E. *Dialogue Concerning the Two Chief World Systems* (1632)

1. The *Dialogue* -- written in Italian, and not Latin -- was obviously aimed at the general educated public, not the international community of astronomers and "scientists"
    a. It succeeded in this respect, becoming the primary source on the controversies over astronomical systems and on new telescopic discoveries for much of the educated public, abroad as well as in Italy -- a wonderfully accessible, entertaining book
    b. Has remained wide-read and influential ever since -- primary source of our stereotypical views about 17th century science -- Ptolemy vs. Copernicus, the scientific revolution, etc.
2. Dialogue style, adapted with great success from Plato, enabled him to portray the dogmatic opposition of the Peripatetics with a great deal of scorn and humor
    a. Salviati: a learned proponent of Copernicanism
    b. Sagredo: a thoughtful, well-educated, open-minded layman
    c. Simplicio: a rigid follower of Aristotelian, that is, Scholastic, doctrine
3. First Day: a sustained attack on Aristotelian natural philosophy (*Physics*) and Cosmology (*De Caelo*), the philosophical world-view Scholasticism had attached to the Ptolemaic system
    a. An attack on Aristotle's account of motion (natural and violent), invoking experiments (mostly thought experiments)
    b. An attack on Aristotle's claims about the perfections of celestial realm, invoking telescope observations (e.g. Moon and Sun)
4. Second Day: responds one-by-one to all the traditional arguments against the diurnal rotation of the Earth, arguing that the phenomena are more straightforwardly saved by postulating it
    a. Attacks on Aristotle -- even more so, on the dogmatic followers of Aristotle who accept him blindly as the ultimate authority -- especially strong in Second Day
    b. Mentions for the first time in print his findings on projectiles, falling bodies, and pendula (see *Two New Sciences*)
5. First two Days thus amount to a devastating attack on Aristotelian natural philosophy, at least as put forward by the Scholastics, and an espousal of Galileo's new natural philosophy
    a. What the book is now most famous for, painting a portrait of intellectualism in late Scholastic years
    b. Many attributions of advances in physics by Galileo stem from this half of the *Dialogue*, in which he uses thought experiments to teach a new way of thinking
6. Third Day: a sustained defense of the Copernican system, especially of the annual motion of the Earth, covering both Copernicus's non-empirical reasons and the evidence from the telescope
    a. Includes discussions of stellar parallax, limitations in the astronomical observations of the times, etc., and even an extended discussion of Gilbert's *De Magnete* (pp. 464-477)
    b. Brings out forcefully the impact of the telescope -- e.g. on planetary sizes
7. Fourth Day: presents Galileo's "proof" of the diurnal and annual motions of the earth, turning on the claim that the tides can be explained by, and only by, such motion

a. Galileo's solution to one of the more perplexing problems of the time, the tides
b. An idea he had had for explaining the tides since the 1590's, perhaps the source of his initial turn to Copernicanism
c. (Ending with a short, but forceful attack on Kepler, followed by what Urban VIII took as a parody of his own principal argument for thinking that the question of the systems is beyond our capacity to resolve)

8. Book as a whole presents a devastating contrast between the open-minded pursuit of knowledge, reflected by the modest Copernicans, and a closed-minded, know-it-all dogmatism, reflected by the Scholastic proponents of Ptolemy and Aristotle (Galileo's life-long opponents)
   a. A great strength: displays how empirical considerations, including results of experiments, can be marshalled into compelling arguments
   b. A great fault: makes empirical science sound much too easy -- just get rid of dogmatism and let the world answer questions
   c. A myth about 17th century science and science generally that persists even today

