De Gravitatione Reconsidered: The Changing Significance of Experimental Evidence for Newton's Metaphysics of Space

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ABSTRACT I argue that Isaac Newton's *De Gravitatione* should not be considered an authoritative expression of his thought about the metaphysics of space and its relation to physical inquiry. I establish the following narrative: In *De Gravitatione* (circa 1668–84), Newton claimed he had direct experimental evidence for the work's central thesis: that space had "its own manner of existing" as an affection or emanative effect. In the 1710s, however, through the prodding of Roger Cotes and G. W. Leibniz, he came to see that this evidence relied on assumptions that his own *Principia* rendered unjustifiable. Consequently, he (i) revised the conclusions he explicitly drew from the experimental evidence, (ii) rejected the idea that his spatial metaphysics was grounded in experimental evidence, and (iii) reassessed the epistemic status of key concepts in his metaphysics and natural philosophy. The narrative I explore shows not only that *De Gravitatione* did not constitute the metaphysical backdrop of the *Principia* as Newton ultimately understood it, but that it was the *Principia* itself that ultimately lead to the demise of key elements of *De Gravitatione*. I explore the implications of this narrative for Andrew Janiak's and Howards Stein's interpretations of Newton's metaphysics.

KEYWORDS Isaac Newton, absolute space, void, vacuum, matter theory, atomism, corpuscularianism, Roger Cotes, G. W. Leibniz

1. INTRODUCTION

NEWTON'S COMMITMENT TO ABSOLUTE SPACE—the immobile, eternal arena in which all things exist—is well known.[1] Before 1962, it was studied through three

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main sources: the scholium to the definitions of the *Principia* (1687, 1713, 1726 [hereafter: *E1*, *E2*, *E3*]), the General Scholium (*E2*, *E3*), and the Leibniz-Clarke correspondence (1717). Other historical evidence was scarce.[2] In 1962, A. Rupert Hall and Marie Boas Hall published a previously unknown Newtonian manuscript they titled by its incipit *De Gravitatione et aequipondio fluidorum et solidorum in fluidis* (hereafter: *DG*).[3] The work begins as a synthetic treatment of hydrostatics, but shortly after digresses into an anti-Cartesian polemic that contains Newton's most extensive treatment of the metaphysics of space.[4] Written in Newton's hand, it contains relatively few corrections and additions, suggesting it was a cleaned-up, considered copy of earlier, messier work. Its dating is unclear. Newton certainly authored it between 1668 and 1684, likely in stages, but there is no scholarly consensus.[5] Since 1962, *DG* has come to tower in importance over the remainder of Newton's philosophical writings, even as more of these have come to light. Its richness of argumentation, attentive engagement with metaphysics and theology, and explicitly philosophical goals make it a favorite of historians of philosophy. In fact, scholars often take *DG* to represent *the* Newtonian position on the metaphysics of space, the position he purportedly held to his death in 1727.[6]

The present essay challenges this interpretive tradition. I argue that historians of philosophy cannot continue to consider the manuscript an authoritative expression of Newton's mature thought, specifically about the metaphysics of space and its relation to physical inquiry. There are several prima facie problems in doing so, but I address just one. *DG* was authored before the *Principia*: before Newton formulated his laws of motion, discovered universal gravitation, and much before he explored their full, sometimes startling, implications. Taking it as authoritative

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[2]The *Opticks*'s aether queries (1717) were available, but are enigmatic and only indirectly related to space. Some of Newton's other writings were published in 1838 (Stephen Peter Rigaud, *Historical Essay*) and 1893 (W. W. Rouse Ball, *An Essay*), but the significant writings on space were only published in the past 60 years, most thanks to J. E. McGuire. See McGuire and P. M. Rattansi, "Newton and the 'Pipes of Pan'"; McGuire, "Newton on Place, Time, and God," and "Body and Void." The interpretive weight proper to the Leibniz-Clarke correspondence is a subject of debate; see Ezio Vailati, *Leibniz and Clarke*; and Alexandre Koyré and I. Bernard Cohen, "Leibniz-Clarke."

[3]*Unpublished Papers*, 89–156. References below are to the newer English translation in *Philosophical Writings*, 12–39, although I have often modified it with the help of Howard Stein's translation (http://strangebeautiful.com/other-texts/newton-de-grav-stein-trans.pdf). I refer to propositions and corollaries in the *Principia* as, e.g. *E2*.2.24.c5, indicating second edition, Book II, Proposition 24, Corollary 5. I refer to manuscript material available through Cambridge University Library (CUL) by manuscript number and folio page, e.g. CUL Add 4005, folio 28r–29r. I refer to transcriptions available at The Newton Project (http://www.newtonproject.ox.ac.uk/) by catalogue ID, e.g. The Newton Project NATP00063.

[4]Newton never called *DG* his "metaphysics," but we have come to use the term. See Howard Stein, "Newton's Metaphysics." I thank an anonymous referee for urging me to stress this.

[5]See J. A. Ruffner, "Newton's *de Gravitatione*."

[6]I know of no one who takes *DG* to represent the Newtonian position *simpliciter*. In fact, scholars often use the extent to which *DG* diverges from Newton's "mature" views about, say, inertia or active principles as a parameter by which to date the work. Nevertheless, many take *DG*'s metaphysics of space—clearly the heart of the work—to represent Newton's mature views on space; cf. n. 7.

thus presumes a conceptual fixity across one of the largest natural-philosophical leaps in the early-modern period.[7] This presumption is unjustified.[8]

My argument is this: In *DG* (and likely *E1*), Newton thought he had direct experimental evidence for his metaphysics of space. In particular, he had evidence that space lacked all causal power and so (unlike causally efficacious substances and their accidents) had "its own manner of existing."[9] This tight evidentiary connection between experiment and metaphysics was central to *DG*. However, likely in the 1710s, Newton was forced to sever this connection. Through the prodding of Roger Cotes and G. W. Leibniz, he came to see that his experimental evidence relied on assumptions that his own rational mechanics rendered unjustifiable.[10] That is, he realized that the metaphysical theses of *DG* outstripped the experimental warrant the *Principia*'s natural philosophy could provide them with. Because this warrant was central to Newton's account of space, its failure induced him to (i) revise the conclusions he explicitly drew from the experimental evidence, (ii) reject the idea that experimental evidence grounded his spatial metaphysics, specifically the idea that space had "its own manner of existing," and (iii) reassess the epistemic status of key concepts of his metaphysics and natural philosophy. I focus on (i) and (ii) here.[11]

To establish (i) and (ii), I trace a line of thought from Newton's ideas about space and experimental evidence in *DG* and *E1*, through his correspondence with Roger Cotes regarding *E2*, to draft definitions of 'body' and 'vacuum' intended for *E3*. These draft definitions achieved a polished state likely in 1716, but Newton

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[7]Problems I do not address: After *DG*'s philosophical digression, the manuscript returns briefly to hydrostatics and mysteriously cuts off. Why hydrostatics—and not physical astronomy or Galilean-style mechanics—provided the appropriate context for this digression has not been well explained. Second, there is the matter of *DG*'s unity as a text. The evidence that Newton authored it in (incompatible) stages is compelling, but if so, why were the stages combined as they were? Third, the text went unpublished. Newton was famously reticent about publication, but often for good reasons (e.g. avoiding theological heterodoxy and public conflict). What reason is appropriate for *DG*? As many have noted, the views espoused therein were far from unusual in Newton's Cambridge. Fourth, neither Newton nor his acquaintances mentioned the text in any known manuscript or correspondence. The latter is significant, for Newton was not averse to discussing his views with confidants. In the 1690s, for example, he shared the heterodox Classical Scholia with David Gregory, yet (as far as I know) he did not share *DG* with anyone. It is possible that *DG* was a subject of conversation between Newton and Locke, as many understand Pierre Coste to have suggested, but there is no corroborating evidence (see Locke, *Essai Philosophique,* xliv).

[8]This view is also expressed to differing degrees by Steffen Ducheyne, *The Main Business,* 269–83; John Henry, "Gravity and *de Gravitatione*"; and Robert DiSalle, "Transcendental Method." Ducheyne argues that Newton's use of metaphysics/theology to "reach conclusions about the empirical world" changed over time. I wholly agree and focus on the opposite inferential direction, on Newton's changing use of empirical facts to reach conclusions about metaphysics/theology. Henry convincingly argues for an early dating of *DG*, and so holds that the work fails to represent many of Newton's mature views to a much greater extent than most other scholars. In particular, he rightly notes that "the discussion of body [in *DG*] is a unique one-off" (23). DiSalle explicitly rejects the idea that Newton's metaphysics of space achieved stable form in *DG*. I engage his view directly in Zvi Biener, "Geometrical Definitions."

[9]*DG* 21.

