MODELS OF PLANETARY MOTION
The "first anomaly"

The guiding principle of ancient astronomy—a principle that guided early European astronomers as well—was *uniform circular motion.* It became the task of astronomy to explain the apparently non-uniform motions of the planets with models that obeyed the principle of uniform circular motion.

There are two major anomalies to be explained. The first is the observation that the planets (including the sun) do not appear to move at constant speeds in their orbits. The second is the phenomenon of retrograde motion. There are, of course, other irregularities—for example, the motion of the planets in latitude (that is, north and south of the ecliptic). But these two are the main ones, and they are often referred to as the first and second anomalies.

In the following diagrams, I have tried to show how both ancient Greeks and early modern Western European astronomers accounted for the first anomaly—that is, for the fact that the planets do not always travel at the same speeds in their orbits. These diagrams can be interpreted in *either* a geocentric or a heliocentric context!

Let us see how both heliocentric and geocentric astronomers might use these models.

Diagram 1
(unlabeled)
uniform motion

This diagram shows how a deferent circle would look if the motion of the planets were uniform.

- For Ptolemy, the point C would represent the earth, and point P might represent either the Sun, or the center of a planet's epicycle.
- For Copernicus, point C would represent the Sun! Point P could represent either the earth or the center of a planet's epicycle.

In both cases, the angle ACP increases *uniformly* with time.

Diagram 2
Eccentric

Since the apparent motion of the planets is *not* uniform, the model shown in the first diagram won't work. What was needed was a scheme that would preserve the principle of uniform motion, and at the same time display non-uniform apparent motion. The second diagram (labeled "eccentric") shows a model first introduced by Hipparchus, about 150 BC. Here the earth (or sun) is offset a little from the center of the deferent.

- For Ptolemy, C represents the center of the deferent circle. But the earth is offset a little from that center, so that it is located at point S, at a distance CS from the center. As before, point P might represent either the sun, or the center of a planet's epicycle.
- For Copernicus, the only difference is that S now represents the sun. Point P might represent either the earth or a planet.

For both astronomers, the model works in exactly the same way. The angle ACP still advances uniformly with time. For example, if P is the sun, the sun might start from some point A and in one quarter of a year, advance exactly 90° to the point P. In the next quarter year, it would advance another 90° to point B. The motion is uniform.

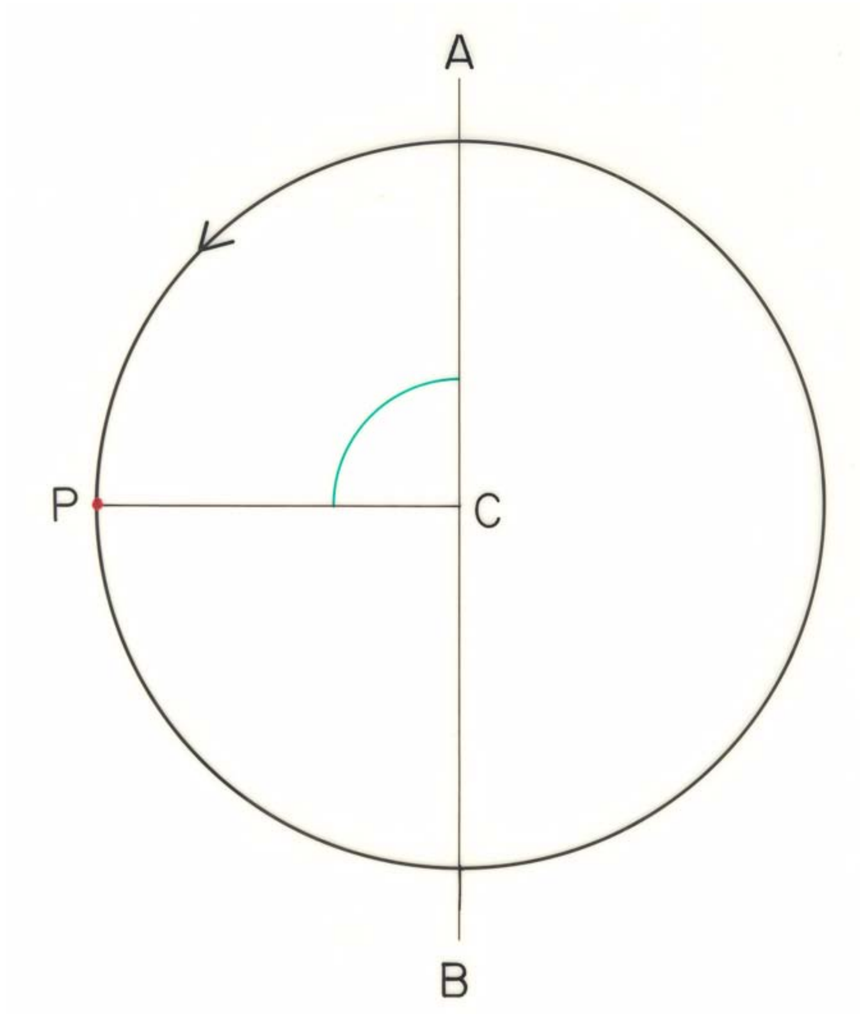
Nevertheless, the motion would *appear* non-uniform to an observer at point S. In the first quarter, that observer would see the point P move through the angle ASP, which is less than 90°. But in the second quarter, P would apparently move through the angle PSB—greater than 90°! In this model, therefore, the motion is uniform about the center C. Nevertheless, someone at S would see the motion appear to be non-uniform—point P would appear to move faster in some parts of the orbit than in others.

