Lecture 2

Fundamentals of Physics

Phys 120, Fall 2014

Astronomical Observations

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Astronomy - an example of a paradigm shift

- Foundations of scientific thought
- Astronomical observations
- Ptolemy's model of the cosmos (simplified)
- Copernicus' simplification
- Resistance and its reasons
- Tycho Brahe and Kepler
- Summary

The basis of science

Contrary to popular believe, what makes good science above all else it *finding a good problem.*

A good problem is a problem that is
a) complex enough to be interesting
b) simple enough so that you can understand it
and b) is much more important than a)!

In order to develop a scientific understanding of something you need to look at something that is repeating (or at least repeatable) so that you can check and check again if your explanation is really working.

What is special about Astronomy

Aristotle separated the world into the worldly sphere and the celestial sphere where different laws of nature appeared to rule.

In Nature many things change. If you look at a bit of water, it can spill and evaporate, or seep into the ground, changing its appearance all the time. This makes it difficult to get a grasp on what is really going on. The few things that are persistent, like a stone that can survive with little change over millennia, are often unchanging, making them not that interesting to study. Even the apparently simple phenomenon of a falling stone took millennia to understand.

There are very few everyday phenomena repeat themselves in the same way twice. An important exception are celestial phenomena. Here we see change, but many of them appear to return to a previous state, allowing us to build up a clear expectation of what is going to happen next. Because of the demands of Astrology such phenomena were considered very interesting, and because of their repeating nature there was also a chance to build predictive models.

Which phenomena can you think of, that predictably repeat themselves?

Predictably periodic phenomena in nature

In a somewhat loose order of decreasing quality of periodicity/repeatability:

- Day/night cycle
- Movement of the stars, i.e. rotation and inclination of the firmament
- Monthly cycle of lunar phases
- Cycle of the tides
- Movement of the planets
- Lunar eclipses
- Solar eclipses
- Weather phenomena
- Observations of comets
- Observation of meteorites
- Observations of supernovae

A word about models

The main purpose of science is to build abstract models that are typically much simpler than the real thing, but complex enough to reproduce the key phenomena we are interested in.

What scientific models can you think of, and what do they explain?