[10]Christiaan Huygens also challenged Newton, but about the universality of gravitation and on different grounds. See Eric Schliesser and George E. Smith, "Huygens's 1688 Report," and Smith, "Closing the Loop," 275–77.

[11]I continue the argument for (iii) in a companion piece to the present essay, Biener, "Geometrical Definitions."

never incorporated them into the published work. They were brought to light by J. E. McGuire almost 50 years ago, but I believe he was not in a position to appreciate their full significance.[12] McGuire situated them against Newton's continuing battles with Leibniz—an undoubtedly important context—but consequently only emphasized their polemical dimension. They take on a new meaning when set against Newton's more sincere interactions with Cotes—interactions that were intended not to win debate, but to genuinely sort out the implications of Newton's new dynamics. I argue that sorting out these implications ultimately led Newton to reject the idea that experimental evidence grounded his spatial metaphysics—specifically the idea that space had "its own manner of existing." This was a marked change from the position expressed in *DG*. The view I am developing thus opposes a common trope in the Newtonian secondary literature: not only did *DG* not constitute the metaphysical backdrop of the *Principia* as Newton ultimately understood it, it was the *Principia* itself that ultimately led to Newton's rejection of key elements of *DG*.

Sections 2 and 3 set the scene. In section 2, I show that much of Newton's metaphysics in *DG* relied on the claim that space is causally inert. In section 3, I review Newton's evidence for space's inertness. I argue that, in both *DG* and *E1*, Newton held that this evidence directly established the failure of Cartesian metaphysics and thus the success of his alternative. In section 4, I discuss the implications of a challenge to this evidence leveled by Roger Cotes, as well as its broader 1710s context. In section 5, I discuss Newton's draft definitions to *E3*: how they alter the significance of his original evidence, and how they address Cotes's concern. In section 6, I spell out the implications of these definitions for Newton's metaphysics of space and connect my conclusions to Andrew Janiak's and Howard Stein's influential interpretations.

2. EMPTY SPACE, POWER, AND INERTNESS IN *DE GRAVITATIONE*

In *DG*, Newton's stated goal was to demonstrate the failure of Descartes's definition of motion. To this end, he offered a variety of conceptual and empirical arguments that mostly reappeared in the *Principia*'s scholium on space and time. From the failure of Descartes's definition, he drew the further conclusion that the conceptual framework on which it relied—primarily the identification of space and body—was itself bankrupt. Newton took Descartes's abstractionist argument of *Principia Philosophiae* II, §11 as the primary justification for this identification (more on this later), and declared that "lest any doubt remain about the nature of motion, I shall reply to this argument by saying what extension and body are, and how they differ from one another."[13] His alternate account of space followed.

[12]McGuire, "Body and Void." McGuire was not in a position to appreciate their full significance because maturity had not yet been reached by the line of research that issues from Stein, "Newtonian Space-Time"; Cohen, "The *Principia*, Universal Gravitation, and the 'Newtonian Style'"; and William Harper and Smith, "Newton's New Way of Inquiry." This research reveals the central role of the laws of motion in constituting Newton's conceptual framework. I return to this role in sect. 5 and discuss it further in Biener, "Geometrical Definitions." See also Katherine Brading, "Law-Constitutive Approach."

[13]*DG* 21.

On Newton's account, six characteristics capture space's physico-geometry, modal status, and ontology. Geometrically, space is (1) three-dimensional and teeming throughout with one-, two-, and three-dimensional forms, (2) actually infinite in all directions, and (3) motionless. Modally and ontically, space is (4) "an affection of being just as being."[14] However we read this claim—and scholars disagree—Newton clearly intended to stress that whatever exists, necessarily exists spatially; that there is no existence besides spatial existence.[15] The necessity of spatial existence grounds space's fifth characteristic. Since everything exists spatially, and since space is geometrical, everything is related to space geometrically. It is consequently possible—and given the anti-Cartesian arguments from motion, necessary—to treat motion as motion with respect to space, using the tools of geometry. In other words, (5) "the positions, distances, and local motions of bodies are to be referred to the parts of space."[16] And all the above claims are forever true because space is (6) "eternal in duration and immutable in nature."[17]

Immediately after the fifth characteristic—Newton's alternative to the Cartesian definition of motion—but before the sixth, Newton added an unnumbered, easy-to-overlook feature of space. It is this feature that makes space a truly *physico*-geometrical entity, by revealing its position in the causal order:

> 5. The positions, distances, and local motions of bodies are to be referred to the parts of space. . . . To this it may be further added *that there is no force of any kind present in space* that would impede or promote or in any way change the motions of bodies. And hence projectiles describe straight lines by uniform motion if they do not meet impediments from a different source. *But of this more later.*[18]

In other words, space has *no* position in the causal order. It is entirely inert. This may seem like an offhand remark to modern readers, but that is only because we have come to think of Newtonian space's lack of causal powers as obvious, even intuitive. Newton did not think so, and he promised to return to the inertness of space "later" because, in fact, the entirety of *DG*'s metaphysics depended on it. In the remainder of this section, I review some familiar aspects of *DG* in order to emphasize their deep connection with the inertness of space. I leave Newton's arguments for space's inertness to the next section.

In *DG*, Newton held that space was ontically distinctive:

> [I]t may be expected that I should define extension as substance, or accident, or else nothing at all. But by no means, for it has its own manner of existing which is proper to it and which fits neither substances nor accidents. It is not substance: first, [1] because it subsists not absolutely in itself, but, as it were, as an emanative effect of God and a certain affection of every being; then, [2] because it is not among the proper affections of the sort that denote substance, namely actions, such as are thoughts in the mind and motions in body. [3] For although philosophers do not define substance as a being that can act upon something, yet all tacitly understand this of substances,

[14] *DG* 25.

[15] See McGuire, "Predicates of Pure Existence"; John Carriero, "Newton on Space and Time"; Stein, "Newton's Metaphysics"; Geoffrey Gorham, "The Cartesian Framework"; McGuire and Edward Slowik, "Newton's Ontology"; and Schliesser, "Newtonian Emanation."

[16] *DG* 26.

[17] *DG* 26.

[18] *DG* 26, emphasis added. *DG* defines "force" as a "causal principle" (36).

> as for instance is plain from this, [4] that they would easily concede extension to be a substance like body if only it could be moved and could engage in the actions of body. And on the other hand, [5] they would by no means concede that a body is a substance if it could neither be moved nor excite any sensation or perception in any mind whatever.[19] Moreover, [6] since we can clearly conceive extension existing as it were without any subject, as when we imagine spaces outside the world or places void of any body whatsoever, and we believe it to exist wherever we imagine there are no bodies, and [7] we cannot believe that it would perish with the body if God were to annihilate some body, it follows that it does not exist in the manner of an accident inherent in some subject. And thus it is not an accident.[20]

Newton's criterion for substantiality is two-fold: substances must subsist in themselves (1), and substances must have a power to act (2). The power to act, however, is clearly dominant: it is necessary and sufficient for substantiality (4, 5) and epistemically prior to independent subsistence (5). Moreover, it is what philosophers really mean when they talk about substantiality (3). Subsistence itself is under-theorized in *DG* and its status vis-à-vis agency unclear.[21] Newton's criteria for accident-hood is more complex, but suffice it to say that it presumes accidents must be co-present with the substances that possess them (6, 7), and so, given the criterion for substantiality, must be co-present with powers to act. Where there are no powers, there can be no substances and, a fortiori, no accidents.

The inertness of space is central to *DG* because our knowledge of space's status as an affection/emanation rests on it.[22] On the one hand, this inertness rules space out as a substance. On the other, it allows us to conceive of space as existing where there are no non-divine powers and thus no created substance—it rules space out as an accident. Since it is neither substance nor accident but is something nonetheless, space must have "its own manner of existing."

In the passage above, Newton focused on the causal powers appropriate for body, but space is clearly lacking *all* powers. Later in *DG*, he wrote:

> [E]xtension is eternal, infinite, uncreated, uniform throughout, not in the least mobile, nor capable of inducing change of motion in bodies or *change of thought in the mind.*[23]

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[19]*DG* 21–22.

[20]*DG* 21–22.

[21]The reason subsistence is under-theorized may be that it is only metaphorically ascribed to created substance: "[the] notion of bodies having, as it were, a complete, absolute, and independent reality in themselves . . . all of us, through negligence, are accustomed to have in our mind . . . [yet] God does not sustain his creatures any less than they sustain their accidents, so that created substance, whether you consider its degree of dependence or its degree of reality, is of an intermediate nature between God and accident" (*DG* 32).

[22]There are debates about Newton's use of 'emanation' and 'affection,' their meaning, and the extent to which one or the other is the preferred concept. I remain agnostic about this. Different passages in *DG* recommend subtly different readings and choice among them is not relevant to my thesis. See works in n. 13.

