1. Since distances of planets from sun known relative to distance of earth from sun -- the astronomical unit -- and apparent diameters reasonably determinable empirically, all that is needed to fix the scale of everything is the distance from the sun to the earth
   a. I.e. the solar parallax -- the difference in the angle to the sun from a point in line with the center of the earth and a point on the tangent line from the sun to the earth
   b. A value that is much smaller than tradition would have had it, and consequently proved hard to pin down (8.8 arcsec)
2. Determines actual sizes of planets from apparent diameters, for once sun-earth distance known, can infer earth-planet distance at any time from orbital theory, and then get actual planet diameter versus earth's via simple trigonometry
   a. Hence of interest from Apollonius and Hipparchus on, though only successful determination was moon's size versus earth's
   b. Ptolemy's value of sun-earth distance: 1210 e.r., 19 times the distance from the earth to the moon (solar parallax = 2.84 min)
3. Tycho had adopted a solar parallax of 3 min, slightly greater than Ptolemy's value
   a. Had used this value as a basis for making parallax corrections to observations, reflecting the latitude of the observer -- corrections that were then offset by estimated corrections for atmospheric refraction
   b. In particular, then, Tycho's solar theory -- most notably, its eccentricity -- ultimately was based on his value for solar parallax
4. Kepler adopted half of Tycho's value of solar eccentricity -- 0.018 – for his bisected eccentrcity of his earth-sun orb it in both *Astronomia Nova* and the *Rudolphine Tables*, but he had also found the parallax of Mars to be undetectable
   a. This had led him to conclude that the Solar parallax had to be no more than 1 min of arc, a value he announced in the *Epitome* and in the *Rudolphine Tables*
   b. But did not go back and alter Tycho's corrections to his observations, nor Tycho's solar eccentricity
   c. (Nor did he incorporate his corrections for atmospheric refraction into the *Rudolphine Tables*, but stayed with Tycho's set of corrections)
5. Thus, as was clear to a variety of astronomers working on questions of celestial scale after the 1631 transit of Mercury, the whole issue of scale was somewhat up in the air until the Solar parallax was determined with greater confidence
   a. A central concern in astronomy over the next decades, affecting even Newton -- another evidential problem, though in fact tied to the classic problem of distances
   b. Raising immediate questions about the exactness of some of the observations on which tables were being based
   c. (An issue not entirely resolved until 1740s)

F. Horrocks on Venus: *Venus in sole visa* (1662)

1. Perhaps the most insightful response to this problem in the decade we are examining (1632-1642) was by Jeremiah Horrocks (1618?-1641), a young midland English (near Liverpool) follower of Kepler who had studied astronomy while at Cambridge, 1632-35
    a. Horrocks notably impressed by the *Epitome*, which he had read by 1637, and the *Rudolphine Tables*, which he acquired in May of that year (so far as I can tell, he never read *Astronomia Nova*)
    b. But bothered by thought that astronomy might not be perfectible -- i.e. bothered by Kepler's announced problems with the moon and with Jupiter and Saturn -- and by Kepler's physics
2. Very careful observations using an astronomical radius (without micrometer or telescopic sights) convinced him that Kepler's orbits for Venus and Jupiter needed refinement
    a. Table in Appendix shows discrepancy between Horrocks's measurement and predicted value based on the *Rudolphine Tables*
    b. And it confirms that Horrocks's observations were accurate, this by comparing with values obtained from Tuckerman's *Planetary, Lunar, and Solar Positions, A.D. 2 to A.D. 1649.*
3. First step was to reduce the eccentricity of the Earth's orbit from Tycho's and Kepler's 0.018 value to 0.0173, giving as immediate justification that the *Rudolphine Tables* have the vernal equinox occurring too soon
    a. Value of 0.0173 obtained by replacing Tycho's horizontal Solar parallax of 3 min with Kepler's value of 1 min, and then inferring the corrected eccentricity in Tycho's solar theory
    b. Horrocks did not know that Tycho's correction for refraction was also mistaken (too small by 40 sec for equinoctal sun); if he had, would have obtained a value still closer to 0.01688, our (Newcomb-based) calculated value for 1600.
4. Based on careful observations of Venus as it came toward inferior conjunction in April 1638, and after months of puzzling over numbers, he proposed new orbital elements (at end of September)
    a. Including an eccentricity of 0.00750, compared with Kepler's 0.00692, and a semi-major axis of 0.7233(3), compared with Kepler's 0.72413
    b. In other words, Kepler's eccentric circle was slightly (0.11%) too large, throwing the longitudes ever so slightly off
5. Horrocks notes that this not only brings Venus to within observational accuracy, but makes Kepler's 3/2 power rule hold exactly for it (removing the 0.11% discrepancy noted last time)
    a. One implication: put effort into cleaning up Kepler's orbital elements before drawing conclusions about discrepancies involving second-order physical effects and the imperfectibility of astronomy
    b. Another implication: can use very small discrepancies between carefully made observations and *Rudolphine Tables* to infer improved values in parameters underlying latter!
    c. Third implication: perhaps better to take 3/2 power rule to be exact and determine *a* from P (which is how Horrocks himself obtained the fifth digit in 0.72333)

d. Table in Appendix shows the advantages of doing this, though when Horrocks tried it for Saturn, encountered difficulties raising questions about perfectibility of astronomy

6. These results, along with his observation of the 1639 transit of Venus, reported in his *Venus in sole visa*, which was finally published in 1662
   a. Found that the apparent diameter of Venus during transit was 76 sec (versus 12 min predicted by Tycho); and from this concluded that both Mercury and Venus subtend 28 sec of arc when viewed from the sun
   b. Using this same value for earth, obtained a horizontal solar parallax less than 15 sec -- one of the first to offer a half-way right value!
   c. (The Flemish astronomer Wendelin had proposed 15 sec of arc in 1630)
7. Notice Horrocks's research strategy here: faced with discrepancy between observations and theory, don't immediately abandon the theory, but push it for all it is worth
   a. Assume theory correct, and see whether discrepancies telling one something about data used to fix the numerical values of the elements
   b. Regardless of whether theory is right, this way can characterize the discrepancies in a manner that exposes exactly how the theory falls short
   c. Kepler, of course, had done this; but Horrocks unique in doing it with Kepler's theory in the decades immediately following Kepler's death
   d. Horrocks working on Mercury, and still concerned with problems he had in achieving the same success with Jupiter and Saturn, when he died in January 1641
   e. In process made clear that Keplerian orbits more promising even than Kepler himself had shown

G. Horrocks and the Problem of the Moon

1. Interesting to speculate how much more progress astronomy would have made between 1630 and 1660 if Horrocks had not died at the tender age of 22 (give or take a year) or had not been working almost by himself (save for correspondence with Crabtree, who died in 1644, at the not much less tender age of 34)
   a. The one person at the time who was making progress by building directly on Kepler's efforts, as evident throughout the second volume of his Posthumous works (1673), which includes a large array of observations and comparisons of different Tables
   b. (Others pursuing paths parallel to Kepler's that in time lent confirmation to his work)
2. Horrocks's preoccupation with the perfectibility of astronomy led him to reconsider Kepler's lunar theory, attempting to avoid appeal to any extraordinary "intensions and remissions"
   a. Reported by Crabtree to Gascoigne in summer of 1642, distributed privately in 1672, and finally published in 1673 (*Opera Posthuma*)
   b. At Flamsteed's urging, became a key starting point for Newton, and continued to influence people as far afield as Euler throughout next century
3. Horrocks first cleans up Kepler's lunar parameters, initially using observed lunar eclipses and