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

b. His picture of reform was to remove misunderstandings and errors that had made their way into Ptolemaic astronomy, returning to the original but with the sort of superior observational basis Ptolemy had originally called for

c. In early 1460s finished *Epitome of the Almagest*, an abridged Latin translation with comments, begun by his senior colleague Peurbach [1423-1461]); published in print, 1496

d. This became the basic source for Copernicus and subsequent generations

3. Regiomantanus's approach typical of the era: classic learning had become corrupted by the Scholastics; the solution was to return to the original works

    a. Regiomantanus initiated a huge publishing program, including the *Almagest*, *Geography*, and two other works of Ptolemy; Euclid's *Elements*; the surviving works of Archimedes; and the *Conics* of Appolonius (all of which he knew)

    b. His death at age 40 curtailed this project, though they were all published during the next century, in some cases continuing his effort

    c. Before he died he published two works of his own that contributed significantly to astronomy during the next decades: a 7-place trigonometric table to the minute of arc and a nearly 900 page Ephemerides for 1475-1506, giving calculated daily positions of the sun, moon, and planets

4. (One must not underestimate the importance of the invention of the printing press (ca. 1440s) to the emergence of active research in astronomy in Europe at this time

    a. Just as Luther's German translation of the Bible (1536) made it accessible to a large range of people, so too the printed versions of classic and current works in astronomy and mathematics made them widely available

    b. It also opened the way to intellectual careers for the first time to people who lacked voluminous memories, for memory ceased being a prerequisite)

5. Regiomantanus was the most talented of the astronomers of the era, but there were many others too

    a. His associate, Bernhard Walther (1430-1506) continued his program of observations over the period from 1475 to 1504, providing a good deal of useful data, especially of the sun

    b. These observations, together with those of Peurbach and Regiomantanus, were published (by Schöner) in 1544, and republished in 1618 by Snel

E. Nicolaus Copernicus: A Brief Biography

1. Born in 1473 in Torun, son of a well-to-do merchant who died when he was 10, after which he grew up under his uncle, the Bishop of Ermland

    a. Associated with Church all his life: canon, though never a priest

    b. Apparently lived in Ermland, which borders on Prussia, from roughly 1503 on, after completing his education -- i.e. from age 30 on

    c. Performed duties as canon, acted as a medical doctor, and carried on his research in astronomy

2. As good an education as could be had at the time