5. Newton's remark that Kepler merely guessed the ellipse probably reflects his view that Kepler had simply hypothesized his orbital model and then found that it could be made to fit impressively with Tycho's data
   a. Newton was openly contemptuous of such "hypothetico-deductive" reasoning in science, complaining that too many different hypotheses could fit the same data and no empirically based choice could be made among them
   b. The general impression then and now was that this is what Kepler must have done (just as it is that this is what Ptolemy must have done)
   c. This impression stems from not having worked through *Astronomia Nova*
6. Finally, we should note that it is one thing to have evidence for Kepler's conclusions about the trajectory of Mars between 1580 and 1605 and quite another to have evidence for generalizations of these conclusions! -- the central theme of this class
   a. What does the evidence in *Astronomia Nova* say about Mars' orbit in the far past and future?
   b. And what does it say about the orbits of the other planets?
   c. Generalizations beyond Mars in the period covered by Tycho's data involve a huge further leap -- or, to use Nelson Goodman's technical term, a *projection* beyond Tycho's data
      (1) Kepler's claims about the orbit for those years involves a projection from Tycho's data to conclusions that reach well beyond these data
      (2) Still an enormous further projection to this orbit over other times and to the orbits of other planets

B. The Achievement of *Astronomia Nova*: Summary Remarks

1. *Astronomia Nova* did in a sense effect a total reconstruction of mathematical astronomy from the ground up, much as Tycho had hoped for and Kepler had intended
   a. Between one and two orders of magnitude improvement in the accuracy of predicting latitudes and longitudes of the planets over everything that had gone before
   b. Established a new standard for predictive astronomy, replacing a 1400 year old standard -- a new standard that was not itself replaced for the better part of 200 years (telescope notwithstanding)
2. Methodologically, the book also represented a breakthrough of sorts in the problem of turning data into evidence
   a. Showed how to exploit comparatively accurate observational data, with a reasonably well known level of precision, while at the same time making allowances for residual inaccuracies
   b. Turned an age-old question -- what trajectories do the planets actually follow? -- into a question which observations can answer, given some theoretical assumptions, like Tycho's solar theory
   c. That is, Kepler was able to put himself into a position in which a comparatively small range of inexact observations yielded a perhaps qualified, but still unequivocal answer to the question of trajectory (at least up to an appropriate level of approximation) for Mars

d. And in the process put the field in a position where further observations would continue to yield relatively unequivocal answers to other related questions

3. But Kepler was by no means the first to succeed in thus turning questions into empirical questions in the sense just given, for this is precisely what Ptolemy had done too

   a. For example, Ptolemy used observations to generate the bi-section of eccentricity of Mars and Venus, as well as answers to a wide range of specific questions about orbital elements, etc.

   b. Why *Almagest* was so extraordinarily compelling

   c. I say this fully granting that Ptolemy may have played foot-loose-and-fancy-free with observational data, and recognizing that he worked with lower quality data, with less basis for setting bounds on precision; and his circular motion working hypothesis was more confining

4. The point is that Kepler represents a huge step forward because he wanted the "data-determined-answers" to such questions to do more than just be reasonably stable and not totally question-begging

   a. He wanted either to eliminate all further systematic residual discrepancies between observation and theory or to be able to use them as data that could be turned into new, still further evidence for added refinements -- e.g. to refraction corrections

   b. And he wanted to be able to use the "data-determined-answers" as at least an initial evidential basis for answering questions about the physical mechanisms underlying planetary motion

5. Still, do not lose sight of the fact that Kepler started from theories taken from Ptolemy, Copernicus, and Tycho: he can be looked on as the culmination of 1400 or more years of mathematical astronomy

   a. Like them, he fully appreciated that some sort of theoretical assumptions were indispensable to drawing any conclusions from planetary observations

   b. Indeed, he systematically used discrepancies between their theories and Tycho's observations as the evidential basis for his further conclusions

   c. I.e. Kepler's total reformation can equally be viewed as proceeding by successive approximations from already existing theories of a highly advanced science

   d. *Astronomia Nova* written in a way to carry those working in the old astronomy step by step into the new: the new is presented as built on the old, a refinement

6. Finally, keep in mind the extent to which Kepler consistently tried to cross-check each "data-determined answer" -- he fully recognized that observational data can be misleading, whether taken in their own right or in the context of a presupposed initial theory

   a. Cross-check via alternative ways of yielding at least a rough answer to the same question

   b. And cross-checking via considering whether the answer is physically at least reasonable

C. Kepler: The Subsequent Years (1609-1630)

1. In truth, Kepler was quite possibly the only person ever to have been influenced by the evidential argument in *Astronomia Nova*, for he was quite possibly the only person in the era to understand it, and anyway so few copies of the book circulated