Absolute, true and mathematical time in Newton's *Principia*

Katherine Brading

Department of Philosophy, University of Notre Dame, Notre Dame, IN 46556, U.S.A.

kbrading@nd.edu

Abstract

I discuss the three distinctions "absolute and relative", "true and apparent", and "mathematical and common", for the specific case of time in Newton's *Principia*. I argue that all three distinctions are needed for the project of the *Principia* and can be understood within the context of that project without appeal to Newton's wider metaphysical and theological commitments. I argue that, within the context of the *Principia*, the three claims that time is absolute rather than relative, true rather than apparent, and mathematical rather than common, are to be evaluated with respect to the needs of, and relative to the success of, the project of the *Principia*. I claim that Newton is thereby offering a new, and empirical, philosophy of time.

1. Introduction

Newton introduces his discussion of time, space, place, and motion in the scholium to the definitions at the beginning of the *Principia* (published in 1687) as follows (Cohen and Whitman, 1999, p. 408, my emphasis):

> Although time, space, place and motion are very familiar to everyone, it must be noted that these quantities are popularly conceived solely with reference to the objects of sense perception. And this is the source of certain preconceptions; to eliminate them <u>it is useful to distinguish these quantities into absolute and relative, true and apparent, mathematical and common</u>.

What distinctions is Newton intending to draw by his use of these terms, and why does he do so? What do the terms "absolute", "true" and "mathematical" mean within the context of Newton's *Principia*? I will argue that Newton is very deliberate in his use of this terminology. Each of these terms has a distinct meaning important to the project of the *Principia* and which can be understood within the context of that project and without appeal to Newton's wider metaphysical and theological commitments. This is not to say that Newton's philosophy of time can be understood by reading the *Principia* alone. On the contrary, Newton's wider theological and philosophical concerns are essential to his overall account of time (see especially McGuire, 1995). Nevertheless, I argue that narrowing our focus to the use of "absolute, true and mathematical" with respect to time *within the Principia itself* makes evident that Newton is offering us there a new, and empirical, philosophy of time.

1.1 Newton's terminology of "absolute, true and mathematical"

Most of the large and ever-growing literature on the scholium to the definitions has focused on absolute versus relative motion.[1] Recently, however, Huggett (2012) has written about true motion as distinct from absolute motion in Newton's *Principia*, and Schliesser (2013) has written about Newton's absolute time as distinct from his true time. Both Huggett and Schliesser discuss the relationships of "absolute" and "true" to (a) Newton's project in the *Principia* and (b) his wider metaphysical commitments, and they agree that the two terms, "absolute" and "true", should be treated differently in this regard. Specifically, Huggett argues that the meaning of the term "true motion" depends in large part upon the laws of motion (via implicit definition), whereas "absolute motion" is defined explicitly with respect to "absolute space" and does not depend on the laws of motion (or the physics of the *Principia* more generally) for its meaning (see especially pp. 208-9 of Huggett, 2012). Being independent of the laws of motion, absolute space, time and motion might better be understood as deriving from Newton's metaphysical commitments antecedent to the work of the *Principia*.

Inspired by Huggett, Schliesser distinguishes absolute time from true time, but for Schliesser it is the qualifier "true" (rather than "absolute") that takes us beyond what is needed for the physics of the

[1] The first distinction to appear explicitly in Newton's writings is that of absolute versus relative (applying to time, space and motion). However, Newton worked on the motions of bodies long before he introduced this distinction. We first see this terminology appearing only in drafts that immediately preceded his 1684 lectures 'De Motu' (see Herivel, 1965, p. 304), which themselves formed the basis of Books 1 and 2 of the *Principia*. So far as I know, the addition of "true" and "mathematical" does not occur until the *Principia* itself. Moreover, having been inserted at the very beginning of the definitions in the draft (see MS. Xa in Herivel, 1965, p. 304), the account of absolute versus relative time and space is then removed to a scholium to the definitions in the *Principia*.

Principia and into Newton's wider metaphysics. Thus, for both Huggett and Schliesser, the distinction between the terms "absolute" and "true" marks a difference in the relationship of the associated concept to the physics of the *Principia* and to Newton's metaphysics. I will argue for a different understanding of this terminology.

I agree wholeheartedly with Huggett and Schliesser that the terms "absolute" and "true" are not synonymous, and that in order to understand these terms and the work that they do in Newton's overall physical and metaphysical projects we need to pay attention to his writings beyond the scholium to the definitions and indeed the *Principia*. However, I *do not* think that the terms "absolute" and "true" are related in different ways to the project of the *Principia*: I think they have exactly the same status in this regard. Moreover, I think that "mathematical" must be treated as on a par with "absolute" and "true", and not (as Schliesser does) as being an add-on to "absolute" and "true" (so that for Schliesser we have a two-way distinction between absolute mathematical time versus true mathematical time, rather than a three-way distinction between absolute time, true time, and mathematical time). I will argue for these claims in what follows. My purpose is to endorse the importance of, and add to, the discussion of the terms "absolute", "true" and "mathematical" as they are used by Newton in his *Principia*.

1.2 Why focus on time?

My focus will be on absolute, true and mathematical *time*. I have several reasons for focusing on time. Most obviously, it is the first quantity that Newton treats in the scholium, so it is a good place to start. Second, it is the only quantity discussed in the scholium for which the three distinctions (absolute versus relative, true versus apparent, mathematical versus common) appear explicitly. Third, it has been less discussed than motion and space (and even place), and stands in need of independent attention, as Schliesser argues. Fourth, retracing our steps over the ways in which our treatment of time in physics has developed, and the roles for which time is introduced into physical theorizing, is – I believe – important for philosophy of time, a point I will come back to later (see especially sections 6 and 8 below). And fifth, since time is perhaps the thorniest issue in contemporary foundations of physics (witness the vipers nest of technical and conceptual issues associated with the "problem of time" in quantum gravity, for example), such a retracing of our steps may perhaps turn out to be worthwhile for those projects too (though I will not make that case here).

1.3 Newton's philosophical methodology

There is an additional reason that makes the case of time particularly interesting to me. An emerging theme in Newton scholarship is the way in which, during his life and the evolution of his methods for doing natural philosophy, Newton increasingly transformed traditionally metaphysical questions (in the sense of questions to be settled prior to and independently of specific empirical results) into empirical questions.[2] This work also explores the relationships and tensions between Newton's prior metaphysical commitments (e.g. concerning matter) and his empirical approach to the same issues. No-one has done this for time, yet, so far as I know.

A crucial part of the overall story here is Newton's search for quantities, relations between these quantities, and empirical measures of these quantities, that render his project tractable (see especially the work of Bill Harper and of George Smith[3]). For example, in Definition 1 of the *Principia* Newton states that "quantity of matter [or "mass"] is a measure of matter". It is related to "quantity of motion" which is a measure of motion, which itself arises from quantity of matter and velocity jointly. Moreover, changes in motion are related to force, and it is the development of a quantitative relationship between force and quantity of motion that is the key to Newton's project in the *Principia*. Indeed, Book 1 of the *Principia* is concerned with developing mathematical relationships between forces and motions, and these in turn rely on metrical notions of space and time. With these quantities so tied together, empirical access to one provides at least partial access to others. As Newton says at the end of the scholium to the definitions, his project aims to show how we are able to determine true motions from their causes, effects and apparent differences, and how we can determine causes and effects from motions, whether true or apparent (see Cohen and Whitman, 1999, p. 415).

Throughout, Newton is concerned to develop quantities associated with which are empirically accessible methods of measurement, and it is the ability of the empirical project to probe the appropriateness of the concepts of matter and motion (for example) for carrying out the project that makes Newton's methodology a powerful philosophical tool. For example, as Biener and Smeenk (2012) argue, Newton's geometrical conception of matter (very much in evidence in 'De Gravitatione', and familiar from Descartes), turns out to be in tension with his dynamical conception (developed for the needs of the *Principia*) and it is the dynamical conception that proves a powerful philosophical tool in

[2] See especially Howard Stein's work on Newton (including Stein 1970, 1990, and 2002), and also DiSalle, 2006, along with several of the papers in Janiak and Schliesser, 2012.

[3] Harper, 2011; Smith, 2002; and references therein.

pushing (during the course of the project set up by the *Principia*) towards the possibility of atoms that have the same size but which vary in quantity of matter. In so doing, aspects of traditionally metaphysical questions concerning the basic properties of matter become empirically tractable, with their resolution depending on the specifics of empirical enquiry: we discover through the process of doing physics that the nature of matter cannot be characterized by volume alone.

Newton's concern to develop quantities associated with which are empirically accessible methods of measurement involves him in radical conceptual development with respect to mass, momentum and force. But the situation with time is, *prima facie*, very different. Newton is working in a long astronomical tradition in which time is identified with its measure (sidereal time, solar time, mean solar time). Time, it seems, is one quantity that has already been worked through thoroughly with respect to its empirical measure, in terms of motion, so that there is no gap between "time itself" and its measure. One might expect that with some relief Newton would simply adopt the fruits of this tradition and identify time with its astronomical measure. Instead, he makes the opposite move in the *Principia*: rather than stating that motion is the measure of duration, he *distinguishes* "absolute, true, and mathematical time" from motion as our means of measuring time. Why?

These are the specific issues and motivations for this paper. The general theme is the relationship between the physics of Newton's *Principia* and his metaphysics. I argue that Newton offers us in the *Principia* a new and powerful philosophy of time, and at the end of the paper I draw out some lessons more generally concerning the role of physics in contributing to metaphysics.

2. Some preliminaries: absolute versus relative motion, and true versus apparent motion

It is helpful to begin by reviewing the terminology of absolute/relative and true/apparent for the more familiar case of motion. We will then turn our attention to the main topic of this paper, i.e. time.

According to the standard account of absolute versus relative motion, absolute motion is the motion of a body with respect to absolute space and absolute time, whereas relative motion is its motion with respect to other bodies. The meaning of the term "absolute motion" therefore depends on what is meant by absolute space and absolute time. Approaching this just slightly differently is useful for our purposes. We will say that "relative" means in relation to material bodies, with "absolute" being simply the denial of this. Thus the absolute motion of a body is motion of that body that is independent of any relations to other material bodies, whereas relative motion is its motion relative to other material bodies. We can adopt the same usage of "absolute" with respect to time and space. Time is absolute, in contrast to relative, when it is independent of material bodies (including relations between bodies, bodily changes, and so forth). And space is absolute, in contrast to relative, when it is independent of material bodies (including relations between them). If we define "absolute" negatively in this way, as "not relative", then we are free to supplement this with a positive definition, perhaps in terms of a substantivalist account, but the meaning of the term itself does not require this. While this is slightly weaker than the standard account, I take it to be uncontroversial within the literature. We will come back to it below, when discussing time in more detail.

