b. James Gregory had even devised an infinite series solution to Kepler's problem, based on work by Wren on cycloids (and Newton was soon to follow with another such solution)

c. And Horrocks's idea of taking Kepler's third “law” to hold exactly and using it to define mean distances was acknowledged (by some) to yield improved orbital elements

6. Question then becomes, how near to exact do Kepler's “laws” hold -- a question that can best be answered by pushing Keplerian orbits for all they are worth, using data of the highest possible quality

a. In other words, the right conclusion finally gets drawn from Kepler's efforts: focus shifts to determining (refined) residual discrepancies and assessing their implications

b. New tables based on this effort do not finally emerge until well into the 18th century (ultimately by Cassini’s son and Halley) -- i.e. a concerted effort spread over more than a half century

IV. A New Standard in Astronomy: 1670 to 1684

A. The Royal Academy's Expedition to Cayenne

1. Cassini's efforts on the Sun while still in Bologna had shown him that the Academy's program in orbital reform could not go ahead until a proper way of correcting for refraction and solar parallax had been established

a. Two different approaches for correcting for refraction, one of which (Cassini's) used a single table with corrections all the way up to the zenith

b. Measurements at tropical latitudes needed to choose between these two, leading to the legendary expedition to Cayenne of Richer in 1672-73

2. Richer's measured solar declinations at Cayenne over a period of months (covering two equinoxes) showed that Tycho's corrections yielded a different obliquity of the ecliptic from the one measured in Europe, while Cassini's corrections did not

a. Result was a change in the obliquity of the ecliptic from Tycho's 23 deg 31.5 min to 23 deg 29 min, with comparable adjustments to solar eccentricity and the locations of the equinoxes

b. The new values also entailed that the horizontal solar parallax could not be greater than 12 sec -- even smaller than Horrocks' 15 sec, proposed following his work on the orbit of Venus

3. The timing of the expedition to Cayenne was based in part on the fact that Mars would be in opposition while near perigee in 1672, giving a special opportunity to measure its horizontal parallax

a. Since all orbital distances of the planets locked into one another, a successful measure of the horizontal parallax of Mars would establish the horizontal solar parallax as well, at last yielding celestial distances in terms of an earth measure

b. Tycho and Kepler had been unable to detect a Mars parallax, but equipment had improved, and the expedition would allow comparison of time-synchronized measurements between Paris and the western hemisphere

4. As Van Helden describes, the attempts to obtain the Mars parallax through the expedition were confounded by too much measurement error, in part because the telescopes taken to Cayenne did not

include micrometers

a. Cassini's review of the results, combined with (in some ways) more useful results obtained from time-synchronized measurements in Europe, led him to propose a value of solar parallax of 9.5 sec (21,600 earth radii), though not published until the 1680s

b. Flamsteed, working by himself in England, but with great care, obtained essentially the same value, reinforcing the finding and giving welcome support to Cassini

5. The net effect of the expedition, then, which was not fully reported until 1684, was to institute a substantial reform needed for precise measurements

   a. A new obliquity of the ecliptic, the line of reference for latitude and longitude; a sufficiently small value of solar parallax to make parallax corrections less important; and a standardized correction for refraction (influenced by Snel's law, as published by Descartes)

   b. Also such side benefits as Richer's discovery that the carefully calibrated pendulum clock he took with him lost around 2 and 1/2 min every 24 hours in Cayenne

      (1) Implying a 0.35% decrease in the acceleration of gravity between the equator and Paris, contrary to Galileo

      (2) Which Richer then confirmed via repeated measurements with a 1 sec pendulum over several months, revealing a need to shorten the pendulum by 1.25 lines

   c. Richer's report giving the observations was published in the late 1670s, a few years before Cassini's on the conclusions drawn from the expedition

B. Newton on Refraction: the Newtonian Reflector

1. Newton appears publicly on the empirical science scene for the first time during the expedition to Cayenne, submitting two papers (letters) to the Royal Society

   a. Lucasian Professor of Mathematics at Cambridge, following Barrow's resignation in 1669

   b. Had not published his work in math, but had allowed it to circulate among some British mathematicians, establishing him as one of the leading, if not the leading mathematician in England

2. First paper in 1672 describes some extraordinary experiments in refraction, using prisms and yielding compelling empirical evidence that white light is composed of light of the several colors

   a. Brought the constituents of the spectrum back together to form white light in an extremely delicate experiment, though one successfully duplicated by Hooke

   b. Part of the basis for his particle theory of light -- i.e. for the conjecture that light is composed of different kinds of particles, corresponding to different colors

3. Paper also explained the phenomenon of chromatic aberration -- a consequence of different refractions of the different colors, resulting in misaligned focus

   a. Incorrectly concluded that chromatic aberration not correctable in a refracting telescope -- an over hasty conclusion, since proper use of Huygens's eyepiece will permit correction

   b. But still a major breakthrough, for now know what source is