Part B: A Brief History of Space

Supplementary readings:
M Hoskin et al: *Cambridge Illustrated History of Astronomy*
A Koyre: *From Closed World to Infinite Universe*
J North: *Fontana History of Astronomy and Cosmology*

(I) Aristotle of Stagira (384-322 BC)

0) A closed geocentric spherical cosmology. (Adopted from the great mathematician, Eudoxus, c. 400 to 347 BC; via Calippus; but Aristotle unifies their separate schemes for different heavenly bodies).
(Aristotle cites mathematicians as estimating radius of earth: in fact 200% of correct figure. Eratosthenes ca. 250 BC estimates radius of earth as 120% of correct)

1) Spheres of aether (quintessence) carry the Sun moon planets. Each is midway between the poles of the sphere on which it resides.
Unmoved mover, at outermost part of universe is source of all motion of inner spheres. Details ….
For Sun you need at least two spheres, one for day, one for year, with axes suitably related. Similarly for moon: one for day, one for month.
In fact for both Sun and moon, Eudoxus had 3 spheres; for moon, this is probably to take care of the fact that the moon's apparent orbit is at 5° to the ecliptic (=apparent path of sun), intersecting it at nodes that move slowly round the zodiac (period = 18.6 years).
Eudoxus' pivoted spheres give qualitative account of the direct and retrograde motions of the planets: the hippopede. Cf e.g. North pp. 71-77.
Eudoxus had 26 spheres, Calippus 33: but the totals are misleading since neither has a unified system: there is a set of spheres for each planet or luminary. Aristotle sees that for a unified system, each planet needs additional spheres outside those postulated by E & C, to neutralize the motion communicated by its next-outer neighbour. Thus Jupiter needs extra spheres to neutralize motion induced by Saturn, Mars needs extra spheres to neutralize motion induced by Jupiter, etc. Cf. also end of 2) below.

2) That was a first approximation!
To see how to elaborate: Suppose anachronistically, ie. as in fact, a heliocentric system with circular orbits in a common plane. Imagine the concentric circles drawn on paper and put a pin through the earth instead of the sun, and spin! Then the Sun's circle about the earth is a *deferent* (carrying) circle, and the circle of an (inferior, ie Mercury or Venus) planet about the sun becomes a carried circle, an *epicycle*.
(For a superior planet, the radius of the epicycle carrying the planet is always parallel to the line from Earth to mean Sun. (Cf. OP in Figure 2 below).)
NB: only Copernicus realized that Sun is involved in each planet's deferent-epicycle system. See (III).

3) Defining some Ec-words!
Celestial equator = approximate common plane of planetary orbits around sun.
Ecliptic = apparent path of sun.
Tilt of earth means that it intersects celestial equator. The tilt is 23°, but Eratosthenes and Hipparchus are close! They cite 21°. (So the fact that celestial equator is only approximate means that planets move in 'ecliptic latitude'.)

Eccentric: This arises in a scheme equivalent to deferent-epicycle, developed by Apollonius (fl. C. 250-175 BC), and taken up by Ptolemy. Instead of:
planet P circles O, the centre of an epicycle of radius r, that is carried around a circle radius R centred on earth T (for ‘terra’), [solid lines in diagram]
we think of P as orbiting in a circle radius R centred on a point E (*eccentric point*) which orbits T on a circle of radius r [broken lines in diagram]. The movable circle is called the *eccentric circle*. Figure 1 from North p.91:--

This suggests we allow the deferent circle not to be centred on the Earth: this was done, called an *eccentric deferent circle*. Indeed the centre of the deferent circle was allowed to circle the earth (eg in Ptolemy’s moon model).
Equant: introduced by Ptolemy. See Figure 2 from North p.115, for a superior planet.
Instead of postulating that O has a constant angular speed around C = the centre of the deferent circle (which is eccentric in the figure, i.e. C is not T!),
Ptolemy postulates that O has constant speed around the equant point E.
This breaks with tradition of uniform circular motions!

