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Reconsidering Kantian Absolute Space in the *Metaphysical Foundations of Natural Science* from a Huygensian Frame

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Abstract: This essay explores Kant's concept of absolute space in the *Metaphysical Foundations* from the perspective of the development of the relationist interpretation of bodily interactions in the center-of-mass reference frame, a strategy that Huygens had originally pioneered and which Mach also endorsed. In contrast to the interpretations of Kant that stress a non-relationist, Newton-inspired orientation in his critical period work, it will be argued that the content and function of Kant's utilization of this reference frame strategy places him much closer to Huygens' relationism than the absolute notions of space and motion favored by Newton and Euler.

Keywords: Kant, Huygens, relational space, absolute space, dynamics

1. Introduction

The influence of Kant's thought on the natural philosophy of space in the nineteenth and twentieth centuries is, without a doubt, vast and multifaceted. But where should we place Kant in the historical development of the rival Newtonian and Leibnizian traditions, especially as it concerns the concepts of space and motion? That is, does Kant side with the absolute (or substantival) conception of space and motion, championed by Newton and Euler, or the relationist alternative, typically associated with Leibniz and Descartes? (Roughly, the absolutists hold that space is an independent entity of some sort, and absolute motion is relative to absolute space, whereas relationists regard both space and motion as merely the relations among bodies.) These questions raise a number of difficulties, not the least being that Kant dismisses both the absolutist and relationist spatial ontologies in his critical period for his own transcendental idealist solution.

Nevertheless, on a popular reading of Kant, the critical period marks the transition from his early Leibniz-Wolff relationist conception of the material world to a constructivist-oriented philosophy of science dedicated to, and predicated on, Newtonian theory and its corresponding rejection of relationism. In short, so the interpretation goes, it is Newton, and possibly Euler, that awoke Kant from the dogmatic slumber of his early relationism (to turn a Kantian phrase), and thus paved the way for his transcendental idealist alternative to the metaphysics of both absolutism (substantivalism) and relationism, i.e., a transcendental idealist resolution of the problem of space that, nonetheless, appeals to a concept defined as "absolute space" in Kant's most detailed investigation of natural philosophy in the critical period, the *Metaphysical Foundations of Natural Science* (1786). This line of interpretation is advanced by Robert DiSalle, who claims that "Kant's analysis of absolute space [. . .] is an effort to clarify its place within the system of Newtonian principles";[1] and, "Kant's transcendental idealism sets aside the ontological controversy [substantivalism versus relationism], and leaves him free to consider absolute space only insofar as it has a certain function in Newton's dynamical theory."[2] A similar Newtonian-oriented interpretation of Kant's *Metaphysical Foundations* is a central feature of Michael Friedman's research as well, who stipulates that his "reading of Kant's treatise is Newtonian, in so far as I place Newton's *Principia* at the very center of Kant's argument."[3] Accordingly, the upshot of the historical interpretation offered by DiSalle, and possibly Friedman, is that Kant's critical period works, and the *Metaphysical Foundations* in particular, rely on a conception of space and dynamics that more naturally fits the type of world view championed by Newton (and, for DiSalle, Euler) as opposed to the Leibniz-Wolff school. And, since Newtonian dynamics is anti-relationist, it must thereby follow that Kant's later system has more in common with Newtonian absolutism than Leibniz-Wolff relationism—although, to be fair, this last inference is not specifically drawn by Freidman, but it would appear to be an acknowledged consequence of DiSalle's reading. Indeed, as DiSalle comments: "Kant had started from a Leibnizian view of the world as constituted of monads, and consequently a relationalist view of space; he was moved in the direction of Newton's view largely by his reading of Euler. Evidently Kant was impressed by the argument [. . .] that dynamics must assume certain

[1] Robert DiSalle, *Understanding Space-Time*, Cambridge: Cambridge University Press, 2006, p. 67.

[2] Ibid., p. 67; and p. 37 on the importance of Euler's anti-relationism for Kant's development.

[3] Michael Friedman, *Kant's Construction of Nature*, Cambridge: Cambridge University Press, 2013, p. xiv.

aspects of space and time—above all, the idea of a privileged state of uniform motion—that cannot be squared with Leibniz's relationalism."[4]

This essay will challenge this type of Newtonian-leaning, anti-relationist reassessment of Kant's critical period natural philosophy by focusing on the content and function of the concept that he describes as "absolute space," especially as it pertains to Huygens's earlier development of the center-of-mass reference frame as a relationist basis for determining motion. The conclusions reached in this investigation overlap some of the findings of other scholars, it should be noted, but the historical lineage of the type of system that Kant implements in the *Metaphysical Foundations* has hitherto received scant attention. To be specific, while there have been a number of important investigations over the past several decades that have either pinpointed the relationist elements in Kant's theory[5] or stressed the continuity and connection between Kant and the Leibniz-Wolff school as regards dynamical concepts,[6] the close similarity between Kant and the relationist-based center-of-mass frame approach to bodily interactions first pioneered by Huygens, and the way Kant builds upon these precedents, have not been the topic of an extended study. Yet, as will be argued, once Kant's system is viewed against this wider historical backdrop, it becomes rather difficult to single out a fundamental Newtonian orientation, as opposed to a Huygensian outlook, in Kant's critical period work on space and motion. Accordingly, in contrast to the Friedman-DiSalle interpretation of Kant that emphasizes a Newton-(Euler)-Kant lineage, this essay will argue that a Huygens-Leibniz-Wolff-Kant lineage is a more viable interpretation of the system developed in the *Metaphysical Foundations*. This is not meant to downplay the importance of Newton's and Euler's work to Kant; rather, it is simply the case that Kant's "absolute space" concept fits a broadly Huygensian relationist conception of space and motion much better than a Newtonian anti-relationist scheme (and it is for these reasons that Kant's use of that term is placed in quotation marks above). In fact, once the proper historical line of descent is established regarding Kant's system, its close affinity

[4] DiSalle, *Understanding Space-Time*, pp. 60-61.

[5] E.g., Martin Carrier, "Kant's Relational Theory of Absolute Motion," *Kant-Studien* 83 (1992), pp. 399-416; Marius Stan, "Absolute Space and the Riddle of Rotation: Kant's Response to Newton," *Oxford Studies in Early Modern Philosophy* 7 (2015), pp. 257-308 (to name only a few).

[6] E.g., Eric Watkins, "The Laws of Motion from Newton to Kant," *Perspectives on Science* 5 (1997), pp. 311-348; Id., "Forces and Causes in Kant's Early Pre-Critical Writings," *Studies in History and Philosophy of Science* 34 (2003), pp. 5-27; Id., Eric Watkins, *Kant and the Metaphysics of Causality*, Cambridge: University of Cambridge Press, 2005; Marius Stan, "Newton and Wolff: The Leibnizian Reaction to the *Principia*, 1716-1763," *The Southern Journal of Philosophy* 50 (2012), pp. 459-481; Id., "Kant's Third Law of Mechanics: The Long Shadow of Leibniz," *Studies in History and Philosophy of Science* 44 (2013), pp. 493-504; Marius Stan, "Once More onto the Breach: Kant and Newton," *Metascience* 23 (2014), pp. 233-242.

to the relationist strategies devised in the later nineteenth century, most notably by Mach, obtains a more adequate explanation as well.

