

# The Milky Way

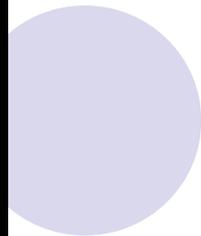


*"See yonder, lo, the Galaxyë  
Which men clepeth the Milky Wey,  
For hit is whyt."*

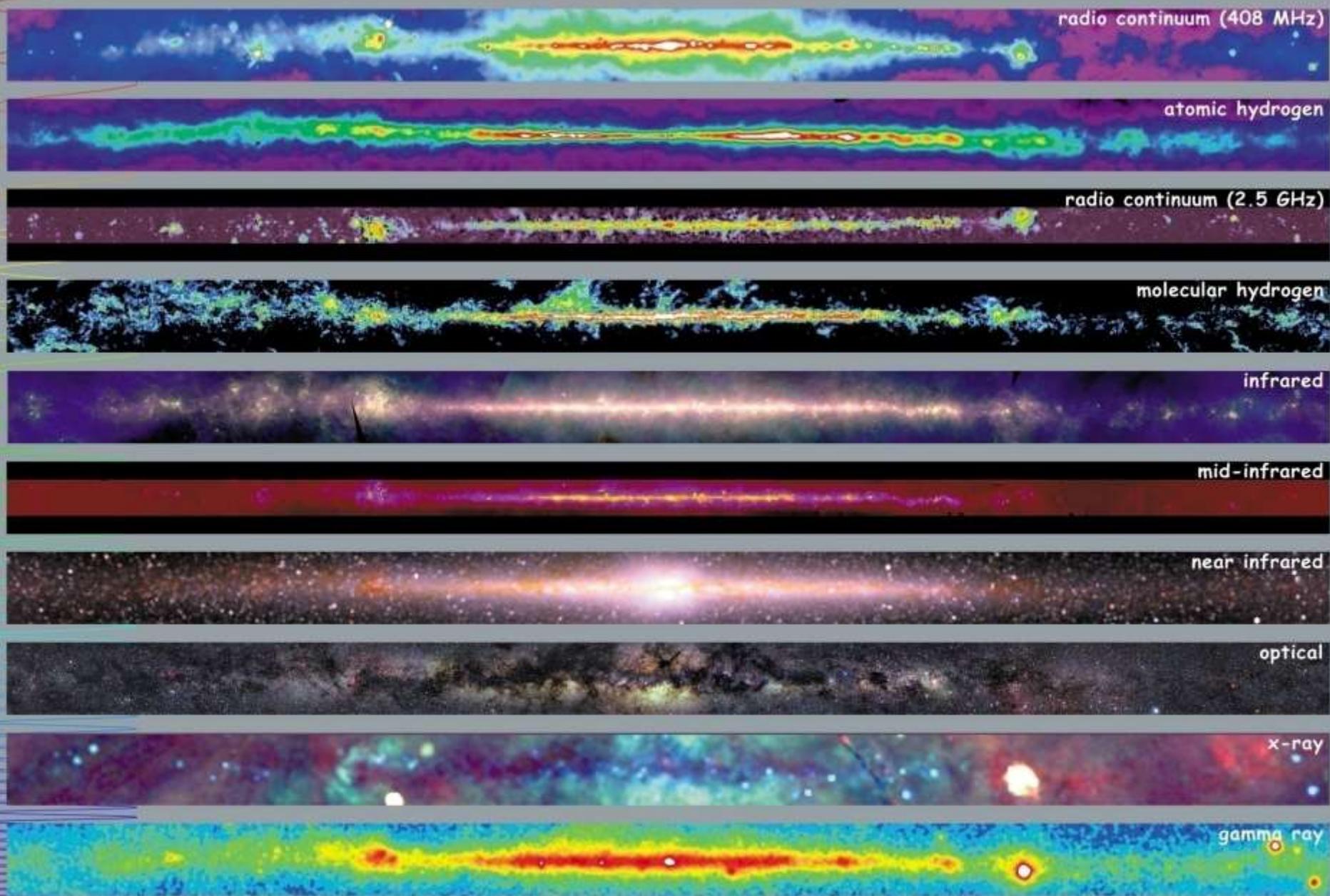
**Geoffrey Chaucer (1343 – 1400)**



(if you flew out sideways for 100,000 lyr)



(if you flew out up for 100,000 lyr)



<http://adc.gsfc.nasa.gov/mw>



# Multiwavelength Milky Way

# Why Are We Here Today?

- Senator to Scientist at a Budget Hearing:  
"Sir, how does your research contribute to the national defense?"
- Scientist:  
"It makes the country worth defending."