[23]*DG* 33, emphasis added. Note that this list is a compressed version of space's six characteristics: "Extension is [6] eternal, [2] infinite, [4] uncreated, [1] uniform throughout, [3] not in the least mobile, [5] nor capable of inducing change of motion in bodies." In this passage, Newton clearly took inertness to be the salient feature of space's fifth characteristic, not the necessity of referring motions to space.

Despite its many anti-Cartesianisms, *DG* is a remarkably Cartesian text.[24] Accordingly, in it, Newton considered only two sorts of (created) substance: body and mind. But, presumably, if there were other sorts of substance, space would be incapable of the actions proper to them as well. This condition is crucial. Space's inertness provides evidence for its distinctive manner of existing, and, as others have argued, its manner of existing grounds its key characteristics: necessity, immutability, eternality, infinitude, and as we saw earlier, ability to support a new definition of motion.[25] If space *were* capable of some action, it would not have its "own manner of existing." Entirely different arguments would be necessary to support its other characteristics. Newton's commitment to inertness is thus indispensable. It lies at the root of *DG*'s account of space.

Space's inertness is also the cornerstone of *DG*'s account of body. Newton famously conceived of bodies as regions of space that God fills with certain powers through a creative act of will:

> [W]e can define bodies as *determinate quantities of Extension which omnipresent God affects with certain conditions*: these are (1) that they be mobile. . . . (2) That two of this kind cannot coincide. . . . (3) That they are able to excite various perceptions of the senses and the fancy in created minds.[26]

Given Newton's criterion of substantiality, it is not surprising that he defined bodies through their possession of powers.[27] This strategy would be rather poor, however, if space were not inert. In that case, the possession of powers would not differentiate bodies from space. Moreover, bodies would not be quantities of extension that God willfully affects with *all* their powers. They would only be quantities that God *partially* affects by his will, with a subset of their powers due to their grounding in space. However, Newton certainly supposed that all bodily powers are willed by God. That supposition would be plainly false if space were capable of action, unless other of its characteristics—first and foremost, its uncreatedness—were rejected as well.

Several more subtle features of *DG*'s metaphysics also depend on spatial inertness. Take, for example, the purported explanatory advantages of *DG*. Newton believed that *DG*'s metaphysics captured whatever insight scholastic metaphysics contained, but more perspicaciously so, by substituting clear and distinct ideas for confused Aristotelian notions. In the case of matter and form:

> [Space] takes the place of the substantial subject in which the form of the body is conserved by divine will; and that effect of the divine will is the form or formal reason of the body. . . . [Consequently, b]etween extension and its impressed form there is almost the same analogy that the Aristotelians posit between prime matter and substantial forms.[28]

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[24] McGuire, "A Dialogue"; and Gorham, "The Cartesian Framework."

[25] On how space's manner of existing as an affection/emanation grounds its key characteristics, see works in n. 13. Notably missing from the above list is space's geometrical character, whose relationship with the emanation thesis is more complex. See Mary Domski, "Newton's Mathematics and Empiricism."

[26] *DG* 28–29.

[27] See Stein, "Newton's Metaphysics," for Newton's concept of 'natural power.'

[28] *DG* 29.

This analogy would be improper if space were not inert. In that case, the relation of space to body would not echo the relation Aristotelians posit between the inherently passive substantial subject and the active form, and so Newtonian metaphysics would not be a deeper explanation than, and replacement of, scholastic metaphysics.

For another example, if space were causally efficacious, Newtonian metaphysics would lose its purported theological advantage over both Cartesian and Aristotelian views. For Newton, our will and God's will are of the same kind, if of vastly different scopes. Consequently, we can understand God's act of willing powers into space—thus creating bodies—by reference to our own acts of willing our bodies into motion: "God may appear (to our innermost consciousness) to have created the world solely by the act of will, just as we move our bodies by an act of will."[29] Since our direct acquaintance with the act of willing makes God's creative act intimately comprehensible, it also appears to our innermost consciousness that the world could not have existed without God's say-so. Newtonian metaphysics thus blocks a path to atheism that, according to Newton, Cartesian and Aristotelian alternatives are unable to block. Yet it would lose this advantage if space were capable of action. In that case, space's power would either be due to a separate act of God's will or be independent of God's will. The first, by making some feature of space an act of God, would destroy space's status as an affection/emanative effect. It thus raises the possibility that space could have been different than it is, and disturbs the grounds for its necessity, immutability, and eternality. The second option is prima facie theologically odious and, moreover, postulates a power whose coming into being is not comprehensible by analogy with our will, one whose existence does not appear to our innermost consciousness to depend on God. A causally efficacious space thus destroys the theological advantage of Newton's view.

No wonder Newton felt obliged to offer "more" on space's inertness "later." Its inertness is deeply woven into the fabric of *DG*'s metaphysics.[30]

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[29]*DG* 30. Newton *literally* took God's will and human will to be of the same kind, although he often insisted that discourse about God is merely figurative. In the General Scholium, for example, he wrote: "All the diversity of created things, each in its place and time, could only have arisen from the ideas and the will of a necessarily existing being. But God is said allegorically to see, hear, speak, laugh, love, hate, desire, give, receive, rejoice, be angry, fight, build, form, construct. For all discourse about God is derived through a certain similitude from things human, which while not perfect is nevertheless a similitude of some kind" (*Principia*, 942). Newton only added the last sentence in E3. See also drafts letters to Des Maizeaux, Koyré and Cohen, "Leibniz-Clarke." He repeated the claim almost verbatim in a query added to the *Optice* in 1706, with no caveat regarding figurative use (Newton, *Opticks*, 403).

[30]There is one loose end to tie up before moving on. Some may think that the counterfactual I have been considering—that space is coupled to some power—is patently absurd. If this were the case, Newton's position would be a default that requires no positive argument. But this was/is not the case. A causally efficacious space was a live option in Newton's time (as it is in ours!) and his rejection of it was a deliberate choice, not a thoughtless fallback. To begin with, I need only point to Cartesian views that equate space with body, and so imbue it with the same causal efficacy as body. Although the ultimate seat of corporeal power is unclear in Descartes (body itself, God, both?), it is clear that Cartesian space is not prima facie inert, for the trivial reason that space is body. More generally, in the longer history of the concept of space, the idea that empty space could be causally efficacious or indirectly structure causal relations—although a minority view—was a repeated motif (see Edward Grant, *Much Ado*, 10, 34). It was certainly not unusual to inquire, as a contemporary of Newton's did: "what Exertion of Power or Action is there in an infinite Vacuum?" even if only to answer negatively (Robert Greene, *Principles*, 17).

3. EVIDENCE FOR INERTNESS

So what is the "more"? What was Newton's evidence for the inertness of space? Immediately after the account of space and body, Newton returned to "respond more concisely" to Descartes's abstractionist argument. In *Principia Philosophiae* II, §11, Descartes argued that if we attend to the idea of some body and strip from it every feature that does not pertain to its essence, we are left with the idea of bare extension. Since extension is also the essence of space, it follows that body is identical with space.[31] Newton responded with two sets of arguments, each about a power he took to be definitional of body: the power to arouse perceptions and the power to move and resist motion.[32] His strategy was to establish that bodies possess these powers, while space does not.[33]

First, Newton argued that removing from bodies the power to "move" perceptions runs counter to broader Cartesian doctrine. He did so by brilliantly mobilizing another touchstone of Cartesianism, the mind/body distinction:

> Let us remove from body (as [Descartes] demands) weight, hardness, and all sensible qualities, so that nothing remains except what pertains to its essence. Will extension alone then remain? By no means. For we may also reject that faculty or power by which they move the perceptions of thinking things. For since there is so great a distinction between the ideas of thought and of extension that it is not obvious that there is any basis of connection or relation [between them], except that which is caused by divine power, that faculty of bodies can be rejected while preserving extension, but not while preserving corporeal nature.[34]

Newton accepted the basic structure of Descartes's argument. We can discover what is essential to corporeal substance by taking the idea of body available in common experience and removing from it all qualities "which bodies can be deprived of, and made to lack, by the force of nature."[35] The power to arouse perceptions, however, fails to satisfy this condition. No natural process can remove *this* power because the chasm between *res extensa* and *res cogitans* guarantees that only a radical change in the divinely instituted frame of nature can alter the way one may affect the other. By Descartes's own lights, since extended things are really distinct from thinking things, no natural change—no change that can be accounted for in terms of extension and its modes—can alter extension's relation to mind. And since the argument from abstraction demands that we strip from body only those features that the force of nature can remove, the abstractive

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[31] CSM II 227.

[32] In the "determined quantities of extension" passage quoted previously, Newton separated the power to move from the power to resist, yet in the span of *DG* we are now considering he regarded motion and resistance as a single power (*DG* 28–29 vs. 34–35). The difference suggests Newton wrote them at different times.