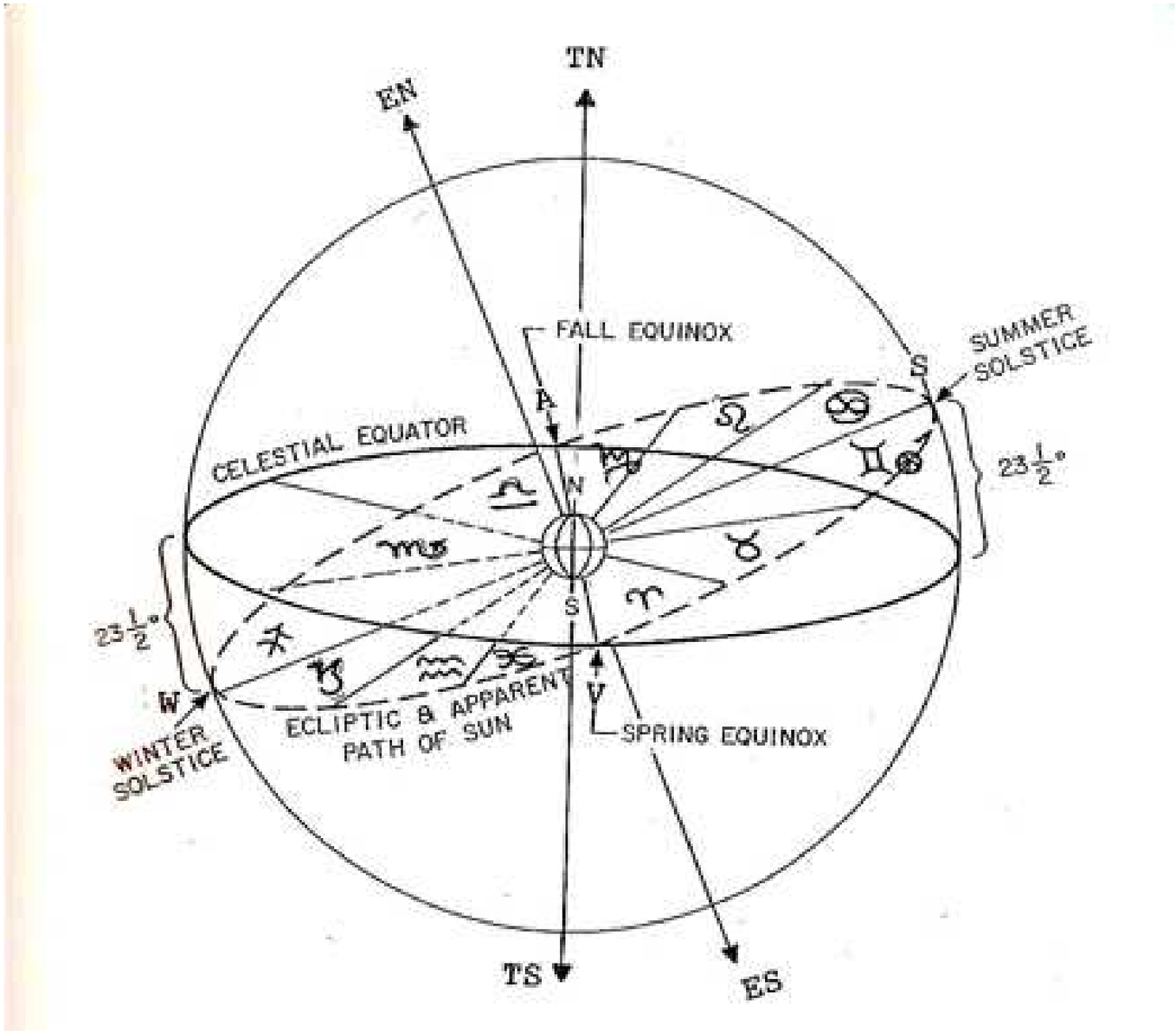
Observations

My son Ahren, fishing at Greenwood lake, Aug. 13,2015

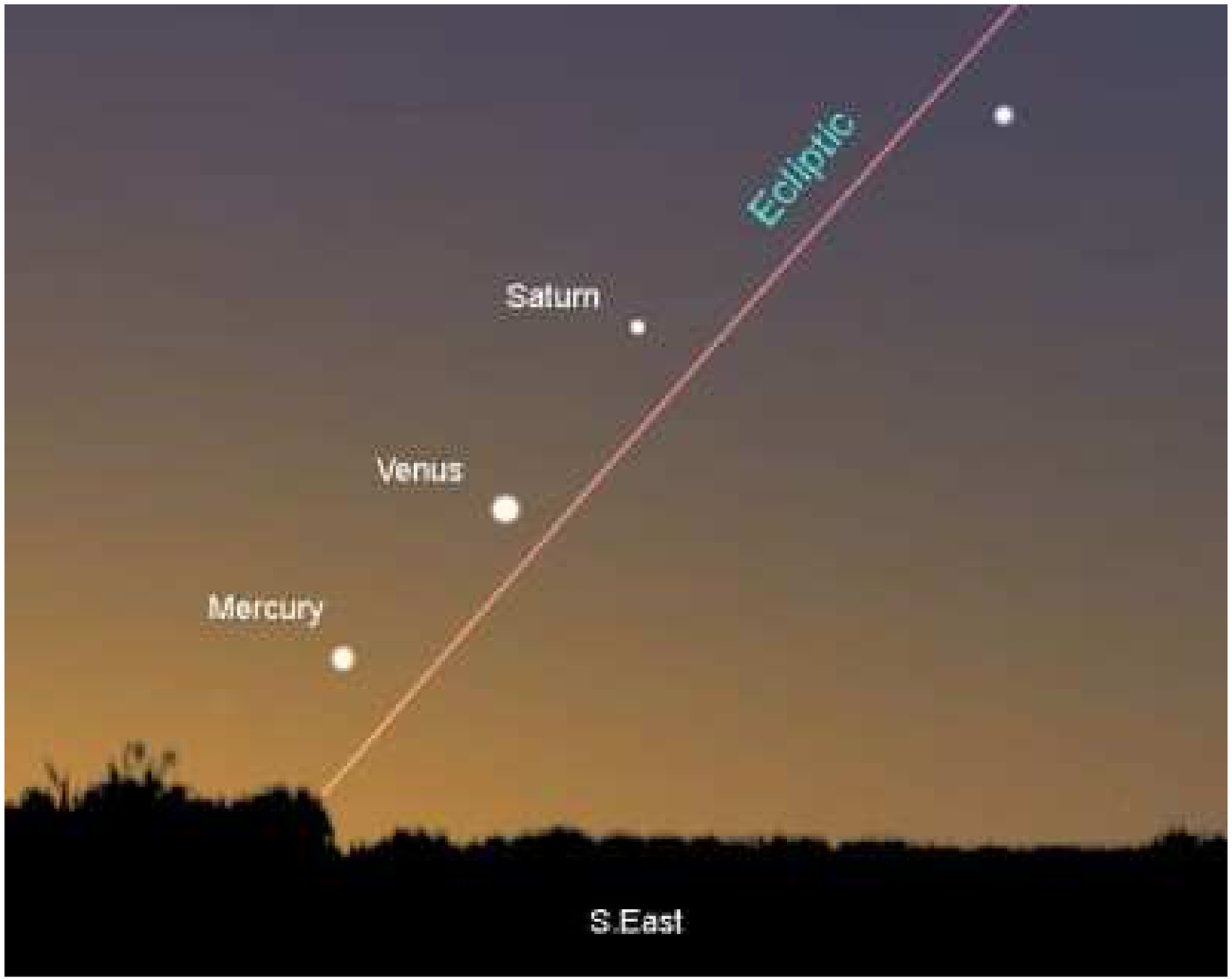
Observations - star signs

Observations - motion of stars

