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MODALIST EMPIRICISM AND PHYSICAL LAWS

Empirismo modal y leyes físicas

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Abstract

From an empiricist perspective, we argue that physical modality best accounts for the modal status of laws (understood in empiricist terms as suitable empirical regularities). Nomic modality need not be construed in terms of metaphysical modal features. Rather, we submit, we live in a world full of physical possibilities and necessities that are investigated by such processes as gathering evidence, improving inferential practices, and undertaking theory and model construction. Empiricists can safely take distance from Humean accounts of nomic modality, hence maintaining that laws are not restricted to yielding summaries of actual phenomena but inform us about the range of physical possibilities and necessities in their domains. None of this requires the introduction of a metaphysical basis for nomic modality.

Key words: Modality; Laws; Empiricism; Possibility; Necessity.

Resumen

Desde una perspectiva empirista, sostenemos que la modalidad física da cuenta de mejor manera del estatus modal de las leyes (entendidas en términos empiristas, como regularidades empíricas adecuadas). La modalidad nómica no tiene que ser construida en términos de propiedades modales metafísicas. En cambio, argumentaremos que vivimos en un mundo pleno de posibilidades y necesidades físicas que son investigadas por procesos tales como acumulación de evidencia, refinamiento de prácticas inferenciales y procesos de construcción de teorías y modelos. El empirismo puede, sin problemas, tomar distancia de las teorías humeanas de modalidad nómica, defendiendo que las leyes no se restringen a ofrecer resúmenes de fenómenos actuales, sino que nos informan acerca de rangos de posibilidades y necesidades físicas en sus dominios. Nada de esto requiere que introduzcamos un fundamento metafísico para la modalidad nómica.

Palabras clave: Modalidad; Leyes; Empirismo; Posibilidad; Necesidad.

1. Introduction

Empiricism has historically faced several challenges when dealing with nomic modality. At least in one reading, Hume (1748/2000) allegedly strips the world away from such features as powers and necessary connections. Similarly, neo-Humeans advocate one version or another of the best system account (BSA), which broadly holds the view that laws are the principles occupying the place of axioms in a theoretical system insofar as they best fulfill the trade-off between simplicity and informativeness (Lewis, 1994; Loewer, 2004; Earman & Roberts, 2005a, 2005b; Cohen & Callender, 2009; Dorst, 2019; Massimi, 2018; Jaag & Loew, 2018, 2020; Filomeno, 2019; Soto, 2021). In every case, empiricism is usually interpreted as rejecting *de re* modality, reducing modal discourse to *de dicto* features of beliefs.

Fortunately, Humean interpretations do not exhaust the conceptual space for empiricism. In what follows, we elaborate a form of modalist empiricism that accommodates modality as a feature of physical domains. As we argue in Section 2, we are not alone in associating empiricism and physical modality, hence accommodating a modal interpretation of scientific theories and models informing us about the physical constitution of various domains. Quentin Ruyant (2021) provides what is likely to be the most thorough elaboration of modal empiricism to date, but others move along similar lines (Ismael, 2017, 2018; Woodward, 2018, 2020; Cartwright, 2019; Norton, 2022). What makes our *modalist empiricism* different is that we focus exclusively on physical laws—which, in the account we favor, are basically empirical regularities—and derive the consequences of an empiricist approach to physical modality for these laws. In particular, we distinguish *physical modality* from *de dicto* (mathematical or logical) modalities and *de re* metaphysical modalities, offering an account that engages with the latter but without metaphysical commitments that outstrip the boundaries of empiricism. In the case of physical laws, a modalist reading tells us that they are not mere summaries of past events, but they inform us about possibilities and necessities belonging to physical domains.

We should immediately dispel a potential confusion. Our move away from Humean views of laws and towards a form of empiricism that embraces physical modality for laws may seem to incline the balance in favor of non-Humean nomic metaphysics. This is not the case. Non-Humean views ground the modal character of laws positing additional ontological layers in terms of universals (Armstrong, 1983) and dispositions (Bigelow, Ellis &

Lierse 1992; Bird 2007), among other ontological posits. Although questions regarding how we should interpret such metaphysical items have led the debate to develop a range of sophisticated options, there is no need to settle them in order to understand the role played by laws in scientific practice, given that none of these metaphysical answers is required to make sense of laws as empirical regularities. The consequences of this metaphysical debate continue to be addressed in recent literature (Ott, 2022; Hildebrand, 2023; Soto, 2024), but our argument for physical modality for laws does not depend on its resolution.[1] We will only engage with the non-Humean view that posits primitive mathematical constrainsts (PMC) as a source of nomic modality (see Section 5).

Our empiricist approach to nomic modality moves beyond the standard Humean vs. non-Humean debate on laws. The standard framework does not exhaust all possible positions, leaving space to move forward in a different direction. We have already highlighted a crucial difference between our form of empiricism and the Humean view given the understanding of physical modality as a feature of physical domains. In empirical investigation, evidence, inferential practices, and the construction of theories and models guide us in formulating physical laws that successfully inform us about possibilities and necessities pertaining to physical domains. Similarly, we take distance from non-Humean approaches to nomic modality insofar as we resist the temptation to ground nomic modality in metaphysical terms. We submit that the modal realm involves physical posits that are the subject of our routine scientific theories and models.[2]

The plan is as follows. Section 2 briefly discusses elements of the background debate that motivates our understanding of nomic modality, emphasizing its relationship with empirical evidence, inferential practices, and the modal reading of theories and laws. In Section 3, we submit that nomic modality is just physical modality. This claim is inherently egalitarian since it assumes that nomic modality does not amount to a special subset within the modal realm. Section 4 rejects a traditional assumption in the

[1] Although dealing with different issues, Hall (2021) contends that there are two kinds of modality, namely, logical and physical. He argues that metaphysical modality should be reduced to physical modality.

