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ORIGINAL ARTICLE

Extending the Dynamics of Reason

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Abstract What I call the dynamics of reason is a post-Kuhnian approach to the history and philosophy of science articulating a relativized and historicized version of the Kantian conception of the rationality and objectivity of the modern physical sciences. I here discuss two extensions of this approach. I argue that, although the relativized standards of rationality in question change over time, the particular way in which they do this still preserves the trans-historical rationality of the entire process. I also make a beginning in extending my historical narrative from purely intellectual history (both philosophical and scientific) to the wider cultural context.

1 Introduction

What I call the dynamics of reason is an approach to the history and philosophy of science developed in response to Thomas Kuhn's theory of scientific revolutions. Unlike many philosophical responses to Kuhn, however, my approach, like Kuhn's, is essentially historical. Yet Kuhn's historiography, from my point of view, is much too narrow. Whereas Kuhn focusses primarily on the development of the modern physical sciences from the Copernican revolution to Einsteinian relativity theory, I construct an historical narrative depicting the interplay between the development of the modern exact sciences from Newton to Einstein, on the one side, and the parallel development of modern scientific philosophy from Kant through logical empiricism, on the other. I use this narrative to support a neo-Kantian philosophical conception of the nature of the sciences in question—which, in particular, aims to give an account of the distinctive intersubjective rationality these sciences can justly claim. By contrast, Kuhn's picture led to philosophical challenges to this claim, I argue, precisely because he left out the parallel history of scientific philosophy.

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The basic ideas of this approach were presented in my *Dynamics of* Reason (2001), and I here want to discuss two extensions of these ideas. First, I want to make clear how the neo-Kantian conception in question presents us with a fundamentally *historicized* version of scientific intersubjective rationality, so that the standards of objectivity in question are always local and contextual. Nevertheless, in spite of, and even because of, this necessary historicization, the way in which such standards change over time still preserves the trans-historical rationality of the entire process. Second, I want to make a beginning in extending my historical narrative from purely intellectual history (both philosophical and scientific) to the wider cultural context. Far from supporting the idea that the relevant kind of scientific change is less than fully rational (because essentially political, for example), I argue that this second contextual extension only further highlights the importance of the neo-Kantian conception I am developing.

2 Kant, Kuhn, and the Relativized a Priori

I begin with the fact that Einstein's theory of relativity is the main example Kuhn gives, in Chapter IX of *The Structure of Scientific Revolutions* (1962), of a genuine revolution in science—a case where the post-revolutionary conceptual framework is *incommensurable* or non-inter-translatable with the pre-revolutionary framework. And I agree with Kuhn that Einstein's general theory of relativity is in an important sense incommensurable or non-inter-translatable with the Newtonian theory of universal gravitation it replaced. Whereas Newtonian theory represents the action of gravity as an external "impressed force" causing gravitationally affected bodies to deviate from straight inertial trajectories with respect to Euclidean space and Newtonian time, Einstein's theory depicts gravitation as a curving or bending of the underlying fabric of space–time itself. In this new framework, in particular, there are no inertial trajectories in the sense of the geometry of Euclid and the mechanics of Newton, and gravity is not an "impressed force" causing deviations from such trajectories. Gravitationally affected bodies instead follow the straightest possible paths or geodesics that exist in the highly non-Euclidean geometry (of variable curvature) of Einsteinian space–time; and the trajectories of so-called "freely-falling bodies"—affected by no forces other than gravitation—replace the straight inertial trajectories of Newtonian theory.

In *Dynamics of Reason*, I explained the relevant kind of incommensurability as follows. It is clear, in the first place, that Einstein's theory is not even *mathematically* possible from the point of view of Newton's original theory, for the mathematics required to formulate Einstein's theory—Bernhard Riemann's general theory of geometrical manifolds or "spaces" of any dimension and curvature (Euclidean or non-Euclidean, constant or variable)—did not even exist until the late nineteenth century. Moreover, and in the second place, even after the mathematics required for Einstein's theory was developed, it still remained fundamentally unclear what it could mean actually to apply such a geometry to nature in a genuine physical theory. One still needed to show, in other words, that Einstein's new theory is *physically* possible as well, and this, in turn, only became clear with Einstein's own work on what he called the principle of equivalence in the years 1907–1912. This principle, as we now understand it, implies that freely-falling bodies follow the straightest possible paths or geodesics in a certain kind of four-dimensional (semi-)Riemannian manifold, and it thereby gives objective physical meaning, for the first time, to this kind of abstract mathematical structure. Einstein's theory thus requires a genuine expansion of our space of intellectual possibilities (both mathematical and physical), and the problem is then to explain how such an expansion is possible. The problem of explaining the rationality of the transition from Newton to Einstein, from this point of view, reduces to explaining how such a conceptual expansion can itself be rational.

