

- 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

- a. Only a relatively small number of people had the background needed to read a book with this much original mathematics etc. in it, and few, if any, of them would have had the patience to work through all the details in order to come to grips with the argument
 - b. Kepler continued to have privileged access to Tycho's data, so few would have been able to assess his reasoning in the light of all the available data
 - c. And within a few years Kepler and then others provided textbooks on the results, obviating the need to read through the original evidential arguments
2. The evidential argument in *Astronomia Nova* led Kepler to pursue three parallel lines of research through the remainder of his life (1630)
 - a. Work out the orbits of all the other planets, and also that of the Moon, yielding a set of tables conforming to the new standard (based on Tycho's data): Venus, 1614; Mercury, 1609, 1614-15, 1616; Jupiter, 1616; Saturn, 1616; Moon 1617-1618, 1619
 - b. Use the now better known features of planetary orbits to search for further phenomena in planetary motion, especially phenomena involving comparisons among planets that would shed insight on the system as a whole
 - c. Use the now better known features of planetary orbits to theorize about the physical mechanisms underlying planetary motion
3. The pursuit of further phenomena involving comparisons of orbits led to his first major work in astronomy after *Astronomia Nova*, his *Harmonice Mundi* (1618)
 - a. Probably his favorite work, though also the one most often used to ridicule him today
 - b. This in turn led him to reissue his *Mysterium Cosmographicum* in 1621, with annotations updating his earlier findings
4. At one point he apparently intended to write a comprehensive treatise on the new astronomy, but perhaps because of difficulties with lunar theory, he ended up instead putting out a textbook, *Epitome Astronomiae Copernicanae*, in 3 installments between 1618 and 1621
 - a. Became a primary source for his mathematical astronomy, but also for his theories about the underlying physics
 - b. Widely read and influential, especially after he died; but did not present the elaborate, intricate evidential reasoning from observations of the sort laid out in *Astronomia Nova*
5. Finally, after many years of effort, including struggles with lunar theory, in 1627 published *Tabulae Rudolphinae*
 - a. Tables, plus explanations on their use, for the Sun, the five planets, and the Moon, plus a catalog of stars and a table of logarithms
 - b. As the title page indicates, the culmination of the project Tycho started almost 50 years before
 - c. A book virtually everyone working in astronomy over the next 100 years referred to in one version or another -- the basic reference work in the field

6. In addition to these major works in the history of astronomy, published a number of other works in science
 - a. *De stella nova* (1606), on the nova of 1604
 - b. *Dissertatio cum Nuncio siderio* (1610) and *Narratio de Jovis satellitibus* (1611), supporting Galileo's telescopic findings
 - c. *Dioptrice* (1611), the first comprehensive treatise on optics, including principles for Keplerian telescope
 - d. *Stereometria dolorioum vinariorum* (1615), a precursor to the calculus, describing the small-interval approximation methods used in *Astronomia Nova*
 - e. *De cometis libelli tres* (1619), on the comet of 1618, leading to conflict with Galileo
 - f. *Somnium seu astronomia lunari* (1634), a fantasy account of a trip to the moon, and how celestial motions would appear from there
 - g. Ephemerides on a regular basis, starting in 1610s, that must have impressed astronomers with their accuracy; note especially the ephemerides for 1631
- D. *Mysterium Cosmographicum* and *Harmonice Mundi*
 1. To understand the kind of thinking Kepler engaged in and is taken to task for in *Harmonice Mundi*, need to go back to his first work in astronomy, *Mysterium Cosmographicum* (1596)
 - a. Question addressed, presupposing the Copernican system: why should there be exactly six planets?
 - b. His answer: They correspond to the five regular solids, nested so that the spheres inscribed in and circumscribing each solid yield the comparative planetary distances from the Sun
 - c. He identified two problems with this answer: (1) the dimensions did not exactly conform with Copernicus's orbital radii, raising questions about the accuracy of the latter; (2) why then eccentric circles, with all the added complications of different centers
 2. All his life Kepler took any open question about the planetary system as an invitation for theorizing, looking always for a signal insight that would have major ramifications
 - a. Looking for a way to gain a key insight into the mind of God
 - b. In this respect, rather like Einstein -- as also in his appreciation for the value of theory
 - c. But always with an insistence on independent empirical assessment
 3. The question about the eccentricities of the nested orbits led him to look for an explanation in terms of some feature of the velocity variations in them, especially the min-to-max velocity ratios
 - a. These concerns, along with worries about correct dimensions, led him initially to wanting to have access to Tycho's data
 - b. With the findings on Mars, the velocity ratios become systematically tied to the eccentricities
 4. *Harmonice Mundi* offers his answer: God deviated from the simple regular solid scheme so that the extremal velocities of the various planets would instantiate the fundamental principles of harmonics