In order to provide a more accurate accounting of the content of the *Metaphysical Foundations* as regards its place in the development of a relationist-based mechanics, it will be necessary to explore the rise of the 'absolute' versus 'relational' dichotomy in the second half of the seventeenth century, especially Huygens's pivotal role therein. Accordingly, section 2 will examine Huygens's center-of-mass frame system and his interpretation of motion, thus setting the stage for the investigation of Kant's critical period approach to Newtonian theory in section 3, along with a more accurate assessment of his conceptions of absolute space and motion given the richer historical background explored in section 2. Finally, section 4 will summarize the findings of this essay.

2. *The Huygensian Background to Kantian Absolute Space*

It may come as a surprise to many philosophers and historians of science, but Newton did not invent the standard "absolute versus relational" dichotomy as regards space and motion. In fact, these ideas probably originated, at least in their more familiar guise, during the medieval period, and they were likely prompted by the relativity of perceived motion, in particular, the need to delineate perceived motions from actual motions.[7] Regardless of its pre-seventeenth century origins, the most likely source of influence on Newton's espousal of the absolute-relational dichotomy can be traced to the numerous works on impact mechanics that preceded the *Principia* in the 1650-1687 period. For instance, absolute and relative space and motion are part of the conceptual apparatus in Giovanni Borelli's *De Vi Percussionis* (1667): "local motion occurs either from one place [*locum*] of world space to another or in the relative space of some container; the former shall be called real and physical motion [*motus realis* & *physicus*], the latter we will call relative motion [*motus*

[7] On medieval theories of motion, see, e.g., John E. Murdoch and Edward D. Sylla, "The Science of Motion," in D. C. Lindberg (ed.), *Science in the Middle Ages*, Chicago: University of Chicago Press, 1978, pp. 206-264; Anneliese Maier, *On the Threshold of Exact Science*, trans. by S. D. Sargent, Philadelphia: University of Pennsylvania Press, 1982; and Marshall Clagett, *The Science of Mechanics in the Middle Ages*, Madison: University of Wisconsin Press, 1959. The use of the terms "absolute" and "relational" was likely common by the seventeenth century, since one can find various natural philosophers in the first quarter of that century that refer to space/place as *ens absolutum* or *ens relativum*, such as Balthasar Meisner (see Cees Leijenhorst and Christoph Lüthy, "The Erosion of Aristotelianism: Confessional Physics in Early Modern Germany and the Dutch Republic," in C. Leijenhorst, C. Lüthy, J. Thijssen (eds.), *The Dynamics of Aristotelian Natural Philosophy from Antiquity to the Seventeenth Century*, Leiden: Brill, 2002, pp. 349-374, at p. 392). From the perspective of our investigation, the main question concerns the specific historical source and inspiration behind Newton's and Kant's adoption of those terms and concepts, hence our treatment of this (immense) topic is fairly limited.

relativus], although oftentimes it does not involve a change of region [*situs*] in the place or the space of the world."[8] Borelli uses the description "world space" instead of "absolute," but another treatise on collisions and bodily interactions from the same period, Ignace Pardies's *Discours du mouvement local* (1670), does employ the latter label for motion, albeit "respective motion" replaces "relative motion": "I call [. . .] *absolute* velocity, that which is consider'd in a Body compared with the Space wherein it moveth; and *respective*, that which is considered in two Bodies compared together, by which velocity these two Bodies mutually approach to, or recede from, one another."[9]

In short, there were several natural philosophers who accepted an absolute/relational motion (and space) distinction prior to Newton's *Principia*, but the person who likely elevated this distinction in the minds of late seventeenth-century natural philosophers, namely, Huygens, did not.[10] Like Newton, Huygens interpreted Descartes's analysis of motion (Pr II 25) as favoring relationism, and relational motion ultimately became a central doctrine of his oeuvre. Huygens specifically affirms several hypotheses that are synonymous with modern relationism. First, he reasons that a single body in an otherwise empty universe cannot move, or that the possibility of its motion is a contradiction (since motion is a relation among bodies). In response to the standard Scholastic counter-argument, that God could move a lone body, he states:

[8] Giovanni Alfonso Borelli, *De Vi Percussionis*, Bologna: Ex typographia Iacobi Montii, 1667, p. 3.

[9] Ignace Gaston Pardies, *A Discourse of Local Motion* (*Discours du mouvement local*), trans. by A. M. London: Moses Pitt, 1670, pp. 28-29. The following abbreviations will be used for frequently cited works: AG = Gottfried Wilhelm Leibniz, *Leibniz: Philosophical Essays*, ed. and trans. by R. Ariew and D. Garber, Indianapolis: Hackett, 1989; DLM = Pardies, *A Discourse of Local Motion*; Pr = René Descartes, *Principles of Philosophy*, trans. by V. R. Miller and R. P. Miller, Dordrecht: Kluwer Academic Publishers, 1983, cited with book, section; H = Christiaan Huygens, *Codex Huygens7a*, in *Penetralia Motus: la fondazione relativistica della meccanica nell'opera di Chr. Huygens*, ed. by G. Mormino, trans. by M. Stan, Firenze: Nova Italia, 1993; N = Isaac Newton, *Philosophical Writings*, trans. and ed. by A. Janiak and C. Johnson, Cambridge: Cambridge University Press, 2004; TP = Immanuel Kant, *Theoretical Philosophy: 1755-1770*, trans. and ed. by D. Walford and M. Meerbote, Cambridge: Cambridge University Press, 1992, cited with volume, followed by a colon, and page number, from the standard Academy edition of Kant's works (same for other Kant works except CPR); MF = Immanuel Kant, *Metaphysical Foundations of Natural Science*, trans. and ed. by M. Friedman, Cambridge: Cambridge University Press, 2004; NS = Immanuel Kant, *Natural Science*, ed. by E. Watkins, trans. by L. W. Beck, J. B. Edwards, O. Reinhardt, M. Schönfeld, and E. Watkins, Cambridge: Cambridge University Press, 2012; PFM = Immanuel Kant, *Prolegomena to Any Future Metaphysics*, trans. and ed. by G. Hatfield, Cambridge: Cambridge University Press, 1997; CPR = Immanuel Kant, *Critique of Pure Reason*, trans and ed. by P. Guyer and A. Wood, Cambridge: Cambridge University Press, 1998, cited with edition, A or B, and line number.

[10] For more on Huygens's physics and the center-of-mass frame, see Julian Barbour, *Absolute or Relative Motion?*, vol. 1, *The Discovery of Dynamics*, Cambridge: Cambridge University Press, 1989, pp. 473-478.

