Saint-Gelais 2014). The sign, as *expression*, stands for something, its *object*. The sign does not include its meaning, rather the meaning is attributed through elaboration of an *interpreter*. So for something to be meaningful, an interpreter is needed, a human being (or other meaning-making creatures) who endows the sign a meaning. A physical phenomenon is meaningless so far as there is no one to recognize it as meaningful. Phenomena that we call biosignatures become meaningful phenomena, when we interpret them as containing a meaning by making a connection between the expression and the object, in other words, between the "biosignature" and "the living organism." The signs are the way we make sense of the world, to approach it, to get access to it and differentiate things from each other. Correspondingly, the biosignatures we detect are one way among many other ways of making sense of the data we receive from outer space. And these biosignatures exist so far as we find them meaningful. In that perspective, the biosignatures are not solely "out there," instead, they are to a great extent in our minds, in the interaction between our minds and the outer world. It is in our meaning-making practices the "biosignatures" become biosignatures. The *semiosis* is the sign process, how the signs operate in the production of meaning. In that sense, when the astrobiologist is interpreting biosignatures, he or she is involved in a meaning producing semiosis. This semiosis is triadic, it contains expression, object, and interpreter – which in our case respond to "biosignature," "life," and "astrobiologist." Depending on how the interpreter makes or interprets the connection between the expression and the object, we have basically three types of signrelations, *icon*, *index*, and *symbol*. But, let us return to these signrelations in more detail later on. For now, it is enough to conclude that the astrobiologist searching for biosignatures is a sort of semiotician, an astrobio-semiotician, trying to establish connections between expressions and objects in the Universe. Semiotics of biosignatures concerns qualities and categories, as well as the search for rules and regularities within such a nomothetic science as astrobiology concerned with generalities. More generally, semiotics of biosignatures concerns the meaning-making processes of astrobiology.

Finding the connection between expression and content are actually mental, in the mind of the interpreter. The search for biosignatures is based on the human endeavour of connecting things with each other, and of selecting the right elements for the connection among a wider range of possible elements. We ask ourselves, what are the meaningful properties of the information we gather through spectrometers, radio or optical telescopes, etc.? Which signatures (phenomena) have meaning and which are just meaningless noises? Hence, we are looking for the meaningful signs among a chaotic "noise" of data, the "biosignatures" that clearly "says" that they are signs of "life." The signifier is directly given, but the signified is only indirectly present, through the link with the signifier. "Life" (the signified) that we are searching for is just indirectly reachable for us, and we have to content ourselves with the only thing that is directly given, the biosignature (the signifier). As interpreters, we determine the relation between the signifier and the signified by picking out those elements we assume to be relevant. The challenge of the astrobiologist is to pick the right elements (properties) of the signifier. For example, when examining a Martian rock, we need to pick out those elements (shapes, molecules, etc.) that direct us to the signified, the living organism. And we need a reasonable explanation of the link between the signifier and the signified. Why, and how come, is this particular gas a result of a certain metabolism of a living organism? In what way is this shape a remnant of the morphology of a living organism? We need to know the physical processes that let us link the signifier with the signified.

In the following three sections, I will show that "biosignatures" is a very diverse category, not only in respect to its immense variety of expressions, but also in semiotic sense. It shows a great variation in signrelations that each has its particular epistemological problems. To begin with, in astrobiology the concept of "biosignature" is not completely unambiguous. The concept of "biomarker" is sometimes used interchangeably with "biosignature," but often restricted to refer to "an organic molecule whose origin can be directly related to an organic component of life" (Horneck et al. 2016, 227), or organic compounds characteristic of certain organisms, for example hopanoids in cell membranes of cyanobacteria. Biosignature, instead, refers to a broader range of signatures of life: morphological, geochemical, and organic – a diverse and ambiguous category of signatures, related to either living organisms or fossilized remains. Biosignatures could be studied in situ, being of physico-chemical, geological, morphological, and mineralogical nature. Or they can be detected by remote methods, such as atmospheric spectroscopy, chemical disequilibrium, isotope ratios, etc. (Hegde et al. 2015). Physical microbial structures, stromatolites, mud mounds, atmospheric gases, etc., could be biosignatures, varying in scale from prebiotic molecular features to entire planets, referring to both life as we know and weird life, past and present life.

