THE NEWTONIAN REVOLUTION – Part One

Philosophy 167: Science Before Newton's *Principia*

Class 3

Kepler's *Astronomia Nova*: The Orbit of Mars

September 16, 2014

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Philosophy 167: Science Before Newton's Principia

Assignment for September 21

Kepler's ASTRONOMIA NOVA and the Orbit of Mars

Reading:

Kepler, Johannes. A Defense of Tycho against Ursus. tr. N. Jardine, Preface, Chapter I, and last two paragraphs, pp. 134-158, 206-207.

Wilson, Curtis. "How Did Kepler Discover His First Two Laws?," a reprint from Scientific American in Astronomy from Kepler to Newton: Historical Studies.

--- "Kepler's Derivation of the Elliptical Path," a reprint from Isis in ibid. (preceding, written for historians)

Questions to Focus On:

1. What empirical evidence did Kepler have for the following claims:

   (a) Mars sweeps out equal areas with respect to the Sun in equal times.

   (b) Mars does not describe a circular path.

   (c) Mars describes an elliptical path.

2. Some 80 years later Newton remarked that Kepler had only guessed that the orbit of Mars is an ellipse. To what extent was Newton right?

3. What enabled Kepler to succeed with the latitudes of Mars when all mathematical astronomers before him had consistently failed with the latitudes of all the planets?

4. In Chapter I of the Apologia Kepler puts forward 11 points in reply to Ursus's suggestions that the hypotheses of astronomy should not be taken as if they were literally true or false. At the time (1600) he had yet to begin his investigations on the orbit of Mars. Which, if any, of the points could he have strengthened if he had revised Chapter I of the Apologia after these investigations had been completed in 1605?

Class 3: Kepler's Astronomia Nova and the Orbit of Mars

I. Prefatory Remarks: Some Background to Kepler

A. Overview of the Class: Planetary Astronomy

1. The Newtonian revolution, and hence this course, really starts with Kepler's efforts on Mars, and in the process on the earth-sun orbit as well, from 1601 to 1605
   a. The first full reconstruction of planetary astronomy since Ptolemy
   b. The first real effort to introduce physics into mathematical astronomy -- this largely in response to the crisis that had been created by competing world systems
2. The first two weeks were intended to accomplish several things, not the least of which was to eliminate some myths about Copernicus's role in the scientific revolution
   a. Ptolemaic astronomy was not self-evidently absurd to anyone with modern scientific sensibilities; in many respects it was remarkably like modern science
   b. The 16th century ended not just with two main competing world systems, the Ptolemaic and the Copernican, but with three; and the third, the Tychonic, raised far more serious questions about the epistemic limitations of planetary astronomy
   c. Copernicus did not revolutionize science by invoking strict empirical standards where none had been in effect before; what he did was to realize that there was an evidence-preserving heliocentric mathematical transformation of Ibn al-Shāṭir's transformation of Ptolemaic astronomy
   d. It was not the case that the evidence immediately made clear that the Copernican system is true and the Ptolemaic false; what the three competing systems did was to pose a rather profound evidence problem
3. The primary focus of this semester is on what those engaged in research did and did not know leading up to 1685 and Newton's *Principia*, when and how they came to know it, and how in the process certain unanswered questions became paramount
   a. Not just what people believed, but what those who examined the available evidence most critically would at the time have rightly concluded about what was known
   b. As you will see, that led those in the forefront of research into discussions of how evidence might be marshaled more effectively
4. The principal thing that had been known for centuries is that the planets, the sun, and the moon appear not to be engaged in uniform circular motion
   a. The first inequality: a regular variation in apparent angular velocity, with period matching one sidereal revolution; e.g. Mars appears to move 40 percent faster when in Capricorn than when on the opposite side in Cancer, with the pattern repeating every 687 days
   b. The second inequality: in the case of the planets, a further variation, evidenced by retrograde motion, with period matching the time between consecutive oppositions; e.g. in the case of Mars the pattern repeats every 780 or so days

c. Copernicus's main point was that the second inequality was in appearance alone -- a point taken over by Tycho

5. The 1400 year tradition in mathematical astronomy that had been initiated by Ptolemy yielded a rich set of mathematical methods

   a. Ptolemy's contribution was not using epicycles for the second inequality -- this he inherited from centuries before

   b. His contribution lay in his handling of the first inequality via bisected eccentricity, and the equant

   c. The success that this 1400 year tradition achieved with salient phenomena in the longitudes was not matched by its efforts on specific values of longitude, nor those on latitude

6. Though I haven't gone into a great deal of detail about it, this 1400 year tradition included sophisticated methods of evidential reasoning -- i.e. reasoning from observations to conclusions beyond them

   a. E.g. inferring r/R and eccentricity for the individual celestial bodies from patterns in the inequalities

   b. Or Ptolemy's reasoning to bisection of eccentricity

7. Kepler had inherited both the mathematical methods and the techniques of evidential reasoning from this tradition when he started on planetary orbits a little after 1600; the singular position he found himself in, however, was marked more by three other factors

   a. The crisis in mathematical astronomy -- at least in some people's eyes -- raised by the challenge of the apparent equivalence of the different systems

   b. Tycho's data, not only the most accurate and reliable data in the history of astronomy, but the first sustained body of data of notable extent and range since the ancient Babylonians

   c. In the light of these data, the indisputable inadequacy of any of the existing systems to match observed longitudes remotely within observational accuracy: see figure in Appendix