My strategy, as already suggested, is to consider the parallel developments in contemporaneous scientific philosophy. I begin with Kant's original attempt—in his *Metaphysical Foundations of Natural Science* (1786), and also in the *Critique of Pure Reason* (1st ed., 1781; 2nd ed., 1787)—to provide philosophical foundations for Newtonian theory.[1] In the following nineteenth century, these Kantian foundations for specifically Newtonian theory were then self-consciously successively reconfigured, as scientific philosophers like Ernst Mach (and others) reconsidered the problem of absolute space and motion, and other scientific philosophers—especially Hermann von Helmholtz and Henri Poincaré—reconsidered the empirical and conceptual foundations of geometry in light of the new mathematical discoveries in non-Euclidean geometry. Einstein's initial work on the principle of equivalence—which culminated, as I said, in 1912—then unexpectedly put these two earlier traditions together, and thereby led to the very surprising and entirely new conceptual possibility that gravity may, after all, be represented by a non-Euclidean geometry.[2]

The crucial breakthrough came when Einstein (in 1912) came upon the example of the uniformly rotating disk or reference frame—where, in accordance with the principle of equivalence, we are considering a particular kind of *non*-inertial frame of reference within the framework of special relativity. The result was a non-Euclidean physical geometry as our novel representative of the gravitational field; and Einstein was only able to arrive at this result (as he himself later tells us in his celebrated lecture *Geometry and Experience* in 1921) by delicately situating himself within the earlier philosophical debate on the foundations of geometry between Helmholtz and Poincaré. It is precisely here, I argue, that Einstein was able to connect this debate with the earlier debate on the relativity of space, time, and motion in an entirely unexpected way—so that a radically new kind of space–time geometry then naturally (and rationally) emerges from an unanticipated convergence or intersection between two previously independent lines of thought.

What all this shows, in my view, is the need to *relativize* the Kantian conception of a priori scientific principles to a particular theory in a given historical context and, as a consequence, to *historicize* the notion of scientific objectivity (that is, intersubjective scientific rationality) itself. Thus, for example, whereas Euclidean geometry and the

[1] For Kant's work on the foundations of Newtonian physics see Friedman (2004). I discuss the relationship between this work and the *Critique of Pure Reason* in the Introduction. See also Friedman (1992).

[2] For more details on the developments described in this paragraph and the next see also Friedman (2002).

Newtonian laws of motion were indeed necessary presuppositions for the objective empirical meaning of the Newtonian theory of universal gravitation, the radically new conceptual framework consisting of the Riemannian theory of manifolds and the principle of equivalence defines an analogous system of necessary presuppositions in general relativity. Moreover, what makes the latter framework rationally acceptable in this new context is precisely the circumstance that Einstein actually arrived at it historically by self-consciously situating himself within the earlier tradition of scientific philosophy represented by Helmholtz, Mach, and Poincaré—just as this tradition, in turn, had earlier self-consciously situated itself against the background of the original conception of "transcendental" scientific rationality first articulated by Kant. It turns out, therefore, that the radically new Einsteinian conceptual framework not only contains a system of possibility-defining necessary presuppositions analogous to those of the Newtonian framework it replaced, but it in fact evolved from this earlier framework as well, through precisely an intervening tradition of mathematics and scientific philosophy. Given the historical context within which Einstein's theory was developed, it arrived at a practically optimal solution to the overall intellectual problem situation it faced—a situation comprising a complex and subtle mixture of mathematics, physics, and philosophy.[3]

In order further to illustrate the force of the relativization and historicization of scientific rationality I am proposing, I will now briefly describe the historical and conceptual context in which Kant's original conception was formulated. Kant, like all those seriously interested in natural philosophy and metaphysics in the eighteenth century, was greatly influenced by the stage-setting intellectual debate between Newton and Leibniz culminating in the Leibniz-Clarke correspondence (1715–1716). Kant, from the beginning, was a convinced Newtonian in physics and natural philosophy, but he was also convinced that a broadly Leibnizean metaphysical foundation for this new physics was urgently needed. In particular, Newtonian absolute space was clearly unacceptable on metaphysical (and theological) grounds, but we still needed to account for the distinction between "true" and merely "apparent" motion Newton articulates in the famous Scholium to the Definitions in the *Principia*. Kant's task, therefore, was to reformulate this Newtonian distinction *without* Newtonian absolute space, against the background of the fundamental metaphysical concepts—substance, causality, and so on—which have their origin, according to Leibniz, in the logical structure of our pure intellect.

