

Greek Astronomy

Aristotelian Cosmology:

At the center of the universe is the Earth:

Changeable and imperfect.

Above the Earth is the heavens:

Fundamentally different than the Earth.

Unchanging and perfect.

Motions in the heavens must be circular and uniform. Why?

Evidence that the Earth does not move:

1. Stars do not exhibit *parallax*:

If the Earth moved, the nearer stars should appear to move amongst more distant stars

Absolutely true, however, the stars are much further away than they supposed.

First successful measurement of stellar parallax was in 1838.

2. We do not experience any motion.

3. An archer firing an arrow vertically into the air would be a prime candidate for a Darwin award.

Aristotelian model based on common sense view of the universe.

Where did he go wrong?

Nonscientific in that common sense facts were not checked against evidence.

Sometimes intuition can lead one astray.

Motions of the Planets

Ptolemy's Geocentric Model

Any model of the sky has to be able to account for the motions of the stars and planets.

Stellar motions are relatively easy to account for using a uniform revolution about the Earth.

What about the sun and moon?

But what about the planetary motions?

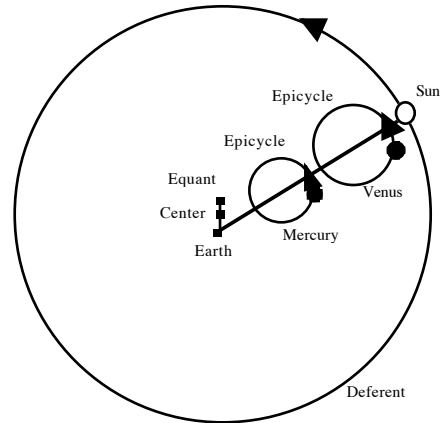
How do inferior planets move?

Superior planets?

How did Ptolemy's geocentric model account for these effects?

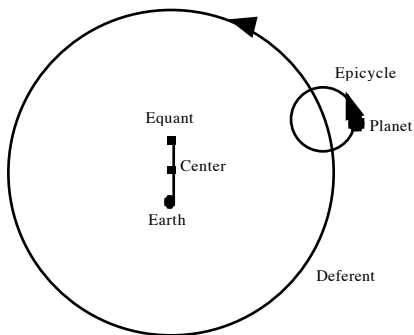
Ptolemy's Geocentric Model

Inferior Planets:



Ptolemy's Geocentric Model

Superior Planet:



Ptolemy found the data could be fit better if the deferent was slightly offset from the Earth

Motion around the deferent is uniform as seen from a point on the exact opposite side of the center of the deferent, the Equant.

Use of the equant stretched Aristotle's rules to the limit—but its use substantially improved the accuracy of the model.

Middle Ages

During the Middle Ages, most of the astronomical works of the Greeks were lost to the west.

Fortunately, much of the works of the Greeks was preserved in the Arab world.

After the fall of Arab Spain the west regained much of its lost legacy.

Came as quite a shock to the west.

Some ideas were so far beyond their current state of knowledge as to be almost incomprehensible.

Ptolemy's geocentric model of the universe was accepted for over a millennium.

Copernicus

Ptolemy's geocentric model worked well for determining planetary positions and those who used it for this purpose were quite satisfied.

Copernicus held Aristotle's view that motions in the heavens must be uniform and circular.

He had great misgivings about Ptolemy's Equant.

By using the equant, motions in the Ptolemaic model were not truly uniform.

Led Copernicus to propose a heliocentric model:

Planetary orbits were assumed circular.

Avoided use of the dreaded equant.

However, because the orbits are actually elliptical, the model still used some small epicycles.

So, why change our view?

Heliocentric model did have some advantages.

Avoids the equant.

Also, provides natural explanations for many aspects of the planetary motions which are puzzling in Ptolemy's system:

Why does the sun's period (1 year) show up in all of the other planet's motions in Ptolemy's model?

Somehow, the motions of the other planets are linked to the sun's motion???

Provides a natural explanation for the different behaviors of the inferior and superior planets:

Retrograde motion—

Yet, Copernicus could not come up with any compelling proof that his heliocentric model was correct.

Also, the publisher of Copernicus' *De Revolutionibus* (probably in an effort to shield Copernicus from controversy) snuck an introduction into it maintaining that Copernicus did not mean to suggest that the Earth actually moved, but rather that the model was a convenient mathematical tool for determining planetary positions.

Obscured Copernicus' message.

Thus, belief in the Geocentric model persisted.

Tycho Brahe

Tycho Brahe believed in the Geocentric model.

Even with his highly accurate observations he could not see any stellar parallax.

Showed that the stars must be at least 700 times further away than the farthest planet.

The example of the archer firing an arrow vertically into the air seemed valid to him.

While Tycho was wrong about the geocentric universe, he did make a number of valuable contributions to science:

Tycho Brahe's Observations

Tycho Brahe's biggest contribution to science was his very precise observations of the positions of the planets and stars.

In 1563 Jupiter and Saturn entered conjunction.

Tycho noted that tables of planetary positions based on Ptolemy were a month in error.

Those based on Copernicus were off by days.

Tycho Brahe thought he could do better.

In 1575 he obtained funding for the first major observatory in Europe on the island of Hven from the Danish king.

Making observations at his observatory he obtained positions of the stars and planets of unprecedented accuracy.

(Typically a few arc minutes or 1/60ths of a °).

All before the invention of the telescope.

Kepler

Kepler was an assistant of Tycho Brahe's.

Unlike Tycho he was a mathematician rather than an observer.

Upon Tycho's death Kepler inherited Tycho's observations.

Using Tycho's observations, Kepler attempted to model the planetary motions.