4) Aristotle on place and motion:
Growth and decay only in sublunar sphere: air extends as far as moon. (This corruptibility mitigates against an exact mathematical science of matter: cf. (mid) Plato.)
Beyond that sphere, stars eternal. (Re latter point: Cf. Plato's being shocked at Anaxagoras' qualitative explanation of eclipses, viz. that the Sun is a burning mass and the moon a sort of Earth that obscures its face)
Idea of natural motions. Sublunar: they are up and down: of earth and fire respectively. In superlunary spheres, natural motion is circular, uniform, speed.
Allows for forced motions (oxen pull a cart, pillars hold up a roof). But even so, there is trouble in accounting for missiles: which continue upward when separated from the force.

As to space: Definition of place as innermost surface of that which contains. No void: the world is a plenum.

5) Notes on 300 BC to 100 CE!
1) Aristarchus of Samos (c.300 -): first clearly heliocentric cosmology; earth circles sun in a circular orbit, sun is also centre of a sphere of fixed stars (very distant, hence no stellar parallaxes). He also had a sound method of estimating the ratio of the distances from earth to moon, and to Sun.
2) Hipparchus of Nicaea (worked in Rhodes) (fl. 150-125 BC).
Giant of quantitative astronomy! Absorbed Babylonian data and arithmetical methods; probably invented astrolabe; used eclipse data to estimate earth-moon distance as between 59 and 67 earth radii; true figure is about 60. Unsurprisingly: much cited by Ptolemy!

He discovered precession of equinoxes: all stars have small increase in their ecliptic longitudes. Until Copernicus, it was called a movement of the sphere of stars. In fact: slow conical motion of earth's axis makes it look as if equinoxes are moving from east to west. Hipparchus estimated the rate at 1° per century. It fact it is 1° per 72 years (roughly 50'' per year). The precession was eventually explained by Newton 1687!: earth is flattened and Sun's greater pull on near side of bulge than far side produces the conical motion of earth's axis.
3) Query: What beyond the outermost sphere?

<u>(II) Ptolemy (c 100 to 170 CE)</u> *Almagest*
More details of closed geocentric spherical cosmology! Note only, as examples:
a) the introduction of equant;
b) allowance of planet's deferent to be at an angle to ecliptic plane (an oscillating angle for inferior planets); with the planet's epicycle in yet another plane.
c) P. continues Aristotle's denial of void: planetary distances are settled so as to 'close-pack' the spheres

Almagest reaches Western Europe in Latin, around 1170, translated from Greek and form Arabic.

On place and motion:
Ptolemy suspects that 'fixed stars' might not be fixed. Compiles catalogues of ca. 1000 star positions "in order to provide those who come after us with a means of comparison over a longer interval". (Halley 1718 demonstrated proper motion of the stars.)

(III) N Copernicus of Torun (fl. Frombork) (1473-1543)
De Revolutionibus (1543); on *Index of Prohibited Books* from 1616 to ca. 1790.
The models of the different planets and of the earth all have a common centre, the 'mean Sun' which rotates around the true Sun.
And Copernicus gets the order of the known planets, right: thitherto not established. That is, he has: Mercury, Venus, Earth, Mars Jupiter, Saturn.
Since the planes of the planets' orbits in fact pass through the Sun, but not the earth, it is possible to make this (roughly) heliocentric theory much simpler than Ptolemy's. In particular:
(i) Copernicus prides himself on avoiding use of equant.
(ii) It explains why the mean Sun or associated notions like the Sun-earth line plays a role the Ptolemaic models of each of the planets.
(iii) It explains why the outer planets are brighter in opposition.
But Copernicus has difficulties due to:
(a) too much respect for faulty records of planetary latitudes in the *Almagest*
(b) not being heliocentric enough! For the planes of planetary orbits pass through the physical Sun, not the mean Sun.

On place and motion:
1) (Cf. note at end of (I)2).) The innovation that Sun is involved in each planet's model does *not* force the earth to be in motion. Hence compromise systems grew up, like Tycho Brahe's and Baer's (idea: the Sun orbits the earth, and the planets orbit the Sun; for Tycho, the earth does not rotate, while for Baer it does). But:--
2) Copernicus and disciples like Rheticus certainly thought the new system true. But there was a deceptive anonymous Preface by Lutheran theologian Andreas Osiander!
'These hypotheses need not be true or even probable.' They are to be taken alongside the ancient hypotheses 'which are no more probable… Let no one expect anything certain from astronomy, which cannot supply it, lest he accept ideas as true that were conceived for another purpose, and so leave this study a greater fool than when he enetered it.'
3) Copernicus: "The sphere of the fixed stars … is unmovable. It is unquestionably the place of the universe, to which the position and motion of all other heavenly bodies are compared."
4) Growing realization of immensely large spaces between planets: Brahe and Kepler et al hypothesize that they are occupied by comets or unrecognized planets. Other troubles for Aristotelianism are: the new stars of 1572 and 1604 (in fact supernovae), and the absence of parallax in comets. Very unnerving! 'the need for support'.