F. The Copernican System of the *Dialogue*, Versus Kepler's

1. The Copernican system defended in the *Dialogue* (p. 376) is one of perfect concentric circles, with satellites in perfect concentric circles about their principals
   a. "Deduced" from telescopic observations of phases, entailing that Venus and, by inference, Mercury go around Sun, while superior planets must have orbits greater than sun-earth distance
   b. Telescopically observed sizes of the planets also relevant -- something inaccessible before the telescope
   c. Only open element in "deduction" is whether the sun moves around the earth, or vice-versa
   d. Passage (pp. 371-381) worth close scrutiny, both of the argument and its limitations
2. Underlying physics: perfect uniform circular motion is natural, and will persist forever unless interrupted from outside
   a. Attack on Ptolemy's equant as violation of uniform circular motion (p. 396f, along with attack on epicycles)
   b. In Fourth Day admits of a yet to be observed, monthly non-uniformity in earth's motion, caused by moon being nearer to and farther from the Sun, explained via analogy with pendulum with a counterbalance, and hence fully consistent with underlying physics
3. No explicit mention of Tychonic system, as such, and the problem of observational equivalence it posed, other than implicitly in the appeal to aesthetics in the "deduction" of the Copernican (see p. 379f)
   a. Aesthetic argument from the way in which the earth-sun period would place it nicely between Venus and Mars, though without mention of the more impressive numerical fit indicated by Kepler’s 3/2 power rule
   b. The two chief world systems, written at a time when the Ptolemaic had almost no surviving

proponents within the astronomical community

c. Tychonic system neutral with respect to all of the telescopic observations, and hence Galileo had no empirical arguments against the sun (and planets) going around the earth, save for his theory of the tides in the Fourth Day

4. No mention of Copernicus's eccentricities and epicycles, nor of Kepler's ellipses, and no mention of need for departures from simple circular motion in order to give an account of retrograde loops and other such phenomena
   a. Never discussed Keplerian motion anywhere, though hard to believe he was unaware of it
   b. The *Dialogue*, for all its concerns with empirical arguments, simply nowhere presents astronomy as a science in pursuit of "perfection" in prediction, or even success in capturing the patterns of varying shapes and timings of the retrograde loops
   c. Thereby suppresses the entire achievement of Ptolemaic astronomy -- the likely source of the historical myth that Ptolemaic astronomy was not first-rate science -- and also the elaborate complexity of both Copernicus's system and his *De Revolutionibus*
5. Can only conjecture on why he chose to ignore the real state of orbital astronomy as a science -- a decision that borders on flagrant intellectual dishonesty
   a. All is fair in polemics when the other side is so obstinate
   b. Truly believed that planets had to follow uniform, circular motion, and hence considered alternatives impossible
   c. Viewed small deviations from uniform circular motion as second-order effects of limited interest
   d. Was aware of residual problems in observational accuracy (pp. 449ff and 527f), and perhaps thought that preoccupation with precision in astronomy was premature
   e. Believed orbital trajectories still wide-open to dispute -- mention of disputes over orbit of Mars and the problems with the moon (p.528) -- giving him room to hold his own dogmatic views about motion
   f. Seems to have had no patience with such preoccupation with detail and exactitude
6. Also, must not lose sight of the fact that the *Dialogue* was more an argument for a philosophical view -- a world-view and an accompanying view of empirical knowledge -- and not a presentation of evidence for a scientific theory
   a. Galileo, unlike Kepler, not especially concerned with problems within the technical discipline of astronomy
   b. Concerned with the general intellectual climate, as reflected in the university curriculum
   c. And, in further contrast to Kepler, arguing for Copernicanism not through the detailed motions of the planets, but from largely qualitative arguments

G. Galileo's Theory of the Tides, Versus Kepler's Theory
   1. The *Dialogue* culminates, in Galileo's own mind, with his theory of the tides, for it provides a "proof" of the motion of the Earth insofar as it is the only possible (?) account of the tides

a. In contrast to aesthetic arguments offered earlier for Copernicanism, an empirical argument
b. And hence the answer to Tychonism until such time that better observational instruments could be built that would reveal the annual parallax of the stars (p. 449f)
c. The argument that Galileo had been developing for decades, finally choosing to publish it here not just as his account of the tides, but as a knockdown case for the Earth's motions

> Certain necessary assumptions having been made, these are that if the terrestrial globe were immovable, the ebb and flow of the oceans could not occur naturally; and that when we confer upon the globe the movements just assigned to it, the seas are necessarily subjected to an ebb and flow agreeing in all respects with what is to be observed in them. (p.484)