Diagram 3
Equant

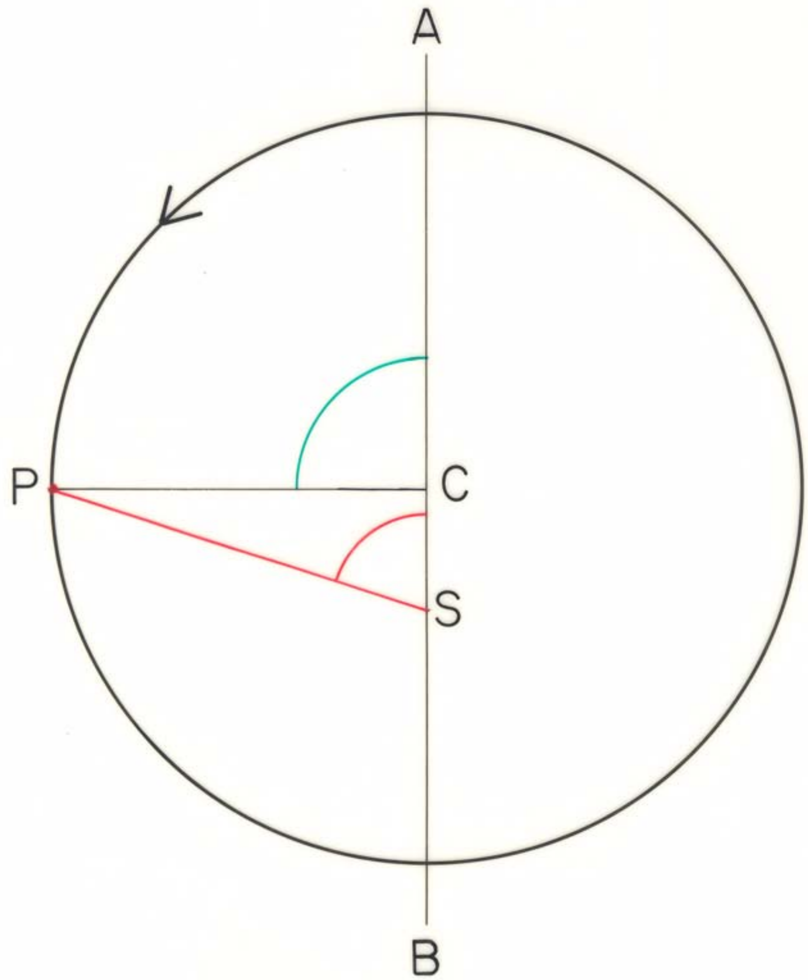
The model shown in Diagram 2 works well enough for the sun (or earth). But it is not good enough for the other planets—that is, the non-uniformities in the motion of the planets (Mars above all) are greater than this model can account for. Around 150 AD, Ptolemy introduced a further refinement, the equant construction shown in Diagram 3. The points C, S, and P are defined as before. But he also introduced a new point Q, the equant point, located so that the distances QC and CS are equal. And in this model, the motion is uniform about point Q, *not* around the center C.

