

Tycho/Kepler/Galileo

Themes for today:

- The effect of a world view on interpretation of the evidence.
- The relation between physics and cosmology.
- Which mathematical constructs stand for “real” entities?

Topics:

- Tycho's Earth-centered universe
- Kepler's solution to the problem of the planets.
- Galileo's overthrow of Aristotle's physics (part 1).

Drawbacks of Copernicus' theory

- The “second and third motions” of the Earth (see Kuhn p. 165)
 - The earth is supposed to be carried around the Sun by a crystal sphere. That would make the Earth's axis (which isn't parallel to the rotation axis) also rotate yearly. But the apparent motions are described by keeping the Earth's axis fixed. So Copernicus adds another wobble to the Earth, which has the odd effect of just canceling the effect of the crystal sphere on the Earth's axis.
 - Notice that we've used *two* hypotheses (crystal sphere and extra wobble) to explain *zero* effects (Earth's axis doesn't wobble.) It seems there should be a simpler way. But then we would need some other way (not attachment to a rigid sphere) to explain why the Earth orbits the Sun.
 - A simpler solution of this problem requires a new dynamics.
- The Earth moves!
 - Doesn't fit with Aristotelian physics, which is strongly based on intuition.
 - Throw a rock up! A falling body would be left behind
 - The atmosphere would be left behind—a huge wind (Aristotle)
 - The earth itself would fly apart owing to force of rotation.
 - Copernicus does not dispute—his hypothesis is simply to make predictions.
- One systematic pattern- the relation between the apparent *type* of object and its cosmic place- is lost. The earth is just one of several planets—it is not unique.
- Stars are far away because parallax is not observed. Why did the creator waste all that space?
- Copernicus explicitly used the same criteria for evaluating a scientific explanation that we typically use today: “We find then in this arrangement an admirable harmony of the world, and a dependable, harmonious interconnection of the motion and the size of the paths, such as cannot otherwise be discovered ... And all this results from the same cause, namely the motion of the Earth. “

