Other Developments in Astronomy from 1642 to 1684

I. A New "Post-Galilean" Generation of Scientists

A. "Forty Years that Shook Science"

1. With the publication of Descartes' *Principia*, the pieces that will come together in Newton's *Principia* are, in a sense, on the table

   a. Kepler's innovations -- e.g. the Sun as reference point, bi-section of the eccentricity of the Earth-Sun orbit -- and his three "laws," have at least set a new standard in predictive astronomy

   b. Galileo's new science of natural motion, including a unified, elaborate mathematical theory and the potential for a wide range of experiments

   c. Descartes' approach to conceptualizing motion, using elastic impact as a paradigm and raising the problem of centrifugal *conatus* in curvilinear motion

   d. (Also basic results in optics, several results in statics and on mechanisms, and initial results on gases, thanks to Torricelli's barometer)

2. On the standard way of viewing Newton as synthesizing Kepler and Galileo, under influence from Descartes, the forty years between 1644 and 1684 tend to be portrayed as a hiatus, awaiting the arrival of Newton's genius

   a. Nothing could be further from the truth; these years, especially starting with the mid-1650's, are among the most intense periods of development in the history of science

   b. The title of Gamow's book on the development of quantum mechanics -- *Thirty Years that Shook Physics* -- is apropos here

   c. "Forty years that shook natural philosophy" forever, pushing it toward the separate, autonomous discipline of physics

3. This is the period in which we start seeing for the first time a large amount of work that meets the standards of the best science today -- work that in every respect looks like science to us

   a. Kepler's reliance on "physics," Galileo's talk of 'impetus' and his attention to Aristotle, and Descartes' arguments for his laws look antiquarian to us in a way that Newton's *Principia* does not

   b. But this change in "scientific style" is something Newton inherited and extended, and not something he invented

   c. It developed over the course of years, roughly from 1655-1685, as we have already begun to see with Huygens's work in mechanics -- "standing on the shoulders of giants"

4. This period is also marked by the emergence of a true scientific community, setting standards, defining problems, and criticizing and even ostracizing those who work under a different conception

   a. For me, perhaps the most exciting and satisfying feature of the period is the extent to which the community pulled together and yet at the same time remained intensely self-critical

   b. Many factors combined to make this possible, but one of the most important was the dominant influence of Christiaan Huygens over these years

5. Perhaps in part as a response to Descartes, perhaps in part because of problems in replicating Galilean experiments, and perhaps in part from the challenge posed by the serious rivals to Kepler, this period is marked by a much stronger commitment to the idea that the empirical world ought to be the ultimate arbiter
   a. One way this shows itself is in closer attention to details of experimentation and observation
   b. But it also shows itself in the form of a constant open recognition of what the evidence has not yet succeeded in doing -- i.e. in a much stronger focus on ways in which specific evidential arguments fall short of settling issues
   c. With this, an increasing recognition of the difference between philosophy and empirical research and between polemics and evidential reasoning

B. The Legacy of Descartes' *Principia*

1. The legacy of Descartes that has been most widely recognized ever since is the impediment to science imposed by his restrictions on theorizing
   a. The insistence on no forces or action at a distance became a major open impediment to the acceptance of Newton's *Principia* -- an obstacle that had to be overcome with argument
   b. But the same is true, though less obtrusive, in the case of those who were looking to draw conclusions for such things as the specifics of orbital trajectories -- an added challenge that had to be overcome
2. A second part of the legacy that has often been noted is the extent to which Descartes' self-confidence -- if not arrogance -- provoked some of those who read him (especially Huygens and Newton)
   a. They may well have been challenged into finding alternatives to his conclusions
   b. In this respect Descartes left a lot of lines of thought to be pursued in response to his claims of having achieved either the best or the only possible explanations of various phenomena
3. But Descartes also had a positive impact, for while the answers he offered were almost uniformly unsuccessful in the long run, the same cannot be said of the questions he asked
   a. Descartes focused attention on new questions; by contrast, Kepler and even Galileo, to some extent, inherited their questions
   b. Even in the immediate aftermath, many people were less worried about Descartes' answers than about whether his questions were appropriate and, if so, how to get at them
   c. Furthermore, Descartes stratifies questions -- i.e. he gives reasons why some questions need to be answered before others are addressed (e.g. why are the orbits curvilinear at all)
4. One such set of new questions concerns the conceptual foundations of "mechanics"
   a. What why-questions are appropriate to ask about motion at all, where the specification of the questions includes the circumstances that give rise to them and a range of possible answers
   b. By raising the question, what are the fundamental, universal laws of nature -- i.e. the governing principles with which all explanation must stop

c. The legacy here also includes change of motion under perfectly elastic impact as the paradigm relative to which such conceptual foundations can be formulated

