Laws of Nature as Epistemic Infrastructure not Metaphysical Superstructure

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"We need to rethink the idea of a scientific law pragmatically or functionally, that is, in terms of what scientific laws let us do rather than in terms of some ideal of a law…" Mitchell (2002).

Abstract
The status of laws of nature has been the locus of a lively debate in recent philosophy. Most participants have assumed laws play an important role in science and metaphysics while seeking their objective ground in the natural world, though some skeptics (Giere, van Fraassen, Cartwright) have questioned this assumption. So-called Humeans look to base laws on actual, particular facts such as those specified in David Lewis's Humean mosaic. Their opponents (including Maudlin) argue that such a basis is neither necessary nor sufficient to support the independent existence of scientific laws.

This essentially metaphysical debate has paid scant attention to the details of scientific practice. It has mostly focused on so-called fundamental laws, assumed to take a particular form (such as Maudlin's FLOTEs). I propose a pragmatist alternative—not as another position in the debate but as an alternative to the debate itself. This pragmatist alternative offers a view that questions the representational conception of truth presupposed by participants to the debate as well as the metaphysical import of fundamental laws.

Statements of law serve many different purposes in science: I'll look at some. But their central role is in inference, primarily to improve the epistemic state of a scientist with limited access to information. To play this role, a scientific law statement need be neither necessary, unconditionally universal nor even true. It must merely be sufficiently reliable within its domain of application. The use of laws in astrophysics and metrology will help to illustrate these points.

1. Introduction

Philosophers have long been puzzled by laws of nature. They strike us as more than brute regularities, and scientists tell us that they have discovered laws that lie behind and perhaps even control the patterns of events. But any such laws are hidden from us: we observe only the patterns, and scientific instruments merely reveal events exhibiting deeper regularities. Taking scientists at their word, contemporary metaphysicians have offered rival analyses of the concept of a natural law. But other philosophers see this analytic project as misguided since scientific practice makes no serious use of the concept. While my sympathies lie with the latter group, I think laws do play important roles in science. But when we see how they play these roles it will become clear that laws of nature are not what metaphysicians have taken them to be.

Laws are important in science even though we know of no empirical laws that apply everywhere, are necessary, or are even true. A law does not need to be any of these things to contribute to scientific knowledge. What it does need to do is to support reliable inferences.

After a preliminary survey of our target in the next section, section 3 distinguishes two rival views of scientific laws—as representations of an objective reality that many philosophers take to consist of more than actual (non-modal), particular facts; or as what Ryle called inference

tickets that make explicit those inferences we find to be reliable but not deductively valid. Taking the latter view helps illuminate the general function of laws in what I call the epistemic infrastructure of science. But a closer examination reveals several ways in which scientists use laws to gain knowledge.

Section 4 gives examples of ways in which laws have been used vastly to increase our knowledge of what there is in the universe and how it behaves. Section 5 exhibits the crucial role of laws in guiding our construction of theoretical models—in many ways the work-horses of contemporary science, whose successful application has given us so much scientific knowledge. Section 6 is devoted to the underappreciated value of scientific laws in metrology. It shows how laws have contributed to what I call the social epistemology of practical knowledge by permitting scientists and technologists to coordinate their actions by calibrating their instruments to shared standards.

While accepting that what pass for scientific laws have functioned to back inferences in all these ways, a proponent of the representational view may nevertheless maintain that an actual scientific law offers a more secure backing because it truly represents a deep feature of objective reality, where depth is measured by the modal strength associated with natural or metaphysical necessity, objective chance, or the logical necessity by which a theorem follows from laws taken as axioms. A law statement could offer such backing only if it were true. But law statements like those used in previous sections to illustrate the varied inferential functions of laws in science are not true. Either we know no scientific laws because none of our law statements faithfully correspond to objective reality, or truth is not a necessary condition on a statement of a scientific law. In section 7 I grasp the second horn of this dilemma.

Section 8 briefly considers rival accounts of laws of nature offered recently in what some call the metaphysics of science. All these accounts take a representational view of laws though they differ as to what exactly law statements represent. All are thereby committed to the truth of any statement at least of a fundamental scientific law (less fundamental laws may then be considered strictly false though approximately true in certain circumstances). But the scientific laws we know admirably serve their general and specific epistemic functions independent of their truth. So all these rival metaphysical accounts impose a requirement on laws of nature that our scientific laws don't meet now, and perhaps never could meet. Some accounts add further superfluous modal requirements.

In conclusion I argue for a turn away from metaphysics and toward pragmatism in our attempts to understand scientific laws. Ramsey took this turn already in 1929 when he denied that law statements are evaluable either as true or as false. Later, Ryle (1949) said that a law statement is true or false. But Ramsey had argued that their role in supporting reliable inferences showed that law statements were neither. Examination of the scientific function of laws reveals only shadows of the metaphysician's requirements of unconditional universality, necessity and even truth. Scientists seek maximal reliability (the shadow of necessity), maximal applicability (the shadow of unconditional universality) and maximal endorsability (the shadow of truth).

2. What is a Law of Nature?
When he called his four key statements about motion and gravitation laws of nature, Newton (1687) enshrined a usage that is now the common currency of scientists, philosophers and the general public. But the modern concept of a law of nature is now largely free of the theological

associations it had for Newton. As a deist, Newton thought God created the world so that it would develop in accordance with these laws, permitting rare violations only in the form of its creator's miraculous interventions. But we still hear echoes of Newton's concept in metaphors like natural laws *governing* what happens, or of natural laws' *dominion*, or of events as *subject to* laws of nature. Such metaphors suggest that events manifest laws that are embedded in or even in some sense prior to any patterns they display.

With the 20th century's linguistic turn, philosophers came to focus on law statements rather than anything in the world they may purport to describe or represent. Many have joined Carnap (1966) in identifying scientific laws with statements expressed by a class of general sentences: Ramsey (1929) had called these variable hypotheticals. But some have more recently returned laws to the world. Maudlin (2007) takes them as ontological primitives, while Weinberg (1996) took them to be as real as the rocks in the fields.

By beginning with language one can avoid premature discussion of what would make a law statement true and whether law statements are even truth-evaluable. Accordingly I'll take scientific laws to be statements expressed by sentences of natural or scientific language, usually if not always universal in form. Newton's laws are of this form, whether stated in a natural language (like Newton's Latin) or mathematics (e.g. $F=d(mv)dt$).

Many laws are usually called something else; equations (like the Schrödinger equation), principles (such as Archimedes principle and the superposition principle), constraints (including the Gauss and Hamiltonian constraints), hypotheses (Avogadro's hypothesis) and rules (the Born rule, Chargaff's rules). These alternative terms often mark the history or some special use of the law in question. In science some things are called laws although they are stated or used rather differently than typical scientific laws (Bode's law, Hubble's law, Moore's law, Zipf's law). Such variations in terminology should not distract attention from something important: that a typical scientific law has a characteristic general function in science. But what is that function?

