Invariance, Interpretation, and Motivation

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In this article I assess the Invariance Principle, which states that only quantities that are invariant under the symmetries of our theories are physically real. I argue, contrary to current orthodoxy, that the variance of a quantity under a theory's symmetries is not a sufficient basis for interpreting that theory as being uncommitted to the reality of that quantity. Rather, I argue, the variance of a quantity under symmetries only ever serves as a motivation to refrain from any commitment to the quantity in question.

1. Introduction. Take the Invariance Principle to be the principle that only quantities that are invariant under the symmetries of our theories are physically real.[1] It is a doctrine with a distinguished pedigree: acclaimed theorists as diverse as the physicist Paul Dirac, the mathematician Hermann Weyl, and the philosopher Robert Nozick were all apparent signatories during their respective lifetimes (see, e.g., Weyl 1952, 132; Dirac 1958, vii; Nozick 2001, 82). Prima facie, however, it is something of a mystery as to how and why the principle is supposed to work. Nevertheless, there appear to be at least some uncontroversial cases in which it—or something very close to it—does work.

One such example can be found in Newtonian gravitation theory (NGT), that is, the theory comprising Newton's three laws, plus his inverse-square gravitational law, governing the behavior of point particles in Newtonian space-time. As is well known, this theory is *Galilean invariant*. This implies, among other things, that if one takes any solution to NGT and "boosts" it—that is, uniformly alters the absolute velocity of each point particle by the

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†For extremely helpful comments and discussion, I would like to thank David Baker, Neil Dewar, James Ladyman, Niels Martens, Tushar Menon, Oliver Pooley, James Read, Simon Saunders, Alex Skinner, Teru Thomas, David Wallace, and audiences in London, Cardiff, and Atlanta.

1. I draw the term from Saunders (2007). Compare also Dasgupta's (2016) "symmetry-to-reality inference."

Philosophy of Science, 84 (December 2017) pp. 1253–1264. 0031-8248/2017/8405-0037$10.00
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https://doi.org/10.1086/694087 Published online by Cambridge University Press

same amount throughout its history—one will invariably get back a solution to NGT. Boosts, in other words, are a *symmetry* of NGT: they are transformations that invariably map solutions of the theory to solutions.

Which quantity varies under this particular symmetry? The answer is obvious: absolute velocity. Thus, according to the Invariance Principle, we should conclude that absolute velocity is not a genuine physical quantity. Conversely, which quantities are invariant under this particular symmetry? Again, the answer is obvious: relative (interparticle) distance and velocity, temporal intervals, and absolute acceleration. Thus, according to the Invariance Principle, we should conclude that NGT's boost symmetry does not threaten these quantities' status as genuinely physical.

As it turns out, one can successfully purge Newtonian theory of the space-time structure required to make absolute velocity a physically meaningful quantity. More specifically, one can move to Galilean space-time (sometimes also called "Neo-Newtonian spacetime"; see, e.g., Earman 1989, sec. 2.4). Here, the Newtonian posit of persisting points of absolute space—persisting points that, crucially, allow for the notion of absolute velocity to be physically meaningful—is done away with, but an *affine structure* is nevertheless preserved, which defines the "straight" or force-free (inertial) paths through space-time. Absolute velocity is therefore not a physically meaningful quantity in Galilean space-time, as it is in Newtonian space-time. Nevertheless, all other Newtonian notions, including the notion of absolute acceleration, remain well defined in Galilean space-time. To the extent that one opts for Galilean over Newtonian space-time, then, one has excised an ostensibly odious piece of theoretical structure from NGT.