> [S]ince I claim that motion is nothing unless in relation to other bodies, without any offense to God we shall say that He cannot make it thus that there is a relation to something that does not exist, i.e., that a body be several bodies. Similarly, I maintain that God also cannot create [*constitui*] a single body at rest, for rest, just as motion, is relative to something else, and neither can be predicated of a single body. (H 27)

This forthright avowal of a central tenet of relational motion is absent in Descartes's work, it is important to note; and, while Descartes offers the fairly neutral suggestion that there may be no motionless points in the material world (Pr II 13), Huygens takes the strict relationist stance that the very question concerning an immovable place/space is meaningless:

> Those who know that the Earth moves will say perhaps that the fixed Stars are at rest. [. . .] [H]owever, when asked what is it to be at rest, [they] have nothing else to answer but that rest is when a body and each of its parts maintain the same place in the space of the World. [. . .] For when they say that this space is immovable, in order that its parts are likewise immovable, I don't know what their idea thereof is. But they don't realize that knowing what it is to be immovable is what we are still searching for, and thus they fall into a vicious circle. [. . .] Instead, they ought to have inferred that neither motion nor rest can be properly ascribed to this space, but only to bodies—or only improperly to space insofar as it is occupied by or enclosed in a body. (H 54-55)

Huygens's second conclusion, that an immovable space is a confused notion, follows from his first, that motion is exclusively a relation among bodies. Descartes, in contrast, admits that a given body's rest or motion can be established from God's perspective,[11] and his laws of nature posit individual (i.e., non-relational) states of bodily motion that directly contravene relationism (as will be explained below). Provided this evidence, it is therefore not surprising that some commentators have singled out Huygens as the first truly modern relationist; e.g., Huygens "was the first physicist who believed in the exclusive validity of a principle of kinematic as well as dynamic relativity."[12]

The most important achievement of Huygens's commitment to relational motion is his use of the center-of-mass reference frame to generalize Descartes's first collision rule (Pr II 46) to cover the impact of all bodies.[13] As hinted at above, even though Descartes seems to espouse the concept of re-

[11] René Descartes, *The Philosophical Writings of Descartes, Vol.3, The Correspondence*, eds. and trans. by J. Cottingham et al., Cambridge: Cambridge University Press, 1991, p. 381.

[12] Max Jammer, *Concepts of Space*, 3rd ed., New York: Dover Publications, 1993 [1954], p. 126.

[13] Throughout our investigation, "center-of-mass" will be used interchangeably with "center-of-gravity," although the two are only identical if the gravitational field is uniform in the region that the bodies occupy.

lational motion in the *Principles* (Pr II 25), his groundbreaking conservation law and collision rules violate relationism in various ways, most notably in the case of the fourth and fifth collision rules: in the fourth, Descartes stipulates that a large stationary body remains at rest after impact with a smaller moving body, while the smaller body reverses its path after the collision (Pr II 49); yet, in the fifth rule, a large moving body will move a smaller stationary one, "transferring to [the smaller body] as much of its motion as would permit the two to travel subsequently at the same speed" (Pr II 50). According to the relational theory of motion, however, rules four and five constitute the very same collision, since both involve the interaction of a small and a large body with the same relative motion prior to impact (i.e., there are only differences in motion among bodies on the relational motion hypothesis), and so the outcomes should be identical. These types of relationist inconsistencies spurred Huygens to modify Descartes's impact rules so as to procure a consistent relationist account, and the center-of-mass frame would provide the means by which he obtained his desired goal. From the perspective of an observer situated at the origin of the center-of-mass reference frame (which is itself often inertially moving), two bodies that approach one another from opposite directions along a straight line, irrespective of their size and speed, will rebound after their collision while retaining their initial speeds; or, more formally, the center-of-mass frame is the point where the ratio of their (non-accelerating) speeds is reciprocal to the ratio of their sizes. The center-of-mass frame not only upholds the Cartesian conservation law for the quantity of motion (product of size and speed; Pr II 43) via Descartes's first collision rule (which is the only correct one out of the set of seven, although confined to equally sized bodies), but, since the colliding bodies move relative to one another, the center-of-mass perspective also upholds relational motion:

> After having shown that the speed [*vitesse*] of rebound, or separation of two elastic or hard bodies depends on the relative speed with which they collide, I shall postulate that there are perfectly elastic bodies that rebound with the same speed with which they approached one another. From this I demonstrate that when they come into collision with velocities inversely proportional to their weights [*poids*] or quantities of matter [i.e., size], they will each rebound with the same speed they had before. And from this I subsequently determine all cases. (H 13)

Overall, one would be hard pressed to find a more faithful exponent of a strict brand of relational motion: "We ought not to say that bodies change their relative distance [*inter se*] and position [*situs*] through motion; rather, motion itself is the change in that distance, and is not anything different from it" (H 24).

Unfortunately for Huygens, many of his contemporaries interpreted his relationist-based work on collisions in a quite contrary manner. Rather than accept his center-of-mass reconstruction as the proper method for understanding Descartes's collision rules and conservation law—a reconstruction that is firmly rooted in relationism—several natural philosophers drew the conclusion that the Cartesian conservation law is erroneous, since it does not hold true with respect to absolute (or world) space, but only works with respect to the relative space and motion of the colliding bodies. Pardies, whose treatise on impact we have examined above, advances this precise claim, arguing that Descartes's quantity of motion is not conserved in impact: "'tis not true that there is always as much *absolute* Motion after the percussion, as there was before. But 'tis easie to demonstrate, that the *respective* Motion is always the same; so that the Bodies recede one another *after* the percussion, as fast as they approached *before* it" (DLM 48). As is clear from the context, Huygens's center-of-mass method forms the basis of Pardies's interpretation, and Descartes's conservation law and collision rules serve as its target: Pardies insists that he has shown "that *Monsieur Des-Cartes* hath been deceived in Six Rules of the Seven, which he hath delivered about Motion" (DLM 71), and that Pardies's own conclusion, quoted above, "is against *Monsieur Des-Cartes*, who hath not distinguished the Motion which is here called *absolute* from that, which is called *respective*. And when he saith, that there is always an equal quantity of Motion *before* or *after* the percussion, he means it of this *absolute* Motion; or it is very apparent, that he hath mistaken" (DLM 71-72). Similarly, Mariotte's treatise on mechanics, first published in 1673, stipulates as one of its three basic definitions that "[t]he respective velocity of two bodies is that with which they approach each other, whatever may be their own velocities."[14] Huygens provides the following rebuttal: "In his Definition 3, Mariotte distinguishes the relative celerity of two bodies from their 'proper velocities.' I contend that there is no proper celerity. Instead of saying, 'no matter what their proper velocities may be,' he ought to say, 'no matter what their velocities relative to some other body'" (H 51).