3. Laws as Inference Tickets

By assuming that our statements about the laws of physics are in a one to-one correspondence with aspects of objective reality, Weinberg (1996) joined a venerable philosophical tradition. This tradition takes it to be the general function of a scientific law to truly represent a widespread if not universal regularity in nature that is more than just a pattern of coincidences. This then explains why by applying such laws we can better predict, explain and control natural events.

But a rival tradition maintains instead that the general function of a scientific law is simply to license inferences, including those required to predict, explain and control natural events. This tradition is skeptical of the idea that a scientific law truly corresponds to any modal aspect of the world like natural necessity, tendency or chance. And it takes improvement in our ability to predict, explain and control events to follow just from successful exercise of this general function in the absence of any such correspondence.

In his (1929, [1990, p. 149]) Ramsey took his place in this rival tradition when he said "variable hypotheticals are not judgments but rules for judging". He maintained further that these sentences (including those used to express causal laws and laws of nature) express cognitive attitudes without [what they express?] being propositions. By doing so he distanced himself from the view sketched in his (1928) that warranted his name's inclusion with J.S. Mill and David Lewis as the second initial of the acronymic MRL view of laws.

His *Concept of Mind* (1948) made Gilbert Ryle a more widely known exponent of an inferential view of laws of nature, especially through his description of them as inference-tickets.

> Law-statements are true or false but they do not state truths or falsehoods of the same type as those asserted by the statements of fact to which they apply or are supposed to apply. They have different jobs. The crucial difference can be brought out in this way. At least part of the point of trying to establish laws is to find out how to infer from particular matters of fact to other particular matters of fact, how to explain particular matters of fact by reference to other matters of fact, and how to bring about or prevent particular states of affairs. A law is used as, so to speak, an inference-ticket (a season ticket) which licenses its possessors to move from asserting factual statements to asserting other factual statements. It also licenses them to provide explanations of given facts and to bring about desired states of affairs by manipulating what is found existing or happening. (p. 105)

Ryle's distinction between two types of truth (statements of fact and the true law statements to which they may apply) is similar to Carnap's (1966). In Carnap's view the distinction is made already at the syntactic level, to be backed up by application of the standard semantics of first order logic. Ryle on the other hand locates "the crucial difference" at a pragmatic level in terms of their distinct functions: unlike statements of fact, the function of law statements is to license inferences. While sharing Ryle's view of the function of law statements, Ramsey takes a further, more radical step. In his (1929) he appears to accept Carnap's view of the logical form of sentences used to express law statements. But by denying these the title of propositions he declines to evaluate them as true or false in accordance with the standard semantics of first order logic. Rather than presenting an alternative semantics of variable hypotheticals he offers a subtle account of a speaker or hearer's differing cognitive attitudes toward an utterance or inscription of a variable hypothetical that may lead him to judge it not true or false but right or wrong.

The dispute within the inferentialist tradition of how law statements are best understood has significant implications for their representational status, so it bears on the metaphysical import of laws of nature. I'll return to this issue after describing and illustrating several ways in which the inferential power of laws contributes to scientific knowledge. The illustrations are of independent interest. But I have deeper motives for offering them. One is to develop the schematic characterization of the goals of science as prediction, explanation and control by exhibiting other ways in which laws undergird the epistemic and practical activities of scientists. I see this as a way of combating skeptics such as van Fraassen (1989), Giere (1999) and Cartwright (2016) who have minimized or dismissed the importance of laws in understanding the scientific enterprise. Another motive is to show how each of these epistemic contributions supports an inferentialist approach by explaining why scientific laws lack many of the features attributed to them by contemporary metaphysicians as well as previous generations of philosophers of science.

4. Laws Extend our Knowledge
A few people have left the earth to visit just a tiny portion of the solar system, and we have sent machines barely outside of it. Yet science has given us a great deal of knowledge of the universe. How has this been possible? The construction of instruments such as telescopes and now

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gravitational observatories like LIGO and VIRGO has certainly played an essential role. But without scientific laws these would be unable to deliver the knowledge we get by using them. Laws fuel such epistemic engines: laws form an essential part of the epistemic infrastructure of the scientific enterprise.

Helium provides a striking example. This element was first found not on earth but on the sun from which it derives its name. Spectroscopic analysis of telescopically collected light from the sun revealed lines that did not correspond to those characteristic of any known terrestrial element. The laws of spectroscopy that underlay this characterization were known well enough to justify scientists in adding a new element characterized by the newly observed spectral lines, even though it was only 27 years later that a sample of an element with this spectrum was isolated on earth.[1] Of course the justification of the claim that a hitherto unknown element was present on the sun depended on much more than just the laws of spectroscopy. But they played an essential role in establishing this as scientific knowledge.

Astrophysics is a rich source of examples of the use of scientific laws to transcend our local situation to vastly expand our knowledge of the universe. We can see laws in action in the current controversy over the value of the Hubble constant H. Recall that Edwin Hubble is credited with the discovery that on a large scale the universe is expanding in such a way that, on average, the relative velocity at which a distant galaxy is receding from the Earth is proportional to its distance from us: $v=Hd$, where H is now known as the Hubble constant.

A chain of inferences in conventional observational astronomy based on the so-called cosmic distance ladder led to the 2017 estimate that $H= 73.2$ km/sec/megaparsec. But, when applied to observations of anisotropies in the cosmic microwave background radiation, laws used to construct current cosmological models license the inference to the value $H= 67.8$ km/sec/megaparsec. This may not look like a big discrepancy. But careful analysis of the observational errors in each case indicated that the two estimates are separated at the 3σ level, meaning that there is a probability of only 0.13% that the conclusions of both inferential chains are correct.

The cosmic distance ladder is based on observation of light emitted by distant stars. Geometric parallax measurements yield good estimates of the distance only to nearby stars in our galaxy. But these include so-called Cepheid variables, whose analysis by Henrietta Leavitt and Harlow Shapley proved crucial to Hubble's work by providing the next rung in the ladder, permitting inference to the distance of other galaxies—indeed, to the *existence* of other galaxies besides our own Milky Way.

