

ESSAY

Scientific Research between Orthodoxy and Anomaly

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Abstract—Scientific research takes place in the field of tension between accepted coherent knowledge and not-understood, not-integrated fragments: between orthodoxy and anomaly. Orthodox knowledge is characterized by laws and norms which can be conceived formally (deterministic or statistical laws), methodologically (criteria for scientific work), or conceptually (frameworks of thinking, regulative principles). I propose to classify anomalies according to their feasibility of being systematically connected with accepted knowledge. In this way, one can distinguish anomalies at the frontier of our knowledge, interior anomalies surrounded by accepted knowledge, and anomalies in no man’s land. I discuss examples which are intended to exemplify essential characteristics of each of these groups. Anomalies are the salt in the soup of science and dissolve where the domain of accepted knowledge extends or deepens—either by being elucidated or by being abolished.

Keywords: anomaly—knowledge—progress

Introduction

The etymological origin of the term “anomaly” is the Greek *ανωμαλια*, derived from the adjective *ανωμαλος*, “irregular”. Thus, there is not a direct connection with *νομος*, “law”, nor with the Latin *norma*, “rule”, nor with the related term *abnormis*, “deviating from the rule”. All this notwithstanding, the meanings of “anomalous” and “abnormal” have to some extent merged in the present-day use of the words. But evolving language practices are not always in line with the purity of philological analyses. Moreover, some relationships between anomalies and abnormalities are so disentangleable that a unique assignment to this or that meaning is impossible.

Since Kuhn’s (1962) book on *The Structure of Scientific Revolutions*, both the history and the philosophy of science are hardly conceivable without the notion of an anomaly. In Kuhn’s parlance, we speak of an anomaly if something cannot be explained in the framework of a given scientific paradigm. Because the notion of an anomaly is therefore always defined relative to a paradigm, we must—to begin with—say more about what is to be understood by a paradigm, and what Kuhn himself understood by it.¹

Kuhn's own usage of the notion of a paradigm changed several times. Originally he referred, without further specifications, to concrete problem solutions accepted by the world of experts. Later, in *The Structure of Scientific Revolutions*, the term received more global significance, indicating essentially all knowledge about which there was agreement in science. In the 1970s Kuhn started to characterize a paradigm as a "disciplinary matrix", a hallmark of mature science, while concrete problem solutions were redefined as "sample examples" (also "paradigms" in a narrower sense). In 1995 he admitted in an interview that "Paradigm was a perfectly good word until I messed it up" (Kuhn, 2000: 298).

What Kuhn wanted to characterize as a paradigm was later, after his early work, renamed in a number of different ways, such as scientific "research program" (Lakatos, 1978) or established "body of knowledge" (Elkana, 1981). They all agree by accepting a kind of textbook knowledge as a reference which is understood as a basis for scientific research at a given epoch and in a specific discipline. The notion of orthodoxy, often used in this context, expresses this as the combination of the Greek words *ορθος*, "correct", and *δοξα*, "teaching".²

In brief, research between orthodoxy and anomaly addresses the tension between accepted knowledge and what happens to be not (yet) included in it. This formulation is certainly quite simplified. Its detailed analysis requires two important questions (among others) to be discussed in depth: (1) What is the categorial relation between anomalies and accepted knowledge? (2) How can it be judged whether or not an anomaly is even accepted as an anomaly?

(1) Scientific knowledge is constituted by the two realms of theories and empirical facts that mutually complement one another. In many cases, theories are conceived as "compact" formalizations permitting the description and prediction of large amounts of empirical facts. Insofar as theories rest on sufficiently fundamental principles, exceeding merely algorithmic reformulations, they are deliberately said to "explain" empirical observations. The residuum that deviates from accepted knowledge, that is not assimilated and thus cannot be described or predicted by it, is a candidate for an anomaly. Such candidates are mostly empirical facts in front of the background of theoretical knowledge. However, there are also examples for theoretical approaches (to be discussed below), which can be called anomalous in this sense.

(2) Not every measured result that somehow "does not fit" qualifies as an anomaly. Trivial measurement errors are likely to vanish unpublished rather than spread around as big news. Before an observed irregularity catches the attention of the experts in a field, it has usually passed a series of filters delineating it against possible conventional explanations. These can be influences due to allegedly irrelevant noise (so-called "dirt effects"), superficial or corrupted statistical analyses, inadequate experimental design, overlooked explanatory alternatives (so-called "loopholes" in the interpretation of measurements), or simply premature conclusions.

A shift of paradigm or a scientific revolution, according to Kuhn—i.e., a substantial alteration of the accepted body of knowledge at a given time—may occur

if the significance and evidence of an anomaly is regarded as so high that it starts to exert pressure onto representatives of accepted knowledge. If this happens, indications of crisis and instability arise—for instance, fluctuations become stronger and even dominant: Intense controversies about alternatives and options increase in the same way as the stubbornness and irreconcilability of opinion leaders and representatives concerned increases.

It is not the rule, however, that a body of knowledge changes under the pressure of an anomaly to such an extent that its successor becomes effectively incompatible or incommensurable with its predecessor. At least in the natural sciences many examples demonstrate that one tries to implement extensions or refinements in such a way that they both integrate new results and conserve existing knowledge proven of value. This transition can often be formulated in a precise manner, thus rendering the shift less dramatic than a revolution.³ Changes between fundamentally incommensurable paradigms, as intended by Kuhn, are special cases and typically characterize (always from a retrospective point of view) particular aberrations or the return from them, respectively (compare, e.g., topics such as phlogiston or ether).

Orthodoxy: Laws and Rules

In order to identify anomalies against the background of a paradigm, let me first address some points that can serve to characterize a paradigm. Primarily these are (a) formal theoretical kinds of lawfulness, (b) methodological rules, and (c) established styles or frameworks of thinking.

Formal Theoretical Laws

Examples of kinds of theoretical lawfulness are, e.g., so-called natural laws of physics, such as Maxwell's equations for electrodynamics and the Schrödinger equation in quantum mechanics, or so-called phenomenological laws, such as in electrical engineering or thermodynamics.⁴ In contrast to these strictly "deterministic" laws, there are also "statistical" laws, for instance, the probability distribution of properties of particles in a many-particle system, the Boltzmann distribution for the population numbers in excited states of atoms and molecules, and the law according to which radioactive substances decay.

The detection of an anomaly is, once the trivial variants listed above are excluded, least difficult if it violates deterministic laws: an electron moving toward the cathode rather than the anode, a levitating stone that does not fall to the ground, etc. So far, there is no convincing evidence for phenomena like this in the framework of the presently established criteria for scientific work.⁵ Important for such evidence would be the *repeated* measurement of a property of the phenomenon with an (unavoidable) *measurement error* significantly smaller than the deviation from the value that is consistent with the respective law.

The issue of repeatability will be revisited later in more detail. As far as the measurement error is concerned, we obviously need criteria for what should be

considered as “significant”. Sometimes a multiple of the standard deviation σ of the distribution of measured values is used (e.g., 3σ). Sometimes—and mostly for deviations from statistical laws—the probability p is given with which the measured value could have been found “by chance”. This does in turn require an appropriate specification of what is assumed as “random”, etc. Often, events with probabilities of $p < .01$ are then already considered as candidates for significant deviations.

