General relativity and the standard model:

Why evidence for one does not disconfirm the other

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Abstract

General Relativity and the Standard Model often are touted as the most rigorously and extensively confirmed scientific hypotheses of all time. Nonetheless, these theories appear to have consequences that are inconsistent with evidence about phenomena for which, respectively, quantum effects and gravity matter. This paper suggests an explanation for why the theories are not disconfirmed by such evidence. The key to this explanation is an approach to scientific hypotheses that allows their actual content to differ from their apparent content. This approach does not appeal to *ceteris-paribus* qualifiers or counterfactuals or similarity relations. And it helps to explain why some highly idealized hypotheses are not treated in the way that a thoroughly refuted theory is treated but instead as hypotheses with limited domains of applicability.

Keywords: Confirmation; Distortion; General relativity; Standard model

1. Introduction

General Relativity and the Standard Model of particle physics often are touted as the most rigorously and extensively confirmed scientific hypotheses of all time. The general attitude in the scientific community is that the evidence available at present confirms these hypotheses to a high degree and that no available evidence disconfirms either hypothesis (Shapiro, 1999; Gaillard et al., 1999). Nonetheless, General Relativity appears to have consequences that are inconsistent with evidence about phenomena for which quantum effects matter. For instance, the theory fails to accommodate uncertainty relations between, say, position and momentum (Baez, 2001). The Standard Model, too, seems to have consequences that are inconsistent with evidence about phenomena for which gravity matters. For instance, observations of gravitational lenses and the deflection of starlight during solar eclipses provide evidence that spacetime is curved near massive objects. But the Standard Model is a quantum field theory and, as such, contains the flatness of spacetime as an essential component (Hartmann, 1998).

If contemporary attitudes toward General Relativity and the Standard Model are correct, evidence about phenomena for which quantum effects matter does not disconfirm General Relativity and evidence about phenomena for which gravitational effects matter does not disconfirm the Standard Model. This paper explores how to accommodate contemporary attitudes toward our current best theories if *Confirmation is Local*—that is, if an hypothesis' confirmation status depends only upon whether the hypothesis, on its own or in conjunction with noncompeting auxiliary hypotheses, characterizes phenomena for which evidence available.

My strategy is as follows. First, I use an interpretation of Newton's attitude toward Kepler's laws of planetary motion in order to motivate and sketch an approach to scientific hypotheses that allows their actual content to differ from their apparent content, and I show how this approach accommodates contemporary attitudes toward General Relativity and the Standard Model if *Confirmation is Local*. Second, I develop an approach for determining when, and in what ways, the actual content of an hypothesis differs from its apparent content. Third, I compare this approach with approaches that invoke *ceteris-paribus* qualifiers, counterfactuals, and similarity relations. I conclude by diffusing some potential objections to the new approach and showing that this approach works even if confirmation is *not* local. My goal is not to address all possible objections but rather to present key ideas at a level of detail that makes exploring further issues worthwhile to those interested in the confirmation of scientific hypotheses.

Before proceeding, there are two terminological clarifications to make. First, I use the term 'phenomenon' to denote anything that is a fact about the physical world. For instance, the precise shape of Mars' orbit is a phenomenon, but the mean average shape of Mars' orbit is a phenomenon too. And both the exact period of a pendulum and the pendulum's period being within some specified range over a given duration are phenomena. Secondly, in saying that a claim characterizes some phenomenon, I do not use the term 'characterize' or its cognates as success terms. That is, I allow a claim to characterize a phenomenon even if it *incorrectly* characterizes that phenomenon.

2. Apparent content vs. actual content

According to one interpretation of Newton's reasoning in *Principia*, he treats Kepler's laws of planetary motion as true and confirmed by available evidence, despite knowing of observed deviations from the apparent consequences of some of those laws (Forster, 1988, pp. 86-94). On this interpretation, Newton takes the attitude he does toward Kepler's laws because he treats those laws as characterizing only the mean average motions of the planets rather than their exact motions. For although Newton's evidence shows that Kepler's laws would not correctly characterize the exact motion of planets, the possibility of invoking additional sources of gravity in order to explain why exact planetary motions deviate from those laws' consequences suggests that they correctly identify the actual mean motions of the planets (see Forster, 1988, pp. 84-85, 89-90). And if Kepler's laws only characterize mean planetary motions, their success in doing so confirms them, and failure to characterize correctly exact planetary motions does not impugn the laws' correctness.

Consider, for example, Kepler's statement of his first law in Proposition 5, Chapter 3, Book 5 of *Harmonices mundi libri:* "the orbit of a planet is elliptical, and ... the Sun ... is in one of the foci of this ellipse" (as quoted in Stephenson, 1994, p. 138). This law appears to characterize not only the mean average shape of each planet's orbit but also the exact shape of each orbit: this is the law's apparent content, which can be gleaned straightforwardly from the statement of the law. Newton, however, treats this law's actual content as something other than its apparent content, even though there is no syntactic indication, in the statement of the law, that this is the case. In particular, Newton treats the law's apparent characterization of exact planetary motions as not part of the law's actual content, because he treats the actual content of the law as being "Every planet travels in an orbit that is, *in the mean*, an ellipse with the sun at one focus."

If this is Newton's attitude toward Kepler's first law, then it is, admittedly, somewhat counterintuitive. After all, the natural interpretation of Kepler's law, especially given Kepler's heavy reliance on geometry and the possibility of stating the law in mathematical language, is that it characterizes planetary orbits as precise, mathematical ellipses. But perhaps the counterintuitiveness diminishes if one keeps in mind that the apparent content of the law is, in part, an artifact of using precise mathematical concepts to express the law. Consider an analogous example. Suppose a bowling ball designer claims, in a patent, that their undrilled ball is a sphere. (See, for example, United States Patent 6569025.) The apparent content of such a claim is that the bowling ball is a precise, mathematical sphere, with all points on its surface equidistant from the ball's center. Yet the discovery of some irregularity on the ball's surface need not cause the designer to retract their claim, if the designer's audience understands the actual content to be that, say, the bowling ball is, in the mean, a sphere.[1]

Nonscientific examples provide further evidence that a claim's actual content need not be its apparent content. Consider a restaurant server's explanation of why the money in the cash register for the shift is less than the total amount of the receipts for that shift:

> A ham sandwich left the restaurant without paying.[2]

The apparent content of this claim is that a ham sandwich left the restaurant and did not pay its bill. The actual content, however, is that a person who ordered a ham sandwich left the restaurant without paying the bill.[3]

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[1] Peter Smith (1998) discusses similar issues, as they pertain to the use of fractal structures in characterizing real phenomena like coastline shapes and fern growth.