# Scientific Method



- The difference between the science and the myth is that a scientific theory is based on *observations* and necessarily makes *predictions*, which again can be tested by observing the real universe.
- The scientific description should be *objective*, i.e. any observation or experiment should be *reproducible* by others.

# Question:

How do scientists make science?

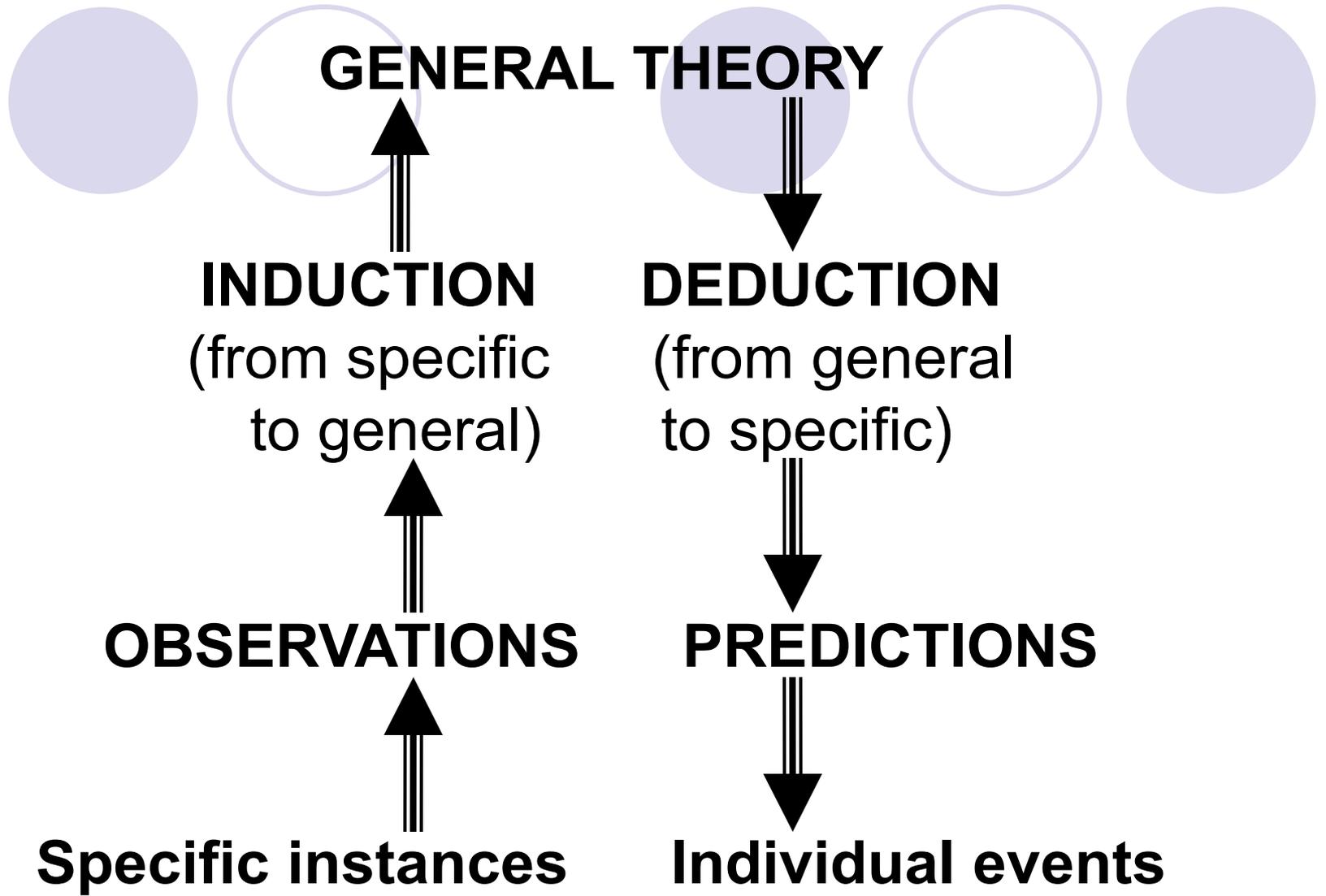
**A:** They sit in the lab/observatory and write in lab/observatory journals.