Deviations from deterministic laws are relatively easy to state because these laws are based on the assumption that precisely one particular value of the measured property is the “correct” value. But from physics to chemistry and biology, psychology and sociology the air becomes thin for deterministic laws. In the latter areas one finds (at best) statistical kinds of lawfulness, for which the detection of deviations becomes correspondingly more complicated.

The variability of measured values in such complex systems includes, in addition to the measurement error itself, a width of variation originating from the fact that there is not only one “correct” value but a whole class of them⁶: reaction times in psychophysical experiments, body sizes of living beings, market indices in economy, and many more. For a proper assessment of the significance of a deviation, thus, the distribution of both measurement errors and “correct” values needs to be taken into account. Things become even more complicated if (partly) deterministic factors must be included additionally.

However, variation in the sense of a distribution of “correct” values also arises in the most basic area of physics: quantum mechanics. It has to be emphasized, though, that these values are only generated by measurement—the system state before measurement is, briefly speaking, a “superposition” of all possible states. This superposition is very special insofar as it does not consist of the individual measurement values: a superposition is a holistic system state typical for quantum physics. The transition from the superposition to a measured value of a quantum system differs fundamentally from measurement processes in classical (non-quantum) systems.

So-called meta-analyses are attempts to group sets of empirical data (usually taken from the literature) together in such a way that a joint significance of the joint result can be determined. It is obvious that—in view of the distributions of variations to be considered—this can be exceptionally difficult and tedious. Eventually, one may have to take into account that the search for anomalies can entail a tendency to not publish results without considerable deviation from the expected. As a consequence, such results do not enter a potential meta-analysis. Estimating a probability distribution of such “selection effects” (a special case of a composite cause for variation) and its combination with the distribution of variations and errors is a challenge even for experienced statisticians.

Methodological Rules

In addition to anomalies against the background of deterministic or statistical laws, methodological rules represent important paradigms, often implicitly

assumed and rarely explicitly pointed out. One of these rules, frequently applied for the formulation of scientific models or theories, is the goal of *simplicity*: “A theory should be as simple as possible—but not simpler” (attributed to Einstein). This means to disregard, to begin with, anything that is only tangential for the subject matter considered—even if this is needed, at a later stage, to enrich an achieved “simple” framework with details. A metaphor for this situation is “Occam’s razor”, an instrument for the elimination of everything dispensable or irrelevant. This can be best illustrated in elementary areas of physics. Details become increasingly less negligible if systems become more complex.

In physics, the ideal of simplicity is connected with the idea of universality. The fundamental laws of physics are assumed to be universally valid, independent of the location or the instant at which the described events occur. In other words: universal laws are formulated as context-free as possible. The myth of “theories of everything” derives from this conception. In order to solve corresponding equations, however, an explicit implementation of contexts is necessary, for instance in the form of initial conditions or boundary conditions. This amounts *de facto* to derogating the universality strived for in the first place.

In the last 20 years, starting with an influential paper by Grassberger (1986), it has become clear that a restriction of the idea of universality is inevitable for the understanding of complex systems. Although it is still useful to look for so-called universality classes in the behavior of such systems, already the definition of complexity expresses a clear dependence on the context of the situation to be addressed. The relation between complexity and randomness plays a central role in this problem. For particular aspects it is useful to characterize the complexity of a system as proportional to the degree of randomness in its behavior. However, from the viewpoint of a statistical description it is often meaningful to consider perfectly random behavior as minimally complex.⁷

But there is more to it: in many cases the behavior of complex systems cannot be described as usual in statistics—namely, applying limit theorems, e.g., the law of large numbers. Essentially this means to assume that a determined distribution of measured values will not change considerably after a sufficiently large number, N , of values have been considered, so that the limit for $N \rightarrow \infty$ is already reached approximatively. Complex systems can foil this assumption by switching into dramatic instationarities after long periods of “benign” behavior. Using limit theorems in such systems always bears the risk of flawed results due to intrinsic instabilities.

Instabilities can be classified and understood only as statistical *ensembles*. Laws of motion for *individual* trajectories of systems in the vicinity of instabilities are outside the scope of contemporary science. Therefore, intrinsically unstable behavior cannot be accessed by deterministic laws. If limit theorems are (often) inapplicable for a statistical analysis of unstable phenomena, they cannot serve as bases for null hypotheses against which anomalies must be delineated. In this case, there is the possibility of investigating the behavior of an observable as a function of N rather than its limit for $N \rightarrow \infty$ and of characterizing the system

by the quantities obtained this way.⁸ Anomalies would then be context-dependent in the unconventional sense that they depend on the number N of measurements carried out.

The criterion of reproducibility mentioned above obviously rests on stability assumptions as well, and can turn out to be inapplicable as soon as these assumptions are violated. In principle, it would still be conceivable in such a situation that the significance of a result varies according to certain rules rather than completely erratically.

For instance, if there were reasons to expect a decreasing significance for an increasing number of attempts to replicate a result, this would open up the interesting possibility of interpreting a decreasing significance as an *argument in favor of rather than against* the corresponding result. From this perspective, the lacking reproducibility of a number of claimed anomalies could turn out to be the key to their proper understanding! However, it must be clear that, given the present state of the art, these are highly speculative dreams of the future.

Conceptual Frameworks

Another possible source of paradigms is philosophical positions whose influence extends as far as to cultural styles of thinking and worldviews as a whole. The 20th century comprises a number of examples in this regard, which illustrate a distinct shift from metaphysical to epistemological points of view.

Entirely in the sense of the empirically oriented positivism of the Vienna Circle in the early 20th century, the just-developed quantum theory was interpreted clearly epistemically by Bohr, Heisenberg, and the young Pauli: The *dictum* of the Copenhagen interpretation, due to Bohr, was that “it is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature” (Petersen, 1963). Although this standpoint was not left unopposed—Einstein, Schrödinger, and others were convinced that it *is* the task of science to find out about nature itself—epistemic, operational attitudes have set the fashion for many discussions in the philosophy of physics (and of science in general) until today.

Moreover, epistemically dominated directions have taken over in other disciplines as well. The *linguistic turn*, often ascribed to the influence of Wittgenstein in the 1930s and 1940s, is of key significance in this context. It was first spelled out explicitly by Rorty (1967) in his anthology *The Linguistic Turn: Essays in Philosophical Method*. It demands, similarly to Bohr’s appeal, that we give up on asking how the world is but, rather, concentrate on how it is described. Philosophy of language becomes a central field in analytic philosophy.

In addition, philosophy of mind together with a conceptually inclined cognitive science (as opposed to experimental psychology) developed as offspring, as it were, of the linguistic turn. The corresponding *cognitive turn* (Fuller et al., 1989) redirected emphasis from language to cognition, and can be traced to the early cognitivism of Chomsky, Minsky, and Simon. Today’s implications of the

cognitive turn are manifest in the study of consciousness, but also have visible repercussions in literature, theater, and film. This has recently led to the notion of an *iconic turn* (Maar & Burda, 2004), based on the idea that our interaction with the world essentially relies on images: classical images in the visual arts and in contemporary media, icons in communications with fellow humans and with computer systems.