Observations - Ecliptic: path of the sun

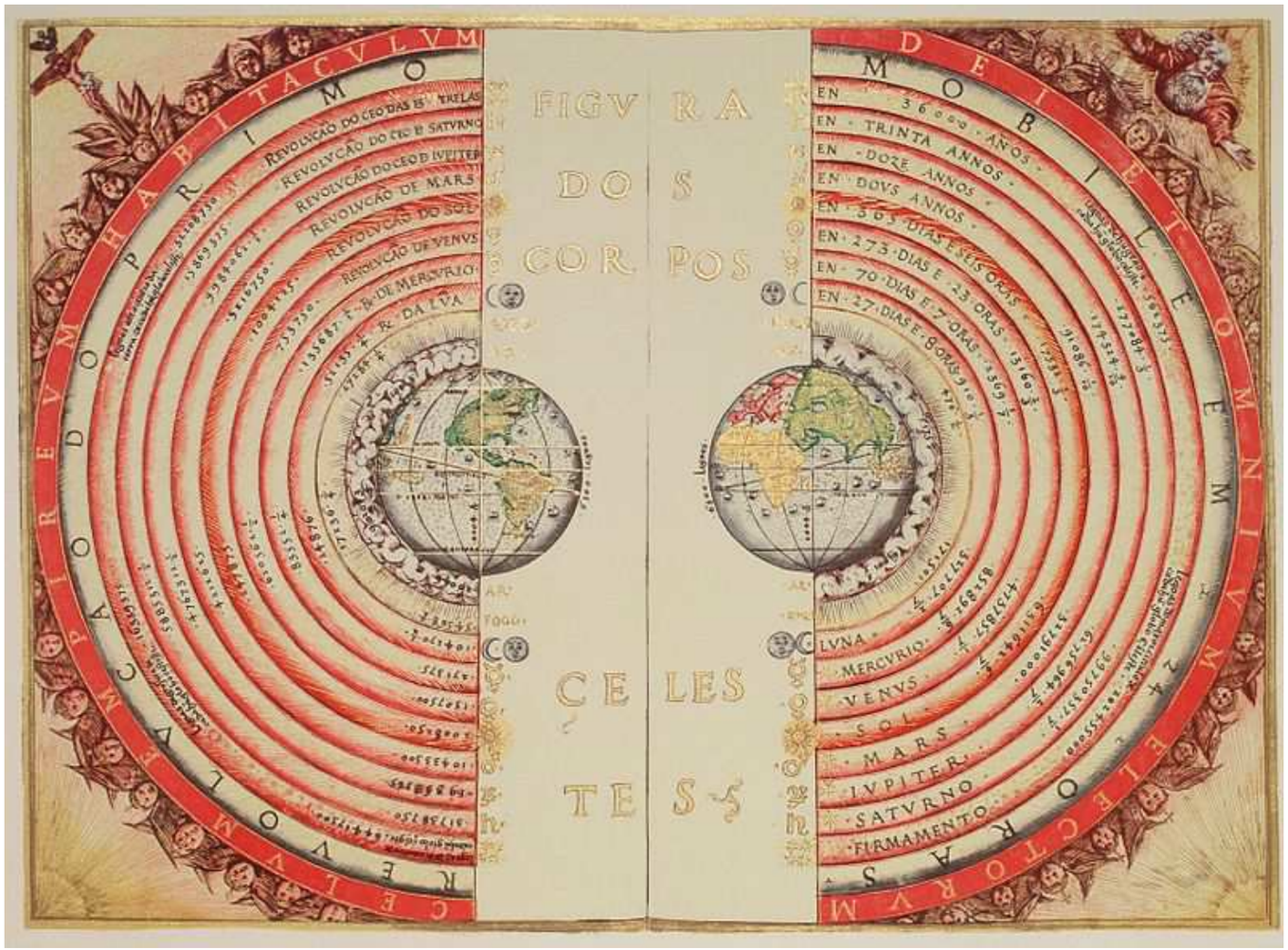


Observations - Ecliptic: path of the planets



A model of the cosmos

Given similar observations the Greek's developed the following model (Bartolomeu Velho 1568):

