c. (Not inconceivable that efforts to do so might have led to using the actual sun rather than the mean sun as a reference, and with them to reduced discrepancies in predicted longitudes -- which might have made the theory even more entrenched

d. Not clear whether comparable progress on latitudes would have been possible, though shift from mean to actual sun might have been enough)

7. Perhaps a better formulation of my complaint is that, for all of Ptolemy's emphasis on empirical evidence, insufficient emphasis was placed on questions that remained open or had been only tentatively closed on the basis of very limited evidence; e.g.

   a. Are the Earth and the mean sun the appropriate points to which to refer all the motions?

   b. What are the distances of the planets from one another (and is the ordering of them correct)?

   c. Would any other object added to the system have to describe basically the same motion?

   d. (Note the subjunctive in this last question; this will become important in a couple of weeks)

C. Background: 13 Centuries of Ptolemaic Astronomy

1. Ptolemaic mathematical astronomy remained essentially intact over the next 14 centuries, forming the basis of the academic discipline of astronomy

   a. In Alexandria, then Arabs (and Iranians), and finally into Europe in the 12th century via the Moor migration into Spain

   b. A discipline within the great universities of Europe that started to be formed in the 13th century: Paris, Oxford, Bologna, etc.

   c. Textbooks explicating the basic system found in the *Almagest*, most notably *Sphaera* of John of Sacrobosco (ca. 1250) the main source until end of 15th century

2. Criticisms directed not at small inaccuracies in daily longitudes, which go virtually unmentioned, but at violations of uniform circular motion and non-centrality of the earth, on "philosophical" grounds

   a. Found how to use a minor epicycle on top of the major one to get same effect as the equant

   b. Worries not just about abandonment of uniform circular motion, but also about underlying physical mechanisms: how to realize equant with nested rotating (solid) spheres

   c. Also some attention to clearly wrong implication about how near the moon comes to the earth

3. Improvements in some aspects of Ptolemaic astronomy, but not in planetary orbits (nor in latitudes)

   a. Some improvement in sun and moon via further observations

   b. Correction to 1 deg per century precession of equinox, which was becoming glaringly wrong, throwing everything else off, after a few centuries

   c. Trepidation, a superposed, cyclic variation in the precession rate, keeping the average between Hipparchus and Ptolemy at 1 deg per century

   d. Alfonsine Tables (around 1270) an updated version of Ptolemy, incorporating trepidation and other small modifications (thought to be improvements), but with same basic treatment of planetary longitudes

4. From 11th century on, increasingly outspoken "doubts" (*Shukūk*) among Islamic astronomers of Ptolemy's violations of such "accepted principles"-- his phrase -- as strictly uniform circular motion and earth in exact center without offering any justifications (see Saliba quotation in Appendix)
    a. Some alternative mathematical approaches, most notably by al-Urdī (d. 1266), al-Ṭūsī (d. 1274), al-Shīrāzī (d. 1311)
    b. Ultimately, a complete alternative system of longitudes by Ibn al-Shāṭīr (d. 1375), obtained through a mathematical transformation of Ptolemaic theories that preserved uniform circular motion throughout with the earth at a center (thereby achieving consistency with Aristotle) while also eliminating empirical shortcoming of his theory of the moon
    c. None of this work was translated into a European language, and hence it remained unheralded in the west until the second half of the 20th century
    d. Nevertheless, as we shall see below, it somehow diffused into European Renaissance astronomy apparently through word of mouth, especially in northern Italy
5. By the late 15th century, when Copernicus was growing up, Alfonsine Tables becoming clearly inadequate -- e.g. several day slippage in vernal equinox, indicating need for calendar reform
    a. In part from failures of trepidation to correct Ptolemy's mistaken precession rate
    b. But also from Ptolemy's use of tropical year as his basic time unit, with Hipparchus's slightly incorrect value (365+1/4-1/300) resulted in a cumulative error distributed throughout his system that had become quite obvious three centuries after the tables were formed
6. Perhaps as part of the spirit of the age, there was a good deal of critical discussion of Ptolemaic astronomy in the European universities at the end of the 15th century, especially in northern Italy, where the Renaissance was flourishing
    a. Attempts to form physical models, with consequent interest in alternatives to equant
    b. Criticisms of implied claim about the moon, and about failures underlying calendar problems
    c. But no radically new systems -- Ptolemaic still taught, though most students of astronomy learned it from watered-down abridgements and commentaries, not from the *Almagest* itself
    d. *Almagest* in Greek published in 1515, ending need to rely on old, inadequate Latin translation

D. 15th Century Planetary Astronomy: Regiomantanus

1. A community of university astronomers in Europe in the 15th century, extending from Poland and Germany into Italy
    a. Spearheaded by Johannes Müller (1436-1476), better known by his Latin name, Regiomantanus
    b. Born in Königsberg, taught briefly in Padua, ending in Nuremberg
    c. Knew the *Almagest* in great detail, as well as at least some Arabic astronomy
2. Based on observations he concluded around 1460 that the Alfonsine tables were seriously inadequate, attributing the cause to a corruption of Ptolemaic astronomy
    a. Called for reform in astronomy based on systematic observations, which he initiated himself