[2] This adapts an example originally due to Geoffrey Nunberg (1979).

[3] The explanation of the relation between a claim's apparent and actual content currently is a topic of dispute among philosophers of language that focuses on the extent to which semantic content is context sensitive. (See, for example, the symposia on Cappelen and Lepore (2005) in *Philosophy and Phenomenological Research, LXXIII*(2) and *Mind and Language 21*(1).) This dispute is tangential to the focus of this paper, since all parties seem to accept that a claim's apparent content can differ from its actual content, and since this paper does not propose to

If the actual content of Kepler's first law is not its apparent content because the actual content does not characterize exact planetary motions, then, despite appearances to the contrary, the derivation of a claim with the actual content "Mars' orbit is a mathematical ellipse with the sun at one focus" from Kepler's first law is invalid, because the law neither affirms nor denies that all planetary orbits are mathematically precise ellipses. (This is analogous to the derivation of "Some ham sandwiches can leave places" from "A ham sandwich left the restaurant without paying" being invalid--assuming that the derived claim is about ham sandwiches rather than guests who order ham sandwiches.) Moreover, there are no relevant auxiliary assumptions that, when conjoined with Kepler's first law, render the derivation of that claim valid. Accordingly, Kepler's first law, on its own or in conjunction with auxiliary hypotheses, does not characterize the shape of Mars' exact orbit. Hence, if *Confirmation is Local*, evidence about Mars' exact orbit does not disconfirm Kepler's first law.

Under this interpretation of Newton's reasoning, Newton's attitude toward Kepler's laws resembles contemporary attitudes toward General Relativity and the Standard Model, inasmuch as Newton treats Kepler's laws as confirmed despite their apparent conflict with available evidence. Hence, regardless of whether the interpretation is correct, the reason it provides for Newton's attitude toward Kepler's laws suggests an explanation for the attitudes of contemporary scientists

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distinguish between the apparent content of scientific hypotheses and their actual content on the basis of contextual factors—but more on this in the next section.

toward our current best theories: the scientists treat the actual content of these theories as being something other than their apparent content, so that General Relativity and the Standard Model do not characterize all of the phenomena that they seem to characterize--and, in particular, they do not characterize phenomena for which quantum and gravitational effects matter, respectively. *Confirmation is Local* thus entails that neither General Relativity nor the Standard Model is disconfirmed by evidence about such phenomena. For, since the incorrect "predictions" of these theories are valid consequences only of their apparent content, the theories are not disconfirmed by evidence that shows those "predictions" to be incorrect.

Consider, by way of illustration, the Standard Model. It is well known that the Standard Model does not account for gravitational interactions between particles. This seems to be why the theory's apparent content incorrectly characterizes phenomena for which gravitational effects matter. The reason that the Standard Model does not account for such phenomena is that applying quantum field theory (the general framework for the Standard Model) to General Relativity yields divergences, such as the claim that the force between gravitons is infinite. (More on the significance of this in the next section.) Scientists agree that such a force is only finite, and yet they generally adopt the attitude that this apparent prediction of the Standard Model does not affect the Standard Model's confirmation. An explanation of this attitude is that the scientists treat the Standard Model's actual content as something other than its apparent content, so that the theory does not characterize phenomena for which gravitational effects matter. For if this is the case, and if *Confirmation is Local*, available evidence about those phenomena does not impugn the theory's correctness, even though the Standard Model appears to characterize such phenomena.

Before proceeding to discuss the conditions under which an hypothesis' actual content differs from its apparent content, it is important to avoid two potential confusions. The first concerns the justification for postulating a distinction between the apparent and actual content of General Relativity and the Standard Model. The example about the ham sandwich illustrates this distinction and shows it to be not *ad hoc*. The interpretation of Newton illustrates the explanatory power of the distinction with respect to a theory's confirmation status. None of this, however, justifies the thesis that the actual content of General Relativity and the Standard Model differs from their apparent content. This justification, so far, comes from the ability of the thesis, together with certain assumptions about confirmation, to *explain* general scientific attitudes toward the confirmation status of General Relativity and the Standard Model.

Further justification for this thesis is that the project of accommodating contemporary attitudes toward these theories *necessitates* a distinction between the apparent and actual content of General Relativity and the Standard Model, regardless of whether *Confirmation is Local*. If there is no such difference, each theory is disconfirmed in virtue of its incorrect predictions. For those predictions follow from the basic structure of each theory: their derivation requires no auxiliary assumptions. And, according to any plausible account of confirmation, an hypothesis' incorrect predictions disconfirm it whenever the hypothesis, apart from any auxiliary assumptions, entails those predictions.

A second potential confusion to avoid concerns the difference between a theory's range of characterization and its range of application. If a theory's range of application is fixed by scientists' choices about which phenomena to apply the theory to, then the claim that General Relativity and the Standard Model do not characterize phenomena that would otherwise disconfirm them should not be confused with the claim that these theories are limited in their range of application. Certainly scientists do not, in practice, apply these theories to phenomena that would disconfirm them. Yet this does not exclude the theories from being disconfirmed by evidence about phenomena outside their range of application, because it is consistent with the theories entailing predictions that disagree with that evidence and the scientists merely not using those predictions. For example, even if scientists do not apply the Standard Model to phenomena for which gravitational effects matter, this restriction on the Standard Model's range of application is consistent with the Standard Model's actual content entailing (incorrect) predictions about such phenomena.

Nonetheless, there is a connection between a theory being limited in its use-determined range of application and the theory's actual content being something other than its apparent content. For the latter can explain the former:

one reason to not apply a theory to certain phenomena is that the theory's actual content does not characterize those phenomena.