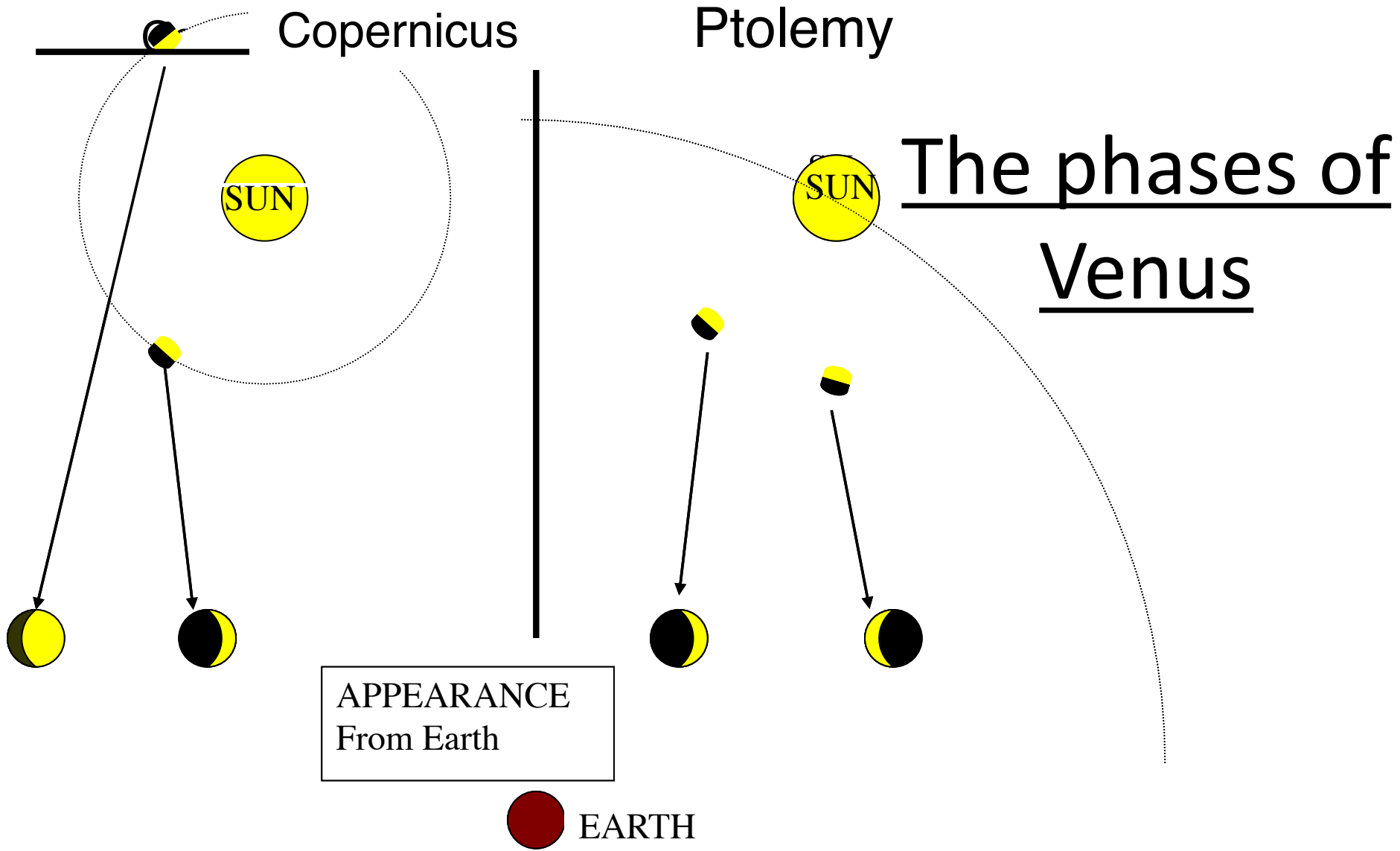
Scorecard

Copernicus	Ptolemy
<u>Approximate</u> mathematical simplicity	Agrees with ordinary physical intuition

Ptolemaic cosmology held on for about 60 years after 1543.

- Is there some crucial observation to settle who's right or wrong?
- If we can eliminate one of these theories, will we then know whether the earth goes around the sun?

The two cosmologies made different predictions, but they were ~unobservable until the invention of the telescope. In 1609, Galileo looked at the heavens with a telescope and observed for himself new “facts” supporting Copernicus. (see Kuhn, pp. 219-225)



Proves that Venus orbits the Sun, and shows that Venus is spherical

Ptolemaic model is completely ruled out

Other telescopic evidence:

- The moons of Jupiter
 - Shows another center of orbital motion.
So why should the Earth be the center of the universe?
- The stars have smaller angular size than was thought.
 - Weakens one argument against their great distance- they might not have to be much larger than the other known source of light, the Sun

Tycho Brahe

- Tycho took *systematic* observations.
 - Still no telescope, but
 - Improved accuracy (by a factor of 2 to 10, reliability, no fudging and continuity).
- No more need for ancient data. (important psychologically)

“In short, the observations with which Brahe and his contemporaries speeded the downfall of traditional cosmology and the rise of Copernicanism could have been made at any time since remote antiquity. The phenomena and the requisite instruments had been available for two millenniums before Brahe’s birth, but the observations were not made or, if made, were not widely interpreted.” (Kuhn p 209)
- Observed a nova and several comets. The stars change!
- Since no theory encompasses every possible observation one must decide which phenomena are important or relevant
 - Planetary motion?
 - Copernicus’ epicycles?
- But Galileo’s new telescopic observations strongly reinforced the Copernican picture.

Are there alternative theories?