[33] One might wonder about the presence of non-corporeal or broadly non-physical powers in space, as Hylarie Kochiras, "Newton's Problem," does. But Newton clearly assumed that created mental powers were not ubiquitous, so there was no need to demonstrate that they could be absent under certain conditions.

[34] *DG* 33–34.

[35] *DG* 34. Newton also claimed that we cannot know "the essential and metaphysical constitution" of bodies (30). In accepting the structure of Descartes's argument, he seems to have accepted only that we know what features of body are essential to our idea of it, not its true, constitutive essence.

process cannot reduce body to extension. The mind/body distinction thus entails the space/body distinction![36]

Second, Newton argued for the space/body distinction using tersely formulated *experimental* evidence, presented in what in what J. A. Ruffner dubbed a "resistance scholium."[37] Newton later incorporated it into several of the *De motu* drafts, the *Principia*, and even the Classical Scholia. The scholium's durability suggests that Newton understood his empirical case against Descartes to extend beyond the analysis of motion and (in the *Principia*) beyond the failure of vortex theories. Newton thought he could directly demonstrate the existence of void space. By 'directly,' I wish to highlight the difference between this demonstration and the arguments from motion that form the core of the scholium on space and time. Since Howard Stein's "Newtonian Space-Time," many have associated those arguments with a more sophisticated, perhaps transcendental, form of reasoning—one according to which the Newtonian concept of space is arrived at by asking what "make[s] possible an adequate expression of the principles of dynamics" as they are embodied in mechanical practice or explicated in the *Principia*.[38] Newton's demonstration in the resistance scholium is different; it draws conclusions from empirical evidence in a way that does not involve judgments about the validity and necessity of the interpretive framework that makes the phenomena of mechanics tractable.

The demonstration concerned the power of bodies to move and resist the motion of other bodies. It began with an experimental criterion for the incorporeality of spatial regions:

> [I]f we set aside altogether every force of resistance to the passage of bodies, we must also set aside the corporeal nature utterly and completely. . . . [In other words,] if there were any aerial or aetherial space of such a kind that it yielded without any resistance to the motions of comets or any other projectiles, I should believe that it was utterly empty [*inane*].[39]

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[36]*DG* 34. I must elide some subtleties in Newton's argument. For example, note that Newton distinguished sensible qualities from the power that underlies their sensibility and held that this power is agentive, not a passive capacity to be perceived. This allowed him to separate sensible qualities—understood as the configurations of matter and motion correlated with certain perceptions—from the power, largely unexercised, that enables those configurations to give rise to occurrent experience. He also explicitly rejected the idea that bodies only have that power temporarily, when united with minds. Even more interestingly, he left somewhat unspecified the relation between the power to arouse perceptions and the power to move and resist motion, alternately suggesting that they are individually sufficient or jointly sufficient for body, and that they are independent powers or necessarily connected.

[37]Ruffner, "Newton's *de Gravitatione*," 242; and Smith, "How Did Newton Discover Universal Gravity?" 43.

[38]Stein, "Newtonian Space-Time," 273. See also DiSalle, *Understanding Space-Time*; and Nick Huggett, "Absolute Motion." For the relation of this form of argument to the *E3* definitions discussed in sect. 5, see Biener, "Geometrical Definitions."

[39]*DG* 34. Newton's concern in *DG* was alternately space (*spatium*), empty space (*inanis spatium* or even *inania*), and vacuum (*vacuum*). He usually reserved 'space' for the general concept synonymous with 'extension.' As far as I can tell, he used 'empty space' and 'vacuum' interchangeably. In the remainder of this essay, I also use the terms interchangeably, in order to maintain the overlap in meaning implicit in *DG*. Part of my overall thesis is that the terms eventually come apart for Newton, but this will take some time to establish.

The evidence followed shortly thereafter, and with it a telling application of the criterion, one that proved to be of decades-long concern for Newton. The evidence reads:

> [I]t should be observed from what was said earlier that there are empty spaces [*inania*] in nature. For if the aether were a corporeal fluid entirely without vacuous pores, however subtle its parts are made by division, it would be as dense as any other fluid, and it would yield to the motion of passing bodies with no less inertia. . . . [But since] the resistance of the aether is on the contrary so small when compared with the resistance of quicksilver as to be over ten or a hundred thousand times less, there is all the more reason for thinking that by far the largest part of the aetherial space is empty, scattered between the aetherial particles.[40]

The source of Newton's numerical estimate for the resistance of the aether—"ten or a hundred thousand times less"—is unclear.[41] What is clear is that the aether is not "without *any* resistance," but only a resistance much lower than mercury's. This is noteworthy. The incorporeality criterion concerned regions of nil resistance. Regions of low resistance are categorically different: they do not allow us to "set aside altogether every force of resistance," and thus do not demonstrate that "in space there is no force of any kind that might impede, assist, or in any way change the motions of bodies."[42] On the face of it, it seems real-world measurements simply do not pertain to the distinction between empty space and body. How, then, did Newton conclude that "by far the largest part of the aetherial space is empty"? Getting clear on this allow us to better appreciate the exchange between Newton and Cotes we will examine in section 4.

Two assumptions are at work in the previous quote. First, Newton held that the quantity of matter in a completely full space is proportional only to the size of the space; that is, that "quantity of matter" is a volumetric, extensive quantity. It cannot increase or decrease without a proportional increase or decrease in the volume fully occupied by matter. I will refer to this idea as Newton's 'geometrical conception of matter.' Trivially, it entails that completely full spaces—for example, the spaces occupied by atoms—are equally dense.[43] Second, Newton assumed that resistance to motion in a given space is proportional to that space's density. He understood resistance as arising from the inertia of minute bodies as they oppose giving way to an object bumping into them. Trivially, spaces offer no resistance iff they are empty.[44]

40 *DG* 35.

41 Ruffner, "Newton's *de Gravitatione*," 252.

42 *DG* 34, 26.

43 For Newton's conceptions of matter, see Biener and Christopher Smeenk, "Cotes's Queries." Newton defined the 'extension' of a power as "the quantity of space or time in which it operates" (*DG* 36).

44 Determining the nature of resistance was one of the major and ultimately frustrated goals of the *Principia*. In it, Newton considered the contribution to fluid resistance of the "tenacity and friction of the parts [of the medium,]" only to dismiss it (*Principia*, 761). Of course, resistance only arises through relative motion of a projectile and a medium, and so features of the projectile—e.g. speed, square of the speed, shape, and internal constitution—also figure in determining resistance. What is important for us is that the contribution of the medium depends only on its density. A fuller discussion of this crucial assumption is beyond our scope, but suffice it to say that Newton expended much effort trying to figure out how to quantify overall resistance and on what features of a medium it depends. What I am considering here is a most simple account, but one that highlights a commitment Newton never rejected; i.e. that resistance is proportional to the density of a medium and arises from the inertia of its parts. For a fuller discussion, see Smith, "The Newtonian Style in Book II of the *Principia*," and "Was Wrong Newton Bad Newton?"

The two assumptions account for Newton's conclusion. They entail that spaces of all but maximal resistance must be partially empty and so partially non-resistive. This is because there is no way to decrease the resistance of a given space without decreasing the quantity of matter in it, and there is no way to decrease the quantity of matter without decreasing the overall volume of full space. Consequently, two identically-sized volumes can only resist differentially if they are made up of different ratios of empty to full parts. The higher the ratio of empty to full, the lower the resistance; and very low resistance suggests a preponderance of empty space. Measurements of low resistance thus provide evidence for the existence of regions of nil resistance. And regions of nil resistance are, by definition, incorporeal.

The argument is straightforward, but fascinating, since in it Newton clearly begged the question. He only concluded from measurements of low resistance that there are spaces "without any resistance" by stipulating that those regions must be partly empty to begin with. In fact, *detailed* empirical information is entirely superfluous. The two assumptions entail that if there is any motion in the universe at all—that is, if there is any resistance that can be overcome—empty spaces must exist.

The reasoning is even clearer in Newton's use of evidence from rise and descent:

> [The existence of non-resistive, empty spaces] may also be conjectured from the various gravities of these fluids [i.e. quicksilver, air, aether], for the descent of heavy bodies and the oscillations of pendulums show that these are in proportion to their densities, or as the quantities of matter contained in equal spaces.[45]

How do "the various [specific] gravities of fluids" show that empty space exists? Given the assumption that the volume of completely full space measures quantity of matter, it follows that differences in density can only arise from differences in ratios of completely full to completely empty parts.