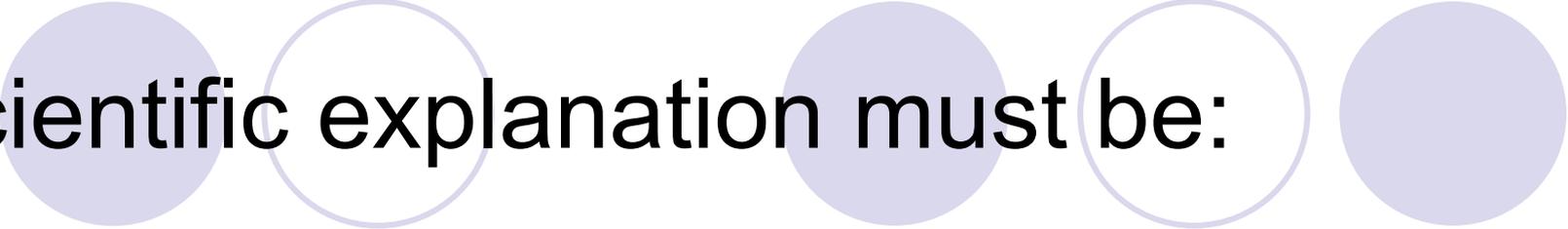
**B:** They walk in the park and occasionally smash themselves at the forehead and exclaim “Eureka!”.

**C:** They stand at the blackboard, talk, and scribble unintelligible symbols.

**D:** They sit at the desk and write pages and pages of dull text and long equations.

**E:** They stand in front of large audiences and make long and boring presentations.



A decorative header consisting of five circles in a row. From left to right: a solid light purple circle, a hollow light purple circle, a solid light purple circle, a hollow light purple circle, and a solid light purple circle.

# Scientific explanation must be:

- relevant (a pure thought does not work);
- falsifiable (this does not mean it is false);
- consistent with previously established theories;
- simple; this is sometimes called *Occam razor* (for medieval English philosopher William of Occam).
- predictive (not the same as falsifiable).

# Question:

Which answer to the question  
“Why does a pen fall on the floor?”  
is falsifiable?

**A:** The Earth's gravity pulls it.

**B:** All things tend to move to the center of the Earth.

**C:** It just feels like doing that.

**D:** It is the God's will.



# Levels of Scientific Truth

- **Law:** short, extremely well-established theory (usually a single equation).
- **Theory:** well established and well tested with the observations. All relevant quantities are known to sufficient precision. Rarely, if ever, wrong.
- **Model:** reasonably well established and tested with the observations. Not all parameters are determined to high precision. Rarely wrong.
- **Hypothesis:** plausible, but not well established; supported by a limited set of observations. Sometimes wrong.
- **Scenario:** quite speculative, supported by only a few observations, if any. Often wrong.
- **Paradigm:** a set of ideas, does not have to be supported by any observations. Usually un-specific.

The text is surrounded by five light purple circles. One circle is positioned behind the letter 'H', another behind the letter 'y', a third behind the colon ':', a fourth behind the letter 'A', and a fifth behind the letter 's'.

**History I:**

**Ancient Greeks**

Ancient Greeks were the first to develop a *scientific* view of the world. They realized that it was possible to observe a natural phenomenon and to seek an explanation for it; it was possible to express this explanation in precise, mathematical terms.

The Greeks knew that:

- the Earth was a sphere;
- the diameter of the Earth was 250,000 stadia;
- But **we** do not know how much a stadia was (or, rather, there were several of them).



For the Greeks

*mathematics = geometry.*

The Greek world was made of straight lines,  
circles, and spheres.

