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Justifying scientific beliefs: an anti-naturalist and anti-pragmatist perspective

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Abstract. This paper defends epistemological scientific realism (ESR), understood as the philosophical position that we have stronger reasons to believe in certain claims about some unobservable entities (conceived as sets of properties) posited by our best scientific theories, rather than withholding judgment about their existence. Following a critique of explanationist defenses based on the "no miracle argument", I propose an empiricist inductivist justification of ESR, drawing parallels with how we justify belief in claims about immediately observable entities in everyday experience. This justification is non-naturalistic, as it is not grounded in the history or practice of science, and it is normative, providing a framework to evaluate the strengths and weaknesses of arguments supporting belief in the reality of entities posited by our best scientific theories.

Today, most empiricists embrace some form of naturalism, viewing philosophy as a scientific discipline. They argue that philosophical claims about science should be grounded in the study of scientific practice. Henk De Regt's book *Scientific Understanding* exemplifies this approach, as he states:

> The aim of the book is to develop and defend a theory of understanding that describes criteria for understanding actually employed in scientific practice. (De Regt 2017, 6)

However, I contend that the role of philosophy is not to describe how scientists, past or present, conduct their work. Philosophy is not a form of metascience whose empirical basis is the practice of scientists. As Bas van Fraassen rightly observes, the aim of philosophy is not to describe facts.

> Do electrons exist? Are atoms real? These are not philosophical questions. Whether electrons exist is no more a philosophical question than whether Norwegians exist, or witches, or immaterial intelligences. Questions of existence are questions about matters of brute fact, if any are, and philosophy is no arbiter of fact. (van Fraassen 2017, 95)

It is the responsibility of scientists, not philosophers, to argue for the existence of entities such as electrons, mitochondria, and tectonic plates. In the debate on scientific realism, philosophers are concerned with the normative task of evaluating the strength of the kinds of arguments that are claimed to justify belief in the reality of certain entities posited by scientific

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theories and the truth of statements about them. This examination of the solidity—or lack thereof—of various types of arguments is an epistemological and logical endeavor. It deserves careful scrutiny because it directly impacts the level of confidence in our best scientific theories.

While the arguments supporting belief in the existence of electrons obviously differ in contents from those justifying belief in mitochondria, some arguments are stronger than others. Philosophers are not primarily interested in specific arguments but in the grounds for the strength of various types of arguments. According to epistemological scientific realism, we have stronger reasons to believe in the truth of scientific claims about some entities inaccessible to direct observation, rather than suspending belief about them. Thus, philosophers face the challenge of identifying the grounds for the cogency of the arguments supporting belief in the existence of entities inaccessible to direct observation.

Most scientific realists rely on a form of reasoning known as "inference to the best explanation" or "abduction" to justify belief in the existence of entities that cannot be directly observed. In the following discussion, I will argue that explanationist strategies fall short of providing sufficient reasons to believe in the existence of certain indirectly observed entities. Instead, I will propose an alternative inductivist strategy that aligns more closely with a moderate version of empiricism and offers robust support for a selective version of epistemological scientific realism.

1 Inference to be the best explanation: A critique

Explanationist strategies that rely on *Inference to the Best Explanation* (IBE), or abduction, as a method for justifying true beliefs have a long-standing role in philosophical reasoning. A typical formulation of IBE can be presented as follows:

1. F is a fact.
2. Hypothesis H explains F.
3. No other available hypothesis explains F as well as H.

Conclusion: H is true.

One of the most famous examples of IBE is Putnam's "No Miracle Argument" (NMA). In this argument, Putnam (1978, 18) asserts that the success of scientific theories in making accurate empirical predictions would be inexplicable—that is to say, *miraculous*—unless we assume that their claims about entities like electrons, genes, and other theoretical posits are at least partially true. His argument can be summarized as follows:

1. Fact F^*: Theory T makes accurate predictions.
2. Hypothesis H^* (Theory T is partially true) explains F^*.
3. No other available competing hypothesis explains F^* as well as H^*.

Conclusion: H^* is true.

It is well-known that such abductive arguments are *logically invalid* since it is always possible that some unknown alternative hypothesis—one incompatible with H—could explain the fact F better. (Stanford 2006) This challenge raises a critical question: Can the No Miracle Argument be made valid, and even sound, by introducing an additional premise? This would be analogous to the approach of making inductive reasoning logically valid by assuming the uniformity of nature.