This series of examples demonstrates how far remote present philosophical and cultural trends are from traditional metaphysics and ontology. It also shows the conjoining massive restriction of the scope of discourse from the quest for the fundamentals of reality to language and cognition and eventually to visualization and its ramifications. In the resulting environment, a Cartesian substance dualism or the research programs of 19th century science must appear extremely naive. On the other hand, a narrow focus always makes it likely that important things outside of it are unduly disregarded. A comprehensive and sensible account of reality is palpably unachievable by elaborate studies of visual communication alone.

This has led to a situation in which metaphysical questions of natural philosophy are either not regarded at all, or are regarded with great skepticism, or even with a clearly pejorative tone.⁹ The similarity to other, purely scientific kinds of anomalies is striking—although anomalies in conceptual frameworks are often predominantly coined by the sociology of scientific discourses rather than by scientific results themselves.

Kinds of Anomalies

Different approaches are conceivable for a systematic classification of anomalies. It seems to be most obvious to distinguish them according to the fields of knowledge in which they appear. This may be a suitable approach for historical examples, which already led to changes in the organization of their respective bodies of knowledge. For anomalies not yet clarified, however, this is not always possible in a unique way—some anomalies occur due to questions that cannot be assigned to individual disciplines, some can be assigned to several disciplines, and some appear so digressive that they are not even considered scientifically relevant.

For these reasons I will follow another approach. It is based on the distinction of various kinds of (potential) connectivity, or distance, to accepted knowledge. Such a discussion is meaningful if the body of accepted knowledge does not consist of a patchwork of disconnected fragments, but rather is organized in a consistent and coherent way. For this to be the case, there are typically two factors to be satisfied: (1) Equivalence classes of facts are all governed by the same (sets of) laws, which serve their description, explanation, or prediction. (2) Different (sets of) laws are related to one another in a well-defined manner, such that *ad hoc* modifications bear the risk of disrupting a whole system of laws, a theory network.

According to these two factors, both empirical and theoretical anomalies are possible. Empirical anomalies refer to observations that cannot be described, explained, or predicted by accepted theories, and theoretical anomalies are best characterized by their missing coherent relation to accepted theories. So far, this is all that is meant by a lack of connectivity in a heuristic sense discussed here.¹⁰

I am not going to address anomalies for which this notion is used in a purely phenomenological sense, for instance with respect to numerous kinds of medical anomalies mostly characterizing anatomical or functional deformities or malfunctions. Such anomalies are often considered simply as deviations in the sense of variation (see above) and rarely imply the power required for a “paradigm shift”.¹¹

The same applies to some kinds of anomalies in technology. For instance, computer scientists speak of anomalies due to weaknesses of a data model (insert anomaly, change anomaly, delete anomaly), due to flawed software or due to incorrectly implemented tests. Such aberrations can, as a rule, be fixed if the underlying mistakes are identified.

Refraining from these “weak” anomalies, let me now turn to those that can be regarded as the “salt in the soup” of science in a more substantial sense. In the following I will refer to three kinds of anomalies, which are distinguished by their (potential) relation to accepted knowledge, and discuss them with selected examples: (1) anomalies at the frontier of accepted knowledge, to be considered, as it were, as an interface to the *terra incognita*; (2) anomalies surrounded by accepted knowledge, representing gaps that are hard to close within such knowledge (interior anomalies); and (3) anomalies in “no man’s land”, which are so far remote from accepted knowledge that systematic approaches are hardly conceivable.

Anomalies at the Frontier of Science

This chapter begins with historical cases of anomalies in physics for which, from the viewpoint of today, it is clear how their incorporation into the state of knowledge of the time being could be achieved: the famous water anomalies, the anomalous Zeeman effect, the anomaly of compounds of noble gases, and anomalies of quantum field theory. Then I describe two anomalies of astrophysics and cosmology, respectively: the mercury anomaly, resolved within the general theory of relativity, and the Pioneer anomaly, not explained yet.

Next, I discuss the area of adaptive mutations and epigenetics, issues of intense research in current molecular biology and genetics. These topics evolved from total heresy to an approved forefront of mainstream research within the remarkably short period of about three decades. Eventually, I turn to an anomaly which is not yet developed as far, but whose distance from accepted knowledge is not devastatingly huge. This anomaly became known as “cold fusion”, but might more carefully be called “excess heat of unknown origin”. Discussion regarding this anomaly became inflamed in 1989 and created an enormous buzz, mainly because of potential technological and economic consequences. Less emotionally

analyzed, there are a number of empirical results provoking questions that need to be studied and clarified.

Of course, these examples do not represent a comprehensive list. For instance, a scientifically sound investigation of the problem area of homeopathy could be very deserving. Insofar as homeopathic substances are dissolved in water, this verges on the question of insufficiently understood properties of water. The investigation of homeopathy and placebos offers room for research that is connected to established knowledge and allows us to explore new scientific territory.¹²

History of Physics and Chemistry

The history of physics offers numerous phenomena that have played the role of anomalies at the frontiers of knowledge. Their integration into an altered body of knowledge, that was *extended* by their understanding rather than completely revolutionized, documents the role of anomalies as driving forces for the course of science. Good examples are various forms of water anomalies, many of which are today explained by the pronounced dipole structure of H₂O molecules and the associated clustering properties. Accordingly, there are a number of properties¹³ with respect to which water behaves differently from what one would expect by extrapolating the same properties of comparable hydrides (H₂S, H₂Se, H₂Te, H₂Po) as a function of molecular mass. The hydrogen bonds responsible for the clustering of H₂O were for the first time described by Latimer and Rodebush (1920) on the basis of the theory of atomic structure by Lewis (1916).

Some years later, Pauli (1925) published the hypothesis that electrons possess a property, unknown at that time, which was later called spin. The electron spin provides a detailed explanation of the splitting of spectral lines of atoms in strong magnetic fields. While the “normal” Zeeman effect can be explained by the classically treated orbital angular momentum of electrons alone, the “anomalous” Zeeman effect requires us to include the non-classical electron spin in addition. In the years of the emerging quantum theory, the anomalous Zeeman effect was one of the first phenomena to exclusively rely on one of the non-classical features of the theory. The electron spin also turned out to be the key to a comprehensive understanding of the periodic table of the elements.

Based on Lewis’s valence theory and its further development by Heitler and London, Pauling (1931) succeeded in describing the chemical bond in the light of quantum theory in his seminal paper on the nature of the chemical bond. Although it was considered an unshakable doctrine that noble gases are chemically inert, i.e., do not bind with other elements, Pauling (1933) predicted chemical compounds of heavy noble gases. Bartlett (1962) was the first to synthesize xenon-hexafluoroplatinate (XePtF₆) as such a compound in the laboratory. Today, noble gas halogenides have important applications, e.g., in excimer lasers.