The following is a first attempt to bring some semiotic order in this chaotic variation of signs. Based on Peirce three signrelations – icon, index, and symbol – one could at least reveal some peculiarities of the semiosis of biosignatures. The meaning of the relation between expression and content, that the interpreter experiences, is based on either similarity (iconicity), proximity (indexicality), or habits, rules, or conventions (symbolicity). An icon is when the expression shares some *similarity* with the object. An index is when the expression has some *contiguity* with the object. And finally, a symbol is when the connection between expression and object is just a mere convention. Thus I put forward three kinds of biosignatures in semiotic sense: bioicons, bioindices, and biosymbols. However, in many cases a sign could be a combination index, icon, and/or symbol, also as we will see in the case of biosignatures.

5.1 Icons of Life

Aristotle noticed similarities between certain seashell-shaped structures found in rocks and those that washed ashore on the beach. Are there a connection between the petrified seashells and the living ones? And how come? In the beginning of the eleventh century, the Persian polymath Ibn-Sīnā (Avicenna) put forward the theory of petrifying fluids as an explanation of the petrification. Through the ages, the question was debated, if these figure stones that resembled living organisms actually were fossilized seashells or just sports of nature, *lusus naturae*, if they grow in the bedrock or were traces of once living animals exterminated by the flood. In 1665, the Danish anatomist and geologist Nicolaus Steno found shark teeth in the Tuscan mountains, suggesting that where it is now high mountains, it had once been a sea (Cutler 2003). Other findings, however, seemed to have no counterparts in the living species.

By the end of the eighteenth century, the French paleontologist Georges Cuvier began realizing that they actually were remnants of extinct species.

The idea of fossils was also combined with the idea of extraterrestrial life. If meteorites were coming from outer space, as it was realized in early nineteenth century, rather than being ejecta from volcanoes, these could be studied by chemical and geological methods. These meteorites from other worlds might contain evidence of extraterrestrial life, if not alive, in fossilized form. The analytical chemist Jöns Jacob Berzelius (1834) discovered that meteorites contained organic materials (hydrocarbons). He examined meteors from a meteor shower in November 1833, made a chemical analysis of a carbonaceous chondrite that had fallen in 1806, in Alais (Alès), France, but could not tell if it contained carboniferous of extraterrestrial origin (Crowe 1986). In the 1870s it was consensus that some meteorites contained organic materials, but no convincing evidence had been found that they contained extraterrestrial life forms. With Berzelius and others the idea of panspermia, that seed-bearing meteoric stones are moving around in outer space, became an increasingly plausible area of research, ending up in the physical chemist Svante Arrhenius's (1907) more elaborated panspermia hypothesis. And still, the hypothesis has not been completely ruled out. Current research has shown that microbial life could indeed travel between planets and survive in space (Horneck et al. 2010).

A theme in the history of palaeontology is the question of how to distinguish real remnants of living organisms from structures that just mimic living forms, to distinguish fossils from pseudofossils. These inorganic pseudofossils can be mistaken for fossils, for example branch-like structures like manganese dendrites in limestone, kidney ore, moss agates resembling moss leaves and other patterns in rock that arise through geological, not biological processes. This is still a challenge in the quest for microfossils for tracing the early history of life on Earth or in order to find fossilized life in Martian rocks. A famous example is the announcement in 1996, that fossilized life had been discovered in the Martian meteorite ALH84001 (McKay et al. 1996). Viewed under an electron microscope, certain tube-like structures in the meteorite resembled fossilized bacteria. It was a premature claim, abiological processes could in fact create these structures (Westall et al. 1998). This calls for new samples when claiming evidence for fossilized life in rocks on Mars or beyond. A second lot is needed to confirm or refute previous hypotheses based on the first batch of samples, or to continue the search.