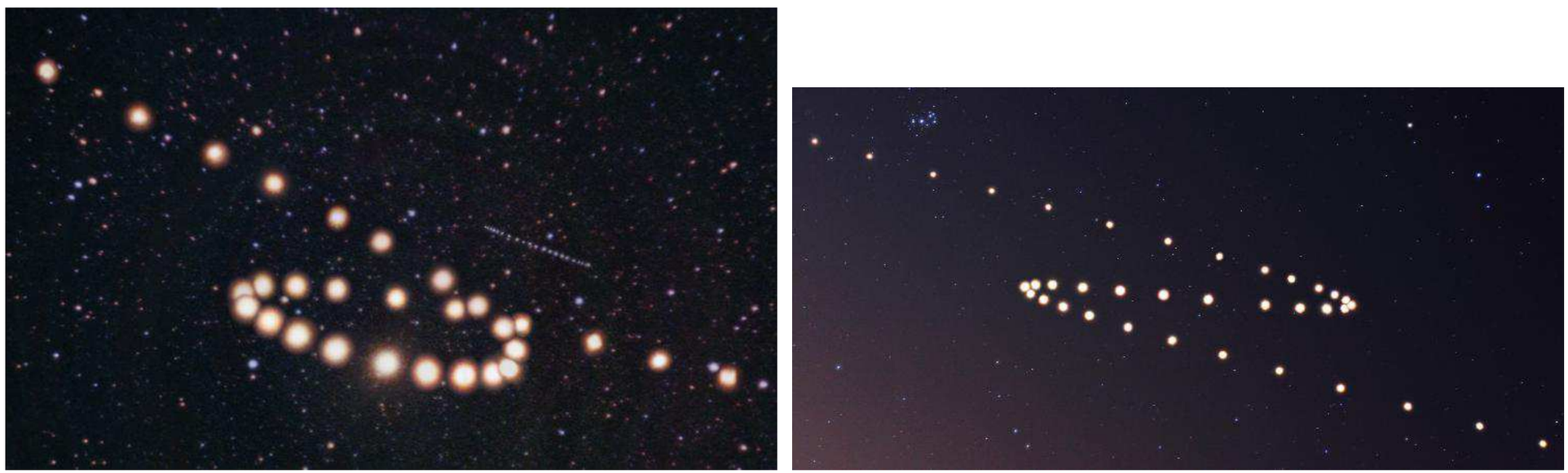


First geometric model

Below a fixed firmament the heavenly bodies move perpetually on spheres that were set in motion by the prime mover.