Huygens's pioneering investigation of collisions in the 1652-1656 period provided the catalyst for the interpretation of Pardies, Mariotte, and several others, such as Déchales, hence the espousal of absolute space and motion by Pardies et al., along with the allegation that his work was not duly cited by these authors, must have been a source of much aggravation to Huygens.[15] He states: "The dispute on absolute and relative motion. It is commonly believed that there is some true motion, as opposed to relative motion. Borelli, Mariotte. Maybe Pardies, too? Newton thinks so. Wallis, perhaps?" (H 21) While the reference to Newton reveals that this passage postdates 1687, the year of

[14] Edmé Mariotte, *Traité de la Percussion ou Choq des Corps*, 3rd ed., 1684, pp. 1-2; trans. in René Dugas, *Mechanics in the Seventeenth Century*, trans. by F. Jaquot, Neuchatel: Griffon, 1958, p. 290

[15] For further details, see Aant Elzinga, *On a Research Program in Early Modern Physics*, New York: Humanities Press, 1972, p. 134.

the *Principia*'s appearance, the essays that sanction absolute space by Borelli, Pardies, Mariotte, Déchales, and likely others, were published in the 1660s and early 1670s, when Newton was just getting started as a natural philosopher. Consequently, given the evidence that Newton was familiar with the work of some of these authors as far back as 1672 (see footnote 16 below), the inspiration for Newton's own use of the absolute/relational distinction likely stems, at least in part, from their earlier efforts.[16] Just as Borelli's, Pardies's, and Mariotte's analyses of mechanical phenomena rely on the distinction between absolute space/motion and relative space/motion (see the passages quoted above), Newton employs this distinction in the exact same manner: "Absolute motion is the change of position of a body from one absolute place to another; relative motion is change of position from one relative place to another" (N 65). However, while Borelli, Pardies, and Mariotte attempt to discern the true motions of bodies from their merely relative motion during impact (with Huygens's center-of-mass frame providing this distinction in Pardies's and Mariotte's treatment), Newton came to the realization that the inertial motion of a colliding pair of bodies (prior to impact) could not reveal the true rest frame of the material world, as is evident in his Corollary 5 (N 78). Rotational motion, on the other hand, is not subject to the same limitations, for the non-inertial effects of the rotation do not align with the presence or absence of a relative rotation.[17]

In section 3, our examination of Kant's critical period concept of absolute space will draw upon these findings, yet a brief summary of the findings of this section is in order first. On the whole, it is fairly safe to conclude that previous investigations of the origins of the absolute-relational debate have hitherto failed to take into account the upsurge in the utilization of that

[16] Richard Westfall (*Never at Rest: A Biography of Isaac Newton*. Cambridge: Cambridge University Press, 1983, pp. 242-245) recounts Newton's correspondence with Pardies on optics in 1672. Furthermore, Marius Stan, who provided the translation of Huygens' codex 7A, comments that the term "absolute" (as regards place/space or motion) does not appear often in the fragments that comprise the codex. He adds that "[t]his suggests that [Huygens] was familiar with this notion (true motion as translation in world space) before 1687, and rejected it before the first edition of Newton's *Principia* came to light," and that Huygens "speaks of 'they' who explicate true motion as change of absolute place," which "may be Borelli, Pardies, and Mariotte" (H 45). That is, Huygens had objected to the use of absolute space (or world space) prior to Newton's more famous treatment of the concept. Of course, even though there were many well-known earlier texts that employed the distinction between absolute and relational space/motion prior to Newton, it is possible that Newton reached his own conclusions on that distinction apart from the work of Pardies et al. In addition, while Newton would attempt to show how "absolute and relative rest and motion are distinguished from each other by their properties, causes, and effects" (N 66), these earlier thinkers (Pardies et al.) did not attempt to provide these details. Rather, they only employed the distinction to demonstrate the general point that the relative motion of a pair of colliding bodies may differ from their (alleged) absolute motion.

[17] See Robert DiSalle, "The Transcendental Method from Newton to Kant," *Studies in History and Philosophy of Science* 44 (2013), pp. 448-456.

dichotomy in the essays on mechanics in the decades prior to its celebrated appearance in the *Principia*; these mechanical treatises, moreover, appear to have been directly inspired by Huygens's study of impact in the 1650s. On the whole, and leaving aside the catalyst of Descartes's rather equivocal conception of motion, the absolute-relational distinction underwent a remarkable transformation in the period 1650-1687, evolving from a largely metaphysical treatment of the relativity of perceived motion within a larger scholastic and theological setting to a conceptual system within mechanics that is designed to gauge the scope and correct application of various conservation laws and rules of impact. In other words, much like natural philosophy as a whole, the absolute-relational distinction was itself swept up and transformed by the increasing mathematization and mechanization of the late seventeenth century's scientific revolution—and it was Huygens's work, prompted by Descartes's earlier effort, that initiated this transition.

3. *The Kantian Synthesis of Relationism and Newtonian Physics*

In the previous section, several developments in the natural philosophy of the late seventeenth and early eighteenth centuries have been examined on the grounds that they may shed light on aspects of Kant's critical period approach to space and motion. Above all, Huygens's relationist interpretation of Descartes's collision rules focused the attention of natural philosophers on the distinction between real and apparent motion within mechanical systems that employ quantitative laws, thereby introducing a basis for the absolutist-relationist distinction in the newly developed science of mechanics. Likewise, although it is not the focus of this investigation (but see the references to Watkins and Stan in section 1), the concepts and debates within the Leibniz-Wolff school had an enormous impact on the development of Kant's understanding of body, force and inertia. It is against this richer historical background that any attempt to situate Kant's critical period conception of absolute space must be gauged, and not a simple "Newton versus Leibniz" dichotomy. Indeed, the evolution of Kant's philosophy of space and motion reflects these different sources of influence, and it also prefigures the difficulties that nineteenth-century natural philosophers would face in reconciling the prevailing Newtonian theory with the challenges imposed by the absolute-relational dichotomy. Whether Kant was actually acquainted with Huygens's writings on these specific issues remains unclear, it should be noted, and is probably unlikely. Nonetheless, the uncanny similarities between Kant and Huygens on space and motion strongly suggests that he was, at the very least, quite familiar with these general concepts and strategies, presumably through his long association with the Leibniz-Wolff tradition and its natural affiliation with relationism. In short, given that the primary goal of this essay is to place Kant's absolute space scheme within a sort of conceptual ancestry, it thus follows that the manner by which Kant obtained these ideas is of less importance than their content and function within his system.