Finally, the notion of an anomaly in quantum field theory means that the quantization of a classical field breaks one of its classical symmetries such that classical conservation laws are violated. Again, this is a historical anomaly:

The framework of the extended theory, here quantum field theory, explains the disappearance of an anomaly that appears as such only with respect to its historically preceding classical theory, here classical field theory. This is yet another illustrative example of how anomalies can be regarded as obstacles to be overcome by a suitable consistent extension of the body of knowledge.

Anomalies in Astrophysics and Cosmology

An often-mentioned example for an anomaly refers to the rotation of the perihelion of the planet Mercury, the point of its orbit that is closest to the sun. This so-called precession was discovered by le Verrier in the mid-19th century. In 100 years, the shift amounts to 572 arcseconds, 529 of which can be explained by the gravitational influence of the other planets. The remaining 43 arcseconds cannot be understood in terms of Newtonian celestial mechanics. In 1916, Einstein's general theory of relativity predicted an effect of 42.98 arcseconds due to the gravitational field of the sun, in perfect agreement with the (later) measured value of 43.11 ± 0.45 arcseconds. For Venus, Earth, and Mars, the relativistic corrections are 8.6, 3.8, and 1.4 arcseconds, respectively.

Another anomaly, so far without accepted explanation, is the so-called Pioneer anomaly, observed with the satellites Pioneer 10 and 11 during their motion out of the solar system. Anderson et al. (1998) found a deceleration of the satellites which is greater than can be explained by the gravitational pull of the solar system alone. Data collected since 1987 give an additional acceleration toward the sun for both Pioneer 10 and 11 of $(8.74 \pm 1.33) \times 10^{-10} \text{ m/s}^2$. This implies that their increasing distance from the sun is 5000 km per year smaller than it should be. A number of possible explanations of this anomaly are currently discussed, ranging from measurement errors over known unconsidered effects to yet unknown laws of physics.

In recent years more and more effects of known physics could be excluded as explanations (see Lämmerzahl et al., 2007). As far as "new physics" is concerned, theoretical ideas of cosmological relevance are primary candidates. Corresponding approaches are supported by the observation that the unexplained acceleration is approximately the product of the speed of light and the Hubble parameter. Among many proposals, those based on a relation to dark matter or dark energy are considered most interesting, two of the big enigmas of modern astrophysics and cosmology. A planned ESA space mission with the working title "Deep Space Gravity Probe" might provide insight into some of these questions.

An alternative cosmological speculation of earlier origin rests on an approach of Weyl and has recently been investigated by Scholz (2008). It amounts to a decrease of the frequency of photons ("tired light") purely conditioned by features of geometry, leading to a redshift not depending on the expansion of the universe. Another variant is the so-called "steady-state" approach, modified several times so far (see Hoyle et al., 1993). In contrast to the standard "big-bang" scenario, it predicts non-cosmological redshifts as well. Such effects can, as Arp (1998) has

argued, appear in the spectrum of extragalactic objects whose distance is too small to explain their different redshifts by space-time expansion.

Especially in the areas of astrophysics and cosmology, two relatively young scientific disciplines, there is certainly no final word spoken yet. There are indirect empirical indications for dark matter and dark energy, but both are hardly understood. It is no risky hypothesis to say that both empirical and theoretical anomalies will keep playing a central role in the search for a coherent cosmological worldview in the future.

Adaptive Mutations and Epigenetics

A particularly interesting chapter on anomalies is an extremely fast development in the last three decades, changing the reception of research on adaptive mutations and epigenetics from wild superstition to an accepted mainstream of genetics.¹⁴ Both topics violate central dogmas of modern neo-Darwinism, a picture that evolved in several steps from Darwin to Dawkins. The first dogma is that mutations of hereditary material are exclusively random, i.e., not governed by deterministic laws (and not directed toward final goals). The second dogma is that the inheritance of phenotypic changes cannot occur without corresponding changes of the genotype. Today, both dogmas are considered to be conclusively refuted. However, this state of affairs began with anomalies that were harshly savaged at the time of their publication and mostly ignored by peers and experts.

A key example of epigenetics can easily be illustrated with the cross breeding of horse and donkey: “equine epigenetics”. The offspring of a male horse and a female donkey is a hinny; in the opposite case it is a mule. It has been known for 3000 years that hinnies *always* have a thicker mane, shorter ears, and stronger legs than mules. The two hybrids are, thus, clearly distinguishable phenotypically, though they are genetically identical. Today it is established that this situation violates Mendel’s laws. How is it possible that this downright conspicuous observation remained disregarded and unexplained by science for so long?

A plausible answer is that only in the second half of the 20th century has the mentioned anomaly gotten close enough toward the evolving frontier of extending accepted knowledge. Today, a number of mechanisms are known which can lead to inheritable phenotypic changes without changes in gene material (methylation, etc.). And it is known that mutations of the genome can massively adapt to environmental stimuli, both in a temporally selective manner (as long as the stimulus acts) and locally along the DNA (where special sequences mutate preferentially). At present there is no doubt that inheritance does strongly depend on environmental influences.

It is still remarkable how hesitantly this overwhelming progress in molecular biology and genetics is being received in the theory of biological evolution. For a long time the problem has been discussed that the evolution of complex living beings such as mammals is extremely unlikely in the framework of neo-Darwinian evolution. Although the new insights in genetics would clearly entail answers to this critical question, they are not assimilated yet. One reason why

adaptive mutations and epigenetics still meet resistance is that they are traditionally linked with Lamarckist or even creationist positions. But they entail neither final causes nor intelligent design—they can be explained by admittedly complex but eventually transparent scientific mechanisms.¹⁵

Excess Heat, Vulgo Cold Fusion

In spring 1989 two chemists at the University of Utah (Salt Lake City), Martin Fleischmann and Stanley Pons, declared at a press conference that they had succeeded in fusing deuterium nuclei to helium-4 using a simple electrolysis gadget with palladium electrodes (Fleischmann & Pons, 1989). As their proof of evidence they reported the measurement of so-called excess heat, which could be explained by neither the contributing chemical reactions nor by defective calorimeters. Since the experiment was carried out at room temperature, this became known as “cold fusion” (originally proposed as early as in the 1920s). The claimed fusion is “cold” in comparison with the 10^7 – 10^9 degrees Kelvin at which nuclear fusion proceeds in stars or is expected in fusion reactors.

The news from Fleischmann and Pons was received with overwhelming response to begin with. But bit by bit it turned out that in a series of further experiments the result of excess heat could not be reproduced. In November 1989 the U.S. Department of Energy (DOE) organized a meeting to investigate the situation. As a main result of this meeting, it was noted that the arising heat could not be traced back to a nuclear reaction. By and large, this conclusion was reluctantly skeptical, while parts of the scientific community quickly started to talk about fraud, pathological science, etc.

The following years brought, in addition to many failed replications, occasional results from laboratories in Japan, Italy, France, and the USA which confirmed the original observation by Fleischmann and Pons. Another review panel of the DOE in 2004 nevertheless did not find sufficiently uncontroversial reasons to recommend this direction of research for comprehensive support by public funding agencies.