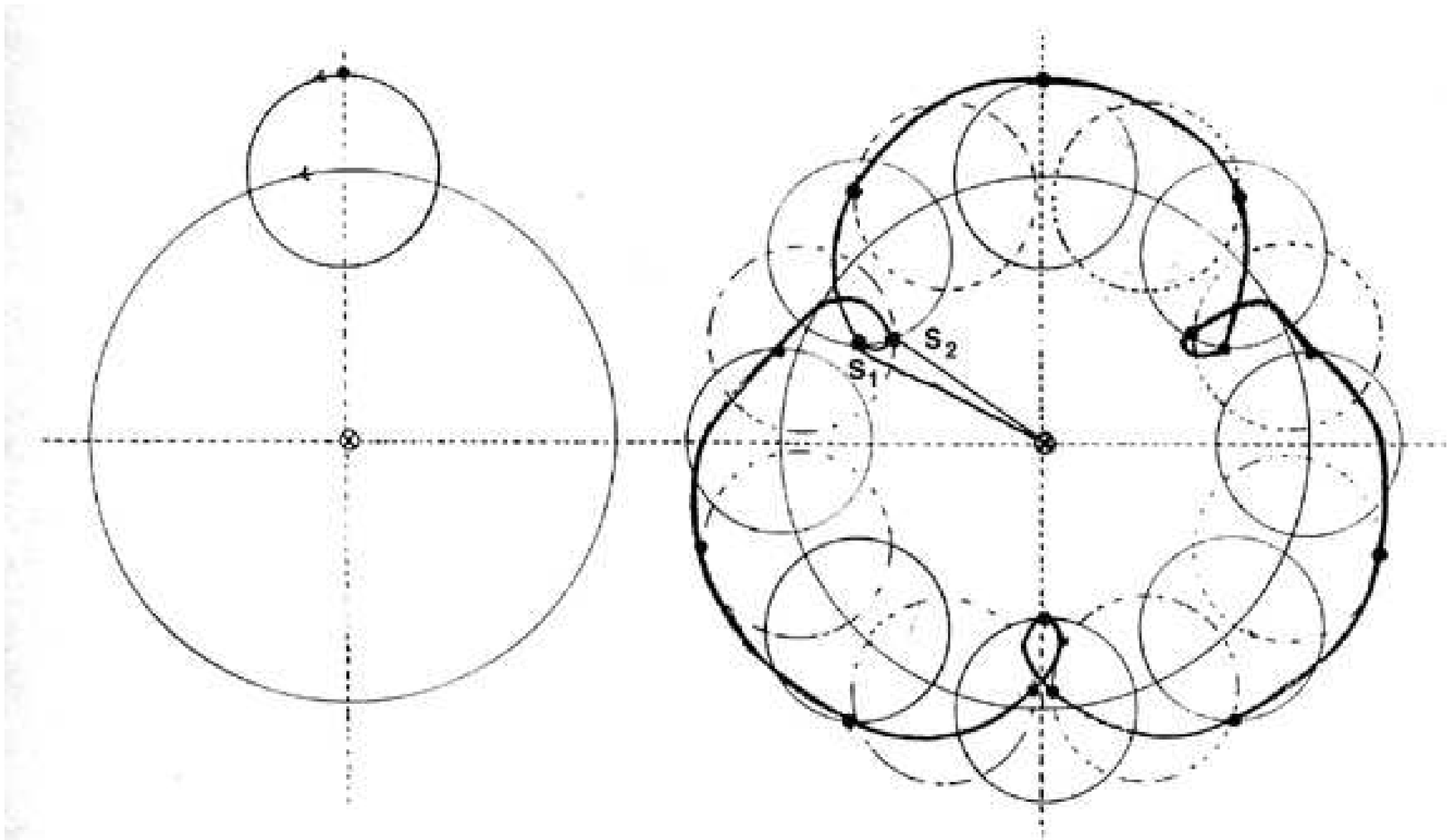
Closest to the earth is the lunar sphere.
The second is the sphere of Mercury.
Next the sphere of Venus.
Then follows the sphere of the sun.
And outside the solar sphere we find Mars, Jupiter, Saturn and last the firmament with all the fixed stars.

The problem of retrograde motion



Observed retrograde motion of Mars in 2003 and 2005.

New and improved model (simplified)



Continuing problems

Qualitatively this gives reasonable agreement. However, the results are not exact. This can be fixed by adding more and more epicycles (another model involved spheres moving inside each other) but sometimes fixing the model to fit a new observation made it fit older observations less well and eventually there were models with 80+ spheres moving inside each other. They described the observed motion of the planets reasonably well, but the models were enormously complicated.

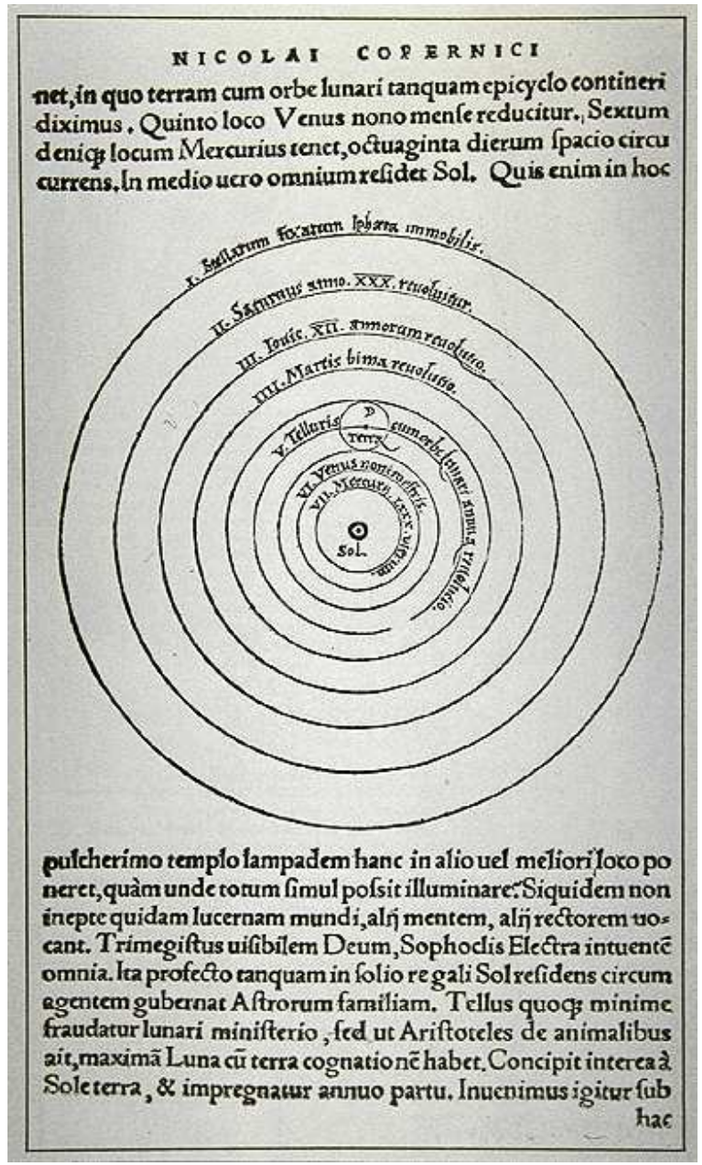
The results of centuries of research in astronomy was summarized in Ptolemy's (85-165 CE) Almagest written in Alexandria.