Now recent scholarship has made it increasingly clear that the Scholium to the Definitions in the *Principia* proceeds against the background, in turn, of Newton's rejection of Cartesian metaphysics and natural philosophy.[4] In particular, Newton needed to reject both the Cartesian version of the relationship between "true" and "apparent" motion, and the Cartesian conception of the relationship between space and matter, in order successfully to arrive at his own revolutionary version of mathematical physics—which, for the first time, introduced Newtonian "impressed forces" (such as the force of universal gravitation) into natural philosophy. This

[3] I further develop the idea of a practically optimal solution to a given (historically contingent) problem situation for this case in Friedman (2009b).

[4] See, for example, Stein (2002).

becomes especially clear in Newton's unpublished manuscript *De Gravitatione* (whose date is uncertain but may have been completed around 1685 during approximately the same time as the composition of the Scholium); for it is here that Newton defends a metaphysics of space and its relationship to God and the divine creation, indebted to the "Cambridge Platonism" of Henry More, which is explicitly opposed to the corresponding metaphysical views of Descartes.[5]

Newton begins by declaring that absolute space is neither a substance nor an accident, but what he calls "an emanative effect of God and an affection of every kind of being" (*De Grav.*, p. 21). In particular, absolute space or pure extension is even an affection of God himself, since God is omnipresent or everywhere. God can thereby create matter or body (as something quite distinct from pure extension) by endowing certain determined regions of space with the conditions of mobility, impenetrability, and obedience to the laws of motion. And God can do this anywhere in space, in virtue of his omnipresence, by his immediate thought and will, just as our souls can move our bodies by our immediate thought and will. It is essentially this doctrine which surfaces in Newton's well-known published statements, in the General Scholium to the *Principia* and the Queries to the *Optics*, that space is the "sensorium" of God.[6]

Why is this important? I do not have space to make the argument in detail here (see footnote 8 below), but I believe that it was precisely this metaphysical background that made it possible for Newton to achieve his revolutionary break from the then dominant mechanical natural philosophy (as paradigmatically formulated by Descartes). For, in order successfully to formulate his theory of universal gravitation, Newton not only needed to articulate a distinction between "true" and "apparent" motion, he also needed to introduce what we now conceive as a fundamental force of nature (gravitation) that acts immediately at a distance. Yet Newton himself rejected action at a distance in the metaphysical sense, as the action of one substantial agent on another not subject to the then universally accepted condition of local presence, and he suggested instead (e.g., in his well-known letter to Richard Bentley of February 1693) that it might well be God himself (or perhaps some ubiquitous immaterial agent directly dependent on God) who is ultimately responsible for gravitational attraction.[7] Newton's "neo-platonic"

[5] An improved translation of *De Gravitatione* by Christian Johnson, made with the assistance of Andrew Janiak, and consulting an earlier unpublished translation by Howard Stein, appears in Janiak (2004); my parenthetical page references to *De Grav.*—and to Newton's writings more generally—are to this volume.

[6] In Query 31, for example, Newton describes God as "a powerful ever-living agent, who being in all places, is more able by his will to move the bodies within his boundless uniform sensorium, and thereby to form and reform the parts of the universe, than we are by our will to move the parts of our own bodies" (p. 138).

[7] Thus the letter to Bentley (pp. 102–103): "It is inconceivable that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact, as it must be, if gravitation in the sense of Epicurus, be essential and inherent in it. And this is one reason why I desired you would not ascribe innate gravity to me. That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe that no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers."

metaphysics of space and divine creation thus made it possible for him to accept gravitational attraction as a real physical force without committing himself to genuine action at a distance.

