(2) But for both this irrelevant to their work

5. The resulting new attitude had benefits for all, for one could now turn to either observatory and get extremely reliable information about what was and was not known
   a. Newton, for example, could write Flamsteed rather than having to search through books and journals or do observations himself
   b. Helped make possible increasing attention to discrepancies between prediction and observation as a source of evidence, for could now rely on statements about the discrepancies themselves

E. Observational Anomalies: The Speed of Light

1. The increased attention to precision in observational astronomy during the 1670's revealed a number of small anomalies that were taken at the time to be a basis for further empirical discovery
   a. E.g. Picard had discovered the "movement" of the North Star in his expedition at Uraniborg
      (1) Hooke detected a similar movement in the 1670s, announcing that it was the long sought annual stellar parallax, but didn't follow it up with supporting measurements and others did not replicate
      (2) An anomaly that was not resolved until after 1725 with Bradley's discoveries of the aberration of light followed by the nutation of the Earth
      (3) This anomaly limited the level of precision in astronomy until then
   b. Also Flamsteed's observations of Jupiter and Saturn, the vagaries in the movement of which he initially thought could be accommodated through improved orbital elements, but whether they could remained open
2. One such anomaly was a perceptible delay in the onset of eclipses of Jupiter's innermost satellite, Io, versus Cassini's tables
   a. This was first noticed by Cassini in the early 1670's, with delays in the range of 10 min (of time)
   b. Cassini apparently at first suggested that a speed of light effect was involved, but dropped this idea because no similar anomaly was noticed with the other three Galilean satellites
   c. Cassini instead concluded that there is an irregularity in the movement of Io, a view he continued to hold long after others had become persuaded by Roemer
   d. (Important because the eclipses of Io were providing a simultaneously observable phenomenon that could be used to determine longitude differences around the Earth, as originally proposed by Galileo, but brought to fruition in expeditions supported by the Royal Academy)
3. Cassini's predictions of eclipses for August to November of 1676 were published in the *Journal des Sçavans* in August, and Roemer then predicted, on the basis of his theory that the effect was due to a finite speed of light, that the 16 November eclipse would be 10 minutes late
   a. The prediction was successful, and the December issue of the *Journal* carried Roemer's brief paper, announcing the view that the speed of light is finite and using the delay to measure it (see Appendix for *Phil Trans* translation of paper)

b. Claimed a speed of light corresponding to 11 min from the Sun to the Earth (versus our mean value of 8 min 19 sec), though it turns out his data would have supported a conclusion of 9 min

c. No attempt at a precise value in terms of an earthly measure because he knew that the solar parallax was still at issue

4. Notice here how the marked increase in precision in orbital astronomy led not only to a fundamental discovery in physics, but to a measurement that could not at the time be done on the ground

a. Galileo's protegés at his center for experimental science in Florence had tried and failed to measure the speed of light, as noted by Descartes in his letter criticizing Galileo

b. Roemer one of the first examples clear to everyone at the time that planetary astronomy had progressed to a point where it could provide "experimental" measurements of a much higher quality than comparable experiments on earth

c. Roemer's measurement presupposed not just Cassini's accurate tables for Io, but also an extremely precise value of Jupiter's heliocentric longitude, as well as precise values for the Earth's longitude and Jupiter-Earth distances

5. Roemer's result, which was accepted right away by Huygens, Flamsteed, and Newton -- and more generally as it continued to account for the variation in the eclipses -- had important implications

a. In astronomy it entails a new round of corrections of observations of planetary position -- e.g. observed oppositions of Mars as great as 7 minutes (in time) off the true opposition

b. In physics it strikes at the heart of Descartes' theory of light in just the way that Huygens describes, opening the way to alternative accounts of the physics of light, including both Newton's particle theory and Huygens's wave theory

6. By 1684, enough had been learned about how to correct planetary observations -- for atmospheric refraction, parallax, and the speed of light -- to permit a substantial improvement over Tycho's level of accuracy

a. Still limited by the "movement" of the North Star, so that full advantage of the telescope could not be taken until after the 1740's

b. But major anomalies leading to potentially conflicting results and hence confusion had been eliminated -- in no small part in the way Kepler had envisaged, by drawing conclusions from discrepancies between observation and increasingly refined theory

V. Astronomy 70 Years After Kepler’s *Astronomia Nova*

A. Mathematical Astronomy at the End of the 1670s

1. By the end of the 1670s seven distinct approaches to calculating the motions of the planets were known to be of the same general level of accuracy, all of them mathematically neutral between Copernicus and Tycho, all of them known to Newton in 1684

a. Kepler's original approach, and Horrocks's variant in which 3/2 power rule used to determine mean distance; of the seven, only Horrocks’s did not include full tables for all of the orbits