[2] The story is not that simple, since parts of our models and theories routinely introduce physically uninformative modalities under the form of idealizations that in some cases rely on surplus mathematical structure that does not accept a straightforward physical interpretation. We shall not address this issue here. See Bueno and French (2018) for an analysis of surplus mathematics structure in physical laws. Also, see Frigg (2022, part three) and Shech (2023) for an updated examination of idealizations in physics.

debate that states that a theory of laws should distinguish between *nomic* and *accidental* generalizations. By contrast, we argue that the modal scope of physical laws is graded in the sense that no such a priori distinction between laws and accidents is to be found in the physical world. Section 5 opposes the primitive mathematical constraint (PMC) theory, which claims that nomic modality flows from mathematical formalisms. Our analysis in Sections 2-5 allows us to put forward, in Section 6, a minimal notion of physical laws as empirical regularities expressing stable generalizations about possibilities and necessities in their physical domains. Finally, we address two counterarguments: that our account of nomic modality is purely epistemic, and that it collapses into either Humean or non-Humean views of laws (Sections 7 and 8, respectively).[3]

2. An Empiricist Road toward Physical Modality

There are many roads toward physical modality. An empiricist one begins by examining accepted theories and models, the evidential support for claims of physical possibility and necessity, and the relevant inferential practices. We start by considering these points.

Insight into one's modal commitments is gained by examining accepted models and theories. In physics, theories and models are routinely expressed in terms of suitably interpreted mathematical structures informing us about modal features of the world (Fletcher, 2021). Most notably, this is the case with physical laws. Presented in terms of (interpreted) mathematical equations of various sorts, physical laws do not restrict themselves to descriptions of actual physical systems. Instead, they codify modal information about scenarios in which certain situations can or must take place. A standard example is the Newtonian law of universal gravitation:

$$F_{grav} = Gm_1m_2/r^2$$

This law specifies modal relations among objects subject to a gravitational force in classical domains. This equation applies to two-body systems in a specific context, where the bodies involved exert a gravitational force on each other. For each scenario, we add relevant information about the masses of two bodies, the distances between their idealized point-like centers, and the value of G.

[3] Due to restrictions of space, we concentrate on physical laws. Sandra Mitchell (2000, 2009) elaborates an account of laws in biology that is similar in spirit to our proposal.

Some may claim that our initial step from models and theories toward physical modality is purely epistemic, hence keeping modal discourse in place "without making any commitment to modality at the ontological level" (Brading, 2011, p. 60). The epistemic reading, the argument would go, makes modality a matter of beliefs imbricated in theories and models. This may sound adequate if we wish to avoid the conundrums of Humean and non-Humean views regarding nomic modality. After all, the hope is that remaining silent about the ontology of modality would prevent us from falling down the slippery slope of reconstructions of reality, as articulated in standard debates on laws. Even more, this move may seem to be perfectly fine, considering that scientific theories and models provide a common ground that is broadly neutral to the debate.

However, the empiricist road toward physical modality is not to be restricted to epistemic matters. In avoiding Humean and non-Humean ontological reconstructions, the epistemic reading takes excessive distance from the modal information theories and models offer about physical systems. It, thus, fails to situate physical possibilities and necessities where they belong in the relevant domains. Modalist empiricism can fully embrace physical modality as a feature of physical systems. Expressed in theories and models, physical modality is relevant given the information it provides regarding the range of possibilities and necessities in phenomena. The phenomena's modal traits are encoded in the relevant models and theories. Yet, recognizing this point does not demand a metaphysical interpretation of modality (e.g., in terms of universals, possible worlds or abstract objects) that goes beyond the stability and control of the phenomena displayed in scientific practice.

Our approach rests on empiricist methodological assumptions, viz., claims about physical modality directly depend upon available empirical evidence supporting our theories and models. Indeed, the identification of possibility and necessity in physical domains is only secured by evidence gathering processes, inferential practices, and the successive construction and refinement of models and theories. Possibility and necessity are features of the relevant domains, and are expressed as the result of suitable evidence.

John Norton has recently addressed this issue. On the one hand, concerning possibility, he maintains: "what is possible, according to the empiricist conception, is what our evidence positively allows" (Norton, 2022, p. 129).[4] This seems to identify possibility with what is allowed by the

[4] Although Norton speaks of *empirical* possibilities and necessities, we prefer the label *physical* for both possibilities and necessities. After all, modality is physical, although the means we employ to investigate it are empirical.

evidence. In contrast, on our view, possibility comes first. Evidential support results from, and thus encodes, a range of *physical possibilities* of specific arrangements in a given domain. This, in turn, contributes to and supports certain inferential practices that are allowed by the available evidence. In this way, evidential support and suitable generalizations are obtained given the identification of the relevant physical possibilities. On the other hand, Norton defines empirical necessity thus: "what is necessary is what [the evidence] compels" (Norton, 2022, p. 129). This idenfies necessity with what is required by the evidence. In contrast, on our view, what the evidence compels is what must hold given the modal traits of the phenomena. Once these traits are identified, certain situations must hold—on pain of incoherence, inconsistency, instability, depending on the case. Given these modal relations, the evidence then compels certain situations. The assessment of *physical necessity* dependes on particular thresholds of accepted evidential standards in a given context. Physical necessity yields evidential compulsion regarding matters of fact that cannot be, or could not have been, otherwise, given the available evidential support. Once again, considerations of physical possibility or necessity should not be understood in metaphysical terms (*via* universals, abstract objects or possible worlds); modality is ultimately primitive (Bueno & Shalkowski, 2009, 2013, 2015; Bueno, 2021).

