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

2. Kepler’s approach was to try to use discrepancies between provisional hypothesized orbits and observation as evidence to reach the correct orbit -- i.e. via successive approximations
   a. In addition to hypothesized orbits for Mars, he used and refined Tycho’s earth-sun orbital theory, as well as assumptions that authorized his interpolating among Tycho’s observations
   b. To constrain his hypotheses, he always demanded of them a plausible physical mechanism
3. One difficulty in trying to use discrepancies as evidence was the variety of sources potentially contributing to them besides inadequacies in the motion hypothesis then under consideration
   a. Tycho’s observations had margins of uncertainty of at least 2 min of arc
   b. Kepler’s approaches to interpolating among them widened their bounds of uncertainty
   c. The supplemental provisional theory -- of the earth-sun orbit when working on the orbit of Mars and of Mars when working on earth-sun orbit -- added still further uncertainty
   d. Kepler often could not make rigorous calculations for hypothesized motions, but had to resort to novel approximations, adding still more uncertainty
   e. (Not to mention calculation errors, from working with six significant figures, or simple arithmetical mistakes of the sort mentioned above and illustrated in the Appendix)
4. Another difficulty: the orbit of Mars is so nearly circular that highly discriminating evidence is needed to establish an alternative to equiangular motion along a circle
   a. Mars as of 1600 had an eccentricity of 0.09304 and a mean distance from the sun of 1.52369 a.u., resulting in a major axis of 304,738 in Kepler's units (based on 100,000 for mean sun-earth distance) and a minor axis of 303,416, so that the oblateness amounts to only 0.43 percent
   b. A hypothesis of equiangular motion along a circle with bisected eccentricity gets within a few min of arc, requiring observations with uncertainty much less than 10 min of arc to establish an alternative to it
5. Thus the problem Kepler took on was extraordinarily difficult, and his success deserves the praise heaped on it by such figures as Charles Saunders Peirce (his exemplar of “abduction”)
   a. Kepler’s successive approximations involved him in several false starts and frequent need to step back and assess whether extraneous sources of discrepancies were invalidating conclusions
   b. This made *Astronomia Nova* extremely difficult to read, for the evidence often depended on the specific false start, and hence they could not be ignored by the reader
   c. Symptomatic of this was the ten years Bill Donahue worked on the translation, having to re-derive, as best he could, the numbers Kepler gives in the book
   d. All of this, especially the convoluted line of evidential reasoning through the book, helps to explain why it seems to have persuaded no one but Kepler himself
   e. Still, historically that was all that mattered, for he then found other ways to connect with others
6. Wilson's reconstruction of Kepler's reasoning, focused as it is on the question of how Kepler reached the ellipse, drops some of the complications of the argument in *Astronomia Nova*

    a. That is, it drops some of the pathways that Kepler reported and inferences drawn from them; also several of the cross-checks he pursued in order not to be misled by discrepancies he had derived; and, in rearranging the logic a little, it glosses over some of the arithmetical errors
    b. Save for its understating how much use Kepler makes of triangulated distances (corrected here), we can think of Wilson's reconstruction as the sort of thing a good reader at the time might have extracted from *Astronomia Nova* in laying out the central argument of the book for the ellipse
    c. Save for its focus on the ellipse, this is what we want, for we are interested more in the development of evidence for the community than in biographical details concerning Kepler himself

B. "Phase 0": On the Real versus the Mean Sun

1. From a quick glance at its Table of Contents, you can see that *Astronomia Nova* has five main parts
    a. On the relationships among the hypotheses
    b. An initial approach to the first inequality, in the manner of the past astronomical tradition
    c. Towards a new approach to the second inequality, through a new account of the earth-sun orbit
    d. The new theory of the first inequality for Mars: the ellipse and area rule
    e. The new theory of latitudes, verified and explained
2. Wilson glosses over the first part, which takes the important step of showing that the choice between using the mean sun and the actual -- i.e. visible -- sun as reference point is potentially important
    a. Astronomically significant by yielding different sun-planet distances
    b. Empirically detectable, though only with a change in evidence practice
3. Kepler himself had shifted from the mean to the actual sun in his *Mysterium cosmographicum*, for reasons of physics, independently of any compelling empirical evidence for doing so
    a. Once one abandons crystalline celestial spheres, the center of the Earth's (or Sun's) orbit ceases to have any physical significance; it becomes a mere point in space, echoing Copernicus's complaint about the equant
    b. The step to the actual sun is thus abetted by a conceptual shift; Kepler, being of the new, post-Copernican generation, saw the mean sun differently
    c. Instead of crystalline spheres, Kepler assumed a physics of forces acting between actual bodies in the manner described in Gilbert's *De Magnete*, generating motions
4. Tycho had challenged Kepler on using the actual sun instead of the mean sun, arguing that, with his theory of the sun, employing the mean sun as reference point, he was able to achieve good agreement with observed longitudes of planets, and hence there was no reason to switch
5. Kepler's reply, in Chapters 5 and 6, argues that Tycho's good agreement may well be misleading (see figure in Appendix)
    a. Chapter 5: So long as one restricts oneself to acronychal observations -- i.e. observations when near opposition, so that Mars rises in evening and sets near dawn -- difference in longitude for the actual and the mean sun will be small, as in the case of X and Y in the figure