3. Determining an hypothesis' actual content

The key to the preceding explanation of general scientific attitudes toward the confirmation of General Relativity and the Standard Model is that the actual content of these theories differs from their apparent content. This explanation is incomplete, however, because it provides no understanding of why each theory's actual content differs from its apparent content. This section presents a novel approach to filling this explanatory gap. I refer to it as a *particularist approach to the content of scientific hypotheses*, because it is committed to the idea that the conditions for determining an hypothesis' actual content give verdicts about that content on a phenomenon-by-phenomenon basis. This differs from other approaches, such as ones that invoke *ceteris-paribus* qualifiers or counterfactuals, that determine an hypothesis' actual content through principles that add logical structure to the hypothesis' apparent content--but more on this in the next section. Accordingly, the particularist approach here is akin to particularist approaches in ethics, which determine the rightness or wrongness of actions on a case-by-case basis rather than by appeal to general abstract principles, and which are driven by analysis of case studies rather than application of theory. (See Arras (2004) for a concise overview of the particularist approach in ethics.)

My strategy in presenting a particularist approach to the content of scientific hypotheses is to propose two conditions for determining when, and in what way, an hypothesis' actual content differs from its apparent content. The approach does not stand or fall with the correctness of these conditions: the conditions themselves are starting points in a research program for further refining these conditions (if need be) and discovering others (if they exist). The approach itself, while independent of these specific conditions, is committed to only the existence of some condition that explains why nonrational paradigm entrenchment does not (arbitrarily) determine the actual content of scientific hypotheses, and that does so without adding logical structure to the apparent content of hypotheses.

The distinctive feature of a particularist approach to the content of scientific hypotheses is that it is a "bottom-up," rather than "top-down," approach. Rather than postulating additional structure as part of an hypothesis' actual content and proceeding to deduce which phenomena the hypothesis' actual content characterizes, a particularist approach examines individual cases in which some hypothesis' actual content differs from its apparent content and generalizes to conditions for determining any hypothesis' actual content. Accordingly, in presenting a particularist approach to the content of scientific hypotheses, I begin with some brief case studies.

The case of Coulomb's law suggests that sometimes the actual content of an hypothesis differs from its apparent content because the hypothesis' apparent content yields a divergence. Coulomb's law is a consequence of the foundational equations of Classical Electromagnetism and, specifically, of Gauss' law for electricity. The law states that the strength of the force between any two charged particles is proportional to the product of each particle's charge strength divided by the square of the distance between the particles. Using Coulomb's law, it can be shown that the electric field of a negatively charged particle (electron), defined as the force that the particle exerts on a positive test charge, is inversely proportional to the square of the distance between the electron and the test charge. It follows that the strength of an electron's electric field increases as the electron approaches any negative charge. This raises the question of how strong the electron's electric field is at the location of the electron. That is: when an electron interacts with its own electric field, what force does the electron exert upon itself?

Classical Electromagnetism, like Classical Newtonian Mechanics, treats objects as particles with zero diameter. Hence, since the theory treats electrons as point charges, the distance between an electron and itself is zero when the electron interacts with its own electric field. (If the electron's diameter were nonzero, it would be possible for the electron to interact with different parts of itself; but this raises a problem about the stability of self-interacting, extended electrons.) Accordingly, Coulomb's law entails that the strength of an electron's field at the location of the electron diverges to infinity. (When an hypothesis yields this sort of result, I say that the hypothesis yields a divergence.) A typical response to this result is to ignore this divergence, on the grounds that the range of application for Coulomb's law--and Classical Electromagnetism--does not include the strength of an electron's electric field when the distance between the electron and the particle with which it interacts is zero. An explanation for this restriction is that the law's actual content does not characterize the strength of an electron's electric field when the distance between the electron and the particle with which it interacts is zero. If this is correct, then a divergence in one of an hypothesis' apparent claims can indicate that the hypothesis' actual content differs from its apparent content.

However, an hypothesis' apparent content yielding a divergence does not always indicate this. Consider the Ising model's characterization of ferromagnetic-paramagnetic phase transitions in metals. When a system characterized by the Ising model approaches its Curie temperature, the system's heat capacity diverges logarithmically. But the typical response to this result is not to ignore the divergence on the grounds that the Ising model does not characterize or apply to a system's heat capacity when the system is at its Curie temperature. Rather, the typical response is to treat the divergence as indicating the occurrence of a phase transition at which, in actual fact, the system's heat capacity is singular. Indeed, the ability of the Ising model to predict this divergence is among the model's most attractive features.

What seems to account for the difference in attitude toward Coulomb's law and the Ising model is that scientists consider the divergence in the latter to represent a real phenomenon while they consider the divergence in the former as merely a mathematical artifact that does not represent anything. This suggests the following condition for when, and in what way, the actual content of an hypothesis differs from its apparent content:

> DIVERGENCE: If the apparent content of an hypothesis entails a prediction about some phenomenon, according to which the magnitude of some quantity diverges, and if the hypothesis is not part of a theory that represents that phenomenon as a singularity, then the actual content of the hypothesis does not characterize that phenomenon.

The apparent content of Coulomb's law entails a prediction about an electron's electric field at the location of the (point-mass) electron, according to which the strength of the electron's electric field diverges; and Classical Electromagnetism--the theory of which Coulomb's law is a part--does not represent any real phenomenon as a singularity at the location of an electron. Hence, according to DIVERGENCE, the actual content of Coulomb's law does not characterize the strength of an electron's electric field at the location of the electron. In contrast, the apparent content of the Ising model entails a prediction about a system's heat capacity at its Curie temperature, according to which the system's heat capacity diverges at that temperature; and Statistical Mechanics--the theory of which the Ising model is a part--represents phase transitions as singularities. Hence, the actual content of the Ising model characterizing a system's heat capacity at its Curie temperature is consistent with DIVERGENCE.

DIVERGENCE helps to explain why the Standard Model's actual content differs from its apparent content. The apparent content of the Standard Model entails predictions about phenomena for which gravitational effects matter; these predictions are divergences (such as the claim that the force between gravitons is infinite); and the Standard Model, not being part of any other theory, does not represent any such phenomena as singularities. Hence, according to DIVERGENCE, the actual content of the Standard Model does not characterize phenomena for which gravitational effects matter.

