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"

a. He thought of himself as showing the world how to bring evidence to bear in astronomy
b. So it is not entirely out of line to consider why he might have thought so

D. Kepler: From Birth to *Astronomia Nova*, 1609

1. Though completed in 1605 following 4 years of intense work, *Astronomia Nova* was not published until 1609 because of disagreement with Tycho's heirs on credits and on who had rights to publish Tycho's data
   a. Difficult to read, because written as if presenting the sequence of his research, including false starts and what was learned from them – see its Table of Contents and display of structure
   b. (I say "as if" because Voelkel's study of manuscripts has shown that his path to his conclusions was not the one laid out in *Astronomia Nova*)
   c. Book contains a good deal of shifting numbers, along with various calculation errors like the one on p. 167, which propagates through the rest of the book (see Neugebauer, p. 461)
   d. (The footnotes correcting prior historians in Wilson's *Isis* article are indicative of this difficulty, as was the more than decade long effort of Donahue's English translation)
2. Kepler, who was born in 1571 to a poor family abandoned by his father, struggled financially his entire life (often because his patrons failed to pay him money they owed him, but sometimes because of the Counter-Reformation)
   a. His brilliance in school gave him his education, in effect through scholarships
   b. Undergraduate, followed by a Masters from Tübingen, concentrating on theology and philosophy, but also studying astronomy under Mästlin, a leading Copernican astronomer of the time
3. Though he would have preferred a position in theology, ended up as professor of mathematical astronomy (in Roman Catholic Austria) upon graduation, leading to his first book, *Mysterium cosmographicum* (1596), which attracted some attention
   a. In part because he sent copies to everyone prominent in the field, eliciting their remarks -- e.g. Galileo, Tycho, and Ursus -- and also perhaps because the Appendix Mästlin added provided such a clear account of the Copernican distances in the *Prutenic Tables*
   b. (All his life Kepler sought approval and recognition from more prominent figures, usually not receiving it)
   c. A somewhat heroic figure who maintained his enthusiasm in the face of great adversity: first wife died, as did 8 of his 12 children, and his mother was prosecuted as a witch
4. In pursuit of better data to bring to bear on the ideas of *Mysterium* Kepler asked to become Tycho's assistant after the latter came to Prague
   a. Tycho insisted that Kepler first write the *Apologia* in order to undercut Ursus's appeal to Kepler in his disputes with Tycho
   b. Not published at the time because of Tycho's death in 1601 -- bad enough form to publish such a polemic when one of the principals was dead, and hence totally inappropriate once both dead

c. Because it was not published until the 20th century, did not become part of science; but still useful in giving Kepler's views of the goals and status of mathematical astronomy

5. On his death-bed Tycho apparently exacted a promise from Kepler to figure out the "true path" of the planets from the data
   a. Kepler kept the promise, working relentlessly on the problem from 1601-1605
   b. The "war on Mars" -- four years of 6 digit calculations (without the benefit of a "computer"), not knowing whether anything was going to come out of it
   c. (Romanticized account in Arthur Koestler's *Sleepwalkers* and *Watershed: A Biography of Johannes Kepler*; see also John Banville's novel, *Kepler*)

II. Kepler and the Crisis in Mathematical Astronomy

A. The Crisis in Mathematical Astronomy

1. The crisis in mathematical astronomy reached its fullest proportions in the last decade of the 16th century, following publication of Tycho's alternative system in 1588
   a. The very years in which Kepler was a college student and beginning professor of astronomy
   b. (Conceivably the thing that swung him away from theology and permanently into astronomy)
2. Outwardly, crisis took the form of challenging the exalted status of the discipline within universities
   a. Does astronomy really deserve its exalted place if it is unable to determine which of three such different systems -- the Ptolemaic, the Copernican, and the Tychonic -- is true?
   b. Does astronomy amount to anything more than just clever calculation schemes for approxi-mating, not all that well, observed locations of celestial objects?
3. Those within the discipline could appreciate even better than those outside that such challenges had a legitimate basis
   a. For they appreciated the extent to which the systems could be mathematically transformed into one another
   b. And hence they understood the extent to which each system could be adjusted to accommodate empirical considerations
   c. And of course they more than anyone saw how the generic Copernican and Tychonic systems appeared to be observationally indistinguishable
   d. Added to which, those astronomers who had access to Tycho's observations were aware of the magnitude of the discrepancies between observations and all the prior systems
4. The issue, then, was whether and how empirical data could be brought to bear to determine which, if any, of the systems was the true one
   a. How is the dispute over the systems to be settled in a principled, empirical way?
   b. An issue that fed, and fed off of, the broader issue that dominated 17th century epistemology -- *how are any questions to be resolved in a principled way on the basis of empirical information, especially given the problems of separating appearance from reality?*

5. During the first decade of the 17th century Kepler gave much thought to this issue within astronomy
    a. Along with other methodological questions: *On More Certain Foundations of Astrology* (1602), *Astronomia pars Optica* (1604), and *Dioptrics* (1611)
    b. *Astronomia pars Optica* covers research Kepler conducted while working on Mars in an effort to get a better handle on atmospheric refraction than he suspected Tycho had; the research led him to read Apollonius's *Conics*, in the process introducing 'focus' as a new word in mathematics
    c. The answer Kepler gave to the fundamental issue of choosing among the three systems on a principled basis was not nearly so influential as his specific astronomical findings were
    d. But in some respects it anticipates Newton's answer

B. Kepler's Response in the *Apologia*

1. Kepler's *Apologia*, originally entitled "Tract on hypotheses," is a direct response to Ursus's claim that astronomical hypotheses should not be taken as true and false, but as mere calculational devices
    a. View now known as "instrumentalism": theories are merely calculation devices which are only required to agree properly with the data, but otherwise make no claims about what is really true
    b. Contrast with the position known as "realism": theories are making claims about what really underlies observed phenomena
    c. Various intermediate positions between these two
2. Kepler asks the key question, the question with real bite:

    "Why, then, you may ask, given that they all demonstrate the same motions of the heavens, is there nevertheless so great a diversity of hypotheses?" (p. 140)

    a. Basic answer (pp. 140-142): equipollence may be illusory, arising from failure to allow for further forms of evidence, like the parallax of Mars; moreover, ultimately no equipollence, for

    "Even if the conclusions of two hypotheses coincide in the geometrical realm, each hypothesis will have its own peculiar corollary in the physical realm." (p. 141f)

    b. Further answer (pp. 142f): two hypotheses that are contradictory may nevertheless not be contradictory, but equivalent, relative to some one set of conclusions being derived from them
    c. Conclusion (bottom of p. 143) Popperian: "... Nor can it happen in astronomy that what was originally founded on a false hypothesis should be true in every respect ...."
3. In his point-by-point reply to Ursus, Kepler emphasizes how hard it is to come up with any hypotheses that allow calculation of the observed motions (p. 147)

    No one denies that there are still some flaws in even the best-constructed astronomy, and hence in the hypotheses also. (p. 147)

    Hypotheses are sought which will correspond to the motions of the heavens. The Alphonsine hypotheses are found to err, likewise the Copernican. But the skillful practitioner, having made a comparison of the two and having removed the sources of error, establishes some third [hypothesis] which avoids all error in the prediction of the motions of the heavens and in that way corrects both hypotheses. (p. 150)

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