The qualifier "true", when applied to motion, also has a standard (and I think correct) interpretation in the current literature. Within the context of the Copernican dispute of the seventeenth century, some argued for geocentrism, some for heliocentrism, and others for relativism (there is no fact of the matter about which body is at rest at the center of the sphere of the fixed stars). Those in the geocentric and heliocentric camps shared a commitment to true motion: whatever apparent motion a given body may have (e.g. the Sun moving across the sky), and of which there may be many, there is nevertheless a unique motion that is its true motion. In other words, one motion is singled out as not mere appearance, but proper to the body, and this is its true motion. Advocates of relativism, on the other hand, deny this.

The distinction between apparent and true motion comes to the fore in the Copernican dispute because of the obvious conflict in Copernicus's system between the appearances (the Sun orbiting a stationary Earth) and the alleged true motions described in the theoretical system (the Earth orbiting a stationary Sun), but even those astronomers committed to a geocentric theory distinguished the apparent motions of the heavenly bodies (how their motions appear to us, viewed from Earth) and their true motions.

Among those committed to true motion, there remained a dispute over its correct definition (and correspondingly over its nature). For example, Descartes sought to give a definition of true motion in terms of the relative motion of a body with respect to its surrounding bodies. His definition (*Principles* II.25) seeks to identify the one true relative motion proper to the body, from among the many relative motions that this body in the plenum undergoes. This is the motion that is at issue in his laws of nature, rules of collision, and so forth. Newton, on the other hand, sought to give a definition of true motion in terms of absolute motion. And, because Newton's absolute motion yields a unique motion for a given body, "absolute" and "true" come together in Newton's theory: the true motion of a body just is its absolute motion.

So, while true motion may be absolute or relative (a better term here would be "relational", to distinguish Descartes's position from the relativism of those who deny that there is any such thing as true motion), it is the unique motion proper to the body, and does not depend on the appearances (that is, how the motion appears to us from where we happen to be viewing it). We can adopt the same usage of "true" with respect to time and space. As a first pass, we can say that time is true, as opposed to apparent, when it is independent of the appearances and is unique and proper to the system in question. I will say more about what this means and why it is important below. True space follows the same pattern, but I will not develop that in this paper.

In sum, absolute motion is independent of the relative motions of bodies, and true motion is a uniquely preferred motion (be that an absolute motion or a relative motion).

4. Absolute time and true time

In this section I offer an interpretation of the terminology of absolute and true, as it applies to time, before returning in section 6 (below) to discuss Newton's philosophy of time, including his arguments for absolute and true time, in more detail.

4.1 Motion as the measure of time

Newton discusses time and its relation to motion in the second paragraph of his discussion of absolute motion. As is well known, the discussion of motion occupies the most extended section of the scholium to the definitions, and this section begins with Newton setting out what he means by absolute motion, and how it is distinct from relative motion, in terms of his distinction between absolute place and relative place. Having done this, Newton moves on to motion as a measure of time. Turning our attention to astronomy, he writes (Cohen and Whitman, 1999, p. 410):

> In astronomy, absolute time is distinguished from relative time by the equation of common time.

The point he makes in this paragraph is that, in practice, we have strong theoretical reasons for believing that we have not yet found bodies whose periodic motions can serve as perfect clocks. I will discuss the details of this further in section 4.2 below, but our purpose now is to understand the argument that Newton is making.

It has proved useful in understanding the argument of the scholium to read it as engaging with Descartes,[4] and the passages on motion as a measure of time are no exception. According to Descartes (*Principles*, I.57; see Descartes, 1991, p. 25),

> in order to measure the duration of all things, we compare their duration with the greatest and most regular motions, which give rise to years and days, and call this duration 'time'.

In the scholium, Newton firmly rejects this position, arguing instead that we need to distinguish absolute time from these "greatest and most regular" relative motions.[5] He says (Cohen and Whitman, 1999, p. 410):

> duration is rightly distinguished from its sensible measures and is gathered from them by means of an astronomical equation. Moreover, the need for using this equation in determining when phenomena occur is proved by experience with a pendulum clock and also by eclipses of the satellites of Jupiter.

---

[4] See Stein (1970) and Rynasiewicz (1995a and b). As Janiak (Newton, 2004, p. xix) writes: "Newton had a Cartesian, and not a Leibnizian, opponent primarily in mind when he wrote his famous articulation of 'absolutism' concerning space and time. It may be thought a measure of Newton's success against his Cartesian predecessors that history records a debate between the Leibnizians and the Newtonians as influencing every subsequent discussion of space and time in the eighteenth century."

[5] Newton makes the case explicitly at the beginning of a manuscript written in the early 1690s when preparing revisions for the *Principia*, a manuscript that McGuire (1978) made available and translated (McGuire, 1978, p. 117, my emphasis): "Time and Place in themselves do not fall under the senses, but are measured by means of sensible things, such as magnitudes of bodies, their positions, local motions, and any changes uniformly made. And the vulgar take these measures to be the things measured, for example days, months, and years to be times, and either positions in relation to surrounding bodies, or the internal surfaces of surrounding bodies, to be places. But the times of the vulgar, because of the inequalities of celestrial motions are and have to be corrected by astronomical equations, in order to correspond to the true times, and the places of the vulgar either have no magnitude if they are positions, or correspond <to the surfaces of the bodies filling them, not to the bodies themselves. And on these grounds true times and places are distinguished from those vulgar and apparent ones."

The argument here concerning motion as the measure of time takes the following form: for the purposes of constructing a physics of matter in motion, it is absolute time rather than relative time that serves our needs. I think it is important to emphasize that this is the *same* argument form Newton uses when, in the ensuing paragraphs, he argues via "properties, causes and effects" that it is absolute motion rather than relative motion that serves our needs for the purposes of constructing a physics of matter in motion.

As with much of his work, Newton begins from a point of agreement with Descartes, and moves from there to his disagreements. He is in agreement with Descartes that motion is a measure of time, reversing the traditional Aristotelian position that time is a measure of motion. Gassendi also argues forcefully for this position in the Physics of *The Syntagma* (Gassendi, 1972, pp. 393ff.). However, Gassendi, and also Newton, then part ways with Descartes, arguing that motion as the measure of time should not be identified with time.[6]

Newton's discussion of motion as a measure of time contains a further deep disagreement with Descartes, not just about the status of time (as absolute or relative) but about mathematical astronomy and its place in natural philosophy. Descartes rejected mathematical astronomy, believing the orbits of the planets to be irregular figures that are unstable, changing over time. His position on this follows naturally from his plenum theory, in which the motions of the planets arise from continual collisions with the matter that surrounds them.[7] One consequence of this view is that, for Descartes, mathematical astronomy was not a route to natural philosophical knowledge. For Newton, in contrast, mathematical astronomy offered profound philosophical possibilities. One example is the way in which, as I argue later on, Newton is able to render metaphysical questions concerning time (such as whether it is absolute or relative) empirically tractable.

4.2 Absolute and true time: the push from astronomy

The most obvious periodic phenomenon in our daily lives is the cycle of day and night itself. Traditionally, and into the fifteenth century, the hour was defined by taking the time from sunrise to sunset and dividing it into twelve (and similarly for the twelve hours of the night). Call this seasonal time. Time understood in this way is relative (it depends on the relative motion of the Sun and the

[6] For more on this point see Arthur, 1995, pp. 344-5.

[7] See Descartes, 1991, *Principles* III.34.

Earth) and apparent (deriving from the motion of the Sun as it appears to us). It is worth pausing over this in order to better understand Newton's reasons for rejecting relative and apparent time.

How would the division of day and night each into twelve hours be achieved? During the day, the Sun appears to us to move steadily across the sky, so the motion of the Sun (assumed to be constant) could be used to divide the day into twelve. During the night, the stars similarly appear to move steadily across the sky, so the motion of the stars (assumed to be constant) could be used to divide the night into twelve.

Does a daytime hour have the same duration as a nighttime hour? Does each daytime hour have the same duration, over the course of a year? Haven't we just defined the hour as our unit of time in this way, so by definition each hour must have the same duration, right? If you think that "hours" defined in this way "vary in duration", how would you tell?

Ancient astronomers did not use hours defined in the above way. Instead, they defined apparent solar time as follows: take one complete circuit of the Sun around the Earth and divide it equally into 24 hours, so that one hour corresponds to the Sun moving through an angle of 15°.

This is apparent solar time. It is a relative conception of time (depending on the relative motion of the Sun and the Earth). During the day, it is directly observable (look and see how long it takes for the Sun to move through 15°, or measure this indirectly by means of a sundial). During the night, we need theory to calculate how far the stars have to move for a corresponding 15° motion of the Sun (postulated to be continuing its motion around the other side of the Earth) . With this calculation in hand, such "apparent solar time" is observable – it is in the appearances and is therefore apparent. According to Audoin and Guinot (2001, p. 40) it was in use in Europe in country areas until the beginning of the twentieth century, but it was *not* the time used by astronomers as referred to in the equation of time. For that, we need a further step, but first things first. Why would astronomers construct and adopt *apparent* solar time in preference to seasonal time? Why would ordinary people switch to apparent solar time too?

Astronomers were engaged in the task of predicting the motions of the heavenly bodies (the stars, the Sun, the Moon and the planets) using uniform circular motion. Any deviations of these bodies from a shared uniform circular motion needed to be accounted for theoretically. By adopting apparent solar time, the motions of the heavenly bodies become less irregular. That is to say, they are less irregular with respect to equal intervals of time defined using apparent solar time. The role of theory in our understanding of time is clear: if one choice of clock (the standard of time that we adopt) yields the result that the motions are highly irregular, while another choice of clock yields the result that the motions are close to regular, then the second clock makes our theoretical task easier as we try to account for remaining irregularities.

