Reading Question

Why didn't Copernicus's model accurately predict the positions of the planets?

A. He had the order of the planets wrong.
B. He had the distances to each of the planets slightly off.
C. His model still had the Earth at the center of the solar system.
D. He used perfect circles for the orbits of the planets.
E. Copernicus's model WAS accurate because he had used a model where the Sun was at the center.

Chapter 3
The Science of Astronomy

Chapter 3

Our goals for learning:

- In what ways do all humans use scientific thinking?
- How did astronomical observations benefit ancient societies?
- What did ancient civilizations achieve in astronomy?
- Why does modern science trace its roots to the Greeks?
- How did the Greeks explain planetary motion?
- How was Greek knowledge preserved through history? How did Copernicus, Tycho, and Kepler challenge the Earth-centered model?
- What are Kepler's three laws of planetary motion?
- How did Galileo solidify the Copernican revolution?
- How can we distinguish science from nonscience?
- What is a scientific theory?

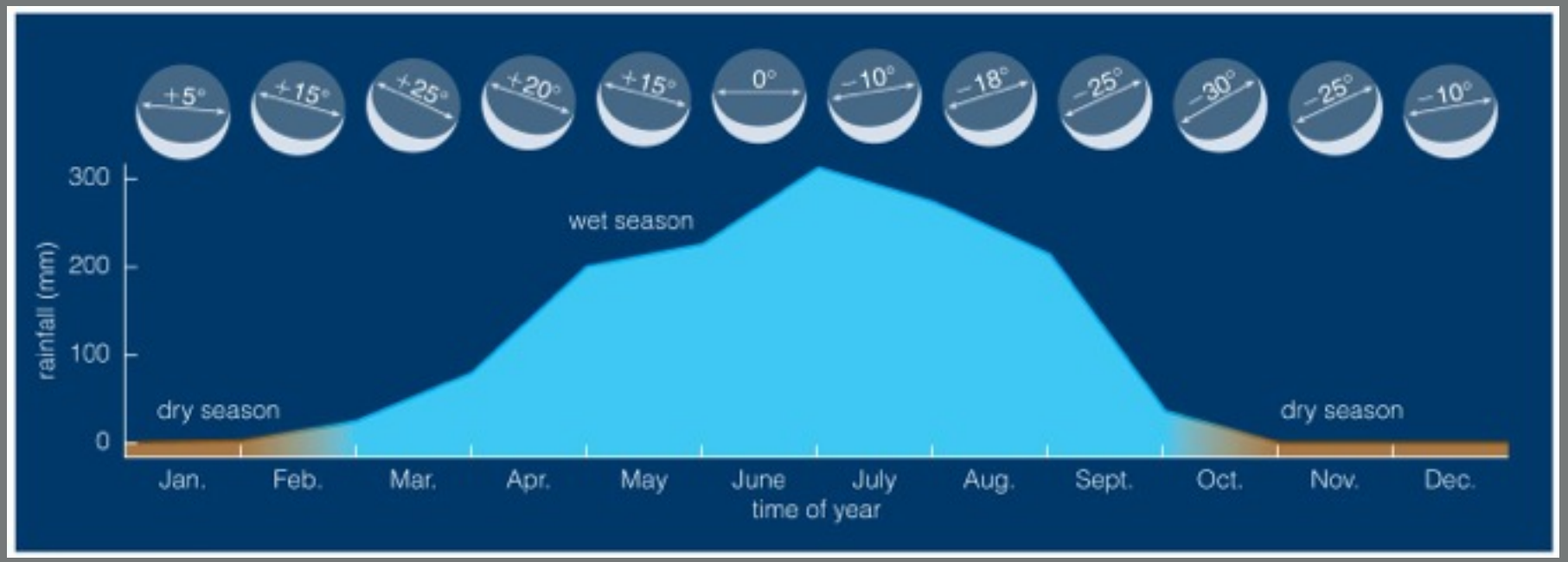
In what ways do all humans use scientific thinking?

- Scientific thinking is based on everyday ideas of observation and trial-and-error experiments.
- Give me examples

How did astronomical observations benefit ancient societies?

- Keeping track of time and seasons
  - for practical purposes, including agriculture
  - for religious and ceremonial purposes

- Aid to navigation



Ancient people of central Africa (6500 BC) could predict seasons from the orientation of the crescent Moon.

TABLE 3.1 The Seven Days of the Week and the Astronomical Objects They Honor

The seven days were originally linked directly to the seven objects. The correspondence is no longer perfect, but the overall pattern is clear in many languages; some English names come from Germanic gods.

Object	Germanic God	English	French	Spanish
Sun	—	Sunday	dimanche	domingo
Moon	—	Monday	lundi	lunes
Mars	Tiw	Tuesday	mardi	martes
Mercury	Woden	Wednesday	mercredi	miércoles
Jupiter	Thor	Thursday	jeudi	jueves
Venus	Fria	Friday	vendredi	viernes
Saturn	—	Saturday	samedi	sábado

Days of week were named for the Sun, Moon, and visible planets.

Egyptians invented first 24 hour day

Calendars

- Lunar - 29 to 30 days/month 354-355 days/year
  - Muslim - pure lunar
    - Ramadan Changes
  - Jewish Metonic -adds months 7 of 19 years
    - Easter changes
    - Eastern Orthodox uses Jullian rather than Gregorian
      - Julian adds leap year to correct
      - Gregorian Further tunes

Julian to Gregorian

- Real year 365.25 days - off 1 day / 4 years
- Julian added leap years in 46 BC to make spring around March 24th
- Gregorian calendar adopted in 1582
  - Spring had moved to March 11th
  - Eliminated ten days (Oct 5-14)
  - Moved spring equinox back to March 21st
  - Leap years skipped when new century turns unless divisible by 400
  - Adopted 1752 England, 1912/1919 China/Russia

Eclipses/Seasons/moon

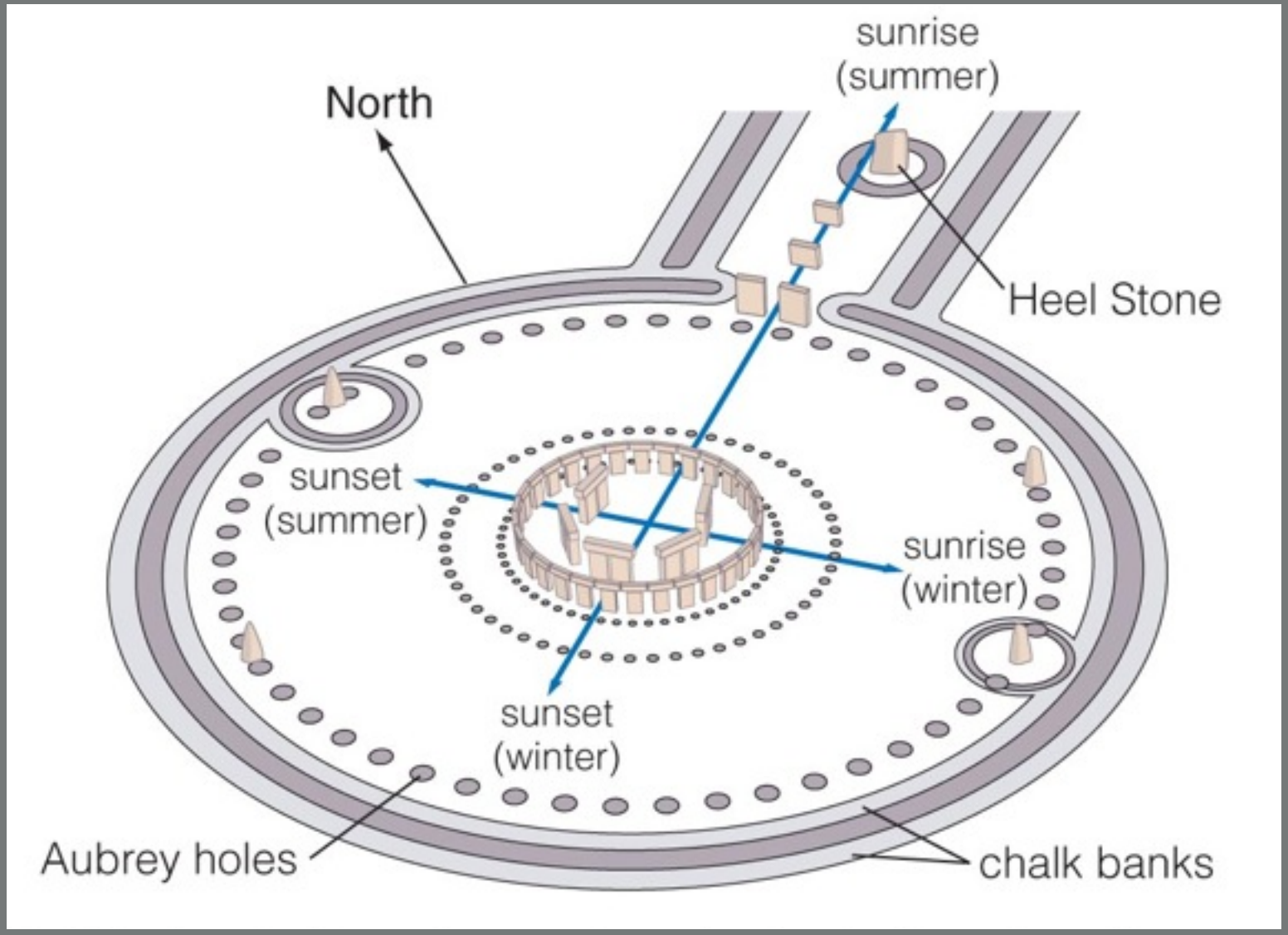
- Mayans calendar revolved around sacred time tied to eclipses
- Anasazi built structures marking points in 18.6 year moon cycle
- Babylonians 2500 years ago knew of the Saros Cycle
  - Recurring eclipse seasons every 18 years and 11.333 days

What did ancient civilizations achieve in astronomy?

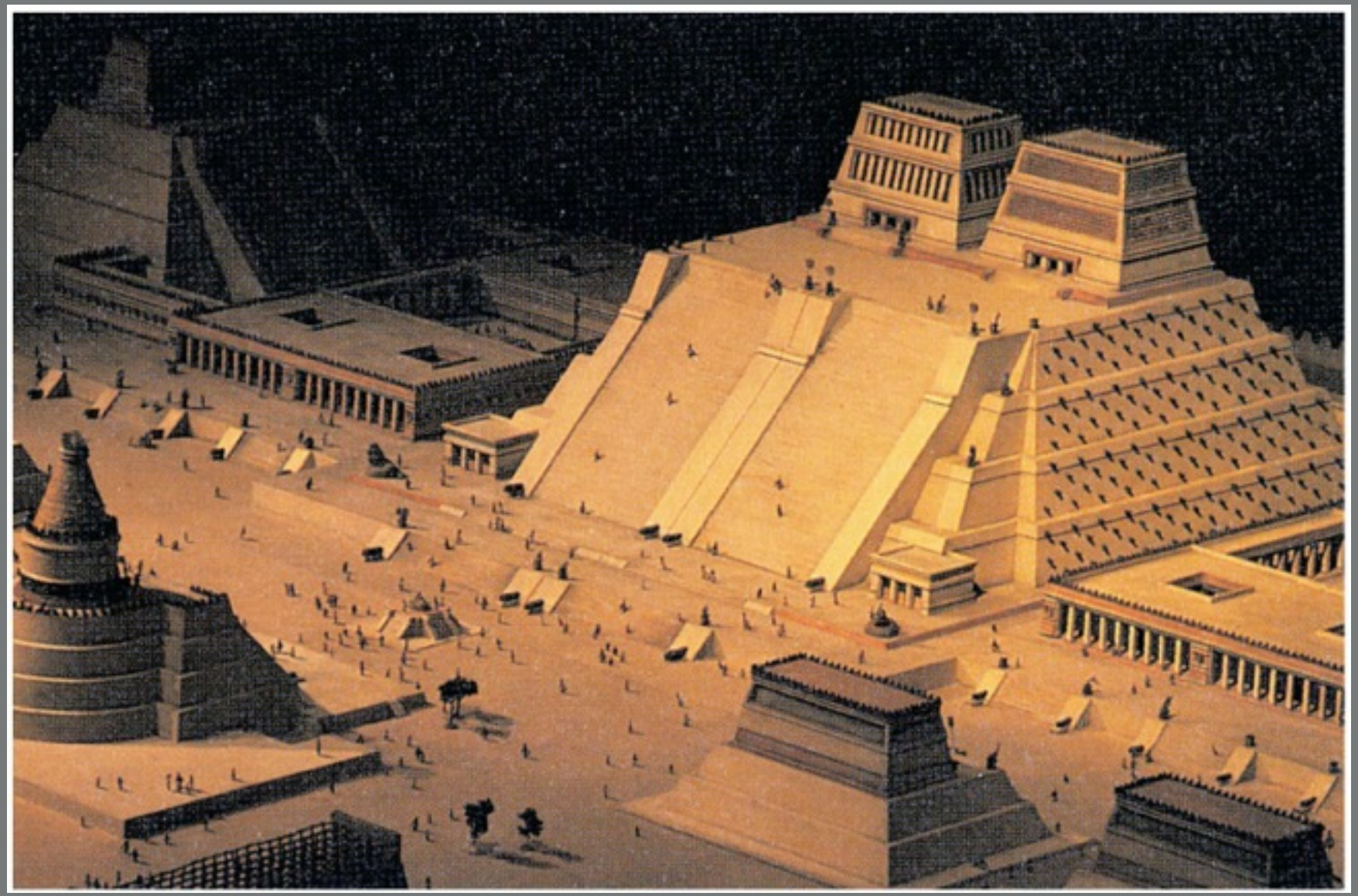
- Daily timekeeping
- Tracking the seasons
- Calendar
- Monitoring lunar cycles
- Monitoring planets and stars
- Predicting eclipses
- And more…