(IV) J Kepler of Stuttgart (fl. Various!) (1571-1630)

1) *Mysterium Cosmographicum* (1597); Platonic solids nesting between planetary orbits; and in same tradition *Harmonice Mundi* (1619).

2) *The New Astronomy* (1609) *Epitome of Copernican Astronomy* (1618-21) Kepler's First law (viz. that planetary orbits are ellipses with (true!) Sun at a focus) is articulated towards end of *New Astronomy*; (which reports theory of Mars, on which Brahe had set him to work in 1600).

There are statements of Kepler's second and third law, and cousins in earlier work, e.g. *Mysterium* has 3rd law as: orbit period is proportional to radius squared. (correct power is 3/2.) But the laws in present form are given prominence in the *Epitome*.

3) Kepler was much influenced (as were others) by Gilbert's argument (*On the Magnet*, 1600) that earth is a spherical magnet. He argued that Sun influences planets magnetically.

4) Much other activity, not only in optics, telescopes etc.; but in carefully empirical astrology and astro-meteorology.

On place and motion:

1) The fixed stars provide the planets with "a place and a base upon which they are, as it were, supported; and movement is understood as taking place relative to its absolute immobility."

2) Overall (Barbour): 'intuitive space' (extending infinitely in all directions as in Euclidean geometry); but no Newton's first law, nor Cartesian coordinates!

(V) Galileo Galilei of Pisa (fl. Padova, Firenze) (1564-1642)
Sidereus Nuncius = The Starry Messenger (1610) *Dialogue concerning the two Chief World Systems, Copernican and Ptolemaic* (1632) *Two New Sciences* (1638)
Galileo is not a quantitative astronomer, but … Telescopes invented autumn 1608. Very soon turned to heavens by Harriott, Galileo et al.; yielding observation of e.g.: growth and decay of sunspots, mountains on moon which are illuminated just like craters on earth, and stars in Milky Way; and more importantly as threats to Aristotelianism, Galileo himself saw:

a) Jovian satellites---so that there are centres of rotation other than the earth

b) Venus fully illuminated, i.e. the phase of Venus seen with the alignment ESV; which is not provided for by the Ptolemaic model (It did exclude the other 'full Venus' alignment SEV, i.e. Venus being in opposition.)

Galileo develops the growing vision of the mechanical philosophy. In particular, he articulates the distinction between primary and secondary qualities. (*The Assayer*, 1623)
"I think that tastes odours colours etc. are nothing but names in regard to the object in which they seem to reside, but have their sole residence in the sensitive body, so that if the animal is removed all such are taken away and annihilated."
[Cf. also Democritus: "By custom, sweet; by custom bitter. By custom, hot; by custom, cold. By custom, colour. In truth: atoms and void."]

And he develops mathematical *terrestrial* physics:
"Philosophy is written in this immense book that stands ever open before our eyes (I speak of the universe), but it cannot be read if one does not learn the language and recognize the characters in which it is written. … Its characters are triangles, circles and other geometric figures …"

In particular he develops a quantitative science of motion. He fashions concepts of:
i) average speed (as we would write it: v = s/t. But in 1600s, such ratios of distinct dimensions were revolutionary!)
ii) uniform acceleration (as equal increments of 'average speed' in equal times: not say, equal distances gone);
iii) missile motion combines uniform horizontal motion and uniformly accelerated vertical motions; which he shows to yield a parabolic path. Yet:
iv) Galileo's law of inertia is not ours:

a) confined to vicinity of earth's surface, and

b) 'horizontal' means that!… as we also see in:

v) Similarly, though Galileo has a principle of relativity, as in the *Dialogo*:
"Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. … With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin … When you have observed these things …have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover no the least change in all the effects named…"

But the principle is not really ours.

