THE NEWTONIAN REVOLUTION – Part One

Philosophy 167: Science Before Newton's *Principia*

Class 2

16th Century Astronomy: Copernicus and Tycho Brahe

September 9, 2014

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Philosophy 167: Science Before Newton's Principia

Assignment for September 9

16th Century Astronomy: Copernicus and Tycho Brahe

Reading:

Kuhn, Thomas. The Copernican Revolution. pp. 1-77, 134-209.

Evans, James, "On the function and probable origin of Ptolemy's equant," American Journal of Physics, v. 52, 1984, pp. 1080-1089.

Gingerich, Owen. "Ptolemy, Copernicus, and Kepler," from The Eye of Heaven, pp. 3-38.

Questions to Focus On:

1. In what, if any, respects was the Copernican system simpler than the Ptolemaic? In answering, consider not just planetary motion, but also diurnal motion and the precession of the equinox.

2. What empirical evidence was there as of 1600 in support of the claim that the Copernican system is basically true and the Ptolemaic system is not?

3. Were there any other considerations as of 1600 that provided grounds, solid or otherwise, for preferring the Copernican system to the Ptolemaic?

4. Were there any reasons as of 1600 for taking the Tychonic system seriously as an alternative to the Copernican and Ptolemaic systems?

5. Why was the Tychonic system incompatible with the classical doctrine of the crystalline spheres? How strongly should this have counted against it?

6. What empirical evidence was there as of 1600 favoring the Copernican system over the Tychonic? Was there any empirical evidence favoring the Tychonic?

7. What suggestions might be given to a practicing astronomer in 1600 looking for some way to adduce empirical evidence that would once and for all resolve the dispute over the three chief systems?

Class 2: 16th Century Astronomy: Copernicus and Tycho Brahe

I. The Copernican Revolution

A. Ptolemaic Astronomy: e.g. Longitudes of Mars

1. The part of Ptolemaic astronomy of chief concern to us is his account of planetary longitudes, using compound circles
   a. Such phenomena as retrograde motion, variations in lengths of retrograde loops and in their timing, and variations in rates of movement (e.g. Mars 40 percent faster in Capricorn than in Cancer)
   b. Two classic inequalities: “first” or zodiacal inequality, the variation in speed around the ecliptic; “second” or solar inequality, retrograde motion (when in opposition to the sun)
   c. Long standing efforts to predict such phenomena, akin to efforts to predict eclipses, which exhibit a similar underlying regularity and a complex pattern of regular variations from it
   d. Contrast Ptolemy's problem with that of being presented with a body of longitude data and finding a "curve" that will fit it
   e. Ptolemy giving a comparatively simple rule that captures to reasonably high approximation a complex pattern exhibited by nature
2. Overall basic system inherited from Apollonius and Hipparchus: geocentric, with major epicycles to account for retrograde motion
   a. Sun and moon without major epicycles, for no retrograde motion
   b. Center of epicycles of inner planets always aligned with mean sun, and angular position of outer planets on their epicycles always aligned with earth-mean sun vector
   c. Distances from the Earth -- radii -- indeterminable save that of moon (and Ptolemy thought sun as well, from eclipses), though ratio of deferent to epicycle radii known
3. Ptolemy takes up device of eccenter from Apollonius and Hipparchus, but then adds bisected eccentricity, and consequently equant, in order to account for variations in basic longitudinal patterns
   a. Same configuration in every case but Mercury: captures a generality
   b. Mercury with center of deferent on inner epicycle, largely because being misled by erroneous observations
   c. Seven parameters or "elements" (six independent), the last two of which simply "starts the clock": ratio of radii, eccentricity, period on deferent, period on epicycle (to return at opposition to same stars), direction of line of apsides, and locations (planet on epicycle and epicyle on deferent) at some (epochal) time
   d. First five elements suffice to represent, to a good approximation, the complexities of the retro-grade phenomena, which exhibit a large number of degrees of freedom: captures a generality
   e. Mars: r/R = 39;30; e = 6;0 (i.e. 0.1); mean motion of anomaly = 0;27,42 per day; mean motion of longitude = 0;31, 26 per day; apogee at Cancer 25;30 (A.D. 139)

4. In representing the phenomena of planetary longitudinal "anomalies", Ptolemy provided a system that predicted planetary longitudes at all times, past and future
   a. Longitudinal discrepancies of the order of 1 to 2 deg not uncommon, though little attention given them (and same for latitudes, though they capture general shape of retrograde loops)
   b. Main emphasis on patterns of anomalies, which Ptolemy was able to represent far more accurately than anyone before him, and how they relate to the values of the orbital elements
5. Ptolemy provides a complete, tractable computational system, and not just a qualitative scheme
   a. Calculational procedures to infer elements from observations, with theory indicating (1) which observations serve that purpose best and (2) how to conceptualize the elements geometrically
   b. Calculational procedures, with Tables, for determining planet location at any time: usually as a series of corrections to a first pass, "idealized" value
   c. Restriction to circles reflects not just "perfection of circular motion", but also calculational tractability of circles
   d. Actual orbits are very nearly circular, so assumption of circularity not a large source of error
6. Moreover, given three working hypotheses proposed at the beginning of the *Almagest* -- (1) the Earth is motionless, (2) all zodiacal motion is centered around it, and (3) all real celestial motion involves compounds of equiangular motion -- Ptolemaic orbital theory was “data-driven”
   a. For under these working hypotheses, retrograde motion is real, not merely apparent
   b. Then, as shown last time, each of the features of a Ptolemaic orbit derive from something specific in the observed motions, and it in turn determines the value of the related parameter
   c. The fact that the same values, to high precision, for those parameters keep being obtained from new observations – i.e. the values are stable -- then provides a continuing test of the models