- Egyptian obelisk: Shadows tell time of day.

England: Stonehenge (completed around 1550 B.C.)



England: Stonehenge (1550 B.C.)

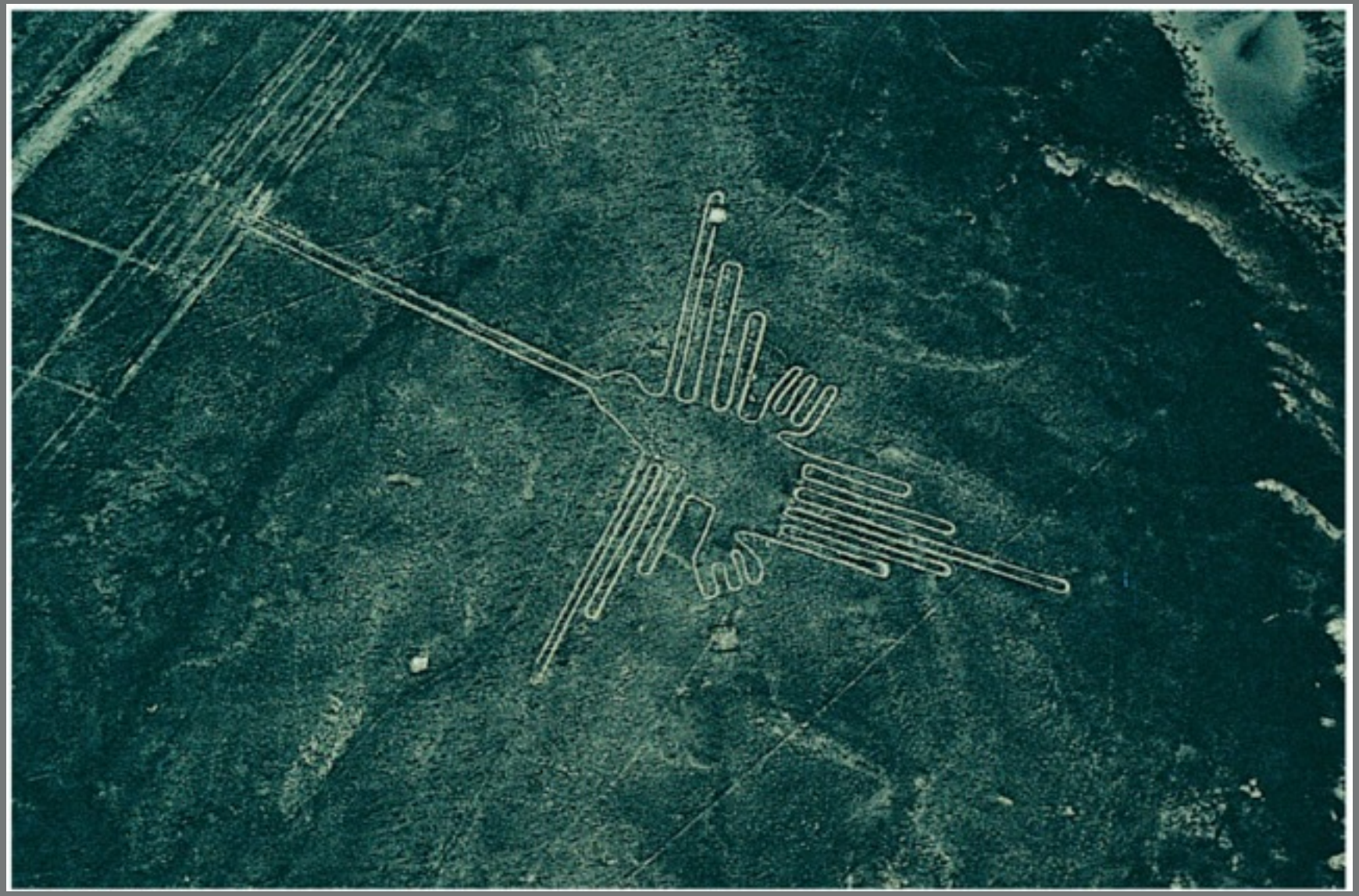


Mexico: Model of the Templo Mayor marked equinoxes

New Mexico: Anasazi kiva aligned north-south

SW United States: "Sun Dagger" marks summer solstice - Anasazi creation in Chaco Canyon

Scotland: 4,000-year-old stone circle; Moon rises as shown here every 18.6 years. (rise and set repeats exactly every 18.6 years)

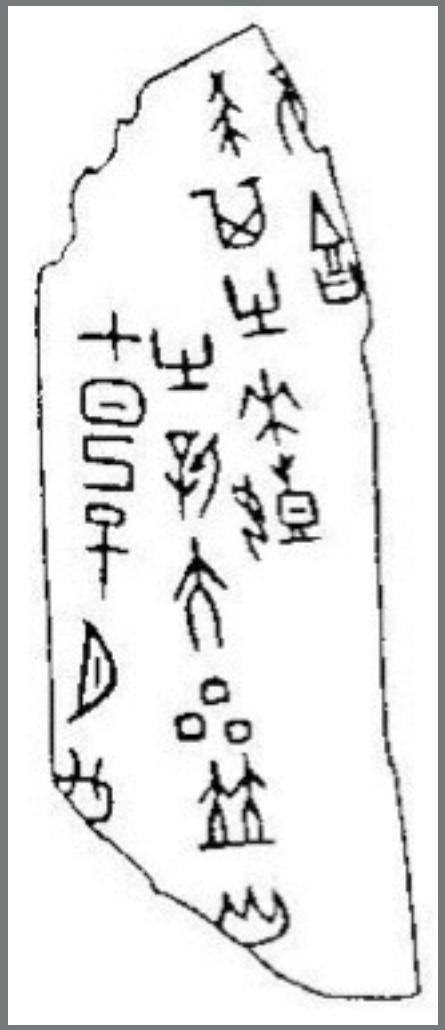


Peru: Lines and patterns, some aligned with stars.

Macchu Pichu, Peru: Structures aligned with solstices.

South Pacific: Polynesians were very skilled in art of celestial navigation.

France: Cave paintings from 18,000 B.C. may suggest knowledge of lunar phases (29 dots)



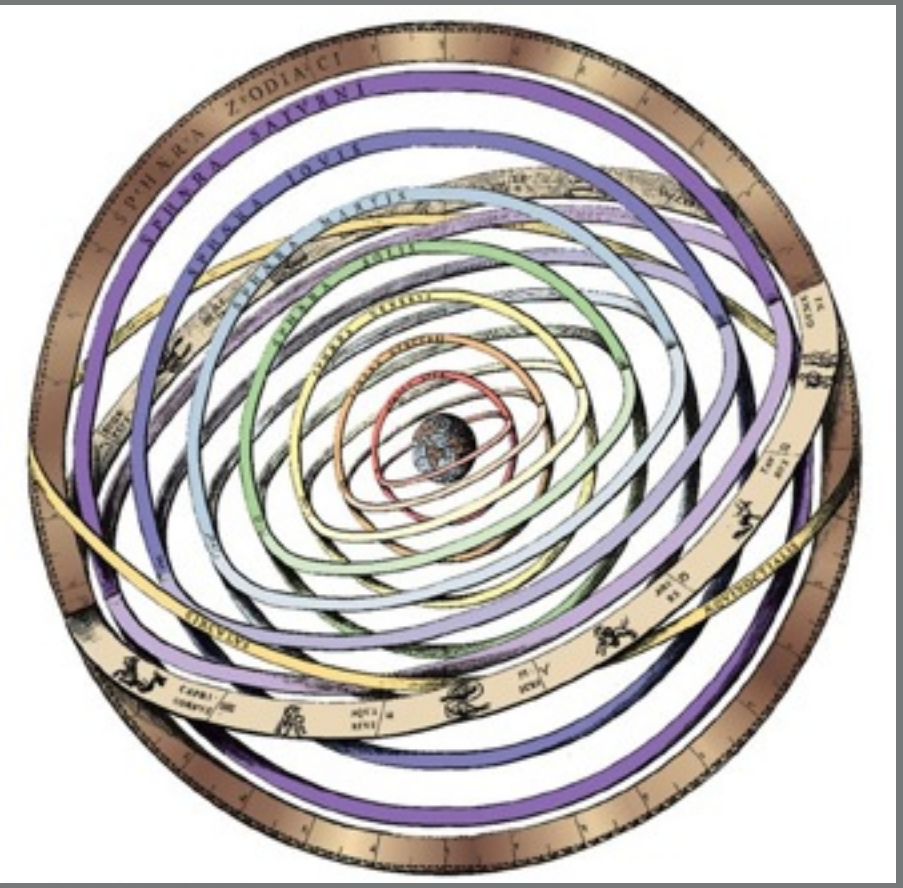
"On the Jisi day, the 7th day of the month, a big new star appeared in the company of the Ho star."

"On the Xinwei day the new star dwindled."