Alan Musgrave proposed to add the following premise $1'$ to the No Miracle Argument to get:

$1'$. It is reasonable to believe that the best explanation of any fact is true.

1. F^* is a fact.
2. Hypothesis H^* explains F^*.
3. No available competing hypothesis explains F^* as well as H^*.

Conclusion: It is reasonable to believe that H^* is true. (Musgrave 2017, 80)

Notice the epistemic shift in Musgrave's version of the No Miracle Argument (NMA), marked by the inclusion of the phrase "it is reasonable to". This addition significantly weakens the position of scientific realism. A scientific realist cannot rest satisfied with the claim that believing in entities like electrons is *not* irrational, since anti-realists like van Fraassen already concede this point. Instead, the realist must go further, showing that it is *more rational* to believe in the existence of entities such as electrons, etc. than to deny their existence or remain agnostic about them.

While Musgrave's reformulation undoubtedly makes the argument deductively valid, does it make the argument sound? Specifically, do we have sufficient justification to believe in premise 1', which asserts a strong connection between the best explanation and its truth, or at least that this connection is more likely to hold?

Following Lipton (2004), we must distinguish between two types of explanations, similar to the distinction between valid and sound arguments. A sound argument is a valid argument in which all premises are true. Analogously, a *true* explanation is a satisfactory explanation in which all premises are true. An explanation is considered satisfactory, or "lovely," if it provides a good understanding, though it may still be false. For instance, Ptolemy's theory of crystalline spheres provides a clear and understandable explanation of the stability of planetary motions. We understand that if planets are attached to hard regularly rotating spheres, their trajectories remain unchanged over time. This is what we observe, at least for short periods of time. However, Ptolemy's hypothesis is false, and so is his explanation.

Proponents of *Inference to the Best Explanation* (IBE) make the distinction between lovely and true explanations since multiple satisfactory explanations of the same phenomena can be provided. By implementing a top-down strategy, the friends of IBE assess the *internal* merits of competing explanations to conclude that the loveliest explanation—the one with the greatest explanatory power—is true or at least more likely to be true.

However, even if we could all agree on the criteria for comparing the explanatory power of competing hypotheses, and even if all possible explanations for a set of data were available (a highly unrealistic scenario), there would still be no stronger reasons to believe that the most satisfactory explanation is true. Why? Because *the explanatory power of a hypothesis does not, in itself, justify belief in its truth.* (Ghins 2024, 61)

This is the fundamental difficulty with any explanationist strategy for justifying beliefs. It may not be irrational to believe in the truth of hypotheses that correctly predict and explain phenomena. But is it *more rational* to believe that nature is organized according to what we deem to be a good explanation, according to our standards of understanding and intelligibility, even if those standards were universally shared or rooted in human nature? What connection to reality could possibly be guaranteed by the explanatory power of a hypothesis, given that this power is evaluated on the basis of subjective criteria for understanding? In my view, none.

As Peter Lipton asks: Is the loveliest explanation—the one that pleases us most (and thus is the most satisfactory to us)—also the likeliest to be true? (Lipton 2004, 61) Is there a pre-established harmony between our explanatory preferences and reality? Such a Leibnizian harmony between reality and the explanatory requirements of our minds *might* exist, but how could we possibly argue for it convincingly? This is what Lipton refers to as "Voltaire's objection."

> (...) supposing that loveliness [of an explanation] is as objective as inference (...) What reason is there to believe that the explanation that would be the loveliest, *if it were true* [emphasis is mine], is also the explanation that is most likely to be true? Why should we believe that we inhabit the loveliest of all possible worlds? (Lipton 2004, 70)

Unlike Lipton, I do not believe that an explanation would be the loveliest "if it were true" or correct. An explanation can be the loveliest or most satisfactory even if its premises are false, and vice versa. I wish to keep the concept of *loveliness* entirely separate from *truth*. However, I do agree with Lipton on the main point: there is no intrinsic connection, let alone harmony, between the beauty or elegance of an explanation and the actual facts of the world. To believe otherwise is to fall into an idealist prejudice, which assumes that our requirements for understanding grant us privileged cognitive access to an external reality.

Bas van Fraassen rightly emphasizes that there is no relationship between explanatory power and truth. If this is correct, then the No Miracle Argument cannot be salvaged, even if we accept that scientific realism is the only acceptable—and therefore the best—explanation for the predictive success of scientific theories. The epistemic gap between explanation and truth makes such a rescue impossible. Abductive arguments may play a valuable heuristic role in generating new explanatory hypotheses, as Peirce highlighted, but their explanatory appeal provides no justification for believing them to be true.