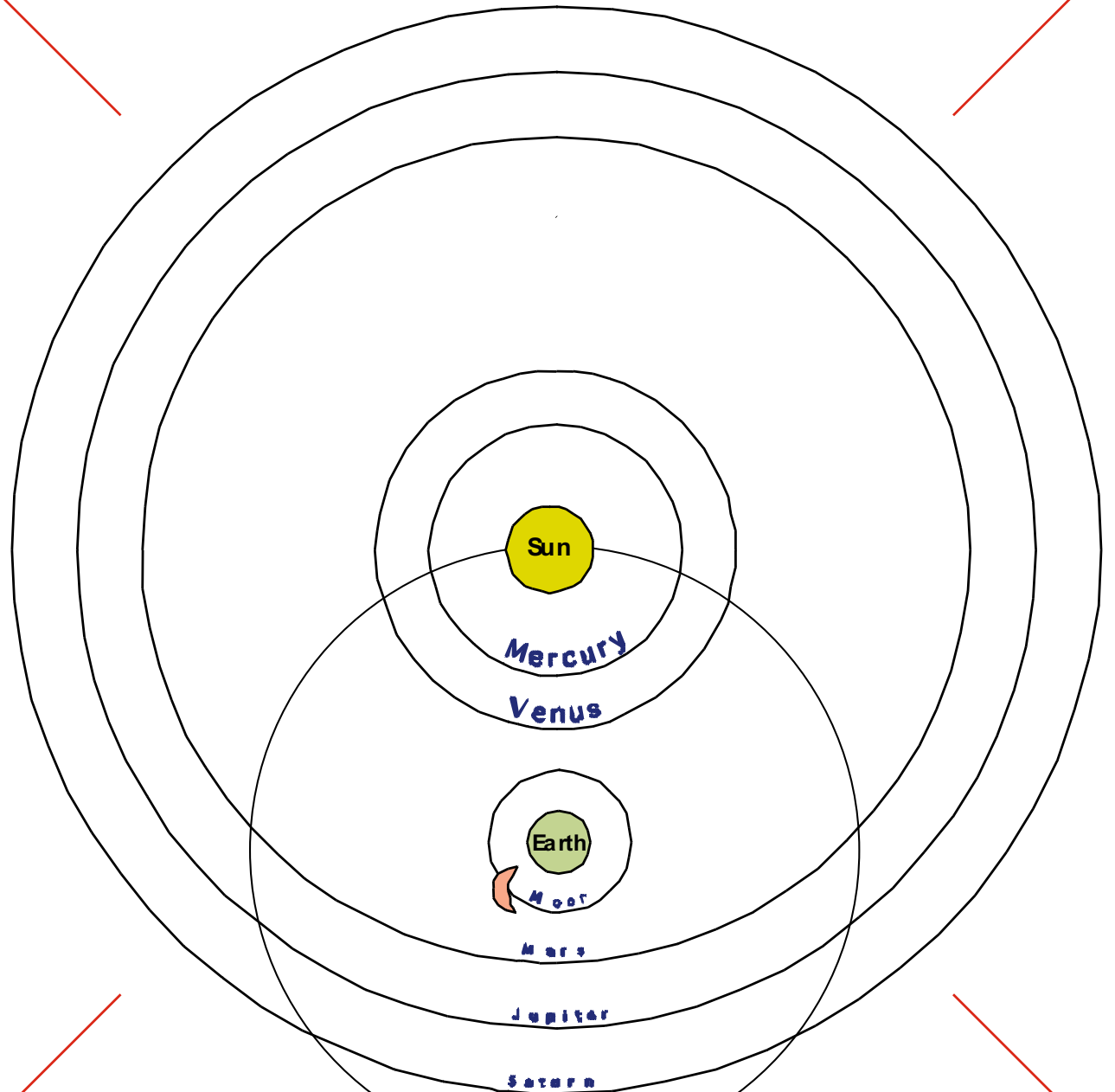
Tycho's Model

Distance to stars
not determined.

The Sun, Moon,
and stars still
orbit the Earth.

The planets orbit
the Sun.

Orbits around
Earth are still
westward,
but orbits about
Sun are eastward.