Biosignatures in the form fossils are distinctly another thing than remote sensing of habitable atmospheres, not because how they are found, in situ, but in its signrelation. Biosignatures that share a similarity with living organisms, for example fossils, are in my terminology *bioicons*. In semiotics, an icon is a signrelation based on similarity, where the expression shares some of the object's properties. The similarity between properties is perceived on the background of other dissimilar properties. The most obvious examples of bioicons are body fossils, the imprints of the hard parts of animals and plants, where the imprints of skeletons or foliage let us, based on morphologic similarity, establish a link between the fossilized structure and the living thing. The very complexity of the expression (the fossil) directs us to the conclusion, based on the supposition that such a complexity cannot be the result of any known abiotic process. Microscopic fossils, microfossils, though, are more challenging. All life as we know it share the characteristics of having internal volumes isolated from the surrounding environment by a cell membrane. Based on this shared morphology, one could search for cellular structures. Well-preserved fossil cells can be identical in size, shape, and structure with living single-cell organisms. Their structures, that show less complexity, make it however more challenging to distinguish a biotic structure from an abiotic. On Earth, the Apex chert from Western Australia, dated at ~3.5 Ga, has been claimed either to be fossilized cells of filamentous bacteria or just a result of an abiotic process (Schopf 1993; Brasier et al. 2005). To be a true biosignature, it is not enough to notice a similarity between the expression and the object. We also need an explanation for how a living organism can become a fossil (a bioicon). If we find something that reminds us of a living thing, a microbe, a cell or that like, we need also a theory that links the living organism with the biosignature, establishing a physical correlation between the bioicon and the thing it signifies. Plenty of performed experimental fossilisation studies give us the right arguments to make this connection. Further more, fossils are not enough if we want to get a complete understanding of the life it refers to; they do not give us complete information of the biochemical nature of the living organism.

Bioicons are not just of visual nature, a similarity based on morphology or structure, they could exist in any sense modality. Based on chemical analyses, the researcher sees similarities between the expression and the content, not because of structural similarity, but because they share some chemical properties. In the case of chemical biosignatures, some are bioicons in that sense that the discovered biosignature has a chemical similarity or shared characteristics with the living organism, for example complex biological macromolecules, like carbohydrates, lipids, proteins, and nucleic acids (RNA and DNA). Most common biomolecules, however, usually modify and degrade, and the products (also called "molecular fossils") of this chemical breakdown (the diagenesis) have instead an indexical relation to the bioiconic biological macromolecules. For example the 2-methyl hopanes that are known to be the diagenetic products of 2-methylbacteriohopanepolyols are second order biosignatures, that is bioindices of bioicons that refer to its content, life in the form of cyanobacteria.

5.2 Indices of Life

“It happen’d one day about noon, going towards my boat, I was exceedingly surpris’d with the print of a man’s naked foot on the shore, which was very plain to be seen in the sand: I stood like one thunder-struck, or as if I had seen an apparition” (Defoe 1719, 122). When Robinson Crusoe, shipwrecked and washed ashore on a seemingly uninhabited island, one day saw footprints in the sand, he knew that there was human life there – Friday. He came to the conclusion, not just because the footprint had a similarity (iconicity) with a human being, but because it had a causal link with the lifeform who made it, as an index of life. An index is a sign caused by its object, it has an unintentional, causal link or contact with its content. “Smoke,” for example, has this indexical relation to “fire,” which it refers to and which we interpret as its cause. Indexicality is, in this respect, meaning by proximity or contiguity. This contiguity does not necessarily have to be of real physical causality, it could consist of the mere perceiving of two objects together in space. Indices could also be related to factorality, when seeing something as a part of something else (Sonesson 1994). The interpretation of indices requires empirical knowledge of the recurrent connection between the sign and what it refers to. The perceptual world consists of a profuse amount of potential indexicality, even though we do not yet recognize these indices as signs with meaning. But the human mind constantly searches for and infers causalities and meaning in things perceived.

Bioindices are thus biosignatures that have a connection to their objects (the living organisms) by contiguity. In other words, the connection between the expression and the content is not based on similarity, but on indexicality, and is in semiotic terms something distinctly different. Perhaps the clearest examples of bioindices are atmospheric, chemical biosignatures that refer to biological processes, such as the metabolism of living organisms. Homochirality and isotopic fractionation have been put forward as molecular evidence of metabolism. Biogenic minerals – deposits of calcium carbonate, calcium phosphate, iron oxides, mangese, and sulphur – could also be the products of microbial metabolic processes, and thus have this indexical relation, but are unfortunately very difficult to distinguish from minerals produced by mere abiotic processes. Fossils that record the behaviour or activity of an organism are another type of bioindices, in contrast to bioicons that has a similarity with the living thing. These artefacts of life, such as stromatolites formed by microbial mat communities, indicate a biotic origin. Other examples of bioindices that trace the behaviour of an organism are borings, burrows, footprints, etc. Again, the challenge here is to distinguish these bioindices from features that are a result of an abiotic process that mimic the biotic behaviour.