Discontent

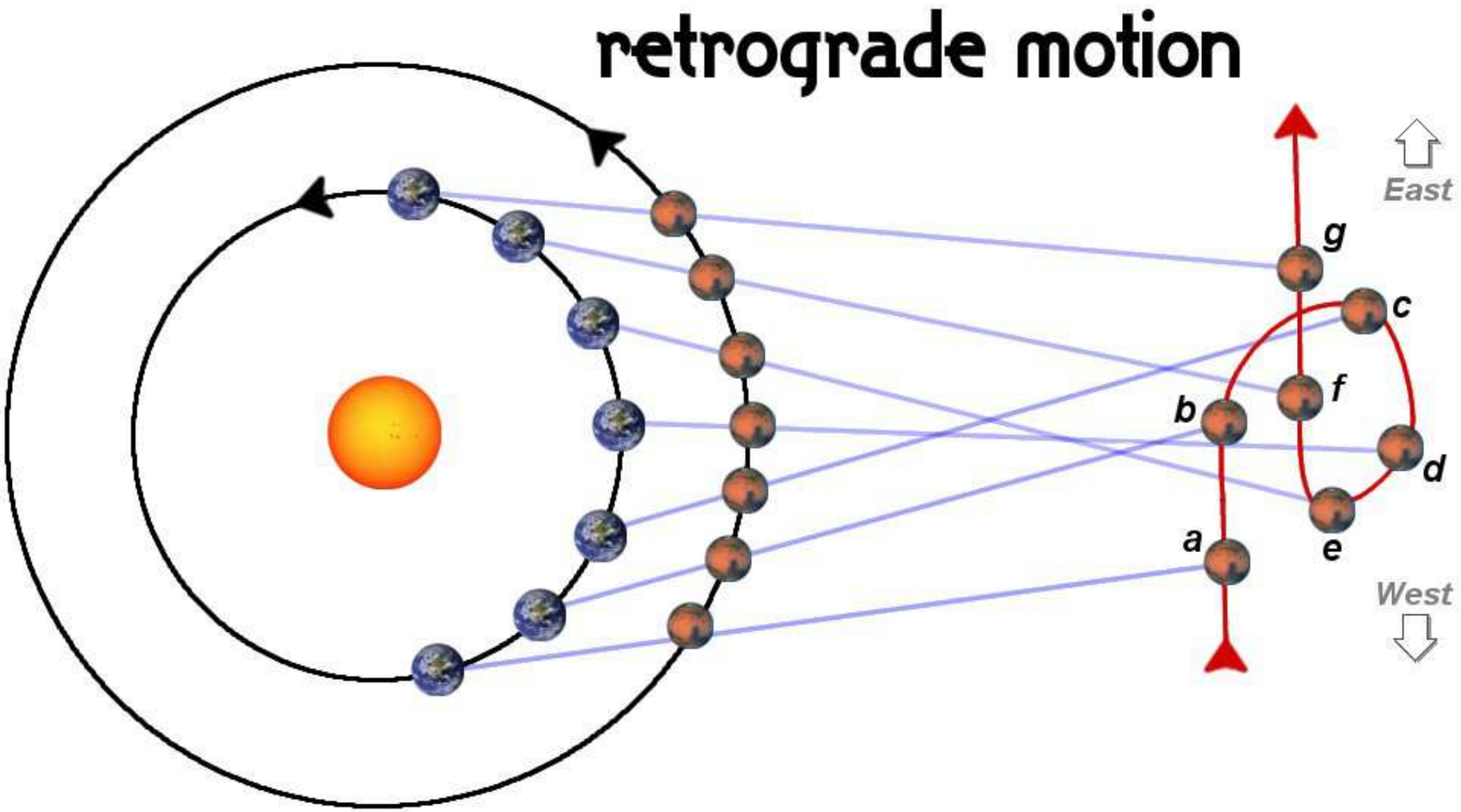
King Alfonso X of Spain (13th c CE)

If the Lord Almighty had consulted me before embarking upon the creation, I should have recommended something simpler.