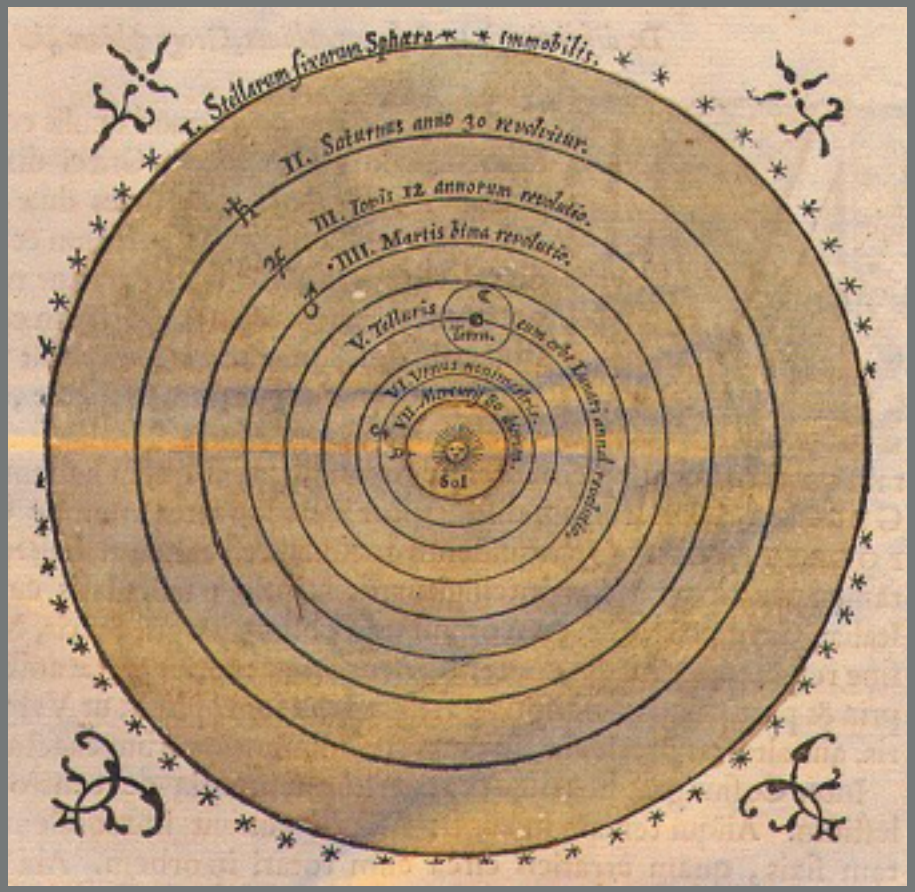
Bone or tortoise shell inscription from the 14th century BC.

China: Earliest known records of supernova explosions (1400 B.C.)

Geocentric vs Heliocentric



Earth-Centered
(Geocentric)



Sun-Centered
(Heliocentric)

Astronomically Important Historians

The Greeks (600 B.C. ~ 200 A.D.)

- Plato
- Aristotle
- Aristarchus*
- Eratosthenes*
- Ptolemy

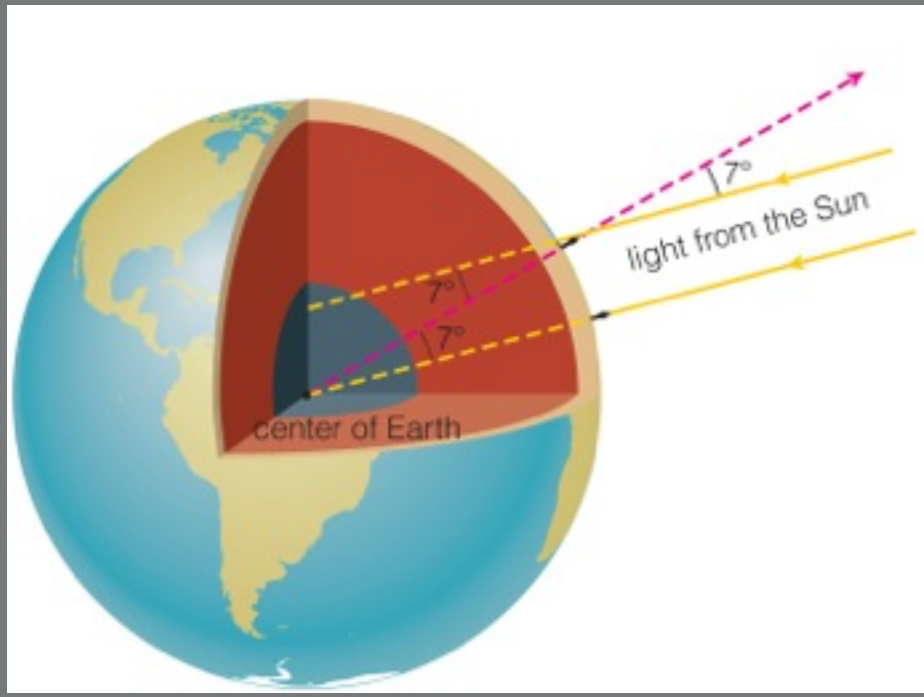
Don't bother with all the Greek details… just their overall view: **Geocentric**

Don't worry about dates - just what they did for astronomy

Copernican Revolutionaries

- Copernicus (1473-1543)
- Kepler (1571 - 1630)
- Galileo (1564 - 1642)
- Newton (1642 - 1727) (Ch. 4)

Special Topic: Eratosthenes Measures Earth (c. 240 B.C.)



Measurements:

Syene to Alexandria

distance ≈ 5000 stadia

angle = 7°

Calculate circumference of Earth:

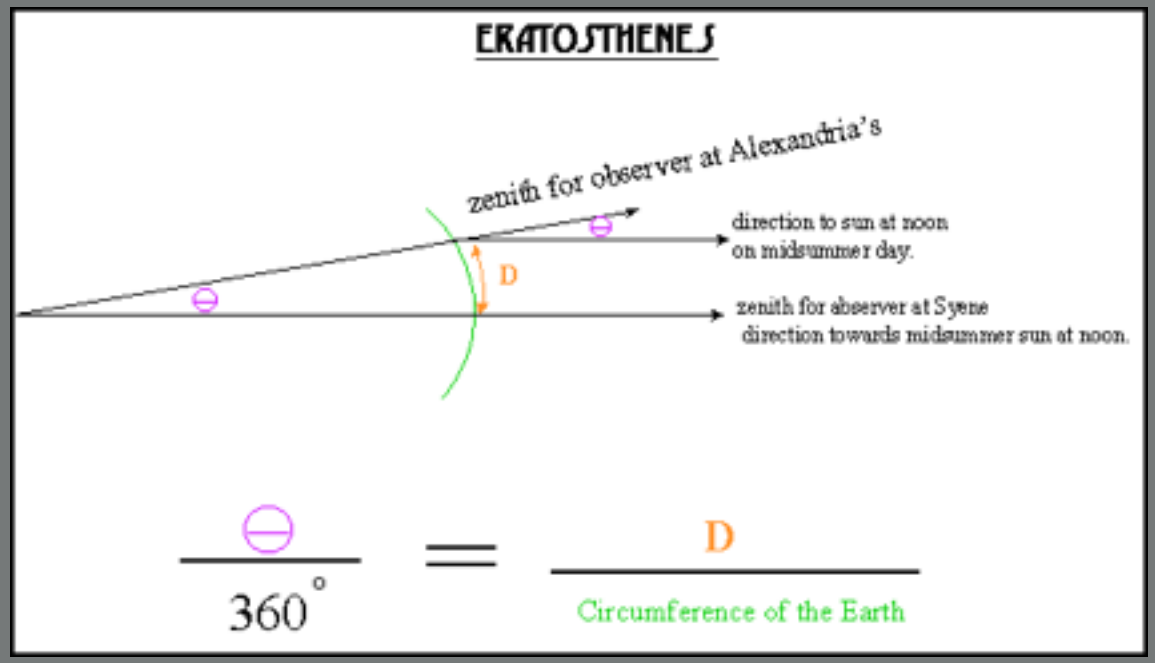
7/360 × (circum. Earth) = 5000 stadia

⇒ circum. Earth = 5000 × 360/7 stadia ≈ 250,000 stadia

Compare to modern value (≈ 40,100 km):

Greek stadium ≈ 1/6 km ⇒ 250,000 stadia ≈ 42,000 km

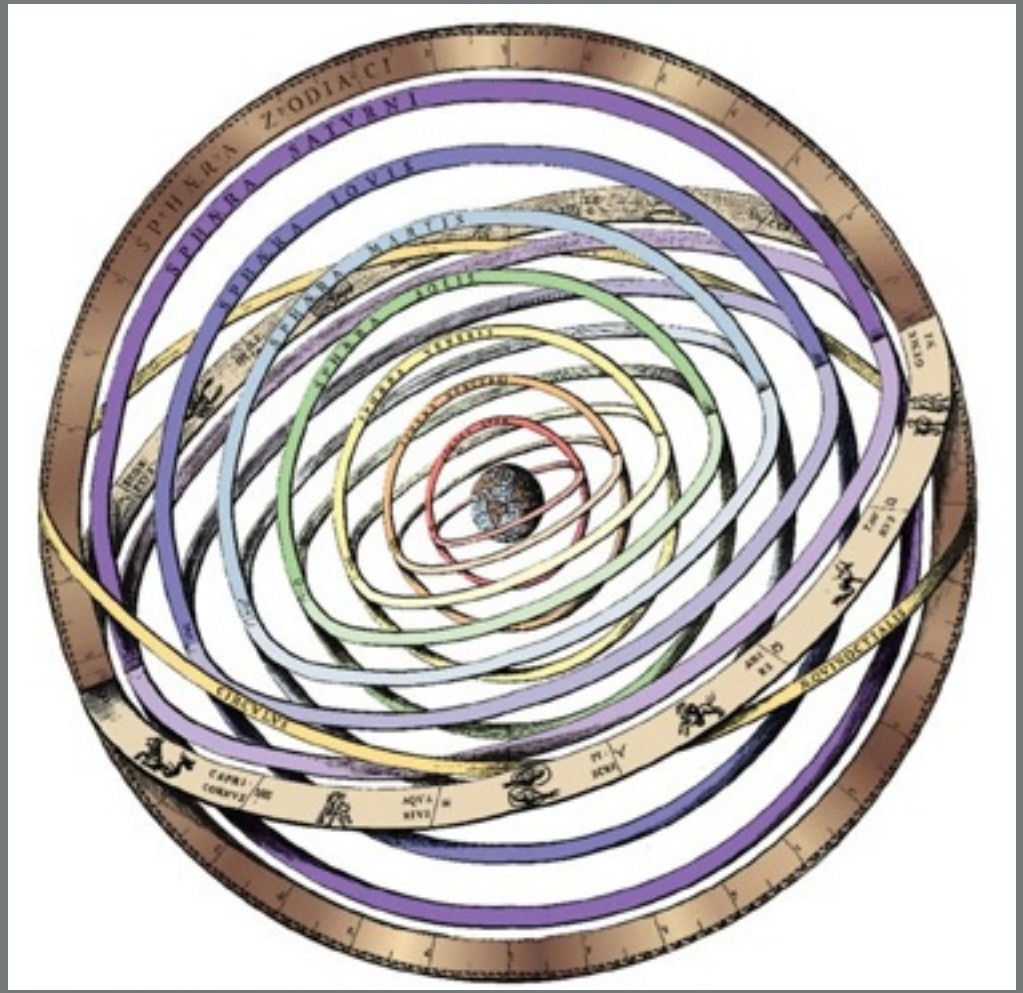
It is a myth that people thought the Earth was flat, educated people have known that to be incorrect for millenia



Planets Known in Ancient Times

- Mercury
- Venus
- Mars
- Jupiter
- Saturn

Why does modern science trace its roots to the Greeks?

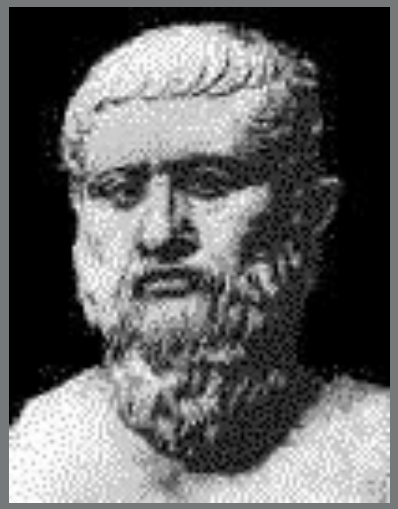


- Greeks were the first people known to make **models** of nature.
- They tried to explain patterns in nature by **rational thinking** and **observations** rather than myth

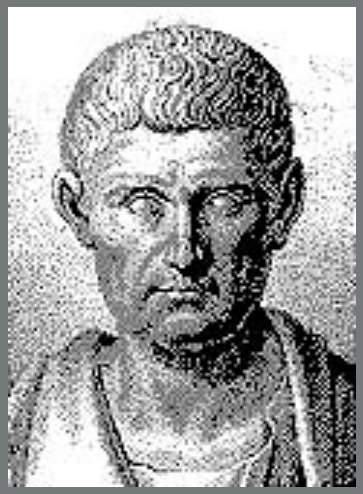
Greek geocentric model (c. 400 B.C.)