The most recent development, though, has become cautiously positive again. A review of the U.S. Naval Research Laboratory in 2007 lists about 10 groups worldwide which measured considerable (50–200%) excess heat. A review of the Indian National Institute for Advanced Studies in Bangalore (Srinivasan, 2008) stated unambiguously that there are novel scientific results to be understood. A conservative assessment (Beaudette, 2002) suggests that the excess heat, meanwhile repeatedly observed, should be taken seriously, even if the underlying nuclear processes remain unclear so far.

It is currently an open question with regard to what theoretical explanations could look like. There are a number of approaches; the most prominent among them is presumably due to Julian Schwinger (1994), an outstanding theoretical physicist. Schwinger argues that the experiments actually show a deuterium-hydrogen reaction leading to helium-3 rather than helium-4. The released energy is absorbed as phonon energy by an emerging palladium-deuterium lattice.

Schwinger's proposal resolves some interpretational problems and has experimental consequences which, to my knowledge, have not been tested so far.

Interior Anomalies

The term "interior anomaly" serves to denote anomalies not located at the frontier of our knowledge, but rather those that represent a white spot on the map of knowledge: an anomaly surrounded by accepted knowledge, but not itself belonging to it. Such a situation can emerge if a problem (i) resists all attempts to be solved, and (ii) does not squarely prohibit further progress. This can imply that corresponding problems disappear out of the focus of research after a while and mutate from white spots to blind spots.

If a problem resists solutions for a long time without blocking progress in individual areas of science, it is often a substantial, difficult problem at boundaries between different disciplines which cannot successfully handle it individually. Seriously interdisciplinary approaches, as occasionally developed in recent years, represent a chance for progress in these cases.

A first example in this regard is part of the millennia-old problem of relationships between mental and material states.¹⁶ This can be understood in a quite general sense, but a specific aspect that has recently seen a renaissance in philosophy, psychology, cognitive science and neuroscience refers to the relation between brain and consciousness. Depending on the disciplinary angle, different types of relations are currently favored.

The second example, similarly fundamental, is the unsettled relation between (objective) physical time and (subjective) experienced time. It can also be expressed as the relation between "tenseless time" and "tensed time", pointing to the fact that physical time does not contain tenses such as present, past, or future. What it contains are relations such as smaller or greater ($t_1 < t_2$ or $t_1 > t_2$), which can be interpreted as earlier or later only within tensed time. The longstanding priority dispute between representatives of the two concepts of time is obviously infertile—at present there are interesting ideas of how well-defined relations between them might be derivable.

Eventually there is, as a third example, the notion of paradox, which represents a paradigm example of an anomaly in the context of classical two-valued (Boolean) logic. Paradoxes are discussed by philosophers (at least) since Epimenides of Crete, and in Zen Buddhism they do even figure, in the form of koans, as a key instrument of spiritual growth. In the specialized sciences, however, paradoxes were long considered marginal. Today they can be investigated both formally and empirically with available approaches and techniques.

These examples for interior anomalies are not *purely* scientific examples, insofar as they stand out against methodological or philosophical "norms" in addition to touching scientific issues and raising scientifically addressable questions. Some of them have been trivialized (such as in physical-reductionist accounts of the mind-brain problem), some have been mostly neglected (such

as the problem of paradoxes), but they all show a strong tendency of resisting attempts to stash them away from the research agendas of the contributing disciplines. As all anomalies, they are anomalous relative to a particular historical context. In contrast to other anomalies, however, interior anomalies are predestined to be particularly persistent and pertinacious.

Brain and Consciousness

One reason for the recent upsurge of the neurosciences is that many regard them as a promising candidate to further our understanding of the human psyche. However, the neurosciences are not concerned with the psyche, with mental states and processes, but with the brain. The brain is usually considered as the material substrate without which mental states would be impossible. For many brain scientists there is no question that this necessary condition is at the same time sufficient: brain science, in this case, would be all we need to understand the psyche.

Scrutinizing this position, it becomes quickly clear that such a premature reduction is questionable. There are several variants of relationships between brain and consciousness (e.g., emergence, supervenience), some of which are even favored against strong reduction in present discussion. Remarkably, the mind-brain connection has defied a precise formulation throughout the entire history of science. Even if both brain and psyche were perfectly understood *per se*, the problem of their mutual relations would not even be touched.

David Chalmers (1995) expressed this quite strikingly in terms of the “hard problem of consciousness”, as the explanatory gap between subjective experience (qualia) and neurobiological states. As ever, there is no convincing solution to this problem. Indeed, a reductive scheme would be attractive because it is so simple—regrettably it is (presumably) too cheap or even simply wrong. Currently, there is an increasingly intense discussion of ideas, going back to Spinoza, assuming a psychophysically neutral domain that can be examined from the perspectives of the material and the mental: the so-called dual-aspect models.¹⁷

An idea that also receives increasing attention presently is the doctrine of panpsychism (see, e.g., Rosenberg, 2005; Seager & Allen-Hermanson, 2005; Skrbina, 2005; Strawson, 2006), adding a radical accent to dual-aspect models. Its essence is that everything possessing material properties also possesses mental properties. A basic form of mentality (not to be identified with human consciousness) pervades everything that exists. With this premise, the problem of how the mental arises would dissolve, but the price to be paid is high. How could, for instance, the mentality of elementary particles be conceived, and how could it be operationalized? What would be a suitable concept for the domain of which matter and mind are aspects? What gives rise to their mutual correlations?

Such questions will certainly engage scientists and philosophers for many years into the far future. It is possible that we do still not have the proper notions today to make progress. It is also possible that false implicit assumptions mislead

us (for instance, the myth of the causal completeness of the physical). It may even be that the focus of discussion is still too narrow, and it is necessary to include psychosomatics or, even more widely, psychophysical correlations in general. It is to be expected that an anomaly of this degree will remain profoundly tenacious for another while.

Physical Time and Experienced Time

It could also be that the problem of mind-brain relations is in some way conceptualized too broadly to allow progress in detail. In this sense, an attractive special variant could be to focus on an essential aspect of the psychophysical problem, referring to the tension between (objective) physical time and (subjective) experienced time.

Modern concepts of time in the fundamental laws of theoretical physics are distinguished by symmetries (i.e., invariances under transformations), namely the invariance under (i) time translation, (ii) time reversal, and (iii) time scaling.¹⁸ This means that (i) there is no distinguished point on the time axis, (ii) there is no distinguished direction of time, and (iii) there is no distinguished intrinsic unit for measurements of time. From (i) follows that there is no notion of the present (nowness), and so there are no past and future. From (ii) follows that each process running “forward” in time could equally run “backward” (and vice versa). From (iii) follows that processes in time can be rescaled without changing the process itself.

In our experience of time, there is a present, the now, which provides a reference point for introducing the relations “earlier” and “later”. On this basis, past and future can be defined and distinguished from each other by facticity and contingency. Thus, symmetries (i) and (ii) are broken. Moreover, there are indications that discrete time quanta of a particular extension are relevant for conscious experience (Pöppel, 1997). Similar to material constants in physics, they are given by neurobiological properties and fix a time scale, thus violating scale invariance (iii). As a further key difference from physical time, the experienced now is a “quale”; it has a quality of “how it feels to be now”, which is not part of physics anyway.