2 Induction as an alternative to abduction: An example

To defend epistemological scientific realism, I propose an inductivist strategy as an alternative to explanationist arguments. In cases where the existence of entities is inferred, the strength of abductive arguments stems from hidden deductions involving causal propositions that are empirically and inductively justified. I will illustrate this with a simple example of *Inference to the Best Explanation* (IBE) discussed by van Fraassen (1980, 19–20):

1. It is more reasonable to believe that the loveliest explanation of any fact is true.
2. Fact F: Grey hair lies on the floor, cheese disappears, and specific little noises are heard.
3. The presence of a mouse (H) explains F.
4. No available competing hypothesis explains F as elegantly as H.

Conclusion: It is more reasonable to believe that H is true, i.e., that a mouse is present.

The persuasiveness of this argument does not come from its abductive character. Rather, if it convinces us, it is because it relies on premises—grounded in induction—that are not explicitly stated, as I will now attempt to show. To avoid circularity, we must first define what a mouse is: by definition, a mouse is an animal with four legs, a long tail, small ears, and a pink snout.

In addition—and this is the crucial point—constant causal correlations between certain events have been observed. In general, causal connections can be established through empirical methods, such as those codified by John Stuart Mill (1843), provided they are sufficiently refined. Causal relations are asymmetrical: causes produce effects, not the other way around. However, once a causal relation has been empirically ascertained, we obtain an "if and only if" logical connection between cause and effect: if the cause occurs, the effect follows, and vice versa. These previously identified causal relations allow us to infer the presence of a cause based on the observation of its effects.

In the current example, finding grey hair on the floor and the disappearance of cheese regularly coincide with the shedding of grey hair and the consumption of cheese by an animal. Through repeated observations, we have learned that mice (as defined earlier) are the only creatures that exhibit these properties (such as grey hair loss) which are causally correlated with the observed effects (grey hair on the floor, missing cheese, etc.). By inductive reasoning, we conclude that the occurrence of these observed effects generally implies the presence of a mouse, which is the cause.

In this particular case, based on the presence of grey hair and missing cheese, we can infer—perhaps to our dismay—that there is at least one mouse in the house. Thus, we have indirectly detected the presence of a mouse by inferring its existence from the evidence, even though we haven't observed it directly. Later, with patience (or luck), we might observe a mouse directly, which would strengthen our belief in its presence, as we would immediately see a larger set of its properties.

The abductive reasoning in this example is supported by the following deductive argument:

1. Facts (F): Grey hair on the floor, disappearance of cheese, specific little noises.

2. Inductively confirmed hypothesis (H): These facts (F) are caused by the presence of animals with grey hair that eat cheese, etc.

3. Inductively confirmed association (A): Mice, defined as four-legged animals with specific characteristics, also shed grey hair and exhibit other associated properties.

4. Alternative hypotheses (e.g., a rat, a mischievous neighbour) are not confirmed by the observations.

Conclusion: It is more reasonable to believe that a mouse is present.

This argument is deductively valid, but it rests on premises whose truth has been established through induction, particularly premises 2 and 3. Why, in addition, do we end up with a "lovely" explanation of the observed facts? Because hypothesis H describes causal processes. The shedding of hair, making noise, and eating cheese are empirically verified causal events—sequences of properties that unfold over time.

Even if we grant that the presence of a mouse best explains the available evidence, this does not necessarily mean it is more rational to believe in the mouse's presence than to suspend our judgment. If we are justified in concluding that a mouse is present, it is because of previously verified causal processes, which enable us to trace back the existence of the cause (the mouse) from its effects (the grey hair, the missing cheese). These causal processes, in turn, form the basis for explaining the empirical evidence.

In summary, the argument for the presence of the mouse is a logically valid deductive argument. If its premises are true, then the argument is sound. By adding the premise that a mouse is present and taking a description of the observed facts as a conclusion, we arrive at a correct explanation of the factual evidence.