In 1912 Leavitt noted a rough empirical regularity between the apparent brightness and period of variation of a number of stars whose brightness varied regularly in the same way over a period of from 1 to several hundred days. Since some she studied seemed to be located at roughly

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[1] The discovery of helium is a bit like that of oxygen (Kuhn (1962, pp. 56−56)). In 1868 Lockyer observed a line in the spectrum of light from the solar corona that he had not seen before in any spectrum, although Janssen had seen this line during a solar eclipse earlier that year. Lockyer first took the line to be produced by an unknown element present in the solar corona which he went on to call helium, but he later came to doubt that a new element gave rise to this line. The spectral line was observed in gases emitted by Vesuvius in 1882, but only in 1895 was a sample of an inert gas producing this line isolated in the laboratory. After obtaining a sample himself and observing its spectrum, Lockyer identified the gas with the new element helium he had initially taken to be responsible for the new spectral line he had observed in light from the solar corona in 1868.

the same distance from the earth (in the small Magellanic cloud) this indicated a corresponding relation between period and absolute magnitude. At this stage no-one knew *why* these stars varied in brightness. It was simply assumed that the regularity was reliable enough to be extrapolated to all similar stars, wherever they were: the regularity was treated as a law licensing subsequent inferences from the apparent brightness of any such variable star to its distance, basing its absolute magnitude on its period and assuming another better-established law—that apparent brightness is inversely proportional to distance squared.

Hubble's first crucial move was to identify individual Cepheid variable stars in "nebulae" and, using the period/magnitude relationship, to estimate their distance from the earth, thereby concluding that these "nebulae" were actually entire galaxies of stars far beyond our own galaxy.[2] His second crucial move was to use other laws to estimate the velocitie*s* of many of these galaxies.

Two kinds of laws were needed here, both on much firmer epistemic ground than the Leavitt-Shapley relation for Cepheid variables. A law associated with the Doppler effect permitted an inference from the observed frequency of a moving source of radiation to its velocity of recession from the observer. And laws of spectroscopy correlated frequencies of particular spectral lines with the element in whose spectrum they lay, so that even a "red-shifted" line in the spectrum of a particular element in a moving source could still be uniquely correlated with the same line for an atom of the element at rest.

After using all these laws to estimate both the distance to and the velocity of several galaxies, Hubble noticed a regular but far from perfect correlation between these two magnitudes. This came to be known as Hubble's law describing the expansion of the universe. A refined version came to stand on firmer ground after further observational and theoretical developments.

The mechanism of Cepheid variability came to be understood, first in terms of thermodynamics and later in terms of the difference between how singly- and doubly-charged helium ions in its outer layers absorb the radiation emitted by a certain kind of large star. These more fundamental laws improved the epistemic status of the Leavitt-Shapley law, while also showing why other kinds of variable stars do not conform to it. This is a nice example of how something that began as a somewhat shaky empirical regularity can be refined as well as strengthened using inferences licensed by other laws, thereby improving the connections in the inferential web constituting what I called the epistemic infrastructure of science.

Many galaxies are still too far away for us to identify Cepheid variable stars in them using even the best telescopes—they are just not bright enough. But more recently astronomers have found a much brighter "standard candle" among supernovae—exploding stars that can briefly outshine their entire galaxy. The mechanism of a particular kind of supernova is believed to be well enough understood for astrophysicists to feel confident that at peak they are all equally bright. (A Type IA supernova is believed to occur when, through accretion from its companion, a white dwarf star orbiting a larger star approaches the Chandrasekhar limit of 1.44 solar masses beyond which it cannot support itself by degeneracy pressure. This can initiate an uncontrolled

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[2] Hubble also used two other plausible principles in a complex interlocking set of inferences to estimate distances. I thank John Norton for alerting me to the finer structure of Hubble's reasoning that he explores in Norton (unpublished), as well as his suggestion to look more closely into the history of the "discovery" of helium on the sun.

fusion reaction in the white dwarf that blows it apart in a few seconds, releasing an enormous amount of energy as radiation.) The peak brightness is constant insofar as it always arises from the same mechanism in stars of the same mass.

It is because the laws used to infer this conclusion are quite fundamental that the observed brightness/actual brightness correlation is taken to permit a reliable inference to the distance of the galaxy in which the supernova occurred. Observations of Type IA supernovae since 1998 provide our strongest evidence that the expansion of the universe is actually accelerating: our distance from a typical distant galaxy is increasing faster than linearly with time. But the Hubble "constant" is not constant but *decreases* with time: a galaxy at a certain large distance from us is typically receding from us slower than another galaxy at that distance in the past. In this case, refinement of a law has shown that it does not hold at all times, contrary to what many philosophers have considered essential to laws of nature. Nevertheless, the inferential procedures I've just sketched seem reliable, and by 2017 they had yielded a value of $H= 73.2$ km/sec/megaparsec for the current value of the Hubble "constant".

Now rungs of the cosmic distance ladder have given way in the past: Using a more primitive form of the same basic methodology, Hubble himself estimated the value of H as 500! And we now have a very different chain of inference to the current value of H that doesn't even involve observing stars and figuring their distances from the Earth. Instead it appeals to a careful analysis of anisotropies in the cosmic microwave background radiation (CMB) that provides some of the most conclusive evidence for the "Big Bang" that initiated the universe's current expansion.

My treatment of this alternative inferential chain will be brief and unoriginal I'll simply quote Joshua Sokol's account from a (March 10, 2017) issue of *Science*.

> In 2003, the Wilkinson Microwave Anisotropy Probe (WMAP) published its first map showing the speckles of temperature variations on the CMB. The maps provided not a standard candle but a standard yardstick: a pattern of hotter and colder spots in the primordial soup created by sound waves rippling through the newborn universe. With a few assumptions about the ingredients in that soup—familiar particles like atoms and photons, some extra invisible stuff called dark matter, and dark energy—the WMAP team could calculate the physical size of those primordial sound waves. That could be compared to the apparent size of the sound waves as recorded in the CMB speckles. The comparison gave the distance to the microwave background, and a value for the expansion rate of the universe at that primordial moment. By making assumptions about how regular particles, dark energy, and dark matter have altered the expansion since then, the WMAP team could tune the constant to its current rate of swelling. Initially they came up with a value $H= 72$. [But more recently] Planck, a European Space Agency mission that has now imaged the CMB at higher resolution and greater temperature sensitivity, has settled on the value for H of 67.8.

In this episode we see a problem in the epistemic infrastructure of science. It's as if two teams, using the most advanced surveying and engineering techniques available, began tunneling from different sides of the Alps to build a road or rail link between Switzerland and Italy, but found that their tunnels failed to meet in the same place under the mountains.

Since 2017 several other relatively independent methods of measuring the Hubble constant have been developed, resting on other observations, laws and astrophysical models. As I write these have still not resolved the discrepancy between estimates based on observations of supernovae and observations of the cosmic microwave background. But the different methods may be reconciled either by locating systematic errors of observation or by suitably modifying astrophysical or cosmological models. The use of laws in constructing these and other scientific models is the topic of the next section.

5. Laws Guide Theoretical Modeling

According to Giere (1999, p. 90)

> ...the whole notion of "laws of nature" is very likely an artefact of circumstances obtaining in the seventeenth century. To understand contemporary science we need not a proper analysis of the concept of a law of nature, but a way of understanding the practice of science that does not simply presuppose that such a concept plays any important role whatsoever.