Kant, in the *Metaphysical Foundations of Natural Science*, reconceives Newton's distinction between "true" and "apparent" motion without Newtonian absolute space, and he also mounts a strenuous defense of gravitational attraction as a true and immediate action at a distance through empty space. In particular, Kant entirely rejects the idea that any other "agent" (including God) is needed to mediate this interaction, and he thereby incorporates the theory of universal gravitation into his own version of a metaphysical foundation for physics. In the context of the more general transcendental philosophy articulated in the first *Critique*, Kant thus arrives at a twofold reinterpretation of Newtonian absolute space. On the one hand, space—empty space—is a form of our pure sensibility, within which all outer objects are necessarily perceived. On the other hand, "absolute space," as an ultimate frame of reference for distinguishing between "true" and "apparent" motions, is reconceived as a forever unreachable regulative idea of reason—where, on the basis of Newton's three laws of motion, we move from our parochial perspective here on earth to a more encompassing frame of reference fixed at the center of gravity of the solar system, to a still more encompassing frame of reference fixed at the center of gravity of the Milky Way galaxy, to a still more encompassing frame of reference fixed at the center of gravity of a rotating system of such galaxies, and so on *ad infinitum*. In particular, it is *our* pure intellect (not God's) which injects the Newtonian laws of motion into the form of *our* pure sensibility (not the sensorium of God); and it is in precisely this way that Kant now decisively transforms the metaphysical tradition he inherited (including Newton's own metaphysics of space) into something radically new: Kant replaces a theological foundation for the metaphysics of nature with his characteristic conception of transcendental objectivity.[8] What is objective, on this view, is precisely that to which all human beings—in virtue of their shared rational faculties of sensibility and understanding—must necessarily agree. And, in this way, Kant's original conception of transcendental objectivity itself arose as a practically optimal solution to the intellectual problem situation *he* faced.[9]

3 Extending the Historical Narrative

I now want to make a beginning in connecting this kind of intellectual history—both philosophical and scientific—with the wider cultural context by sketch an enlarged historical narrative that depicts how some of the developments in modern science and philosophy I have considered have been inextricably entangled with technological, institutional, and political developments—often in surprising and unexpected ways.

[8] For details see Friedman (2009a).

[9] Compare footnote 3 above, together with the paragraph to which it is appended; in my article cited there I further explain the sense in which Kant's original theory was itself practically optimal in context.

The scientific and philosophical developments on which I have focussed so far originate in the history of astronomy—in the attempt to develop rigorous mathematical models of the observed motions of the sun, moon, stars, and planets as seen from our everyday perspective here on the surface of the earth. And this enterprise, in turn, was inextricably entangled, from the very beginning, with a fundamental human interest in keeping track of the progression of the seasons. From this point of view, the most basic astronomical phenomenon involves the observed periodic changes in the daily rising and setting of the sun—as we proceed from the autumnal equinox (September 23rd on the modern calendar), when day and night are equal, to the winter solstice (December 22nd), when night is as long as possible, to the vernal equinox (March 21st), when day and night are again equal, to the summer solstice (June 22nd), when day is as long as possible, and so on. The practice of agriculture, of course, very much depends on our ability to anticipate these seasonal variations, and so does the regulation of the mythical and religious rituals that have gradually grown up surrounding this practice. The calendar, we might say, represents our fundamental material technology for regulating both the practice of agriculture and the associated religious rituals.

But there is a serious technical problem—a technological problem, if you will—in setting up an accurate calendar: the solar year (defined by the periodic progression from equinox to equinox) does not contain an integral number of solar days (defined by the period between one noon—when the position of the sun is highest in any daily cycle—and the next).[10] The earliest (Babylonian) calendars used a year of 360 days, but this led to the result that important seasonal events, like the flooding of the Nile in Egypt, quickly became out of phase with the seasons. The Egyptians therefore added five additional days to the year, but the number 365 is also too short and we were again out of phase with the seasons after about 40 years. Julius Caesar then reformed the calendar in 45 B.C., with technical assistance from the Alexandrian astronomer Sosigenes, using a year of 3651/4 days—so that 3 years of 365 days were followed by 1 year of 366 (a "leap year"), and so on. However, the seasonal year is actually 11 min and 14 s shorter than 3651/4 days, so that, by the time of the publication of Copernicus's *De Revolutionibus* in 1543, the vernal equinox had moved backwards from March 21st to March 11th. The Catholic Church, during the height of the Counter-Reformation, wished to regulate the observance of Easter throughout Christian Europe, and it thus needed to reform the calendar once again. (Easter is defined as the first Sunday after the first full moon after the vernal equinox.) The result, the modern Gregorian Calendar, adopted by the Church in 1582, suppresses a normal leap year three times every four centuries: for example, the years 1600 and 2000 were leap years, but the years 1700, 1800, and 1900 were not—neither will be the year 2100, and so on.[11]

The crucial question from our present point of view is what exactly this modern reform of the calendar had to do with the modern reform of mathematical astronomy

[10] My account here closely follows Kuhn (1957, pp. 11–12).