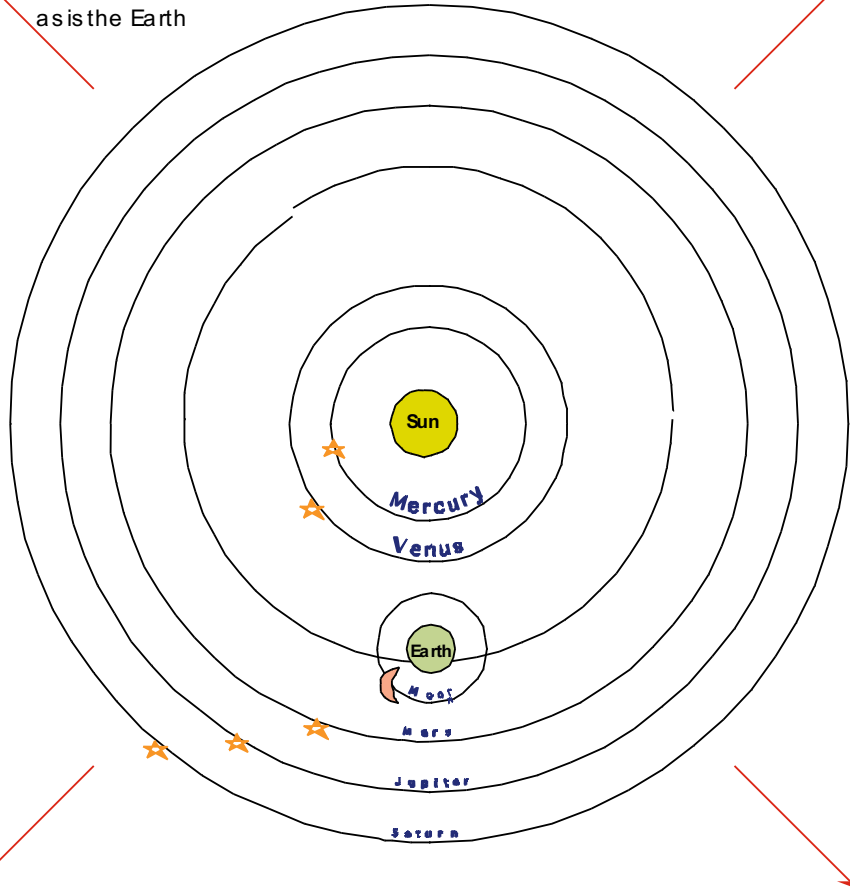


[Is Tycho's model distinguishable from Copernicus'?](#)

Copernicus' universe

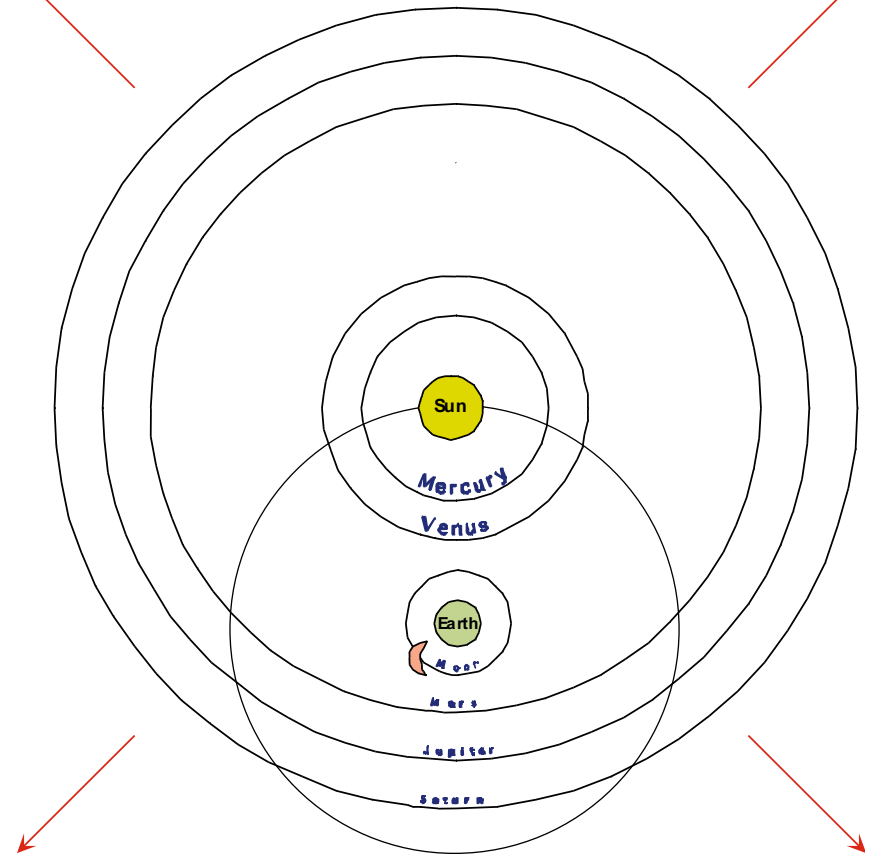
Looking Down at the North Pole
(not to scale)

Stars are at least 1000
times as far from Sun
as is the Earth



Tycho's System

Distance to stars
not determined.