How did the Greeks explain planetary motion?

Underpinnings of the Greek geocentric model:

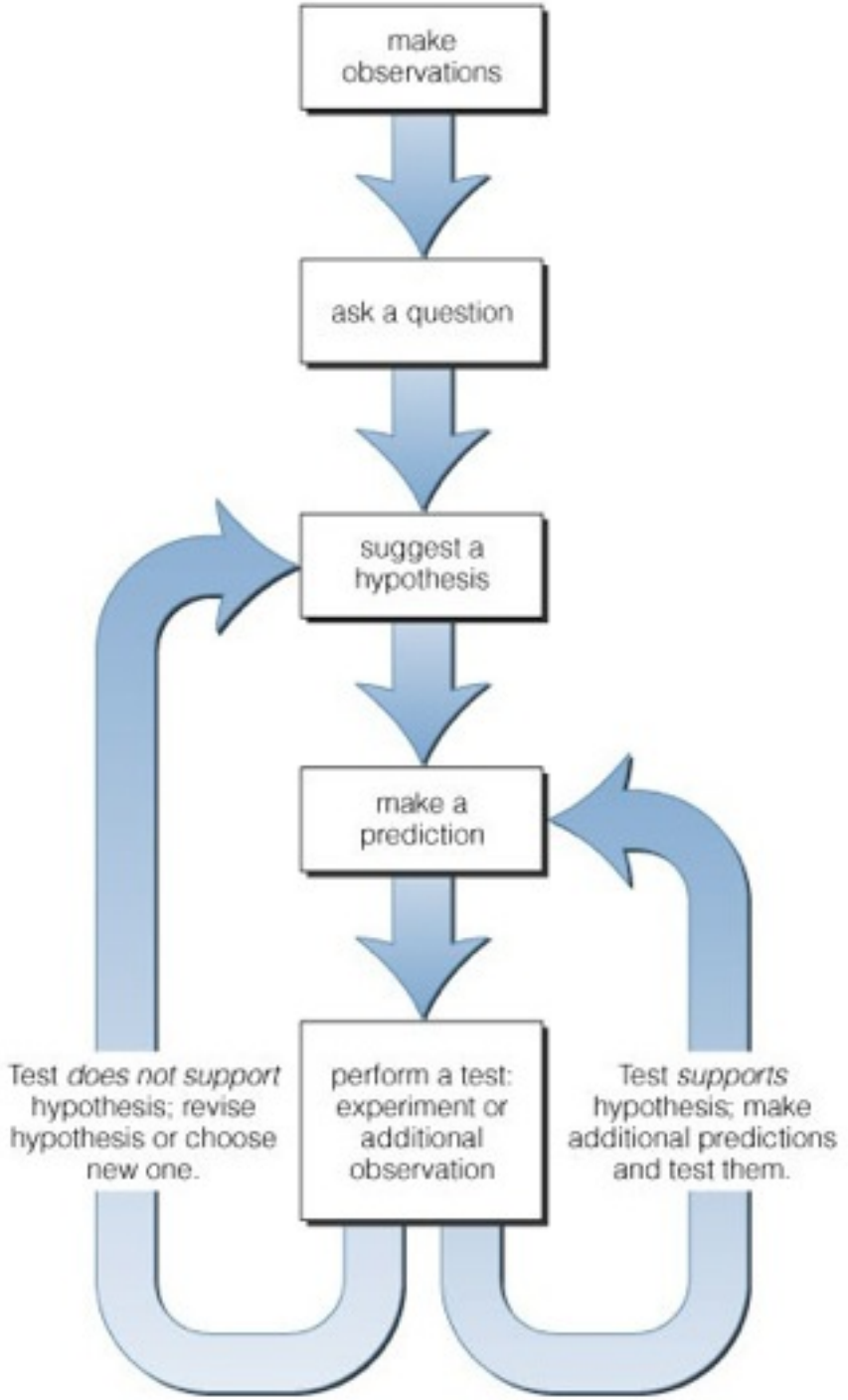


Plato



Aristotle

- Earth at the <u>center</u> of the universe
- Heavens must be "perfect":
  - Perfect spherical objects moving in perfect spheres or in perfect circles

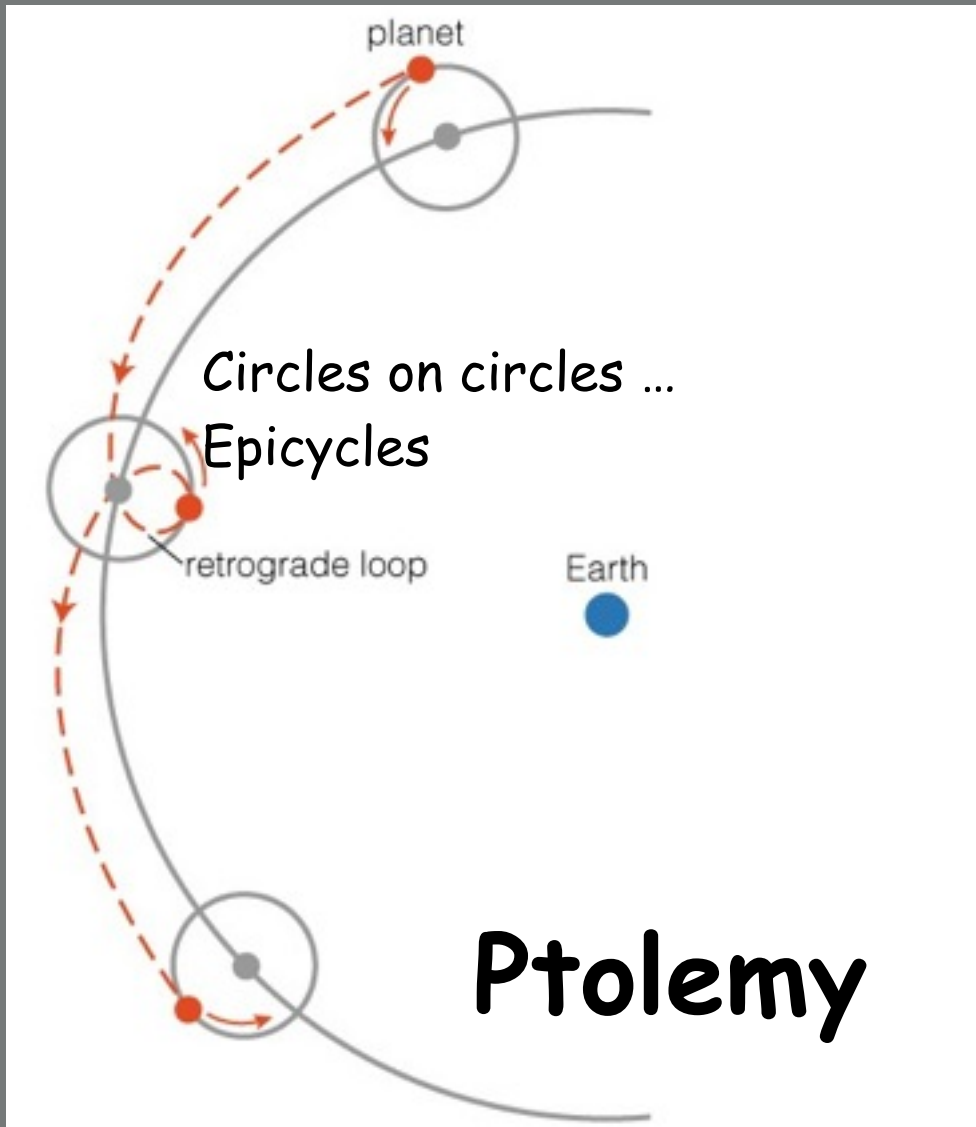


The idealized scientific method

- Based on proposing and testing hypotheses
- **hypothesis** = educated guess
- **Observations** are key
- More accurate observations distinguish between different hypotheses

Retrograde motion? Not a problem!

Still a GEOCENTRIC model



Ptolemy

Thought Question

Was Ptolemy's approach following the correct scientific method?

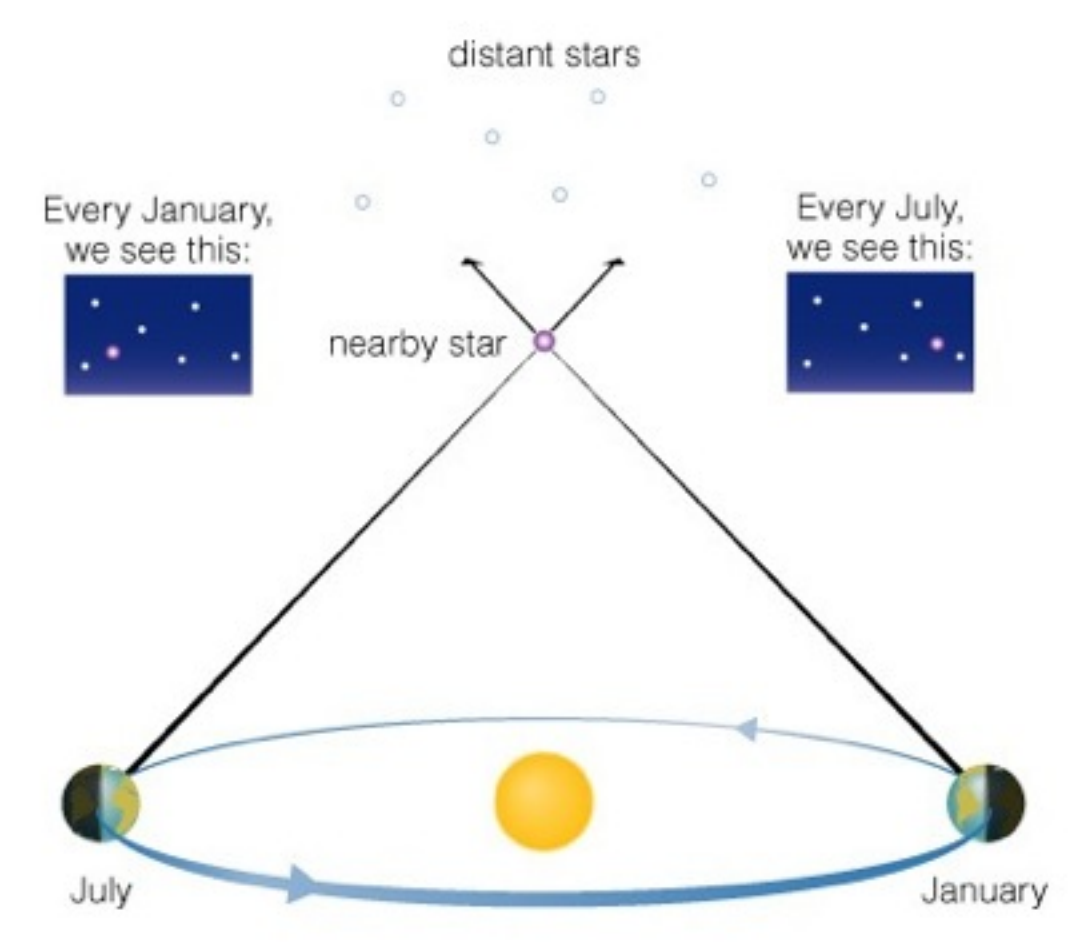
A. Yes
B. No

Explaining Apparent Retrograde Motion

- Easy for us to explain: occurs when we "lap" another planet (or when Mercury or Venus laps us)
- But very difficult to explain if you think that Earth is the center of the universe!
- In fact, ancients **considered** but **rejected** the correct explanation

Why did the ancient Greeks (and everyone else until 500 years ago) reject the real explanation for planetary motion?

- Their inability to observe **stellar parallax** was the key.