Copernicus 1473-1543



How about retrograde motion?



animation

Evaluation of Copernicus

A simpler model that explains the observations almost as well as Ptolemy's model. However, it is not an improvement in the sense of giving better predictions!

And there is a problem with christian scripture:

Genesis 1:6-9
And God said, "Let there be a firmament in the midst of the waters, and let it separate the waters from the waters." And God made the firmament and separated the waters which were under the firmament from the waters which were above the firmament. And it was so.

Joshua 10:12-13
Then spoke Joshua to the Lord in the day when the Lord gave the Amorites over to the men of Israel; and he said in the sight of Israel, "Sun, stand thou still at Gibeon, and thou Moon in the valley of Aijalon." And the sun stood still, and the moon stayed, until the nation took vengeance on their enemies. Is this not written in the Book of Jashar? The sun stayed in the midst of heaven, and did not hasten to go down for about a whole day.

1 Chronicles 16:30
tremble before him, all earth; yea, the world stands firm, never to be moved.

Proverbs 8:27-29

When he established the heavens, I was there, when he drew a circle on the face of the deep, when he made firm the skies above, when he established the fountains of the deep, when he assigned to the sea its limit, so that the waters might not transgress his command, when he marked out the foundations of the earth.

Copernicus, himself a monk, foresaw these difficulties and held off with the publication of his work until after his death. He was subsequently labeled a heretic and his work was declared to be in error.

Question

Try to put yourself in the shoes of a European citizen of the 15th century with a curious mind.

Assume you know about Ptolemy's model of the cosmos, its strength and shortcomings, and now you hold in your hands a copy of Copernicus' new work.

What to you imagine your reaction to this work would be? What would you do to form an opinion about this work? What criteria would you use to decide what you should think about this work?

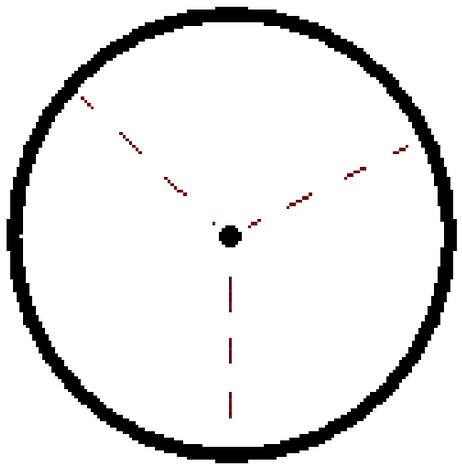
Tycho Brahe

Tycho Brahe [1546-1601] was a noble man who was interested in Astronomy. He had his own ideas about the organization of the heavens, different from both Ptolemy and Copernicus, and since he had the money he decided to set up a state-of-the art observatory to measure the path of he planets more accurately than anyone had ever done before. To help him in this endeavor he employed an assistant, Johannes Kepler, who had fallen on hard times.

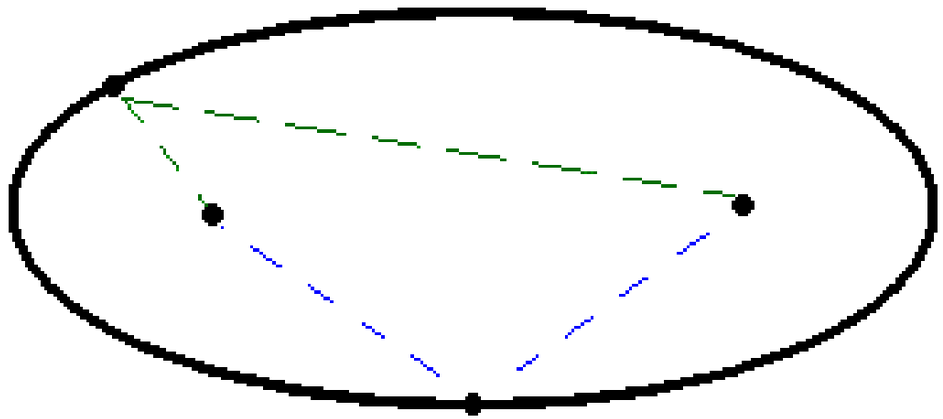
Johannes Kepler (1571 – 1630)

Johannes Kepler was not impressed with the Astronomical theories of Tycho Brahe, but instead was impressed with the Copernican idea. So, without the knowledge of Tycho Brahe he tried to explain the excellent measurements by Tycho Brahe (and himself) by connecting them to the Copernican model.
But the measurements did not fit! Tycho Brahe died, and Kepler took (illegally) all of his data because he felt that the inheritors would not value them. Eventually he found that the data would fit excellently if the planets did not move in circles but in ellipses!