[11] The Gregorian reform was not accepted in Protestant Europe until early in the eighteenth century. The Gregorian Calendar (in the South) and the Julian Calendar (in the North) competed with one another throughout Europe until then. I shall return to this situation below.

initiated by Copernicus. At first sight, the answer may appear obvious. The Gregorian reform occurred 39 years after the publication of *De Revolutionibus*, and the papal commission formed by Gregory XIII—led by the Jesuit mathematician Christoph Clavius—elected to use the Prutenic Tables based on the Copernican system in place of the older Alphonsine Tables derived from Ptolemy. It turns out, however, that this was a mere accident. Copernican astronomy, although in several respects simpler and more harmonious than Ptolemaic, is not intrinsically more accurate; and this is true, in particular, for the Copernican model of the solar orbit (or, in this case, the earth–sun orbit). Astronomy in the Copernican tradition was not able significantly to improve on Ptolemy in this respect until Kepler's radical innovations early in the following century—whereby circular orbits governed by the principle of uniform (circular) motion were eventually replaced by elliptical orbits governed by what we now call Kepler's laws. And this came too late, of course, to influence the initial construction and promulgation of the Gregorian Calendar in 1582.

The true story of how the Gregorian reform was in fact inextricably entangled with the new mathematical astronomy has recently been told by John Heilbron, in *The Sun in the Church: Cathedrals as Solar Observatories* (1999). Beginning before 1582 and continuing well after it, mathematical astronomers took the Church's overriding concern for extremely accurate calculations of the vernal equinox as a golden opportunity to devise more accurate measurements of the solar orbit (or earth–sun orbit) for their own purposes. They realized, in particular, that the great Catholic cathedrals of Europe could function as especially good gnomons—or *meridiane*—for precisely tracking the solar orbit throughout the seasonal year. All one needed was an exact north–south line (or meridian) drawn on the floor of such a cathedral which would be illuminated every day by the sun's light (let in through an aperture high up in the cathedral) at precisely noon: exact measurements of the successive daily progress of the sun's image could then precisely determine the solar orbit. The most important of these *meridiane* was constructed by the Jesuit astronomer Giovanni Domenico Cassini in the basilica of San Petronio in Bologna in 1655—revising and perfecting an earlier meridian line devised by the astronomer Egnatio Danti in 1576. And Cassini's most striking result, derived by precisely measuring the sun's image along his perfected meridian line in San Petronio, was that the solar orbit (or earth–sun orbit) is more accurately described by Kepler than either Copernicus or Ptolemy.

What Cassini confirmed, more precisely, was the bisection of the solar eccentricity first introduced by Kepler while exploring an earlier theory of planetary orbits based on an eccentric circle rather than an ellipse (where the orbital speed of a planet was taken to be inversely proportional to its distance from the sun).[12] On this theory, the distance between the earth and the (eccentric) center of the solar orbit is one-half the amount postulated by Ptolemy (and Copernicus), so that, in particular, the sun is considerably closer to the earth at aphelion and considerably further at perihelion. Kepler himself had confirmed this bisection within his evolving

[12] See Wilson (1989). I am indebted to George E. Smith for helping me to get clearer about the details of Kepler's earlier orbital theory.

planetary theory using multiple observations of Mars at a fixed point in its solar orbit (observations from the earth separated by 687 days, the duration of Mars's orbital period). Cassini, however, using the great *meridiana* at San Petronio, confirmed it directly (independently of orbital theory) by measuring the changes in the apparent diameter of the sun's image on the floor of the Cathedral.