On place and motion:
1) G. believed the Sun is truly at rest and the earth moves (*eppur si muove*). He believed this was shown by the tides, which he understood to be explained by:
the water's alternately absolutely accelerated and absolutely retarded motion, as the earth's spin adds to and subtracts from the water's motion in orbit around Sun.
2) Again: 'intuitive space'

(VI) R Descartes of La Haye (fl. Netherlands) (1596-1650):

Like Galileo an influential propagandist for the mechanical philosophy. But while concepts and details of the physicist Galileo's description of motion will be very fruitful, Descartes the rationalist philosopher announces a worldview, but gives posterity no fruitful details---except for one crucial one: the law of inertia.

But Descartes' worldview is recognizably ours: materialism (mind aside!), with explanation only by motion and contact-action; space homogeneous and isotropic; determinism by instantaneous mechanical states.

Also, as philosophers know well: Scepticism as: i) a mind-clearing preliminary to gaining knowledge of the new science, and ii) a propagandist tool.

Some notes on his version of the mechanical philosophy.

i. He articulates (more clearly than Galileo) the law of inertia as the 'first law of nature'. Indeed, his formulation is essentially Newton's first law. This is even in his early work, *Le Monde*. Consider the stone in the sling, released: "we should ask, instead, why does the stone not continue to move forever?"

ii. He had a law of the conservation of the 'quantity of motion' ('magnitude of body [aka: quantity of matter] times speed'), and he studied collisions. But

a) here, 'speed' not 'velocity' gives an escape route for mind-matter interaction: it allows the human mind to change the direction of particles in the pineal gland!

b) here 'magnitude of body' is *volume*, not our concept of mass: for …

iii. From early on, he denied vacuum ('matter is extension') and had both terrestrial gravitation and planetary motion—and much else---explained qualitatively by hypothesizing:

1. three kinds of matter:

a) luminous (of which Sun and stars constituted),

b) transparent (filled apparently empty space, in particular inter-planetary space),

c) opaque (of which earth and planets constituted)

2. fluid vortices in transparent matter: terrestrial gravitation is like boat sucked to centre of whirlpool, sunspots are lumps of opaque matter floating on Sun's surface awhile, magnetism is … etc.

iv. But though influential, very qualitative—getting Newton's goat! In particular: Not known whether he knew Kepler's laws, certainly he made no effort to explain them.

On place and motion:

1) We must distinguish

(A) *Le Monde*: written 1630-32; heliocentric, so RD decided not to publish on learning 1633 of Galileo's condemnation! He articulates essentially Newton's first law of motion. Overall, uses the intuitive notion of (Euclidean) space.

(B) *Principles of Philosophy* (1644)

This placates the Inquisition by disguising the heliocentrism with:

a) Aristotelian construal of place and motion in terms of immediately contiguous bodies: Motion is "the transference of one part of matter or of one body, from the vicinity of those bodies immediately contiguous to it and considered as at rest, into the vicinity of others."

b) doctrine that earth and planets are carried around the Sun in a fluid vortex relative to (the nearby bits of!) which the earth is at rest!

Principles categorically denies that space exists; and confusedly goes on to state the laws of Motion from *Le Monde*! *Principles* was very influential, not least by the confusion goading Newton into strongly articulating 'intuitive space'.

(VII) I Newton of Woolsthorpe (fl. Cambridge) (1642-1727): *Principia* (1687)

1) The 'Practical Physics': A precise and quantitative mechanics, a universal law of gravitation, with application to: the motion of the planets, of comets, of earth and moon, and terrestrial phenomena: the tides, the flattening of the earth and precession of the equinoxes (discovered by Hipparchus 150 BC!).

2) On action at a distance: Newton's idea of 'deduction from the phenomena'

A) The magisterial `*hypotheses non fingo*' passage, in penultimate paragraph of General Scholium that Newton added to the *Principia* in 1713:

Thus far I have explained the phenomena of the heavens and of our sea by the force of gravity, but have not yet assigned the cause of gravity. This force must arise in any case from some cause that penetrates to the very centres of the sun and planets, without suffering the least diminution of its power; … and whose action extends on all sides to immense distances, decreasing always as the inverse square of the distances. But hitherto I have not been able to deduce from phenomena the reason for these properties of gravity, and I do not contrive hypotheses. For whatever is not deduced from the phenomena is to be called an *hypothesis*; and hypotheses … have no place in *experimental philosophy*. In this philosophy, propositions are inferred from the phenomena, and afterwards rendered general by induction. Thus it was that the … laws of motion and of gravitation, became known. And it is enough that gravity really exists, and acts according to the laws which we have explained, and sufficiently accounts for all the motions of the celestial bodies and of our sea.