B. A Problem Raised for Philosophy of Science
1. Its achievement notwithstanding, Ptolemaic astronomy has to be regarded at least to some extent as a failure in the history of science, an impediment to progress that had to be overcome, at least to get at the physics governing orbital motion
   a. A case can be made that it was a garden-path that had to be abandoned before modern science could get started
   b. Yet a garden-path that had impressive empirical evidence behind it, and hence was more difficult to abandon than if it had been a mere philosophical conjecture
2. Our current science has various mathematical theories -- calculational systems -- akin to Ptolemaic astronomy that are accurate, at least to a reasonable approximation, and offer accounts of prominent regularities -- i.e. phenomena
   a. E.g. classical electromagnetic theory, Newtonian mechanics, and thermodynamics
   b. Were it not for computational intractabilities, quantum mechanics too, which at least in principle covers every question in chemistry

3. This gives us more than just passing reason to want to identify something methodologically unsound in Ptolemaic astronomy, something that differentiates it methodologically from our science
    a. For, if it was methodologically sound in all respects, then perhaps our current science too may turn out to be a garden-path that we will have to abandon at some point in the future, reconstituting science from the ground up in the way that mathematical astronomy was reconstituted following Copernicus and Kepler
    b. Ptolemaic science stood for 1400 years, while the our science has stood for less than 350 years
    c. If we are going to insist that modern science is superior as science, we best identify some features in Ptolemaic science that we can now see were objectionable at the time
4. When one looks in detail at Ptolemaic astronomy, the question of what was wrong with it turns out to be more difficult than one might have first thought
    a. As noted at the end of the last section, it was empirically driven to a remarkable extent -- indeed, more so than Copernicus's astronomy
    b. In many other respects it had a remarkable amount in common with our science -- again, more so than Copernicus's work in many respects
    c. Evidence from (1) success in predicting salient events, (2) while models require only five principal constants (3) whose values come from model-mediated stable measurements
    d. It was at least as good as contemporary economics -- Swerdlow has said that it was much better
5. In particular, the objections to Ptolemaic astronomy that we have inherited from Galileo and others of the 17th century do not stand up so well under scrutiny
    a. Its complexity was empirically driven, and it did succeed in reducing far more complicated phenomena to a comparatively simple theoretical basis
    b. When construed as describing planetary motion relative to the Earth as a reference point, it can arguably be viewed as true to a first approximation
    c. Whatever fudging Ptolemy did was open to correction via subsequent observations; he even showed how to go about using observations to improve the values of his elements
    d. Cumulative or growing inaccuracies were subject to fairly straightforward correction
    e. Inaccuracies in longitude and latitude were not cumulative, and there was no immediately transparent pattern to them
6. My suggestion last time was that the worst feature of Ptolemaic astronomy was that the theory was not used as a tool in ongoing research -- e.g. by defining deviations from the theory and attempting to find patterns in them that would lead to refinements
    a. Ptolemy not so much at fault in this regard, for he had shown how to do this in the case of his lunar theory
    b. But after him, a hiatus in ***empirically driven*** efforts to extend the theory or to gain insights from deviations from it

c. (Not inconceivable that efforts to do so might have led to using the actual sun rather than the mean sun as a reference, and with them to reduced discrepancies in predicted longitudes -- which might have made the theory even more entrenched

d. Not clear whether comparable progress on latitudes would have been possible, though shift from mean to actual sun might have been enough)

7. Perhaps a better formulation of my complaint is that, for all of Ptolemy's emphasis on empirical evidence, insufficient emphasis was placed on questions that remained open or had been only tentatively closed on the basis of very limited evidence; e.g.

a. Are the Earth and the mean sun the appropriate points to which to refer all the motions?

b. What are the distances of the planets from one another (and is the ordering of them correct)?

c. Would any other object added to the system have to describe basically the same motion?

d. (Note the subjunctive in this last question; this will become important in a couple of weeks)

C. Background: 13 Centuries of Ptolemaic Astronomy

1. Ptolemaic mathematical astronomy remained essentially intact over the next 14 centuries, forming the basis of the academic discipline of astronomy

a. In Alexandria, then Arabs (and Iranians), and finally into Europe in the 12th century via the Moor migration into Spain

b. A discipline within the great universities of Europe that started to be formed in the 13th century: Paris, Oxford, Bologna, etc.

c. Textbooks explicating the basic system found in the *Almagest*, most notably *Sphaera* of John of Sacrobosco (ca. 1250) the main source until end of 15th century

2. Criticisms directed not at small inaccuracies in daily longitudes, which go virtually unmentioned, but at violations of uniform circular motion and non-centrality of the earth, on "philosophical" grounds

a. Found how to use a minor epicycle on top of the major one to get same effect as the equant

b. Worries not just about abandonment of uniform circular motion, but also about underlying physical mechanisms: how to realize equant with nested rotating (solid) spheres

c. Also some attention to clearly wrong implication about how near the moon comes to the earth

3. Improvements in some aspects of Ptolemaic astronomy, but not in planetary orbits (nor in latitudes)

a. Some improvement in sun and moon via further observations

b. Correction to 1 deg per century precession of equinox, which was becoming glaringly wrong, throwing everything else off, after a few centuries

c. Trepidation, a superposed, cyclic variation in the precession rate, keeping the average between Hipparchus and Ptolemy at 1 deg per century

d. Alfonsine Tables (around 1270) an updated version of Ptolemy, incorporating trepidation and other small modifications (thought to be improvements), but with same basic treatment of planetary longitudes