Three important caveats are worth noting. First, and most obviously, none of this is to say that Newtonian theory set in Galilean space-time is therefore the true and complete theory of the world. (It is not.) Second, nor is this to say that by moving to Galilean space-time one has thereby purged Newtonian theory of all its "variant" structure. (One has not. The symmetry group of Newtonian theory is actually wider than the Galilean group: it has additional symmetries [see, e.g., Knox 2014]).[2] Third, this is not even to say that the invariant quantities one ends up with following such an application of the Invariance Principle will invariably be preserved in future theories (e.g., there is no notion of "relative spatial distance" simpliciter in special relativity). Given all of these caveats, however, one might well ask: What good is the Invariance Principle, exactly? What purpose, in particular, does it serve?

As I see it—and, I take it, as many other contemporary theorists also see it—the purpose of the Invariance Principle is essentially *comparative*. That is, it is simply supposed to lead you to a better theory—or a better interpretation, or characterization, of the same theory—than the one you started with.

2. I discuss this point further in sec. 4 below.

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To take the case at hand: Newtonian theory set in Galilean space-time is a better theory than Newtonian theory set in Newtonian space-time. It is a theory that possesses all of the theoretical virtues of its rival but lacks any apparent ontological commitment to the unwanted variant quantity in question.

In summary, the Galilean invariance of NGT, in conjunction with the Invariance Principle, is supposed to indicate that neither absolute velocity nor any corresponding persisting points of absolute space are genuinely real. Now to lay my cards on the table: I actually think that something very close to this general kind of inference—that is, from the variance of a quantity under symmetries to that quantity's nonreality—is legitimate. The devil, however, is in the details. In particular, I do not believe that the mere Galilean invariance of NGT is enough to establish absolute velocity's nonreality. And in general, I do not believe that the mere variance of a quantity under symmetries is enough to establish that quantity's nonreality. These beliefs, as far as I can determine, put me in the minority camp in the contemporary philosophical literature on symmetries. Nevertheless, I think they are correct beliefs—and they are precisely the ones that I will attempt to argue for in the remainder of this article.

2. Interpretational versus Motivational. In arguing for the above claims, it will prove extremely useful first to distinguish between two very different ways of thinking about symmetries. Close cousins of the distinction that I have in mind have already been drawn in the literature. Thus, Greaves and Wallace write: "There is a widespread consensus that two states of affairs related by a symmetry transformation are really just the same state of affairs differently described. That is, if two mathematical models of a physical theory are related by a symmetry transformation, then those models represent one and the same physical state of affairs" (2014, 60). They continue: "Although we agree with this consensus . . . even those who do not agree that symmetry-related states of affairs are identical at least agree that they are *empirically indistinguishable* from one another" (60 n. 1).

To illustrate the difference between these two ways of thinking about symmetries, consider again the example of boosts in NGT. According to the "widespread consensus" view alluded to, and endorsed by, Greaves and Wallace, boosted models of NGT are to be taken to represent the same physical state of affairs even when the theory is putatively set in Newtonian space-time. In other words, according to this view, one need not make the move to Galilean space-time in order not to be committed to absolute velocities; there is a way of understanding boosted models' physical equivalence, and their associated noncommitment to the notion of absolute velocity, before making this move.[3]

3. See, e.g., Healey (2007, 114–17), for an endorsement of this view in the Newtonian context.

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Things are very different according to the second conception of symmetries described, and rejected, by Greaves and Wallace. According to this view, boosted models of NGT are to be regarded as physically inequivalent: they are not to be construed as representing the same physical state of affairs. Instead, such models are taken to represent physically distinct scenarios, which differ in what absolute velocity they ascribe to the world's total material content. Nevertheless, such models still represent empirically indistinguishable states of affairs: in a Newtonian universe, no experiment could ever help an observer determine what her absolute velocity actually is. Such boosted models therefore represent physically distinct ways for the world to be, albeit ones that are indiscernible on the basis of measurement.[4]