Distinctions? Parallax?

- It is often said that Tycho's model implies the absence of parallax, and that Copernicus' requires parallax. However, it would not be a major conceptual change for Tycho to have the stars orbit the Sun (like the planets), which would give the same yearly shifts in their apparent positions as parallax gives. Thus if parallax were observed, a flexible Tychonean could adjust the theory to account for it, without undue complexity.
- What if parallax is not observed? For Copernicus, one only needs that the stars be far enough away for the parallax to be too small to see. Therefore the presence or absence of parallax doesn't force the choice of one type of model over the other.
- If different stars were to show *different* amounts of parallax, that would rule out the possibility of them all being on one sphere, but still not really decide between Tycho and Copernicus.

Would other astronomical features help decide?

Tycho-Copernicus Distinction?

- In fact, if we don't worry about the distant stars, these two models describe identical relative motions of all the objects in the solar system. So the role of observation is not as direct as you might have guessed.
- There is no bare observation that can distinguish whether Tycho (taken broadly) or Copernicus (taken broadly) is right.
- Notice that this statement would NOT apply to the Ptolemy/Copernicus dispute.
- You have to be a bit careful in making generalizations about how scientific issues are resolved.

Kepler (1571-1630)

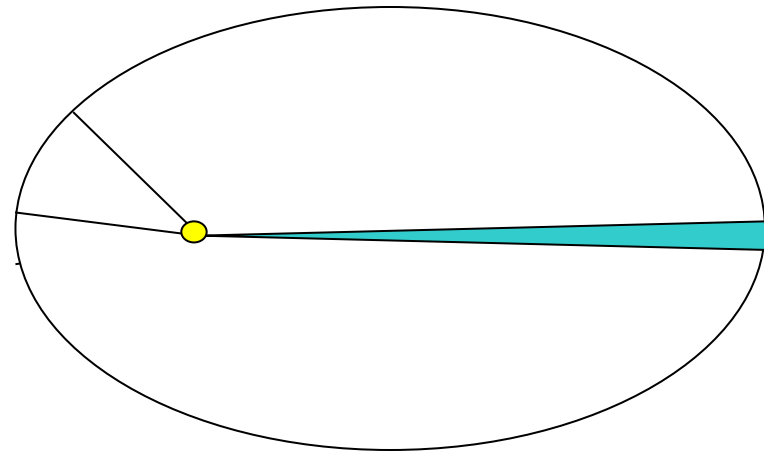
Started as a firm believer in the heliocentric cosmology with a mystical passion for the Platonic ideal. Described orbital distances from sun in terms of embedded regular solids (which has no significance at all from a modern point of view, but shows a fanatical desire to find mathematical patterns.) K inherited T's data in 1602 and used it to achieve a remarkable simplification of the description of the motion of the planets.

Kepler's three laws of planetary motion: (1609, the same year as Galileo's telescope observations)

1: The orbit of each planet about the Sun is an ellipse with the Sun at one focus of the ellipse. (Apollonius 300BC)

2: The line joining the Sun and the planet sweeps over equal areas in equal time intervals as the planet orbits.

3: The square of the period of one complete orbit is proportional to the cube of the length (major axis) of the ellipse. $T^2 = k L^3$



Perspective

- K's 3rd law is only meaningful because the Copernican-Tychonean picture allowed the distances to be inferred from the major deviations from simple apparent orbits, because all major deviations were assumed to come from the same source- the earth's motion- and not from separate peculiarities of each planet.
- Kepler's laws were not easy to find!
 - Direct observation gives you only the angle you have to look out from Earth to see a planet, not the distance! And it doesn't give you how much of the relative motion is due to the Earth and how much is due to the planet. There is an infinite family of mathematical curves to search among to find ones that will describe the motion. In finding curves, you can adjust both the laws for how fast the planets go around different parts and the laws for how the distances change with time- and both types of changes can give the same changes in apparent positions.
 - In fact, the actual orbits are all very close to circles, but with the Sun offset significantly from the center, and with the speeds thus varying significantly over an orbit.
 - One possible route to Kepler's laws is to assume circular motion, but with eccentric orbits and the equal-area law to describe orbital rates. Then converting the eccentric circles to ellipses is a fairly small correction, giving improved fit to the data.

