Lecture Notes: Keple r (1571-1630)

Overview of Kepler's life & celestial writings

***Mysterium Cosmographicum* (1596).** Copernicus's theory had not won many adherents in the decades immediately following his death. One of the few converts was Michael Maestlin, who taught his student Kepler the theory; Kepler says he accepted the theory for "physical, or if you prefer, metaphysical reasons." What motivated Kepler to devote his life to astronomy? He tells us:

> "There were three things in particular, namely, the number, distances, and motions of the heavenly bodies, as to which I searched zealously for the reasons why they were as they were and not otherwise."

In other words, Kepler wanted to know why there were exactly six planets instead of five or seven or... , and why the distances between the planets were exactly what they were, and not a little more or less. [Note: of course, today we say that there are nine planets, but Kepler and his contemporaries didn't know about Uranus, Neptune, or Pluto.]

Kepler's answer to the first two of these questions draws on the **Platonic (or 'perfect') solids**, which we earlier encountered in the *Timaeus*. This answer is the 'cosmographic mystery' referred to in the title of Kepler's book.
Why 6 planets? There are exactly 5 perfect solids, and Kepler had the idea that perhaps the five solids could mark off the boundaries of the six planets' orbits, by nesting the solids one inside the other (there's an orbit inside the innermost solid, and outside the outermost solid). So the reason there are six planets is that there are exactly 5 perfect solids -- if there were 7 perfect solids, God would have created 8 planets, according to Kepler.
Why are the distances between the planets what they are? Furthermore, Kepler found that if he arranged the order of nesting for the spheres in one particular way (Cube outside, then tetrahedron [pyramid], then dodecahedron, icosahedron, and octahedron), then the distances between the spheres drawn in between the solids matched up with the distances between the planets. [see picture]
Kepler describes this project as follows:

> "I undertake to prove that God, in the creation of this moving universe and the arrangement of the heavens, had in view the five regular bodies of geometry celebrated since the days of Pythagoras and Plato, and that he accommodated to these five bodies the number of planets, their proportions, and the relations of their movements."

The data actually matched up fairly well; Jupiter's orbit was not exactly what Kepler's nested-perfect-solid model predicted, though.

Kepler and Tycho Brahe. Kepler's clever(?) connection between the perfect solids and the astronomical data was noticed by the Danish astronomer Tycho Brahe, and as a result, Brahe invited Kepler to come work with him.
~ Brahe held a hybrid Ptolemaic-Copernican view: the Earth is at rest in the center of the universe, and the moon and the Sun orbit the Earth. However, all the other planets orbit the Sun.
~ Brahe improved the accuracy of naked-eye astronomical observation, and had the most complete and thorough data-sets. As a result, he had the best astronomical data in the world at the time. When he died, Kepler took over Brahe's post as Imperial Mathematician, and inherited all of Tycho's data.
~ Kepler tried several different versions of Copernican and Tychonic models to fit all the data, but even the best Copernican model's prediction for Mars's position was off from the actual observations by 8' [said: "8 minutes"]. (8' is tiny: there are 60' in one degree (and 360 degrees in a circle); the minimum distinguishable distance by the naked eye is just 4' -- that is, if two bodies are 3' apart, then we would only see them as one thing without a telescope.)
~ Although Copernicus himslef never hoped that his predictions would be better than within 10', Kepler felt that Copernicanism was true period, and not merely a good approximation to the truth. If it is true, it should give exactly the right answers. This 8' of difference between prediction and observation in Mars's apparent position leads Kepler to reject a fundamental claim of astronomy that had been accepted for at least 2000 years: Kepler suggested that the planets' orbits were not exactly circular.

***Astronomia Nova* (1609).** In this work, Kepler proposed the first two of (what are now called) Kepler's Three Laws. These laws are:
(1) All planets' orbits are *ellipses*, with the Sun at one focus.
(2) A line drawn from a planet to the Sun will sweep out *equal areas in equal times* (often called the "Area Law" today). Qualitatively, the planet moves faster when it's closer to the Sun, and slower when it's farther away.
And in 1619's ***Harmony of the World***, Kepler proposed the third:
(3) Let 'D' be the average distance of a particular planet to the Sun, and let 'T' be the time it takes that planet to complete one revolution around the Sun. For all planets, D^3/T^2 is <u>the same</u>.

Our Text: *Epitome of Copernican Astronomy*

Kepler's "physics of the sky." Kepler's writings unite projects that Ptolemy (and many other pre-modern astronomers) would want to keep distinct: (i) A mathematical model that will correctly predict the observed positions and movements of the celestial bodies ["astronomy" in Ptolemy's sense, a branch of mathematics] and (ii) a study of the material causes and effects of the celestial bodies ["physics" in an Aristotelian-Ptolemaic sense]. Because Kepler wants to combine astronomy with celestial physics, he has to address the traditional-classical theories of both.

Kepler's response to Ptolemy's views on celestial physics.

<u>Ptolemy's views</u>:
Ptolemy, Kepler tells us, did "not worry as to how the planets completed these circles [i.e., the path the

planets had according to the Ptolemaic model]." But Ptolemy should be worried, according to Kepler, because the models constructed were extremely complicated -- what could make the planets *really* be tracing out these paths? Ptolemy's answer:

> "We should not judge what is simple in celestial bodies by examples of things which seem to us to be simple... Therefore we must not form our judgement upon terrestrial things, but upon the nature of the things in the heavens"

So there is a sharp division between the way things work on Earth and the way they work in the heavens.