The Greeks knew that the lack of observable parallax could mean one of two things:

1. Stars are so far away that stellar parallax is too small to see (with the naked eye)
   - No way!

2. Earth does not orbit Sun; it is the center of the universe

That was the state of astronomy for about two millennia

Knowledge

- Greeks 600 BC - 415 AD
- Library of Alexandria on Nile Delta 300 BC - ~415 AD, 1/2 million books, fell with Hypatia
- Islamic scholars preserved,named constellations, multiple discoveries in optics, mathematics, astronomy
- Byzantine falls 1453 Scholars headed to Europe, helped spark the Renaissance

How did Copernicus challenge the Earth-centered idea?

Copernicus (early 1500s):

- Proposed Sun-centered (heliocentric) model

  - with circular orbits to determine layout of solar system

But . . .

- Model was no more accurate than Ptolemy's model in predicting planetary positions

Tycho Brahe (late 1500s)

Greatest naked eye astronomer of all times - observations over three decades to one arc minute(fingernail thickness)

Duel at 20 left him with silver/gold piece on is nose

More accurate measurements than ever before

Tycho Brahe

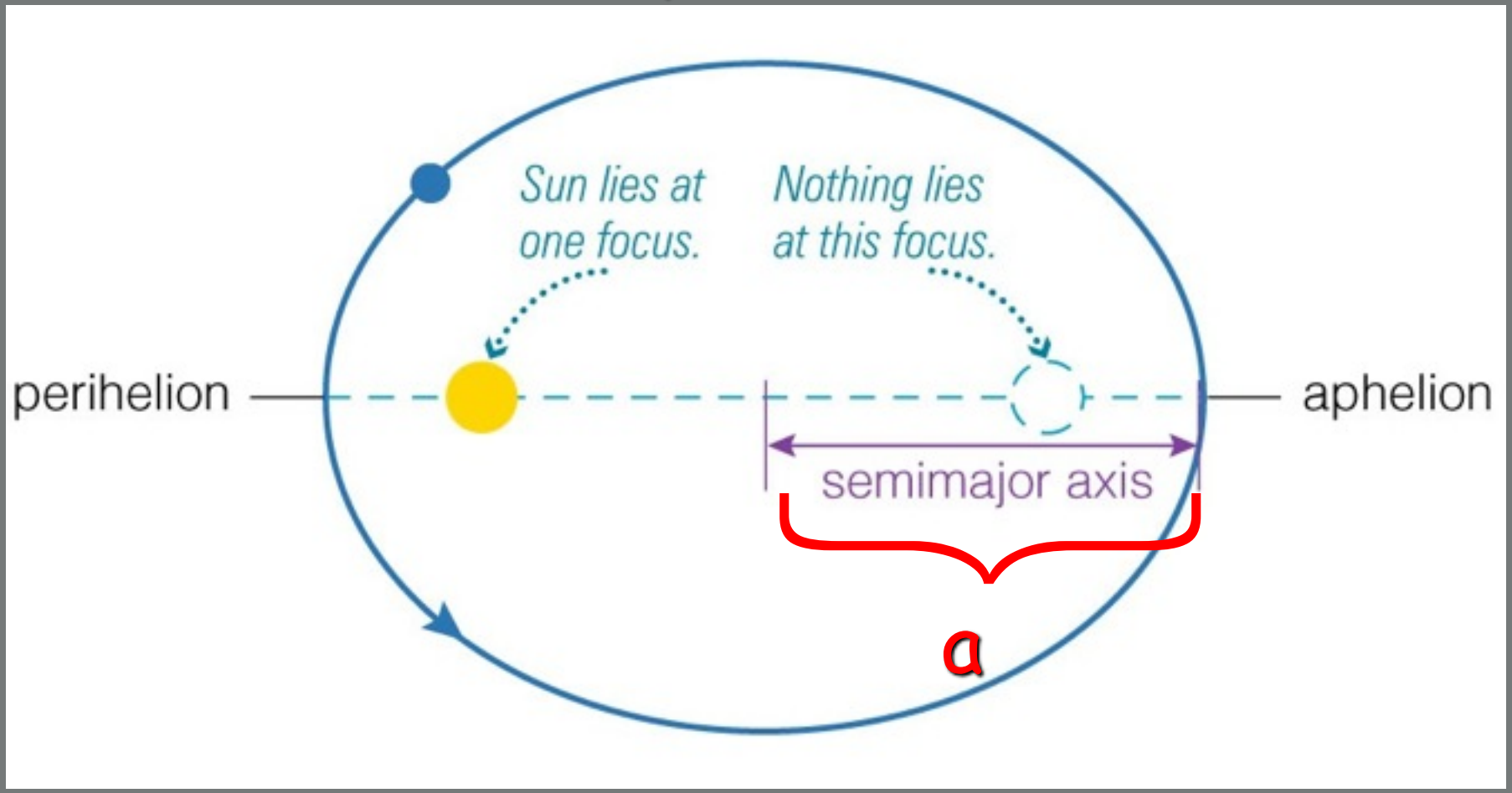
Johannes Kepler

"If I had believed that we could ignore these eight minutes [of arc], I would have patched up my hypothesis accordingly. But, since it was not permissible to ignore, those eight minutes pointed the road to a complete reformation in astronomy."

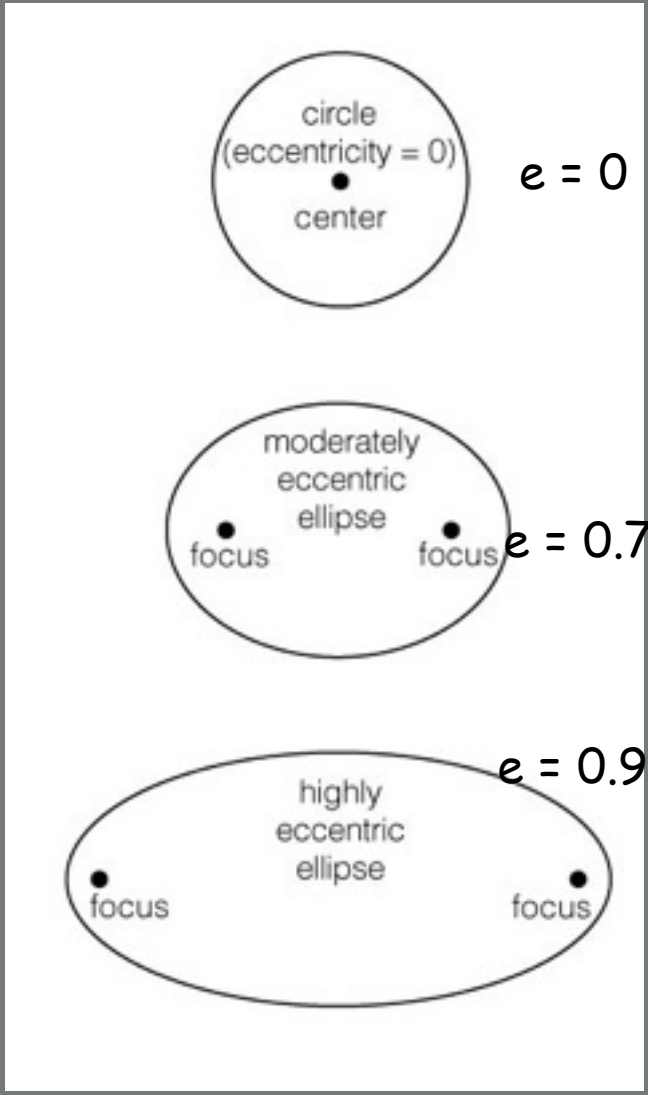
- Kepler first tried to match Tycho's observations with circular orbits (one fourth the diameter of a full moon)
- But a small discrepancy led him eventually to try **ellipses**
  - These orbits allowed him to match the data (and predict future observations) nearly perfectly

Kepler's 3 Laws of Planetary Motion

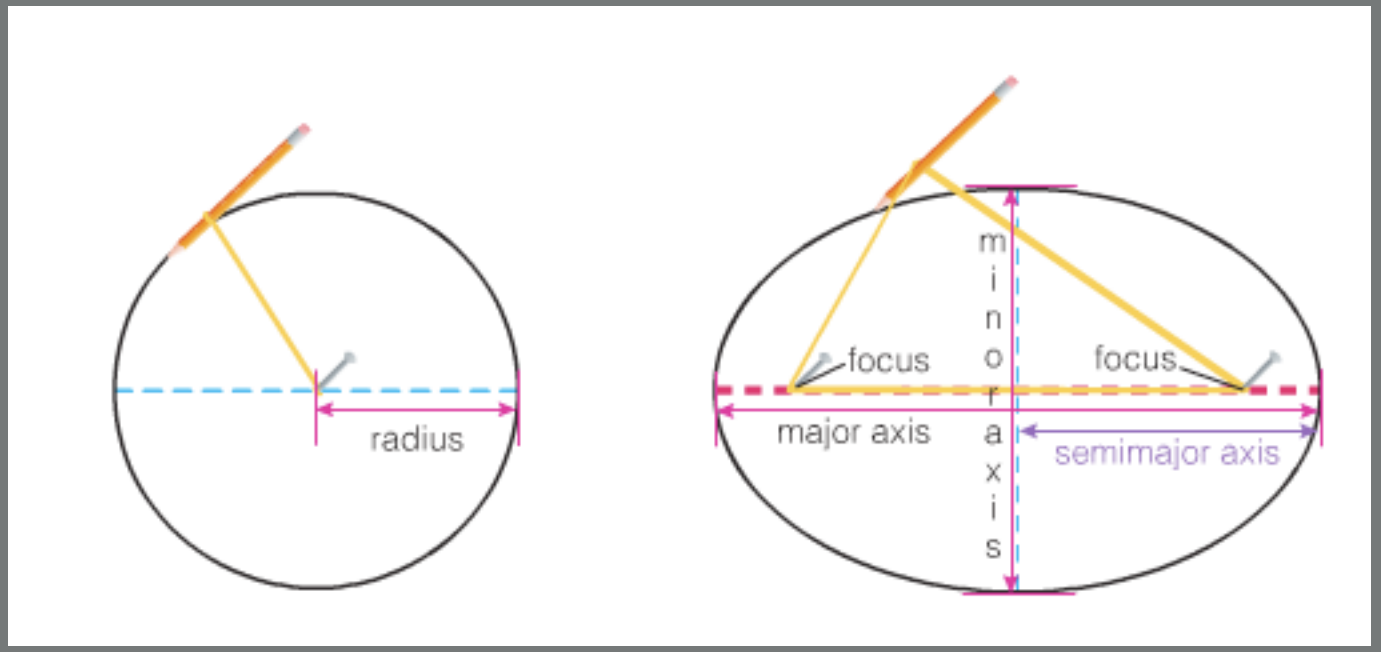
Kepler's First Law: The orbit of each planet around the Sun is an **ellipse** with the Sun at one focus.

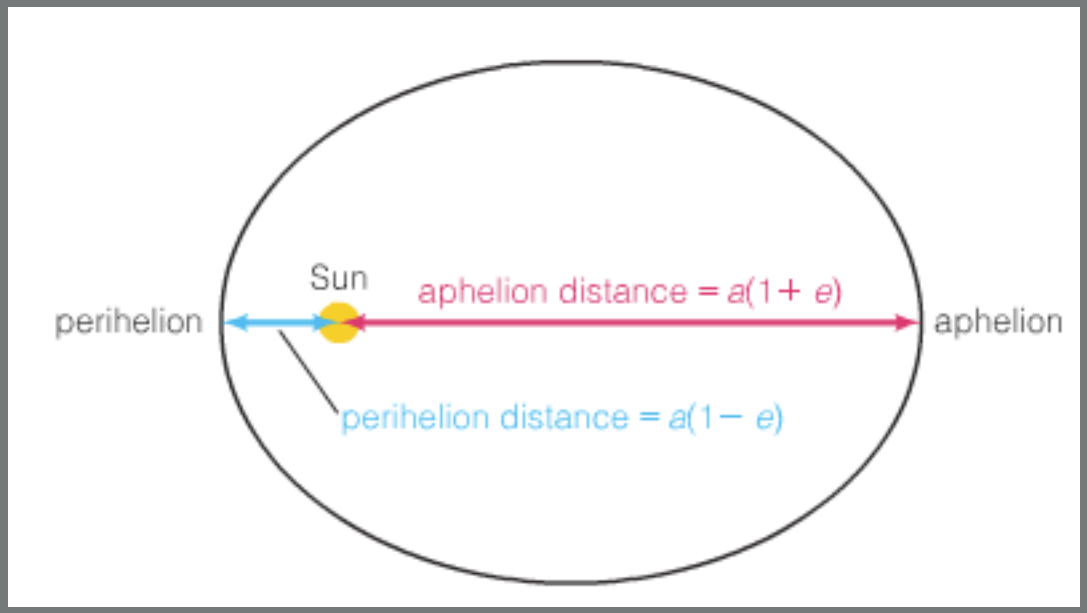


What is an ellipse?