Circular motion is gone.

- Refutes one of Aristotle's fundamental physics principles:
 - Let this suffice to prove that no change can be infinite or continuous with the exception of circular motion. (Aristotle, *Physics*, book Q)
- This development is a major blow to the long habit of accepting Aristotle's vague arguments as the final word on science. The whole tradition of categorical reasoning was thrown into doubt.
- These simple laws reproduce the observed motion “perfectly”, (within the accuracy of Tycho's measurements). Only *two* numbers are required to describe each planet's motion.
- For someone who gives mathematical simplicity the highest priority, this “proves” the validity of the (modified) Copernican system.
- But one could also make a “Tychonean” model with elliptical orbits.

Question: Is there an observation which would distinguish an elliptical Tychonean model from an elliptical Copernican model?

Can we keep Tycho's Model?

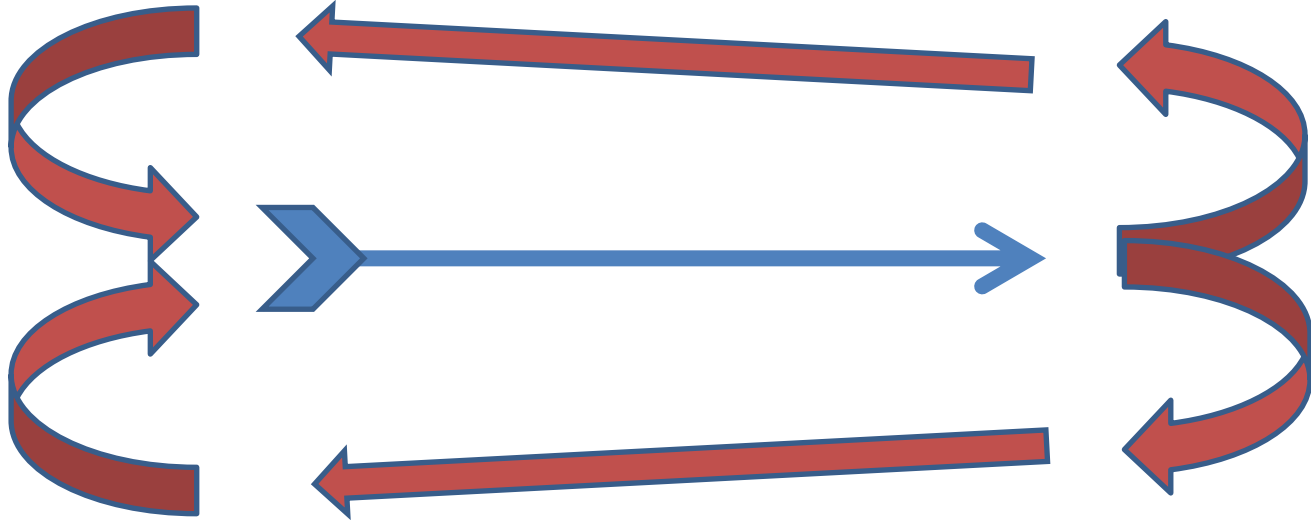
- Tycho's model now requires that the Sun's motion about the Earth is described in the same way as the planets' motions about the Sun.
 - the period of the Sun's orbit around the Earth is exactly the same as would be the period of the Earth's orbit around the Sun, if the Earth were a planet!
 - And the Earth happens to be about the same size as some other planets.
 - All the other instances we see have the smaller object going around the larger object.
- If it orbits like a planet and looks like a planet.....
- Astronomy is now MUCH simpler if we say the Earth moves like other planets.
- But if the Earth moves, we need a new physics of motion.
- So at this point we have a choice:
 - astronomy seems to need the Earth's motion for simplicity,
 - but terrestrial dynamics (as seen by Aristotle) requires that the Earth stand still.