For modalist empiricism, theories and models are both evidence-guided and inference-guiding.[5] They are guided by the evidence since the construction and refinement of theories and models relies on our ability to access to relevant information about physical domains by means of gathering new evidence, performing new observations, and carrying out additional experiments. Models and theories guide inference since they encode information about what is possible and necessary regarding the relevant phenomena and, in this way, can be used as reliable sources in the formulation of explanations and predictions about the objects under consideration. The link between physical modality and inferential practices is crucial for an empiricist account of nomic modality. Jenann Ismael (2017, p. 117), for instance, contends that "[s]cientific models—on the local and global scale—are embodiments of our very best inductive practices", and their modal content is to be "understood in terms of their role guiding prediction and decision". Although it is unclear whether there is any need for inductive inferences to make sense of scientific practice, since hypotheses can be freely introduced and later deductively tested (see

[5] Comparing modal and moral concepts, Cartwright (2019, p. 83) maintains that both are "evidence-guided, prediction-guiding". We draw from this to articulate our view of laws as evidence-guided, inference-guiding. Our access to laws rests on evidence, and they can be used as inferential tools about various physical domains.

Popper, 1963, Miller, 1994, and van Fraassen, 2002), modality does play a prominent role. Ismael applies her account to an array of modal notions, encompassing dispositions, capacities, and potencies. For the purposes of the present discussion, we focus exclusively on laws—despite the fact that the considerations we offer can be extended to other modal traits.

Ismael's empiricism can be further developed. She claims that "everything that there is to know about laws, chances, and other scientific modalities is given in the account of how beliefs about chances are formed, their inferential implications, and the role they play in our practical and epistemic lives". When it comes to nomic modality, Ismael's account provides "shadows of law" (2017, p. 123).[6] But this restriction only emerges if proposals are expected to adjust to the standard Humean or non-Humean framework, which either does away with *de re* modality or introduces ontological groundwork for modal claims. But this is not the only available approach, and modalist empiricism need not fall prey to excessive humility. The road to the recognition of modal content and the role played by theories and models in this context is part of a stretch we must walk, but it is only part of the story.

A primary concern is assessing the scope of possibilities and necessities, which is ultimately dictated by the relevant physical domains, not by our networks of modal beliefs. We refine or abandon modal beliefs in view of what the world tells us in empirical research. Our theories and models may be proved wrong or inaccurate, and the increment of evidence can teach us whether that is the case. If theories and models encode information about the relevant domains, they are candidates for expressing conjectures about the range of physical possibilities and necessities at a certain time. We perform observations, run experiments, gather data, and undertake model and theory construction only to submit the results to further empirical investigation. The outcome is acquiring more reliable information about the constitution of physical domains. This is what modalist empiricism needs in order to account for nomic modality in terms of physical possibilities and necessities that we access through empirical means.

3. Nomic Modality Is Physical Modality

Modalist empiricism maintains that we live in a physically modal world. This only means that the constitution of physical domains determines

[6] For an analysis of modality in debates about chance and determinism, see Hoefer (2008, 2019), Frigg and Hoefer (2010), Frigg (2016), Gyenis (2020), Herrera and López (2020), and Maudlin (2007).

their possibilities and necessities. We need not find a source of modality elsewhere, as Descartes believed he had found in the immutability of God's will or contemporary metaphysicians in universals and dispositions, among other posits. The possibilities and necessities of a physical system are determined by its physical constitution, that is, by its physical properties and relations with other things. Consider the modal claim 'salt is soluble'. Its modality does not have to do with a linguistic convention but with the molecular structure of sodium chloride, which entails a range of physical processes should it interact with solutes. Yet, it would be better to make the relatively moderate claim: sodium chloride dissolves in specific solutes assuming that the latter are not already saturated with salt. Hence, we can express our modal statements in various ways. Some would say that 'sodium chloride necessarily dissolves in solutes'. But at some point, we will require an additional set of *ceteris paribus* conditions: 'granted initial conditions $C_1, C_2, \dots C_n$', each of them introducing additional information: the relevant solute is not saturated with sodium chloride; no other environmental factors are intervening or eventually inhibiting the solubility process from taking place, and so forth.

The claim that the world is physically modal is not a metaphysical reconstruction of reality but a straightforward way to make sense of what we observe: the theories and models we accept inform us about the physical constitution of various domains which possibly or necessarily behave in one way or another in different environments. To attribute modal features to a system, we need pertinent information about its physical makeup and environment. Just like the case of sodium chloride, the same goes for the flammability of various materials; for the dynamics of systems described in terms of laws of temporal evolution; for the possibility of certain particulars to be electrically conductive; for the fact that nothing can travel faster than the speed of light; and for the unrealized, but theoretically possible event that a blackhole swallows our universe.