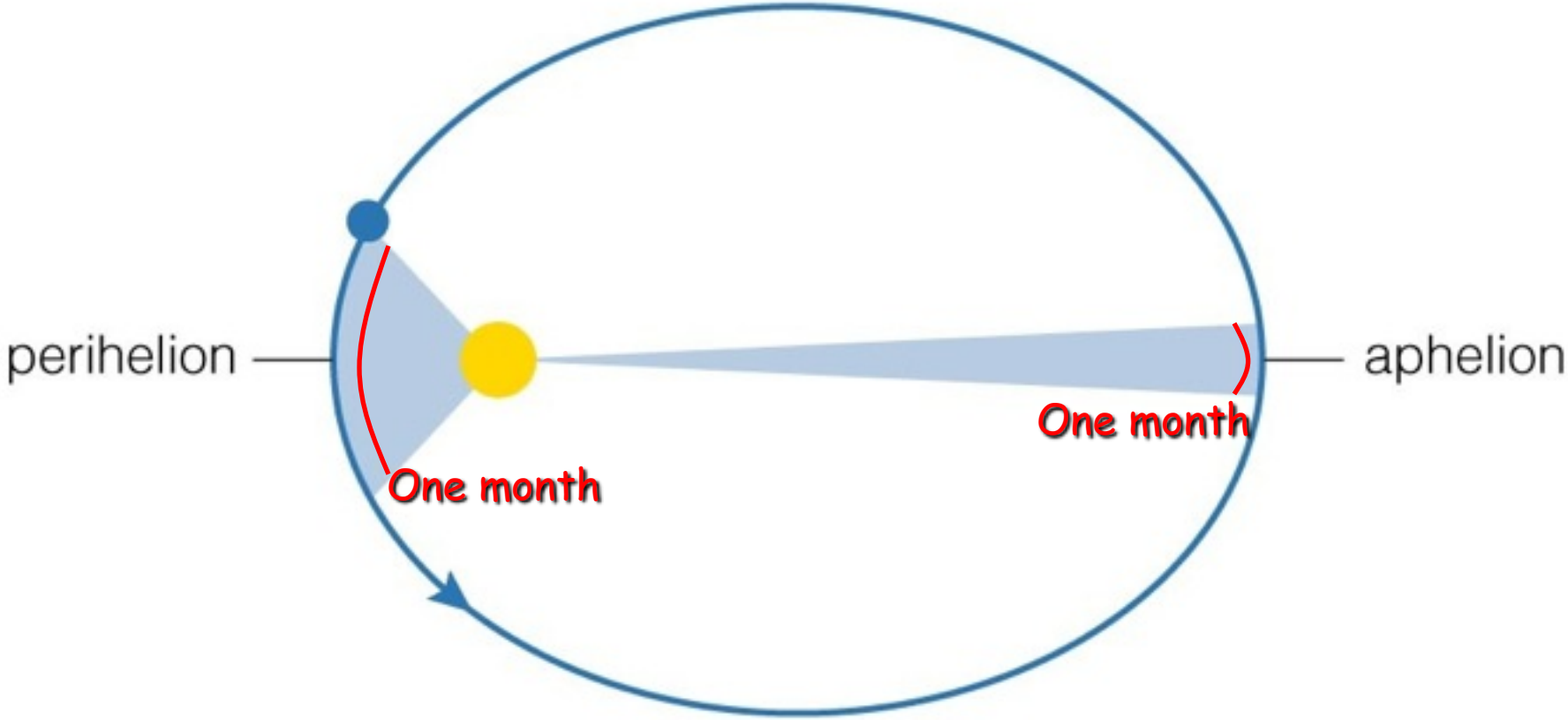
- An ellipse is just an elongated (or squashed) circle
- Eccentricity = how much is it squashed
  - Eccentricity goes from 0 to 1
    - 0 = not squashed at all (a perfect circle)
    - 1 = very squashed (a flat line)


radius
focus
focus
minor axis
major axis
semimajor axis


perihelion
Sun
aphelion distance = a(1+ e)
aphelion
perihelion distance = a(1− e)

Kepler's 3 Laws of Planetary Motion

Kepler's Second Law: As a planet moves around its orbit, it sweeps out equal areas in equal times



The area swept out during both months are equal

Thought Question

According to Kepler's second law, a planet with an orbit like Earth's (a=1AU, e=0.017) would:

A. move faster when further from the Sun.

B. move slower when closer to the Sun.

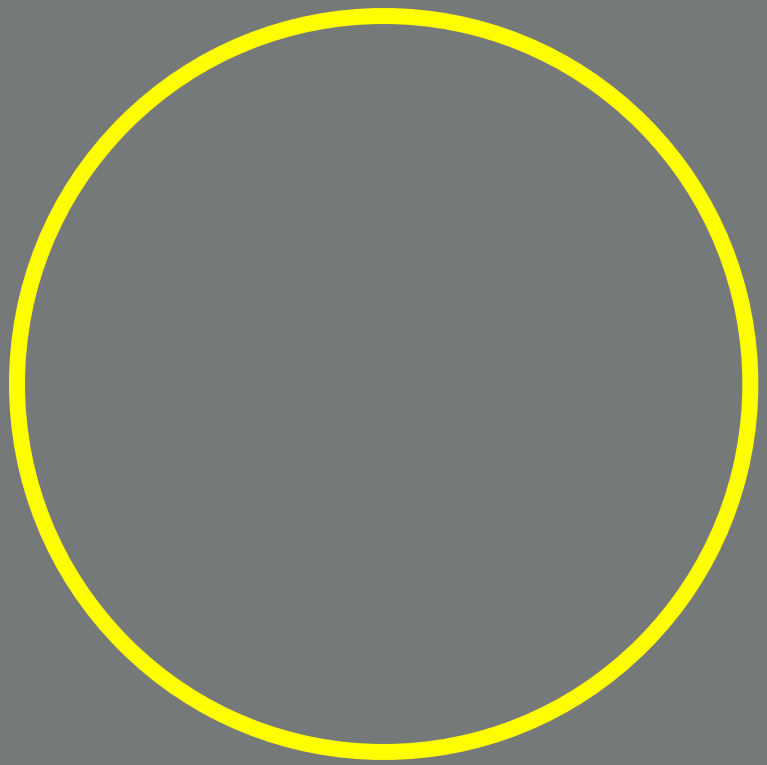
C. experience a dramatic change in orbital speed from month to month.

D. experience very little change in orbital speed over the course of the year.

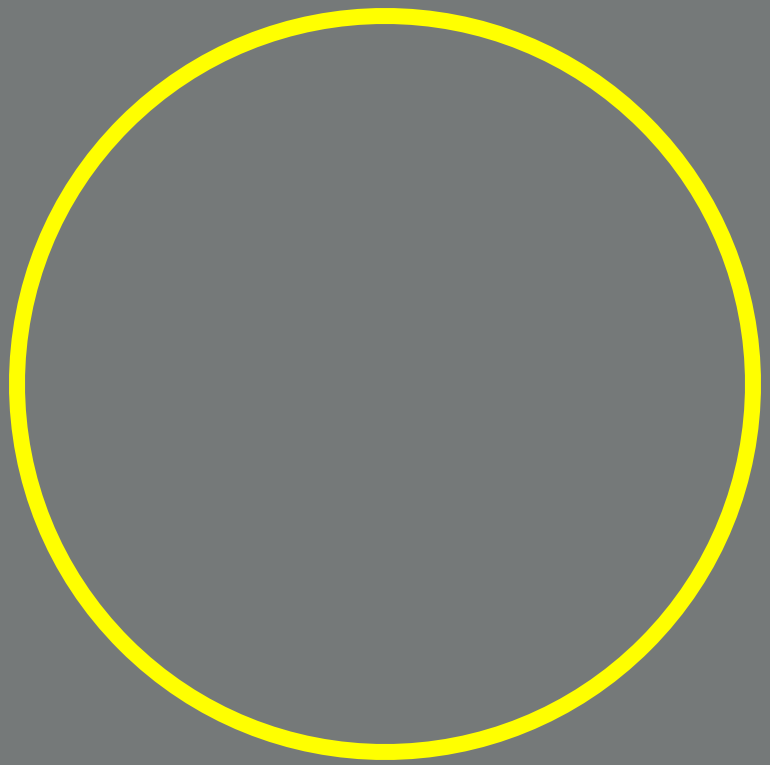
E. none of the above.

Earth's orbit around the Sun

e = 0.017



$e = 0$



Kepler's 3 Laws of Planetary Motion

Kepler's Third Law: Planetary orbits follow the **mathematical relationship:**

$$p^2 = a^3$$

p = orbital period **in years**

a = avg. distance from Sun **in AU**

= semi-major axis of elliptical orbit

Thought Question

Which of the following best describes what would happen to a planet's orbital time if its mass were doubled but it stayed at the same orbital distance?

A. It would orbit half as fast.
B. It would orbit less that half as fast.
C. It would orbit twice as fast.
D. It would orbit more than twice as fast.
E. It would orbit with the same speed.

Kepler's 3 Laws of Planetary Motion

Kepler's Third Law: Planetary orbits follow the mathematical relationship:

$$p^2 = a^3$$

p = orbital period **in years**

a = avg. distance from Sun **in AU**

= semi-major axis of elliptical orbit

Planet's mass doesn't matter!

Reading Question

Astrology can be tested by

A. Asking astrologers if it works.
B. Seeing if any of the predictions come true.
C. Polling people to find out what percentage believe their horoscopes to be accurate.
D. Comparing how often the predictions come true to what would be expected by chance.
E. None of the above. Astrology is inherently wrong and can't be tested.

Kepler's 3 Laws of Planetary Motion

REVIEW

1. Planets move on elliptical orbits with the Sun at one focus
2. As a planet moves around its orbit, it sweeps out equal areas in equal times
3. (Orbital Period)^2 = (Semi-major axis)^3

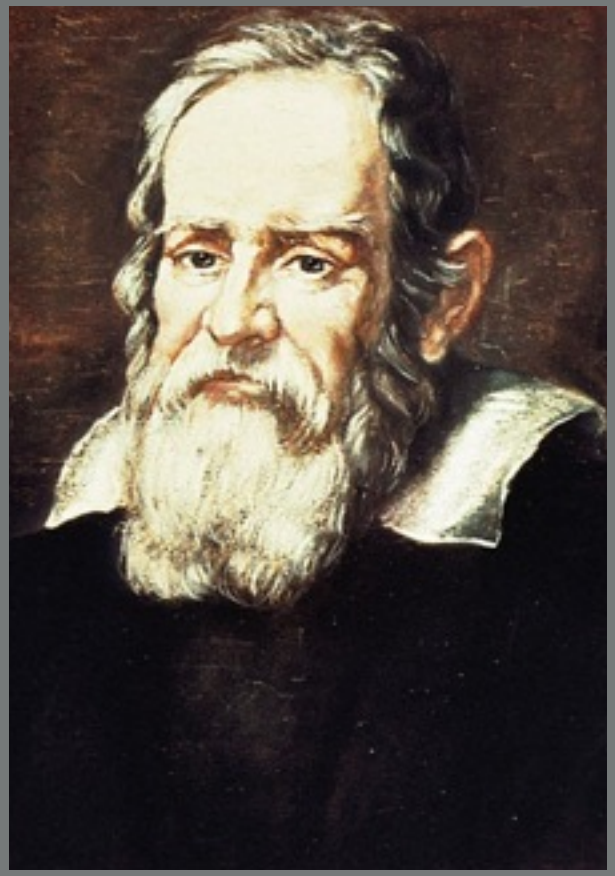
P^2 [Years] = a^3 [A.U.]