As previously mentioned, this distinction between different ways of thinking about symmetries is close, but not identical, to the one that I want to draw. The key reason why it is not identical is because Greaves and Wallace say nothing to the effect that the person who subscribes to the second conception of symmetries—that is, who believes that symmetry-related models invariably represent empirically indistinguishable, but not necessarily physically equivalent, states of affairs—should still be *motivated to seek* an alternative theory, or an alternative interpretation or characterization of the same theory, according to which such models do not merely represent empirically indistinguishable scenarios but rather represent physically equivalent states of affairs.[5] Moreover, I claim, it is precisely this notion of *motivation* that plays a central role in correctly understanding the philosophical significance of symmetries in the general case.[6]

Here, then, is what I take to be the appropriate distinction between these two different ways of thinking about symmetries:

> **Interpretational:** Symmetries allow us to *interpret* theories as being committed solely to the existence of invariant quantities, even in the absence of a metaphysically perspicuous characterization of the reality that is alleged to underlie symmetry-related models.
>
> **Motivational:** Symmetries only *motivate* us to find a metaphysically perspicuous characterization of the reality that is alleged to underlie symmetry-related models, but they do not allow us to interpret that theory as being

4. See, e.g., Maudlin (1993, 192), for an endorsement of this view in the Newtonian context.

5. Compare (again) Maudlin's (1993, 192) discussion in the Newtonian context.

6. Note that I do not intend any of this as a criticism of Greaves and Wallace's paper. Indeed, as Greaves and Wallace (2014, 60 n. 1) are careful to remark, the distinction they draw is orthogonal to the central topic of their paper, namely, the issue of which symmetries have "direct empirical significance" (i.e., have analogues to Galileo's ship).

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solely committed to the existence of invariant quantities in the absence of any such characterization.

The central claim of this article may now be neatly summarized: the (orthodox) interpretational view is mistaken; the (unorthodox) motivational view is correct.

Drawing the distinction in the way that I have done, however, invites the rather obvious question: What, precisely, is meant by a "metaphysically perspicuous characterization" of reality? This is the question addressed in the next section.

3. More on Metaphysical Perspicuity. In intuitive terms, a metaphysically perspicuous characterization of reality is one that corresponds to, or "limns," reality's structure in some suitably faithful way. To use another common (Platonic) metaphor, a metaphysically perspicuous characterization of reality is one that "carves nature at its joints." (In comparative terms: a description of reality is more metaphysically perspicuous than another precisely to the extent that it corresponds to, or limns, reality's structure more faithfully than its rival does.)

As many readers will be aware, such a notion is frequently alluded to, and made use of, in contemporary analytic metaphysics (see, e.g., O'Leary-Hawthorne and Cortens 1995, 154–57). But metaphysical perspicuity is also, I think, a notion that is reasonably serviceable in physical (rather than "merely metaphysical") contexts. One particularly illustrative example—albeit a slightly misleading one, for reasons that I will soon explain—drawn from physics may plausibly be found in classical electromagnetism.[7] As is well known, this theory may be formulated in two different ways.[8] According to one such formulation, EM_1, the theory is expressed in terms of the Faraday tensor, F_{ab}, satisfying the (Maxwell) equations $\nabla_{[a} F_{bc]} = 0$ and $\nabla_a F^{ab} = J^a$, where J^a is a vector field representing the charge current density. According to the second formulation, EM_2, however, the theory is expressed in terms of the vector potential, A_a, satisfying the equation $\nabla_a \nabla^a A^b - \nabla^b \nabla_a A^a = J^b$.

These two formulations of electromagnetism are related to one another. In particular, any model $\langle M, \eta_{ab}, A_a \rangle$ of EM_2 corresponds to a unique model $\langle M, \eta_{ab}, F_{ab} \rangle$ of EM_1, via the equation $F_{ab} = \nabla_{[a} A_{b]}$. The converse, however, is not true. That is, a typical model of EM_1 does not typically correspond to a

7. Here and below, I take this theory to be set in Minkowski space-time. Thus, the space-time models of this theory are of the form $\langle M, \eta_{ab} \rangle$, where M is a four-dimensional differentiable manifold, and η_{ab} is the Minkowski metric.