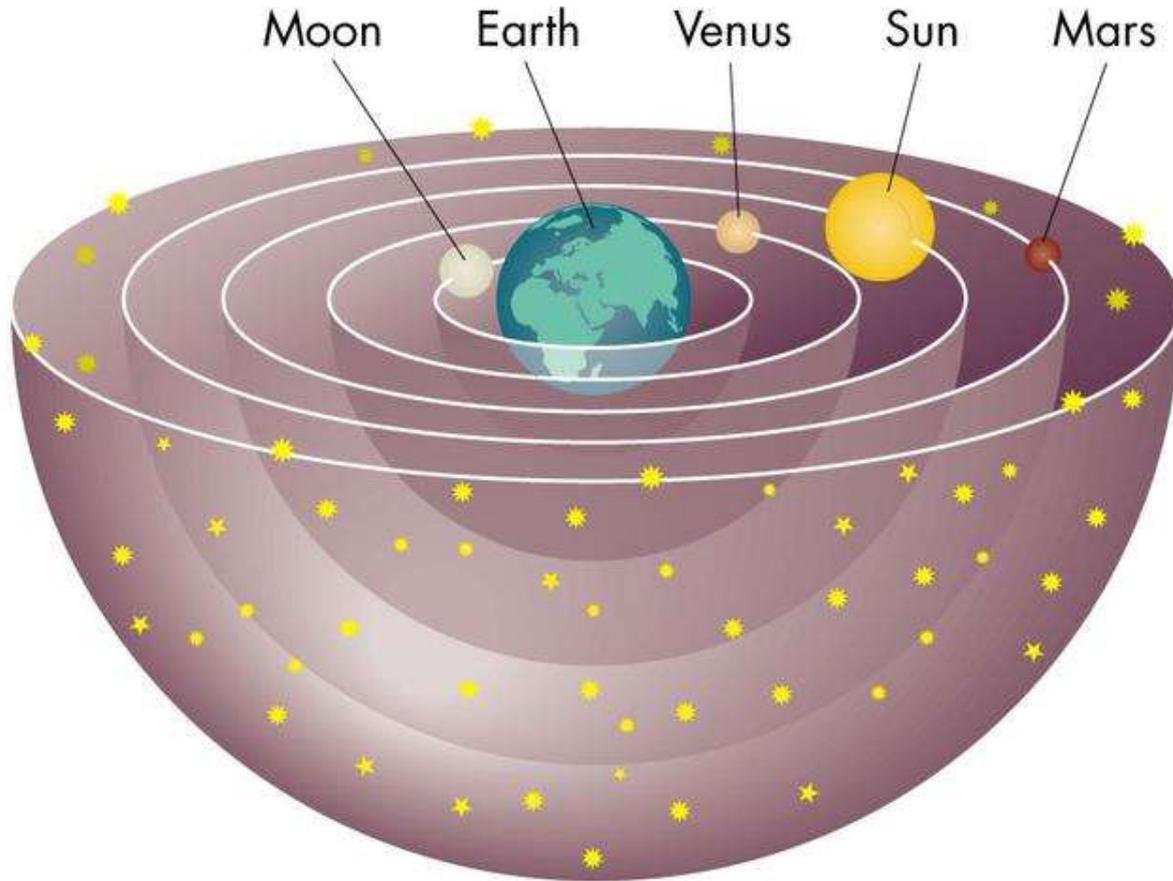
The Greeks considered pure mathematical thought to be supreme over the observations. The modern science is based on the opposite relationship (well, almost).

# Eudoxus (410/408 – 355/347 BC)

*(neither a sculpture of him nor his works survived to present)*

- A student of Plato
- Believed to be the first to introduce geocentric (with Earth as the center) model of the solar system.