One might object that while the argument presented is valid, it is not sound, as we must establish in this particular instance that the alleged causal connection holds—specifically, that premise H is true. Indeed, it is possible that another cause could explain the observed facts. For example, a malevolent neighbour could be playing tricks by deliberately placing grey hair on the floor and creating other clues. Such alternative explanations are often hypothesized and then discarded in abductive reasoning as less elegant or "lovely." However, I argue that we should rely solely on empirical evidence rather than the subjective appeal of an explanation. If there is no empirical evidence to support the hypothesis of a mischievous neighbour, we have no reason to entertain that possibility. Observational evidence of external facts is far more reliable than the supposed internal virtues or elegance of competing explanations.

But what about the possibility of alternative causes that have not yet been conceived? (Stanford 2006) Inductivists need not be overly concerned with these, as unknown alternatives cannot be empirically tested or inductively confirmed. The mere possibility of unconceived alternative explanations does not undermine the evidence we currently have, which provides stronger reasons to believe in the presence of a mouse. However, we must acknowledge that since premise H is not established with certainty, we should treat it as only having a higher probability of being true.

3 Direct and indirect observation

In the previous section, I have shown that belief in the instantiation of properties is justified when we rely on deductive arguments whose premises describe causal connections, and which have been inductively confirmed. Notice that such confirmation is possible because, in the previous example, we were dealing with immediately observable properties. But can this approach be extended to properties that are only accessible through instruments, such as telescopes, microscopes, and other observation devices?

In addition to directly observable properties—like hardness, roundness, or hairiness—I also include in the category of observable properties certain scientific properties, such as mass, charge, and temperature. However, I exclude properties like internal spin, strangeness, and charm from this category. Some philosophers may rightly object that terms like "mass," "charge," and "temperature" belong to a theory-laden language. Moreover, the meanings of these terms have only become clear and stabilized through a long and painstaking historical process. However, once we have grasped the meaning of a term like "gravitational mass," we can readily verify that my teacup is heavier than my pen through direct observation. Similarly, once the meanings of "positive charge" and "negative charge" are understood, we can empirically verify the presence of charges of the same sign (positive or negative) by directly observing the repulsion of thin leaves in an electroscope. Although the presence of charges may initially have been hypothesized through abductive reasoning—the heuristic value of which I do not dispute—only observation can support belief in their instantiation.

Critics might immediately object that there is a distinction between observing a property P and observing *that* something possesses the property P. For instance, observing the property of hardness is not the same as observing *that* an object is hard. Actually, this distinction has little bearing on the issue of realism, since the truth of propositions and the instantiation of properties are closely connected. Is it true that there is a hard object on my desk? The truth of this statement depends on a fact: the instantiation of the property of hardness, which is confirmed through direct perception. Similarly, is it true that the gravitational mass of my teacup is greater than that of my pen? This assertion, too, can be verified or falsified through direct observation.

According to my empiricist stance, no property is cognitively accessible unless it is observable by us, either directly or indirectly. However, I include in the category of observable properties some scientific properties, such as charge and gravitational mass, which are not considered observable by most empiricists. These properties, like many other properties in science, can assume various continuous or discrete values and are referred to as *determinable properties* because they can take on specific determinate values.

Due to the limitations of our senses, we cannot directly perceive very large or small values of mass, charge, volume, velocity, and similar properties. However, since we can observe some values of these properties directly, I submit that very large or small values of them can still be considered observable in a broader sense. Even though an extremely high velocity isn't directly perceivable, it is still a velocity and thus resembles directly observable velocities. While this expanded notion of observability is not consistent with strict empiricism, such extension is justified because resemblance allows us cognitive access to similar properties through detections whose reliability is supported by empirical induction, as I will show below.

Now, let us turn to properties that are unobservable in principle, which I refer to as *purely theoretical properties.* These properties are beyond the reach of any possible observation—either direct or indirect—not only in practice but in principle. In this sense, they are transcendent. Purely theoretical properties, which do not resemble anything accessible to perception, are common in elementary particle physics. Examples include internal spin, strangeness, and charm. Unlike properties such as volume or mass, these cannot be verified through ordinary sensory experience. Therefore, we are never justified in believing in the instantiation of such purely theoretical properties.