8. For a recent intriguing study of the relationship between these two different formulations of electromagnetism, see Weatherall (2016). I draw heavily on his discussion over the next couple of paragraphs.

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unique model of EM_2. More specifically, if $\langle M, \eta_{ab}, A_a \rangle$ is a model of EM_2 corresponding to a model $\langle M, \eta_{ab}, F_{ab} \rangle$ of EM_1, then so will any other model of EM_2 $\langle M, \eta_{ab}, A'_a \rangle$, where A'_a is related to A_a by a "gauge transformation" $A'_a = A_a + \nabla_a \chi$, where χ is some smooth scalar field.

It is EM_1 that, I take it, constitutes the metaphysically perspicuous characterization of this theory. That is, it is the tensor F_{ab} that faithfully represents the fundamental ontology of the theory, namely, the electromagnetic field. Not so EM_2. This second formulation may, of course, be useful for various calculational or heuristic purposes. But the key point is that the vector potential A_a does not directly represent a genuinely real field: rather, it is merely a mathematically convenient "shorthand" way of characterizing and determining the values of the Faraday tensor, which is taken to represent the genuine material ontology of the theory.[9] Moreover, it is precisely by construing the vector potential in this way that plausibly allows us to explain and understand, in a fully transparent way, gauge-symmetry models' physical equivalence in EM_2—namely, for the reason that they are merely notationally distinct ways of representing the same fundamental physical ontology.

As mentioned above, I think this example of metaphysical perspicuity is apt to be slightly misleading, at least when taken on its own. This is because this example might make it seem as though having a metaphysically perspicuous characterization of the (putative) reality underlying symmetry-related models crucially relies on one having to *mathematically reformulate* the relevant theory (or at least on having such a mathematical reformulation already in hand), and in particular on having to reformulate the theory so as to remove any relevant representational redundancy. However, I think this is incorrect. That is, I believe that one can, in fact, be in possession of a metaphysically perspicuous characterization of the reality underlying symmetry-related models even in the absence of any mathematical (re)formulation of the theory that removes the relevant representational redundancy.

Let me illustrate this point with two simple examples. First, consider the case of *shift symmetry* in NGT. This symmetry is subtly different from the case of boost symmetry, discussed above. Here, instead of uniformly altering the absolute velocity of each particle throughout its history, one enacts a global, time-independent repositioning of all matter in space. Thus, for instance, in the shifted world all material content will (prima facie) be located 3 meters to the left of where it is in the original world. The basic idea behind the "Leibniz shift" argument—the famous argument associated with this symmetry—is that the substantivalist's admission of points of space as primitive objects (allegedly) has the undesirable consequence of committing her to regarding shifted worlds as physically distinct yet nevertheless empirically

9. Modulo, that is, certain concerns that arise as a result of the Aharonov-Bohm effect. See, e.g., Healey (2007).

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indistinguishable:[10] in intuitive terms, everything would look, feel, taste, touch, and sound the same in the two (putatively distinct) shifted worlds, just as in the case of boosted worlds.

It will prove helpful to express all of this in terms of the models of the theory. Thus, take a generic model of NGT to be of the form $\mathcal{M} = \langle M, t_{ab}, h^{ab}, \sigma^{a}, \rho, \varphi \rangle$, where M is a differentiable four-dimensional manifold, t_{ab} is the temporal metric, h^{ab} is the spatial metric, σ^{a} is the time-like vector field whose integral curves represent the persisting points of absolute space, and ρ and φ represent the matter density and the gravitational potential field respectively.[11] A shift symmetry can then be characterized as the application of the appropriate diffeomorphism (corresponding to a spatial translation) d so as to yield a new model $\mathcal{M}_{\text{static}} = \langle M, t_{ab}, h^{ab}, \sigma^{a}, d^{*}\rho, d^{*}\varphi \rangle$. It is then alleged that $\mathcal{M}$ and $\mathcal{M}_{\text{static}}$ differ precisely insofar as they each represent the world's matter content as being located at distinct places in absolute space. More specifically, such Leibniz-shifted scenarios are alleged to differ precisely with regard to which particular points of space are underlying various parts of the matter fields.