# Geocentric model of the universe

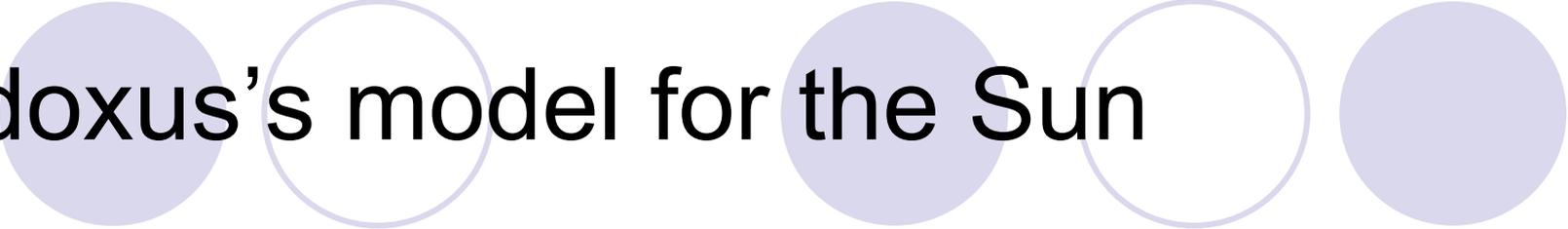


# Main Assumptions of Eudoxus's model



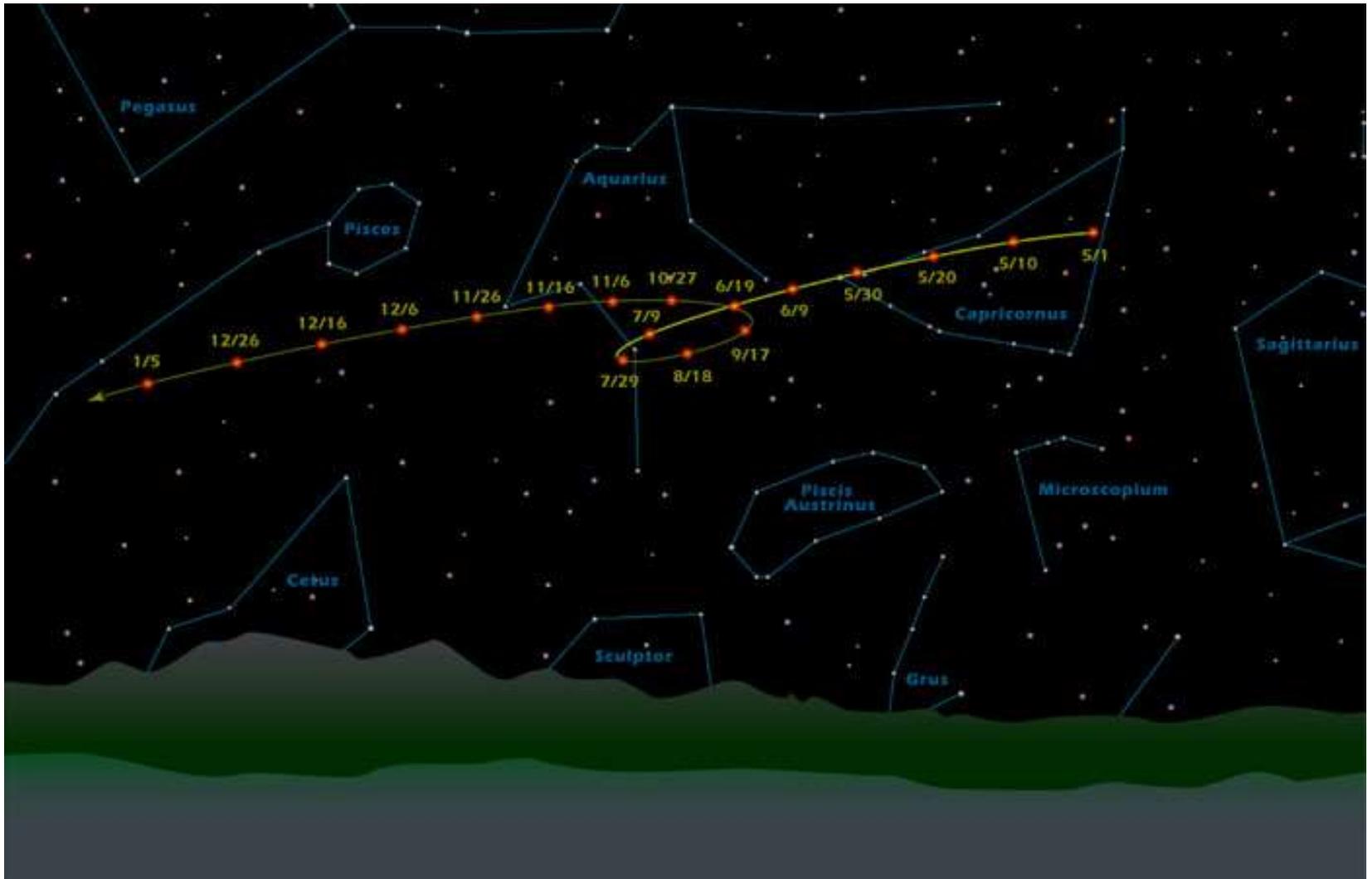
- Unmovable Earth is at the center of the world.
- The Sun, planets, and stars lie on rotating spheres.
- All stars are at the same distance from the Earth.
- There are 3 spheres for Moon and the Sun, 4 spheres for each of the 5 planets, and a sphere of fixed stars (27 celestial spheres altogether).