2. The problem of the tides arises because of three distinct regularities they exhibit (as stated on p. 485), though somewhat complicated from meteorological and local variations
   a. A roughly twelve hour cycle -- two high tides per day
   b. A monthly cycle, correlated with the Moon in two ways (positionally and vis-a-vis the changing time of high tide)
   c. An annual cycle, correlated with position of the Sun
3. Galileo's explanation of the tides turns on the fact that the absolute velocity of the surface of the earth is greater on the side opposite the sun than on the side nearer the sun (p. 494f)
   a. Hence, surface accelerating and decelerating, which produces an east-west sloshing motion of the oceans and large seas
   b. A 12 hour instead of 24 hour period because secondary effects (length and depth of water) impose their period on the vibration of the water (p. 500!)
4. Monthly cycle then explained via the yet-to-be-observed monthly variation in the earth's motion associated with the changing position of the moon, acting as a pendular counterbalance, and the annual cycle by effects of the tilted axis (pp. 519-534)
   a. Monthly variation: pp. 522-527
   b. Annual variation: pp. 530f
   c. (Note discussion of solar variation, p. 528f, including Drake's footnote, p. 576)
5. Attack on Kepler for lending "his assent to the moon's dominion over the waters, to occult properties, and to such puerilities." (p. 536)
   a. Reflects Galileo's complete opposition to forces acting at a distance, part of his atomistic version of the "mechanical philosophy" we will be looking at later (with Descartes)
   b. I suspect that this short remark did much to discredit Kepler in the eyes of the subsequent learned public -- this in spite of the fact that Kepler proposed gravity to be a mutual inter-action and conjectured a gravitational cause of the tides
6. Notice, however, that with the exception of no appeal to action at a distance, Galileo's approach here ends up being akin to Kepler's in one respect: reasoning from the phenomena to (conjec-tured) physics back to second-order features of the phenomena, with ad hoc moves as needed
7. Galileo's account of the tides has long been ridiculed in our post-Newtonian age, but Paolo Palmieri showed in his dissertation that there is much more to it than generally recognized

a. (Palmieri a former Ferrari engineer specializing on sloshing fuel in tanks of race cars)
b. Actual tides, ignoring meteorological effects, result from a combination of (1) gravity toward the moon and sun, (2) rotation of the earth, and (3) depths and widths of channels
c. Palmieri (see Appendix) argues that Galileo recognized the last of these, and to some extent the second, so that his mistake concerns only the driving source of the tides

H. Galileo's Trial and Recantation (1633)

1. In spite of the numerous Imprimatur's, the *Dialogue* was condemned within 6 months of its publication, and Galileo was ordered to stand trial for "vehement suspicion of heresy" before the Inquisition, where he was treated with due leniency
   a. Though shown the instruments of torture, was never tortured (nor really imprisoned while awaiting trial)
   b. Result (see Appendix): convicted of vehement suspicion of heresy (Copernicanism and freedom to hold opinions after declared contrary to Scriptures), which would be absolved provided he abjured; never convicted of heresy
   c. Sentenced to (palatial) house "arrest" for remainder of his life, and promises no subsequent publications (violated)
      (1) Initially with Cardinal of Siena, then at Arcetri, finally in Florence itself
      (2) Care from daughter Virgina, especially after going blind (see Sobel's book)
2. An immediate *cause celebre* throughout the educated world: the world's foremost scientist being made to abjure views for which he had marshalled strong empirical evidence
   a. An important element in anti-Catholicism, reinforced by fact that the *Dialogue* and other Copernican works were not removed from the Index until 1822 (with revised Index in 1835)
   b. A subsequent decline in science and mathematics in parts of Italy, with distinct shift toward England, Holland, and France
   c. In 1897 Leo XIII announced a view of relation between science and Scriptures akin to Galileo's (1616 letter to duchess); in 1979 John-Paul II acknowledged that Galileo suffered unjustly, and in 1992 Church acknowledged he was innocent of wrongdoing
   d. (See Finocchiaro's *Retrying Galileo* for the history of reconsideration of Galileo's trial)
3. One long investigated and much disputed question: why did the Church choose to try Galileo and risk the very response that it received -- e.g. de Santillana's *The Crime of Galileo* and Redondi's *Galileo Heretic* , and (best) Fantoli's *Galileo for Copernicanism and for the Church*
   a. Galileo's Jesuit enemies within the Vatican, including Father Grassi; on this view Copernicanism a lesser consideration; Urban VIII himself and his sense of a violation of trust and friendship the key to the 1633 outcome
   b. A question of authority -- intellectual and otherwise -- aggravated by Bruno's conviction, Campanella's defense, and Urban VIII's difficult political position at the time owing to pressure on him to commit Vatican resources to the Thirty Years War
   c. Urban VIII continued his animus against former friend, even denying a request for a