Circles and ellipses



A circle. All lines from the center to the edge are the same length.



An ellipse. The two green lines, added together, are the same total length as the two blue ones, added together.

Kepler's revolution

What sixteen years ago I urged as a thing to be sought that for which I joined Tycho Brahe . . . at last I have brought to light and recognize its truth beyond my fondest expectations . . . The die is cast, the book is written, to be read either now or by posterity. I care not which. It may well wait a century for a reader, as God has waited six thousand years for an observer.

Kepler's results were not immediately accepted, but eventually were confirmed. They were the basis for Newton's discovery of the laws of gravity which we will discuss in chapter 4.

The scientific method

The scientific process

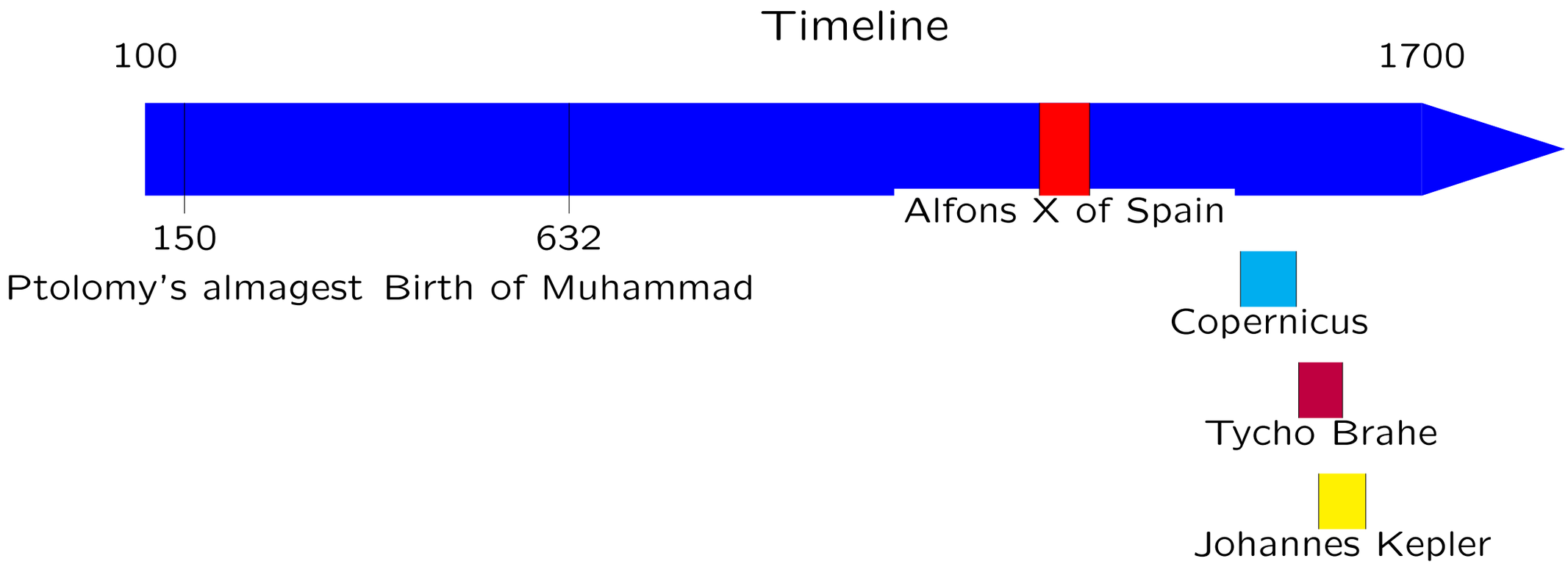
Science is a process, a way of learning, rather than a set of conclusions. It is the process of using evidence (experiments and observations) an reason (hypothesis and theories that correlate the evidence) to develop testable knowledge about the natural world. This basis in evidence and reason distinguishes science from other form of knowledge based on belief, intuition, personal authority, or authoritative books.

Question

Comparing the models of Ptolemy, Copernicus, and Kepler, which view is correct?

Why?

Are you sure?


Timeline
100
1700
150
632
Alfons X of Spain
Ptolomy's almagest
Birth of Muhammad
Copernicus
Tycho Brahe
Johannes Kepler

Summary

- The nature of scientific inquiry
- Ptolemy's theory of the cosmos.
- Copernicus' heliocentric theory.
- Kepler's observation that planets move on ellipses.
- This is one of the most impressive examples of a paradigm shift in our view of the world.
- Beware of certain knowledge.