Our view of a physically modal world is egalitarian in spirit: when it comes to *de re* modality about the world, there is just physical modality.[7] Importantly, nomic modality is just physical modality, and nothing makes

[7] Platonists would like to claim that there is mathematical modality. Modalist empiricists recognize the modal content of mathematics but resist the need for its reification (in terms of abstract objects) to make sense of scientific and mathematical practice. Since without a suitable interpretation, mathematics does not concern the physical world, its modal content is not physical. Yet here we need to recall that most empiricists have traditionally been nominalists about modality both in mathematics and elsewhere (see van Fraassen, 1980 and 1989; see also Field, 1989—although, of course, Hartry Field is not an empiricist). For a discussion, see Bueno (2019) and Ruyant (2021).

it different in kind from other physical modalities we do not identify as laws. Here we clash with a longstanding tradition that assigns laws a special place in ontology. After all, philosophers and scientists have usually claimed that laws govern. In their remote origins, laws were once believed to be God's commands. And metaphysicians have greatly endeavored to secure the status of laws in various ways. For modalist empiricism, laws are not a special kind of entity, nor are they mysterious, unexplainable primitives. Laws are not second-order, relational universals imparting modality top-down. Nor do we need to think of them as an exceptional kind of nomic facts whose necessity makes them more akin to the God of natural philosophers than to worldly objects of routine scientific investigation. We shall return to these issues in Section 4. Likewise, in Section 5 we shall argue that, although laws are routinely formulated in mathematical terms, mathematical structures need not be conceived of as a primitive mathematical constraint actively imposing restrictions on physical domains. For modalist empiricism, this all goes unnecessarily too far in the direction of reifying metaphysical posits in the attempt to account for scientific and mathematical practice.

If anything, what makes laws distinctive is this: they are attempts at codifying more or less highly stable physical possibilities and necessities that can be found in several situations and that range from local to global modalities, from stochastic to deterministic systems. Consider Hooke's law for springs or Einstein's field equations for general relativity. The phenomena they describe are not different in nature from the solubility of sodium chloride. Nevertheless, what makes them distinctive is their exceptional ability to provide us with empirical generalizations about regularities in their domains. Indeed, there is a difference in scope between them. The field equations enjoy an application domain far broader and more complex than the Hooke equation for springs. But that does not require the introduction of a metaphysically motivated distinction between two kinds of laws (nor between laws and accidents, as we shall argue in Section 4). They differ only in the scope of the generalization they provide in their respective domains.

Given its deflationary approach, why should modalist empiricism bother with referring to something as a law? One attractive option for empiricists is nomic eliminativism (van Fraassen, 1989; Giere, 1999), which recommends doing away with laws altogether, both as an ontological posit and as a term in physical discourse. We do not explore this avenue in this paper, although we do so elsewhere (Soto, 2024), examining the motivations for nomic eliminativism and assessing its revisionary character that imposes philosophical constraints on scientific practice. For now, we leave this issue aside.

Another response available for modalist empiricism comes from its inherently pragmatic stance: nomic modality is unique *for us* in a pragmatic sense (Jaag & Loew, 2018). In fact, laws deliver guides for explaining and predicting phenomena, and for deciding how to interact with natural or artificial environments in experimental settings. Physical laws allow us to anticipate experiences regarding how things can or must behave under certain circumstances. We use the field equations of general relativity to draw inferences about phenomena at a cosmic scale, such as the bending of light passing along a massive body. Yet, we may continue to use classical gravitational physics to explain and predict the falling of objects near Earth's surface and to predict the orbits of satellites and the Moon around Earth for most human purposes. And we employ Hooke's law when determining the stiffness of specific springs across various environments, under the pressure of applied weights, and in different mediums and conditions. In these cases, laws provide us with pragmatically relevant information about the range of possibilities and necessities in their respective physical domains.

The pragmatic take goes further. Consider the event 'the cup of tea is on the desk now'. This refers to a physically modal situation that depends upon the physical constitution of the particulars involved. Furthermore, the situation conforms to several physical laws, including those of thermodynamics and classical mechanics. The possibilities involved are nevertheless unstable. The teacup may break should it fall or be hit by another object; the liquid will change its temperature if enough time elapses or if the temperature of its immediate environment varies. Even though the circumstances are fully modal, clearly the statement 'the cup of tea is on the desk now' fails to state a physical law, since it does not provide a physical generalization that informs about physical possibilities or necessities that are pragmatically significant beyond the opportunity for an individual to enjoy a cup of tea while sitting at a desk.

4. The Scope of Nomic Modality

One dogma that has prevailed in the laws of nature debate contends that any theory of laws must provide a principled distinction between laws and accidents (or between nomic and accidental generalizations). We inherit this dogma from a 17th-century tradition that goes back at least to Descartes' early manuscript *The World* that separates between the laws secured by God's will and the accidents emerging from specific collisions of bodies. Throughout the 20th century, although without appealing to theology, non-Humean views have kept the distinction in place by introducing several metaphysical posits. Humeans, on the other hand, can do away with the dogma, but at the cost of dispensing with *de re* modality.

Here is a standard formulation of the distinction. According to Marc Lange (2000, p. 11), a separation is to be drawn between laws of nature, on the one hand, and accidental generalizations, universal coincidences, or historical accidents at a cosmic scale, on the other. He compares the following two claims:

- All gold spheres have a diameter of less than a mile.
- All uranium spheres have a diameter of less than a mile.