Thought Question

Kepler's laws imply …

A. Comets (with orbits that take them well outside the known planets) spend most of their life very close to the Sun.
B. Comets spend most of their life very far from the Sun.
C. Outer planets move faster than inner planets.
D. Planets all move at the same speed, the outer ones just have more distance to cover.
E. Comets with highly eccentric orbits take longer to orbit the Sun than planets with similar semi-major axes but low eccentricity (round orbits).

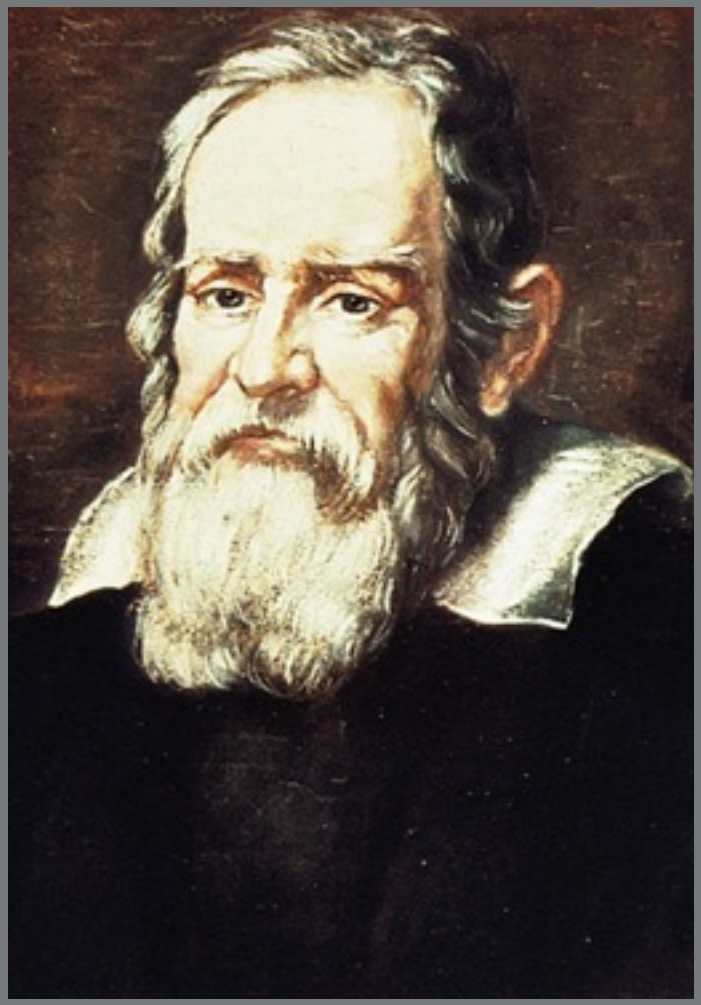
Galileo's observations solidified the Copernican revolution



Galileo Galilei

Objections

- 1: If Earth was Moving things should be left behind
- 2:Universe is perfect, must be n circles
- 3:No parallax detected



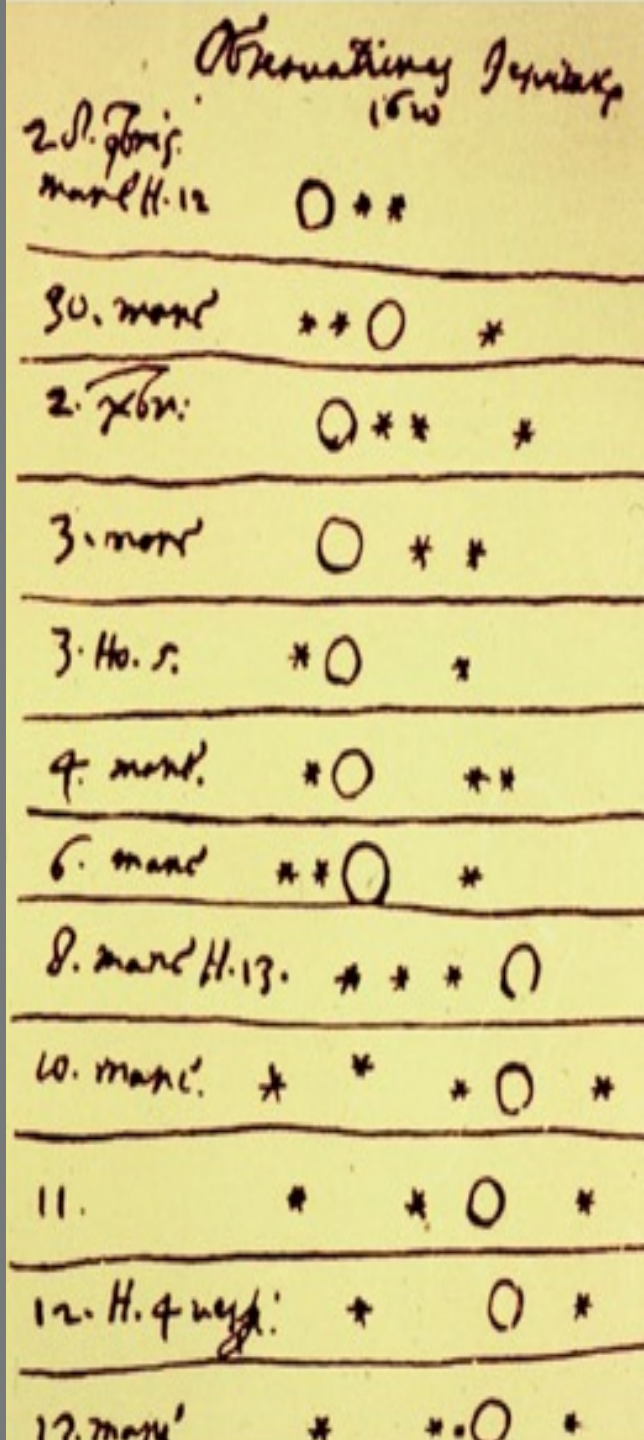
Galileo Galilei

One of first people to turn the new, Dutch invention - **the telescope** - to look at the sky

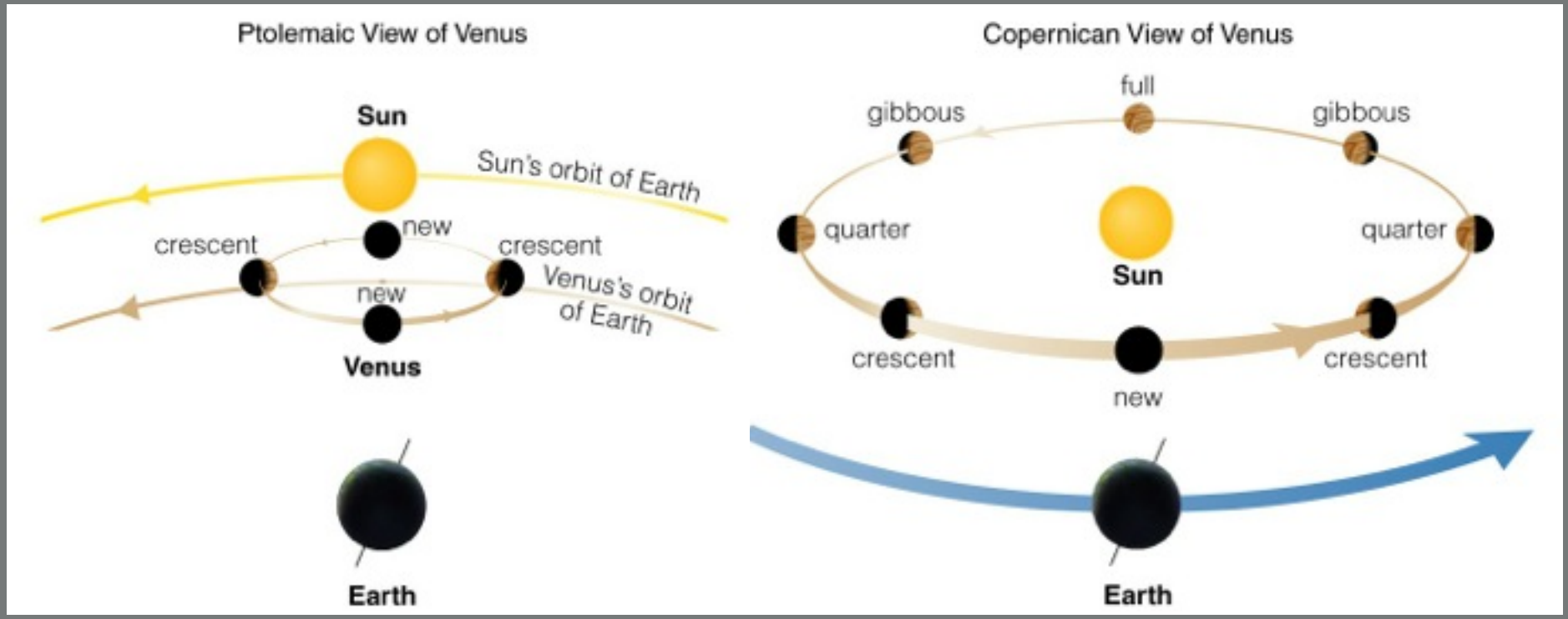
Final nails in the Geocentric coffin

Part I: Moons of Jupiter

- Day by day observations of motion of "stars" orbiting Jupiter
  - Galileo later realized these "stars" were moons
- Showed these are objects that <u>do not</u> orbit the Earth



Final nails in the Geocentric coffin
Part II: Phases of Venus



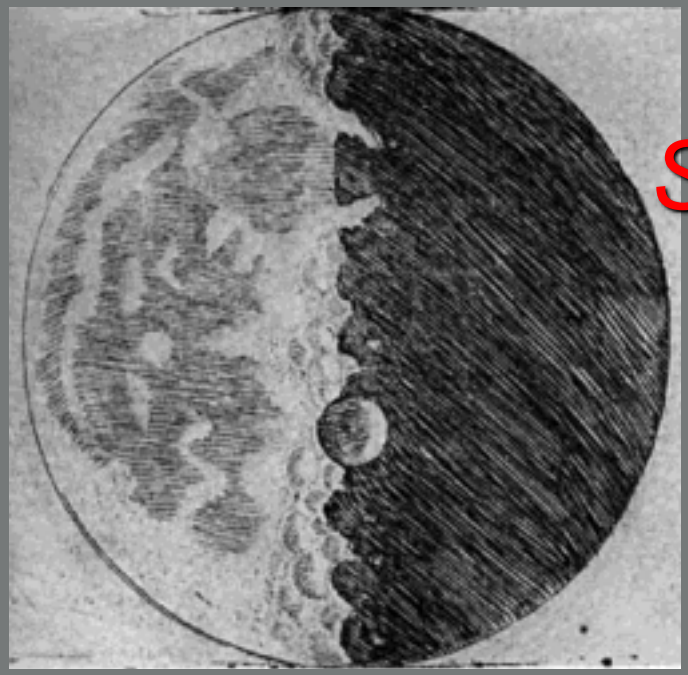
- Galileo's observations of phases of Venus proved that it orbits the Sun and not the Earth

- Demonstrated Newton's Law that things move unless something stops them
- Telescope showed the Milky Way was many stars SUGGESTING they were far away,
- Did not detect parallax

Thought Question

Since Venus is in various orientations (during its orbit) with respect to the Sun, we see it in various phases. What phases should we be able to see?