Giere proposed instead that we should understand science as essentially a modeling activity. He allows that there are principles that guide scientists in constructing the models they use to represent natural systems and he includes Newton's "principles" of mechanics in this category. Newton's three key "principles" of mechanics continue to serve as exemplary scientific laws whatever he may have believed about their pedigree. So while Giere was right to stress the importance of modeling as a scientific activity it is no abuse of usage to acknowledge the vital role of laws in guiding the practice of theoretical modeling in science.

The previous section gave several examples in which laws have been used in constructing models of natural systems: the laws of thermodynamics and laws of the emission, absorption and propagation of radiation are involved in modeling the behavior of Cepheid variables; Pauli's exclusion principle and laws from the theory of relativity are involved in modeling type 1A supernovae; laws of general relativity and equations of state for different forms of matter are involved in cosmological models. But laws are used to guide modeling in quite different sciences.

The Hodgkin-Huxley model of the creation and propagation of action potentials in the giant axon of the squid was a seminal achievement in neuroscience. The mathematical model is a set of nonlinear differential equations representing currents through and voltages across channels in the axon through which may flow sodium and potassium ions. Simple laws of electric circuits form the basis of the model. The model equations were constructed by inserting variables and constants into these laws to represent the conductances of channels through which ions pass or the level of a channel activation. The way these additional variables varied with voltage differences and time was modeled by independently postulated equations containing parameters that could be estimated experimentally by fitting the model to experimental data.

While used by Hodgkin and Huxley to construct a model in neuroscience, Ohm's law, the capacitance equation and Kirchoff's laws of electric circuits are laws of physics. But laws of other sciences are also used in model construction. The Hardy-Weinberg law is used as a starting point for constructing models in population genetics, typically by modifying it to represent the

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effects of factors it does not represent, such as migration, mutation or selection. The Lotka-Volterra equations form a basis for constructing more realistic models of predator-prey dynamics.

Many laws are used in constructing climate models of the earth. These include the laws of thermodynamics, the Navier-Stokes equations for fluid flow, the Stefan-Boltzmann law, the Clausius-Clapeyron equation, and the laws of conservation of mass and momentum. Key inputs to these models include generalizations about the absorption by various gases (including carbon dioxide, methane and water vapor) of electromagnetic radiation at different wavelengths. These are sufficiently insensitive to environmental conditions to warrant classification as scientific laws.[3]

It is common for scientists to respond to skepticism about the use of climate models by appeal to the epistemic pedigree of the laws used in their construction. They say that most if not all of these laws have been thoroughly tested and used for a very long time successfully to predict, explain and control a wide range of phenomena otherwise unrelated to the climate.

> Each of the components (submodels) and the individual processes must obey the basic physics and chemical laws of the world around us. An important overlooked fact is that the fundamental principles of climate modeling are not new. Simulating the earth system relies on principles of physics and chemistry that have been known for 100–300 years. (Gettelman and Rood (2016, p. 38))

These laws are fundamental to the construction of successful models of the climate and many other phenomena. But as Gettelman and Rood (*ibid*) go on effectively to acknowledge, few if any of them are universally applicable.

> The existence of a new subatomic particle does not require us to change our climate models. They contain no complex physics (like presumptions of warping space-time).

All the laws mentioned in the previous paragraph fail to apply to phenomena that are believed to occur in extreme conditions, some of which can be created in the laboratory while others obtain at other space-time locations in the universe. Most physicists would be willing to call a law fundamental only if it applied even to such phenomena.

6. Laws Align Individual Actions Section 4 showed how scientific laws may be used to extend our knowledge of the universe. By using them we first learned that helium exists on the sun and now know that it composes 24.7% of its mass. Section 5 illustrated the use of laws to construct models. By using law-based models of nuclear physics, gravity and thermodynamics we now understand how the sun is able to continue radiating vast amounts of radiant energy, primarily through the so-called *p-p* fusion process that produces helium from the hydrogen that the sun is mostly made of.

This knowledge is all theoretical. But more practical knowledge also depends on the use of scientific laws. Geometry (earth-measurement in the original Greek) has been a source of practical knowledge at least since the Babylonians used Pythagorean triples of numbers to form

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[3] They are strong, stable and relatively abstract in Mitchell's (2000) dimensions of scientific law.

right angles when dividing up land. But since then empirical laws of Euclidean geometry (including Pythagoras's theorem) have been successfully used by surveyors, architects, builders and mechanics of all kinds as a basis for their practical knowledge. Today our knowledge of where we are and how to get where we are going increasingly depends on the laws of general relativity incorporated in the software of the satellites whose precisely timed signals form the basis of the global positioning system. Warped space-time is not just a presumption: even practical knowledge depends on its laws when these are applied in situations in which Euclidean geometry is no longer applicable.

We measure a lot more than just the earth. My high-school physics teacher offered a definition of physics as the science of measurement. But that title has already been bestowed on metrology, the science which, "embrac[es] both experimental and theoretical determinations at any level of uncertainty in any field of science and technology" to quote the International Bureau of Weights and Measures (BIPM, 2004). Scientific laws are basic to metrology. Metrology, in turn, is basic to practical knowledge.[4] This is made manifest by a recent episode.

As of May 20th, 2019 the basic units of measurement of the international SI system have been redefined. No longer is the unit of mass defined as that of the standard kilogram—a particular platinum-iridium cylinder stored in a vault near Paris. Just as the meter is now defined in terms of a fundamental constant c (the speed of light in a vacuum) the kilogram is now also defined in terms of another fundamental constant—Planck's constant h—which has also been assigned a fixed value by definition, as has the unit of electrical current, the ampere, which is defined in terms of the now fixed value of a third fundamental constant, the charge e of the electron. As before, the second is not defined in terms of a fundamental physical constant, but nor is it defined in terms of any *particular* object: one second is defined as the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of any cesium 133 atom. The fundamental constants c, h, and e all figure in fundamental physical laws. The dimensionless fine structure constant $2\pi e^2/hc$ is a fundamental number in physics representing the strength of the electromagnetic interaction between two elementary charges

The place of fundamental constants in fundamental laws suggests that the idea behind these changes in standards is that a standard unit should be accurately reproducible by anyone anywhere, given enough effort. This implies that a fundamental standard should not depend on the properties of any particular object, and preferably not on those of a particular kind of object. Realizing the standard should be possible "whatever objects are to hand": and its realization should involve the most accurate[5] measurements that are available.

But there is a problem with this idea. The constraint of accurate measurement is in severe tension with the constraint of universal availability of materials. A more adequate justification will illustrate several important contributions scientific laws make to what we might call the social epistemology of practical knowledge.