# Eudoxus's model for the Sun

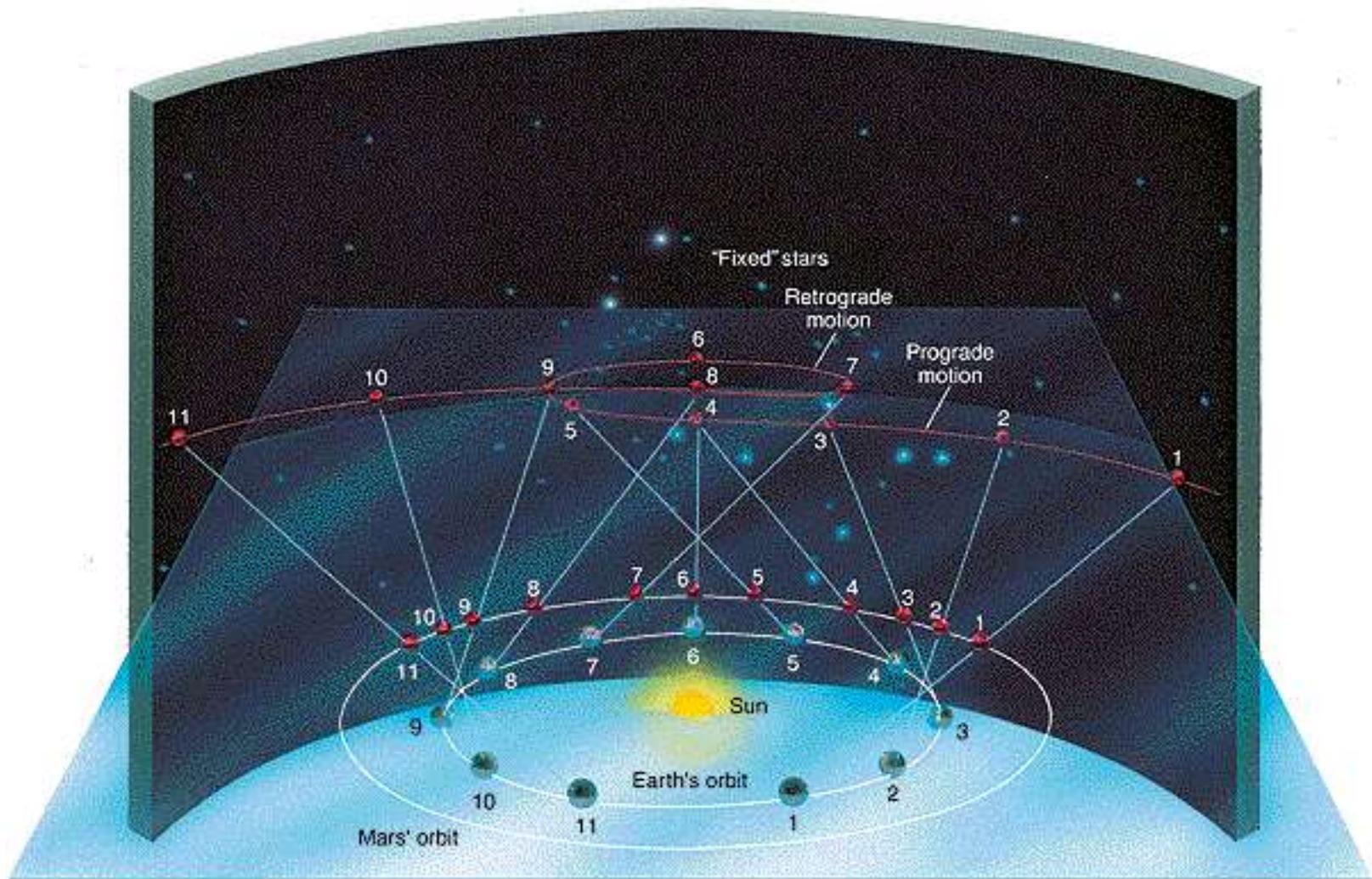


- Sun is assigned three spheres:
  - The outermost rotates westward once in 24 hours, explaining rising and setting.
  - The second rotates eastward once in one year, explaining seasons.
  - The third he included by mistake.

