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 Cosmigraphicum* 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

   a. Five books: (1) Geometrical, on constructible figures; (2) Arithmetical, on solid ratios; (3) Musical, on the causes of the harmonies; (4) Astrological, on the causes of Aspects; and (5) Astronomical, on the causes of the periodic motions
   b. Systematically relates planetary periods, dimensions, and eccentricities to one another via the basic rules of harmony

5. Whether you consider this the worst sort of pseudo-science mysticism, or instead an adventurous essay in theorizing that ended up being a dead end, I leave to you
   a. Regardless of Kepler's own view toward it, all his detailed work on planetary orbits and their physical causes is almost entirely independent of it
   b. This in part because of his view that, once God had settled on the scheme, it was implemented and continued via simple physics
   c. Anyway, our concern is not with Kepler himself, but with the public evidence his work produced

E. Kepler's Discovery of His Third "Law" (1618)

1. One important by-product of *Harmonice Mundi* is Kepler's discovery of his third "law"
   a. Had looked for a systematic relation between velocity and the sizes of the orbits since 1596, in large part in keeping with the view that the Sun provided the impetus for planetary motion
   b. Original idea that the mean velocities varied inversely in proportion to distance from the Sun did not conform exactly with the known values
   c. Came upon a relationship that does conform during the last stages of completion of *Harmonice Mundi* (on March 8, 1618, he tells us)
2. "But it is absolutely certain and exact that *the ratio which exists between the periodic times of any two planets is precisely the ratio of the 3/2th power of the mean distances, i.e. of the spheres themselves*" (Book 5, Part 3, p. 180)
   a. In modern form, the ratios of the periods squared = the ratio of the major semi-axes cubed, where the major semi-axis does in fact give the spatial mean distance from the principal at a focus (though not the temporal mean) -- $a^3 \propto P^2$, henceforth the "3/2 power rule"
   b. Found that it applies not only to the planets, but also within a rough approximation (30 percent) to the newly discovered four Galilean satellites of Jupiter, using Marius's elements (Book 4, Part 2, p. 78f)
3. In stating the "law" Kepler did not bother to present the evidence for it, though elsewhere in the *Harmonice Mundi* he does give numbers that allow the reader to verify it (see tables in Appendix)
   a. Not perfectly exact, though discrepancies impressively small with these numbers
   b. Perhaps the most disturbing feature is the relatively large percent discrepancy for Venus
   c. (Data inaccurate for Mercury, because of reliance on correction for refraction, and Tychonic data limited for Saturn because of 29+ year period)

4. Notice that this third "law" differs from the first two: it has much more the character of an inductive generalization from "data"
   a. Of course, the periods, but far more so the semi-major axes, are scarcely data, for they are both being inferred from observations, especially so in the case of the semi-major axes
   b. But the evidence here akin to classical induction from cases, as well as to "curve fitting" -- i.e. formula fitting
5. Kepler's subsequent physical explanation of this law, in the *Epitome*, turned on the claim that the period is proportional to (path length ∗ quantity of matter) / (magnetic strength ∗ volume)
   a. For the amount of matter in the planet provides resistance to continued motion, and the larger the volume (*moles*), the more magnetic effect can be "soaked up"
   b. On Kepler's view the magnetic strength diminishes as $1/r$ (in contrast to the intensity of light, which he had correctly concluded diminishes as $1/r^2$)
   c. Thus, the "law" entailed a potentially testable consequence, viz. the ratios of densities of planets vary as $1/\sqrt{r}$; problem, of course, was to determine densities independently of it

F. *Epitome Astronomiae Copernicanae* (1618-1621)

1. The *Epitome* was published in three separate installments, covering three different subjects:
   a. Books I-III (1618) dealing with (largely conventional) spherical astronomy
   b. Book IV (1620) dealing with theoretical astronomy, including discussions of underlying physics -- "Celestial Physics, i.e. Every Size, Motion, and Proportion in the Heavens Explained by a Cause Either Natural or Archetypal" -- preceding Books V-VII
   c. Books V-VII (1621) dealing with practical geometric problems that arise in the new astronomy; V on orbital geometry, VI on the individual planets, VII a rap-up with comments on Ptolemy etc.
2. With its three opening books on spherical astronomy, it was clearly intended to be a comprehensive text in astronomy for universities
   a. A textbook in Copernican astronomy, more accessible than Copernicus's *De Revolutionibus*, yet presenting not Copernicus's system, but the "Copernican-Keplerian system" -- "the Copernican system as expostulated by Kepler," to quote Newton's statement of the matter
   b. But with a large amount of conjectural physics, from which the motions are derived, and complicated efforts on a number of recalcitrant problems, most notably that of the Moon
   c. Confidently Copernican, and not Tychonic, because so much of this physics turns on the Sun; indeed, offers 18 reasons to reject Tychonic (pp. 71-78), none knockdown
3. Successful as a textbook -- e.g. reissued in 1635 after the initial successes of the *Rudolphine Tables* began securing converts
   a. "For many years it remained one of the few accessible sources for the details of the Copernican system (including, of course, those essential revisions introduced by Kepler)" -- Gingerich, p.75