Aristotle's physics

- Aristotle argued that the Earth can't be moving because "everything not actually standing on the Earth would seem to move together the opposite way." This argument is based on the assumption that the air, *etc.* tries to stand still (zero velocity) in some absolute sense.
- Aristotle describes both a natural motion and a natural position:
 - The natural motion of the Earth and its parts is to the center of the Universe
 - It is not every chance direction which is up, but where fire and what is light are carried ... Down is where what has weight and is made of earth are carried. These places do not differ merely in relative position, but also as possessing distinct potencies. i.e. heavy bodies fall toward the center of the Earth not because it is the center of the Earth, but because it is the center of the universe- that's why the Earth is there.
- This is the first appearance of a recurrent issue:
Is there a structure to space, or only to the stuff in it?

Aristotle against Inertia

- He argued that an arrow in flight was kept in motion by the displaced air rushing in behind the arrow.



Question: what evidence comes to mind as to whether the medium sustains the motion?

Metaphysics: Aristotle → Galileo

- Aristotle

- mechanics blended with a sense of purpose. e.g. the gods were immortal, the stars never changed, therefore the gods dwelt in the eternal stars. Both embodied perfection unknown on Earth. Some version of these ideas predated Aristotle and continued into medieval thought.

- Galileo: a whole new way of looking

- Believed there is a reality independent of our senses. In fact, our senses often mislead us (*e.g.*, the Earth does move).
 - “I cannot sufficiently admire the eminence of those men’s [Aristarchus and Copernicus] wits. ... They have been able to prefer that which their reason dictated to them to that which sensible experiments represented most manifestly to the contrary.” (*Two Great Systems*)
- Performed systematic experiments to determine the behavior of objects. Words alone are not significant.
 - “Our disputes are about the sensible world, and not one of paper.” (*Dialog Concerning the Two Great Systems of the World*)
- The idea of cause is separated from any notion of purpose. Cause is merely the effect one object has on another. “Purpose” implies a more global interaction (a goal). Huygens and Leibniz were more radical; they spoke of the universe as a machine.

Galileo: Reason and Data

- Data are not the whole story; mathematics is also needed to organize observation into a coherent whole. One must follow the logic wherever it goes.
 - "Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the symbols in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures... Without these one wanders about in a dark labyrinth." (Il Saggiatore)
- Once a mathematical picture is formed, you can reason beyond the data:
 - "The knowledge of a single fact acquired through a discovery of its causes prepares the mind to understand and ascertain other facts without need of recourse to experiment." (*Two New Sciences*)
- Galileo's outlook is still questioned. "*The Two Cultures*" of C.P. Snow about the gulf between scientists and others. Note his comment about wandering in a dark labyrinth if you don't know math.
- There is a common myth that Galileo was devoted exclusively to data, and a common scholarly rejoinder that he was really the last Aristotelian, a big believer in formal arguments and perfect forms. What was special about Galileo was his integration of these two approaches.

Galileo's observational method

- The moons of Jupiter were seen, not deduced from some prior theory.
- The Orthodox Objection to Galileo's moons:

“There are seven windows in the head, two nostrils, two ears, two eyes, and a mouth: so in the heavens there are two favorable stars, two unpropitious, two luminaries, and Mercury alone, undecided and indifferent. From which and many other phenomena of nature such as the seven metals, etc... we gather that the number of planets is necessarily seven. Besides, ...[we] have adopted the division of week into seven days, and have named them for the seven planets; now if we increase the number of planets, this whole system falls to the ground. Moreover, *the satellites are invisible to the naked eye and therefore can have no influence on the Earth and therefore would be useless and therefore do not exist.*” [*Dianoia astronomica*](#) Francesco Sizi, Florentine astronomer, 1611.

Galileo's theoretical method

Aristotle claimed that heavier bodies fall faster. So if you tie a 1 lb weight to a 10 pound weight, does the 10 lb weight

- a) fall faster (now 11 lb)
- or
- b) slower (held back by the 1 lb) ?

Galileo is really using a deep principle here:

The laws of nature must predict the same phenomena regardless of our choice of verbal expression or of measuring conventions.

(e.g. scientists often use “dimensional analysis” Mathematical laws are independent of units of measuring things.)

We will see these principles again.