As far as I know, Newton did not repeat the argument from abstraction in any context outside *DG*. It seems to have died with the work. However, he did repeat *DG*'s empirical arguments in the first edition of the *Principia*, after his theory of resistance became considerably more sophisticated. In *E1*.3.6.c3, he wrote:

> And thus a vacuum [*vacuum*] is necessary. For if all spaces were full, the specific gravity of the fluid with which the region of the air would be filled, because of the extreme density of its matter, would not be less than the specific gravity of quicksilver or of gold or of any other body with the greatest density, and therefore neither gold nor any body could descend in air. For bodies do not ever descend in fluids unless they have a greater specific gravity.[46]

By the time Newton authored this proposition, he had significantly better evidence that aetherial resistance near the surface of the earth was virtually nil.[47] Even more importantly, he had proved that Kepler's area law holds exactly for a body in motion iff the only force acting on it is centripetal.[48] Although Kepler's law does

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[45] *DG* 35.

[46] *Principia*, 810. For a more thorough discussion of this proposition, its use of pendulum experiments, and its role in the argument for universal gravitation, see Biener and Smeenk, "Cotes's Queries," and Harper, *Newton's Scientific Method*, ch. 7.

[47] Ruffner, "Newton's *de Gravitatione*," 252–54.

[48] I thank an anonymous referee for catching an error in my statement of this biconditional.

not hold exactly, Newton also showed that departures from Keplerian orbits are due to mutual perturbations and are distinct from departures due to resistance. He had every reason to believe that celestial spaces offered only vanishingly small resistance.

But the increased precision is beside the point. The structure of the argument remained the same. As in *DG*, Newton used the phenomena of rise and descent to show that *vacua* exist, but only given non-negligible assumptions about the extensive nature of matter and the nature of resistance. The parallel to *DG* highlights the point made above: Newton's anti-Cartesian case in *E1* extended beyond showing that Cartesian vortices cannot account for planetary motion and beyond the arguments from the nature of motion whose sophisticated methodology Stein made famous. In *E1*, Newton offered direct empirical evidence against Cartesian metaphysics, but left it to the reader to connect the dots. When we connect them, *E1*.3.6.c3—as much as the scholium on space and time and *DG* itself—becomes a window onto *Newtonian* metaphysics.

Newton later considered making the connection between *E1*.3.6 and *DG*'s metaphysics explicit. In aborted 1690s revisions to the *Principia*, he considered adding the following corollaries. They demonstrate again the move from the vacuity of space to space's unique connection to the divine:

> Corol. 6. Vacuum is granted. . . .
>
> Corol. 8. Atoms are granted.
>
> Corol. 9. An infinite and omnipresent spirit in which matter is moved according to mathematical laws is granted.[49]

Newton also explicitly indicated that this proposition and its corollaries pertained to his anti-Cartesian arguments. In the same set of draft corollaries, he wrote:

> I am not at all disturbed by that vulgar sophism by which inferences opposed to the concept of the vacuum are drawn from the nature of bodies as extension; since bodies are not so much extension as extended, and they are utterly distinguished from extension by their solidity, mobility, force of resistance, and hardness.[50]

Clearly, he thought *E1*.3.6 established, and was thus the relevant context for discussing, the metaphysical theses of *DG*.

To close this section, let me reemphasize the main claim developed in sections 2 and 3: in *DG*, Newton's *empirical* case against the Cartesian identification of space and body lay at the root of his metaphysics of space, since it established the absolute absence of corporeal powers from space. He repeated this case, albeit in telegraphic form, in *E1*.3.6.c3. Once we recognize the centrality of that corollary to Newtonian metaphysics, we can see—as we will in section 5—that Newton's reevaluation of it signals his reevaluation of the epistemic status of his metaphysics.

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[49]Add. 3695, 266v. Proposition 6 of the 1690s also included material on Fatio de Duilier's mechanical aether hypothesis, which also implied that a vacuum is necessary and that the primary constituents of matters are homogenous. See *Unpublished Papers*, 312–18. I thank Steffen Ducheyne for correspondence on this. I should also note that this revision does not speak to space's manner of existing directly, but rather to the omnipresent spirit whose existence grounds that of space. Like *DG*, however, it argues from evidence concerning resistance to 'metaphysical' theses concerning space.

[50]UCL Add 4005 folio 28r–29r. Translation in *Unpublished Papers*, 313, 316.

Before continuing, I should mention that I have purposely left out the theological motivations for Newton's account of space and his claim that it is *necessarily* true. I bracket theology here because, although the content of Newton's conception of space drew significantly from scriptural sources, he did not offer scriptural evidence for its truth in either *DG* or *E1*. In those two texts—unlike the General Scholium, "Tempus et Locus," or the Classical Scholia—Newton limited himself to conceptual or natural philosophical arguments. My aim here is to explore to what extent they were central to his metaphysics. I turn now to Newton's struggles with them.

4. EVIDENCE CHALLENGED

In 1709, Newton began preparing *E2* with the editorial help of the recently appointed first Plumian chair of Astronomy and Experimental Philosophy, Roger Cotes. In this section, I focus on only one of Cotes's numerous contributions to the new edition, his objection to the corollary just examined.[51] First, I show that this objection caused Newton to reconsider the empirical evidence for the emptiness of space. Second, I draw out the implications of Cotes's objection for *DG*'s metaphysical theses. In the subsequent section, we will see that Cotes's exchange with Newton provides an important context for understanding Newton's late 1710s definitions of 'body' and 'vacuum.'

Cotes's objection to *E1*.3.6.c3 relied on the idea that a body's quantity of matter—its mass—is measured throughout the *Principia* by its inertia; that is, by its response to impressed force. Although 'quantity of matter' is also defined as "a measure of matter that arises from [a body's] density and volume jointly," the definition notes that this quantity "is *known* from a body's weight;" that is, from its response to gravity.[52] The measure should come as no surprise: the laws of motion only relate mass to change of motion caused by force, not to any other characteristic of either body or motion. The *Principia*'s method of quantifying mass is also consonant with what Howard Stein called Newton's metaphysics of natural power. *Vis inertia* is the natural power of body; namely, "the power of resisting by which every body, in so far as it is able, perseveres in its state of either resting or of moving uniformly straight forward."[53] Strictly speaking, in the *Principia* mass measures the magnitude of a body's power.[54]

Cotes's objection was that *E1*.3.6.c3 assumed more than this about mass, thus importing unjustified content into the *Principia*. In 1712, he wrote to Newton:

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[51]Biener and Smeenk, "Cotes's Queries," consider this objection in more detail. I should note that Cotes only effectively edited half of *E2*. Newton delivered the first half of the work, up to proposition 2.10, as a single installment. Although there are no surviving exchanges about this first half, Cotes challenged almost every page of the remainder. I thank an anonymous referee for this point.

[52]*Principia,* Definition 1, emphasis added.

[53]*Principia*, 404, Definition 3; Stein, "Hypothesis or Deduction?"

[54]Newton also called inertia a "passive principle" and *contrasted* it with "power," but only after becoming increasingly interested in "active principles." He never revised the *Principia*'s definition to reflect this. The distinction is surely another sign that *DG*'s metaphysical framework—which included no such distinction—was becoming less and less relevant in the 1700s. See CUL Add. 3970, folio 619r; The Newton Project, NATP00055; and Query 31 of *Opticks.*

> I will take notice of an Objection . . . against the 3d Corollary Prop: VI. Libr III. [Itaque Vacuum *necessario* datur.] Let us suppose two globes A & B of equal magnitudes to be perfectly fill'd with matter without any interstices of void Space; I would ask the question whether it be impossible that God should give different *vires Inertiae* to these Globes. I think it cannot be said that they must necessarily have the same or an equal *Vis Inertiae*. Now You do all along in Your Philosophy, & I think very rightly, estimate the quantity of matter by the *Vis Inertiae*. . . . Tis possible then, that ye equal spaces possess'd by ye Globes A & B may be both perfectly fill'd with matter, so no void interstices remain, & yet that the quantity of matter in each space shall not be the same. Therefore when You define or assume the quantity of Matter to be proportionable to its *Vis Inertiae*, You must not at the same time define or assume it to be proportionable to ye space which it may perfectly fill without any void interstices; unless you hold it impossible for the 2 Globes A & B to have different *Vires Inertiae*. Now in the 3rd Corollary I think You do in effect assume both these things at once.[55]

Cotes's objection should be familiar. It notes that *E1*.3.6.c3 assumes the proportion of a body's power to the volume it "perfectly fill[s] without any void interstices" is the same for all bodies. That is, it assumed that all the fundamental constituents of matter have the same density. The assumption does not follow from the *Principia*'s laws or definitions—a point Cotes first put in voluntarist language. Later in the correspondence, he put the point in terms of evidential relations:

> [The corollary] is true upon this concession, that the Primigenial particles . . . have all the same *Vis Inertiae* in respect to their magnitude or extension in *Spatio pleno*. I call this a concession because I cannot see how it may be certainly proved either a Priori by bare abstracted reasoning; or be inferr'd from Experiments.[56]

While the *Principia* is compatible with a fixed proportion of mass to extension, it is equally compatible with a proportion that varies, perhaps even radically. Cotes's point was that there are no theoretical considerations internal to the framework of the *Principia* that can decide the matter. Moreover, there are no empirical considerations, for the proportionality concerns objects beyond experimental reach: either gross bodies that are impossibly compressed or imperceptibly small atoms.[57]

Newton was slow to see Cotes's point and then reticent to accept its implications. His commitment to the homogeneity of matter and the essential, determinate proportion between extension and inertia was not quickly overcome.[58] Nevertheless, he ultimately conceded. In *E2* (unchanged in *E3*), a revised corollary 3 repeated the evidence from rise and descent, and a new corollary 4 read:

> If all the solid particles of all bodies have the same density and cannot be rarefied without pores, there must be a vacuum. I say particles have the same density when their respective forces of inertia are as their sizes.[59]

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[55] *Correspondence,* V 228, original brackets.