The case of Nonrelativistic Newtonian Mechanics suggests a second reason why an hypothesis' actual content differs from its apparent content, namely, that predictions derived from the hypothesis' apparent content disagree with experimental evidence. Nonrelativistic Newtonian Mechanics seems to entail predictions that disagree with evidence about quantum and relativistic phenomena. For this reason, scientists do not apply the theory to such phenomena. Nonetheless, scientists continue to apply the theory to phenomena that involve slow-moving, medium-sized objects, placing great confidence in the theory's reliability for these phenomena. Indeed, the general scientific attitude seems to be that the theory is confirmed by evidence about such phenomena, and this demands that the theory not be disconfirmed in an absolute sense by evidence about quantum and relativistic phenomena. An explanation of this is that scientists treat the theory's actual content as something other than its apparent content. If this is correct, then the incorrect predictions are consequences of the theory's apparent content but not its actual content.

However, it is not always the case that disagreement between experimental evidence and the predictions of an hypothesis' apparent content indicate that the hypothesis' actual content differs from its apparent content. Consider phlogiston theory. The theory seems to predict (incorrectly) that phosphorus and sulfur, when burned, lose some of their weight. In practice, scientists do not apply this theory to the burning of sulfur and phosphorus. Yet neither the incorrect prediction from the theory's apparent content nor the limitation on the theory's range of application indicate that the theory's actual content does not entail that phosphorus and sulfur, when burned, lose some of their weight, because the theory is taken to be disconfirmed by this prediction (among others). In this case, perhaps the explanation of why scientists do not apply phlogiston theory to the burning of sulfur and phosphorus is that the theory is disconfirmed (in an absolute sense) in virtue of the incorrect prediction being a consequence of its actual content: presumably some disconfirmed theories have no range of application.

Any condition that explains why scientists have differing attitudes toward Nonrelativistic Newtonian Mechanics and phlogiston theory should satisfy the following desiderata. First, it should not entail that phlogiston theory's actual content does not characterize what happens to phosphorus and sulfur when they are burned. Second, it should entail that the actual content of Nonrelativistic

Newtonian Mechanics does not characterize phenomena for which quantum and relativistic effects matter. Finally, it should entail that the actual content of General Relativity and the Standard Model do not characterize, respectively, phenomena for which quantum and gravitational effects matter. The following condition satisfies all of these requirements:

> DIFFERENCE: If an hypothesis distorts the magnitude of a physical quantity that makes a difference to a phenomenon and the hypothesis's apparent content incorrectly characterizes that phenomenon, then the actual content of the hypothesis does not characterize that phenomenon.

This condition appeals to several notions that require further elucidation, namely, the notion of an hypothesis distorting some factor and of a factor making a difference to a phenomenon.

An hypothesis distorts the magnitude of a physical quantity by treating that quantity as having a magnitude it does not have. For example, in discussing the prospects for a quantum theory of gravity, John Baez (2001) remarks that General Relativity "idealizes reality by treating [Planck's constant] as negligibly small" and that Quantum Field Theory idealizes reality by treating Newton's gravitational constant as negligibly small (p. 182). These idealizations are distortions, in virtue of those constants *not* being negligibly small. Similarly, Nonrelativistic Newtonian Mechanics distorts reality by treating Planck's constant as negligibly small and the speed of light as having no upper limit; and Classical Electromagnetism distorts the size of electrons by treating them as point-particles.

One account of the notion of distortion appeals to what the semantic view of scientific theories calls a *theoretical model* for an hypothesis. This is a nonactual (and perhaps abstract) entity of which the apparent content of the hypothesis is exactly and correctly true (see Giere, 1988, pp. 78-80). For example, a theoretical model for the ideal gas law is an ideal gas in which there are no intermolecular forces; and the theoretical model for the Standard Model includes a Minkowski spacetime that serves as the fixed background on which particle interactions occur (because the Standard Model is a quantum field theory). This notion of a theoretical model figures in the following condition for when an hypothesis distorts:

> DISTORT: An hypothesis distorts the magnitude of a physical quantity if the theoretical model for the hypothesis is one in which that physical quantity has a magnitude that it does not have in reality.

(If there are multiple theoretical models for the same hypothesis, then the magnitude should be incorrect in *every* such model.) According to DISTORT, the Standard Model distorts the magnitude of Newton's gravitational constant because that constant is negligibly small in the Standard Model's theoretical model but not in reality; and General Relativity distorts the magnitude of Planck's constant because that constant is negligibly small in General Relativity's theoretical model but not in reality. (Note that DISTORT does not require that anyone be aware that an hypothesis distorts the magnitude of some quantity in order for the hypothesis to distort that quantity: in this sense, it is an externalist criterion. Note also that DISTORT does not require a distorted magnitude to be approximately correct or an idealization: distortions need not be approximations or simplifications.)

The notion of difference-making that appears in DIFFERENCE is more difficult to explain, primarily because of the wide variety of accounts available and the lack of consensus as to which of the available accounts is best. (See Strevens (2004) for a nice summary of various accounts of difference-making.) In order for DIFFERENCE to satisfy the preceding desiderata, the following claims must be true: a finite upper bound on the speed of light makes a difference to phenomena for which relativistic effects matter; a finite, nonzero, nonnegligible gravitational constant makes a difference to the affect of matter fields on the underlying structure of spacetime; and a finite, nonzero, nonnegligible Planck's constant makes a difference to gravitational lensing (and other phenomena for which gravitational effects matter). These claims generally are not considered to be problematic. And their acceptability here does not require support from a rigorous philosophical analysis of the notion of difference-making. For, given their *prima-facie* plausibility, they are evidence that philosophical analyses should accommodate.[4]

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[4] In any case, it is relatively easy to show that the main competing accounts of difference-making support these claims. For instance, if a factor makes a

If these facts about difference-making are granted, then DIFFERENCE satisfies all of the required conditions. Since the Standard Model distorts the magnitude of Newton's gravitational constant but the actual value of this constant makes a difference to gravitational lensing and other such phenomena, and since the Standard Model's apparent content incorrectly characterizes such phenomena, DIFFERENCE entails that the Standard Model's actual content does not characterize those phenomena. Similar reasoning shows that General Relativity's actual content does not characterize phenomena for which quantum effects matter and that the actual content of Nonrelativistic Newtonian Mechanics does not characterize phenomena for which quantum and relativistic effects matter. Finally, although the theoretical model for phlogiston theory includes nonexistent entities (namely, phlogiston), this feature of the model does not involve attributing a nonactual magnitude to some physical quantity. Hence, phlogiston theory does not distort the magnitude of any quantity that makes a difference to the behavior of phosphorus and sulfur when burned and, accordingly, DIFFERENCE is consistent with phlogiston theory characterizing such phenomena.