At least since McTaggart’s essay on the “unreality of time” (McTaggart, 1908), there is a vivid debate about which of the two concepts of time is more fundamental, why this could be so, and which consequences it might have. More recently, there are speculations about a complementarity of the two concepts, partly worked out in a conceptually appealing and formally demanding way. Publications by Franck (2004) and Primas (2008) can be consulted to catch the ideas.¹⁹

A key point for promising approaches is that physical time and experienced time need to be related to each other in a way that clarifies the transition from one to the other step by step, in minute detail. On the one hand, such a theoretical project contributes to a specific question of the mind-matter problem. On the other hand, it bears fundamental significance for our understanding of time. The

fact that successful research in many areas requiring time concepts has been possible points to a typical feature of interior anomalies. Much work based on the notion of time could be and has been carried out without any basic explanation of the “nature of time” itself.

Paradoxes

The notion of a paradox is related to the notion of orthodoxy insofar as both derive from the Greek root $\delta\omicron\xi\alpha$, “teaching”. Paradoxes are something that stands $\pi\alpha\rho\alpha$, that is, off the mark or even against accepted knowledge.²⁰ Broadly speaking, the core of a paradox is, thus, a conflict between a subject matter and a given (accepted) opinion.

In philosophical terminology, the notion of a paradox is applied in a narrower sense. Often one speaks of a (semantic) paradox if the three conditions of (i) inconsistency, (ii) self-reference, and (iii) circularity are satisfied together (see, e.g., Rescher, 2001, or Sainsbury, 1995, for more detailed accounts). Inconsistency touches the criterion of correctness or truth. For self-reference the criterion of identity is crucial. And circularity has to do with causation (not in a temporal sense, but rather in the logical sense of an implication).

Inconsistency alone is not sufficient to make a sentence paradoxical: “The earth is a globe and it is no globe” is inconsistent, contradicts itself, but is not paradoxical. Self-reference alone is insufficient as well: “This sentence consists of six words” refers to itself, but is not paradoxical. Also, circularity alone is not sufficient: “What came first, hen or egg?” leads to a circular pattern which is not paradoxical. Similarly, combinations of two of the given conditions do not yield a paradox.

“This sentence is false” is the paradigm of a paradoxical proposition, which shows with particular clarity how all three conditions are satisfied. The logician Blau (2008) has devoted a demanding thousand-pages book to it. “This sentence is false” contradicts itself by its content, refers to itself, and its (serial) analysis leads to its dissolution into a circular oscillation of “true” and “false”.

There are syntactic paradoxes (mainly in mathematics), semantic paradoxes (in epistemology, literature), and pragmatic paradoxes (e.g., in applied psychology or spiritual practice).²¹ It is a crucial point of all paradoxes that they cannot be classified in the framework of a strictly Boolean analysis. Paradoxes undermine—some of them in delicate ways—the “either–or” of a logic with two definite truth values. In this sense, paradoxes are anomalies for Boolean classification systems. It depends on the kind of paradox considered which extensions of such systems are required for its dissolution.

Niels Bohr, one of the pioneers of quantum theory in physics, once said that a deep truth is characterized by the fact that its opposite is a deep truth as well. As is well known, this statement of Bohr’s referred to the concept of complementarity that he imported into physics from psychology. In simple words, two

descriptions are complementary if they contradict each other and, at the same time, are both necessary to describe a situation completely. In this sense, one could try to formulate paradoxes as complementarities which can, as in quantum theory, be formulated by non-Boolean structures.²²

Extensions in the direction of such a non-Boolean analysis enable a coherent discussion of paradoxes. But this requires a radical rethinking that can, particularly for the pragmatic paradoxes mentioned above, assume existential dimensions. Non-Boolean systems no longer permit a unique assignment of matters of fact to mental categories, but they permit the assumption of “acategorical” states (Atmanspacher, 1992). As Freud referred to dream as the royal road to the unconscious, paradox can be understood as a royal road to modes of consciousness beyond stable binary categories.

Anomalies in No-Man’s Land

By “anomalies in no-man’s land” I refer to anomalies for which contact options to accepted scientific knowledge are not visible. Of course, this is a matter of assessment, and without a serious study of such an anomaly and what it might conceal it will hardly be possible to come to a reasonable judgment. Moreover, as mentioned before, there is no authoritative metric which could serve to measure a distance from the frontiers of knowledge. Therefore, any assessment remains an arguable affair and is, at least in part, unavoidably contaminated in a subjective fashion.

In the following I will comment on two selected representatives of this genre. The first example concerns the situation with respect to a class of phenomena usually called psychokinesis (PK). As a rule, this refers to some kind of mental influence on material processes and is intended to be as general as including volitional alterations of radioactive decay processes (micro-PK) or levitating tables (macro-PK). The other example concerns astrology, the idea of using the constellation of celestial objects to infer statements about human dispositions and destinies.

Psychokinesis

Usually PK means a causal influence (intended or unintended) upon the behavior of matter, which is not mediated by known physical interactions. In a sense, this is the psychophysical problem in its most radical form: not only are brain or body and consciousness at stake, but a correspondence of mental and physical processes outside one’s “own” brain or body are addressed.

This raises two complexes of questions. How is an influence to be conceived if physical interactions are excluded? The exclusion condition is, in a sense, already the criterion for a lacking connection to the *status quo* of physics and opens the door for all kinds of speculation. The crucial issue from a philosophical point of view is to identify a mode of causation that is capable of acting between two

distinct categorial systems (mental–material). Such a mode easily triggers the suspicion of a category mistake and, thus, requires substantial arguments against this kind of flaw.

An elegant variant of psychophysical relations, proposed by Carl Gustav Jung under the notion of “synchronicity”, is so-called meaningful coincidences.²³ However, an essential feature of them is that they are to be understood exactly *not* in the sense of a causal influence. Rather, the correlative connection is assumed to be a “meaningful correspondence” between mental and material events arising as particular manifestations of a hypothetical, psychophysically neutral domain.²⁴ This way, both the risk of a categorial confusion of mental and material domains and the problem of the causal completeness of the physical are avoided. The price to be paid is the assumption of a common ground for psyche and physis (Jung’s *unus mundus*), about which contemporary science has nothing to say.

A second problem area is the empirical detection of such anomalies. For a number of decades, laboratory studies have tried to provide evidence for deviations from well-defined physical processes by the mental influence of human subjects. Particular interest in this context has been focused on the investigation of stochastic processes (e.g., radioactive decay) that are determined only statistically. The idea is that any kind of mental influence might be “facilitated” in processes that are not governed by strictly deterministic laws.

Although there are occasional reports of positive evidence from corresponding experiments, analyses of the entire body of published results (so-called meta-analyses) cause doubts concerning the validity of the claimed evidence of PK. An especially careful and mathematically sophisticated meta-analysis by Ehm (2005)²⁵ yielded no significant PK effect for a large collection of data from which positive conclusions in favor of PK had been drawn previously with less subtle statistical methodology (Radin & Nelson, 1989). A large-scale empirical replication study (Jahn et al., 2000) of a certain type of micro-PK also yielded no significant evidence for the effect investigated.