3.1. The Center-of-Mass Frame as Absolute Space

While Kant's critical period no longer champions a Leibniz-Wolff metaphysics of monads, Kant's treatment of spatial hypotheses at the material level relevant to his physics is continuous with the approach that he had espoused in various pre-critical works, specifically, in that he utilizes a Huygens-style center-of-mass (or center-of-gravity) frame to construct a relationist interpretation of the Newtonian distinction between absolute and relative space (as will be explained below). In the first few pages of his most elaborate treatment of physics in the critical period, the *Metaphysical Foundations of Natural Science* (1786), Kant lays out the major themes of his unique relationist-inspired interpretation of absolute space:

> [A]ll motion that is an object of experience is merely relative; and the space in which it is perceived is a relative space, which itself moves in turn in an enlarged space, perhaps in the opposite direction, so that matter moved with respect to the first can be called at rest in relation to the second space, and these variations in the concept of motions progress to infinity along with the change of relative space. To assume an absolute space, that is, one such that, because it is not material, it can also not be an object of experience, as given in itself, is to assume something, which can be perceived neither in itself nor in its consequences (motion in absolute space) . [. . .] Absolute space is thus in itself nothing, and no object at all, but rather signifies only any other relative space, which I can always think beyond the given space, and which I can only defer to infinity beyond any given space, so as to include it and suppose it to be moved.[18] (MF 4:481)

In short, all motion is relative and perceived in a relative space, which is the empirical (sensible) space of material bodies.[19] Absolute space, on the

[18] In the final pages, he reiterates these points: "Absolute space is therefore necessary, not as a concept of an actual object, but rather as an idea, which is to serve as a rule for considering all motion therein merely as relative; and all motion and rest must be reduced to absolute space, if the appearance thereof is to be transformed into a determinate concept of experience (which unites all appearances)" (MF 4:560).

[19] "*Matter*, as opposed to *form*, would be that in the outer intuition which is an object of sensation, and thus the properly empirical element of sensible and outer intuition, because it can in no way be given a priori. In all experience something must be sensed, and that is the real of sensible intuition, and therefore the space, in which we are to arrange our experience of motion, must also be sensible—that is, it must be designated through what can be sensed—and this, as the totality of all objects of experience, and itself an object of experience, is called *empirical space*. But this, as material, is itself movable. But a movable space, if its motion is to

other hand, is not an "object of experience" and "is thus in itself nothing," but is simply an "idea of reason" that assists in the construction of a series of ever larger empirical relative spaces that proceed to infinity. Since one of Kant's main objectives in this work is to supply his own interpretation of Newtonian gravitation theory, the application of the conceptual apparatus outlined above to the celestial realm, as Friedman explains, ultimately "indicates how the earth's state of true rotation can nonetheless be empirically determined, and concludes by considering the cosmos as a whole, together with the 'common center of gravity of all matter,' as the ultimate relative space for correctly determining all true motion and rest."[20] Consequently, it is "the common center of gravity of all matter," using Kant's phrase (MF 4:563), i.e., the center-of-mass frame of all matter, and not the inertial structure of space *per se*, that constitutes absolute space.[21]

One of the truly novel features of Kant's system, which also ties into the discussion in section 2, is that he envisions his center-of-gravity approach as an instance of a larger strategy for interpreting all bodily interactions that also includes within its scope the center-of-mass frame collision model first pioneered by Huygens (although Kant may have been unaware of this history). As regards impact, Kant provides an example involving two bodies, A and B, that approach from opposite directions along the same rectilinear path, collide, and reverse their motion:

> [T]he change of relation (and thus the motion) between the two is completely mutual; as much as the one body approaches every part of the other, by so much does the other approach every part of the first. [. . .] On this basis, the motion of a body A with respect to another body B at rest, in regard to which it can thereby be moving, is reduced to absolute space; that is, as a relation of acting causes merely related to one another, this motion is so considered that both have an equal share in the motion which, in the appearance, is ascribed to body A alone. And the only way this can happen is that the speed ascribed in relative space to body A alone is apportioned between A and B in inverse ratio to their masses. (MF 4:546)

In short, the center-of-mass frame is the position where the "speed ascribed in relative space" is "apportioned between A and B in inverse ratio to their masses." As briefly noted above, Kant had earlier employed the center-of-mass

be capable of being perceived, presupposes in turn an enlarged material space, in which it is movable; this latter presupposes in precisely the same way yet another; and so on to infinity" (MF 4:481). As the last few sentences indicate, the relativity of perceived motion is an integral part of Kant's conception.

[20] Michael Friedman, "Introduction," in Immanuel Kant, *Metaphysical Foundations of Natural Science*, ed. and trans. by M. Friedman, Cambridge: Cambridge University Press, 2004, pp. vii-xxx, at p. xiii.

[21] On this issue, see Friedman, *Kant's Construction of Nature*, pp. 503-509.

frame in this same manner in his pre-critical 1758 *New Doctrine of Motion and Rest* (NS 2:18-25), alongside the same relationist conception of place and motion that one finds in Huygens: before introducing his impact model, he argues that "the place of a thing is known by its position, situation, or by its external relationship to other objects around it," which he dubs a "relative space" (NS 2:16), and he insists that the terms "motion and rest" should never be used "in an absolute sense but always relatively" (NS 2:17). The relationist version of absolute space that he would later develop in the critical period is absent in the *New Doctrine*, however.[22]

Returning to the *Metaphysical Foundations*, the assimilation of gravitation and impact using the center-of-mass frame strategy falls under his third law of mechanics, which stipulates that "[i]n all communication of motion, action and reaction are always equal to one another" (MF 4:544). After detailing his impact model, he comments that "the communication of motion through *impact* differs from that through *traction* [gravitation] only in the direction in which the matters resist one another in their motions. It follows, then, that *in all communication of motion* action and reaction are always equal to one another" (MF 4:546-547). The basis of Kant's third law of mechanics has, furthermore, distinctly Leibnizian, or (more accurately) Leibniz-Wolffian, roots, since Wolff and his followers were the likely source of Kant's dynamical notion.[23] In short, and leaving aside the obvious influence of Newton's third law of motion (N 71), the attempt to merge a kinematical treatment of the motions and quantities conserved in collision with a dynamical action/reaction principle employing the center-of-mass frame can be found in Leibniz' "Specimen Dynamicum" (AG 117-138), and, more generally, the action/reaction principle was taken up and developed by Wolff and his school. In the pre-critical *New Doctrine*, the action/reaction principle is also introduced (NS 2:19), but it is the *Metaphysical Foundations* that incorporates the impact model and the action/reaction principle with gravity under the same center-of-mass (center-of-gravity) scheme, as well as introduces the absolute-relative space distinction surveyed above.

[22] In Kant's first published work from 1747, the *Thoughts of the True Estimation of Living Forces*, there are a few references to absolute rest and motion (NS 1:90, 125-126, 158), but the context suggests that he is using "absolute" to indicate real versus apparent motion, since he contrasts an absolute motion with a body being "at rest with regard to all things," which is consistent with a relationist conception (NS 1:126), and there is no corresponding references to absolute space.

[23] On the action/reaction principle and the center-of-mass frame method in Leibniz, see Edward Slowik, "The 'Dynamics' of Leibnizian Relationism: Reference Frames and Force in Leibniz's Plenum," *Studies in History and Philosophy of Modern Physics* 37 (2006), pp. 617–634; and for the action/reaction principle among the Wolffians in general, and other related themes, see the Watkins and Stan references cited in section 1. Stan ("Absolute Space and the Riddle of Rotation") explores in part the inadequacy of Kant's use of the center-of-mass frame to support a consistent relational account, although that topic will not be addressed below.