8. Will do three things this class

   a. Consider Kepler's reaction to the "crisis" in astronomy that developed especially after 1588, when Tycho published his system -- the crisis I laid out last time

   b. Then review the steps Kepler followed to the discovery of his first two "laws" -- i.e. to the discovery that Mars orbits the sun along an elliptical path, conforming to the area rule

   c. Finally, step back to assess Kepler's "evidential argument" for his findings on Mars

B. Turning Data into Evidence: Evidential Arguments

1. I should first say something about the phrase "evidential arguments" and related talk of turning data into evidence

   a. When I say to philosophers that the fundamental problem in doing science is to turn data into evidence, they are often surprised, asking me what the difference is between data and evidence

b. When I say it to scientists, they usually react as if I have uttered a truism, and they are quick to grant that certain sciences have more success in turning data into evidence than others do
c. What this amounts to, of course, is just that some sciences have more success in establishing theoretical claims than others do

2. An evidential argument consists of step-by-step reasoning from statements describing observations to a conclusion that reaches beyond these statements
   a. Such arguments in empirical science are the analog of proofs in mathematics, and like the latter they are rarely fully spelled out in scientific practice
   b. If our goal is to understand what evidence in science amounts to, then at some point we need to look at some evidential arguments in great detail to see what they really do and do not achieve
3. In spite of the fact that the course is supposed to be about the process by which successful sciences turn data into evidence, this will be the first time in it that we will be looking in any detail at the evidence behind a major scientific finding
   a. Little on the details of how Ptolemy's working hypotheses enabled evidence on various features of the motions to be derived from observations
   b. In the case of Copernicus, went further by sketching a reason for preferring his (or Tycho's) system to Ptolemy's, but the reason did not involve an appeal to discriminating data at all
   c. Rather, the idea was that the working hypothesis that the five planets orbit the Sun potentially opened the way to converging evidence on the distances of those planets from the Sun in a.u. through triangulation
   d. The idea behind both cases is that some sort of theoretical apparatus is needed to turn data into evidence, and in the early stages of theory construction, this is often a working hypothesis
   e. But we have yet to see in detail how such a working hypothesis can pay off, and what empirical requirements have to be met to adopt one without undue risk of a garden-path
4. Kepler's evidence for his conclusions about Mars is, in many respects, a much more transparent example of the sort of evidential argument modern science has employed in the early stages of theory construction, when little in the way of theory is available to help turn data into evidence
   a. Contrasts with mere "saving the phenomena," as well as with invoking aesthetic and philosophic reasons to support theoretical claims
   b. As such, it really does engage in a process of turning data -- viz. Tycho's observational data -- into specific evidence for a series of novel claims
5. I find Kepler's evidence on Mars an especially instructive example of scientific evidential reasoning
   a. It raises most of the issues about scientific evidence that we will be concerned with during the rest of the year
   b. Issues at the heart of Kuhn's and others' claim that evidence plays less of a role in science than has generally been thought

c. Distinctive features of this evidence: (1) limiting its dependence on specific working hypotheses; (2) remaining cognizant at all times that observations are inexact; (3) requiring plausible physics to go from conclusions about approximate to decisions about exact

6. Anyway, Kepler's discoveries about Mars are one of the great watersheds in the history of astronomy
   a. As many have remarked, rarely has a book been more aptly named, for modern planetary astronomy starts with *Astronomia Nova*
   b. And, for the first time in this course, it presents major theoretical conclusions that remain essentially intact today

C. The Kepler of Legend: A Contemporary Version

1. Rather ironic to be using Kepler as a prime example of evidential reasoning in science at its best, for historians of science sometimes use him as an example of just the opposite
   a. As someone who got several things right for the wrong reasons
   b. As someone who was persuaded by arguments that no entirely rational person then or now would have been so persuaded by
2. Indeed, the Kepler of legend is a person bordering on madness, a mystic prepared to believe in things that today seem preposterous
   a. The legend probably began with Galileo's *Dialogues*, where he takes Kepler to task for proposing the crazy idea that the moon somehow governs the tides
   b. But the legend is still being fed: e.g. Gingerich's reference to his "mathematical mysticism",
   c. And, in taking Kepler's "intense faith in number harmonies" to be typical of scientific reasoning, Kuhn turns the issue upside down by using him to argue that scientific evidence is not all that it is cracked up to be
3. Even the best historians who are looking at Kepler's work in detail -- including his manuscripts and notebooks -- tend to be critical of his evidential argument
   a. Wilson less so than, say, Gingerich, but both reflect the view (more than Stephenson does) that Kepler's evidential arguments show much less than he took them to be showing
   b. Finding faults with Kepler remains a popular sport
4. By contrast -- and I say this to warn you -- I will be defending Kepler as someone who may well have had a deeper understanding of what is involved in scientific evidence than many of those who criticize him -- especially evidence in the early stages of theory construction
   a. Few have had a keener appreciation of the value of theory in the process of marshaling evidence
   b. And few have exhibited higher empirical standards of a certain sort
5. Furthermore, as the full title of *Astronomia Nova* attests -- *A New Astronomy Based on Causation, or a Physics of the Sky Derived from Investigations of the Motions of the Star Mars, Founded on Observations of the Noble Tycho Brahe* -- Kepler himself intended the book to be a watershed in the history of "scientific method"