[56] *Correspondence,* V 242.

[57] I mean 'impossibly' literally. The compression would have to remove the void spaces that remain between atoms after close packing.

[58] Newton's reticence is remarkable, since years earlier he had speculated that God may have created "Particles of Matter of several Sizes and Figures, and in several Proportions to Space, and perhaps of different Densities" (Query 23 of the 1706 *Optice*). In fact, he only conceded when Cotes gently alluded to this passage. His reticence suggests that, at least in 1712, he was still committed to two potentially incompatible conceptions of matter: matter as a thing that fills space and matter as a thing that moves and resists. See Biener and Smeenk, "Cotes's Queries."

[59] *Principia,* 810.

The conditional is important. It amounts to Newton's admission that the antecedent is unjustified. And so, only *if* the proportion of mass to extension is fixed—and we have no reason to believe that it is—a vacuum is granted. The available empirical evidence simply does not guarantee the existence of vacuum. The conditional confutes *E1*.3.6.c3's argument for the existence of empty space, and thus jeopardizes *DG*'s and *E1*'s case against the Cartesian identification of space and body. Moreover, by confuting the argument for empty space, the conditional threatens *DG*'s positive theses about the nature of space, particularly the affection/emanation thesis. Recall, Newton had argued in *DG* that space's status as an affection/emanation followed from space's inertness, and that our evidence for this inertness was the very low resistance of aerial and celestial spaces. That very low resistance implied that regions of space could be wholly free of resistance, and so proved that "every force can be removed from space."[60] The inference from low resistance, however, depended on the idea that the fundamental constituents of matter are homogenously dense—precisely the assumption Cotes took to task. Without the homogeneity assumption, the evidence is inconclusive, and so the case for space's unique "manner of existing" falters. Given that in the 1690s Newton had considered addressing his metaphysics of space in this very proposition, it is unlikely the point was lost on him.

The basic premise of Cotes's critique—that mass only measures the magnitude of a body's power—has also a deeper implication. Cotes seems to have been aware of it immediately, but there is no evidence that Newton recognized it before 1716, when he authored the draft definitions we will examine in section 5. In correspondence with Samuel Clarke (a few months after the above exchange), Cotes revealed that his problem with the idea that the fundamental particles of matter are equally dense was not merely that there was no compelling evidence for equality. Rather, his problem was that there was no compelling evidence that *vis inertia* had *any* necessary connection to extension. The occasion was a revision of Cotes's preface to *E2* and the topic of discussion was essential properties of matter. Cotes wrote:

> I understand by Essential propertys such propertys without which no others belonging to the same substance can exist: and I would not undertake to prove that it were impossible for any of the other Properties of Bodies to exist without even Extension.[61]

Cotes was willing to entertain unextended bodies, bodies whose *vis inertia* is not accompanied by extension. Of course, he was also willing to entertain bodies whose mass-to-extension ratio varies. His point was simply that he "would not undertake to prove" either.[62] Cotes saw that the only property necessary for the *Principia*'s

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[60] Grant, *Much Ado*, 35.

[61] *Correspondence*, V 412–13.

[62] Cotes knew quite well that the *Principia* proved a variety of facts about the extendedness of bodies, for Newton went to great lengths to show that both inertia and gravity are extensionally well-behaved. He showed that the inertia of an extended whole equals the inertia of its parts, and the gravitational force of a whole equals the gravitational force of its parts. Nevertheless, these mereological relations do not entail that the fundamental constituents of matter are extended. They are compatible with point-sized particles distributed in space. See Ori Belkind, "Conceptual Argument"; and *Principia* Propositions 1.69–1.71.

treatment of bodies was their *vis inertia*. Concerning powers and properties other than inertia, we must either provide additional evidence or remain mum.[63] Yet he did not present this point in its full generality to Newton. His exchange with Newton focused exclusively on the determinate proportionality of extension to inertia and did not broach at all how "other Properties of Bodies" related to *vis inertia*.

Nevertheless, as we shall see in the next section, Newton recognized precisely this implication, at least by 1716. It forced him to reconsider his idea of empty space in a radical way. The case requires a bit of context.

5. BODY AND EMPTY SPACE REVISITED

After 1712, Newton increasingly labored to distinguish his experimental philosophy from the more metaphysically speculative philosophy of Cartesians and Leibnizians. The attacks, particularly from Leibniz himself, had become numerous and weighty. Leibniz's exchange with Hartsoeker (1711), as well as his simultaneous engagements with Newton through the mediation of Abbé Conti (1715/16) and Samuel Clarke through the mediation of Princess Caroline (1715/16), drove similar points home. Newton had not established the existence of universal gravitation. He had made non-negligible metaphysical claims that, in his metaphysical naiveté, he refused to acknowledge. Thus, his claims that there were no plausible vortical theories of gravity—like the one Leibniz offered in *Tentamen de motuum coelestium causis* (1689)—were unfounded.[64] Flames were only further fanned by the continued calculus dispute. Leibniz's death in 1716 did not lay matters to rest: the Leibniz-Clarke and Conti exchanges were multiply reprinted in the next years, and Leibniz, of course, was not without supporters. Leibniz's overarching charge was that Newtonian theses were plainly conjectural. In November 1715, for example, he wrote in a letter to Conti, one full of similar charges:

> I am strongly in favor of the experimental philosophy but M. Newton is departing very far from it when he claims that all matter is heavy (or that every part of matter attracts every other part) which is certainly not proved by experiments . . . and M. Newton adduces no experiment or sufficient reason for the existence of a vacuum or for atoms or for the general mutual attraction.[65]

Multiple, extended drafts of Newton's seething response survive, although the final version is rather brief. They uniformly take issue with Leibniz's "collu[sion] in the

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[63]Cotes thought that there was sufficient evidence to show that *gravity* was necessarily conjoined to inertia, and so suggested in a rejected draft of his preface to *E2* that gravity was essential. The above quote is from his response to Clarke's objection to the essentiality of gravity.

[64]The exchange with Hartsoeker was published in English in the May 1712 issue of *Memoirs of Literature*, and Cotes brought it to Newton's attention in March 1713. Newton's response to the exchange is undated, however, and it is possible that he was already aware of it, wrote his response shortly after its publication, but withheld publication until further prompted by Cotes. I thank an anonymous referee for stressing this point.

[65]*Correspondence*, VI 252. Leibniz's first letter to Clarke is also dated November 1715, and both were sent in December. Leibniz repeated similar criticisms in the postscript to his fourth letter to Clarke. I should note that the ellipsis above hides an explicit reference to Christiaan Huygens. Leibniz cites him approvingly (likely) because he had disputed universal gravitation on the basis of measurements of the length of the second-pendulum. This issue is distinct, however, from that of the vacuum. See Schliesser and Smith, "Huygens's 1688 Report."

significations of words" and his malevolent misappropriation of "experimental philosophy," often regarding specific theses.[66] In general, in the 1710s Newton aimed to distinguish his philosophy from that of his competitors by its assiduous grounding in phenomena and experience. The strategy is well documented.[67]

Yet, one topic Newton sought to defend was somewhat special. The charge Leibniz levied in the first Conti letter—that the existence of empty space was based on "no experience or sufficient reason"—echoed Cotes's charge that it could be proved by neither "abstracted reasoning; [n]or be inferred from Experiments."[68] Unlike many of Leibniz's complaints, this one had first been brought to Newton by a close ally. It stood independently of Leibnizian presuppositions and could not be attributed merely to bad faith. This fact is underappreciated. No doubt, Newton's writings in the 1710s permeate with anti-Leibnizian polemics. Yet among the rhetorical and conceptual moves aimed at winning debate, there were also genuine attempts to clarify the extent to which Newtonian natural philosophy, by its own lights, did or did not rest on empirical foundations. We see these in Newton's writings on vacuum and body. If we do not come to these assuming their only function was to silence opposition or assuming *DG* as their interpretive framework, they offer conceptions of empty space, body, and their relation to empirical evidence that are importantly different than *DG*'s in ways that are genuinely responsive to Cotes's 1712 insight about the centrality of *vis inertia*. I will focus here on proposed revisions to Book III.[69]

In drafts intended for *E3* but never published, Newton defined what he took to be the key concepts of his *System of the World*. He began with 'body' and 'vacuum,' later added 'rule,' 'hypothesis,' and 'phenomena,' and finally returned to only 'body' and 'vacuum.' They were likely written in 1716, while or shortly after Leibniz and Clarke corresponded on the question of the vacuum.[70] Newton had used 'corpus' and 'vacuum' throughout the *Principia*, but the first mention of vacuum in the proposition sequence of Book III—the book that "come[s] down to physics"—was in *E2*.3.6.c4, the corollary studied in the previous section. This corollary was the first point in the book at which Newton argued for the existence of vacuum, and so in the draft definitions he certainly had its interpretation in mind. All drafts champion the point with which Cotes had launched his critique; that in the *Principia* body is, and should only be, defined by its *vis inertia*:

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[66] *Correspondence,* VI 285.