Besides the replacement of the orthodox interpretation of absolute space (as an independent, fixed world space, etc.) with a materially-based reference frame, the relationism inherent in Kant's *Metaphysical Foundation* becomes all the more evident once the details are specified. First of all, Kant's approach to motion matches the standard relationist conception that one finds in, say, Leibniz (at the level of well-founded phenomena, excluding force) and Huygens, where the individual states of motion assigned to the bodies are perspectival but the invariance of the relative change in distance *among* the bodies is emphasized: "all motion of material things [. . .] count as merely relative with respect to one another, as alternatively mutual, but none as absolute motion or rest" (MF 4:559-560). Second, Kant's explication of rotation, a form of motion that had stymied so many earlier accounts of relational motion, appeals to the dynamic (force) effects among the bodies undergoing the rotation, thus providing an empirical means of distinguishing these cases from an identical, non-rotating configuration. In short, Kant converts one of Newton's empirical arguments for absolute space, via the rotating globes thought-experiments (N 68-70), into a form that, allegedly, upholds relational motion among the material parts of the rotating system: "circular motion, although it in fact exhibits no change of place in the appearance, [. . .] exhibits nonetheless a continuous dynamical change, demonstrable through experience, in the relations of matter within its [relative] space, for example, a continual diminution of attraction in virtue of a striving to escape" (MF 4:561). Kant's account, in effect, mimics the types of hypotheses offered earlier by Huygens (H 39-47) and Leibniz (AG 135-136), i.e., where one appeals to a set of resting external bodies as a backdrop, or the relative motion among a body's parts or a pair of bodies, to explicate rotational motion and its effects. Concerning the rotation of the earth, for instance, he states:

> [T]his motion, even though it is no change of relation to the empirical space, is nevertheless not absolute motion, but rather a continuous change in the relations of matters to one another, which, although represented in absolute space, is thus actually only relative, and, for just that reason, is true motion—this rests on the representation of the mutual and continuous withdrawal of any part of the earth (outside the axis) from any other part lying diametrically opposite to it at the same distance from the center. (MF 4:561-562)

Third, Kant rejects as "utterly impossible" (MF 4:563) a scenario wherein the entire cosmos moves uniformly and rectilinearly through space, and likewise denies a potential cosmic rotation, but concedes that "it is always possible to think such a [rotational] motion, although to suppose it would, so far as one can see, be entirely without any conceivable use" (MF 4:563). Since a uniform rectilinear or rotational motion of the entire cosmos would not be relative to another body, a relationist must forbid, or deem as useless, these scenarios. Unlike Euler,[24] whose conception of absolute space would sanction the motion of a lone body in an otherwise empty universe, Kant reasons that "absolute motion, thought without any relation of one matter to another, is completely impossible" (MF 4:559). Fourth, Kant reflects on various meanings that can be ascribed to empty space, either within or outside the material world, and he ultimately concludes that these possibilities are, at a minimum, "not *necessary*," and potentially impossible on dynamic or physical grounds (MF 4:563-564). By taking this stance, Kant is thereby relieved of the burdensome task of explicating the ontological status of a vacuum, a possible state of the world that many natural philosophers of the time period would have interpreted as supporting absolutism over relationism.

3.2. Kant's Relationist "Applied Metaphysics" of Motion and its Aftermath

While there have been many notable exceptions over the past few decades (once again, see the references in section 1), the relationist orientation of Kant's natural philosophy of space and motion is—somewhat remarkably—largely unknown outside perhaps a small subsection of Kant scholars. Part of the reason for this oversight may lie in the tendency to treat Kant's transcendental idealist notion of space in the critical years as an ontological alternative to substantivalism and relationism, with the *Critique* and the incongruent counterparts argument (more on this below) forming the primary supporting evidence. Allison has denounced this outlook, claiming that Kant's idealist standpoint should be understood as an attempt to opt out of the ontology dispute, rather than as another ontological choice.[25] Yet, a more prosaic reason for the curious oversight of Kant's relationism may stem from the simple fact that the *Metaphysical Foundations* and the relevant pre-critical works that advance relationism are themselves largely overlooked, and/or that recent influential investigations of the center-of-mass frame strategy (e.g., Friedman's) have failed to discuss its many relationist elements against the backdrop of the traditional spatial ontology debate.[26] DiSalle, on the other hand, focuses his attention on Newton and Euler's contribution, concluding that Kant's "mature concern was not to establish one of two opposing metaphysical positions

[24] Leonhard Euler, "Réflexions sur l'espace et le temps," *Histoire de l'Academie Royale des sciences et belles lettres* 4 (1748), pp. 324-333, at pp. 329-330.

[25] Henry E. Allison, *Kant's Transcendental Idealism*, New Haven: Yale University Press, 1983, p. 25.

[26] Friedman, *Kant's Construction of Nature*. Freidman does note that "[f]or Kant, [. . .] space, motion, and rest are always relative concepts" (p. 43), which he describes in the context of the "Copernican revolution in astronomy" (p. 41). The point is, however, that a discussion of the distinctly relationist conclusions that Kant reaches utilizing his system, and of how it relates to prior and past relationist hypotheses, is not a part of Freidman's ground-breaking investigation.

[absolutism versus relationism],"[27] but to demonstrate that "[t]he metaphysical concepts that occur in physics—body, force, motion, space, time—become intelligible to us precisely, and only, as they are constructed by physics itself; physics provides us with the only intelligible notions we have on these matters."[28] Therefore, since the physics of Kant's day was Newtonian, "the metaphysical concepts underlying the sensible world first become intelligible," for Kant, "in the framework of Newtonian physics";[29] and, "Kant's analysis of absolute space, accordingly, is an effort to clarify its place within the system of Newtonian principles."[30]

Nevertheless, the evidence of the texts presented in section 3.1 indicates that various non-Newtonian principles played a role in Kant's system at least as important as Newton's, with his rejection of a uniform inertial motion of the material world presenting the most conspicuous example.[31] If perchance a body were located outside the cosmos, Kant reasons that the mutual gravitational interaction between the cosmos and the body (which falls under the "the law of antagonism in all community of matter through motion") would "shift the common center of gravity of all matter, and thus the entire cosmic system, from its place," but "then the motion would already be relative" (MF 4:562-563). As it stands, this hypothesis is perfectly consistent as well as relational, but it runs afoul of Corollary 4 in the *Principia*, which holds that *"the common center of gravity of all bodies acting upon one another (excluding external actions and impediments) either is at rest or moves uniformly straight forward"* (N 76). That is, while Newtonian theory sanctions the inertial motion of the center-of-mass frame, Kant apparently reasons that only an "external action" (to use Newton's phrase), such as the gravitational pull of a body outside the cosmos, can move the world's center-of-mass frame. Yet, it is not only the content of this hypothesis but the manner in which Kant reaches it that demonstrates his divergence from the *Principia*, especially when it is juxtaposed with his second law of mechanics, which holds (following Newton's first law of motion) that "[e]very body persists in its state of rest or motion, in the

[27] DiSalle, *Understanding Space-Time*, p. 66.