Following Aristotelian thought, Kepler spent years trying to fit the motion of Mars using circular orbits.

However, Tycho's observations were of high enough accuracy to exclude circular orbits.

Eventually, he gave up on circles and tried elliptical orbits.

They worked!

Paradigms

Generally accepted set of scientific ideas.

Often molds our mode of thinking about a problem and the kinds of questions we ask.

Roman's could have discovered America:

They had the necessary technology.

It just didn't occur to anybody that there might be a whole new land on the other side of the Atlantic.

Even Columbus was only looking for an easier way to the Far East.

Galileo saw Neptune:

While observing Jupiter through his telescope, Galileo noted a star which appeared to move amongst the background stars.

However, he didn't think much of it.

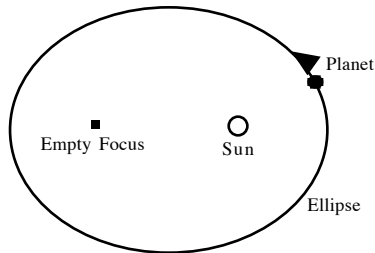
It didn't occur to him that there might be more planets than those visible with the naked eye.

We had to wait another 200 years for Neptune's discovery.

Other examples?

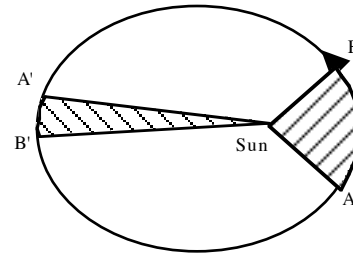
Kepler's Three Laws of Planetary Motion

1. Planets travel in elliptical orbits with the Sun at one focus:



Implication:

2. A line from the planet to the sun sweeps out equal areas in equal times:



Implication:

3. The period of a planet's orbit is proportional to its distance from the sun:

Rudolphine Tables

Tables based on Kepler's model were published in 1627.

How accurate were the predictions based on Kepler's model?

Spectacular proof of their accuracy came 4 years after they were published when a transit of the Sun by Mercury was observed.

The prediction based on Kepler's model were more than 30 times as accurate as those based on Copernicus' model.

Galileo

Contemporary of Kepler's.

Did not invent the telescope.

However, he was the first to use one to systematically study the heavens in 1609.

Made some fantastic discoveries.

Galileo's Discoveries

Resolved the Milky Way into individual stars.

Planets were resolved into disks. However, stars remained point like sources:

Observed mountains and craters on the Moon and sunspots on the Sun:

Why was this important?

Phases of Venus:

What prediction does Ptolemy's model make for the phases of Venus?

What prediction does Copernicus' heliocentric model make for the phases of Venus?

Moons of Jupiter:

Perhaps Galileo's most striking discovery was the moons of Jupiter:

Upon first observing Jupiter he noted four stars curiously in a line with Jupiter.

Moved with Jupiter!

Alternated between being east and west of the planet.

How could this be explained?

Why would this be considered important?

Newton

Kepler's laws of planetary motion describe the motion of the planets well.

However, why do they move that way?

In antiquity this wasn't considered a problem:

It was assumed the planets were attached to crystal spheres moved naturally or by divine direction.

However, the comet of 1577 seen by Tycho moved right through the planetary system—

But if the planets are not connected to anything. What drives their motions?

Newton's Law of Gravity

The gravitational force between two objects is proportional to their masses and the inverse square of the distance between them:

$$F = -G Mm/r^2$$

Newton showed that Kepler's three laws of planetary motion can be derived from his theory.

He also showed that the force of gravity that we feel at the Earth's surface (for example causing apples to fall from trees) is the same as that which keeps the Moon in orbit.

Thus, same forces act in the heavens as on Earth.

The Birth of Modern Science

The Copernican revolution was not just the birth of modern astronomy but modern science in general.

Use of observations of the universe in an attempt to understand it.

It also gives a good example of how science evolves:

Scientists do not work in isolation.

Build on the work of others. Examples?

As each scientist makes his or her contribution, scientific thought continually evolves

Communication is important!

The Scientific Method in Action:

Newtonian Mechanics

Newton showed that Kepler's laws could be derived from his theory of gravity.

Thus, it could fit past observations. But could it make any predictions?

Actually, because the planets all pull on each other Newton predicted their orbits are not exactly ellipses.

Motion of the Moon:

Because of the pull of the sun, the Moon's orbit should deviate significantly from an ellipse.

Predicted Return of a Comet in 1759:

According to Newton's theory, comets should be on elliptical orbits just like the planets and thus should return periodically.

One such return in 1759 was successfully predicted by Halley.

Discovery of Neptune:

The planet Uranus was discovered by accident by William Herschel in 1781.

Soon it was discovered that Uranus was deviating from its predicted orbit.

How might this be explained?

Working independently, two scientists, Adams in England and Le Verrier in France, used Newtonian mechanics to predict the location of the unknown planet.

In 1846, on the first night of looking for the planet astronomers at an observatory in Berlin found it almost exactly where it was predicted to be.

Planet Vulcan

Like Uranus, it was found that Mercury's orbit also deviated slightly from its predicted orbit.

Occurred even when the pulls of the other planets were accounted for.

Might there be another planet inside Mercury's orbit?

In 1859, Le Verrier showed that a Mercury sized planet at half of Mercury's distance from the sun could explain the deviation.

While some observers reporting seeing such a planet. The observations turned out to be false.

No planet Vulcan!

Observations could not be explained by Newton's Theory.

According to the scientific method what must we do in this case?

In 1915 Einstein showed that his General Theory of Relativity could explain the observation.

Newtonian mechanics is still often used, though we now know it is only an approximation.