An interesting hypothesis in this regard is the idea that PK phenomena under replication might be subject to a systematic attenuation, leading to their decline over a long series of experiments. As a methodological consequence of such a hypothesis, the empirical criterion of the reproducibility of results under identical conditions would be severely challenged—or, put the other way around, any repetition might undermine the identity of the conditions. We know that this is plausible in sufficiently complex systems (Atmanspacher & Jahn, 2003), but there are no detailed studies of such effects or related effects so far.

Another empirical side of PK phenomena is their spontaneous occurrence outside controlled laboratory conditions. Braude (1997) has vigorously advocated the importance of such “non-experimental” evidence. In this case, reproducibility is not an issue anyway, because spontaneous cases do not have fixed boundary conditions. If pertinent reports are taken seriously, there are indications that psychologically and/or socially unstable situations promote the appearance of spontaneous PK effects.

By and large, the empirical situation concerning PK today is unclear and unsatisfactory. The occasional claim of successful observations beyond all doubt typically meets, probably appropriately, something in between skepticism and rejection. As far as the option to connect to existing knowledge is concerned, the situation looks similarly murky. Although there are interesting speculative ideas (e.g., in the style of Jung), they do not comply with thorough step-by-step scientific work yet. It might be a promising attempt in contemporary discussion to subject the criterion of reproducibility to a profound analysis. This could lead to both intelligent experiments and conceptual progress.

Astrology

Astrologers try to interpret the relative positions of celestial bodies, moving in front of the background of the fixed stars, in such a way that they can infer conclusions about individuals, institutions, or other “agent systems”. Astrology exists as long as humans exist who observe the sky. Western astrological systems essentially go back to the Babylonians, who named the moving stars according to their gods and goddesses. Their spheres of action were then regarded as the essence of the corresponding planet.²⁶

Moreover, the astrological standard system includes the 12 signs of the zodiac, related to the four elements water, fire, earth, and air, and 12 houses positioned in the zodiac with respect to the instance to which the interpretation refers. The first house begins at that zodiac location which just rises at the horizon at the instance under consideration (hence, this position marks the “rising sign”). Typical characteristic instances for interpretation are birth dates of individuals, dates of important events in life, founding dates of institutions, etc.

Astrology is based on a hybrid system in which astronomically precise data are interpreted psychologically.²⁷ Stated simply, the “planets” represent motivations and needs, the signs of the zodiac and their elements stand for general inclinations (intellectual, material, sensible, creative), and the houses refer to areas of experience, such as partnership, profession, social life, property, etc. The resulting $12 \times 12 \times 10$ combinations *per se* provide a rich variety of potential details of interpretation. This is increased by the important feature of angular relations among “planets” (aspects) and other particulars.

This rough characterization (for a more detailed overview see Fankhauser, 1980) shows how difficult a clear differentiation and analysis of the available room for interpretation must be. For this reason, astrologers keep emphasizing over and over how important experience is for a proper interpretation of astrological charts. Scattered anecdotal reports about astrological success stories (see Braude, 2007) are truly startling, but—again—these cases are distinguished by abstaining from laboratory conditions and statistical analysis.

Insofar as particular constellations can favor or block particular inclinations and faculties in particular areas of life, astrologers consider themselves capable

of predicting partner relations, professional success, etc. Such predictions can be compared with corresponding data, an undertaking for which the French astrologer Gauquelin (1994) spent much time and energy. He did not succeed, however, in a sustained confirmation of certain astrological hypotheses.²⁸ A recurrent problem in such studies is the formulation of suitable null hypotheses, connected with the identification of adequate reference distributions.

This deficient empirical situation notwithstanding, there are also no promising theoretical ideas of how correlations between celestial bodies and properties of the human psyche could be understood. (The point here is not sleeping problems at full moon—the moon as an astrological “planet” serves much more specific purposes.) After all, astrology might be another candidate for an anomaly whose value for the progress of science still lies hidden in darkness. It could also be a candidate for rank nonsense. At present it remains undecided which of these options may be the case.

Concluding Remarks

Many historical examples of anomalies demonstrate that their explanation became possible when they approached the frontier of accepted knowledge sufficiently closely. With all necessary caution, one can say that too much distance from the scientific state of the art renders the search for an understanding of anomalies, in the sense of their connection to current research, largely ineffective. Scientific giants on the order of a Newton, Gauss or Einstein confirm this rule by exception. In scientific no-man’s land success will be extremely unlikely, even if the commitment to a corresponding problem area is as intensive (or obsessive) as can be.

Already at the frontiers of knowledge, progress in science is so subtle and difficult that it is not only justified but absolutely correct to characterize it with the notion of “high-risk” research (as opposed to what Kuhn, 1962, called scientific crossword-puzzle-solving). There may be differences in detail, depending on the necessity of methodological innovations, the availability of theoretical models, the inevitability of genuinely interdisciplinary approaches, etc. A careful balance of the risk of failure with the chances of success is especially important in “high-risk” research. If a systematic connection between a purported anomaly and the scientific body of knowledge is incomprehensible, high risk can easily turn into pure hubris.

Successful innovative scientific research is always subject to the tension *between* orthodoxy and anomaly. In this sense, a rigid fixation on existing knowledge is as unproductive as an obstinate insistence on anomalies whose coherent relation to such knowledge is written in the stars. Scientific progress arises where orthodoxy and anomaly are balanced as well as possible. It would be a rewarding goal for sustainable research funding to provide suitable conditions for such a balance.