For a second example, consider *diffeomorphism symmetry* in general relativity (GR). Here, similarly, the existence of this symmetry is alleged to commit the substantivalist to a plurality of physically distinct possibilities that are nevertheless empirically indistinguishable. In terms of the models of the theory, taking a generic model of GR to be of the form $\mathcal{M} = \langle M, g_{ab}, T_{ab} \rangle$ and applying an arbitrary diffeomorphism d to yield a new model $\mathcal{M}_{\text{diff}} = \langle M, d^{*}g_{ab}, d^{*}T_{ab} \rangle$ (where M is again a differentiable four-dimensional manifold, g_{ab} is the metric tensor, and T_{ab} is the stress-energy tensor that, roughly speaking, represents the model's matter content), the two scenarios represented are alleged to differ with regard to which particular points of the space-time manifold are underlying various parts of the metric and matter fields.[12]

It is my contention that neither the shift symmetry of NGT nor the diffeomorphism symmetry of GR by itself motivates any mathematical reconstrual of the respective theories. This is because I believe there is a perfectly transparent, antihaecceitist, "modestly structuralist"—but nevertheless

10. Although see Maudlin (1993), who notes that there is an interesting (epistemological) sense in which shifted worlds in NGT are not indiscernible after all.

11. Note that the canonical presentations of Newtonian space-time (e.g., Earman 1989, sec. 2.5) take the affine connection as ideologically primitive. I find such presentations unsatisfactory for historical rather than for philosophical reasons: in particular, it threatens to make the move to Galilean space-time seem almost trivial and the associated time-like vector field trivially superfluous. For more on this point, see Pooley (forthcoming, secs. 4.4–4.5).

12. For further details see, e.g., Earman (1989, sec. 9).

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fully substantivalist—way of understanding such models' representational equivalence even in the absence of any such mathematical reformulation. On this view, space-time points are construed as genuinely real, fundamental entities. However, they are "contextually individuated": they are not to be understood as being anything more—or less—than "nodes" in the relational, geometrical structures in which they are embedded. Shifted models in NGT and diffeomorphically related models in GR are thus to be understood as representing the same physical state of affairs precisely because the exact same pattern of relational, geometrical structures is represented as obtaining in each case. Moreover, this view denies that there are any primitive, singular ("haecceitistic") facts about space-time points that would even allow for a distinction between shifted or diffeomorphically related scenarios to be coherently drawn.[13]

Whence the difference, then, between the case of gauge symmetry in electromagnetism, on the one hand, and shift and diffeomorphism symmetry in NGT and GR, on the other? I think the answer is straightforward. In the latter cases, the models in question are *isomorphic*: they represent worlds that differ at most with regard to which particular objects are playing which qualitative roles (i.e., they represent at most haecceitistically distinct possible worlds). Hence, adopting modest structuralism (which implies antihaecceitism) about space-time transparently collapses the number of possibilities represented by these models to one. In the former such case, however, the relevant models are not isomorphic—read "literally," gauge-related models of EM_2 assign qualitatively distinct arrangements of the vector field over space-time. Hence, adopting a modestly structuralist ontology does not by itself collapse the number of represented possibilities to one. In order to transparently understand such models' physical equivalence, then, a mathematical reformulation of the theory is required.

To summarize the claims made thus far: according to the motivational view of symmetries, one is invariably only motivated to regard symmetry-related models as physically equivalent; moreover, one is justified in regarding such models as physically equivalent only insofar as one is in possession of a metaphysically perspicuous characterization of the reality that is alleged to underlie them. However, it is possible to be in possession of a metaphysically perspicuous characterization of the reality underlying symmetry-related models even in the absence of a mathematical formulation of the theory that removes the relevant representational redundancy. Such a metaphysically perspicuous characterization is possible just in case the symmetry-related models in question are isomorphic, or are naturally understood as

13. For further defense of this view—which is sometimes also called *sophisticated substantivalism* in the literature—see, e.g., Saunders (2003), Ladyman (2007), and Pooley (2013).