[28] Ibid., p. 60.

[29] Ibid., p. 64.

[30] Ibid., p. 67.

[31] The other noteworthy facet of Kant's system that favors relationism is his reluctance to embrace the possibility that the entire cosmos rotates, even though each sequence in his series of ever larger center-of-gravity systems apparently does (in order to preserve the stability of the order of bodies within each concentric system via a balance of gravitational and centrifugal forces; MF 4:557-563). According to Friedman (*Kant's Construction of Nature*, pp. 501-502), this restriction stems from the *Critique*'s first antinomy (in particular, CPR A429/B457), which rules out any completion of an infinite sequence of this sort, hence the rationale behind Kant's belief that a rotation of the entire cosmos is "without any conceivable use." But this reasoning, which is quite dubious in its own right, is purely metaphysical, and not grounded in the physics at hand.

same direction, and with the same speed, if it is not compelled by an external cause to leave this state" (MF 4:543). This law figures prominently in Kant's assessment of the observed non-inertial force effects of rotation: "according to the law of inertia [. . .] the body, at every point on [a] circle (according to precisely the same law), is striving, for its own part, to proceed in the straight line tangent to the circle" (MF 4:556). Consequently, by stipulating a decidedly Newtonian concept of inertia, a uniform inertial motion of the entire cosmos should be a possible state-of-affairs, rather than rejected out-of-hand as "utterly impossible."[32] Or, to put this point in specifically Newtonian terms, Kant's hypothesis (where only a gravitational interaction with an outside body can cause a rectilinear unison motion of the cosmos) is tantamount to claiming that the world's inertial motion, which comes under Newton's first law of motion, would violate Newton's third law of motion, the latter holding that every action has an equal and opposite reaction (and which also comprises Kant's own third law of mechanics, as explained above). This maneuver essentially constitutes a fundamental reconstruction of Newtonian physics, a revaluation of basic principles that just so happens to fall in line with a Huygens-style center-of-mass frame version of relationism and an action/reaction principle that, as Stan concludes, Kant "developed by constructive engagement with post-Leibnizian dynamics, rather than Newton's *Principia*."[33] Accordingly, perhaps it would be more accurate to infer that, for Kant, "the metaphysical concepts underlying the sensible world first become intelligible"[34] in the framework of Huygens-Leibniz-Wolffian physics.

Indeed, once the details are taken into account, it is rather difficult to avoid the conclusion that one of the chief goals of the *Metaphysical Foundations* is to provide an anti-absolutist interpretation of Newtonian physics that generally follows the relationist precedent set by such thinkers as Huygens, as well as his own earlier *New Doctrine*. In the *Critique*, as is well known, Kant rebuffs the metaphysical doctrines of *spatial* absolutism and relationism (respectively, as an entity or the relations among entities; CPR A23/B38) in favor of space as an a priori intuition (and the same for time), i.e., as a subjective feature of the mind's operation. But, as uniquely revealed in the *Metaphysical Foundations*, the application of this critical period doctrine results in a sort of "phenomenalized" Huygensianism (see section 2). To be more precise, it is not space as a non-empirical intuition that is at issue. Like Leibniz, Kant is

[32] As noted above, given Kant's acceptance of a Newtonian form of inertial motion, something like Newton's Corollary 4 should be in effect, namely, that the center-of-mass of the world is either at rest or moves uniformly in a straight line; as well as Corollary 5 (Galilean relativity), that one cannot distinguish a state of rest from a state of uniform rectilinear motion (see, N 76-79; and Friedman, *Kant's Construction of Nature*, pp. 443-445, who explores the absence of these corollaries in Kant's work).

33 Stan, "Kant's Third Law of Mechanics," p. 503.

34 To use DiSalle's phrase in *Understanding Space-Time*, p. 64, with a twist.

quite clear that "[s]pace is not an empirical concept which has been derived from outer experiences" (CPR A23/B38), yet, Kant holds that motion is an empirical concept (CPR A41/B58), and it is in the *Metaphysical Foundations* that this topic is addressed at length:

> [S]ince the *movability* of an object in space cannot be cognized a priori, and without instruction through experience, I could not, for precisely this reason, enumerate it under the pure concepts of the understanding in the *Critique of Pure Reason*; and that this concept, as empirical, could only find a place in a natural science, as applied metaphysics, which concerns itself with a concept given through experience, although in accordance with a priori principles. (MF 4:482).=

To summarize, while the contention that Kant did not try to establish either an absolutist or relationist *spatial* ontology in the critical period is thus technically correct, he did offer a devoutly relationist construal of the phenomenal world of bodily motion, which he categorizes as "applied metaphysics" in the passage above.[35]

Consequently, it would seem that the relationism that Kant espoused in his pre-critical period was never really abandoned, but simply transformed into a version more amenable to his newly developed species of subjectivism/ idealism. The straightforward ontological form of relationism that one finds in the *New Doctrine* has been dropped, of course, but a subtle form of relationism is still operative which prefigures the sophisticated strains that would be developed in subsequent centuries—that is, in conjunction with the relative space of actual bodies, Kant's "absolute space" signifies the *possibility* of constructing ever larger relative spaces, and thus the function this concept has in Kant's *Metaphysical Foundations* strongly resembles the sophisticated modal varieties of relationism currently in vogue in the philosophy of space and time,[36] albeit at the subjective level of phenomena. In the *Directions in Space* (1768), where Kant first launches his criticisms of spatial relationism and invokes absolute space, there is no corresponding sanction of the *ontology* of spatial absolutism. Rather, Kant seems already inclined towards an idealist interpretation, for he concludes that "absolute space is not an object of outer sensation; it is rather a fundamental concept which first of all makes possible all such outer sensation" (TP 2:383). In addition, the *Directions in Space* puts forward a critique of Euler's well-known argument for absolute space (see above), concluding that it "does not quite achieve its purpose," rather, "[i] t only shows the difficulties involved in giving a determinate meaning to the

[35] See also Jill Vance Buroker, *Space and Incongruence: The Origins of Kant's Idealism*, Dordrecht: Reidel, 1981, pp. 123-130.

[36] E.g., the relationist alternatives surveyed in Kenneth L. Manders, "On the Spacetime Ontology of Physical Theories," *Philosophy of Science* 49 (1982), pp. 575-590.

universal laws of motion if one operates with no other concept of space than that which arises from abstraction from the relation between actual things" (TP 2:378). Kant's evaluation of Euler's argument, in effect, mirrors the rationale that sophisticated modal relationists offer to justify their rejection of the strict eliminative brand of relationism; specifically, that a spatial concept abstracted from the relations among *actual* bodies is incapable of meeting the demands of physics. Unlike modern sophisticated relationists, however, Kant does not regard the requisite modality as a primitive ontological fact grounded in actually existing bodies, but as an a priori contribution of the mind that secures the unity (or holism) of spatial geometric structure.

