Lecture Notes: Galileo

The status of Copernicanism in 1600.

Copernicus' *De Revolutionibus* was published in 1543. But throughout the rest of the 1500s, very few people became completely committed Copernicans, i.e., people who claimed that the Earth revolves around a resting Sun. (Recent scholarship has shown that there were astronomers in the later 1500s who used and developed his models instead of Ptolemy's for doing calculations, without committing themselves to the claim that the Earth rotates around a resting Sun.) There were only around 10 or so committed Copernicans at the end of the 16th Century. Why?
1. Osiander's preface was thought to be Copernicus' for a while.
2. Still questions about how we don't fly off the Earth or at least feel its motion if it is, as Copernicus suggests, moving several miles per second.
3. **(The big one)** There was no developed physical theory that made sense of the heliostatic cosmos: in the traditional/ Aristotelian picture, the physics governing the Earth was very different from the physics governing the heavens. For both the materials and the motions of the terrestrial world were different [earth-air-fire-water vs. aither, and up-down vs. circular]. How do we make sense of the apparent up-and-down motions here on the Earth if we're rotating and revolving? The celestial bodies appear unchanging and eternal, whereas everything on Earth is mutable and ephemeral. In short, the Earth and the heavens seem obviously very different, and Copernicus' theory puts the Earth in the heavens, violating this apparently obvious distinction.

An overview of Galileo's early contributions to Copernicanism

1. (Before *The Starry Messenger*) Galileo showed that the nova of 1604 occurred out above the Moon, not in the Earth's upper atmosphere. 2. The moon has mountains and valleys. Thus it is not a perfect sphere, but is covered with features very much like the Earth's.
3. There are bodies revolving around Jupiter. This shows that not everything revolves around the Earth.
4. (After *The Starry Messenger*, but with his telescope) Venus has phases like the moon. These phases can only be explained on the heliocentric hypothesis.

(1) The nova of 1604. Recall that, according to Ptolemy and Aristotle, the celestial realm is *unchanging* and its objects are *eternal*. Tycho Brahe observed a bright new object in the sky -- a nova, which we now know occurs when a star explodes -- in 1572, and a nova was seen all over Europe in 1604. The followers of Ptolemy and Aristotle claimed that this change was not actually in the celestial realm, but in between the moon and the Earth. Galileo showed that the nova had to be above the moon, for there was no observed parallax. Here we see Galileo's typical method: start from an observed phenomenon and use some mathematics to analyze and understand that phenomenon.

Another important example of the Galilean approach: free fall. Galileo provided (pieces of) a terrestrial physics that was nonetheless fully mathematical. One of the foundation-stones of Galileo's

physics is his law of free fall, which asserts that, for a body falling freely from rest, the vertical distance covered by the body is proportional to the square of the time it has been falling. That is, if I drop a ball, in the first second it will travel one unit of distance, after two seconds it will have traveled (a total of) four units of distance, after three seconds, nine units of distance, and so on (4-16, 5-25, 6-36, ...). Galileo confirmed this hypothesis by performing experiments on an inclined plane. Finally, from this law and other reasonable assumptions, Galileo shows that the motion of a projectile on Earth must follow the shape of a parabola (i.e., y = x^2).

The Starry Messenger (Siderius Nuncius)

The dedication to Grand Duke Cosimo II de Medici. The first section of *The Starry Messenger* is a dedication to Cosimo II de Medici. Why does Galileo do this? Galileo is, at the time he writes this book, a professor at the University of Padua. Galileo considered this job acceptable, but what he really wanted was a position in a noble's court: not only would he be rubbing shoulders with the powerful, famous, and wealthy, but he could spend more time on his research, since he would have little-to-no teaching.
But how to get one of these cushy jobs as court astronomer and mathematician? A: Suck up to the noble family you want to work for. After Galileo observes (what we now call) the four largest moons of Jupiter, he names them after the de Medici family, calling them 'the *Medicean* Stars.' Galileo's sucking up paid off, and he was hired by the Medici court, so Galileo returned to Florence, his favorite place in Italy.

Galileo and astrology: Galileo is often depicted as a hard-headed skeptic, a modern scientist born ahead of his time. But Galileo makes astrological pronouncements in his dedication to Cosimo II:

> "For just as these stars [the 4 moons of Jupiter]... never leave the side of Jupiter by any appreciable distance, so ... clemency, kindness of heart, gentleness of manner, splendor of royal blood, nobility in public affairs, and excellency of authority and rule have all fixed their abode and habitation in Your Highness. And who... does not know that all these virtues emanate from the benign star of Jupiter, next after God as the source of all things good? Jupiter... at the instant of your highness's birth, having ... occupied the midst of the heavens, ... looked out from that exalted throne upon your auspicious birth and poured forth all his splendor and majesty in order that your tender body and your mind ... might imbibe with their first breath that universal influence and power." (pp. 24-25)

Virtually all court astronomers were required to draw up horoscopes for the nobles they served, so Galileo may simply be attempting to show that he has the skills necessary for the job he is applying for.

The Moon through the telescope. What did Galileo actually **see** when he looked at the Moon through the telescope? He tells us (p.31) that he saw many dark "spots" on the moon's surface, besides the ones that are visible to the naked eye. He then *infers* what the surface of the Moon must be like:

> "From observations of these spots... I have been led to the opinion and conviction that the

> surface of the moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it (and the other heavenly bodies) to be, but is uneven, rough, full of cavities and prominences, being not unlike the face of the Earth, relieved by chains of mountains and deep valleys."