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difference to a phenomenon just when the factor changes the probability for the phenomenon's occurrence, then a nonnegligible gravitational constant makes a difference to the affect of matter fields on the underlying structure of spacetime, because the probability of spacetime being flat if that constant is negligibly small is greater than the probability of spacetime being flat if the constant is not negligibly small.

One dissatisfying feature of the preceding presentation of a particularist approach to the content of scientific hypotheses is that neither DIFFERENCE nor DIVERGENCE provide guidance about what an hypothesis' actual content *does* characterize. The easiest way to remedy this is to introduce a *ceteris-paribus* condition:

> DEFAULT: An hypothesis' actual content characterizes a phenomenon if its apparent content does, unless DIVERGENCE, DIFFERENCE, or some other such condition entails otherwise.

If there are no conditions other than DIVERGENCE and DIFFERENCE, then DEFAULT entails, among other things, that phlogiston theory's actual content characterizes the behavior of phosphorus and sulfur when burned, that the Standard Model's actual content characterizes certain quantum phenomena, and that the actual content of Kepler's first law characterizes the mean orbits of the planets.

To summarize the discussion so far: General Relativity and the Standard Model are not disconfirmed by evidence about phenomena for which, respectively, quantum and gravitational effects matter, because the theories do not characterize those phenomena. According to the preceding particularist approach to the content of scientific hypotheses, conditions like DIVERGENCE, DIFFERENCE, and DEFAULT explain why this is so, because they determine what an hypothesis' actual content is and when that content differs from the hypothesis' apparent content. And even if these conditions are incorrect, they illustrate a general strategy for explaining why an hypothesis' actual content differs from its apparent content.

4. Other approaches to the content of scientific hypotheses

The preceding particularist approach to the content of scientific hypotheses resembles approaches to scientific hypotheses that treat them as *ceteris-paribus* claims or counterfactuals or approximations. These other approaches also entail that an hypothesis' actual content can differ from its apparent content, insofar as many scientific hypotheses do not contain explicit *ceteris-paribus* qualifiers, are not stated as counterfactuals, and are not explicitly qualified as being approximations. The difference between these approaches and the particularist approach concerns the conditions about what determines the actual content of an hypothesis. (The particularist approach also avoids some of the traditional problems that beset the alternatives; but, apart from a brief discussion in the next section, exploring this issue is beyond this paper's scope.)

4.1. The ceteris-paribus approach

According to the *ceteris-paribus* approach to the content of scientific hypotheses, the actual content of an hypothesis is its apparent content affixed with a *ceteris-paribus* qualifier. (See Lange (2002) for a defense of this approach.) For instance, as a *ceteris-paribus* hypothesis, the generic law "Every *F* is a *G*" has the actual content "Every *F* is a *G*, *ceteris paribus*"--that is, "Every *F* is a *G*, unless there is some factor that interferes with an *F* being a *G*." And, as a *ceteris-paribus* hypothesis, the actual content of Kepler's first law is: "Each planet's orbit is a mathematically precise ellipse with the sun at one foci, unless certain factors, such as the gravitational pull from other planets, interfere with a planet's orbit."

Ceteris-paribus hypotheses only characterize phenomena that occur when interfering factors are absent. For instance, if *I* is some factor that interferes with whether *F*s are *G*s and *I* occurs in some system that contains an *F*, then the claim "Every *F* is a *G*, *ceteris paribus*" entails neither that the *F* in the system is a *G* nor that the *F* is not a *G*. Likewise, as a *ceteris-paribus* hypothesis, the actual content of Kepler's first law is: "Each planet's orbit is a precise, mathematical ellipse, unless there is a factor that interferes with this." This does not characterize the orbital shapes of actual planets, because gravitational effects interfere with those orbits being precise ellipses. If an interfering factor occurs in some system, then a *ceteris-paribus* hypothesis makes no claims about the system, even if its apparent content does.

According to the particularist approach to the content of scientific hypotheses, the actual content of an hypothesis need not characterize only phenomena that occur when interfering factors are absent. For example, according to the particularist approach developed in the previous section, since Kepler's first law distorts the magnitude of interplanetary gravitational forces and this makes a difference to actual, exact planetary orbits, the actual content of Kepler's first law does not characterize exact planetary orbits. This agrees with the *ceteris-paribus* approach. But since, according to that approach, the *ceteris-paribus* qualifier is built into the law's actual content, the actual content of Kepler's first law does not characterize any phenomena concerning actual planets, because interfering factors always are present. The particularist approach can avoid this further result. For that approach allows the actual content of Kepler's first law to characterize mean planetary orbits even when gravitational forces are present, provided that conditions like DIVERGENCE and DIFFERENCE do not entail otherwise. And there seems to be no *a priori* reason that there must be conditions that restrict the law's actual content to the same extent as the *ceteris-paribus* approach does.

Accordingly, the particularist approach can allow the actual content of an hypothesis to characterize a phenomenon that, according to the *ceteris-paribus* approach, the hypothesis' actual content does not characterize. The central reason for this is that the particularist approach does not add logical structure to the actual content of hypotheses. Determining actual content on a phenomenon-by-phenomenon basis avoids the need to do this.