The example bears a long tradition in the literature going back to Reichenbach (1947, p. 368; 1954, pp. 10-11), Hempel (1966, p. 55), and van Fraassen (1989, p. 27). The reasoning goes as follows: nothing prevents a solid gold sphere from existing at a particular spatiotemporal location, apart from the conditions related to the amount of available gold. Nevertheless, the fact that we cannot possibly have a solid uranium sphere whose diameter exceeds a mile in length is, Lange would say, a nomic fact. Should a sphere of uranium reach such a dimension, its critical mass will lead to spontaneous atomic fission. If the story so far is correct, then certain facts would be nomic in character, and they will serve as a source of necessity, whereas other facts would merely be amodal accidents. The former serves as a groundwork for laws of nature, whereas the latter reflects a mere accidental generalization.[8]

Our empiricist account of nomic modality rejects the law-accident distinction. We are not forced to accept the distinction as an a priori conceptual truth of laws.[9] And it is not an empirical truth of science that its laws provide us with reasons for endorsing a clear-cut distinction between laws and accidents. The physical world does not seem to be arranged in two groups, namely, laws and accidents. By contrast, what we find in nature is a continuum that goes from very unstable phenomena to more or less stable regularities, some of which among the latter are captured by our statements of physical laws.

[8] The distinction pervades the debate on laws among non-Humean views. To ground the distinction between laws and accidents, Lange suggests nomic facts and counterfactual conditionals (Lange, 2001 and 2009, respectively). Other views appeal to universals (Armstrong, 1983), dispositions (Bird, 2007), structures (Berenstain & Ladyman, 2012; French, 2014), and primitives of various sorts (Maudlin, 2007). We shall return to the primitive mathematical constraint theory in Section 5.

[9] Several supposedly a priori conceptual truths have been built into the imaginary of laws of nature. One is the above mentioned distinction between laws and accidents. Yet another is the assumption that laws do not change. For a critical examination, see Sartanaer, Guay, and Humphreys (2021).

Abandoning the distinction between laws and accidents allows for a better understanding of nomic modality and its place in scientific theorizing. Against this dogma, we suggest embracing varying scopes of nomic modality, viz, laws provide information about the range of physical possibilities and necessities.[10] Here is how this works:

- Some laws have a local scope, such as Hooke's law for springs that holds the relation $Fs = kx$, where F is the force, x is the distance, and k is the constant characterizing the spring's stiffness. This is a local generalization.
- Other laws, such as Fresnel's equations for the reflection and transmission of light, purport to enjoy a broader scope stating that light behaves as a transverse wave incident on an interface between different optical media.
- The second law of thermodynamic represents a different scenario, applying globally while referring to inherently stochastic systems, providing information about the irreversibility of thermodynamical processes and the existence of entropy (two initially isolated systems, each of them in thermodynamic equilibrium, are deemed to reach joint thermodynamic equilibrium if they interact).
- And another group of laws describes deterministic systems at a global scale, displaying a high level of stability, as in the case of Einstein's field equations in general relativity.

The boundaries between the four groups of laws are aptly blurry, reflecting the scopes of generalizations that various research field in physics have managed to articulate. Overall, the morals we derive from our analysis contributes to debunk the dogma of the laws of nature debate. First, the laws that we have do not rely on the distinction between nomic and accidental generalizations. There is no difference in kind between these laws, but only a difference in the scope of the modal information they provide about their respective domains. Some laws apply locally, whereas others globally. Some laws refer to inherently stochastic systems, whereas others work well in deterministic scenarios. Nothing in empirical research warrants access to unrestricted necessity, and the empiricist will decline the temptation to secure the distinction between laws and accidents by

[10] Theories of nomic stability (Mitchell, 2000, 2009) and nomic invariance (Woodward, 2003, 2018, 2020) advance reasons for endorsing different scopes of nomic modality, and so does Smart's (1985) analysis of laws and cosmic coincidences.

positing metaphysical or mathematical commitments. Each law expresses a generalization of a particular scope about possibilities and necessities in their domains. It specifies the range of possibilities and necessities in each case. Some laws are pragmatically interesting given their informative inferential power regarding what is physically possible, which serves as a guide for empirical research. But nothing else is to be found or posited beyond (below or above) them.[11]

And second, modalist empiricism embraces the ultimate contingency of the physical world, while at once keeping physical modality for laws in place. Contingency appears in our most robust modal claims about physical domains. Think of the principle of the speed of light, which holds that nothing can travel faster than 299,792,458 meters per second. For modalist empiricism, the speed of light is not something one can discover by conceptual analysis. The determination of its value can only be achieved through empirical investigation. Although amounting to a robust modal claim, it remains thoroughly contingent: "No background logic or mathematics make 299,792,458 the unavoidable value of light's speed. No amount of reflection alone renders it inevitable" (Bueno & Shalkowski, 2021, p. 1). We happen to know as much about the speed of light as empirical investigations can convey. Our understanding of physical possibilities and necessities go as far as empirical research goes, being thus supported by empirical evidence which offers no instances of unrestricted necessities. The case of the speed of light illustrates a common feature of scientific knowledge, which identifies possibilities and necessities in each domain. In the end, all physical laws exhibit the same ultimate contingency: theories may get things wrong, and there may well be things we ignore at present that violate the light-speed postulate.

5. Nomic Modality Does Not Flow from PMC

We have previously observed that most physical laws are expressed in terms of mathematical equations. Mathematics' apparent indispensability for physical laws sets out a fertile domain for philosophical reflection. For some, the effectiveness of mathematics in the formulation of physical laws seems to be unreasonable (Wigner, 1960; Steiner, 1998), with some arguing that physical laws are purely mathematical statements (Feynman, 1965),

[11] This goes along with our egalitarian approach to nomic modality. Ordinary physical possibilities and necessities in daily life do not differ in nature, but only in degree, when compared to possibilities and necessities captured by physical laws. It is a matter of the scopes of our generalizations, which rests upon the physical constitution of the regularity in each domain. For a similar observation, see Norton (2022, Section 9).

or that the world must ultimately be mathematical (Tegmark, 2008) (see Soto, 2020a). Furthermore, in some cases of mathematically expressed physical laws, there are parcels of surplus mathematical structure. The latter may yield novel physical interpretations, thus providing a crucial contribution to inferential practices and facilitating solutions to the relevant mathematical equations (Bueno & French, 2018).