In order to see the astronomical significance of this issue, note that Ptolemy had used bisected eccentricity for the planetary orbits, but not for the solar orbit—where, for the planets, this involved the use of an equant point relative to which the angular speed is constant. Moreover, such a Ptolemaic orbit with bisected eccentricity and equant point is very close to the finished Keplerian orbital theory—with ellipse and area law—when the eccentricity is very small. Yet, as we have seen, Kepler did not arrive at this finished theory all at once, and the intermediate stage of using circular orbits with bisected eccentricity (and the inverse-proportionality to distance law for orbital speed) marked a crucial transition in the evolution of his thought. For it showed that the solar orbit (the earth–sun orbit) behaves, in this important respect, just like the other planetary orbits. (When the eccentricity is very small, the inverse-proportionality to distance law is very close to both the area law and the Ptolemaic equant law.)

Heilbron argues, on this basis, that the *meridiane* constructed in some of the great Catholic cathedrals of Europe during the years preceding and following the initial Gregorian reform show that the Church's relationship to the new mathematical astronomy was much more complicated and interesting than is typically thought. During the same period in which Galileo was very publicly condemned for defending the Copernican system, the Church itself—because of its overriding interest in precisely fixing the date of Easter once and for all—was providing the new astronomy with important observational support. The Catholic Church, on Heilbron's telling, was thus far from a monolithic opponent of the new astronomy. But what is the precise relevance, we now need to ask, of Heilbron's lovely story for the modified form of Kantian history and philosophy of science I have been developing?

To begin with, the events described by Heilbron are intimately connected with the purely intellectual narrative presented above. In the very first proposition of Book 1 of the *Principia*, for example, Newton showed that Kepler's area law—now assumed to manifest the action of what Newton calls a centripetal force—is mathematically equivalent to the law of inertia. Indeed, it was this fundamental Newtonian derivation that convinced most astronomers of the truth of the area law by indicating its precise dynamical significance.[13] And, although Newton carefully leaves it open, in Phenomenon 4 of Book 3, whether the solar system as a whole is Copernican or Tychonic, he finally arrives, in Propositions 11 and 12 of Book 3, at the result that it is the center of gravity of this system (which is always very close to the center of the sun) that defines a privileged (approximately inertial) frame of reference for describing the totality of orbital motions therein. Newton thereby

[13] A variety of empirically acceptable alternatives to Kepler's area law existed at the time. For a detailed discussion of how Newton's *Principia* first led to the recognition of Kepler's rules as "laws" see Wilson (1970).

defines both a privileged absolute space and a privileged absolute time; and Kepler's description of the earth–sun orbit (and the other planetary orbits) was thus grounded in the abstract theoretical standard of temporal measurement defined by the Newtonian laws of motion. But this standard is also seen to be inextricably entangled, via Heilbron's story, with the institutional history of the Church; and the metaphysical and theological aspects of Newton's achievement (his neo-platonic metaphysics of space) are thereby seen to be similarly entangled with the wider cultural struggles of the time, as the whole of Christian Europe wrestled with the radically new configuration of science, society, religion, and philosophy emerging from the aftermath of the Reformation and the scientific revolution.

Now Leibniz, more than anyone, was deeply involved with the totality of these cultural struggles. He was personally involved, in particular, with what we might call the "second" Gregorian reform of the calendar: the events at the turn of the eighteenth century that finally brought Protestant Europe on board. As Heilbron explains, Cassini found a mistake in Clavius's original calculation of the lunar cycle that would seriously distort the Gregorian predictions for Easter after 1700 (the first suppressed leap year after the Gregorian reform), and this gave the Church a golden opportunity officially to correct this mistake and thereby get the Protestant lands to go along with the Gregorian calendar as so corrected and revised.[14] Pope Clement XI, with Cassini's help, commissioned a new *meridiana* in Santa Maria degli Angeli in Rome for this purpose, and the publication of the official results from this *meridiana* in 1703—which confirmed the original Gregorian determination of the vernal equinox—was then an important factor in securing the cooperation of Protestant Europe. The construction of this new *meridiana* was overseen by the astronomer Francesco Bianchini, and Leibniz corresponded with Bianchini about the project (concerning which he was very enthusiastic) during the years 1700–1705.[15]

Here, as Heilbron also explains, Leibniz was concerned with both furthering his goal of the reunification of Protestant and Catholic churches and, at the same time, using Clement XI's interest in astronomy to promote a grand compromise between the Church and Copernicanism in which the Church would allow Copernicans to hold that their opinion is the simplest and most intelligible—and in this sense "truest"—hypothesis, and the Copernicans would concede that there is no need to reinterpret Scripture from a heliocentric point of view. Of course Leibniz failed in both of these grandiose schemes; but the crucial question, from our point of view, concerns the role Leibniz's theological and political ambitions played in his assimilation and response to Newton's *Principia*—and the way in which these ambitions, in turn, then impacted on Kant's assimilation of Newton.