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[4] An engineer once offered this alternative definition: "Metrology is the science of measurement and the technology behind the quality assurance processes in manufacturing that ensure a car runs the way it should, the computer's processor works properly, aircraft stay in the air and more aspects of daily life that we take for granted – until something goes wrong." (https://www.ee.co.za/article/metrology-the-science-of-measurement.html online 4th February, 2019).

[5] Here the term 'accurate' may be taken in any of the five senses distinguished by Tal (2011, pp. 1084-5).

Our science and technology increasingly depend on the coordination of actions throughout a network of diverse and spatiotemporally separated groups and individuals. This is true whether the goal is to build and operate a commercial jet or a new astronomical telescope. Since many of these actions depend on locally performed measurements, their outcomes must have the same significance throughout the network, lest (to take an extreme case) a tire measured in one country last year to have internal diameter 36 cm in one factory fail to fit the rim of a wheel measured in another today to have 36 cm external diameter. Epistemic as well as practical considerations are best served by locating epistemic authority for standardization of measurement units with a group (BIPM) delegated with the task of defining those units and certifying methods for their accurate material realization and global dissemination. Currently the most accurate realization of a standard kilogram is provided by a watt balance.

A measurement with a watt balance involves accurate measurements of a current and a voltage. The connection to Planck's constant and the elementary charge comes in because two quantum effects permit the extremely precise calibration of this current and voltage against standards directly related to h and e.

A law associated with the Josephson effect connects the voltage drop V across a junction in a superconducting circuit to Planck's constant h and the magnitude of the charge e of an electron by $V=nhf/2e=nf/K_J$, where f is the (accurately measurable) microwave frequency with which the junction is illuminated, n is an integral number of voltage steps, and K_J is known as the Josephson constant. A law associated with the quantum Hall effect connects quantized values of the "resistance" R exhibited in a special kind of electrical circuit in a strong magnetic field at low temperatures to the same magnitudes by $1/R=I/V=ne^2/h=1/R_K$ where n is an integer or simple fraction and R_K is known as the von Klitzing constant. Together these laws imply $h=4/K_J^2 R_K$, so precise determinations of Josephson and von Klitzing constants formerly permitted a precise determination of h and e by reference to accurately measured currents and voltages. But since the values of h and e have been fixed *by definition* measurements in the Josephson and quantum Hall effects may be taken instead to permit the accurate reproduction of standards of voltage V and resistance R, hence current $I=V/R$ and power $W=VI$.

Determining the mass of an object by a Kibble balance requires measurements in two stages. In weighing mode the object is placed in one pan of the balance. The downward force on the object due to gravity is balanced by an upward force whose origin is electromagnetic. This force is exerted on a coil connected to the side of the balance containing the object because a current is passed through the coil as it sits in a strong magnetic field. When the forces are equal
$$Mg=IBl \qquad (1),$$
where M is the mass of the object to be measured, g is the local acceleration due to gravity, l is the length of the coil through which current I is passing, and B is the magnetic field strength where the coil is. The stationary balance point is located using laser interferometry.

In moving mode the object is removed and the same side of the balance is slowly moved vertically at a constant speed u through the magnetic field B, inducing a voltage V in the coil, where
$$V=uBl \qquad (2)$$
Putting (1) and (2) together we get
$$Mgu=VI \qquad (3)$$
The watt balance gets its name from equation (3), equating (virtual) mechanical and electrical

power. A laser interferometer is used to accurately measure u, and g can also be measured extremely accurately, essentially by dropping the mirror of an interferometer and applying Galileo's law!

Many different laws are used to model a watt balance, from very different areas of physics and with very different pedigrees, from Galileo's law of free fall through basic laws of classical mechanics and electromagnetic theory to quantum theoretic laws of the Josephson and Hall effects. Many other laws are used to correct for potential errors, including laws of the relativistic 2nd order Doppler effect; and laws of classical rigid body mechanics.

Note that the watt balance does not realize a mass unit by comparison to the mass of a real or ideal mass: this is no Reichenbachian coordinative definition. By contrast, realizations of the second are made by comparison to oscillation periods of real or ideal Caesium atoms. Instead the watt balance realizes a mass unit by relating mass to other quantities whose values are now fixed by definition: Planck's constant, the elementary charge, the speed of light, and a hyperfine frequency of an ideal caesium atom. The law stated by equation (3) is key to establishing these relations. So this law plays a role in coordinating the quantitative mass concept to objects and processes in the physical world. But other laws are also involved in the coordination, such as the laws of the Josephson and quantum Hall effects and some form of Galileo's law.

By fixing the values of fundamental constants, the new definitions of SI units leave open the possibility for improved realizations of a mass unit that relate mass to quantities that are more accurately measurable, *via* other laws involving these constants. This is one way in which the discovery of scientific laws like those of the Josephson and quantum Hall effects has contributed (and they or other laws may in future contribute again) to improvement of scientific concepts.

Tal (2017) has offered another justification for the 2019 change in SI units that assigns a further role to laws. A theoretical model makes it possible to estimate the systematic errors involved in the readings of any instrument by comparison to the outcomes of a second instrument whose measurement outcomes are taken as reference values of the measured quantity. Multiple such pairwise comparisons can secure coherence within a group of instruments: they are coherent only if the deviations of each instrument's outcomes from the outcomes of any other instrument lie within that instrument's range of uncertainty. But such pairwise comparisons are impracticable in a large network of instruments, and coherence within each small part of the network does not guarantee global coherence.

By adopting a measurement standard scientists can secure coherence across an epistemic network. The assumptions used to model a standard measurement process then *prescribe* how the measured magnitude is to be applied in that process by regulating the correction of systematic errors across the network: the standard is taken to be subject to no systematic errors. Since this involves the laws used to construct the model, those laws become more than just empirical generalizations. When a standard so modeled is declared free of systematic errors the laws used to model it acquire normative authority over the network.

For a while before the 2019 redefinition, the Josephson and quantum Hall effects realized working standards of electrical measurements and so regulated the treatment of systematic errors in electrical measurements. Since the definitions of basic SI units already had standard realizations regulating systematic errors, electrical measurements drifted free from the rest of the network. That epistemic electrical "island" has now been reconnected to the main network by giving the working electrical standards legislative authority as a measurement standard also for

mass and electric current.

The new SI definitions effect an improvement in the social epistemology of science by enabling the consistent application of measurement standards for magnitudes represented in the SI system by all scientists everywhere. The uniform calibration of instruments under the ultimate authority of these standards is important practically, not only in science but in any activity that involves accurate measurement. A great deal of practical knowledge is required to realize the new standard of mass, since a watt balance is very difficult to construct and operate successfully. But, somewhat paradoxically, adoption of the new standard has had only minimal impact on the practical activities of most "end users" in science and technology, very few of whose instruments are sensitive enough to require recalibration.