Notes

- ¹ Kuhn's analysis was influenced by Fleck's (1935) monograph *Entstehung und Entwicklung einer wissenschaftlichen Tatsache* (English translation: *Origin and Evolution of a Scientific Fact*), in which Fleck coined the concepts of a "thinking style" ("Denkstil") and of a "thinking collective" ("Denkkollektiv"). Kuhn mentions Fleck in the introduction to his book. Kuhn's theses were critically discussed in Hoyningen-Huene's (1993) *Reconstructing Scientific Revolutions: Thomas S. Kuhn's Philosophy of Science*. Further interesting information is contained in two long letters (undated, probably 1960) found in Feyerabend's estate after his death, in which he responds to a draft of Kuhn's book (Hoyningen-Huene, 1995). An alternative approach is described by Hübner (1983) in his *Critique of Scientific Reason (Kritik der wissenschaftlichen Vernunft*, German original 1978).
- ² Here, the intention is not to understand accepted knowledge in the sense of orthodox belief like in theology. Rather than a fixed and unchangeable canonical dogma, "correct teaching" is intended to refer to a correct reproduction of a body of knowledge that serves as a starting point for further developments.
- ³ Einstein's development of special relativity is a most illustrative example in this respect. Its key idea is an extension of the Galilei-invariant (Newtonian) mechanics to the Lorentz invariance of electrodynamics, such that Newtonian mechanics can be regained in the (hypothetical) limit of an infinite speed of light. This simple picture does, of course, not do justice to the revolutionary impact that Einstein's theory had on science and technology. But the famous-infamous equation $E = mc^2$ is nothing more than a by-product, a spin-off as it were, of the conceptual extension that he was able to formalize.
- ⁴ Evidently, such laws exist also in chemistry (Nernst's equation for the dependence of the concentration of the electrode potential of a redox pair), in biology (Mendel's law for the inheritance of properties), or in psychology (Weber-Fechner law for the relation of the intensities of subjective sensual perceptions and objective stimuli).
- ⁵ This is not to say that there is a canonical set of clearly defined and obeyed rules for sound scientific work. It is well known that different standards are dominant in different disciplines and that they are applied in different ways. However, it is fair to say that some criteria are, in one or another way, regarded as relevant in many disciplines throughout science. An example is the issue of reproducibility, which will be critically discussed in detail below.
- ⁶ In the statistical modeling of such situations one speaks of "fixed effects" versus "random effects".
- ⁷ See Wackerbauer et al. (1994) for a review of complexity measures and Atmanspacher and Wiedenmann (1999) for a conceptual account of basic problems with complex systems.
- ⁸ In the field of "large deviations statistics", which has acquired an important role in statistical physics, the so-called "large deviations entropy" is used for this purpose. For an introduction and further references see Amann and Atmanspacher (1999).
- ⁹ There are indications, though, that this tendency becomes attenuated more recently: in recent debates in the philosophy of science, for instance, the question for ontological dimensions of reduction, supervenience, and emergence is of proliferating significance. See, e.g., Esfeld (2009).
- ¹⁰ The requirement of a well-defined metric or similar elaborated concepts to address distances in the space of accepted theories or in the space of equivalence classes of empirical results remains disregarded here.

- ¹¹ Interestingly, such anomalies are sometimes regarded as important for *biological* evolution (rather than the evolution of paradigms) insofar as they represent significant mutations. Blumberg (2009) has given an in-depth account of such “freaks” and “monsters” in biological development.
- ¹² A review of anomalies at the frontiers of contemporary science under the title *13 Things That Do Not Make Sense* was published by Brooks (2008). For an earlier, condensed version see the *New Scientist* of March 19, 2005.
- ¹³ For example, critical point, boiling point, melting point, latent heat, density, melting heat, entropy of vaporization, molar volume, volume change at the melting point, viscosity, surface tension, specific heat, etc. Some authors list up to 40 water anomalies.
- ¹⁴ An extensive and very readable account of this development, with numerous original references, can be found in Jablonka and Lamb (2005).
- ¹⁵ Insofar as epigenetics turns against weak points of neo-Darwinism in a scientifically intelligible way, it does in fact counteract creationist propaganda that attacks those weak points with nonscientific criticism.
- ¹⁶ This topic figures under a number of terms emphasizing different viewpoints, respectively: mind-matter problem, soul-body problem, psychophysical problem, first-person versus third-person perspective, etc.
- ¹⁷ For instance, related approaches have been proposed by Fechner, Wundt, Whitehead, Russell, Feigl, Jung, Bohm, Chalmers, d’Espagnat, and Velmans, to name a few. They typically combine an ontic monism with an epistemically dualistic view. Davidson’s (1970) “anomalous monism” moves this picture from type identity to token identity and draws basically physicalist conclusions from it. An interesting twist on dual-aspect models results by tightening the duality of aspects by the concept of complementarity (in the sense of quantum theory), as suggested by Pauli (1952) and developed by Primas (2008).
- ¹⁸ Phenomenological theories of physics, such as thermodynamics, typically break these symmetries.
- ¹⁹ An empirically confirmed model of time perception by Wackermann and Ehm (2006) is interesting in this context, and a recent proposal by Franck and Atmanspacher (2008) sketches a possible way to characterize the intensity of the mental present by its duration measured in terms of physical time.
- ²⁰ The related notion of an antinomy is of similar etymological origin: $\alpha\nu\tau\iota$ = against, $\nu\omicron\mu\omicron\varsigma$ = law.
- ²¹ Particularly well-known examples in psychology are Bateson’s concept of the double bind (Bateson et al., 1956) and Watzlawick’s therapeutic instrument of paradoxical intervention (Watzlawick et al., 1967). Paradoxical koans in Zen Buddhism and the paradoxes of Christian mysticism, e.g., Meister Eckhart, are key examples for the usage of paradoxes in spiritual frameworks of thinking.
- ²² This does not mean to use the notion of complementarity as an excuse for everything that sounds inconsistent. A formal approach called “generalized quantum theory”, which avoids this, has recently been developed and applied to non-physical examples (Atmanspacher et al., 2006). See also Primas (2007) for an alternative formulation.
- ²³ The notion of synchronicity was first mentioned by Jung in an obituary for Richard Wilhelm in *Neue Zürcher Zeitung*, March 6, 1930. After years of hesitation to publish his corresponding ideas, Pauli encouraged him to write them down as a comprehensive

account. The final version (Jung, 1952) was the result of several revisions inspired by Pauli's numerous comments. See the Pauli-Jung correspondence between June 1949 and February 1951 in Meier (1990).

- ²⁴ The correspondence is *meaningful* if meaning is attributed by a subject's mental state and, thus, becomes a feature of the correspondence relation. Note the similarity to reference relations for intentional states.
- ²⁵ A main merit of this metaanalysis is a *combined* assessment, known as "corrections metaanalysis" (Copas, 1999), of target effects (fixed as well as random) *and* selection effects. A technically simpler meta-analysis by Bösch et al. (2006) includes more recent data not contained in Ehm (2005). Both studies found no significant target effect, mainly as a consequence of significant selection effects. Notably, Ehm (2005: Sect. 7.4) discovered that a major subset of close to 50% of the total sample of 597 studies analyzed by Radin and Nelson (1989), stemming from the Princeton Engineering Anomalies Laboratory, showed no significant selection. Moreover, the significant selection that Ehm (2005: Sect. 6) detected for the total sample is not necessarily restricted to publication bias and could be due to any unknown systematic effect in addition to the target effect (Ehm, 2005: Sect. 5.3, 7.5). Various speculations have been raised about the possible origins of such additional effects (see, e.g., Jahn et al., 2000). But in view of the complexity of the situation it is arguable whether tedious follow-up searches for specific and robust effects within the bunch of possible interdependent candidates would produce more insight or more confusion. The overall situation is clearly inconclusive and might support Braude's (1997) arguments that experimentally well-controlled laboratory studies are of limited relevance in the field.
- ²⁶ In addition to the planets in our current understanding, astrologers count the sun and moon as "moving stars" as well. Thus, the geocentric system of classical astrology comprises the 10 "planets" sun, moon, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.
- ²⁷ Due to the precession of the earth, the positions of the signs of the zodiac on the sky are displaced by 30 degrees every 2000 years. Therefore, present actual astronomical positions lag behind the fictitious astrological positions by approximately one sign.
- ²⁸ See, e.g., the criticism raised by Ertel and Irving (1996); see also Eysenck and Nias (1982). As an interesting side remark, Jung's (1952) article about synchronicity also uses astrological data, also without convincing results.

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