

ASTRONOMY 9: HISTORY OF COSMOLOGY
Assignment #10—Sample Solutions

2000 March 3

1. **Short essay (about 1 page): Choose one or more of the readings from Copernicus, Kepler, Bruno, Galileo, or Newton, and briefly discuss. Questions you might address are: What importance did the work have for cosmological thought? What do the writings reveal about the personalities of the authors or the societies in which they lived?**

Sample essay:

A. Johannes Kepler, from "The Epitome of Copernican Astronomy"

Kepler, [who is in many ways] the father of astro[physics], had a profound influence on modern cosmological thought. The Pythagoreans, Copernicus, and Tycho influenced Kepler. [Like] the Pythagoreans, Kepler believed that numbers and geometry formed the basis of the world. According to Kepler, the cosmos had to be geometrically beautiful. Most of his work was [based on new] observational [data]; when Tycho the great observer died, Kepler received all of his data. His careful observations led him to discover an error of eight arc minutes, and because of this, circular motions had to be thrown out. The most important of his contributions was his first law: that the planets orbit around the sun in ellipses. This discovery is by far his most important, because [it overturned 2000 years of circular dogma]. His second law was that [as a planet is moving around the sun] in an ellipse, equal areas are swept out in equal times, and [he believed] that magnetism is what keeps the planets orbiting the sun. During his lifetime, Kepler made another important contribution to cosmology, encompassed in his third law, which [states] that [the] period [of revolution] squared is proportional to the major axis [of the orbit] cubed. In the year 1619, he [published a work describing his attempt to create] music out of the [celestial] spheres. In his writings he also reveals [his ideas about] the mystery of the universe. He was a religious man and correlated the sun, sphere [of the fixed stars], and motion to God, the Son, and the Holy Ghost. He was an obsessive man and his greatest obsession was rooted in discovering why there existed only six planets. His writings reveal a poetic personality: he said the cosmos was a harmony of movement. Kepler lived in an era of Church dominance, [but] his ideas were [not persecuted, in part] because he correlated the cosmos to the divine trinity.

B. Galileo, from "Dialogue Concerning the Two Chief World Systems"

Galileo's greatest contribution to astronomical thought was his explanation of mechanics (motion). He described inertia: objects in motion remain in motion and objects at rest remain at rest. Motion is relative, discrediting [the impetus theory of] Aristotle. He was an advocate of Copernicanism. He was also the first to write his findings in Italian, a language that more people understood; therefore he made cosmological knowledge accessible to the common folk.

Unfortunately, he was very sensitive to criticism and was afraid of being laughed at, and because of this he hesitated to publish his discoveries. He also lived in an era where the Church dominated and controlled what was [considered to be cosmological "truth"]. However, at first] Galileo had a strong supporter within the Church, [who became Pope Urban VIII]. When Galileo was being attacked because of his beliefs, his supporter came to his aid. Yet in 1630, he wrote a dialogue in which he portrays his supporter [the Pope] as foolish, which gets Galileo in trouble. The Church was willing to pardon him as long as he did not claim his hypotheses to be [proven] true.

Due to his old age and [his] feeling [of] being defeated by the Church, he went back on his ideas. The Inquisition placed him under house arrest, [during which] he continued to publish. He was very arrogant: he claimed discoveries that had been previously discovered to be his. Both men scientists [Kepler and Galileo] were anti-social.

2. **An idea that had some popularity in the 1980s was that periodic mass extinctions every 26 million years were caused by an unknown tenth planet or small star orbiting the sun, called "Nemesis". If the orbital period is 26 million years, what is the mean distance**

from the sun (i.e., the semi-major axis of the elliptical orbit) of Nemesis? Express your answer in both A.U. and km.

For this problem, we use Kepler's third law, $P^2 \propto a^3$. If we use units of years and A.U.,

$$\left(\frac{P}{1 \text{ yr}}\right)^2 = \left(\frac{a}{1 \text{ AU}}\right)^3.$$

Solving for a ,

$$a^3 = \left(\frac{P}{1 \text{ yr}}\right)^2 \text{ AU}^3.$$

Note the *units* on this expression; many of you were quite sloppy with the units in this problem. Taking the cube root and substituting the value for P ,

$$a = \left(\frac{2.6 \times 10^7 \text{ yr}}{1 \text{ yr}}\right)^{2/3} \text{ AU} = (2.6 \times 10^7)^{2/3} \text{ AU} \approx 88,000 \text{ AU}.$$

Note the attention to *significant digits*. You generally only want to keep as many of these as you are given in the problem. In this case, we are given only two significant digits; the period is 26 million years, and not 26,763,827.5 years. So in the answer we only keep the first two significant digits. Although my calculator says "87,763.8295537", I round this to "88,000 AU". Now converting to kilometers,

$$a = 88,000 \text{ AU} \times \left(\frac{1.5 \times 10^8 \text{ km}}{1 \text{ AU}}\right) = 1.3 \times 10^{13} \text{ km}.$$

So we see that Nemesis is, on average, 88,000 times farther from the Sun than is Earth! Sometimes it would be much closer—the whole idea is that it is in a highly elliptical, or eccentric, orbit, so that once every 26 million years it comes in and knocks a few comets around, setting a few up for a collision with Earth! The collisions kick a lot of dust into the atmosphere, cooling the planet and killing lots of species; for example, the dinosaurs are thought to have been killed by a giant impact near the Yucatan peninsula some 65 million years ago.

Now, this large mean distance is one of the reasons why Nemesis is not a very popular idea any more. The nearest star other than the sun is less than 300,000 AU away. This means that other stars passing by the solar system would be expected to have a big impact on the orbit of Nemesis, probably knocking it out of orbit, or at least messing up the periodicity.