4 Four conditions for justified belief in the instantiation of properties

The primary challenge faced by epistemological scientific realists is justifying belief in properties that, while directly unobservable due to practical constraints or perceptual limitations, are still detectable. The first condition for believing in the reality of such properties is that they must not only be observable in principle but they must also have been actually observed. This leads us to formulate the following observation condition:

Observation Condition (O): *To have stronger reasons to believe in the existence of a property rather than to suspend judgment or disbelieve, it is necessary for that property to be either directly observed or indirectly observed through detection.*

In scientific observation, sight holds a privileged status, and various detection instruments enhance its capabilities. For example, consider ordinary eyeglasses, used by those with impaired vision. Who would argue that a farsighted person's observations of distant objects are less credible simply because they use glasses rather than relying on unaided vision? Now, let us consider more powerful optical devices, such as telescopes. Inside a telescope, we directly see what we typically refer to as "images" with specific properties, such as geometric shapes. Geometric shape is a directly observable property of celestial objects, such as planets. If we were close enough to a planet, we could directly observe its approximately spherical shape.

Thus, we commonly say that we "observe" a planet through a telescope. In fact, what we directly observe are the properties of the image inside the telescope, but the shape of the image (A) corresponds to the shape of the planet (B) through a logical *iff* (if and only if) relation: if A, then B, and conversely. Moreover, B causes A. Thus, according to my terminology, the telescope allows us to indirectly observe or *detect* the shape of the planet.

These remarks can be extended to various types of microscopes and telescopes, which permit us to see entities such as viruses and distant galaxies. When direct observations and those made with the aid of a microscope agree, we can consider the microscope reliable—at least within the overlapping domain of these observations. By induction, we then extend the microscope's reliability to properties that are not immediately visible. Furthermore, our knowledge of the laws of optics, verified through induction in the realm of directly observable properties, justifies trusting the microscope when detecting properties invisible to the naked eye. Gradually, through inductive reasoning, we expand the domain of accessible observable properties to increasingly broader realms of detection. For this reason, it is legitimate to regard very large or very small values of these properties as "observable" in a broad sense, even if they are only detectable.

It is important to note that it is not always necessary to know the causal laws underlying the workings of an instrument in order to trust its results. For example, the ancient Romans used polished lenses to correct vision, despite being unaware of the laws of refraction, let alone electromagnetism. Similarly, Galileo and his contemporaries knew very little about the inner workings of the *canocchiale* (telescope). Nonetheless, when close-range observations of an object, such as a ship, matched those made from a distance using the *canocchiale*, they could empirically confirm a causal connection between the properties directly observed through the telescope and the detected properties of the distant object. Even the Aristotelians, who at first were skeptical, quickly acknowledged the reliability of Galileo's telescope.

This inductive approach, which Philip Kitcher calls the "Galilean strategy" (2001, 173–174), can also be applied to other instruments, such as the microscope. (However, unlike Kitcher, I do not believe the Galilean strategy can be applied to purely theoretical properties.)

In cases of indirect epistemic access to properties, we rely on the causal relationships between the properties being detected and those that are directly observed. The verification of these causal relationships depends upon previously confirmed inductive generalizations. By knowing these relationships, we can trace back the causes (the detected properties) from their effects (the directly observed properties).

In everyday experience, what justifies us in asserting the existence of objects such as a teacup or a rose is their immediate presence in perception, provided good observational conditions obtain. This perception is supported by underlying causal connections, which, although we may not fully understand them, we have stronger reasons to believe that such causal links exist, based on Mill's rules. For instance, when we manipulate a perceived object in certain ways, we observe systematic changes in how its properties are perceived, further reinforcing our belief in the presence of a causal link.

As we saw earlier, in order to check the reliability of a new instrument, we compare its measurements with those obtained with an already established, accurate instrument in the same empirical domain. If the results from both instruments concord in such overlapping domain, we inductively extend the reliability of the new instrument to broader detection domains. This method follows what Kitcher calls the "Galilean strategy" I mentioned above. Step by step, through this methodical process we justify the significant expansion of the range of detectable properties made possible by the invention of new instruments and measuring devices.

What is more, when we have detailed knowledge of the empirical causal laws governing the mechanisms that underlie the functioning of instruments or observation devices, we have strong grounds to believe that the causes of the observed effects possess certain specific properties. These causes—such as mass, charge, or velocity—are instantiated properties that, while not directly observed, can be judged to have been detected. From this, we can establish a second condition that must be met to hold a justified belief in the existence of detected properties.