4.2. The counterfactual approach

According to the counterfactual approach to the content of scientific hypotheses, the actual content of an hypothesis is a counterfactual, the consequent of which is the apparent content of the hypothesis and the antecedent of which is the conjunction of the distortions upon which that description is based. (See

Niiniluoto (1986) and Suppe (1989) for examples of this approach.) For instance, if the ideal gas law is a counterfactual hypothesis, then its actual content is: "If the components of a gas were point-particles that interact only by contact, then the product of the gas' pressure and volume would be equal to the product of the gas' particle number and temperature times a proportionality constant." Evidence that the equality in the consequent fails to hold of dense gases does not disconfirm this counterfactual hypothesis, insofar as such gases do not instantiate the counterfactual's antecedent.

Counterfactual hypotheses characterize only the counterfactual structure of the world. For instance, as counterfactuals, the ideal gas law characterizes only how a gas would behave were it an ideal gas and the Standard Model characterizes only how particles would behave if Newton's gravitational constant were negligible. Of course, sometimes the antecedent of a counterfactual hypothesis is realized fortuitously or in the construction of experimental situations. When this happens, counterfactual hypotheses make claims about the actual structure of the world, because the world's actual structure coincides with its counterfactual structure. But these situations are exceptional.

According to the particularist approach to the content of scientific hypotheses, the actual content of an hypothesis need not characterize only the counterfactual structure of the world. Consider, for example, Mercury's anomalous precession and the expansion rate of the universe. These are not counterfactual features of the world. Nor do they obtain only in ideal systems for which Planck's constant is negligibly small. But, provided that the actual content of General Relativity's Einstein equation characterizes systems other than those in which Planck's constant is negligible, they are phenomena that General Relativity characterizes. Indeed, the attitude of practicing scientists seems to be that General Relativity's actual content characterizes such phenomena, and neither DIVERGENCE nor DIFFERENCE tell against this attitude.

The central reason that the particularist approach allows hypotheses to have actual content that characterizes the noncounterfactual structure of the actual world is the same as the reason for why the approach allows hypotheses to have actual content that characterizes phenomena that occur when interfering factors are present: the approach does not introduce logical structure into an hypothesis' actual content that is not present in the hypothesis' apparent content. According to the counterfactual approach, the actual content of an hypothesis is a counterfactual, even if the hypothesis' apparent content is not. Since the particularist approach does not require introducing this logical apparatus, it allows hypotheses to have actual content that characterizes the world in a way that is not conditional upon the realization of a set of counterfactual assumptions.

4.3. The approximation approach

According to the approximation approach, scientific hypotheses do not precisely characterize the world. Rather, they provide approximate characterizations of the way the world is. (See Weston (1992) for an example.)

For instance, according to this approach, the actual content of the ideal gas law is: "It is approximately the case that the product of a gas' pressure and volume is equal to the product of that gas' particle number and temperature times a proportionality constant." The key advantage of approximate hypotheses over their precisely-construed counterparts is that the former need not be disconfirmed by evidence that is inconsistent with the latter. Another advantage is that approximate hypotheses need not characterize only counterfactual features of the real world, because approximations need not be counterfactuals: approximations can, and often do, characterize (approximately) some noncounterfactual features of the real world. Finally, approximate hypotheses, unlike *ceteris-paribus* ones, can characterize systems in which interfering factors are present.

Comparing this approach to the content of scientific hypotheses with the particularist approach from the preceding section faces the difficulty that there is no general agreement on how to construe the notion of approximation. There is debate about whether the notion of approximation is absolute or context-dependent. And there is uncertainty about the conditions under which an hypothesis approximates the evidence.

The difficulties in taking approximation to be context-independent include the problem of there being no nonarbitrary standard that determines whether an hypothesis approximates the evidence in an absolute sense, the problem that the approximate truth (in an absolute sense) of two hypotheses need not transfer to their conjunction being approximately true, and the problem that whether an hypothesis approximates the evidence in an absolute sense seems to depend upon the language in which the hypothesis is cast. (See Teller (2001, pp. 402-406) and Giere (2006, pp. 59-82) for details and elaborations.) These problems suggest that the only coherent notion of approximation (if there is one at all) is context-dependent.

Paul Teller's (2001) claim that "talk about approximate truth comes down to the same issues as those covered by talk of the similarity between models and their objects of representation" (p. 404) represents the dominant--and currently most plausible--account of context-dependent approximation. This account relies upon a particular version of the semantic view of scientific theories. So it will be useful to sketch that view before presenting the account.

According to what I shall call *the agent-based conception of theories* (following Giere (*forthcoming*)), the actual content of a scientific hypothesis is a claim that a certain abstract model is similar to the world in relevant respects and to relevant degrees of accuracy. This abstract model, itself neither true nor false in virtue of being nonlinguistic, is a system of which the apparent content of the scientific hypothesis--such as Kepler's first law or the ideal gas law--is exactly and correctly true. For instance, the abstract model for the ideal gas law is a nonactual gas composed of point-particles that, among other things, affect each other only through perfectly elastic collisions. The actual content of the ideal gas law is not its apparent content ("The product of a gas' pressure and volume is equal to the product of that gas' particle number and temperature times a proportionality constant") but rather the claim that the hypothesis' abstract model is similar to the actual world in relevant respects and degrees.

What determines which respects and degrees of the world are relevant to any given model-world pair's similarity is not some general principle, according to this conception of theories, but instead the purposes for which scientists intend to use the model. For example, if scientists intend to use the ideal gas model for the purpose of determining whether the pressure and volume of real gases at fixed temperatures in closed environments exhibit a rough, qualitative, inverse proportionality (so that the pressure increases just when the volume decreases), then the ideal gas law is true just if this feature of ideal gases occurs in actual gases, regardless of whether the ideal gas law's precise details about the proportion match the details for actual gases. Similarly, if scientists intend to use Kepler's first law only for predicting the mean orbits of the planets, then the orbits of the abstract model for that law are similar to actual planetary orbits, even though the actual planets exhibit slight variations in each of their successive orbits but the planets of the abstract model do not.[5]

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[5] The preceding sketch of the agent-based conception of scientific theories introduces terminology--such as the notions of actual and apparent content--that advocates of the conception do not employ. This is for the sake of facilitating comparison with the previous section's approach to the content of scientific hypotheses. See Giere (1988), Giere (*forthcoming*), and Teller (2001) for further details on this conception of theories.