Considerations like this have led some philosophers to hold the view that laws' modality must at least be partly mathematical. The primitive mathematical constraint (PMC) theory develops this intuition in more detail, maintaining that nomic modality flows from the mathematical equations that are used to formulate laws. This view assumes that mathematical structures can somehow determine the space of possibility and necessity of physical domains.

Although without endorsing the PMC theory, Carl Hoefer notes regarding the Schrödinger equation:

> [quantum mechanics] offers us a well-defined differential equation and at least clearly says: "This mathematical law *governs* the structure of matter". When you work through the exact solution of the hydrogen atom, you see that in some very important sense, at least, this claim has to be right […]. What is particularly salient about the hydrogen solution is that its achievements transparently *flow* from the solution of an equation and from nothing else (Hoefer, 2008, pp. 309-310; italics added).

This point finds numerous reverberations in the philosophy of physics literature dealing with laws.[12] Here is a passage from Tim Maudlin:

> Partial differential equations of the form used in physics have been intensively studied by mathematicians, as have equations describing stochastic processes. In each case, there are models or solutions of the equations (with the models of a stochastic process having an associated probability function) […]. From these mathematical results modal conclusions *flow* like water from an open spigot. All one does is treat the set of mathematical models of the basic dynamical equations as the "possible worlds" in a standard modal semantics. A set of events

[12] In the opening pages of a *Foundations of Physics* volume on modality in physics, Gábor Hofer-Szabó, Joanna Luc and Tomasz Placek maintain: "a theory of physics comes with some laws which are encapsulated in its mathematical formalism. Now, laws of nature are uncontroversially believed to be a *source* of natural necessity, as they *impose* some sort of necessity on the facts they cover or, more precisely, on the propositions expressing those facts" (2020, p. 515, italics added).

> is physically possible only if there is a mathematical model of the fundamental dynamical laws that corresponds to those events taking place (Maudlin, 2020, p. 525; italics added).

Although the ability of mathematical formalisms to describe a modal space is undeniable, the PMC theory faces significant difficulties. The PMC theory rests on a metaphor according to which mathematics is a source of physical modality, as though mathematical formalisms could constrain physical domains. However, its advocates do not provide an account of precisely how mathematics can perform that work. To provide such a story, a thorough defense of something along the lines of Pythagoreanism would be needed (Steiner, 1998). Nevertheless, the PMC theory does not take this route, but instead assumes a highly controversial claim to the effect that mathematical truths can (somehow) constrain physical possibility and necessity (Lange, 2017; Adlam, 2022; Chen & Goldstein, 2021). Given the abstract character of pure mathematics, it is unclear exactly how such constraints are even possible in the first place.

Quite to the contrary, in developing an account of nomic modality, modalist empiricism fully recognizes mathematics' contributions to the formulation of physical laws, as well as to the exploration of their consequences. However, the empiricist remains agnostic about the capacity of mathematical formalisms to constrain the space of physical possibility and necessity for situations to unfold. Excessive focus on fundamental physics' laws can be misleading due to their allegedly global universality.[13] In the present case, mathematical formalisms provide a framework in which physical generalizations can be codified and expressed, enabling us to systematize modal information about specific systems. Physical modality, nonetheless, does not flow from sets of mathematical equations, but from the physical constitution of the relevant physical domains. Whereas we do not intend to undermine the inferential power of mathematically expressed physical laws, which facilitates the derivation of physically informative inferences in the relevant domains, we nevertheless stress that mathematical formalisms are empirically sensitive only after suitable physical interpretations of the relevant mathematical structures are provided. Mathematics does not lead one blindly, as it were. In contrast, only the scrutiny of empirical evidence can ultimately tell us whether our inferential practices are reliable.

[13] Ismael offers an appropriate diagnosis of the situation: "[p]hilosophers tend to be uninterested in partial views of the world. They make a lunge for the most encompassing view. Most day-to-day science, however, is not concerned with the world as a unit, but is focused on local subsystems" (Ismael, 2018, 176).

The modalist empiricist approach to nomic modality requires an account of how mathematics is applied to the formulation of physical laws. Some efforts in this direction are available in the literature (Dorato, 2005; Islami, 2017; Bueno & French, 2018; Soto & Bueno, 2019; Soto, 2019, 2020b; among others). One moral is that physical laws model scenarios employing abstractions and idealizations that enable us to capture with a certain precision the relations between variables, functions, forces, and else that may be relevant to identify relations among objcets. Once equations expressing laws are tentatively formulated, the road from such equations to actual physical scenarios is usually complex and multi-directional, requiring the introduction of additional adjustments so that lower-level models specifying features of narrower domains can be formulated. Throughout this process, the key challenge concerns the need to provide adequate physical interpretations of mathematically expressed physical laws.