To us, to ordinary people not engaged in the details of mathematical astronomy, it is "obvious" that seasonal hours differ in duration. We can tell because we can compare the duration of these hours to other regular or periodic phenomena (the time taken for a candle of a given length to burn down and the number of times the sand runs through an old-fashioned egg-timer are examples of external periodic phenomena; our own biological rhythms are also sufficient for us to be able to "experience" a difference in the length of seasonal hours). In other words, there are different apparent times, arising from different choices of bodies whose relative motions we use to construct a clock. Faced with such a disagreement, it can be convenient for a society to make a choice that is shared among its members.[8]

Despite its great practical utility, apparent solar time was nevertheless also deemed "irregular" by astronomers (including Ptolemy, c. 150 A.D.). In fact, astronomers worked not with the apparent position of the Sun, but with the mean Sun (the mean Sun moves along the ecliptic at a constant angular speed over the course of a year, rather than varying in speed along the ecliptic as the true Sun does), and thus not with apparent solar time but with mean solar time. The reason for so doing is the goal of constructing a predictively adequate theory using regular motions: irregularities in the appearances (the apparent motions) are to be accounted for by such things as the eccentricity of the Sun's orbit, and so forth. Regularities in the irregularities are golden clues: mean solar time "corrects" apparent solar time by removing periodic irregularities via the "equation of time", with a maximum difference between the two on any given day of approximately 15 minutes.[9] Notice that we are using theory here to move from apparent time, derived from the most regular apparent motions that we observe (celestial motions), to an abstract theoretical time. Moreover, *astronomers knew of no relative motions that could serve as a clock with respect to this time.* Thus, as Newton knew well, the "time" that is appropriate for astronomy is neither relative nor apparent. Since it is not relative it is, by definition, absolute.[10] Since it is not

---

[8] Note also that the disagreement among different apparent times indicates that at least one of our clocks is not telling *the* time, if *the* time is unique and common to everything.

[9] For more details, see Audoin and Guinot, 2001, pp. 40ff.

[10] The philosophical question at issue concerns the nature of time: is time to be identified with the actual changes of bodies, including changes in their relative positions, or is it distinct from these changes? Thus, the relative motions being considered here are all *actual* relative motions. Newton's opponents, when he was constructing the *Principia*, offered a relational account of time based on actual motions. The possibility of constructing a relational account of time based on *possible* relative motions of bodies is a further move in the philosophical debate, most

apparent, it is, according to Newton's contrasts, true. We need to say more in order to make the significance of this second contrast explicit.

What exactly does Newton mean by "true" in connection with time? True motion, we said, is a unique motion proper to the system in question. Similarly, I claim, true time is a unique time proper to the system in question. True time, just like true motion, is a property of the body or system itself, not of the appearances. The apparent motion of the Sun and of the Moon with respect to the fixed stars may each be used as a clock, but they do not tick regularly with respect to one another. In the equation of time, we search for a single time parameter to be used in common for all astronomical bodies, relative to which we can construct a theory of their motions. If successful, this time parameter corresponds to the true time of the system of the world. For example, the sidereal year and the solar year are different apparent measures of time, but belief in true time is the belief that underlying these differing apparent measures is the one true time which these motions approximate to a greater or lesser extent. It is perhaps relevant here that Gassendi's argument against relative time (i.e. against identifying time with the motion of the heavens, for example) makes use of an appeal to true time in the sense we have given it here. Using the terms "relative" and "true" is anachronistic, but the thrust of the argument is clear: relative motions if identified with time lead to multiple times, and this is to be rejected in favor of a single unifying time (see Gassendi, 1972, pp. 393-4).

The abstract theoretical time of the equation of time would, in the limit of successful astronomical theorizing, correspond to Newtonian absolute (because not relative) and true (because unique and proper to the system of the world as a whole) time.

---

notably associated with Leibniz, and it concedes at the outset the claim at stake here, viz., that Newton's empirical arguments settle the issue against a relational account of time based on actual motions. It is perhaps also worth noting that a response which appeals to *possible* relative motions of bodies depends upon a modal characterization of bodies (or the grounds of bodies) sufficient to yield determinate possible motions and to support the distinction between these and impossible motions. Pursuing this next stage in the argument over the nature of time therefore takes us into the characterization of bodies, about which Newton also had a great deal to say (see, for example, McGuire, 1995; Biener and Smeenk, 2012; Brading, 2012). To address this here would take us too far from the concerns of the present paper.

4.3 Absolute and true time and the project of the *Principia*

The argument for absolute time that I have presented thusfar (as a "push" from astronomy) is that, since it is known from astronomy that the most regular relative motions we know of are not in fact regular, time must be something distinct from regular motions. Of course, this does not prove that there are no relative motions that constitute a perfect clock. Rather, it is an empirical argument for the claim that in fact time turns out to be distinct from relative motions of material bodies. And therefore, as such, it is open to empirical refutation, by the finding of a material system that constitutes a perfect clock.

The argument for absolute time is strengthened when we see what work it does in the *Principia*. The end goal of the *Principia* is to establish the "system of the world": that is, to decide between the traditional geocentric, the Tychonic geocentric, and the heliocentric systems by establishing the true motions of the bodies in our planetary system.[11] Successful completion of the project of the *Principia* requires true motion: without true motion, there is no determinate answer to the question of the system of the world. The scholium to the definitions argues that true motion must be absolute motion. Thus, insofar as true motion is necessary for the project, we also need absolute motion. But we cannot have absolute motion with relative time, since the resulting motion would then be dependent on the material bodies constituting the relative time. Therefore, successful completion of the project of the *Principia* requires that time must be absolute.

The argument from the *Principia* for true time proceeds similarly. Successful completion of the project of the *Principia* requires true motion, and true motion in turn requires true time: there must be a unique time parameter proper to the system of the world, for if there is not, then a second "time" might give different conclusions concerning the motions and forces, and therefore concerning the system of the world.

True motion is necessary for successful execution of the project of the *Principia*, but it is a contingent matter whether any such true motions exist: it might turn out that there are no true motions and thus there is no answer to the problem of the system of the world. Through their connections to the problem of true motion, the questions of whether time is absolute and/or true become subject to empirical investigation. (Notice, however, that failure to determine true motions need not undermine the postulation of absolute and/or true time. For example, one might interpret Galilean relativity as

[11] In the end, of course, Newton replaces all of these with a system in which none of these bodies remains at rest at the center of the system. Nevertheless, in doing so he establishes the true motions of these bodies.

indicating that true time is necessary but not sufficient for true motion, since there we have true time, and absolute (i.e. not relative) motion, but seem not to have true (i.e. unique) motion.[12])

There is much more to be said here concerning the execution of the project in the details of the *Principia*, in the uses of time that Newton makes in his mathematical arguments, his search for empirical clocks,[13] and the interplay between these and his construction of absolute and true time. It is by understanding these details and their relationship to the empirical successes and failures of the *Principia* that we will find out the extent to which time turns out to be absolute and/or true. One thing is for sure, however: these aspects of time (whether or not it is absolute and true), and of the philosophy of time, have become empirical rather than metaphysical questions. The distinction I have in mind here is the following. Prior to Newton, such questions as whether time is relative (depending on the actual motions of bodies) or absolute (independent of these motions), and as whether there is one time or many, were questions that could be tackled independently of the details of empirical enquiry. In the wake of the *Principia*, this is no longer the case: any legitimate exploration of these questions must take into account the kind of detailed empirical enquiry pursued in the *Principia*. Newton provided empirical purchase on metaphysical questions concerning the nature of time, such that settling these questions depends on the details of empirical enquiry. It is in this sense that he transformed those metaphysical questions into empirical ones.

5. Mathematical time

5.1 Time as a quantity

Newton's time is not only absolute and true, it is also mathematical. Whether or not time is mathematical is independent of whether time is either absolute or true, and needs to be addressed as such.

Newton introduces his discussion of time, space, place and motion in the scholium by saying that "it is useful to distinguish these *quantities* into absolute and relative, true and apparent, mathematical and common" (Cohen and Whitman, 1999, p. 408; my emphasis added). Thus, each is referred to as a *quantity*. This means that associated with each is a *measure*, be it ontological (it is in

[12] For more on this see section 7, below.

[13] It would be especially interesting to look at Book II in this regard, where the methodology of the *Principia* runs into difficulties.

itself a quantity), definitional (concerning the linguistic behavior of the term, including within mathematical expressions), conceptual (it stands in certain relations to other quantities such that they are thereby a measure of the original quantity), or epistemological (we can measure that quantity, operationally, by specified means).

Absolute, true, and mathematical time, Newton writes, is by another name called duration. This is a clear statement that the feature of time we are concerned with explicitly here is duration (i.e. temporal intervals), and not simultaneity.[14] The passage reads as follows (Cohen and Whitman, 1999, p. 408):

> Absolute, true, and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly and by another name is called duration. Relative, apparent, and common time is any sensible and external measure (precise or imprecise) of duration by means of motion; such a measure ... is commonly used instead of true time.

Newton has already stated that time is a quantity. The qualifier "mathematical" here makes precise one respect in which time is a quantity: time, in itself, is metrical.[15] This can be taken as either an ontological claim, or as a definitional claim if you prefer to eschew ontology; either way, time is characterized as metrical in and of itself. To see what this means and why it is important, we first need to see how it could be that time in and of itself might *not* be metrical. Material clocks provide a temporal measure, ticking off intervals of time. If time *just is* the ticking of material clocks, then time is itself metrical. If, however, time is not to be *identified* with the ticking of material clocks, then time *in and of itself* could lack the necessary structure for any one interval of time to be determinately longer or shorter than another: time could be topological, rather than metrical, for example. If this were the case, then material clocks could be a means of *adding* structure (metrical structure) to the underlying topological

[14] I think it is dangerous to separate duration and simultaneity when discussing Newton's philosophy of time, as I will return to below (see section 6.6), but for clarity it is helpful to make this distinction at this stage of my argument.

[15] I mean this in the standard sense of a metric space, where between any two elements there is a determinate distance.

temporal structure, but time itself would not be metrical.[16] According to Newton, however, duration *is* in and of itself metrical. This is one aspect of what Newton means by saying that time is mathematical.

5.2 Mathematical time: an epistemic problem

It is helpful, I think, to understand why Newton needs to say explicitly that time itself is mathematical. The reason is as follows. Duration is measured by us by means of motion: the repeated circling of the Earth by the Sun, for example, measuring out days. But, according to Newton, any such "sensible and external measure" is to be distinguished from time "in and of itself". Since time is absolute and true, not relative and apparent, this means that *our measures* of duration are silent on whether time itself is metrical: there is a gap between our measures of time and "time itself", and so Newton must state explicitly that time itself is mathematical (i.e. has a measure, or is capable of receiving a measure).