5. A second set of new questions concerns planetary motion
   a. The primary question becomes, why are the trajectories curvilinear at all
   b. Other questions are not just secondary; whether they have any interesting answers at all depends on the answer to this question
   c. Descartes does not as such deny the possibility of discovery through detail, but he does force people to question whether various details can ever be the basis for discovery
6. Finally, Descartes' legacy includes a whole host of other questions in physics
   a. E.g. what is light, what is the difference between iron and non-magnetic substances, etc.
   b. The questions about the cosmos that came to be addressed by cosmology, including questions about what gravity is

C. The New Generation: Huygens among Others

1. A large number of figures achieve prominence in the 43 years between the publication of the two *Principia*'s, including people who will be central throughout the rest of the course
   a. In England: Wallis (1616-1703), Ward (1617-1689), Horrocks (1618-1641), Wing (1619-1668), Mercator (1619-1687), Streete (1622-1689), Boyle (1627-1691), Wren (1632-1723), Hooke (1635-1702), James Gregory (1638-1675), Newton (1642-1727), Flamsteed (1646-1719), Halley (1656-1743) -- Halley belonging in the group because, as a prodigy, he interacted with the others
   b. On the Continent: Borelli (1608-1679), Hevelius (1611-1687), Picard (1620-1683), Mariotte (1620-1684), Rohault (1620-1672), Auzout (1622-1691), Pascal (1623-1662), Cassini (1625-1712), Huygens (1629-1695), Richer (1630-1696), Campani (1635-1715), la Hire (1640-1718), Roemer (1644-1710), Leibniz (1646-1716)
2. All of these people are post-Galilean in the sense that they all came of age after his trial
   a. Whether because of the trial, or for some other reason, all of them (save for Leibniz) maintained a strict separation between their work in empirical science and other matters
   b. And Leibniz was the only one of them who made any sort of lasting contribution to philosophy
3. A post-Keplerian and post-transit-of-1631 generation too: for all of these individuals, and hence for science in their times as well, Kepler’s ellipse, if not his entire orbital theory, was a starting point
4. The dominant intellect, and consequently leading figure among them throughout the 1657-1687 period was clearly Christiaan Huygens
   a. Visits to Paris starting in mid-1650's, which became his primary residence from 1666 until France turned anti-Protestant in the 1680s, although he also traveled widely -- e.g. repeatedly to England (1661, 1663, 1689, etc., FRS 1663)
   b. Personally acquainted with everyone on the above list except perhaps Hevelius, Campani, Ward, and Flamsteed, thereby replacing Mersenne as the principal unifying figure

5. Huge amount of research over 45 year period, especially from 1655 to 1665, with profound influence on others through personal contact
   a. Work in astronomy primarily in 1650's -- including lense grinding and the better telescopes in the first of these years -- culminating in *Systema Saturnium* (1659), which established him worldwide as a major figure
   b. In mechanics, from 1640's on, culminating in *Horologium Oscillatorium* (1673), which in a sense completes and replaces last two days of Galileo's *Two New Sciences*
   c. In other areas of physics -- most notably optics and light and gravity -- from the late 1660's on, culminating in *Traité de la Lumière* (1678 (draft), 1690) which presents a wave theory of light and *Discourse on the Cause of Gravity* (1669, 1678, 1684 (drafts), 1690)
   d. In mathematics, the first textbook in probability theory (1657), the theory of evolutes, and extensions of post-Cartesian geometry to numerous further curves, including logarithmic and exponential, tied to quadratures of hyperbola
   e. In technology, the leading designer of clocks, as well as several other contributions, and for a period in the 1650s the source for the world's best telescopes, with his correcting eyepieces
6. The person on the list who may have known Descartes best from his teen years and, because of his research in the third of the above categories, often thought to be a Cartesian; nevertheless, more accurately thought of as the chief follower of Galileo and Mersenne
   a. Extends the best in Galileo -- mathematical theories, telescopes, experiment, uniformly accelerated motion, etc. -- but with Mersenne's emphasis on clear empirical confirmation
   b. As such, the style-setter in science in the years between the two *Principia*'s

II. Astronomy from 1642 to 1660: Revisitations

A. Boulliau's Geometrical Orbital Theory

1. Need to start with another French priest from Descartes' generation, Ismaël Boulliau (1605-1694), who developed the first serious rival to Kepler's orbital theory
   a. Opposed not just to Kepler's physics, but to all physics in mathematical astronomy -- restore discipline to branch of geometry by insisting throughout on geometrical arguments
   b. Restore Copernican foundations by insisting on uniform circular motion, while allowing ellipse

      "To bring the motions of Mercury under numerical laws was difficult if not in fact impossible for pre-Keplerian astronomers who used only the circular hypothesis." (Boulliau, 1645)

   d. Thus with an underlying cosmology of sorts, though no physical explanation for the ellipse or for timing along it, and nothing about what resists tendency to recede from center
   c. Because area rule not geometrical, insofar as no geometrical solution to Kepler's equation, Boulliau rejected it as part of his goal of returning astronomy to branch of geometry
2. Basic idea: planet slides from circle to circle defined on a conical surface, resulting in an ellipse with one focus on axis of cone and the other at the Sun (see Appendix); in *Astronomia Philolaica*, 1645