Torretti (p. 79) comments:

`With his talk about the cause of gravity, did Newton mean to say that something was wanting in his theory, which another more fortunate scientist might find? I do not think so. His remark that the force of gravity does not operate like the usual mechanical causes seems designed to warn us that the phenomena effectively *preclude* that kind of explanation that his adversaries foolishly *demanded*. And the curt *satis est* (``it is enough that gravity really exists, and acts according to the laws which we have explained ... '') ... does not encourage any further search for the missing cause. In this matter ... Newton quite resolutely sets the path of future science while still paying lip service to the notions of his time'.

On the other hand, Newton also writes in the third letter to Bentley:

"It is inconceivable that inanimate brute matter should, without the mediation of something else which is not material, operate upon and affect other matter without mutual contact."

And indeed Clarke writes: "That one body should attract another without any intermediate means, is indeed not a miracle, but a contradiction, for 'tis supposing something to act where it is not."

From now on, I turn to: Newton on Place and Motion: cf. esp. Scholium (to Definitions I-VIII, of mass, centripetal force etc); in Alexander ed. pp. 152-160).

3) Tradition vs Rynasiewicz

The customary view is that the Scholium aims to argue from the existence of rotational effects, whether in bucket or globes, to the validity of the notion of 'absolute motion', and from that to existence of absolute space. Authors then differ on whether the postulation of absolute space was 'reckless reification', or 'reasonable inference to the best explanation', at least given the mathematics of the time [noone knew how to have a 4D connection without a privileged state of rest].

R Rynasiewicz argues against this:--

(1) Newton and contemporaries *agreed* that physics need some notion of 'true' 'philosophical' 'absolute' motion, (that 'x moves' can be a complete predicate, not just an ellipsis from 'x moves …'). But they differ about how to construe it …

(2) But Descartes Huygens Leibniz want true motion to be a *species* of relative motion. (Exactly *which* species, they disagree about and each agonize about!).

(3) Newton gives several arguments against this idea, urging instead the merits of his alternative, *announced at the start* of Scholium (paras labelled I-IV by Newton, ie paras 1-4 in RR's system, i.e. counting paras from 0,): namely that absolute motion is motion with respect to absolute space.

(4) These arguments *assume* that absolute rest and motion have certain features; and proceed to exhibit how a relational conception does not guarantee, or even fit comfortably with, these features---while Newton's preferred conception does so.

(5) These features are the 'properties, causes and effects' as announced at start of para 8f . Newton treats: properties in para 8-10 (one in each of the three paras);
causes in para 11,
effects in para 12 (this is the rotating bucket para.)

Example A, para 8 (a 'property'): It is a property of rest that bodies that are each at rest are also at rest w.r.t. each other. (IE: this feature is a premise for Newton.) But this property is not entailed by a definition of rest as 'no change of distances to other nearby bodies'.

Example B, para 11 (a 'cause'): True motion is generated or altered by and only by the application of forces to the very body in motion. (IE: this feature is a premise for Newton.) But any kind of relative motion lacks this feature: for consider applying the forces to the other bodies w.r.t. the relative motion is defined.

Example C, The 'argument from effects' the bucket: para 12 of the Scholium
In parallel to previous arguments:--

(i) It is a *premise* that the water's endeavour to recede from the axis is an effect of absolute circular motion, and is greater for a greater quantity of such motion.
(ii) It is to be *argued for* that the centrifugal endeavour is not an effect of purely relative rotation.

(c) On the globes: para 14 = last para.

This is *not* just 'the bucket argument, but with another example'. Rather: having now concluded that true motion is motion w.r.t. absolute space, N asks: since the parts of absolute space are not perceivable, can we know the true motions of individual bodies. The globes show that indeed, 'the thing is not altogether desperate' (i.e. the situation is not hopeless).