Causality Condition (C): *To have stronger reasons to believe in the existence of a property that is not directly observed, this property must be detected—i.e., empirically verified as causally linked to properties that are directly observed through the use of reliable instruments.*

To reinforce my belief in the instantiation of a property, I can mobilize several perceptual modalities and check whether they give concordant results. For example, to confirm that an object on my desk is hard, I can touch it, strike it to hear the characteristic sound of a hard object, and observe its visual properties that suggest hardness. Here, three distinct perceptual modalities—touch, hearing, and sight—come into play, each functioning independently. Each modality provides empirical access to the property of hardness.

Within each modality, I can repeat observations in various ways to ensure that the results are consistent. For instance, through different forms of touch, I consistently confirm the presence of hardness. Likewise, though the sounds I hear vary slightly with each strike, they all consistently indicate hardness.

Additionally, I can apply similar methods to verify other properties that distinguish the object as a teacup rather than a vase or another type of item.

These observations suggest the need for an additional requirement—an invariance condition—to justify belief in the existence of directly observed properties:

Invariance Condition (Ia): *To have stronger reasons to believe in the existence of a directly observed property, it is necessary and sufficient that repeated observations of the property, through distinct and independent perceptual modalities, yield invariant results, at least approximately.*

For a directly observed property, the invariance condition is both necessary and sufficient to justify belief in its instantiation. There is no doubt that this condition of invariance is rooted in the truth of generalizations describing Millian causal connections between the perception of property (under favorable conditions) and the actual instantiation of that property. Perception is known to be a complex process involving causal links—still not fully understood—between external properties and the properties of our sensory organs, nervous system, and brain.

When different observations, relying on distinct causal pathways, yield consistent results, our confidence in the reality of a given property increases. Why? Because previous experience has shown that this approach minimizes the risk of error. Over time, we have learned that beliefs supported by such a procedure are less likely to be falsified. Indeed, when we seek to resolve doubts about the properties attributed to an entity, we repeat and vary our observations. This method, again, is justified by induction.

It is important to emphasize that our belief in the instantiation of a property (or set of properties) is not based on an argument that the property best explains the concordance between different perceptions. This is *not* an inference to the best explanation of the agreement of various observations. Rather, in each perception, the property is directly observed. Repetition simply provides new instances of perceiving the same property, and the consistency of these observations reinforces the stability of our beliefs. This stability arises because, through induction, we have learned that beliefs strengthened in this manner are more resistant to potential falsification.

What can we now say about indirectly observed, or detected, properties? To justify belief in the existence of such properties, we must empirically verify that causal connections exist between directly perceived properties (clues) and the detected properties. However, by analogy with the invariance condition for directly observed properties, we must also require that repeated detections using different empirical methods yield consistent results.

Invariance Condition (Ib): *To have stronger reasons to believe in the existence of a detected property, it is necessary that repeated detections of this* *property, using distinct and independent empirical methods, yield invariant results, at least approximately.*

For detected properties, this condition is necessary but not sufficient, as the distinct empirical methods must also be reliable. This reliability is grounded in the causal requirement outlined earlier. Some methods of detection, such as those used in astronomy, involve instruments, while others, like the detection of a mouse, may not.

In many scientific contexts, determining the exact value of a detectable property is impossible without the aid of measuring instruments. Therefore, we must introduce an additional condition: the measurement condition.

Measurement Condition (M): *In the quantitative sciences, to have stronger reasons to believe in the existence of a detected property with a specific value, it is necessary for the property to be quantitatively measured using instruments whose reliability has been previously and independently established.*

Together, we now have four conditions for justified belief: Observation, Causality, Invariance, and Measurement. For brevity, I will refer to these as the OCIM conditions. The satisfaction of all four OCIM conditions is both necessary and sufficient to justify belief in the instantiation of a detectable property. These conditions—crucially the causality condition—allow us to ascend, in a bottom-up approach, from directly observed properties to the properties that cause them.

On the other hand, there are never strong reasons to believe in the instantiation of purely theoretical properties. Why? Simply because such properties transcend any empirical cognitive access. For empiricists, they are beyond cognitive access *tout court*. These properties are epistemically transcendent. It is impossible to empirically verify that purely theoretical properties are causally connected to observed properties. Regarding such theoretical properties, I recommend adopting an agnostic stance: while these properties might exist, we will never have compelling evidence to believe in their reality.