This illustrates a *very* widespread phenomenon in science that is not always fully appreciated: when scientists perform observations in order to formulate or test a theory, those observations often contain a great deal of inference. To say that Galileo saw that there were mountains and valleys on the Moon is not quite right -- as he tells us, what he sees are spots, but he infers from the nature of those spots what the surface of the moon is like.

Galileo's arguments that the moon's surface is not uniform and smooth.
1. The boundary between the light and dark portions of the moon (the 'terminator') is jagged.
2. The small dark spots always have "their blackened parts directed toward the sun, while on the side opposite the Sun they are crowned with bright contours, like shining summits. There is a similar sight on Earth when we behold the valleys not yet flooded with light though the mountains surrounding them are already ablaze with glowing splendor" (32). See the two pictures on p.35.
3. In the darkened part, but near the terminator, there are many bright spots -- Galileo suggests these are like mountain peaks.

We've seen Galileo say that the moon has mountains and valleys like the Earth -- specifically, he claims that a certain area looks like the European region of Bohemia would look from outer space (36). He even mentions the Pythagorean notion that "the moon is another Earth." But from our modern viewpoint about the moon, Galileo takes this basic idea too far: Galileo also suggests that the large darker portions of the moon are seas, and the rest is land (34). But also all those circular craters do not look all that much like a mountain ranges and valleys here on earth, which tend to be linear, not spherical.

Galileo also calculates the height of a **mountain** on the moon, and he also provides an explanation of (what is now called) **Earthshine**: the darkened part of the moon, on certain days, has a faint glow. Galileo argues that this is reflected light from the earth -- just as the moon's reflected light lights up our nights here on earth. "The earth, in fair and grateful exchange, pays back to the moon an illumination similar to that it receives from her throughout the darkest gloom of night" (44).

What's the point? If the moon is very much like the Earth, then there is probably not some special celestial material, and thus perhaps no special physics of the stars, different from terrestrial physics. The Earth is not different from all the other bodies in the universe. This does not provide direct evidence for Copernicanism, but it does answer an objection to it.

The fixed stars. Through the telescope, Galileo saw many, many stars that had never been seen before. The Milky Way, though the telescope, is seen to be a tremendous number of stars, not a fluid or cloud. Also important is that although the planets are seen to be spherical through the telescope, the stars do no appear any bigger. This lends support to Copernicus's claim that the stars were much, much further from

the Earth than the Ptolemaic astronomers held.

Jupiter's four moons. One night, Galileo noticed three little stars next to Jupiter, all three lying on the ecliptic (= the plane all the planets and the sun lie in), 2 to the east of Jupiter, and one to the west. The next night, all 3 were to the west. Galileo thought that they were fixed stars, and that Jupiter had moved past them -- though Jupiter was supposed to be in retrograde motion at that time, so it should have been moving in the opposite direction. Only after observing Jupiter for a few nights did he realize that these little 'stars' were orbiting Jupiter.

What's the upshot? There is, indisputably, circular movement in the universe whose center is not the Earth. Thus there must be something wrong with the Aristotelian-Ptolemaic picture. Of course, this (again) is not a direct argument in favor of Copernicanism, since it does not show that the Earth and the other planets revolve around the sun.

Samuel Edgerton's "Geometrization of Astronomical Space"

Why did Galileo see dark spots on the moon as mountains and valleys? This question is especially pressing, because someone else looked at the Moon through a telescope before Galileo did: Thomas Harriot. (Galileo did not know about Harriot.) Harriot, though he (in some sense) saw more or less what Galileo saw of the moon, did not realize that the moon's surface was uneven. What did Galileo have that Harriot lacked?

Edgerton's answer: Italian techniques in painting and drawing. In Italy during the Renaissance, Leonardo da Vinci and Raphael were developing new techniques for generating the appearance of three-dimensionality on the canvas. A primary technique was **Chiaroscuro** - from Italian, meaning 'light and shade.' Chiaroscuro makes objects in a two-dimensional painting or drawing appear to have depth or volume by (i) shading parts of them lighter and other parts darker, as well as (ii) having the objects cast shadows. There is some evidence that Galileo studied these techniques, and if he did, then we see why he was prepared to interpret the spots on the moon as mountains and valleys: he already had a great deal of practice converting two-dimensional representations into three-dimensional ones, and vice-versa. Harriot had none of this knowledge -- as Edgerton points out, British painting was well behind the Italians at this stage.

Galileo, the moon, and the Catholic Church. Galileo, as you may know, was condemned by the Inquisition for writing a book which claims to prove that the Earth orbits a stationary Sun. (The book was *Dialogue on Two Chief World Systems*, and Galileo was tried in 1632.) However, Galileo's relationship with the Catholic Church, which he was a member of, was not always so strained. Mary mother of Jesus was often traditionally depicted as having some close connection with the moon -- for it was assumed to be perfect, like her. We see that in officially-sactioned church depictions of Mary after Galileo's *Starry Messenger* appears, however, that Mary is standing on a moon covered with craters and imperfections. So Galileo's findings with his telescope did not create trouble for him within the Church.