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representing at most haecceitistically distinct possibilities. In brief: symmetry-related, isomorphic models invariably do not motivate a mathematical reformulation of the relevant theory (modest structuralism invariably suffices), but symmetry-related, nonisomorphic models invariably do.[14]

4. In Defense of the Motivational View. Let us return once more to the case of NGT. As alluded to in section 1, the symmetry group of this theory is quite large. For not only does it include transformations corresponding to global velocity boosts of solutions' matter content, but it also includes transformations corresponding to time-dependent translational accelerations of such content (so long as the gravitational potential field is also appropriately transformed). Thus, read "literally," the symmetries of this theory include transformations that map solutions to solutions that represent physically distinct, but nevertheless empirically indistinguishable, states of affairs in which a given material system is:

1. Force-free and stationary with respect to absolute space.
2. Force-free and moving at constant absolute velocity.
3. Absolutely accelerating under a gravitational force field.

According to the interpretational conception of symmetries, we may legitimately take all of these symmetry-related solutions to in fact represent the same physical state of affairs—despite the fact that they are naturally understood as representing radically distinct physical situations. Things are very different, however, according to the motivational conception of symmetries. On this view, we are merely motivated to regard all such solutions as representing the same physical state of affairs, the motivation arising from the general Occamist principle that, other things being equal, our preferred scientific theories should not allow for solutions that represent physically distinct but nevertheless empirically indistinguishable possible worlds. According to the motivational view, then (to repeat slightly), absent a metaphysically perspicuous characterization of the reality underlying these symmetry-related models, we have no choice but to regard them as representing physically distinct states of affairs.

For our purposes, the crucial thing to note about all of these models is that none of them are isomorphic—naturally understood, they do not represent at most haecceitistically distinct possible worlds. According to the criterion laid down in the previous section, then, in order to be able to transparently understand how it could be that such models may be said to represent physically equivalent scenarios, a mathematical reformulation of the theory is required.

14. See also Pooley (2013, 576–77) and Weatherall (2016) for recent related arguments to this effect.

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As it turns out, such a mathematical reformulation of the theory is possible. In brief, in this reformulation one replaces the vector field σ^a with a new kind of *dynamical* inertial connection ∇^{NC}, with models of the form $\mathcal{M}_{\mathrm{NC}} = \langle M, t_{ab}, h^{ab}, \nabla^{\mathrm{NC}}, \rho \rangle$. Up to isomorphism, any two symmetry-related models of NGT correspond to a unique model of Newtonian gravity geometrized in this way. Thus, it is said, by moving to this "Newton-Cartan" theory one successfully removes the undesirable "gauge redundancy" inherent in all nongeometrized versions of NGT.[15]

What might the defender of the interpretational view of symmetries say in defense of her view—in this context, that the move to Newton-Cartan theory is not required in order to be able to legitimately regard all symmetry-related solutions of NGT as physically equivalent? I anticipate two likely lines of response. First, she might attempt to establish the preferability of her view over the motivational view by noting that the defender of the motivational view is committed, at least before the appropriate theory's reformulation (in the context of NGT), to the existence of in-principle undetectable (symmetry-variant) matters of fact. Moreover, the defender of the interpretational view might argue, this is an unpalatable consequence, one that we would do best to avoid—and one that, she might point out, the interpretational view does in fact avoid.