By the time of the *Prolegomena* (1783), the idealist lesson that Kant draws from the incongruent counterparts argument is made clear (PFM 4:286), but the transformation to space as an a priori intuition, which is tentatively suggested in *Directions in Space*, is largely complete in the *Inaugural Dissertation* penned two year later (1770): "Space is not something objective and real, nor is it a substance, nor an accident, nor a relation: it is, rather, subjective and ideal; it issues from the nature of the mind in accordance with a stable law as a scheme, so to speak, for co-ordinating everything which is sensed externally" (TP 2:403). Nevertheless, as demonstrated above, this "scheme" becomes overtly relational in the *spatiotemporal* context of the experience of bodily motion, although it is confined to the "subjective and ideal,"

Finally, it should be noted that, after Kant, the utilization of the world's center-of-mass frame as a substitute for the standard Newton/Euler conception of absolute space would find many advocates, most notably Mach,[37] although one should also include other material-based reference frame schemes, such as Neumann's "body Alpha."[38] In fact, the center-of-mass frame strategy remains to this day the default relationist approach, e.g., the Barbour-Bertotti program, which employs a least-action principle in order to secure a non-rotating universe (and thereby recover the standard Newtonian results).[39] And, much like the quandary over the proper categorization of Kant's own achievement in the *Metaphysical Foundations*—as either relationist, absolutist, or something else—there were equivalent disagreements among the nineteenth-century advocates of a materially-conceived surrogate for absolute space. Mach, for instance, forthrightly sides with a relationist classification for his center-of-mass frame method, and he even accepts a fully relational account of rotational

[37] Ernst Mach, *The Science of Mechanics*, 6th ed., trans. by T. McCormack, London: Open Court, 1960 [1893], p. 287.

[38] Carl Neumann, "On the Necessity of the Absolute Frame of Reference," trans. by Milič Čapek, in Milič Čapek (ed.), *The Concepts of Space and Time: Their Structure and Their Development*, Dordrecht: Reidel, 1976 [1870], pp. 125-127.

[39] Julian Barbour and Bruno Bertotti, "Gravity and Inertia in a Machian Framework." *Nuovo Cimento* 38B (1977), pp. 1-27; Id., "Mach's Principle and the Structure of Dynamical Theories," *Proceedings of the Royal Society* 382 (1982), pp. 295-306.

motion (i.e., the water would rise up the bucket's sides if the bucket is at rest and the universe undergoes the rotation).[40] Neumann, in contrast, argues that his body Alpha scheme, which stipulates a single inertially-moving rigid and unchanging body to which all other motions are referred, undermines a relational account of motion since there is a privileged basis for determining all motions, and hence motion relative to the body Alpha is absolute.[41] Russell finds these types of strategies implausible, for the question regarding the state of motion of any privileged material frame naturally arises, and hence only a non-material (and hence non-empirical) conception of absolute space is acceptable.[42] Regardless of these disputes, Kant's relationist appropriation of the term "absolute space" can be viewed, in hindsight, as having foreshadowed the future direction of the absolute versus relational debate, a controversy that would grow ever more ambiguous as fundamental disagreements over the meaning and scope of the dichotomy's basic concepts and terminology gradually engulfed the rival camps.

4. Conclusion

It would be worthwhile at this point to summarize the relationship, as presented in this essay, between Kant's critical period natural philosophy and Newtonian physics. While Newtonian physics is, needless to say, central to the *Metaphysical Foundations*, is it due to (i), the established status that Newtonian theory had obtained by Kant's later years, such that it had to be accommodated in any system of natural philosophy; or, is it that (ii), for Kant, "Newtonian physics is in itself a philosophical critique of metaphysics as traditionally practiced"[43]? On the basis of the evidence presented above, i.e., the many non-Newtonian and relationist features in Kant's theory, option (i) appears to be the better interpretation. In essence, Kant's chief innovation in the *Metaphysical Foundations*—the incorporation of gravity within the same bodily action/reaction center-of-mass frame model as used for impact, and based on the same relationist interpretation of that strategy for gravity as for impact—is thoroughly Huygensian in character. Newton also employed the center-of-mass frame, but he did not sanction a relational interpretation of that system. That is, Newton's Corollary 4 sanctions the inertial motion of the cosmos, and his rotating bucket and globes thought experiments admit the possibility of the cosmos' rotation, two scenarios that Kant either outright dismisses or ignores.

To be fair, Huygens was adamantly opposed to Newtonian gravity, so Kant does side with Newton on this issue. Nevertheless, returning to the discussion

[40] Mach, *Science of Mechanics*, p. 284.

[41] Neumann, "Necessity of the Absolute Frame of Reference," p. 127.

[42] Bertrand Russell, *The Principles of Mathematics*, New York: W. W. Norton, 1938, p. 491.

[43] DiSalle, *Understanding Space-Time*, p. 57.

in section 2, Newton's conception of gravitational attraction is identical to the interpretation of impact favored by Pardies, Borelli, Mariotte, et al. in that they all distinguish an absolute (or world) space from the merely relative space of bodies. Kant, on the other hand, sides with Huygens in sanctioning a relative space interpretation alone, while simultaneously rejecting the reality of absolute space—and, as revealed in section 3.2, Kant even goes so far as to reinterpret fundamental Newtonian principles in order to uphold his relationism, contra (ii). Therefore, by specifically rejecting both a uniform inertial motion and rotation of the world, Kant has exposed his true allegiance to the non-Newtonian relationist cause, notwithstanding the many Newtonian trappings of his approach, especially the use of the term "absolute space" to signify a scheme for constructing relative spaces. Put simply, Kant's non-trivial deviations from Newtonian orthodoxy undercut the claim that he deems Newtonian physics to be a philosophical critique of metaphysics as traditionally practiced; rather, the evidence points in the opposite direction: a *relationist* "applied metaphysics" serves as the basis of a philosophical critique of Newtonian physics as traditionally practiced. Kant was deeply impressed by the Newtonian accomplishment, needless to say, but his goal in the *Metaphysical Foundations* would appear to have been a reconstruction of Newtonian theory grounded in a strict relationist conception of space and motion. Kant's achievement, accordingly, places him in a line of development that starts with Huygens and extends forward to Mach (and even Barbour and Bertotti), namely, a center-of-mass frame relationist mechanics. Kant, in fact, stands at the exact midway point of the evolution of this approach to physics, incorporating both the earlier Huygensian impact version of this strategy as well as the later Machian gravitation type. Historians and philosophers of science should not allow themselves, therefore, to be (with apologies to Alexander Pope) blinded by Newton's light in seeking a full accounting of Kant's strategy and innovations in the *Metaphysical Foundations*.

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