Remote sensing of planetary environments for habitability and biosignatures goes back to the nineteenth century. In his *Cours de philosophie positive* (1830–1842) the French positivist

Auguste Comte said, concerning the celestial bodies, that “we will never by any means be able to study their chemical composition or their mineralogical structure” (Comte 1835, 2; Crowe 2008, 312). Some few decades later spectroscopy was developed. The turning point came with spectroscopic astronomy that gave a new powerful tool for searching extraterrestrial life. By analysing the spectra caused by the molecular absorption or emission at molecule-specific photon wavelengths, the spectroscopists could infer the chemical composition of the atmospheres of distant planets. The first spectroscopic observations aiming for detecting oxygen and water in the Martian atmosphere were made by the astronomers William Huggins and Jules Janssen in the 1860s. By assuming water as a necessary condition for life, and by linking planetary environmental conditions (presence of water vapour in the atmosphere and liquid water on the surface) with the possibility for life to emerge and subsist, they got a clue. A detection of water vapour in the atmosphere of a planet would then be a crucial indication that it might be life on its surface. In 1867, Janssen claimed that he had discovered the presence of water vapour in the Martian atmosphere, but in fact it was probably terrestrial signatures, already refuted by the American astronomer William Wallace Campbell in 1894 (Raulin Cerceau 2013).

There are hopes that we in the future will be able to observe the absorption or emission properties of atmospheres of small, rocky exoplanets (Seager 2014; Seager and Bains 2015). A first step in the search for biosignatures of exoplanets would be to study the temperature, size, mass, density, gravitation, and light conditions of the exoplanet. Next, to search for indications of atmosphere, liquid water, clouds, surface, plate tectonics, daily rotation, seasons, and weather. The third step would be to look for bioindices. For sure, we will not be able observe any surfaces of exoplanets with current technology, but we might soon be able to detect certain gases that we connect with life by remote sensing, even though the interpretation of the spectra involves a number of difficulties. In the future, the European Extremely Large Telescope (E-ELT) will make it possible to perform spectroscopic analysis of the faint light of an exoplanet, and might result in the first exoplanet atmospheric biosignatures. Our hopes rest on the assumption that certain gases in the atmosphere are produced by life (as we know from studies of our own terrestrial atmosphere), such as oxygen, ozone, methane, and carbon dioxide. Oxygen enrichment in the atmosphere could indicate the presence of oxygenic photosynthesis. Ozone, which is produced photochemically from biologically produced oxygen, could be another indication of biological activity. And methane could likewise be connected to the metabolism of living organisms. However, these gases could also be produced by abiological processes and exist without any biological activity. Some gases that are products of life on Earth, such as CH_3Cl, CH_3SH, NO_2, NH_3, would not be detected with current technology, due to low amounts, others, such as water and carbon dioxide have significant abiotic sources, and are less suitable as conclusive signatures of life. To conclude, the argument starts from the premises: (P_1) that life produces certain gases as a by-product of metabolism; (P_2) some of theses gases will accumulate in the atmosphere; and (P_3) that these gases show a unique spectrum. From these premises – which we hold to be true and to be sufficient for detection – we conclude that life could, in theory, be detected through spectroscopy. But if P_1 is false (there are metabolic processes that do not produce gases) or if P_2 is false (these gases do not leak into the atmosphere) or we do not recognise the unique spectrum (P_3), we will fail.

It might rather be the combination of gases and the quantity of them, that closer reveals if there are life on the planet. Life leads to disequilibria, for example in respect to atmospheric chemical composition, entropy, etc. Earth-like atmospheric biosignatures disappear relatively quickly on a planet where life has ceased to exist. If there is a certain amount of a biosignature gas, it needs to have a continuous source. That gases in disequilibrium could be diagnostic for life was first suggested by Joshua Lederberg and James Lovelock in 1965 (Lederberg 1965; Lovelock 1965; Catling and Kasting 2007). And this atmospheric disequilibrium is detectable by spectroscopy, as in the case of spectral analysis of Earthshine (Arnold et al. 2002, 2008). The simultaneous presence of oxygen and methane indicates an atmospheric disequilibrium that could be assumed as a spectral evidence of life. The sustainable source of these gases, in this ratio, is life. The discovery of significant amounts of methane in the atmosphere of Mars then implies that there must exist a recent or current source, otherwise the methane would rather quickly disappear. The source could be geological activity and water in the subsurface – or subsurface biology (Domagal-Goldman and Wright et al. 2016). As a recurrent theme in the search for life, the signs are ambiguous.