Each of the different laws involved in modeling the operation of a watt balance played its role in building the tight inferential web supporting the final inference to the mass of an object weighed by the balance. Once built, this web better coordinates our quantitative mass concept with the physical world. Adopting the watt balance as a standard realization of this concept endows the laws involved in modeling its operation with epistemic normative force in regulating systematic errors involved in mass measurements over a global social network. But each of these laws was applied only in a domain in which it could be relied on, despite the fact that the conjunction of all these laws would quite likely be inconsistent. Here, as elsewhere, the reliable inferential application of a law in science does not require either its truth or its unconditional universality, let alone its necessity. Scientific practice reveals these requirements as philosophers' myths, even when laws are applied in pursuit of a goal requiring maximum overall accuracy.

7. Are Laws True?

If it were the general function of a scientific law truly to represent a universal empirical regularity that is more than just a pattern of coincidences then every law mentioned in this paper falls short, since none of them are applicable to all physical phenomena. Considered as universal empirical generalizations, most or all of them are known to be subject to exceptions and hence not to be true. Even the law of conservation of mass-energy is problematic in its application to general relativistic phenomena where the concept itself is difficult to define.[6]

It is common to locate the best current candidates for fundamental laws of nature in the physics of the Standard Model of so-called elementary particle physics and in the general theory of relativity. But despite its unblemished record of success, the Standard Model is now regarded as merely an effective theory—a low energy limit of some unknown (quantum field?) theory that is still applicable at the higher energies where the Standard Model breaks down. And there are believed to be extreme phenomena involving black holes and the early universe that cannot be modeled by general relativity, whose laws do not encompass quantum effects. If unconditional truth were a requirement for a law of nature then no laws of nature are known to current science.

Undeterred by this absence of examples, a proponent of the representational conception of scientific laws as unconditionally (i.e. not *ceteris paribus*) universal, non-accidental, empirical

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[6] Carroll (2010) argues that it is less misleading to call this conservation law false in general relativity than to say that mass-energy cannot there be defined. But he acknowledges that "plenty of experts in cosmology or GR would not put it in these terms. We all agree on the science; there are just divergent views on what words to attach to the science. In particular, a lot of folks would want to say 'energy is conserved in general relativity, it's just that you have to include the energy of the gravitational field along with the energy of matter and radiation and so on.'"

truths may hold up this conception as a regulative ideal of science—an ideal that science has been approaching by way of progressive approximation. But the radical conceptual changes revealed by the history of fundamental science render this notion of approximation dubious at best. More importantly, what science has come up with by way of scientific laws have admirably performed epistemic and practical functions including those described earlier in this paper. Our scientific knowledge rests on the epistemic infrastructure they constitute.

In general epistemology a statement is usually considered to be known only if it is true. If a scientific law is not true then how can it contribute to scientific knowledge? The inferential conception of scientific laws offers an answer to this question: whether or not it is true, a scientific law contributes to knowledge by licensing inferences that are generally reliable in those contexts in which they are licensed. Physicists often call such a context a regime, as when they say that Newton's law of gravity is applicable in a regime of low relative velocities and small space-time curvature. If several laws are used in constructing a model of an object or process, it becomes important to judge that all of them together permit reliable inferences in that context. Physicists prioritize the search for a theory of quantum gravity because laws of currently fundamental theories of quantum theory and general relativity do not permit reliable inferences in regions in the interiors of black holes and in the early universe. So we don't know what happens there. Some may share Weinberg's (1992) dream of a final theory whose laws would be universally applicable and truly correspond to objective reality at the deepest level. But during their waking hours scientists have more modest goals whose attainment they could recognize.

While agreeing about the inferential function of laws, Ramsey and Ryle disagreed about their truth status. Ryle (1949) claimed that law-statements are true or false, while Ramsey (1929) claimed that they are not propositions capable of the two cases of truth and falsity: as he put it, they are not judgments but rules for judging. Ramsey here embraced the instrumentalist view that a law-statement (a "variable hypothetical") lacks a truth-value.

A standard objection to such instrumentalism is to point to examples in which a scientist makes an inference from the conjunction of two or more scientific laws that is not a logical consequence of any single one of them (as in the derivation of Galileo's law of free fall from Newton's laws of motion and gravity). Such an inference may be deductively valid, but it is sound only if the premise laws are true.

What the objection fails to recognize is that scientific inferences from laws need not be sound but merely reliable in the context in which they are made. Hubble's inference to the existence of other galaxies was based on Leavitt's generalization about Cepheid variables as well as the inverse square law for light intensity. But Leavitt's law was not even true of the observed instances on which it was based: she arrived at it only by fitting a curve to data points that clearly failed to lie on it. When a scientist makes an inference from a law she does not assume its truth: she assumes only that she is warranted in using it to infer her conclusion in this specific context. Further investigation may undermine her assumption or bolster it while more precisely delineating the scope of the law's reliable application. This is an important example of the fallibility of scientific knowledge.

Even if scientific laws are not true, it seems harsh to call them all false. Elgin (2017) calls them (along with much else in science and art) true enough, thereby nicely alluding to their function in serving our purposes. Ramsey's alternative was to take laws' constitutive role in inference as a reason to refuse to evaluate them in terms of truth or falsity. How or whether we

choose to apply the term 'true' to scientific laws is not of great importance in understanding science. I think we should take our cue from scientists themselves who rarely use the term in this context, talking instead of a law's scope, limits and reliability. When a scientist talks of known and unknown laws this conception of knowledge rarely carries a commitment to truth.

8. Laws and Naturalistic Metaphysics

According to a contribution (Dorato and Esfeld (2015)) to a recent collection of essays on metaphysics in contemporary physics, there are three main stances with respect to laws of nature in current philosophy of science: Humeanism, primitivism and dispositionalism. I stand for none of these. As a philosopher of science focusing on physics I have illustrated my general arguments here mostly by examples chosen from that science. But the arguments are meant to apply anywhere scientific laws are used to gain knowledge of the world: and their conclusions are about science, not about metaphysics. They seek not only to undermine all "three main stances" but also to motivate a turn away from metaphysics in the philosophy of science and toward pragmatism.

Humeans consider the world to be a mosaic of matters of actual, particular fact, and laws to be the axioms of the description of this mosaic that achieve the best balance between simplicity and strength. Lewis (1994) gave a seminal presentation of this view, and others have offered modifications, following in his footsteps (e.g. Cohen and Callender (2009), Hall (2015), Loewer (2021)). Lewis credits Ramsey with a forerunner of this view in a paper (1928) whose main idea Ramsey summarized later (1929): "…laws [are] a consequence of those propositions which we should take as axioms if we knew everything and organized it as simply as possible in a deductive system".