The agent-based conception of scientific theories explicates the notion of approximation in terms of similarity: an hypothesis is approximately true just if the hypothesis' abstract model is similar to the world in relevant respects and degrees. Teller (2001), for example, holds that asking whether a statement warrants the title of being approximately true of a situation is the same as asking whether the statement describes a nonactual situation that is relevantly similar to the actual one (p. 403). This explication of the notion of approximation allows an hypothesis to be approximately true even if some predictions of its apparent content are incorrect. Moreover, this explication accommodates the demand that the notion of approximation be context-dependent. For contextual purposes help to determine the actual content of an hypothesis: if context alters these purposes, there can be a corresponding alteration in whether the hypothesis is approximately true. For example, were scientists to use the ideal gas model for the intended purpose of predicting exact behaviors of dense gases, the ideal gas law would not be approximately true.

This sketch of the approximation approach to the content of scientific hypotheses, itself motivated by the agent-based conception of scientific theories, provides sufficient detail to show that this approach is an instance of a particularist approach. For it determines an hypothesis' actual content on a phenomenon-by-phenomenon basis, namely, on the basis of whether the intended purpose of the hypothesis' abstract model requires that model to be similar to the world with respect to a particular phenomenon.

This approach differs from the particularist approach of the preceding section in virtue of the kinds of conditions it provides for determining an hypothesis' actual content. According to the approximation approach, the conditions are teleological (purpose-determined). The approach in the preceding section shows that particularist approaches to the content of scientific hypotheses need not be teleological, for the conditions there make no reference to the purposes of scientists. That approach--which I shall refer to as nonteleological--also shows that a particularist approach need not invoke the notion of similarity. For example, if a quantity makes a difference to a phenomenon whenever its presence affects the probability of a phenomenon's occurrence, then whether a quantity makes a difference to a phenomenon does not depend upon the existence of appropriate sorts of similarity relations.

These differences are significant. The first signals a fundamental disagreement about whether the confirmation status of an hypothesis depends in any way upon the purposes for which scientists use it. According to the approximation approach, whether an hypothesis' actual content characterizes certain phenomena depends upon the purposes for which scientists use the hypothesis; hence, whether evidence about those phenomena confirms or disconfirms the hypothesis depends upon those purposes. In contrast, the nonteleological approach allows an hypothesis' confirmation status to be purpose-independent, since reference to scientists' purposes is not essential to explications of difference-making and other notions central to the approach.

The second difference marks conflicting attitudes toward the theoretical promise of the notion of similarity. Progress in clarifying this notion mainly concerns a comparative notion of whether the similarity between two things is more or less than the similarity between one of those things and some third thing. (See, for example, Gärdenfors (1990) and (2000).) But the approximation approach requires a noncomparative notion of similarity between theoretical models and the world, and there recently has been more progress in clarifying the notion of difference-making than there has been in clarifying a noncomparative notion of similarity. (See, for example, Pearl (2000) and Strevens (2004).) Perhaps this is a virtue of the nonteleological approach.

It is possible, of course, that the approximation and nonteleological approaches agree perfectly concerning whether, for any given hypothesis, the hypothesis' actual content characterizes a certain phenomenon. Ideally, scientists intend to use an abstract model to characterize exactly those phenomena that, according to the nonteleological approach, the actual content of the model's hypothesis characterizes. But there is nothing in the agent-based conception of scientific theories that requires scientists to do this: scientists are, according to that conception (as it has been presented by others), unconstrained in the purposes for which they intend to use abstract models. Accordingly, when these two approaches to the content of scientific hypotheses agree on what the actual content of a particular hypothesis characterizes, that agreement is contingent rather than a consequence of one approach merely being a restatement of the other.

5. Objections

Any approach to the content of scientific hypotheses should avoid three canonical problems. First, the approach should not entail that distorted hypotheses--that is, hypotheses that distort certain factors of real systems--characterize almost no actual phenomena; second, it should explain why scientists are justified in applying distorted hypotheses to actual systems; and third, it should permit distorted hypotheses to be falsified or disconfirmed by evidence. Sheldon Smith (2002) illustrates these problems in his criticism of the *ceteris-paribus* approach (pp. 235-237). He argues that the approach succumbs to *the problem of instantiation*: *ceteris-paribus* hypotheses characterize almost nothing actual because interfering factors normally occur in actual systems. He argues that the approach succumbs to *the problem of application*: scientists are not justified in applying these hypotheses to systems in which interfering factors are present because the hypotheses do not characterize those systems. And he argues that the approach succumbs to *the problem of falsification*: the *ceteris-paribus* qualifier immunizes *ceteris-paribus* hypotheses from falsification and disconfirmation because any apparent disagreement with evidence indicates the presence of an interfering factor.

The nonteleological particularist approach to the content of scientific hypotheses avoids all three of these problems. First, it already has been shown that the nonteleological approach allows hypotheses to have actual content that characterizes phenomena that occur when interfering factors are present as well as noncounterfactual features of the actual world. This solves the problem of instantiation. Second, the approach avoids the problem of application, since scientists surely are justified in applying an hypothesis to a system when the hypothesis' actual content characterizes phenomena in that system (unless, of course, disconfirmation of the hypothesis defeats that justification).

Avoiding the problem of falsification requires that the approach allow some hypotheses to incorrectly characterize some phenomena. The approach does this. If an hypothesis characterizes some phenomenon then, according to DIVERGENCE and DIFFERENCE, both of the following disjunctions are true: *either* the apparent content of the hypothesis entails the hypothesis is part of a theory that represents that phenomenon as a singularity *or* the hypothesis entails a prediction about that phenomenon according to which the magnitude of some quantity diverges; and *either* the hypothesis does not incorrectly characterize the phenomenon *or* the hypothesis does not distort the magnitude of some quantity that makes a difference to the phenomenon.