Another shipwrecked traveller in foreign territories, the ancient Greek philosopher Aristippus, was cast ashore on the Rhodian coast. But when he found geometrical figures in the sand, he became convinced that he had come to a land inhabited by civilized people (Vitruvius *De architectura*, 6.1). These Rhodian bioindices did not only indicate life, people, they indicated civilization. A certain class of bioindices could be categorized as *technoindices*, a second order index that indicate technology, which in its turn could indicate life. When analysing the spectra of exoplanets, one might find signs that do not have any known natural origin, such as industrial pollution, artificial molecules, for example pollutants like chlorofluorocarbons (CFCs), or other artificial traces of environmental disequilibrium that reverberates across the biosphere (Lin et al. 2014; Shostak 2015; Frank and Sullivan 2016), which we interpret as technoindices of advanced life forms that are able to artificially manipulate their environment. Monitoring the stars and planets in our galaxy we perchance come across signs of extraterrestrial civilizations revealed by their use of technology, for example radio emissions or other electromagnetic radiation leaking out from their planet voluntarily or involuntarily. Finding signs of technology does not necessarily lead to the conclusion that they originate from a civilization consisting of biological creatures, if one think of the highly hypothetic self-replicating “von Neumann machines” that replicate and disperse themselves without the dependence of biological creators.

The search for indices of life is a way of connecting phenomena around us, inferring that certain signs indicate a causal connection to their object and origin – life. This semiosis or meaning-making endeavour is however triadic, includes something more than expression and object, the biosignature and the living organism. As the astrophysicist Arthur Eddington (1920) touched upon: “We have found a strange footprint on the shores of the unknown. We have devised profound theories, one after another, to account for its origins. At last, we have succeeded in reconstructing the creature that made the footprint. And lo! It is our own” (Sullivan and Baross 2007, 6). It is ourselves, the interpreters that make this connection between expression and content. Searching for indices of life may reveal some knowledge about the living Universe wherein we live, but also an understanding of how we search for meaning in the seemingly chaotic world around us.

5.3 Symbols of Life

August 15, 1977, the Big Ear radio telescope in Ohio received a very strong narrowband radio signal that lasted for 72 seconds. While reviewing the record date, the astronomer Jerry R. Ehman was stunned and wrote the comment “Wow!” on the computer printout. This anomaly has not been confirmed nor repeated (Kraus 1979). The first problem one faces in such a situation is to determine if it is a natural or an artificial signal, if one could rule out all known natural causes of the signal and conclude that it is an artificial signal caused by an intelligent civilization with advanced technology. This *technosignature* might indicate the existence of technology, as such a technoindex. The next problem that arises is to determine if it is something more than just an index of technology, but actually contains a message, a content that is meant to be communicated, deciphered, and understood by the receiver. Probably, we would not be satisfied with a mere conclusion that it is a technoindex, but that it contains symbolical information, that it is a *technosymbol*.

Searching for extraterrestrial intelligence by means of radio astronomy has been an exciting challenge ever since the start of Project Ozma in 1960 (Sagan 1973; Weston 1988; Tarter 2001; Drake 2011; Schuch 2011; Dunér 2015, 2017; Traphagan 2015; Vakoch and Dowd 2015; Cabrol 2016). The starting point of the argument is plausible. Electromagnetic leakage from

Earth is detectable from outer space, and likewise, if an extraterrestrial intelligence is engaged in radio communication, we would be able, at least in theory, to detect its voluntary or involuntary broadcasts. The problem of interstellar communication lies not so much in the physical or technological constraints, even though they very much challenge our scientific and technological skills, but in the cognitive and semiotic problems that interstellar message decoding provoke (Vakoch 1998; Dunér 2011b, 2014; Sonesson 2013).

Intelligence could be seen as an evolved mental gymnastics required to survive and reproduce within its specific environment. This includes the capability of representing activities and being able to make inner models of reality. By using symbols an intelligent creature could engage in abstract thinking detached from the environment, by which they can reason about things not existent; things that are not right in front of them, in a specific moment in time. Very effective tools for symbolizing thought are our communicational devices. According to the cognitive linguist John Taylor (2002), language can be understood as a set of resources that are available to the language user for the symbolization of thought, and for the communication of these symbolizations.