# Retrograde motions: the bane of the geocentric model



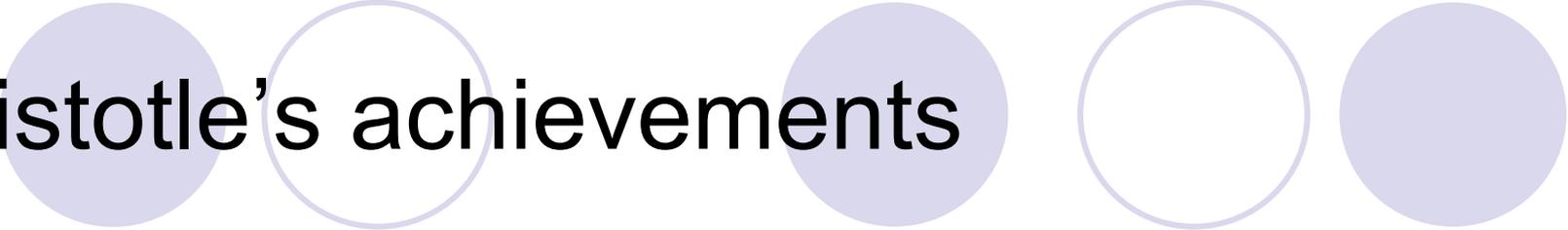
# Retrograde motions: the bane of the geocentric model