But Ramsey here summarized his earlier view only immediately to completely reject it on the grounds that it is impossible to know everything and organize it in a deductive system. Doubtless Lewis was well aware of Ramsey's change of mind, but he offered no good objection to Ramsey's reason for rejecting his former view, despite the fact that it would apply equally to Lewis's own account of laws of nature. Scientists rarely try to formulate even a single theory as an axiomatic system; the scientific laws we have are not even true, let alone universally applicable; and we have excellent reasons to doubt that the progress of science will converge on any body of knowledge that could be organized as a single axiomatic system.

According to primitivism, true scientific law-statements correspond to modal facts about the world over and above all (or even any) matters of actual, particular fact. In Maudlin's (2007) version, fundamental laws of temporal evolution (FLOTEs) do not organize but *generate* actual, particular facts as well as whatever consequent patterns these display. I find talk of a generation relation among particulars as obscure as Ramsey found talk of a real relation among universals:

> … may there not be something which might be called real connections of universals? I cannot deny it, for I can understand nothing by such a phrase; what we call causal laws I find to be nothing of the sort. (1929; [1990, p. 160]).

What about dispositionalism? On this view (Dorato and Esfeld (2015)) local matters of particular fact instantiate one or more properties that fix the behavior of these local happenings, for example the temporal development of an initial configuration of particles. Such properties are

dispositions or powers that ground a law in the sense that the latter is made true by the former. So in this view laws are not primitive but nor do they offer a simple yet strong summary of non-modal facts. Instead laws inherit their modal content from that of modal properties instantiated by local matters of particular fact.

But as we have seen, whether a law fulfills its function in science is largely independent of whether it is true or even truth-evaluable. Hence a scientific law requires no ground of truth in dispositions, powers or other modal properties. This is fortunate because we have no epistemic access to any such modal properties even if we can convince ourselves that we mean something when we talk about them.

While doing science, scientists seldom evaluate the laws or theories they use in terms of truth or falsity. But when reflecting on what they have done they are prone to join some philosophers and other commentators in applying those terms quite casually. Praising the achievements of fundamental physics while commenting on its currently fluid state, an August 2021 issue of *The Economist* included the following passage.

> Physicists have got used to the idea that mathematical theories can be turned into reliable representations of reality, thus producing understanding. And one discovery based on maths that physicists were pretty confident of making was of a phenomenon called Supersymmetry, which gives coherence to the current, rather ad hoc explanation of the menagerie of fundamental particles that has been collected since the 1890s. Supersymmetry is a stalking horse for a yet-deeper idea, string theory, which posits that everything is ultimately made of infinitesimally small objects that are most easily conceptualised by those without the maths to understand them properly as taut, vibrating strings.
>
> So sure were most physicists that these ideas would turn out to be true that they were prepared to move hubristically forward with their theorising without experimental backup—because, for the first decades of Supersymmetry's existence, no machine powerful enough to test its predictions existed. But now, in the form of the Large Hadron Collider, near Geneva, one does. And hubris is turning rapidly to nemesis, for of the particles predicted by Supersymmetry there is no sign.

The passage never mentions laws, and it applies the term 'true' directly not to the theories it does mention but to the ideas behind them. But it is not unreasonable to assume that its authors share the popular view that a theory contains laws, and that the threatened nemesis would involve rejection as false of some law or laws of supersymmetry.

It is noteworthy that the quoted passage also assigns to fundamental physics the role of reliably representing reality. The passage suggests (without quite endorsing) the view that it is a distinctive goal of fundamental physics to contribute to metaphysics by faithfully representing reality at the deepest level. The contrast is with other parts of physics and the rest of science which may achieve their goals by deploying idealized models and laws that are at best only approximately true in certain circumstances. In this view, whatever the function of laws in other parts of science, fundamental physics seeks laws whose function is to offer objectively true representations of reality.

Weinberg (1998) expressed this view as follows

We hope that in the next great step forward in physics we shall see the theory of gravitation and all of the different branches of elementary particle physics flow together into a single unified theory. This is what we are working for and what we spend the taxpayers' money for. And when we have discovered this theory, it will be part of a true description of reality.

Earlier in the same essay he had defended such uses of the terms 'true' and 'real'

I know that it is terribly hard to say precisely what we mean when we use words like "real" and "true." That is why, when I said that the laws of nature and the rocks on the ground are real in the same sense, I added in parentheses "whatever that is." I respect the efforts of philosophers to clarify these concepts, but I'm sure that even Kuhn and Rorty have used words like "truth" and "reality" in everyday life, and had no trouble with them. I don't see any reason why we cannot also use them in some of our statements about the history of science.

But in his (1996) Weinberg had acknowledged that he was "making an implicit assumption (which in everyday life we all make about rocks) that our statements about the laws of physics are in a one-to-one correspondence with aspects of objective reality". Ramsey (1929) would have rejected this assumption, while Rorty exposed its vacuity in his essay "Thomas Kuhn, Rocks and the Laws of Physics" (1999).

If fundamental physics were to offer a true description of reality including laws in a one-to-one correspondence with basic aspects of objective reality, then this could justifiably be considered a contribution to naturalistic metaphysics. Maudlin (2007) took physics to have even greater metaphysical content when he said

I am a physicalist about laws: the only objectively primitive laws I believe in are the laws of physics. Speaking picturesquely, all God did was to fix the physical laws and the initial physical state of the universe, and the rest of the state of the universe has evolved … from that. Once the total physical state of the universe and the laws of physics are fixed, every other fact … supervenes. (p. 158)

But even Weinberg took the search for a theory whose laws offer true descriptions of objective reality as a work in progress, motivated by the hope that we will eventually succeed in finding a true, powerful, unified theory in terms of which we will be able to understand the world at the deepest level. Even if there is such a theory, we have no reason to believe that it will include any of the empirical laws that physicists have formulated so far. For we have good reasons to doubt that any of these is both universally applicable and true.

I have argued that a scientific law can admirably serve its purposes without being true. But a law that is not true, or not a proposition capable of the two cases of truth and falsity, is not something to support a metaphysics.

A naturalist metaphysician may well object to this quick argument by making the following analogy between the methods of science and metaphysics. Scientific progress validates

the worth of an older scientific theory by showing it to be derivable as a limiting case of current theories in certain regimes, so we can regard it as a useful approximation. Arguably, this permits one to claim that the earlier theory was approximately true, at least in some of its key claims. Similarly, we can make progress in the metaphysics of science by basing metaphysics on the best current science, confident that our metaphysical conclusions will also be approximately true, at least in part.

But as McKenzie (2020) has pointed out, whatever one thinks of attempts to portray science as progressing toward the truth by successive approximation, metaphysics does not deal in approximations. Either laws of nature are primitive or they are not: laws of nature either have or lack modal content. Metaphysicians' shared assumption that there are true laws of nature seems non-negotiable: and a metaphysics of the non-true laws that science continues to produce is of questionable value.