The case of phlogiston theory satisfies the second disjunct of both of these disjunctions for the phenomenon of sulfur weighing more after it is burned. So, according to DEFAULT, phlogiston theory's actual content characterizes this phenomenon. And this characterization is incorrect. (Incidentally, if there are conditions other than DIVERGENCE and DIFFERENCE that determine whether an hypothesis's actual content characterizes a phenomenon, the requirement that the approach avoid the problem of falsification translates into a constraint that these further conditions not override the verdict that phlogiston theory's actual content incorrectly characterizes some phenomena. This constraint sets an agenda for a research program that extracts from scientific attitudes further conditions for determining whether the actual content of an hypothesis characterizes some phenomenon, and that perhaps further refines DIVERGENCE and DIFFERENCE.)

Having addressed the standard set of potential objections for various approaches to the content of scientific hypothesis, I consider two objections based upon the specific details of the nonteleological approach. The first is based upon the approach's consequence that (for instance) the ideal gas law is not disconfirmed by evidence about the behaviors of dense gases. For, according to DIFFERENCE, since the ideal gas law distorts the extension and intermolecular interactions of a gas' constituents and these factors apparently make a difference to the behavior of dense gases, the actual content of the ideal gas law does not characterize those behaviors. This result violates the intuition that such evidence disconfirms the ideal gas law (if *Confirmation is Local*). Hence, according to the objection, even if the approach succeeds in accommodating general attitudes toward General Relativity and the Standard Model, it succumbs to straightforward counterexamples.[6]

However, there is some reason to think that the objection's guiding intuition is mistaken. The (admittedly few) working scientists with whom I have spoken report that they do not take the ideal gas law to be disconfirmed by available evidence because the hypothesis has a limited range of application. They report similar attitudes toward Kepler's and Newton's laws. The conception of confirmation that underlies these attitudes seems to involve exempting hypotheses from disconfirmation by evidence about phenomena to which they do not apply. This is exactly what the nonteleological particularist approach does, assuming that hypotheses apply only to the phenomena they characterize. Hence, it is *prima-facie* reasonable to conclude that the approach captures attitudes toward confirmation that are implicit in scientific practice and methodology, despite intuitions to the contrary.

A second potentially objectionable consequence of the nonteleological approach is that it is possible for the inventors or practitioners of an hypothesis to not know what the hypothesis' actual content is. This is a result of the DIFFERENCE condition making no reference to scientists' knowledge of what factors an hypothesis distorts and whether those factors make a difference to various phenomena. For example, suppose that in formulating his first law of planetary motion, Kepler did not know that law distorts something that makes a

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[6] I thank [omitted] for pressing this objection.

difference to exact planetary motions. Then, even if Kepler believed his law to characterize exact planetary motions, DIFFERENCE entails that he was mistaken. According to this objection, such a result is implausible.

There are two ways of responding to this objection and, for the purposes of this paper, either is equally good. The first is to bite the bullet and insist that scientists can be mistaken in what they take an hypothesis to characterize. For example, according to this approach, Kepler just did not know the actual content of his first law, and Newton did not know that the actual content of his laws characterize only medium-sized objects moving significantly slower than light speed. The second strategy is to concede the force of the objection and modify conditions like DIVERGENCE and DIFFERENCE so that they are sensitive to the state of scientific knowledge concerning whether an hypothesis distorts a difference-maker for a phenomenon. For instance, according to this strategy, DIFFERENCE should begin "If *it is known that* an hypothesis distorts the magnitude of a quantity that makes a difference to a phenomenon, ..." This second strategy entails that an hypothesis' actual content--and its confirmation status--can vary over time, due to changes in scientific knowledge. In contrast, the first strategy entails that an hypothesis' actual content--and its confirmation status--is invariant with respect to such changes and treats advances in knowledge of what hypotheses distort as evidence that allows scientists to better understand the actual content of those hypotheses. Which strategy is most appropriate depends upon issues about meaning and confirmation that are best addressed elsewhere.[7]

6. Conclusion

A nonteleological particularist approach to the content of scientific hypotheses accommodates contemporary attitudes toward the confirmation status of General Relativity and the Standard Model. This is true even if confirmation is *not* local and the confirmation status of an hypothesis can depend upon the empirical content of competing hypotheses. Consider, for example, the Standard Model's confirmation status if Bayesian confirmation theory is correct. If the Standard Model's actual content is the same as its apparent content, the likelihood of the Standard Model relative to evidence about spacetime's nonzero curvature is zero, since the Standard Model predicts, all on its own, that spacetime is flat. Hence, if the Standard Model's actual content does *not* differ from its apparent content, Bayesianism entails that available evidence disconfirms the Standard Model, contrary to the general attitude of the scientific community.

Of course, accommodating this attitude requires Bayesians to take into account the confirmation status of the Standard Model's competitors in addition to distinguishing the Standard Model's actual content from its apparent content. It

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[7] But see, for example, Michael Strevens' "Ceteris Paribus Hedges: Causal Voodoo That Works" (unpublished manuscript) for arguments that favor the first strategy.

seems plausible that no such competitor disconfirms the Standard Model in virtue of correctly characterizing some available evidence that the Standard Model does not. (General Relativity's predictions about spacetime curvature and other large-scale phenomena need not make General Relativity a competitor to the Standard Model, insofar as the Standard Model's actual content does not characterize those phenomena.) Establishing this, however, is beyond the scope of this paper. Here it suffices to note that doing so is possible insofar as Bayesianism is correct. For this shows that a nonteleological particularist approach to the content of scientific hypotheses can accommodate contemporary attitudes toward the confirmation status of the Standard Model even if confirmation is *not* local.

This approach does not address all the concerns about the confirmation of scientific hypotheses when distortions are involved. For instance, it does not address the apparent fact that confirming evidence often is idealized, due to the elimination of noise, the omission of outliers, and so on. Nor does the approach address the apparent fact that the background knowledge relative to which hypotheses are confirmed tends to be idealized. But it explains the apparent fact that the incompatibility of some predictions of General Relativity and the Standard Model with available evidence does not disconfirm these theories. It also helps to explain why some distorted hypotheses are not treated in the way that a thoroughly refuted theory is treated but instead as hypotheses with limited domains of applicability. And it does all of this without appealing to *ceteris-paribus* qualifiers or counterfactuals or similarity relations.

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