In order to see this more clearly, it is instructive to consider the difference between Newton's treatment of spatial interval and his treatment of duration. Spatial intervals are measured by rulers; rulers are bodies, and according to Newton place is a part of space which body fills. A body of unit length by definition fills a region of space of unit length. There is no distinction between the metrical characteristics of bodies, as occupiers of space, and the metrical characteristics of the parts of space that they occupy. All rulers are, in this sense, perfect rulers: no question arises as to whether a unit ruler measures a unit interval of space, and indeed whether that unit ruler at one location and at one time measures a unit interval of space when moved to another spatial location and/or at another time.[17]

By contrast, not all clocks (indeed perhaps no clocks) are in an analogous sense perfect clocks. Newton is very alert to the question of whether a unit tick of a clock at one time measures a unit of duration at another time: it is a live possibility for Newton that the length of time between any two ticks of a clock may not be equal. For Newton, there is a gap between duration and our measure of duration, and it's one that does not arise for length and our measure of length. This is why Newton need not

[16] Note also that relative time need not be metrical: it might be identified with qualitative, non-metrical change rather than with the ticking of material clocks. Whether or not time is mathematical is logically independent of whether it is absolute (and indeed of whether it is true).

[17] Treated as an isolated system, any ruler is a perfect ruler in the sense intended here. While a non-isolated ruler may, for example, undergo thermal expansion, and thereby occupy more than one unit of space, that is not the issue here. On the other hand, treated as isolated systems, clocks need not be perfect clocks, as explained in what follows.

specify explicitly that space is metrical, whereas he *must* – and does – do so for time. Moreover, this marks a difference as compared to mass, as a measure of matter, and momentum, as a meaure of motion, for example, where Newton is able to formulate quantities that do not suffer from the same kind of epistemological gap. In the case of time, it seems that no amount of conceptual work will remove the gap. In sum, the gap between duration and our measure of duration presents us with an epistemic problem, in that we cannot measure duration directly, but only indirectly by means of motion. This gap leaves open the question of whether time, in itself, is metrical, and Newton answers this question in the affirmative: time is mathematical.

The epistemic gap leaves open the relationship between the metric of time and the behavior of material clocks. To address this, Newton asserts that time flows equably: the metric of time is not capricious in relation to physical processes. The evidence for this is the practical success achieved by astronomers with the equation of time, and by Huygens with the pendulum clock. Nevertheless, there may be no perfectly equable motion to be found in the material world, since there may be no material clock that ticks precisely in accordance with the metric of time. Following Arthur (1995), we should regard Newton's assertion that time is mathematical as asserting that it flows equably, as well as that it is metrical. For more on the centrality of equable flow for Newton's conception of time, see Arthur (1995).

In asserting that time is mathematical (i.e., that it is metrical, and that it flows equably), Newton attributes to time characteristics necessary for his project to succeed.

4.3 Mathematical time and the project of the *Principia*

As we have seen, Newton had very good reason to maintain that time, as appropriate for astronomy and discovering the system of the world, is absolute, true and mathematical, as distinct from relative, apparent and common: each of these distinctions is independently necessary for characterizing time as used in astronomical practice and it is therefore likely to be what Newton will need in his discussion of the system of the world. Thus, his characterization of time as absolute, true and mathematical makes perfect sense in relation to the ultimate goal of his project.[18] To strengthen our case, what we need to

[18] I have argued that Newton had good reason to believe that no material system is a perfect clock, and that time should therefore be considered absolute and not relative. My focus was on astronomical clocks, but Schliesser (2013) reminds us of the importance of seventeenth century advances in pendulum clocks, and their connections with time-keeping in astronomy. Newton was, of course, deeply immersed in this work too, especially through the

do is to look at the details of the *Principia*, the manner in which Newton carried out his project, and the work that "time" does. This would enable us to see the extent to which the execution of the project of the *Principia* demands that time be absolute, true, and mathematical. At this stage, I can offer only the preliminary sketch of an argument for mathematical time as necessary to the project of the *Principia*. The sketch is as follows (four premises and a conclusion):

(1) Newton's proposed method for solving the problem of the world is to systematically correlate forces with true motions.

Newton's ultimate goal, as we have said, is to establish the system of the world, geocentrism or heliocentrism, and indeed thereby refute relativism. This means establishing the true motions of the astronomical bodies: can the Sun, Earth and planets be proven to execute true motions (in the sense that each can be shown to have a specific and determinate motion), such that a decision can be made between the Copernican and Tychonic systems? Newton set out to solve this problem by means of forces, and for this strategy to succeed forces must be systematically related to true motions.

As early as 'De Gravitatione', the seeds of Newton's method are present. In his criticisms of Descartes he is quick to point out (Newton, 2004, p. 15) that Descartes's definition of true motion does not lead to a correlation between the presence/absence of motion in the planets and the presence/absence of their "tendency to recede" from the Sun. Newton takes this to be a serious problem with Descartes's definition of motion, and it is a theme he returns to several times in the manuscript. By the time of the *Principia*, the method is of course explicit, beginning with the definitions of forces at the very beginning of the book. The scholium to the definitions ends with the following statement (Cohen and Whitman, 1999, p. 415):

> But in what follows, a fuller explanation with be given of how to determine true motions from their causes, effects, and apparent differences, and, conversely, of how to determine from motions, whether true or apparent, their causes and effects. For this was the purpose for which I composed the following treatise.

---

tight interconnections between the study of the pendulum and of gravitation, and he was intimately engaged in studying the precise limitations and approximations involved in pendulum clocks. This work serves to reinforce the need for a distinction between the material clock and the absolute time that it approximates. See Schliesser's paper for much greater contextualization of Newton's treatment of time than I have given here.

In sum, Newton's strategy for solving the problem of the system of the world is to systematically correlate the presence/absence of forces with the true motions.

(2) Moreover, this systematic correlation is to be a quantified correlation (witness the upshot in Newton's second law of motion), which requires a *mathematical* treatment of forces in relation to true motion.

(3) This, in turn, requires (in the mid 1600s) a *geometrical* treatment of the correlation.

(4) The desired quantitative geometrical correlations between forces and true motions relies upon time being metrical.

In his laws and the early propositions of the *Principia*, Newton relies from the outset on *equal intervals of time*.[19, 20] Law 1, of course, requires equal intervals of time for the distinction between uniform and non-uniform motion, and this is at the heart of the distinction between the presence and absence of forces. Consider also Corollary 1, which concerns the composition of forces. It is crucial for the proof of Corollary 1 that in the geometrical diagram each path represented by a line in the diagram be traversed (hypothetically) in an equal unit of time. The next crucial place to look is Book 1, Proposition 1, theorem 1, in which equal intervals of time are represented in the diagram. In case all this seems trivial it is perhaps worth pointing out that the problem of how to bring motion and forces together under a single treatment was unsolved at the time, and this includes the problem of how to represent forces geometrically. Geometric treatments of motion, in which a line can be used to represent a motion (i.e. unit distances *and unit times* are both represented in the diagram) were available, as was the idea that the shape of the trajectory is related to gravity in projectile motion, for example, but (to my knowledge) there was no systematic way of incorporating quantity of force as correlated to change of quantity of motion into a geometric treatment. What we have in Galileo's treatment of a horizontal projectile, for example, is that unit distances in the horizontal direction correspond to unit times, and this is what allows acceleration due to gravity to be calculated. However, all of this goes beyond the work that I have been able to do so far (either in the secondary literature or

[19] Newton's work on the motions of bodies goes back decades, and even in his earliest manuscripts he appeals to equal intervals of time.

[20] See, for example, Maudlin (2012, p. 10-11) on the metric of time as required by Newton's first law.

in working through the relevant aspects of the *Principia* myself). To the extent that (4) can be established by detailed consideration of the *Principia*, the conclusion (5) follows.

(5) Hence the conclusion: it is essential to the project of the *Principia* that time is mathematical.

Further evidence for the importance of mathematical time to the project of the *Principia* comes from Newton's mathematical techniques, as Arthur (1995) argues. Arthur argues persuasively that equable flow is of central importance to the temporal limiting procedure in Newton's method of fluxions, that it is intimately tied to his conception of time in the *Principia*, and that these aspects of the method can be seen at work in the proofs of the *Principia*. Again, I leave for future work the further exploration of the roles of mathematical time in the details of the *Principia*.

In sum, Newton's assertion that time is mathematical is deliberate: it makes a substantive claim about the nature of time, it draws our attention to an epistemic problem associated with time but not with space in Newton's *Principia*, and it is intimately tied to the details of the *Principia*, i.e. to the tools Newton is able to develop by which he is able to solve the problem of the system of the world.

6. Newton's philosophy of time

My thesis is this: In his *Principia*, Newton offers us a radically transformative philosophy of time, in which traditionally metaphysical questions are transformed into empirical questions, and in which the empirical stringencies of his project demand conceptual distinctions and clarifications beyond traditional philosophy of time. The shift I have in mind is from questions appropriately tackled independently of the details of empirical enquiry to questions whose resolution depends intimately on such details. For example, the question of whether time is independent of motion is a long-standing metaphysical question, but in light of the *Principia* this issue of whether time is absolute or relative becomes one whose answer depends on the details of, and outcomes of, empirical enquiry. Moreover, additional distinctions are brought out explicitly by the demands of the project of the *Principia*, such as those between true and apparent time, and mathematical versus common time. These distinctions enrich and clarify the conceptual tools with which we are working.

Central to supporting this thesis is my claim that the terms "absolute", "true" and "mathematical" as Newton uses them in the scholium to the definitions mark distinctions *internal* to the empirical project of the *Principia*, supported by arguments from within the *Principia*. This is not to deny that Newton had *other* arguments (for absolute time for example), but I reject the claim that in order to understand these terms as they appear in the *Principia* one either needs to or should draw on resources from outside the *Principia*.[21] In this, I disagree with Gorham (2012), Huggett (2012) and Schliesser (2013) over the relationship of the terms "absolute" and "true" to the project of the *Principia* and to Newton's wider metaphysical and theological commitments.[22] I reject the suggestion, made in different ways in Gorham (2012), Huggett (2012), Schliesser (2013), that Newton is importing metaphysical claims (in the sense of claims that are made prior to and independently of specific empirical results) into the *Principia* in the scholium to the definitions, through his terminology of "absolute, true and mathematical". I also maintain that his arguments for time as absolute, true, and mathematical as found within the *Principia*, are *sufficient* for the needs of the *Principia*. The upshot is, I argue, a transformation of metaphysical questions concerning time into empirical questions, in the above sense.