With respect to Leibniz's assimilation and response to Newton's *Principia*, we can rely on the detailed and insightful work of Domenico Bertoloni Meli.[16] In 1688 Leibniz read the *Principia*, paying particular attention to Proposition 1 of Book 1,

[14] See footnote 11 above. The English delayed acceptance of the Gregorian reform for another 50 years.

[15] This correspondence appears in Celani (1888).

[16] See Bertoloni Meli (1988, 1993, 1999). Heilbron cites the first of these in the discussion I have been summarizing.

and, on this basis, he developed his own mathematical decomposition of orbital motion governed by Kepler's area law into a circular component and a continuously varying radial component. This led to the publication of his *Essay on the Causes of Celestial Motions* in the following year, where Leibniz embedded this mathematical decomposition within a vortex theory aiming to give the true physical causes of the planetary motions. He appealed not only to Kepler's laws, but also to Kepler's notion of "true hypothesis"—as the simplest and most intelligible account of a given phenomenon. And it is clear from "On Copernicanism and the Relativity of Motions," composed in 1689, that this notion of true hypothesis, for Leibniz, was closely related to the one he used in his attempt to fashion a grand compromise between Copernicanism and the Church.

Leibniz aimed, with his Keplerian vortex theory, to supplant Newtonian orbital theory with his own, and he even pretended that he had developed this theory prior to reading the *Principia*. But Leibniz was not successful in convincing the learned on either count, not even his erstwhile friend and mentor Christiaan Huygens in their correspondence of 1690–1694. Thereafter, Leibniz moved away from directly challenging Newton in celestial mechanics and increasingly concentrated on metaphysical and theological issues, culminating in the publication of the *Theodicy* in 1710. When his friend and patroness Caroline Ansbach became Princess of Wales in 1714, Leibniz seized on this new opportunity, not only to challenge Newton on his own soil, but also to further the project of reconciling the principal Protestant denominations—Lutheran, Calvinist, and Anglican. The enduring result of these endeavors was the celebrated correspondence between Leibniz and Clarke (1715–1716), which, as Bertoloni Meli has convincingly demonstrated, exhibits clear traces of Leibniz's ecumenical ambitions for reconciling the Protestant denominations.

The main question relevant to these ambitions, as discussed explicitly in both the *Theodicy* and Leibniz's correspondence with Caroline, concerned the precise way in which the body of Christ is supposed to be present in the Eucharist—a question which, as Bertoloni Meli argues, is intimately related to Leibniz's rejection of both real action at a distance between bodies and the Newtonian doctrine of divine omnipresence in space. Thus, for example, whereas Catholicism taught that the substance of the bread in the Eucharist is miraculously transformed into the substance of the body of Christ, the Lutheran position endorsed by Leibniz held only that both substances, while still remaining separate, were nevertheless miraculously received at the same time and place. Moreover, whereas the Newtonians adopted the absurd position that God was himself substantially present throughout all of infinite space, Leibniz required only God's virtual presence in space through his action—which, in the Eucharist, brought it about (miraculously) that we are acted upon by both the bread and the body of Christ at the same time and place. Leibniz's essentially *dynamical* conception of corporeal substance, which took action rather than spatial extension as the mark of its substantiality, was thereby inextricably connected with his ongoing program for Church reunification.[17]

[17] These issues of Church reunification, together with Leibniz's hopes for a grand compromise on the Copernican question, converge in his correspondence with Bianchini concerning the second Gregorian reform of the calendar (footnote 15 above). See Friedman (2010) for the details of this convergence—as well as for further details concerning Leibniz's involvements more generally.