4) <u>Evaluation of Rynasiewicz</u>: Even if you are not convinced of this reading---
The main target of the bucket argument, and of much else in the Scholium, is *certainly* Descartes' 1644 relationism. Indeed, more generally: the roots of Newton's views on space and motion lie in good part in his critique of Cartesianism: which he developed early in the unpublished *De Gravitatione* c. 1668: Thus, he writes against Descartes.

"I shall endeavour to dispose of his fictions. … he says that speaking properly and according to philosophical sense the earth and the other planets do not move … yet later he attributes to the earth and planets a tendency to recede from the sun as from a centre about which they are revolved … What then? Is this tendency to be derived from the (according to Descartes) true and philosophical rest of the planets, or rather from their common and non-philosophical motion?
[Conclusion]: So it is necessary that the definition of places, and hence of local motion, be referred to some motionless thing such as extension alone or space in so far as it is seen to be truly distinct from bodies."

IE: Newton aims to refute the idea that a physically significant ('true, philosophical') but relationally acceptable concept of motion is determined by relation to *contiguous* bodies, in particular by relative motion wrt them.

Examples of other evidence that Descartes is a target in the Scholium: RR thus analyses paras 6 and 13, and there is evidence external to the text---not just *De Grav* but also *De Motu* of ca. 1684, which is v. similar to Scholium. Cf. Rynasiewicz II, 299-306, or Barbour Sections 11.3-11.6, 12.5, and esp. Sec 11.3-4, p.609-623.

(Cf. RR. p. 306-311 for discussion of how the usual (mis)reading of the Scholium got established and entrenched: (a) translation should be 'define' not 'determine'; and (b) with rise of Newtonianism after 1700,'absolute motion' *came to* mean just 'motion with respect to absolute space').

5) Barbour's Reading

Overall, Barbour's reading of the Scholium (1989: Sec 11.3-11.6, 12.5) is much closer to the customary view that the Scholium aims to argue from the existence of rotational effects to the existence of 'absolute motion', and even of absolute space. And having strongly Machian sympathies, Barbour thinks that Newton, for all his genius, over-reaches himself: though Barbour does not go as far as Reichenbach et al. in saying that Newton forsakes empiricism, and indulges in 'reckless reification'.

Thus Barbour writes that the Scholium aims to be "a demonstration that the existence of an absolute immovable space follows of necessity from the observed phenomena" and as such "it failed" (p. 629; cf. also e.g. p. 630, 668). See 5C) below. First, I pick out just two aspects of Barbour's discussion.

5A) Like Rynasiewicz, Barbour (rightly!) sees Cartesianism as the Scholium's main target (which he thinks distorts the argument of the text).

Indeed, Barbour propounds a 'but for the want of a nail …the kingdom was lost' story, that links Descartes in 1632 ('the nail') with Einstein in 1915 ('the kingdom'). He writes:
"I will go so far as to say that if Descartes had finished *The World* a few months earlier, and hence published it before the Inquisition condemned Galileo … Newton might never have felt the need to formalize his views about space and time in such an outspoken manner---and then general relativity might never have been created." (p. 598, also eg. p. 611)

5B) Side-Remark about Time: para 1, 5 of the Scholium (counting paras from 0, like RR) Maybe no single body's motion is exactly periodic with respect to absolute time "which from its own nature flows equably without relation to anything external." So maybe solar time and sidereal time (given by return to a 'position' of the sun, and of a given star, respectively) do not measure (ie stay in step with) absolute time. Barbour urges:

(a) that Ptolemy came close to recognizing this (by having a common time parameter for motions of different celestial bodies); and

(b) remarkably, solar and sidereal times 'sufficed' until 1900s, when astronomers had to resort to *ephemeris time*. One determines the time parameter by requiring many bodies' motions to obey a law of motion with that parameter. (JB, Sec 3.15, esp. p. 181-2)

5C) According to Barbour, Newton's 'over-reaching himself', ie the argument of the Scholium 'failing', is a matter of (pp. 630-1, 637-8, 668-672):

1. Newton's forgetting, in this context, the Galilean invariance of his mechanics; as stated in Corollary V to his Laws of Motion:

"The motions of bodies included in a given space are the same among themselves, whether that space is at rest, or moves uniformly in a right line without any circular motion."