This may also seem to be in conflict with the claims of McGuire (1995) concerning Newton's philosophy of time, but it isn't. We need to distinguish two different questions. One question is how to understand Newton's views on space and time, in general, inclusive of the statements about space and time that Newton makes in the *Principia*. For this, understanding Newton's broader theological concerns, and the philosophical and theological context in which he was working, are essential, as McGuire has shown. With this in place, a different question is how to understand the argumentative structure of the *Principia* itself, and the extent to which that argumentation relies on resources and commitments not explicitly stated in the *Principia*. It is here that I part ways with Gorham and Schliesser concerning Newton's philosophy of time: I claim that the argument of the *Principia*, and the account of time therein, is complete in itself and, moreover, only when understood as such do we see how radically transformative it truly is.

6.1 Newton's arguments for absolute time

[21] I do not wish to be misunderstood. I am a long-time proponent of the view that in order to understand Newton as a philosopher we must look well beyond the *Principia*, and that we must situate the *Principia* within the context of Newton's wider intellectual endeavors in order to understand its significance for Newton. However, we should take care that this richer understanding does not obscure the arguments contained within the text of the *Principia* itself.

[22] The disagreements that I have with Gorham, Huggett and Schliesser are small compared to the overall content of their papers, from which I learned much. As so often happens, the many points of agreement and enlightenment I pass over in silence, to focus on what we may learn from a point on which we disagree.

Gorham (2012) situates Newton's philosophy of time within a tradition of metaphysical arguments for and against the possibility of empty space, in which conclusions about time are drawn by analogy with conclusions about space. Gorham points out that Newton does not argue for absolute time using the kind of metaphysical arguments traditionally offered in support of absolute space, claiming that in this Newton is following in the above-mentioned metaphysical tradition. I think that there is another way to understand the absence of traditional metaphysical arguments for absolute time in Newton's philosophy of time, and this is that he is transforming the questions into empirical questions so that a different type of argumentation is required. I see a rich and radical philosophy of time in Newton's work.

The theme developed in Gorham's paper is that space was given primary treatment by many early modern philosophers, and that time was treated secondarily by analogy with space, in large part due to the close connection between space and body in Aristotelian philosophy. Gorham claims that (2012, p. 26):

> The extrication of space from body depended on a collection of theological and metaphysical considerations that were ill suited to time. As a result, anti-Aristotelian philosophers initially retained the traditional motion-dependent view of time. But the success of spatial absolutism, given the tradition of space-time parallelism, encouraged seventeenth-century philosophers to freely extend attributes of absolute space to time with little independent rationale. This largely analogical and parasitic foundation for absolute time is apparent, I will argue, even in Newton's account.

I disagree with this characterization of Newton's philosophy of time. To see why, it is helpful to backtrack from the *Principia* to consider first what Newton says about time in 'De Gravitatione'.

In 'De Grav', Newton diagnoses the problems with Descartes's definition of true motion as arising from his identification of body with space. His arguments are directed at undermining this identification, and therefore the natural focus is on space, rather than on time. In fact, the way that he uses the analogy with time is not to say "and so it goes for time", but to bolster his arguments concerning space by drawing attention to analogous claims about time. There are two examples of this, in between which a third use of time is made where the analogy concerns not space but God. The first example occurs in the passage concerning the immobility of space (the third characteristic of space that Newton discusses, see Newton, 2004, p. 25), when Newton says:

Moreover, the immobility of space will be best exemplified by duration. For just as the parts of duration are individuated by their order, so that (for example) if yesterday could change places with today and become the later of the two, it would lose its individuality and would no longer be yesterday, but today; so the parts of space are individuated by their positions, so that if any two could change their positions, they would change their individuality at the same time and each would be converted numerically into the other.

Here, Newton is using the example of time to help explain his thesis concerning space. It is not the case that he is extending a thesis concerning space, independently argued for, to a thesis about time.

Thus, as Schliesser says (2013, p. 93), the analogy works not from space to time but in the other direction: Newton takes his claim about temporal ordering as basic. However, Schliesser goes on (p. 94): "The lack of argument for either the existence claim or the nature of time's characteristics is, thus, all the more puzzling...". I disagree: in the context of 'De Grav', where Newton's target was the identification of space and body as an obstacle to an adequate theory of motion, the absence of arguments concerning time doesn't seem puzzling at all. Moreover, as we will see below, it is not puzzling in the context of the *Principia* either.

The next place where time occurs in 'De Grav' is once again as a useful analogy, this time in explaining the way in which God is present in space.[23] With respect to time, the claim he is making use of here (in explaining how God is present spatially) is that a moment of duration should not be thought of as having spatial parts, despite being spatially extended. Indeed, a moment of duration is extended "throughout all the heavens" or, as he says in the General Scholium, "every [temporally] indivisible moment of Duration is everywhere". So Newton *is* committed to this claim about absolute time (that there is only one such time, common to all spatial regions of the universe), but he is not arguing for it

[23] Newton says: "Moreover, lest anyone should for this reason imagine God to be like a body, extended and made of divisible parts, it should be known that spaces themselves are not actually divisible, and furthermore, that any being has a manner proper to itself of being present in spaces. For thus the relation of duration to space is very different from that of body to space. For we do not ascribe various durations to the different parts of space, but say that all endure simultaneously. The moment of duration is the same at Rome and at London, or the earth and on the stars, and throughout all the heavens. And just as we understand any moment of duration to be diffused throughout all spaes, according to its kind, without any concept of its parts, so it is no more contradictory that mind also, according to its kind, can be diffused through space without any concept of its parts."

here. Newton's claim is that just because God is present spatially, this does not mean he is present in the same way as bodies are, and therefore that he is spatially divisible; rather, he is spatially indivisible despite being spatially extended, and this is something we are already familiar with from the case of time.

The second use of time in analogy with space is in the paragraph concerning the sixth characteristic of space – that is it eternal in duration and immutable in nature. Here, time is mentioned in passing in support of the claim that "although we can possibly imagine that there is nothing in space, yet we cannot think that space does not exist". Newton supports this first with an analogy with time ("just as we cannot think that there is no duration, even though it would be possible to suppose that nothing endures") and then with the traditional arguments that Gorham describes. I see nothing here that indicates that Newton is in any way arguing for these characteristics of time, rather than presupposing them and using them to support his arguments concerning space.

I therefore disagree with Gorham's claim that in 'De Grav' Newton's writing "conforms to the well-established practice of treating space and time in tandem, with features of the former established by powerful metaphysical and empirical arguments, extended, with little or no argument, to the latter." I do not think this is the right way to read how Newton is thinking about time. Gorham claims that the same approach is to be found in the *Principia*, and I wish to challenge this view also.

A first clue that something different is going on is simple but, I think, important: absolute time is introduced *first* in the *Principia*, prior to absolute space; thus, not only is it *not* introduced by analogy with absolute space, it precedes absolute space in the order of Newton's presentation. In a text as carefully structured as the *Principia*, it would be unwise to assume that this is a mistake concerning the conceptual ordering of Newton's project.

The tradition that Gorham describes includes Patrizi for whom, according to Gorham (2012, p. 6), "time is the measure of motion; therefore motion necessarily precedes time in order to be measured by it." Newton reverses this position: motion is an external measure (more or less precise) of time. This is in agreement with Descartes. And he qualifies it: motion is an *external* measure, i.e. it is not to be identified with the intrinsic metric of time itself. This is in agreement with Gassendi.

The traditional arguments concerning the possibility of empty space are entirely missing from the *Principia*, as are the arguments found in 'De Grav' designed to distinguish body from space (contra the Cartesians). Therefore, whatever Newton's arguments for absolute space and time may be in the *Principia*, he is not arguing for absolute time on the basis of an analogy with absolute space, for which independent arguments have been given.

Gorham's main evidence that Newton is arguing for absolute time on the basis of arguments that much more strongly support absolute space comes from his reading of the bucket and globes arguments. The purpose of the bucket experiment is to show that absolute motion is distinguished from relative motion by its effects. The backdrop to this argument is the Cartesian thesis that the true motion of a body is a specific relative motion (i.e. motion relative to the immediately surrounding bodies themselves considered to be at rest), and the bucket experiment provides support for the claim that true motion is absolute rather than relative. For Newton, absolute motion is motion with respect to absolute space and absolute time, and one might think that the bucket experiment therefore lends equal support to both absolute space and absolute time. Gorham argues not. As he reads this argument (2012, p. 38),

> although this way of distinguishing absolute and relative motion seems to require a space, or at least a reference-frame, independent of the bucket-water system, regular succession or 'equal times', the temporal component of absolute motion, can be identified with the unchanging rotation of the bucket itself, without adverting to a time that 'flows equably without relation to anything external'. In Aristotelian terms, there is no necessity to posit time apart from the measure of motion.

He goes on:

> Granted, in Newton's thought experiment the motion of the bucket is not perfectly regular: the degree of concavity of the water increases as the rope unwinds, indicating that its absolute rotational velocity (change of absolute space per unit of time) also increases. But perfectly regular clocks are available in principle.

Specifically, Newton offers us the rotating globes: constant tension implies constant rotation.

But I think there is no such asymmetry between space and time in this way. Just as perfectly regular clocks are available in principle, thereby making possible a non-absolute (i.e. relative) treatment of time, so perfectly resting bodies are available in principle, thereby making possible a non-absolute (i.e. relative) constitution of the resting frame. Newton has already called into doubt whether there are any bodies truly at rest, just has he has called into doubt whether there are any bodies that constitute a perfect clock. The purpose of the bucket experiment is not to rule out these possibilities and thereby establish absolute space and absolute time, but to show that if we adopt absolute space and time, then our definition of true motion (i.e. as absolute motion) is consistent with our observations, and specifically with the observable effects of true motion.

While Schliesser (2013) claims that in both "De Grav" and the *Principia*, time is treated as more basic than space, he nevertheless (p. 92) endorses Gorham's position that

> While Newton offers considerable argument for the existence of, say, absolute space, he offers ... no argument for the existence of true time (or "duration"), which, "in and of itself and of its own nature, without reference to anything external, flows uniformly."

I would like to look at things a little differently. Consider first 'De Grav'. It is true that we find no arguments concerning absolute time analogous to those found in 'De Grav' concerning absolute space. But this is not surprising: the arguments in 'De Grav' for absolute space are arguments intended to distinguish space from body in order to remove this obstacle to the development of a successful theory of matter in motion. Time plays no role in this particular obstacle, and absolute time is simply assumed in 'De Grav'. So now let's turn our attention to the *Principia*, and consider the arguments that Newton makes there.