The problem with symbols is that they are conventional, or arbitrary, as the founder of semiology Ferdinand de Saussure (1916) called them. Icons and indices are signs that have some *non-arbitrary* similarity or contiguity with the signified, in contrast to the symbols' completely *arbitrary* relation. For example the word "life" has no causal link to what it stands for, nor does it resemble what it signifies. There are no intrinsic relationship between the expression and content whatsoever. It is the interpreters (the ones that construct the message and the ones that decode them, respectively) that joins them together and establish the connection between the expression and the content. And the matching between the transmitters' and the receivers' interpretation of the symbols is by no means self-evident. We may figure out the reference of the signal, but will probably have severe problems understanding extraterrestrial symbols. It is not impossible to imagine that the aliens would have certain knowledge about their environment that in its content is similar to our own knowledge of mathematics, physics, and chemistry. But their expression of it would most likely be very different from ours. It is the message's expression rather than its content that becomes the difficulty for the interpreter. In symbols, there is a gap between the sign and meaning. Nothing in the physical appearance of the sign gives any clue to its object; they are instead linked by an arbitrary correlation. In fact, most attempts at interstellar message constructions violate this basic semiotic understanding of signs that distinguishes between expression and content. Symbols are detached representations and, as such, dependent on cultural and social interactions that create some specific regularities that have their origin in more or less stochastic habits, conventions, etc., of the species (Sonesson and Dunér 2016). Our communication and symbolization have evolved through an evolutionary and cultural-historical process here on Earth, and are thereby constrained by our human bodies, terrestrial environment, and the socio-cultural characteristics of our species. And likewise, a potential information transfer containing a symbolic message from an alien civilization would be constrained by the bio-cultural coevolution of the extraterrestrial intelligence that coded it.

6 Conclusion

So far, we have no conclusive evidence of the existence of extraterrestrial life. But could we ever be hundred percent sure that we are alone? One might object that the plurality of life hypothesis labours under a major problem: unfalsifiability. According to the philosopher of science Karl Popper (1963), theories that are unfalsifiable and rich in explanatory power are often known to be wrong. In our case, there is no method or way of proving that life does not exist and cannot exist elsewhere in Universe. Astrobiology has an attractive flexibility and opens up for a richness of various explanations for the failure to prove the existence or for future success in discovering life. If we do not find life on the surface of Mars, we continue searching under its surface. If we do not find life in our solar system, we continue searching in other solar systems. If one exoplanet does not show any signs of life, we go on to the next, and so on. When will we give up and conclude that life most likely does not exist elsewhere? After hundred thoroughly studied exoplanets, after thousand, millions? We will never be able to search for life in every corner of the Universe, doing in situ investigations on every exoplanet in all galaxies in the entire Universe. We will never know empirically that life does not exist on other planets. We can just move on, refining our methods, observations, theories, etc., but never reach a final conclusion beyond uncertainty. It is just a question of probability. But to verify the hypothesis, it is just enough with one single sample. Finding life is not empirically falsifiable, but, in principle, verifiable.

Anyhow, one day we might encounter signs of another living planet. We will then get some potential knowledge, among other things, about its chemical composition and environmental circumstances. But above all, the descriptions, interpretations, and conclusions concerning this new world will also tell something about ourselves and our place in the Universe, and how we interpret and understand that reality we experience. There are things we know. Even though life might not exist out there, it is we human beings with our brains, bodies, and cultures who are searching for it. The history and philosophy of biosignatures is centred on humans, or more specifically, on the scientific endeavour’s dependence on the human mind and human culture (Dunér 2011a, 2013a; Dunér et al. 2013). Astrobiologists have brains, for sure; they are using cognitive tools that are a result of the bio-cultural coevolution of human cognitive abilities. Certain cognitive processes are at work when astrobiologists encounter unknown things, when interpreting potential signs of life, when they gather and classify information, and make conclusions from the observational data. This does not go on in subjective isolation. Astrobiologists live in a culture, in a certain time in history, in a specific research environment, and collaborate with other thinking beings. In this chapter, I have touched upon some epistemological issues in the search for biosignatures, how we conceptualize things, make analogies, how we perceive our surrounding world and endow it meaning. The quest for signs of life rests on the cognitive and socio-cultural capabilities of that human species that makes this lonely planet alive and thinking.

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