We can now summarize these four conditions as follows:

Requirement R: *To have stronger reasons to believe in the existence of a detectable property, it is necessary and sufficient that this property has been detected multiple times using various methods, whose reliability is grounded in empirically and inductively confirmed causal connections between the detected property and directly observed properties. Furthermore, the results of these observations or measurements must be consistent.*

This requirement is *normative*, meaning that the fulfillment (or lack thereof) of the four OCIM conditions provides a general framework for evaluating the strength or weakness of an argument supporting the existence of a particular entity (which is understood as a set of properties). The scientific realism I propose is thus a decisively normative philosophical stance. Its plausibility does not depend on whether scientists actually use arguments that conform with this requirement when arguing for the existence of specific entities. Instead, the strength of this realist position lies in the similarity between the arguments used to support belief in detectable entities and those used to support belief in ordinary, immediately observable entities.

This form of realism harmonizes with the idea that science is an extension of common sense, a view supported by philosophers such as W. V. O. Quine, who remarked:

> Science is not a substitute for common sense but an extension of it. (Quine 1976, 229)

The scientific properties we are justified in believing to be instantiated are either identical or similar to the properties of everyday objects, which we access through direct perception. These properties are all observable in a broad sense. Moreover, the existence of properties posited by a theory can be ascertained as long as their detection is confirmed using procedures akin to those employed in everyday life—that is, through repeated and varied observations.

The adoption of this inductive empirical strategy for defending selective scientific realism offers a valuable alternative to traditional vindications of scientific realism that rely on the no-miracle argument and explanationist strategies. While I do not deny that the prediction of novel and unexpected facts is relevant for reasonable belief in certain parts of a theory, it is important to clarify the nature of that relevance. If the observation of a novel fact provides grounds for believing in specific components of a theory, it is not because such observations evoke psychological feelings of surprise or awe, since these lack epistemological significance, nor because the theory has the capacity to explain the novel fact. Rather, the epistemological power of novel observations stems from the presence of convincing empirical evidence establishing a causal link between specific parts of the theory and the novel fact.

This kind of novelty can also be linked to the invariance condition, when new detection methods enable the connection between theoretical properties and new observations, thereby reinforcing belief in their existence. Classic examples from the history of science illustrate this point, such as the observation of a bright spot in the center of the circular shadow cast by a circular screen (providing additional evidence for the wave nature of light), and the deflection of starlight near the Sun (which supported Einstein's construal of the gravitational field in his general theory of relativity).

5 The case for the existence of Neptune

In this section, I illustrate the bottom-up inductive strategy I advocate by examining the well-known argument for the existence of the planet Neptune, which is often cited as a classic example of inference to the best explanation.

Consistent with my opposition to naturalism, I do not believe it is legitimate to use facts drawn from the history of science to justify any philosophical position. Moreover, it is well-known that different interpretations of historical episodes can support various, even opposing, philosophical views. The empirical basis of historical inquiry consists of traces (artifacts such as texts, tombs, etc.), which differ fundamentally from the empirical basis provided by observation and experimentation in scientific contexts. While empirical data in science are also subject to interpretation, they consist of facts that, at least in principle, can be repeatedly tested or observed. In contrast, historical facts are only accessible through these traces and cannot be reproduced at will.

Despite the differences between observational or experimental facts and historical facts, it can still be instructive to examine key episodes from the history of science that illustrate the position I defend. In doing so, we can assess whether the four OCIM conditions mentioned earlier are satisfied by prominent scientific arguments supporting the existence of certain detected entities.

At the beginning of the 19th century, astronomer Alexis Bouvard detected (with the telescope ...) that the positions of Uranus did not conform to the predictions of classical mechanics. Several hypotheses were proposed to explain these anomalies: the influence of known planets or a comet, the presence of magnetic forces, an unknown planet, or even a revision of the mathematical formulation of the gravitational force. However, calculations based on Newton's laws suggested that the best explanation for Uranus' detected anomalies with respect to its predicted trajectory was the gravitational influence of a previously unobserved planet. This abductive reasoning led John Couch Adams and Urbain Le Verrier to conclude that an unknown planet was causing the discrepancies in Uranus' orbit.

In 1846, Johann Galle discovered this new planet, which was named Neptune, near the predicted location. (A similar reasoning process was later applied by Le Verrier to the anomalous precession of Mercury's perihelion, leading to the conjecture of a hypothetical planet "Vulcan" between Mercury and the Sun. However, Vulcan was never detected. (Baum and Sheehan 1997) In 1915, Einstein's theory of general relativity provided a new explanation for Mercury's precession, showing that Newton's theory of gravitation fails for strong gravitational fields.)