In the *Principia* the arguments for absolute space and absolute time take a very different form from the traditional metaphysical arguments. As is familiar, the argument for absolute motion takes the following form: (1) relative motion is inadequate for the purposes of a natural philosophy founded on matter in motion because relative motions do not correlate appropriately with the presence/absence of forces; (2) absolute motions do correlate appropriately with the presence/absence of forces; (3) therefore we should attempt our natural philosophical project using absolute motion. The key factor here is whether the definition of the concept (in this case motion) is adequate or inadequate for the work that is required of it in the theory. The same form of argument is offered for absolute time: in his discussion of the equation of time, Newton is arguing that relative time is inadequate for the purposes of his project, and that therefore absolute time is what we should use instead.

In my opinion, it is not surprising that we find none of the traditional metaphysical arguments concerning time and space in the *Principia* (setting aside the General Scholium for a moment): Newton is changing the type of argument that is appropriate for establishing the conclusions that we are interested in. The issue of whether or not time is relative, for example, is not to be settled prior to and independently of specific empirical results; rather, it is to be settled by the process of empirical enquiry associated with a theory of matter in motion.

This is consistent with a theme in recent Newton scholarship that, during his lifetime and the evolution of his methods for doing natural philosophy, Newton gradually transformed traditionally metaphysical questions into empirical questions. For example, in their paper on Newton's conceptions of matter, Biener and Smeenk (2012) argue that two conceptions of matter can be found in Newton's work from early on, a geometrical conception (in which the quantity of matter associated with a body is its geometrical volume, as argued for in Descartes's metaphysics) and a dynamical conception (in which the quantity of matter associated with a body is measured through a body's response to impressed force, as is required by the project of the *Principia*). The geometrical view is argued for on the basis of very general empirical considerations, prior to the specifics of physics, whereas the dynamical view depends for its elaboration on the empirical details of the project of the *Principia*. Biener and Smeenk argue that the dynamical conception began to take precedence for Newton once a conflict between the two emerged. In Brading (2012), I argue that Newton solves a problem in Descartes's account of body by incorporating the laws that apply to bodies into the account of what bodies are, thereby making basic metaphysical questions concerning the nature of body subject to empirical investigation.

The underlying methodology that produces this result is the demand that our concepts of matter, body, time, space and motion be adequate for the project of founding natural philosophy on a theory of matter, motion, and laws of nature, in accordance with the basic framework set out by Descartes, and using the best tools of the day (including the work of Galileo).

We can see this methodology at work already in Newton's earliest considerations of time. As Palmerino (2013) makes clear, Newton began as an atomist about time but became a continuity theorist due to the needs of a theory of motion.[24] This methodology continues through into the *Principia*, where Newton is using the demands of an adequate theory of motion as a tool for developing his philosophy of time. Newton argues that absolute (i.e. not relative) time is what is needed for the project of the *Principia*. Thus, in the wake of the *Principia*, whether or not time is relative is no longer a metaphysical question (in the sense that it can be addressed prior to and independently of the details of empirical enquiry), but an empirical one; whether or not time is relative can now be answered only through pursuit of a project such as that of the *Principia*.

[24] See Palmerino (2013) for a discussion of the evolving relationship between Newton's atomism concerning space, time and matter.

6.2 The empirical status of absolute time

In his paper on Newton's philosophy of time, Schliesser (2013) draws our attention to the limits of absolute time as an empirical concept. According to Schliesser's analysis, absolute time is approximated by a "shared temporal frame" that is constructed by us by empirical means, using the motions of the planets with respect to the fixed stars etc., and the empirical reach of this "temporal frame" is as far as those planets and not beyond. That is to say, the abstract theoretical time of the equation of time is constructed empirically using the motions of the Sun, the planets, and their moons, relative to the background of the fixed stars (i.e. the stars are assumed to remain fixed in relation to one another), and the upshot is a shared time parameter for the system, i.e. the solar system including all and only those planets and moons so far discovered, *and not beyond*. Motions of bodies outside the system (if any such were observed) could also be evaluated as regular or irregular with respect to this time parameter but, as Schliesser emphasizes, within the context of the *Principia* it remains an open empirical question whether the time parameter constructed using observations of our solar system will be the most appropriate standard of regularity for either a larger system of which the solar system is merely a part, or for some other system isolated from the solar system. In other words, it remains an open empirical question whether the absolute time appropriate to the solar system extends to other material systems. I think this is exactly right.

Schliesser places a lot of weight on this distinction, arguing that absolute time should be understood as having the above empirical status in the *Principia*, and claiming (1) that the extension of this absolute time "from infinity to infinity" is what Newton means by "true time" in the scholium, and (2) that this "true time" is a metaphysical commitment going beyond the demands of the *Principia*. I disagree. While I agree with Schliesser that, given the project of the *Principia* (to determine the system of the world, i.e. our planetary system), Newton does not need his absolute, true and mathematical time to extend from infinity to infinity, I do not think that this is marked by the distinction between absolute and true. Indeed, notice that in the scholium Newton does *not* make the positive assertion that absolute, true and mathematical time is eternal in duration, nor does he assert that space is infinite, and nor does he assert that each moment of time extends from infinity to infinity. In this part of the text, where he is setting out what is needed for the project of the *Principia*, no such positive claims are necessary, and Newton does not make them. That said, Newton has just as good reasons to think that his absolute (and true and mathematical) time extends to the physics of the distant stars and to the planetary systems around distant stars (if any such exist) as he does to think that the laws of motion and the law of universal gravitation apply to such bodies. In applying Rule 3 to bodies beyond the solar system, we would certainly be wise to be tentative given the flimsiness (even non-existence) of our empirical evidence, but there is nothing in Newton's writings to indicate a sharp cut-off at the outer edges of the solar system such that we should not consider distant stars to be bodies. On the contrary, the possibility of other worlds around other Suns, governed by the same laws, is very much part of Newton's thinking. For example, in the manuscript "Cosmography" (see Hall and Hall, 1962, pp. 374-7), Newton asserts that the fixed stars are bodies just like our Sun: they are formed into spheres by their own gravity, and since they are bodies they are, by definition, subject to the laws of motion.[25]

The connection between this extension of his principles beyond the reach of evidence and his postulation of space as eternal and infinite when he's talking about God is clear in paragraph three of a draft of the General Scholium (Hall and Hall, 1962, p. 359): "And if the fixed stars be the centres of similar systems, all these are under the same one dominion. This Being rules all things not as the soul of the world (for he has no body)... He is Eternal and infinite. He endures for ever and is everywhere present: for what is never and nowhere is nothing."

I turn to the theological status of absolute time below. For my purposes here, and with the above considerations in mind (Newton's care not to over-reach empirically when setting out his accounts of time and space in the scholium, and his epistemological methodology as described in his Rules of Reasoning), I see no reason to think that Newton's account of time in the scholium over-reaches itself empirically. Within the project of the *Principia*, whether time is absolute, and how far such an absolute time extends spatially, are empirical questions. Similarly, as I argue below, whether or not time is *true* becomes an empirical question within the context of the *Principia* (see section 6.4).

---

[25] Newton writes (Hall and Hall, 1962, pp. 374-7): "The Universe consists of three sorts of great bodies, Fixed Stars, Planets, & Comets, & all these have a gravitating power tending towards them by which their parts fall down to each of them after the same manner as stones & other parts of the Earth do here towards the earth & by means of this gravity it is that they are all sphericall. ... The fixt Stars are very great round bodies shining strongly with their own heat and scattered at very great distances from one another throughout the whole heavens. ... The fixt stars are bodies subject to various changes. For there are seen frequently spots upon the Sun ... and these spots are generated & corrupted like scum upon a pot ... And to the like mutations the fixt stars are subject: For some of them have grown brighter others darker, some have vanished others appeared anew & some have appeared & disappeared & appeared again by many vicissitudes." There is no question, in my mind, that for Newton the fixed stars are bodies falling within the laws and principles of the *Principia*.

6.3 The theological status of absolute time

Newton's claims that time is eternal (and space infinite) are no part of Newton's commitments in the scholium to the definitions. The only place that they appear in the *Principia* is in the General Scholium, added later. Indeed, the positive claims about the eternal duration of absolute time and the infinite extension of absolute space occur only within a theological context in Newton's writings. The argument goes like this:

1. God is omnipotent and omniscient.
2. God cannot act where he is not.
3. From (1) and (2): Therefore, God is omnipresent (i.e. present at all times and in all places).
4. God is present in space and time, but he is not space and time.
5. A creative act requires a pre-existing creator (not necessarily in a temporal sense).
6. If, when God created the material world, He went from *not* being spatially and temporally present to *being* spatially and temporally present, He would undergo change in carrying out His creative act.
7. God is unchanging.
8. From (4), (5) and (6): Therefore, God did not create his own omnipresence.
9. God is without limit.
10. From (3) and (8): Therefore God's omnipresence is without limit.
11. From (3) and (9): Therefore space and time are without limit: they are infinite and eternal
12. From (3) and (7): Therefore, all times and all places follow from the existence of God.
13. From (11) and (10): Therefore infinite space and eternal duration follow from the existence of God.

In arriving at (12) we enter into the discussion of space and time as emanative effects of God, but we will not pursue the details of this here:[26] for our purposes, it is sufficient to see why space and time must be related to God by emanation rather than by means of a creative act. The reason is that, for Newton,

[26] See Slowik, 2013, and references therein.

God created the material world and is present in that world, and so, in order to avoid the conclusion that in the act of creating the material world He Himself underwent change, space and time themselves must be uncreated (steps (5)-(8)). Thus, they must be absolute, i.e. not relative to material bodies. This is Newton's theological argument that space and time must be absolute.

The arguments of the *Principia* for absolute time (and absolute space) are independent of this argument, and are empirical not theological. Moreover, steps (9)-(11) tell us that this absolute space must be infinite, and this absolute time must be eternal, but as positive assertions these claims are not part of the project of the *Principia*.[27]

There is consistency between Newton's claims about absolute space and time in the *Principia*, on the one hand, and his theological position on the other, but the claims in the *Principia* stand on their own and do not require any theological underpinning.

If we want to understand the *status* of space and time in Newton's overall philosophy, then we must look outside the *Principia*, as McGuire (1995) argues, and here Newton's theology is of crucial importance. But as regards the project of the *Principia* itself, Newton is extremely precise, and careful, in his use of the terms absolute space and time.

6.4 The empirical status of true time

Schliesser (2013) argues that true time (understood as an extension of absolute time from the "local temporal frame" of the solar system to spatial infinity) is a metaphysical commitment going beyond the demands of the *Principia*, rooted in Newton's rational theology. I have proposed an alternative way of understanding the terminology of absolute and true time, and on my approach not only does the question of whether time is absolute become an empirical matter, but also whether time is true.