# Aristotle (384-322 BC)

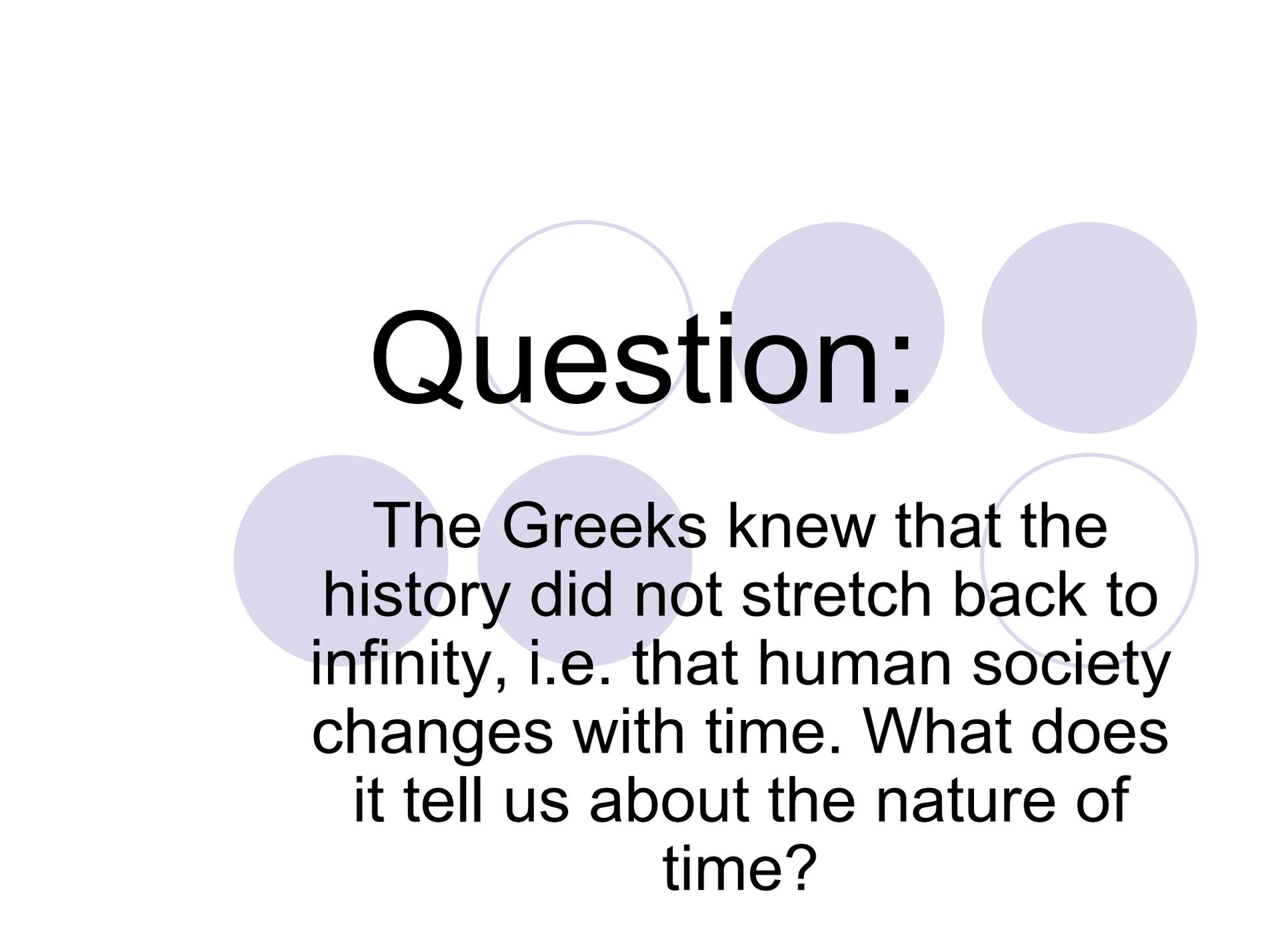


- Plato (Aristotle's academic advisor) thought that the observations are not important, perhaps even misleading. The pure geometry is the ultimate reality.
- Aristotle took observations seriously (but still he considered them inferior to the pure thought, more like servants of the theory).



# Aristotle's achievements

- Aristotle was the first to introduce the theory of motion, i.e. ***mechanics***, even if we now consider his mechanics to be wrong.
- He refined Eudoxus' model: it now included 55 different spheres.



# Question:

The Greeks knew that the history did not stretch back to infinity, i.e. that human society changes with time. What does it tell us about the nature of time?



**A:** Time had a beginning. The world did not exist before the beginning of time.

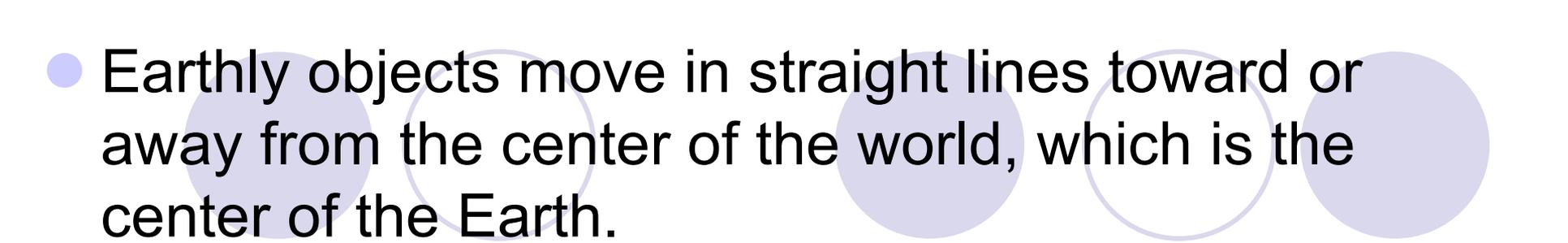
**B:** Time and the world always were and always will be. It is the Earth that changes, the heavens are eternal and unchangeable.

**C:** Time and the world always were and always will be, but the whole world is changing all the time: the past is not like today, and the future will also be different.

# Aristotelian physics



- All earthly things consist of 4 elements: earth (rocks), water, air, and fire. They all move differently: earth goes down (i.e. to the center of Earth), fire goes up, water and air stay in between. Air bubbles go up in water, and rocks sink. Thus, the composition of an object determines the way the object moves.
- If let go, an object will move to the position in the world order predefined by its composition.
- To keep an earthly object moving, a force has to be applied to it constantly.

- 
- Earthly objects move in straight lines toward or away from the center of the world, which is the center of the Earth.
  - Objects move along this line with different speeds, depending on their composition.
  - An object at rest (i.e. in its natural, predefined place in the world) will remain at rest unless is acted upon by a force.
  - A celestial motion is perfect, it continues indefinitely without any force.

- All celestial objects are made out of *ether*, the fifth element. Ether exists only in the cosmos, it is not present on earth.
- The time and the world always were and always will be. It is the Earth that changes, the heavens are eternal and unchangeable.
- The Earth is at the center of the world.
- Celestial objects move on rotating spheres; there is more than one sphere per object.

- Aristotle was one of the first scientists to propose a **model** for the Milky Way.
- He believed the Milky Way to be caused by "the ignition of the fiery exhalation of some stars which were large, numerous and close together" and that the "ignition takes place in the upper part of the atmosphere, in the region of the world which is continuous with the heavenly motions."  
(*Meteorologica*)