The Leibniz-Clarke correspondence then set the stage, in turn, for the great debates in metaphysics and natural philosophy of the eighteenth century, and, in particular, for the critical philosophy of Kant—whose intellectual career, I have suggested, is best understood as a succession of increasingly sophisticated attempts to fashion some kind of synthesis of Newtonian physics and Leibnizean metaphysics.[18] The problem, as it presented itself to the eighteenth century—and, especially, to Kant—was that, since Newtonian physics had clearly won the day, the great metaphysical project of the seventeenth century of showing that it is the new science, after all, that best conforms with orthodox Christian theology, had decisively failed. Leibnizean metaphysics was the last best hope for such an orthodox theological foundation for the new science, and Newton's own metaphysics—which essentially involves a real (substantial) omnipresence of God throughout all of infinite space—could not possibly be harmonized with any variety of orthodox Christianity. The solution Kant came up with, as I have also suggested, was to break fundamentally with the metaphysical-theological tradition he inherited.[19] The phenomenal world in space and time is indeed Newtonian. It even involves a new notion of substantial interaction modelled on gravitational attraction at arbitrarily large distances across empty space. But the supersensible world beyond space and time—the world containing God and human souls, which Leibniz had correctly characterized in the *Theodicy* as the "kingdom of grace"—is no possible object of theoretical knowledge at all. It is instead the subject of purely *practical* (i.e., *moral*) cognition, as presenting us with an infinitely distant ideal of a perfect moral community (the "kingdom of ends") which we can only successively approximate but never actually attain.[20] In this way, Kant's assimilation of Newton, refracted through Leibniz's complex set of ambitions in physics, metaphysics, politics, and theology, eventually led to the radical new idea of a purely moral religion.[21]

In this essay, more generally, I have been exploring a complicated and subtle set of interactions among mathematics, physics, philosophy, technology, religion, and politics. And it is clear, I hope, that this inextricable entanglement between abstract theory (mathematical, scientific, and metaphysical) and its concrete cultural context

[18] For discussion of the development of Kant's thought from this perspective, see again the two works cited in the first footnote above.

[19] See again the paper cited in footnote 8 above for details.

[20] Kant provides an especially striking re-interpretation of the Newtonian doctrine of divine omnipresence in a footnote appended to the General Remark to the Third Part of *Religion Within the Limits of Reason Alone* (1793). I quote from Kant (1960), p. 130; translation slightly amended): "When Newton represents [the universal gravitation of all matter in the world] as, so to speak, divine universal presence in the appearance (*omnipæsentia phenomenon*), this is not an attempt to explain it (for the existence of God in space contains a contradiction), but rather a sublime analogy, in which it is viewed merely as the unification of corporeal beings into a world-whole, in so far as we base this upon an incorporeal cause. The same would happen in the attempt to comprehend the self-sufficient principle of the unification of the rational beings in the world into an ethical state and to explain the latter from the former. We know only the duty that draws us towards this; the possibility of the intended effect, even when we obey this [duty], lies entirely beyond the limits of all our insight."

[21] For a classic discussion see Wood (1970). This idea decisively shaped nineteenth-century German Protestant theology, as represented by such figures as Friedrich Schleiermacher and Ludwig Feuerbach.

is just that—a mutual interaction between equally important quasi-autonomous processes, where, in particular, neither is simply determined by the other. Thus, for example, while the institutional and political interests of the Church substantially conditioned, as we have seen, the practice and reception of the new mathematical astronomy, these interests by no means determined the surprising and entirely unexpected result: that the cathedral observatories constructed in the context of the Gregorian reform of the calendar turned out to provide the new astronomy with one of its most important sources (at the time) of direct observational confirmation. Similarly, the circumstance that the Kantian philosophical synthesis of early modern thought at the end of the eighteenth century was substantially influenced, through the great confrontation between Newton and Leibniz, by the wider cultural struggles emerging from the aftermath of the Reformation and the scientific revolution, by no means detracts from its intellectual integrity. Just as the Kantian synthesis provided a revolutionary solution to the purely intellectual problem situation with which it was faced, it provided a perhaps even more important response to these wider cultural struggles—a response, once again, that fundamentally transformed the original Leibnizean cultural and political ambitions into something entirely new. For this synthesis also led, through the science, philosophy, and technology of the nineteenth century, to the early twentieth century age of secular ideology, and, eventually, to ourselves.[22] But a proper treatment of these developments must definitely wait for another occasion.

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[22] In order to trace the development of the radically new cultural context to which Kant then decisively contributed, one would need to consider such topics as, for example, the influence of Hegel and Feuerbach (see footnote 20 above) on Karl Marx, and the way in which this influence, in turn, was entangled with Marx's response to the nineteenth-century industrial revolution.

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