Thus Barbour says that Newton writes about the globes as if one can determine not only their circular motion w.r.t. absolute rest, but also their rectilinear motion (if any) w.r.t. it. For the final lines of Newton's discussion consider the case where the two globes are not alone in the universe, but accompanied by 'some remote bodies .. that kept always a given position one to another, as the fixed stars do in our regions. And Newton goes on:

> "if we observed the cord, and found that its tension was that very tension which the motion of the globes required, we might conclude the motion to be in the globes, and the bodies to be at rest; and then lastly, from the translation of the globes among the bodies, we should find the determination of their motions."

So Barbour reads "might conclude" as "can legitimately conclude". (pp. 630-1, 637-8)

2. Barbour claims this error of Newton's is associated with Newton's desiring to prove that velocity is absolute, and trying to do so by showing circular speed to be absolute (i.e. determinable), and so his losing sight of the main distinction between unaccelerated and accelerated motion (p.669-671).

3. Barbour claims this error of Newton's arises from ignoring the need for material objects to define inertial frames: a topic that was only properly sorted out (in the framework of Newtonian mechanics) by authors like Neumann, Lange and Mach in the 19th century (pp. 671-672).

I confess Im not convinced by 1. and 2. here!

6) An Anachronistic Intervention! From the perspective of today …
Nowadays, it is often stressed that Newton's bucket and globes thought-experiments are equally valid in special relativity (SR) and general relativity (GR). This can mean at least the following two points: (both are true, but there are subtleties worth teasing out).

6A) SR and GR, no less than (the various versions of) Newtonian mechanics have a 4-dimensional affine connection. That is, they have:
a standard of unaccelerated motion (= a standard of what counts as a timelike geodesic, i.e. a timelike straight line in spacetime), and
associated measures of amounts of acceleratn (= amts of curvature of worldline).
In SR, this connection is absolute in the sense of non-dynamical (not influenced by the matter-distribution), just as Newton's is. But in GR, it is dynamical.

6B) But in both SR and GR, the connection---more precisely, the spacetime geometry and how bodies relate to it---is *not* determined by (supervenient upon) the spatiotemporal relations among bodies (in the traditional sense of 'body' as hunk of ponderable matter). To see this, we can argue with naivety, or sophistication!

Naivety: the globes again! Consider two globes, with nothing else in the universe, except an inextendible cord stretching between them. Two different cases, that differ as to how bodies relate to spacetime geometry, while the spatiotemporal relatons between the three bodies (2 globes and a cord) remain exactly the same, are surely possible ---so that there is no determination (supervenience). Namely:--

(i) the globes are not rotating, each travels an inertial worldline, there is no tension in the cord;

(ii) the globes are rotating about their common centre of gravity, each travels a spiral worldline, there is tension in the cord.

Indeed, (ii) represents many cases, infinitely many according to the various possible speeds of rotation.

Three glitches in this naïve argument. (a) Maybe tension in the cord counts as one of the facts that are allowed to do the determining of spacetime geometry (in the jargon: 'allowed in to the determination-basis/supervenience basis).
(b) What about gravitational attraction between the globes?
(c) In GR, the globes will have an effect on the 4D connection, or more generally on the spacetime geometry: maybe this effect is sensitive to whether or not they are rotating.

Sophistication: The idea is to simplify the physical situation considered, but preserve the strategy of showing that the theory admits pairs of solutions which agree on their matter distributions but differ metrically. For general relativity, the most-cited cases are the vacuum (i.e. matter fields zero, T = 0) solutions. But there are non-vacuum examples, e.g. the Schwarzschild and Kerr metrics---representing respectively, a non-rotating and a rotating mass in an otherwise empty universe.

Three comments on this non-determination:--

[1] Although such pairs show that the metric is not determined by, i.e. supervenient upon, matter, there are ``Machian effects'', such as inertia-dragging, in general relativity. Some were found as early as 1918; indeed, Einstein found similar effects in the course of his struggle towards general relativity.

[2] Mach apparently hoped for such determination; at least, 'the relationist' does. They can respond to the results just cited 'so much the worse for the theory, including general relativity!, as it comes to us from physics'. We should add constraints (like extra boundary conditions), so as to eliminate all but one of the cases concerned. Indeed, Einstein himself was sympathetic: already in 1918, when he coined the phrase 'Mach's principle'! A tangled history---uncovered by Barbour et al.