[67] Alan E. Shapiro, "Newton's 'Experimental Philosophy'"; and Ducheyne, *The Main Business,* ch. 5.

[68] *Correspondence,* V 242.

[69] Drafts for the 1717 *Opticks* are similar. There, for example, Newton asked, "Can any space be wthout something \in it/ & what is that something in space void of matter [& what are its properties & operations ~~on matter~~]." He also made clear that "By a Vacuum I do not mean a space void of all substances." See Newton Project NAT00055; and Ducheyne, "Newton on Action at a Distance," 697. As Ducheyne rightly notes, in these drafts Newton was concerned with spatially pervasive active principles.

[70] McGuire, "Body and Void," is still the authoritative study of these definitions. Instead of repeatedly citing it, I note here that much of what I say below has been said there more eloquently. The translations below are in McGuire's section 3 and are only slightly modified. Newton's most mature page indications, on ADD 3965 504r, show that he intended the definitions to precede the *Regulae philosophandi*. I am taking them to be significant despite the fact that they never appeared in print because they dovetail with a good deal of Newton's statements from the mid–1710s. If they were actually errant, abandoned thoughts, my overall case becomes weak.

> Body I call every thing which can be moved and touched, in which there is resistance to tangible things, and its resistance, if it is great enough, can be perceived.[71]

Newton had already announced this conception in *E1* (in Definition 3 of Book I), but in the 1716 drafts he stressed its extreme narrowness. Newton claimed that body is only to be understood as a thing that moves and resists. The drafts completely lack *DG*'s conception of body as a determinate quantity of extension that resists. It is simply a thing that moves and impedes the motion of other things:

> [In] the third Definition [of Book I] I said that the force of inertia was proportional to the body and was innate and essential, and that this force is the power of resistance by which every body attempts to stay preserves in its state of rest, or moving uniformly in a straight line. By body I understand everything tangible, in which there is a resistance to bodies touching it, and whose resistance, if it is great enough, can be perceived. . . . *I understand body in [what follows] in no other sense than the one which I have defined.*[72]

Newton characterized body here through a single feature, the power to resist a change of state, and left unaddressed whether other features are equally "innate and essential." The narrowness was not due to lack of options. Newton was well aware of other possible powers, such as those associated with electricity, vital processes, and alchemistry. But, strictly speaking, "body" pertained to none of them.

The definition of 'vacuum' is more important for us. The Cotes exchange yielded a conditional in *E2*.3.6.c4: given the assumption that the fundamental constituents of matter are equally dense, a vacuum is granted. But what is "the Empty" empty of? A reader of *E2* could have easily understood Newton to assert that, conditionally, an *absolute* vacuum exists. However, the narrowness of the definition of 'body' forecloses this possibility. It entails that "the Empty" is only empty of one thing: the power to resist. In the previous section, we saw that Cotes's comment to Clarke indicates that he likely realized this, but let the matter go. The definition of 'vacuum' shows that, at least by 1716, Newton had caught up. His new definition suggests that questions about the absolute fullness or emptiness of space are distinct from questions about the presence or absence of the power to resist, unless by 'fullness' or 'emptiness' we merely indicate the presence or absence of resistance:

> Vacuum [*vacuum*] I call every place [*locum*, later *spatium*] in which bodies can be moved without resistance. . . . For just as geometers define a line that has length without breadth, so that their propositions concerning lines of this sort are merely [*solummodo*] understood, and in mechanics, however, and other sciences the line having breadth has a place; thus body and vacuum are here defined so that these words may be understood in the sense defined in what follows. About other bodies and another vacuum let authors in other sciences dispute.[73]

The correlative understanding of body and void through the presence or absence of a single power leaves open the possibility that space empty of *this* power may be full of others, powers that "authors in other sciences" are left to discuss. I can

[71] CUL Add 3695 422r.
[72] CUL Add 3695 403r, emphasis added.
[73] CUL Add 3695 422r. The final draft, on 504r, is virtually identical.

only scratch the surface of these definitions here.[74] But their main point should be clear. As far as the investigations of the *Principia* are concerned, only entities possessed of *vis inertia* matter. Inferences that stretch the *Principia*'s conclusions to apply to other sorts of entities are unwarranted.

Of course, we can also read Newton polemically. We can read "let authors in other sciences dispute" as sarcasm, as Newton's eye-rolling dismissal of objects of natural investigation other than his "body."[75] There is even supporting textual evidence. For example, Newton wrote in these drafts that:

> The Quintessence is different from the four elements and is subject to none of the senses nor can it be numbered among phenomena. Prime matter which is neither a thing nor possessed of quality nor a thing that can be measured is not a phenomenon. The subtle matter by which the heavens are filled . . . is not a phenomenon. And things which are not phenomena, have no place in experimental philosophy.[76]

If these were Newton's "other sorts of bodies"—the sorts of bodies entertained by speculative Aristotelians and Cartesians—certainly he believed that they did not exist. And if they did not exist, the possibility that space may be full of powers not studied by the *Principia* is an empty possibility, one raised only to ridicule opponents.

But this is not the whole picture. Immediately after the above quote, Newton asserts with no hint of sarcasm that his experimental philosophy is only the first step in an investigative sequence that *ought* to involve "other sciences." He reiterated the limitations imposed on the *Principia* by his new definitions and suggested that the goal of inquiry is to exceed them:

> Inductive argument taken from experiments and the observations of sensible things on which experimental philosophy is based, cannot be applied to hypothetical or metaphysical entities except by means of hypotheses . . . therefore the things which are said in this book concerning bodies by the power of induction bears no reference to entities of this sort. . . . From this philosophy to efficient and final causes and to hypothetical philosophy men must proceed.[77]

Newton was not one to mock arguments from design. In fact, several times in the drafts he repeats the idea that experimental philosophy must eventually argue to design, "hypothetical philosophy," and metaphysics. Moreover, there is clear evidence that Newton did not think his "body" was the only object of natural investigation. Since at least the early 1700s, he conceived of matter as a "passive principle" by which "there never could have been any Motion in the World" and "to affirm that there are no other[s] is to speak against experience."[78] A sarcastic reading of the *E3* drafts belies the fact that Newton was entirely committed to the extension of natural philosophy beyond the scope of mechanics, traditionally

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[74]In particular, there is much more to say about Newton's claim that he is defining the physical concepts of Book III "just as geometers define a line that has length without breadth." I take up the idea that these definitions are like geometrical definitions, but nevertheless preface the physical portion of the *Principia*, in Biener, "Geometrical Definitions."

[75]I thank Evan Thomas for pressing me on this.

[76]Add 3965 641r. The ellipsis contains the words *genus resistentia*, but the remainder of the phrase is unclear.

[77]Add 3965 641r.

[78]*Opticks*, 397. Draft to Query 23 of 1706 *Optice*, in McGuire, "Invisible Realm," 171.

conceived. He held that things possessed of powers other than *vis inertia* existed and were open to natural philosophical investigation. Given his long-standing belief that all existence was spatio-temporal, it seems reasonable to me that he would have asked whether those things (or simply those powers) filled space. I thus find a genuine admission behind the sarcasm: there are more things on heaven and earth than are dreamt of in experimental philosophy. The admission is important for understanding how Newton conceived of the relation between his metaphysics and the experimental evidence regarding aetherial resistance.