I will now attempt to show that the strength of this abductive reasoning lies in a bottom-up argument, regardless of whether Adams and Le Verrier explicitly framed their argument this way, which is a matter of historical fact.

Planets are observationally defined as bright spots that, when seen from Earth, move periodically along the constellations of the zodiac. According to Newtonian mechanics and the classical formulation of gravitational force, planets orbit the Sun and possess properties such as mass, velocity, and acceleration. By relying on the inductively confirmed causal laws of classical mechanics, we can infer from the detected effect—the anomalies in Uranus' trajectory detected through telescopic observations—the existence of its cause, namely a new planet whose motion conforms to the theory of classical mechanics.

While the discovery of Neptune is often cited as a prime example of a top-down inference to the best explanation (Douven 2021), this reasoning can also be reconstructed as a bottom-up argument. Instead of focusing on explanationist reasoning, we can construct a sound deductive argument grounded in empirical observations and inductively verified laws as follows:

1. Facts (F): Anomalies are detected in the trajectory of Uranus.
2. Inductively confirmed causal hypothesis (H): According to Newtonian mechanics, such anomalies imply the presence of a celestial body with a specific mass orbiting the Sun along a specific trajectory, which causes these anomalies.
3. Inductively confirmed association (A): Planets, defined as bright spots moving periodically along the zodiac, possess mass and follow Newtonian mechanics.
4. Alternative hypotheses (H', H''—such as a comet or magnetic forces) are not supported by observations.

Conclusion: It is more reasonable to believe in the existence of a new planet, named "Neptune".

By reconstructing the argument for Neptune's existence in this way, we see that its form is identical to the one of the "mouse argument" discussed earlier. Just as the observations of grey hair served as evidence for the presence of a mouse, the detected anomalies in Uranus' trajectory provided evidence for the existence of Neptune. The strength of the argument for Neptune's existence does not rest on the claim that it offers the best explanation for the anomalies in Uranus' orbit. Granted, we must ensure that premise H is true. While abduction leads us to consider alternative explanations for the observed anomalies, these alternatives are not rejected because they are less lovely, but because they lack sufficient empirical support. Available competing hypotheses—such as the influence of a comet or the presence of magnetic forces—are discarded *not* due to their lesser "loveliness" as explanations, but because they don't enjoy the necessary inductive observational backing.

However, premise H can only be considered likely rather than conclusively true, as we cannot entirely rule out the possibility of some unknown cause of the anomalies, even though we have no strong reason to believe in the existence of such an unknown cause.

While abductive reasoning can be useful for generating new hypotheses, it holds only heuristic value. As I have argued, abduction is not truth tropic. To evaluate the credibility of alternative explanatory hypotheses, we must investigate whether observations warrant belief in alternative causes, such as the presence of a comet, by relying on inductively confirmed laws. This process is not abductive. If alternative hypotheses lack sufficient empirical backing, they are rightly dismissed. Thus, premise H is probably true, making the deductive argument for Neptune's existence sound.

If this reasoning is correct, there were strong grounds to believe in Neptune's existence even before its shape, color, and brightness were detected. Of course, Johann Galle's subsequent telescopic observations further strengthened this belief.

Clearly, the examples of the mouse and Neptune differ in several important respects. First, belief in the anomalies in Uranus' trajectory is based on telescope images, and this belief is justified by the inductively established reliability of telescopic observations. In the case of the mouse, however, we started from immediately observed properties—such as grey hair and the disappearance of cheese—rather than images. Additionally, multiple clues were available in the mouse scenario, while for Neptune, the only initial clue was the detected anomalies in Uranus' trajectory. This is why Johann Galle's telescopic observations were particularly crucial in dispelling any doubts about Neptune's existence.

However, what ultimately justifies our beliefs in both cases—the existence of Neptune and the presence of the mouse—is the prior empirical confirmation of the relevant causal connections. These confirmations form the basis for the soundness of bottom-up deductive arguments.

To conclude, let us briefly verify that the argument for Neptune's existence meets the OCIM conditions and the requirement R. First, all the properties involved are observable, in the broad sense defined earlier. Second, the anomalies in Uranus' trajectory were repeatedly observed using a reliable telescope, yielding concordant measurement results, thus satisfying both the measurement and invariance conditions. Finally, by combining these observations with Newton's laws, a causal connection was established between the novel facts (the anomalies) and the presence of a new planet—Neptune—characterized by a specific mass and trajectory.

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