In some cases, the task proves easy, particularly for local laws rooted in direct empirical observation, as in the case of Hooke's law. In other cases, the situation is more complex, mainly if surplus mathematical structure occurs in the formulation of the law. Consider the case with the general form of the time-dependent Schrödinger equation:

$$i\hbar \frac{d}{dt}|\Psi(t)\rangle = \hat{H}|\Psi(t)\rangle$$

where i is an imaginary number, $\hbar$ is the reduced Planck constant, and Ψ is the state vector of a quantum system. Imaginary numbers, the reduced Planck constant, and the state vector of a quantum system present various difficulties when mapping from the mathematical structure to the target physical domain. In this case, imaginary numbers find no counterpart in the world, making a case for the claim that the equation allows for more mathematical structure than the physical structure that can be identified in the target system. Beyond the interpretive difficulties, the general form of the time-dependent Schrödinger equation provides information about the wave function of a quantum system evolving through time. Applications of this equation require the specification of the Hamiltonian for the quantum system, considering the kinetic and potential energy of the particles involved. The modal content of the situation is clear as the equation "delivers a space of physical possibilities for a quantum system, which can be adjusted to specific physical scenarios by considering the relevant Hamiltonians in each case" (Soto & Bueno, 2019, p. 432).

The empiricist features of our account provide a reminder, once more, that we should not fall for the illusion of the mathematical character of nature. Since mathematics is typically understood as being abstract and causally inert, it alone provides no constraints on the physical world—except perhaps for cardinality restrictions. The systematic mathematization of nature is a particular historical contingency that was deeply congenial to the emergence and consolidation of the widespread use of laws of nature in scientific inquiry. Geoffrey Gorham, Benjamin Hill and Edward Slowik (2016, pp. 5-6) offer an outline of how this process came to happen in 17th century natural philosophy, and Olivier Darrigol's (2015, Chapters 1 and 2) historiographical study of necessity in physics illuminates the rationalist pursuits involved in early conceptions of laws. Sandra Mitchell (2009, p. 39) insightfully points out how easy it is to inadvertently project the (apparent) necessity of formal languages onto our representation of physical domains. In each stage, there is no need to reify mathematics. The world is full of physical possibilities and necessities, not mathematical structures and deductions.

6. A Minimalist Definition of Physical Laws

Those coming from the Humean versus non-Humean debate on laws are likely to press us to define laws of nature. On the best system tradition, Humeans claim that laws are those principles satisfying a desired balance between syntactic simplicity and informational strength. Laws would be statements describing the spatiotemporal distribution of amodal particulars and relations belonging to the Humean mosaic. In the opposite direction, non-Humeans define laws in a variety of ways, as second-order relational universals, as the modal space determined by inherently modal dispositional properties, and so forth.[14]

Modalist empiricism suggests we should carefully consider the laws in scientific practice. Very minimally, laws can be thought of as *empirical hypotheses, routinely formulated in mathematical terms, that express generalizations about physical domains, including their modal properties.* Should they get things right, physical laws serve as a guide for the derivation of physically relevant information about their intended targets. This proposal manages to take distance from the standard Humean versus non-Humean debate, while also providing an empiricist account of nomic modality. Let us mention three features of this minimalist account:

[14] Definitions of laws of nature in the literature go beyond the standard framework. Structuralism (French, 2014; Berenstain & Ladyman, 2012), primitivism (Maudlin, 2007, 2020), and advocates of counterfactual conditionals (Lange, 2000, 2009) provide different approaches.

- First, physical laws are empirical hypotheses expressed in mathematical terms. Yet, that does not entail that nomic modality is a *de dicto* property of theories and models. In contrast, physical laws inform us about physical possibilities and necessities that are described by law. Nomic modality is just physical modality that, as argued above, is particularly interesting given the information they provide about physical possibilities and necessities in their respective domains.
- Second, from an empiricist perspective, physical laws are *empirical hypotheses* that are routinely expressed in mathematical terms, but which occasionally can also be cashed out in a nonmathematical language—as many principles in chemistry are. But as with any piece of scientific theorizing or modelling, physical laws are hypothetical. They articulate conjectures about how the world is in certain respects, hence being always open to refinement or abandonment in light of new evidence.
- And third, as empirical hypotheses, physical laws codify and express *generalizations* about physical possibilities and necessities. Hence, they are not purely mathematical statements or mere linguistic devices. They capture more or less highly stable regularities in the phenomena, regarding the behavior of springs, gases, electricity and magnetism, gravity, electrons, and so on. There are various stabilities in the phenomena, and empirical research endeavors to capture them in as much fine-grained detail as possible.

7. Two Counterarguments

We anticipate two objections that may be raised by those who understand nomic modality in terms of the standard Humean versus non-Humean framework, namely: (i) that modalist empiricism is inevitably restricted to epistemic considerations; and (ii) that it collapses into either Humean or non-Humean options.

(i) *Facing epistemic fears.* Our understanding of physical modality may appear to be predominantly epistemic rather than ontological in character. If this were the case, it would be a problem since the aim is to provide an account of the modal character of physical laws granted that they offer information about physical domains. The situation worsens if the epistemic threat becomes radically instrumentalist: the modality at stake may be largely linguistic, having to do with models and theories and not with the world. After all, on the instrumentalist reading, one need not care about whether the relevant beliefs are informative about the physical domain, but only whether they save the flow of experience. The coda is well known: theories and models embodying modal beliefs are only expected to be useful tools, and not to yield information about the constitution of physical domains—let alone their modal features.

In response, we argue that access to physical modality is obtained empirically via the gathering of empirical evidence and the refinement of inferential practices involved in the construction of theories and models that encode modal information. Ultimately, physical domains embody modal features (which are *not* understood in metaphysically contentious tems): theories and models are evidence-guided in their construction, and they are inference-guiding in practice provided that they successfully offer information about possibilities and necessities in their domains. Scientific theories and models are corrected or abandoned given the outcomes of experiments and observations, and evidential support for modal claims results from information gathered from the physical world. The process does not involve reification, nor does it treat modality as a linguistic feature or a trait of models. It is an objective aspect of the world, just as straightforwardly detectable as the fragility of a table or the solubility of salt.