Kepler's response:
we should **not** think the celestial and terrestrial realms are completely and absolutely different. Even if there are some differences between the eearthly and the heavenly, "it does not follow that with respect to the celestial movements no terrestrial causes are akin." Knowing how things work here on Earth may reveal some clues about how things work in the heavens. This breaks down the old Aristotelian-Ptolemaic division between the mathematical science of astronomy and physics.

Kepler's response to Aristotelian celestial physics.

Basics of Aristotelian celestial physics:
(1) Heavens are made of solid spheres. The planets are embedded in the spheres. In order to fit the theory to the observations, some spheres must turn in one direction, others turn in others. There is no gap between the nested spheres; this explains what supports the planets, i.e., what keeps them from falling down or moving out of their positions.
(2) Each sphere is turned by a 'motor intelligence,' i.e. a (divine) mind capable of moving the sphere on its axis (like my mind moves my arms and legs).

Kepler's responses:
Against (1) [solid spheres]:
(i) Comets cross planetary orbits.
(ii) Argument from optics: if we were inside eccentric spheres (as the Ptolemaic-Aristotelian must assume), the light from planets would look different than it does.
(iii) Mars is sometimes closer to the Earth than the Sun, but other times Mars is farther from the Earth than the Sun. In a Ptolemaic-Aristotleian cosmos, the Sun's sphere would have to intersect Mars's sphere.
(iv) What's supporting the last sphere? Our air is certainly not solid enough to support the weight of so many gigantic spheres.

Against (2) [motor intelligences]:
(i) Mind *by itself* cannot move anything; it must be directly connected to bodily parts and their powers. (A paralyzed person can think just fine, but cannot move parts of their body.)
(ii) If a (divine) mind were the cause of the planetary orbits, then (according to Kepler) those orbits would be **circles**, not ellipses. So minds cannot be the cause of the planets' motions.

The cause of the planets' motions, according to Kepler

Do we need to postulate any cause for the planets' movements? Could we simply say that planets move in these motions without something **causing** them to move? I.e., they move 'of their own accord,' so to speak, as opposed to being moved **by** something else? Kepler says *no*: a planet is made out of (some sort of) matter, and all matter has a certain 'laziness' or 'powerlessness' [inertia] that makes it come to a stop if nothing is acting on it. (For example, baseballs don't move of their own accord -- someone (or something) has to move them.) Note: because planets have this tendency to resist moving, nothing is needed to "hold the planets up" -- thus there is no need for the solid celestial spheres of the Aristotelians.

Why does Kepler think the planets have this 'inertia'?
If planets had no inertia/ resistance to movement at all, then it would not take them any time at all to complete their movements: e.g., the Earth would complete a rotation in an instant, not 24 hours.

The Sun is the cause of the planets' movements. What is Kepler's evidence for this claim?
(1) The planets whose orbits are nearer the Sun have a higher average velocity than those planets whose orbits are farther away from the Sun.
(2) When any particular planet is closer to the Sun, it has a higher velocity than when that same planet is farther away from the Sun. (This follows from the 2nd Law.)
(3) The Sun is "beautiful" and the source of life and heat.
(4) [Kepler considered this his best argument] The Sun's rotation is in the same plane and in the same direction as the plane and direction of the planets' orbital revolutions.

***How* does the sun move the planets?** Answer: through its **moving soul**. Here, a *soul* is understood as whatever it is that makes a living thing alive -- so plants and animals have a sort of soul. A soul is thus not the same as a mind, which only humans and God have. Kepler does not have particularly good arguments for his claim that the sun has a soul -- the best one is probably the following: since the sun is the source of life and soul for things here on Earth, it must have a soul itself.

How does this moving soul move the planets?
~ Answer: Like a **magnet** moves iron -- without bodily contact. This is only an ANALOGY; Kepler is not claiming that magnetism moves the planets around. The Sun acts LIKE one end of a magnet, and each planet acts LIKE it has both ends of a magnet within it, i.e., an attractive side and a repulsive side (Kepler calls them the 'friendly' and 'unfriendly' sides of the planet.) [Note: William Gilbert had just argued a few years before that the Earth is a giant spherical magnet.]
~ So why do the planets orbit around the Sun? Answer: Because the Sun **spins** on its axis, and it drags the planets around with it. But the planets take much longer to complete one orbit than it takes the sun to spin once on its axis (25 days) -- Kepler says this is due to the planet's *inertia*.
~ In describing the relationship between the planet and the Sun, Kepler uses very Platonic language: the Sun has an active power "that smells more of form," whereas the planets have a "passive" tendency that "verges more towards matter" (897-8). The active and passive tendencies are "at war with one other.

Each has its share of the victory" (899) because the Sun does move the planets around, but the planets 'win' in that they move around more slowly than the Sun spins.

This conception of the Sun-planet relationship (partially) explains Kepler's first two laws.
First Law (Elliptical orbits). When the 'friendly' part of the planet faces the sun, the planet is drawn towards the sun; when the 'unfriendly' part of the planet faces the sun, the planet is pushed away from the sun.
Second Law (Area law). The closer a planet gets to the Sun, the stronger the Sun's pull or push on the planet will be. (Just as a magnet's force is stronger the closer you get to it.)