a. An emphasis on precision of agreement, if not on exactitude, which was missing from Ptolemy and Copernicus, along with open admission that not yet there

b. A criterion for preferring one hypothesis to another, other things remaining the same: the one that is more accurate

4. But calculational accuracy not the sole criterion or constraint:

> There are two distinct tasks for an astronomer: one which truly pertains to astronomy, is to set up astronomical hypotheses such that the apparent motions will follow from them; the other, which pertains to geometry, is to set up geometrical hypotheses of whatever kind... such that from them those prior astronomical hypotheses, that is, the true motions of the planets unadulterated by the distortion of the sense of sight, both follow and can be worked out. (p. 154)

a. Astronomical hypotheses required to give the true motions -- the trajectories

b. And required not to entail physical falsehoods -- i.e. not as such required to include an account of the underlying physics, but required not to imply things false of the underlying physics

c. Contrasting equivalent devices like the eccenter and a minor epicycle, while geometrically different, are astronomically the same in that they yield the same trajectory -- alternative calculation devices

5. Remainder of the *Apologia* reviews the history of astronomical hypotheses, showing not only that Ursus's historical claims are false, but that the view that hypotheses are to be taken seriously was held by ancient astronomers as well

a. Ends with defense that Tycho did not steal his system from anyone else, including Copernicus

b. And calls attention to the fact that Tycho has added features (that could be added to the Copernican)

C. Kepler's Response in *Astronomia Nova*

1. As the full title of *Astronomia Nova* suggests, the idea that the physical cause of the actual motions is directly germane to astronomy even more in the forefront there

a. The "physics" generally appealed to is derivative from Gilbert's *De Magnete* (1600), which attracted a good deal of attention

b. Not physics in our sense, but a thorough description of the phenomenology of magnets, including pole effects, the earth's magnetic field, etc.

c. "Naturalistic" in contrast to "theoretical" science

2. As you will see in reading the Introduction for next week, Kepler starts from an open statement that the three chief systems are, at least up to a point, observationally equivalent

> The three opinions are for practical purposes equivalent to a hair’s breadth, and produce the same results. (p. 48)

a. Qualification because they are not physically equivalent -- i.e. each has physical implications incompatible with the others

b. Still, Kepler acutely aware of the observational equivalence problem

3. Primary purpose is to correct astronomical theory of Mars to remove discrepancies with observation

   My aim in the present work is chiefly to reform astronomical theory (especially of the motion of Mars) in all three forms of hypotheses, so that our computations from the tables correspond to the celestial phenomena. (p. 48)

   a. E.g. Prutenic tables off by almost 4 deg in August 1608, and almost 5 deg in August and September 1593
   b. Note the claim that he is correcting Mars for all three systems: knew that his results for Mars and earth could be compounded into a Ptolemaic account

4. Secondary purpose is to show, from consideration of the underlying physical causes, that "only Copernicus's opinion concerning the world (with a few small changes) is true, that the other two are false, and so on." (p. 48)
   a. Openly admits that much of the physics is (and he says always will be) conjectural -- indeed, has to be, given the state of physics at the time!
   b. Conjectures in which the Sun plays a central role
   c. But also directly challenges the physical plausibility of the motion attributed to Mars by Ptolemaic and Tychonic systems, displaying the “pretzel” shape of the motion in Chapter 1 in the process of reviewing restrictions in the traditional approach taken to the two inequalities (see Appendix)

5. Kepler's response to the crisis, then, is that the three systems are not empirically equivalent once one attacks the matter properly
   a. Through a combination of demanding full agreement with observations, on the one hand, and considering possible lines of physical causation, will be able to show that Copernican is, if not correct, is at least the most plausible of the three
   b. Key thing to note here is the idea of playing off precise agreement with observation, on the one hand, with some sort of physical considerations, on the other
   c. This last was the primary respect in which Kepler’s approach anticipated Newton’s

III. Kepler's Discovery of his Five Revolutionary Reforms in Orbital Theory

A. The Empirical Problem of Determining an Orbit

1. Observed geocentric longitudes (and latitudes) cannot be brought to bear on questions of planetary trajectories and motions -- i.e. orbits -- in the absence of some theory or working hypothesis
   a. E.g. the classic working hypothesis adopted by Ptolemy and Copernicus that the motions are compounded out of uniform, or at least equiangluar, circular motions
   b. Upon abandoning this hypothesis, Kepler had to come up with other hypotheses in order to derive any conclusions about the orbit of Mars (and of Earth) from Tycho’s observations
   c. One worry with any such hypothesis was to avoid its begging the question of the orbit from the outset; another worry was a need for different mathematics from the known geometry of circles