True time for Newton, I suggested, is time that is unique and proper to the system of the world. The "system of the world" for Newton is the solar system, but the empirical status of true time (on the view I advocate) is independent of whether the "system of the world" is our solar system or some other system or the material universe as a whole. Rather, the issue is whether, for the system of interest, there is any such thing as true time. As an empirical question, this becomes: can we construct a satisfactory physical theory for this system using a single time parameter?

[27] The possibility of bringing the infinity of space and the duration of time under empirical investigation arises only with the advent of General Relativity.

There are at least two ways in which this could fail. One possibility is that we could get close but not quite there, so that we are left with irregularities that cannot be accounted for either by modifying the time parameter or in terms of forces: we are not able to come up with a satisfactory physical theory using a single time parameter, and so we are unable to supply this empirical warrant for the existence of a true time associated with that system. A second possibility concerns a specific way in which this might happen: subsystems dominated by different forces might tick irregularly with respect to one another with no common underlying metric. For example, there is no guarantee a priori that an atomic clock, governed primarily by the laws of quantum mechanics, will tick regularly with respect to a pendulum, whose rate of ticking is governed primarily by gravitation; the two could turn out to tick irregularly with respect to one another with no common underlying metric. There would then be no such thing as "true time" for any system in which both quantum mechanics and gravitation play a role. Specifically, were it to happen for the solar system, then there would be no such thing as true time for the system of the world.

Notice, however, that the true time of a system may be absolute or relative: it may be independent of the relations between the material bodies constituting the system in question, and therefore absolute, or it may depend on those material bodies and therefore be relative.

Schliesser claims that absolute time, in the sense of a time parameter for the solar system, is needed by Newton for his dynamics in order for Newton to "identify and assign accelerations to moving bodies in a consistent fashion", but that Newton's inclusion of something called "true time" turns out to be a metaphysical importation into the *Principia*. I think that Schliesser is right about the need for such a time parameter for the project of the *Principia*, but that this parameter must be both absolute (that is, not relative) and true (that is, unique and proper to the solar system) in order for it to serve Newton's purposes in his dynamics. As argued above (see section 4.3), the project of determining the system of the world requires that time be absolute and true.

6.5 The empirical status of mathematical time

In section 4.3, above, I offered a preliminary sketch of an argument in support of the claim that mathematical time is necessary for the project of the *Principia*. Insofar as this is right, the claim that time is intrinsically metrical becomes an empirical claim that can be investigated through pursuit of the project of the *Principia*. There are two important caveats that I want to make clear.

First, from the research I have managed to do so far, Newton's mathematical time seems to be highly under-explored. The details of the argument sketched in section 4.3 need to be made out, and only then will we be able to see the nature and extent of the dependence of the project of the *Principia* on the claim that time is mathematical.

Second, Newton's explicit claim that time is mathematical marks a difference in epistemic status between time and space, for Newton, or so I claim in section 4.3. Subsequent developments in philosophy of space and time provide us with the tools to probe this alleged difference, and this may also have significance for the status of Newton's claim that time is mathematical. Again, this is work that remains to be done.

6.6 Duration and simultaneity

In this paper I have focused on duration, and have excluded discussion of simultaneity. A complete account of Newton's philosophy of time would need to address both, and I am unable to do so here. In my discussion of Schliesser's (2013) "temporal frames", I restricted my attention to duration, and to the notion of a time parameter for a system. But Schliesser's "temporal frame" involves both duration and simultaneity. A "temporal frame" requires not just that distant clocks tick regularly with respect to one another, and not just that they agree about the rate at which physical processes take place, so that a unit of time on Earth is of the same duration as a unit of time on Mars. A "temporal frame" also requires that a moment of time spread through space be the very same moment of time on Earth as on Mars: it requires a time coordinate.

Schliesser (2013) includes both duration and simultaneity, and I think he is right to do so. Indeed, as noted above (see fn. 14), I think it is dangerous to separate duration from simultaneity when considering Newton's account of time. Schliesser (2013) begins his paper by describing two questions left by Galileo to his successors. One concerns the possibility of a pendulum which is a perfect clock. The second concerns the comparison of times at different locations: given a set of sufficiently similar pendulum clocks at various locations on Earth, how can noon at one location be connected to noon at another location so that astronomical observations "made at the same time" but at these different locations can be compared? In other words, how do we go from local mean solar time to global mean solar time: how do we operationalize distant simultaneity? Already at the time Newton was writing, observations of the moons of Jupiter indicated a finite light speed, and Newton continued throughout his life to consider the possibility of an ether theory of gravitation, so it is far from obvious that Newton was committed to instantaneous gravitational interactions. Also requiring further investigation is the question of whether a Newtonian "moment" of time possesses or lacks duration, and this depends in part upon our understanding of the relationship between the mathematical tools by which we carry out our physical reasoning and the physical claims that we are willing to make, specifically for the case of time (see Arthur, 1995, and Palmerino, 2013). In sum, at the time Newton was writing developments in the pendulum clock along with the demands of observational and mathematical astronomy were forcing conceptual development and clarification with respect to time, and a treatment integrating simultaneity and duration is required for a complete account of Newton's philosophy of time. My attention in this paper is restricted to duration, and there is much work to be done beyond the scope of this paper.

7. Absolute and true motion again

According to Huggett's (2012) proposal, "true motion" is a theoretical term integral to the project of the *Principia*, getting its meaning at least partially via implicit definition. Thus, for something to move truly *just is* (pace true rest) for it to move in accordance with the laws of motion.[28] Newton's concept of true motion therefore stands and falls relative to the success or failure of the project of the *Principia* in determining the true motions of bodies via the laws of motion. It is an empirical concept.

By contrast, absolute motion, according to Huggett, is defined independently of and antecedent to the laws of motion, as motion with respect to absolute space and absolute time (themselves similarly prior to the laws). Thus, the concepts of absolute space, time, and motion are conceptually prior to the project of the *Principia*, and answerable to different demands, perhaps the demands of Newton's metaphysical and/or theological enquiries. In this sense, absolute space, time and motion are not empirical concepts.

Huggett suggests that the arguments of the scholium are intended to show that true motion (assumed to exist, but yet to be defined by the laws of motion, since these occur later in the text) must be absolute and not relative. The empirical question with respect to absolute space, time and motion, is whether true motion (an empirical concept, in the sense of being implicitly defined via the laws) does in fact turn out to be absolute motion (a non-empirical concept, in the sense of being defined independently of the laws).

[28] Implicit definition doesn't get us all the way to the meaning of the term because Newton distinguishes between true rest and true motion, but since the laws are Galilean invariant they do not yield such a distinction and this must be added by hand.

I like a lot of what Huggett is doing in his paper, but I don't think this analysis is quite right. I agree completely with Huggett that the argument of the scholium is targeted at those who believe that there is such a thing as true motion, but who think that it is relative rather than absolute, and that the argument is intended to show that the true motion of a body is its absolute motion. However, I believe that Newton is using the term "true" in its familiar sense from the period, as unique and proper to the body, and "absolute" in contrast to the familiar sense from the period of "relative". Having shown that the true motion of a body must be absolute, rather than relative, the project of the *Principia* is to determine what the true (and therefore absolute) motions of bodies in fact are. In my opinion, it is *this* motion that is to be characterized implicitly by the laws: for something to move *just is* for it to move in accordance with the laws of motion.

The project of the *Principia* requires that this motion (as implicitly defined by the laws) turns out to be both true and absolute, or so Newton maintains. It must be true, because determining the system of the world, which is the purpose of the *Principia*, requires that there be true motions; and it must be absolute because, as the scholium shows, true motions are absolute motions. However, whether motion as characterized by the laws in fact turns out to be either true, or absolute, or both, is an empirical matter depending on the details of how the project of the *Principia* play out in practice.

Thus, on this approach, "true" and "absolute" have the same status with respect to the project of the *Principia*: they are introduced in the scholium via their contrasts (absolute in contrast to relative, true in contrast to apparent), because the project of the *Principia* requires motion that is absolute and true.

One advantage of the approach to the terminology that I am proposing for is that instead of true and absolute being treated differently for time as compared to motion, as they would be if we accepted both Schliesser's (2013) account for time and Huggett's (2012) account for motion, the terminology is uniform across time, space, place and motion.

I freely admit that there are things that Newton *says* about true motion and absolute motion (e.g. that true motion is distinct from true rest, and that absolute motion is distinct from absolute rest) that go beyond the contrasts by which he introduces them and, as it turns out, beyond the needs of the *Principia*. Moreover, it is of course true that Newton had a theological argument for why space and time must be absolute (see section 6.3, above), but this argument appears in the *Principia* only with the addition of the General Scholium and lies, I would argue, outside the project of the *Principia* itself. Nevertheless, I maintain that "absolute" and "true" are on a par when it comes to their relationship to the project of the *Principia*, and are to be treated in the same way.

Specifically, it is a matter for empirical investigation whether motion as it is implicitly defined by the laws of motion and the *Principia* more generally turns out to be either absolute or true. Newton argues in the scholium that true motion must be absolute, but these two notions remain independent and may come apart depending on the details of how the project of the *Principia* unfolds. For example, if "absolute" is understood to mean "not relative" (as described in section 2 above), then *absolute* motion is not threatened by Galilean relativity, but *true* motion (understood as "unique and proper to the system") might seem to be. However, a different way to understand what is happening here is available; through the project of the *Principia* the question that was at stake at the outset is transformed, as follows. The problem of the system of the world inherited by Newton was to determine the true motions of the Earth, Sun and planets. In the hands of Newton, the concepts through which the problem is defined are transformed, and the problem along with it, in the process of which we learn that the original problem was ill-posed. The transformed problem is this: relative to our planetary system treated as an isolated system (ruling out the freedom introduced by corollary VI), what are the motions of the bodies among themselves, as determined by the forces between the bodies? For *this* question we can determine the true (because unique) and absolute (because not in relation to bodies) motions of the bodies in our planetary system, and it turns out that they are *all* moving, but that the Sun stays always close to the center with the other bodies in orbit around it. This is Newton's solution to the problem of the system of the world.

8. Doing metaphysics after Newton

Newton has good reasons to assert that the concept of time appropriate to the project of the *Principia* should be absolute, true and mathematical. Within the context of the *Principia*, whether time is absolute and/or true and/or mathematical become empirical questions to be answered through pursuit of the project of the *Principia*. What were formerly metaphysical questions, to be addressed prior to and independently of detailed empirical investigations, are now dependent on the details of empirical enquiry for their resolution. Newton's theological arguments concerning time, interesting as they are, are to be distinguished from the arguments of the *Principia* (excepting the General Scholium). It is the arguments of the *Principia* that represent a breakthrough in philosophy of time, in showing us how to begin the process of transforming metaphysical questions concerning time into empirical questions, i.e. into questions that are empirically tractable.