In other words, the angle AQP advances uniformly. Again, let the point P start at point A, and suppose P takes some well-defined period—one year, for example—to make one complete revolution. Thus in one quarter of a year, the angle AQP increases by 90°. But the apparent motion seen at S—the angle ASP—is considerably smaller than in the simple eccentric model, as you can see by comparing that angle in the two diagrams. Similarly, in the second quarter of the orbit, the angle PSB is larger than in Diagram 2. Thus, the equant model has the effect of increasing the apparent non-uniformity of the motion.

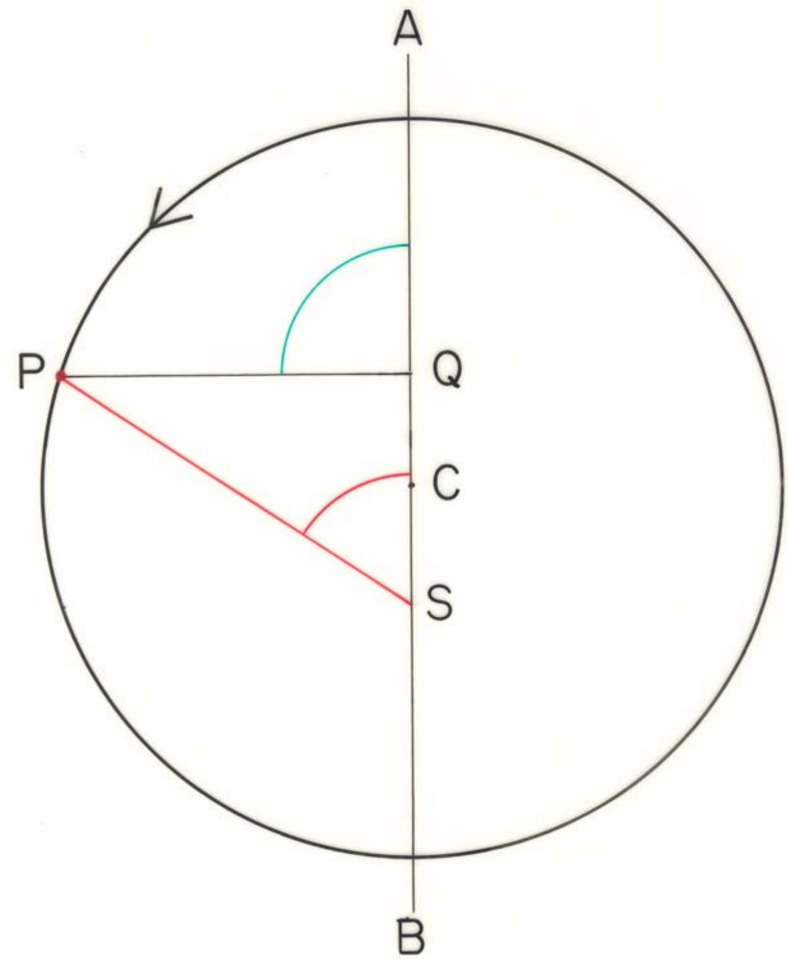
The equant model turns out to be surprisingly accurate. But one pays a price; for now the motion is no longer uniform about the center of the circle, but about the seemingly arbitrary equant point Q.



UNIFORM



ECCENTRIC



EQUANT