9. Conclusion

Natural laws function in science as inference-tickets or rules for judging rather than judgments. In so doing they provide science with an epistemic infrastructure that helps us expand our knowledge of the universe far beyond its starting point here and now. Laws guide scientists in constructing models and coordinating our interventions. We use them to predict, explain and control the world. We can use laws successfully to do all these things even while none of them live up to their philosophical billing as necessarily true, unconditionally universal generalizations.

Metaphysicians have proposed analyses of laws of nature that take them to be something more than reliable empirical generalizations about actual, particular facts. For Humeans they are not much more since they are determined by such facts, given our proclivity to axiomatize as well as our standards of simplicity and strength. Primitivists and dispositionalists add more by way of objective modal content, whether inherent in the laws themselves or inherited from their ground in particular modal facts about the world. All these views saddle laws of nature with excess metaphysical baggage by adding a metaphysical superstructure to the world that science investigates—a world consisting of a rich tapestry of actual physical events.

But behind the use of laws in science we can see shadows of the traditional philosophical conception of laws of nature as necessarily true, unconditionally universal generalizations of unlimited scope.

. Scientists seek laws of maximal applicability because a law of wider applicability permits reliable inferences in more domains of inquiry and thereby forges more epistemic connections between otherwise disparate fields of knowledge. The application of laws of particle physics to cosmology is one salient example. We can see another in the current drive for unification in fundamental physics. The search for laws of maximal applicability is the epistemic shadow of the metaphysical condition of unconditional universality.

Hume was right to relocate necessity from the world to us. But we see the shadow of natural laws' modal content not in an individual mind's felt necessity when confronted with a causal sequence, but in the demand that a scientific law support *reliable* inferences. Ryle's analogy of laws to season-tickets works insofar as both can be relied on to get you where you want to go, in science as in life. The demand for reliability is so important in science that, on finding a scientific law, it is hard to resist the temptation to project necessity onto the law itself

rather than resting content with the reliable inferences it permits. Dispositions lie not in the states but in ourselves. Having learnt them, we are disposed to apply terms like 'red', 'flat', 'mass' and 'force' to particulars in the same way as each other. One can reasonably infer from one's correct application of such a term not only that others would generally apply it to the same things; but also that they, too will bleed red and stop at red lights, rest wine glasses only on flat surfaces, and see forces at work whenever a massive body accelerates.

Truth may be the hardest condition to abandon in an analysis of scientific laws. Earlier we saw Ryle still clinging to its possibility, even while advocating an inferentialist conception of laws. Did Ramsey give up too much by denying that laws of nature are even truth-evaluable? The fate of superseded theories provides a reason to think he did. After the general theory of relativity had passed its three classic tests, Popper was by no means alone in taking Newton's law of universal gravitation to have been falsified. Since then general relativity has successfully predicted many other phenomena like black holes whose occurrence seems clearly incompatible with Newton's law.[7] Surely we can now evaluate Newton's law of universal gravitation as false rather than true, even while continuing to use it to make reliable inferences in many applications?

A good inferentialist response to this rhetorical question is beyond the scope of this paper since it would require a defense of a non-representationalist account of the function of truth like that proposed by Price (2003). But Ramsey (1929) took the first steps toward such an account by considering various possible attitudes one could take toward a present annunciation of a law such as Newton's law of universal gravitation (not his example).

Suppose that someone who knows nothing of 20th or 21st century science has learned Newton's laws of motion and the law of universal gravitation and has acquired some skill in using these to make reliable inferences about the behavior of various bodies in the laboratory as well as the solar system (someone like Halley or Wren, perhaps). All his experience (including the testimony of his teachers) supports Newton's law. So his unprovoked annunciation of that law seems clearly to take the form of an assertion: he is neither play-acting nor acting as historian of science. In the light of contemporary science, what is the appropriate attitude to what he says?

Clearly not to believe his assertion. But also not to disbelieve it on the grounds that there is a pair of Newtonian masses separated by a Euclidean distance exerting on each other gravitational forces that differ from those predicted by Newton's law. According to general relativity there can be no such counter-instances of the law since there is no force of gravity or Newtonian masses and no enduring Euclidean space. No force of gravity accelerates a falling apple—the apple does not accelerate since its world-line traces out a straightest path in a space-time curved by the nearby earth. One can say that the attitude he has expressed toward Newton's law is not right but wrong; but one's own attitude should not be to disbelieve his assertion as false because one believes the negation of Newton's law.

The key question is not whether a law of nature is evaluable for truth but whether the sincere annunciation of a law of nature should be counted as an assertion of that law. As Ramsey said elsewhere (1927, [1990, p. 38]) "there is really no separate problem of truth, but merely a linguistic muddle"; "the problem is not as to the nature of truth and falsehood, but as to the

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[7] Although an appendix in Hawking and Ellis (1973) includes an English translation of Laplace's striking 1798 demonstration of how a large body could prevent all the massive light corpuscles it emits from escaping from its Newtonian gravitational attraction.

nature of judgment or assertion" [1990, p. 39]. Only if an annunciation counts as an assertion should it be considered evaluable as either true or false. That in turn depends on what social commitment accompanies the annunciation. If Price (2003) is right, the notion of truth has the social function of spurring rational debate as to whether everyone should accept the commitments undertaken by treating the annunciated sentence as an assertion, and therefore subject to criticism if and when these commitments come to be judged as untenable. In their work, scientists rarely if ever undertake such commitments in their use of laws, and so rarely assert those laws. Only when reflecting on their scientific activities do some adopt an uncritical view of truth as something a law either has or fails to have whether or not anyone should or even could assert it, but simply according to whether or not it in itself corresponds to objective reality.

In her (2016), Misak considers Ramsey and Price to be practitioners of what she calls Cambridge pragmatism. Here she means the English Cambridge, not Cambridge, Massachusetts where pragmatism originated in the work of Peirce and James. All these philosophers have rejected correspondence to reality as anything more than an unhelpful metaphor when trying to understand the concept of truth. James is notorious for his view of truth as what works, especially after its uncharitably hostile treatment at the hands of analytic philosophers like the (Cambridge!) philosophers Moore and Russell. But the Peircean strand of pragmatism took root in the fertile mind of Ramsey, who took a very different view of truth. As true pragmatists, Ramsey and Price have asked not what truth represents or corresponds to, but what function the concept of truth serves in our intellectual lives. I take a consequence of their answers to be that there is little or no point in applying the concept to scientific laws.

My treatment of scientific laws here has been in the same pragmatist spirit. By examining several important functions of laws in science I have tried to show that these can all be understood as ways in which laws support scientists' epistemic and practical activities. They do so without being necessary, unconditionally universal or true. All a scientific law needs to do is to support reliable inferences in each domain in which it can be responsibly applied—a domain whose extent science itself explores and strives to maximize.

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