As I have said, this is not to disagree with McGuire that in order to understand Newton as a philosopher we must understand his conception of God's nature and existence, and the arguments of the *Principia* in that context.[29] If we want to understand Newton's overall philosophy of time, then we must draw on resources beyond those of the *Principia* and we must situate the *Principia* within them. However, cogniscent of this context, we should also take care to attend to the details of the *Principia*, and to what this text offers in its own right, as a stand-alone text, as Newton published it. This is what I have been trying to do here.

Moreover, Newton says very little about the philosophical significance of the moves that he is making. We come to understand their philosophical significance by looking at what Newton does, rather than by having access to much that he himself offers by way of explanation for what he does. Because of this, any claims to be offering a faithful interpretation of Newton must be tentative, and my interest here is in the philosophical significance of the moves that Newton makes, rather than in what Newton took himself to be doing. For example, I am not claiming that Newton's goal is to turn metaphysical questions into empirical ones, but rather that by doing what he does in the *Principia* he thereby transforms metaphysical questions (including ones that we might have thought to be well out of the reach of empirical work) into empirical questions.

One aspect of the clash between Leibniz and Samuel Clarke over absolute versus relative time in the Leibniz-Clarke correspondence is a clash between Leibniz and Newton over methodology for doing natural philosophy. For Leibniz, the question of whether time is absolute or relative is answered by appeal to intelligibility as a criterion of metaphysical reasoning, it is answered prior to the details of empirical enquiry, and the answer represents a constraint on empirical theorizing. For Newton, the question has already been transformed into an empirical one, in the sense that it is through empirical enquiry itself that the question is to be addressed.

The dispute between Leibniz and Newton is not to be adjudicated on the basis of who fares better according to a given methodology; rather, at stake is the comparative ability of the distinct methodologies to deliver with respect to the most basic questions of the world and our place in it that drew us into philosophy in the first place. But Newton's philosophical methodology and its fruits await thorough integration into our philosophical inheritance, and philosophy today is (in my opinion) all the poorer for this lack. The work of George Smith and Bill Harper, and of those following their lead, may help to precipitate a sea-change. The comparative success of different methodologies with respect to

[29] See, for example, McGuire, 1995, chapter 1.

our most basic philosophical questions tells us a great deal about our epistemic situation in the world, and thereby contributes to the progress of philosophy, if we care to pay heed.

In being transformed into an empirical question, absolute versus relative time becomes a richer question: absolute time is distinguished from true time, and from mathematical time, each of which are independent of one another, and each of which can be addressed as separate questions. The question of what it means to say that the same moment of duration is spread throughout all space becomes pressing (leading eventually to Einstein's 1905 analysis of simultaneity), and the empirical project leads to a distinction between parameter time and coordinate time. Because of this richer conceptual space, we cannot return to the metaphysical questions concerning time as they were prior to Newton and pretend that they remain philosophically live questions today: those very questions have been transformed by his work. As noted in the introduction (see section 1.3), Newton applied his methodology for rendering metaphysical questions empirically tractable not just to time, but to other basic concepts such as matter, space, and force, and the same lessons for metaphysics apply in those cases too.

The distinctions which are hard-won, and the concepts which are transformed and developed, by means of Newton's philosophical methodology remain part of our inheritance within physics, and as the current situation in physics itself indicates, we have a long way to go. For this reason, I give the last word to two physicists:

Julian Barbour begins his book *The End of Time* (1999) as follows:

> Two views of the world clashed at the dawn of thought. In the great debate between the earliest Greek philosophers, Heraclitus argued for perpetual change, but Parmenides maintained there was neither time nor motion.

He goes on:

> Over the ages, few thinkers have taken Parmenides seriously, but I shall argue that Heraclitan flux ... may well be nothing but a well-founded illusion. I shall take you to a prospect of the end of time.

Lee Smolin, in his recent book *Time Reborn* (2013), begins thus:

> What is time? This deceptively simple question is the single most important problem facing science as we probe more deeply into the fundamentals of the universe.

He continues:

> All of the mysteries physicists and cosmologists face – from the Big Bang to the future of the universe, from the puzzles of quantum physics to the unification of the forces and particles – come down to the nature of time.

Then he says:

> [P]hysicists and philosophers alike have long told us (and many people think) that time is the ultimate illusion.

Before turning us around:

> Not only is time real, but nothing we know or experience gets closer to the heart of nature than the reality of time.

Julian Barbour and Lee Smolin are long-time friends and collaborators. Each has a philosophically rich research program in the foundations of physics. In the quotations given above (which are separated by a 14 year time interval) they disagree on the answer to the question "What is time?", but they agree that developments in contemporary physics are deeply relevant to how we should go about answering it. As well as being central to contemporary physics, time and change are, of course, among the oldest and most venerable topics in philosophy, and philosophy of time continues to be an active area in metaphysics. I agree with Barbour and Smolin: if we want to understand and address the question "What is time?", then we shall need to take on board the significance of developments in physics for this question. I have argued here for the under-explored richness of Newton's treatment of time in his *Principia* as a chapter in this history.

Acknowledgements

I am grateful to the following people for discussion and input: the participants in my graduate spacetime seminar (spring 2013), and to our visiting speaker Eric Schliesser; the Pittsburgh Center for Philosophy of Science for their colloquium invitation, and all those present at my talk; and Ori Belkind, Anja Jauernig, Jennan Ismael, and Michael Strevens. Special thanks to Meghan Dupree, Xavi Lanao, and Monica Solomon for their comments and discussion.

References

Arthur, R. T. W., 1995. "Newton's Fluxions and Equably Flowing Time". *Studies in History and Philosophy of Science*, 26(2), pp. 323-351.

Audoin, C., and Guinot, B., 2001. *The Measurement of Time*. Cambridge: Cambridge University Press.

Barbour, J., 1999. *The End of Time*. London: Weidenfeld and Nicholson.

Biener, Z., and Smeenk, C., 2012. "Cotes's queries: Newton's empiricism and conceptions of matter". In Janiak and Schliesser (2012), pp. 105-137.

Brading, K. A., 2012. "Newton's law-constitutive approach to bodies: a response to Descartes". In Janiak and Schliesser (2012), pp. 13-32.

Cohen, I. B., and Whitman, A., 1999. *Isaac Newton, The Principia, Mathematical Principles of Natural Philosophy: A New Translation*. Los Angeles: University of California Press.

Descartes, R., 1991. *Principles of Philosophy*. V. R. Miller and R. P Miller, trans. Dordrecht, Boston, London: Kluwer.

DiSalle, R., 2006. *Understanding Space-Time*. Cambridge: Cambridge University Press.

Gassendi, P., 1972. *The selected works of Pierre Gassendi*. C. B. Brush (ed. and trans.). New York, London: Johnson Reprint Corporation.

Gorham, G. 2012. "The Twin-Brother of Space': Spatial Analogy in the Emergence of Absolute Time". *Intellectual History Review*, 22(1), pp. 23-39.

Hall, A. R., and Hall, M. B., 1962. *Unpublished Scientific Papers of Isaac Newton*. Cambridge: Cambridge University Press.

Harper, W. H., 2011. *Isaac Newton's Scientific Method*. Oxford, New York: Oxford University Press.

Herivel, J., 1965. *The Background to Newton's Principia*. Oxford: The Clarendon Press.

Huggett, N., 2012. "What did Newton mean by 'Absolute Motion'?". In Janiak and Schliesser (2012), pp. 196-218.

Newton, I., 2004. *Philosophical Writings*. A. Janiak (ed.). Cambridge: Cambridge University Press.

Janiak, A., and Schliesser, E., 2012. (Eds.) *Interpreting Newton: Critical Essays*. Cambridge, New York: Cambridge University Press.

McGuire, J. E., 1978. 'Existence, Actuality and Necessity: Newton on Space and Time', *Annals of Science* 35, 463-508. Reprinted in McGuire (1995) 1-51.

McGuire, J. E., 1995. *Tradition and Innovation: Newton's Metaphysics of Nature*. Dordrecht, Boston, London: Kluwer.

Maudlin, T., 2012. *Philosophy of Physics: Space and Time*. Princeton, Oxford: Princeton University Press.

Palmerino, C. R., 2013. "The composition of space, time and matter according to Isaac Newton and John Keill". In S. Roux (ed.), *The Mechanization of Natural Philosophy (Boston Studies in the Philosophy of Science)*. Springer. pp. 117-142.

Rynasiewicz, R, 1995a. "By their properties, causes and effects: Newton's Scholium on time, space, place and motion (I)". *Studies in History and Philosophy of Science* 26(1), pp. 133-53.

Rynasiewicz, R, 1995b. "By their properties, causes and effects: Newton's Scholium on time, space, place and motion (II)". *Studies in History and Philosophy of Science* 26(2), pp. 295-321.

Schliesser, E., 2013. "Newton's philosophy of time". In H. Dyke and A. Bardon (eds.), *A Companion to the Philosophy of Time*, First Edition. Edited by Heather Dyke and Adrian Bardon. John Wiley and Sons, Inc., pp. 87-101.

Slowik, E. 2013. "Newton's Neo-Platonic Ontology of Space". *Foundations of Science* 18(3), pp. 419-448.

Smith, G. E., 2002. "The methodology of the Principia". In I. B. Cohen and G. E. Smith, eds., *The Cambridge Companion to Newton*. Cambridge: Cambridge University Press. pp. 138-73.

Smolin, L., 2013. *Time Reborn*. Boston, New York: Houghton Mifflin Harcourt Publishing Company.

Stein, H., 1970, "Newtonian Space-Time", in R. Palter (ed.) *1666: The Annus Mirabilis of Sir Isaac Newton*. Cambridge, Massachusetts; London, England: MIT Press. pp. 258-284.

Stein, H., 1990. 'On Locke, the Great Huygenius, and the incomparable Mr. Newton'. In P. Bricker, and R. I. G. Hughes (eds.), *Philosophical Perspectives on Newtonian Science*. Cambridge, Massachusetts; London, England: MIT Press. pp. 17-47.

Stein, H., 2002. 'Newton's metaphysics'. In I. B. Cohen and G. Smith (eds.), *The Cambridge Companion to Newton*, pp. 256-307. Cambridge: Cambridge University Press.