[3] Any modern discussion of relationism must take cognizance of the rise of field theory from the mid-nineteenth century:-- On the one hand, physics revealed some traditional characteristics of bodies---such as impenetrability and continuity---to be only apparent. And on the other hand, the electromagnetic field was discovered to possess mechanical properties like momentum, angular momentum and (after the advent of special relativity) mass-energy. Besides, matter itself was eventually modelled, with outstanding success, as a field on spacetime; namely in quantum field theories. Thus Newton's, Leibniz' and Mach's `bodies' had become diaphanous and omnipresent fields.

7) A Glance at Two of Newton's Contemporaries: Berkeley and Leibniz

Both these authors illustrate the points in (1) and (2) of Rynasiewicz's reading (Section 3) above): Newton and contemporaries *agreed* that physics needs some notion of 'true' 'philosophical' 'absolute' motion, but *differ* about whether to construe it as a *species* of relational motion.

In *The Principles of Human Knowledge* (1710), Berkeley summarizes the Scholium (Article 111), and then registers first his disagreement with Newton (Art 112) and then his admission of 'true motion' (Art 113):

> "But notwithstanding what has been said, it does not appear to me that there can be any motion other than *relative* …Hence if there was only one body in being, it could not possibly be moved.
> But though in every motion it be necessary to conceive more bodies than one, yet it may be that only one is moved, namely that on which the force causing the change of distance is impressed, or in other words, that to which the action is applied."

Thus Rynasiewicz goes on (RII, 315-316) to discuss how, on his reading of the Scholium, Berkeley's view of the bucket-experiment is close to (a part of) Newton's account.

G. Leibniz (1646-1716; fl. Various!) writes in his Fifth paper in the Leibniz-Clarke correspondence (p. 74 of Alexander ed.), along much the same lines as Berkeley:

"I find nothing in the Eighth Definition of the *Mathematical Principles of Nature,* nor in the Scholium belonging to it, that proves, or can prove, the reality of space in itself. However, I grant there is a difference between an absolute true motion of a body, and a mere relative change of its situation with respect to another body. For when the immediate cause of the change is in the body, that body is truly in motion; and then the situation of other bodies, with respect to it, will be changed consequently, though the cause of that change be not in them,. 'Tis true that, exactly speaking, there is not any one body that is perfectly and entirely at rest; but we frame an abstract notion of rest, by considering the thing mathematically. Thus have I left nothing unanswered, of what has been alleged for the absolute reality of space. …

Rynasiewicz comments that:

(i) on the usual reading of the Scholium, Leibniz seems here to be rejecting without argument, the good Newtonian argument for the existence of absolute space, (though it is perhaps not a watertight one---it is an inference to the best explanation).

(ii) on his reading of the Scholium, Leibniz is not rejecting Newton without argument, but stating a definition of absolute motion in terms of *causes*, which is relationally acceptable and apparently viable.

Bottom line:---but which did not lead to successful physics to rival Newton's.

<u>Conclusion:</u>

1) Note how both Berkeley and Leibniz propose as their relationally acceptable notion of absolute motion, motion for which the 'immediate cause of change is in the body'.

2)And recall that a similar topic arose in 3) above 'Tradition vs Rynasiewicz', about para 11 of the scholium. Newton argued (as read by RR):

True motion is generated or altered by and only by the application of forces to the very body in motion. (IE: this feature is a premise for Newton.) But any kind of relative motion lacks this feature: for consider applying the forces to the other bodies w.r.t. the relative motion is defined.

3) Clearly, both sides have a point, and one can endorse BOTH:

(A) Berkeley and Leibniz's proposal that absolute motion is relative motion for which the 'immediate cause of change is in the body'

(B) Newton's point that relative motion can be generated or altered by the application of forces to another body

… or more exactly: we can endorse both (A) and (B) UNLESS we also endorse Newton's premise in para 11, (in 2) above) in a strong sense of being true of the whole universe.

That is: unless we believe there can be an absolute motion of the whole material universe, by an equal force being applied to all bodies.

Thus we have arrived at some central elements of the debate in the Leibniz-Clarke correspondence!