6. EVIDENCE AND METAPHYSICS, JANIAK AND STEIN

Newton's admission that the *Principia*'s conclusions were of limited scope implies that his evidence regarding aetherial resistance did not support the claim that "there is no force of *any kind* present in space," even assuming the homogeneity assumption made in *DG* and *E1*. At best, they supported the claim that there is no resistance. The connection to *DG*'s metaphysics should be clear. Since the inertness of space was the cornerstone of *DG*'s spatial metaphysics, a failure to infer that there is no force of any kind in space amounts to a failure to empirically support that metaphysics. Given that Newton wrote *E3*'s draft definitions as part of his overall attempt to clarify the empirical foundation of his philosophy, and given that they concern the very same evidence and very same proposition Newton had previously used to support his metaphysics, I believe the point could not have been lost on him.

I am not suggesting that Newton abandoned his core metaphysical beliefs at the time of *E3*'s draft definitions, certainly not his belief in the constitutive role of God vis-à-vis space or his belief that space per se is causally inefficacious. Newton expressed these beliefs in ways entirely consonant with *DG* even in 1720.[79] Rather, I am suggesting that Newton abandoned a different but equally central belief, one that was essential to *DG*: that the empirical evidence first reported in the Resistance Scholium and later repeated in Proposition 6 supported, and partially implied, his metaphysics.

There is an important give-and-take here. Newton's aim in the draft definitions was to respond to Leibniz's charge that Newtonian theses exceeded the empirical warrant available to them. This was a touchy matter, particularly regarding the emptiness of space. Newton had a remarkable body of empirical evidence showing that the *Principia*'s dynamical framework—the laws of motion and their implications—were grounded in experience.[80] Yet, as Cotes first emphasized, that framework concerned a particular sort of entity, one defined by its *vis inertia*. Broader conclusions were not equally well-grounded. *E3*'s draft definitions took

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[79]In drafts for Des Maizeaux's 1720 publication of the Leibniz-Clarke correspondence, Newton wrote: "infinite space or Immensity & endless duration or Eternity, are . . . modes of existence in all beings, & unbounded modes & consequences of the existence of a substance which is really necessarily & substantially Omnipresent & Eternal: Which existence is neither a substance nor a quality, but the existence of a substance with all its attributes properties & qualities, & yet is so modified by place & duration that those modes cannot be rejected without rejecting the existence." Subtleties aside, the terms are quite similar to the ones he used in *DG*, the Classical Scholia, the *Opticks*, and the General Scholium. See Koyré and Cohen, "Leibniz-Clarke," 96–97; and Pierre Des Maizeaux, *Recueil*.

[80]Harper and Smith have repeatedly explored Newton's subtlety in constructing evidence. See, in particular, Harper, *Newton's Scientific Method*, and Smith, "Closing the Loop."

this point to its logical conclusion. They explicitly limited the types of entities to which the *Principia* applied and claimed ignorance about all others. For this reason, the definitions allowed for a tight connection between the *Principia*'s dynamical framework and the concepts of body and void appropriate to it, and thus a tight connection between Newton's experimental evidence and the conclusions drawn from it, specifically about the newly-defined emptiness of space.[81] Yet the cost of establishing that tight connection was *severing* the connection Newton once believed existed between the experimental evidence and his metaphysics. In other words, in his effort to distinguish his philosophy from his opponents' by its grounding in phenomena, Newton ensured that his evidence no longer supported those metaphysical claims he had once taken it to support. In other words, he severed the link, so central in *DG*, between natural philosophy and metaphysics. I thus read these definitions as Newton's self-conscious retreat from metaphysics, an admission that the power of experimental evidence is rather modest, at least in this case.

Let me state what is at stake in the line I have drawn from *DG* to the *E3* revisions in a different way, in order to engage with two of the most influential interpretations of Newton. According to Andrew Janiak, there are two types of metaphysics at play in Newton's thought. First, there is an autonomous "divine metaphysics" that "represents a fundamental conception of God's nature and relation to the natural world that is not subject to revision; hence it might be understood to represent a basic framework for all of Newton's thinking about the physical world."[82] Janiak includes in this divine metaphysics Newton's metaphysics of space, in no small measure because of space's necessary connection to God in *DG*. Second, there is a "mundane metaphysics" that "occurs within the basic framework centered on the divine; it is subject to precisely the sorts of revision and refinement that characterize all of Newton's other work . . . [on] the nature of motion, the existence of various types of forces in nature, the types of causation involved in natural change, and so on."[83] Janiak's view refines Howard Stein's "empiricist" interpretation of Newton. According to Stein, there is no element of Newtonian metaphysics that is immune from revision.[84] Experimental investigation may throw doubt on any metaphysical claim and must be appealed to in order to ground any such claim. For Stein, the idea that a claim may transcend experimental/experiential warrant betrays Newton's deepest commitments as a philosopher.

The first half of the present essay points to a problem in Janiak's account. In *DG* and *E1*, Newton believed that his conception of space and space's relation to the rest of creation—part of his "divine metaphysics"—was responsive to experimental findings in a way that falls through the cracks of the divine/mundane divide. In those texts, Newton thought he justified his metaphysical claims about space by means of experimental evidence about the absence of corporeal powers in aetherial spaces. That approach would be superfluous if his metaphysical beliefs were wholly beyond revision. The approach does, however, capture what Stein takes Newton to

[81]For more on this connection, see Brading, "Law-Constitutive Approach," and Biener and Smeenk, "Cotes's Queries."

[82]Janiak, *Newton as Philosopher*, 45.

[83]Janiak, *Newton as Philosopher*, 45.

[84]E.g. Stein, "Newton's Metaphysics."

have done throughout his life: appeal to findings in natural philosophy to properly ground metaphysics. The second half of the present essay shows that Janiak's "divine metaphysics" captures an important element of Newton's later thought: as the link between Newton's experimental evidence and spatial metaphysics became more tenuous, he did not come to reject his metaphysics. Rather, he came to sever its connection with the experimental evidence; that is, to reassess its relation to natural philosophy. In short, I believe that what Janiak portrays as the autonomy of Newton's divine metaphysics of space *emerged* in Newton's thought in the 1710s, as he was forced to engage vociferous opposition (at least insofar as the status of space as an affection/emanation is concerned).[85] And it emerged because he realized that his beliefs about space could not be grounded in experimental evidence as he once thought. Stein's "empiricist" interpretation captures Newton of *DG* and *E1* well (at least concerning the empirical grounds of the emanation thesis), and it even captures many of Newton's later statements about the relation of metaphysics to experimental philosophy, but it does not capture what I have argued is a shift in the actual structure of his beliefs. Insofar as Stein's view is the "mundane" subset of Janiak's view, my point can also be put like this: the boundary between Newton's divine and mundane metaphysics moved in the course of Newton's life. The extent to which he believed, at any given time, that experimental evidence grounded his metaphysical beliefs depended on the beliefs in question, the evidence available, and his interpretation of the evidence.

7. CONCLUSION

I have argued that the significance of experimental evidence for Newton's metaphysics of space changed from *DG* to *E3*'s draft definitions. In *DG*, Newton thought empirical evidence that there was no force of any kind in space directly supported his account of space as an affection/emanation. He said so. In *E1*, he did not say so, but Proposition 6 and its abandoned 1690s revisions show he still thought so. In *E2*, after being confronted by Cotes, Newton recognized that his previous inferences gratuitously assumed the proportionality of *vis inertia* to extension, and so changed the claim that "a vacuum is necessarily granted" to a conditional. This already made the connection between his spatial metaphysics and the available evidence somewhat tenuous. It is not clear to me whether at the time of *E2* Newton was as cognizant as Cotes about the deeper limitations of his own argument, but by the time he authored the draft definitions to *E3*, he certainly realized that even the conditional's significance was rather circumscribed. Given the way bodies are treated in the *Principia*, the conditional could at best show that space is only empty of one kind of entity—the entity defined by its *vis inertia*—and still only conditionally. About other entities and their presence in space, we must remain (at least for the time being) mum. With this realization, the evidentiary link between Newton's metaphysics of space and his measurements of aetherial resistance was completely severed. This narrative fits well with the epistemic bent

[85]Whether the autonomy of *all* elements of Newton's divine metaphysics emerged or was a fixed presupposition is a different question. My argument concerns a single, albeit key, element in that metaphysics.

that distinguishes *E3* from the *Principia*'s first two editions, and may go some way towards explaining it. It also complicates the relationship between Stein's empiricist and Janiak's divine/mundane interpretations of Newton.

I believe the broadest conclusion to draw is that *DG* does not represent Newton's understanding of the metaphysics of space *simpliciter*. It is an early text, written before Newton took many of the conceptual leaps that made the *Principia* so revolutionary. His own thought, as much as the thought of his contemporaries, was profoundly changed by the work.[86]

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[86] I have left many issues and texts undiscussed. I have considered neither the scholium on space and time nor the complications introduced by the third rule of philosophizing—a rule explicitly concerned with the experimental ground of universality claims—to my narrative. I have also not considered the relation of the *E3* definitions to Newton's theological and optical writings. I consider the first of these in Biener, "Geometrical Definitions."

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