In responding to a similar concern, Norton suggests that epistemic modality (he speaks, for instance, of epistemic possibility) is defined in terms of agent-based knowledge. This is correct as an epistemic account of modality, albeit the proposal is not ours. Of course, we would never deny our all-too-human epistemic circumstances, but our focus is not on epistemic modality. Norton suggests: “Empirical possibilities are defined positively, as propositions accruing some inductive support, even if small, from a designated body of propositional evidence” (Norton, 2022, pp. 145-146). Nevertheless, he also claims that empirical modality is defined “as an inductive-logical relation over propositions, independent of agents with thoughts” (2022, pp. 145-146). We take the objectivity of empirical modality to emerge from the relevant modal properties of the objects in question, which obtain quite independently of what may be thought or not about them. These modal properties, however, we insist, should not be characterized in metaphysically loaded ways, e.g., in terms of instantiated universals, tropes, or sets of instances throughout possible worlds. They are simply traits of the objects under consideration, similar to their size or shape.

Norton’s move is interesting. But some further work is needed. As noted above, we do not think that inductive support is in fact required—inductive inferences are not called for to make sense of scientific practice. Relevant evidence, deductively managed, yields information about physical possibilities and necessities. Theories and models encode such information and they are judged to be reliable guides for inferential practices insofar as they are supported by empirical evidence. What motivates changes in modal beliefs is the continuously increasing evidence for the refinement of generalizations. Modality thus remains physical throughout. And although it is not a matter of mere belief—as the epistemicist or instrumentalist would have it—it is not detachable from agents. In creating models and formulating theories about the world, scientists are agents, after all.

(ii) *Avoiding the collapse.* Some will be quickly, though wrongly, inclined to think that the physical modality favored here ends up collapsing into either a Humean or a non-Humean view regarding laws of nature. The deflationary character of physical modality makes our minimalist approach to laws akin to Humean accounts, sharing with them the rejection of additional metaphysical posits as they are found in non-Humean views and claiming that physical laws are statements that take the form of empirical hypotheses expressing generalizations across various domains. Nevertheless, for Humeans (at least on the best system account), if laws earn a modal status at all, it is only if they occupy the place of principles that systematize the relevant information, hence reducing modality to a *de dicto* feature of beliefs.

We reject this and argue that modalist empiricism can accommodate genuine physical modality in an account of laws rather than just a pale *de dicto* feature. But here non-Humeans will raise their heads. For them, if nomic modality is something at all, its modal character must be grounded in a modal source, which metaphysicians fill in with a number of reified alternatives, such as the aforementioned universals and dispositions, or the primitive mathematical constraints examined in Section 5. Yet, once again, no such metaphysical interpretations are needed on the modalist empiricist approach, as physical modality rests on features of physical domains rather than on their reconstructed metaphysical counterparts. As suggested here, the modal is genuine rather than *de dicto*, in contrast to Humean approaches, but it is not metaphysically overblown, in contrast to non-Humean views. In this way, the modalist empiricist approach carves an alternative to both extremes of the standard framework.

Our account is not alone in facing this purported dilemma. In a recent elaboration of the invariance-based account of laws, James Woodward (2018, pp. 158-159; 2020) runs into similar considerations regarding standard ways of framing the debate. With Humean views, the invariance-based approach rejects the need to posit non-Humean metaphysical additions, but against Humean views, the invariance-based account contends that laws cannot be reduced to non-modal traits. Finding a middle ground may seem impossibly difficult only if the available options are determined by the standard Humean versus non-Humean framework. But nothing forces us to accept the terms of the debate. The middle way suggested by the invariance-based account relies on physical modality, similarly to the path recommended by modalist empiricism. The emphasis on primitive modality is another shared feature among both approaches. The crucial difference is that rather than focusing on the identification of invariances, we emphasize the modal properties of the relevant domains.

Not only is our analysis of physical modality for laws neutral with respect to further commitments along the lines of Humean and non-Humean views, but it can also dispense with presuppositions accepted in that debate. Modal beliefs embodied in models and theories offer information regarding possibilities and necessities across physical domains. Physical modality, we insist, is not restricted to our belief systems, but it rests on the support stemming from empirical evidence. Theories and models are shaped by what the world is like, being responsive to the features exhibited across physical domains. By denying the terms of the debate, the account recommended here carves out an additional alternative, which delivers more than Humean views, but restricts *de re* modal talk to the strenuous testing of empirical investigation.

8. Conclusion

The modal scope of laws of nature has posed a challenge for scientists and philosophers alike. We have put forward a modalist empiricist perspective on nomic modality, which suggests understanding it in physical terms. Physical laws are empirical hypotheses expressing generalizations informing us about possibilities and necessities across domains. When they get things right, they enable the derivation of relevant physical informative about their targets (Suárez, 2024). Theories and models embody modal information about various physical domains. Physical modality serves as a guide to inferential practices. It is ultimately grounded in what the world is like and in what such world provides as evidence for our generalizations.

Our account of physical modality advances a fresh perspective on philosophical issues associated with laws. Even though laws are routinely formulated in mathematical terms, they are intended to offer information about physical domains. The challenge is to advance a physical interpretation of mathematical formalisms that express such laws. On the account of physical modality suggested here, nomic possibilities and necessities come in gradually and are responsive to the evidence gained about the relevant domains. Once it is accepted that the world is full of possibilities and necessities, no further philosophical groundwork to devise a source of modality is ultimately called for. The result is a form of empiricism that embraces modality without turing it into something metaphysically contentious or mysterious.

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