I agree that the admission of such in-principle undetectable facts is an undesirable consequence of the motivational view. However, I do not think that this admission is sufficiently unpalatable so as to be capable of refuting the motivational view or even of establishing the preferability of the interpretational view over the motivational view. After all, prohibitively strong versions of verificationism aside, there is nothing obviously absurd about admitting in-principle undetectable facts into one's ontology. Nor is there any obvious reason why we should always be capable of discovering a theory, or a perspicuous characterization thereof (the case of isomorphic models excepted), that succeeds in transparently explaining such solutions' empirical equivalence by virtue of their actual physical equivalence. Nor indeed is there even any obvious way of guaranteeing that there will always be such a theory or characterization (again, isomorphic models excepted) waiting in logical space to be discovered.

15. For further details, see, e.g., Knox (2014). Note also the important point that moving to Newton-Cartan theory is not by itself sufficient for one to be able to transparently understand as physically equivalent all symmetry-related models of Newtonian theory set in flat space-time. This is because—as mentioned above—such symmetry-related models will typically correspond to a single model of Newton-Cartan theory only up to isomorphism. Thus, in order to have a fully transparent understanding of how it is that symmetry-related models of Newtonian theory set in flat space-time can correspond to a single model of Newton-Cartan theory, a modestly structuralist conception of space-time ontology is also required.

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Furthermore, although it is to be admitted that the Newtonian who subscribes to the merely motivational view of symmetries might indeed be committed to the possibility of there being facts beyond her epistemic grasp, it nevertheless bears emphasizing that for such a Newtonian there is a perfectly good explanation as to why such facts are epistemically inaccessible: they are inaccessible precisely because the world is in fact accurately described by the laws of NGT, with associated models of the form $\langle M, t_{ab}, h^{ab}, \sigma^{a}, \rho, \varphi \rangle$, and because all any Newtonian observer ultimately has empirical access to are the relative distances and velocities between material entities. For such a Newtonian, then, the empirical phenomena underdetermine the genuine physical facts, but the theory itself is able to provide a perfectly transparent explanation of the reality behind the phenomena in terms of which the underdetermination can be straightforwardly understood.

The Newtonian who adopts the interpretational construal of symmetries, however, would appear to lose this explanatory transparency. In other words, she might know that she may legitimately regard all symmetry-related solutions as physically equivalent, but the reality in terms of which this physical equivalence is to be understood will (absent a reformulation of the theory) remain opaque to her; she is offered no immediate explanation as to how such physical equivalence is to be construed or how it could even be said to arise.

These considerations naturally suggest a second possible line of response for the defender of the interpretational view. In particular, she might claim that she does, in fact, have a transparent understanding of the reality underlying NGT's symmetry-related models and that such a transparent understanding is in fact attainable before the move to Newton-Cartan theory.[16]

Such a response evidently leads into deep philosophical waters very quickly. (After all, what does it mean to be in possession of a "transparent understanding" of anything?) But let me make a brief remark as to why I find this particular claim to be implausible. For note that in NGT the persisting points of absolute space are not merely "idly turning wheels" that can simply be expunged from the theory without explanatory loss: they are not "explanatorily idle" posits. This is for two main reasons. First, such points play a crucial role in the metaphysical explanation of what quantities like relative velocity and absolute rotation and absolute acceleration truly are: for the Newtonian, facts about particular interparticle velocities and absolute rotations and absolute accelerations are naturally understood as being grounded in particular facts about (rates of change of) absolute velocities (cf. Pooley, forthcoming, 118). Second, such points provide the crucial transtemporal standard that is required

16. Dewar (2015, esp. 322)—who is a recent, explicit defender of the interpretational view—is plausibly read as making this claim.

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in the realist's causal explanation of the observable effects of noninertial motion (e.g., Newton's famous "bucket experiment"): a standard without which Newton's laws simply cannot be formulated (at least, absent any other way of construing the transtemporal structure required to underwrite the distinction between inertial and noninertial motion). In short—and to the extent that the interpretational view is not supposed to reduce to a rather uninteresting form of scientific instrumentalism—it is simply not clear what causal-explanatory, realistic picture of the world is being propounded by the defender of the interpretational view, at least in this particular (Newtonian) context; it is simply opaque what, according to her, the world is really like.

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