A. Crescent only
B. Gibbous only
C. Full & New only
D. New & Crescent only
E. All phases



Some of Galileo's arguments were more philosophical than scientific proof

- Using his telescope, Galileo also saw:
  - Mountains and valleys on the Moon
  - Sunspots on Sun

Celestial objects were not "perfect"

Some of Galileo's arguments were more philosophical than scientific proof

- Using his telescope, Galileo also saw:
  - Mountains and valleys on the Moon
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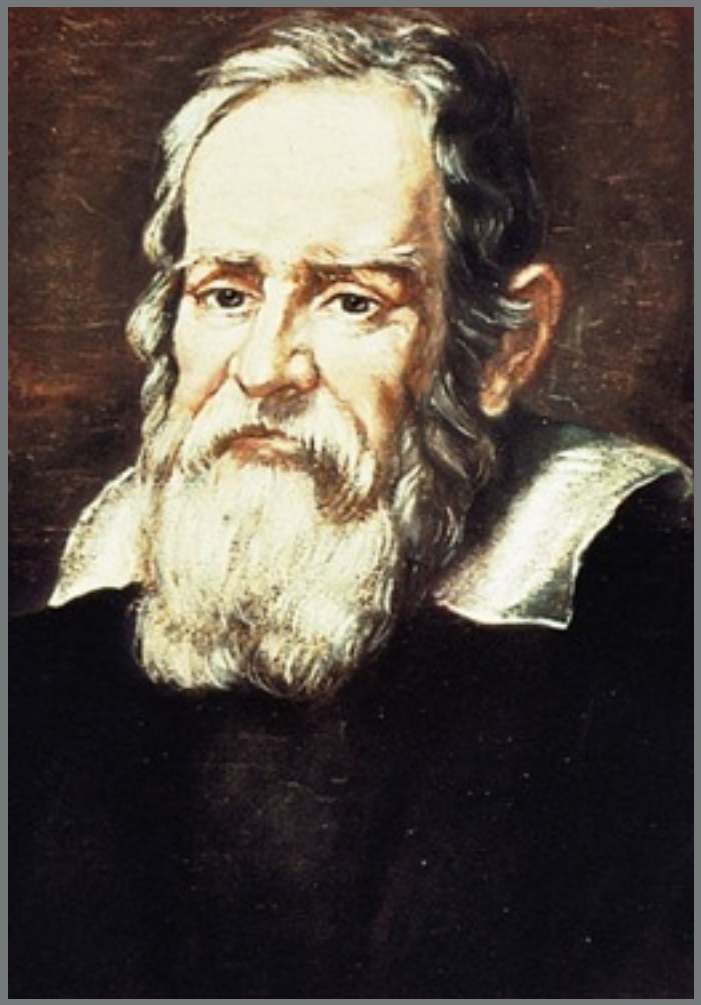
Celestial objects were not "perfect"



Galileo Galilei

The Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun in 1633

His book on the subject was removed from the Church's index of banned books in 1824

Galileo was formally vindicated by the Church in 1992

What have we learned?

- Ptolemy: geocentric model
  - worked pretty well
- Copernicus: heliocentric model
  - Worked pretty well but no better than Ptolemy
- Kepler: really good heliocentric model
  - 3 Laws of Planetary Motion

They all created a model and then scientifically tested and revised it to the best of their data.

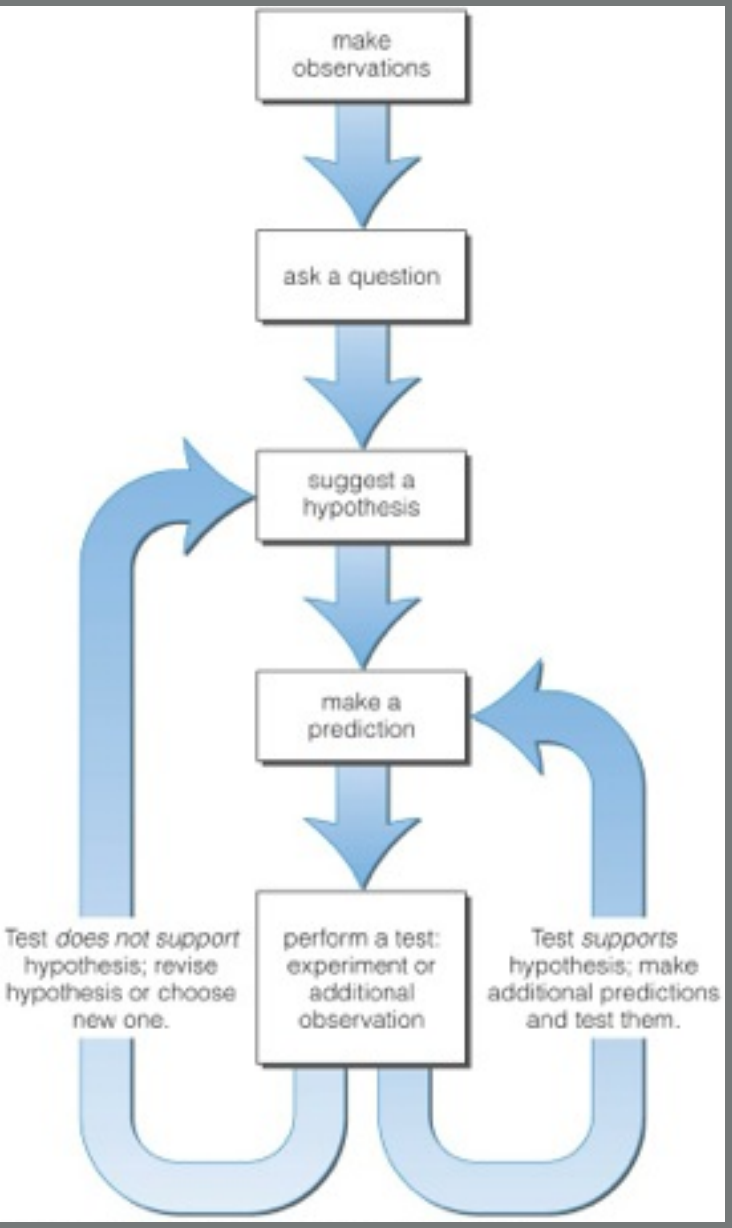
- Galileo: irrefutable observational support for heliocentric model
  - sent his book to the kings of Europe - along with a telescope

Reading Question

What is an epicycle?

A. The smaller circle around which the planets moved in Ptolemy's model of the solar system
B. A model in which the Sun is at the center of the Solar System.
C. When the Moon blocks only part of the Sun's shadow.
D. The point in a planet's orbit when it is closest to the Sun.
E. The believed orbit of the Sun around the Earth in early Greek models.

The Nature of Science



Science doesn't always proceed in an idealized way…

- Sometimes we start by "just looking" then coming up with possible explanations.
- Sometimes we follow our intuition rather than a particular line of evidence.

How can we distinguish science from non-science?

Hallmarks of Science: #1

Modern science seeks explanations for observed phenomena that rely solely on natural causes.

- A scientific model cannot include divine intervention
  - This means that science can never prove or disprove religion

Hallmarks of Science: #2

Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

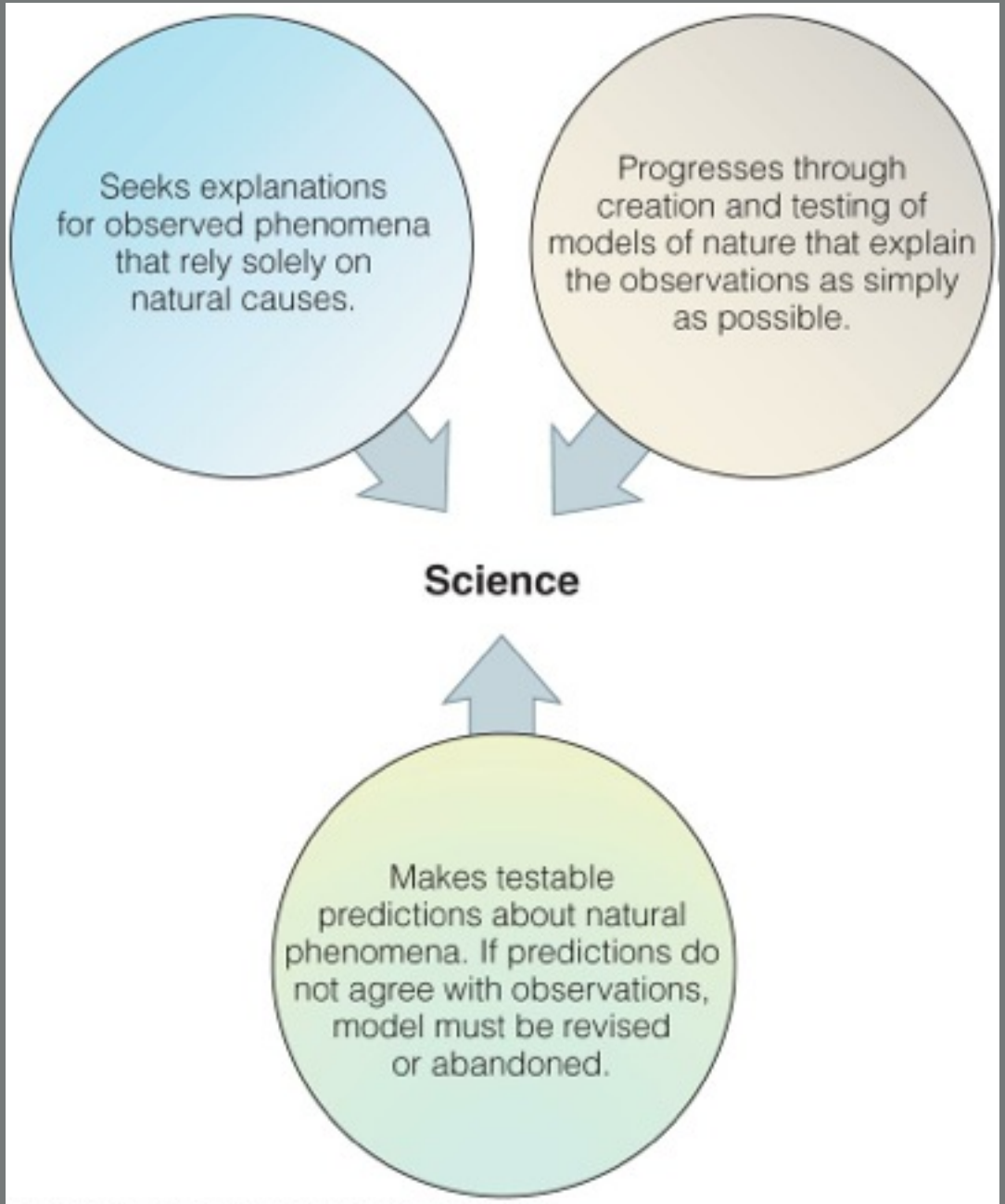
(Simplicity = "Occam's razor")

Hallmarks of Science: #3

A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

The potential for an accepted model to be proven false is ALWAYS there

The Hallmarks of Science



Science is FALSIFIABLE

Law vs Theory

- A **scientific law** describes the behavior of something that occurs. It is often described in mathematical relationships. For example the general law of gravitation describes the force between objects of various masses at various distances HOW,WHEN,WHERE,WHAT'S NEXT?
- A **scientific theory**, however, attempts to describe why something works. There are several theories of gravity, which attempt to explain why it occurs as it does. ALSO WHY, includes law, broad, not theory as in question.

Induction/Deduction

- ***Inductive reasoning*** moves from specific details and observations (typically of nature) to the more general underlying principles or process that explains them (e.g., Newton's Law of Gravity). "All of the ducks I have seen are black therefore all ducks are black." Bottom up reasoning. Generally closer to the scientific method
- ***Deductive reasoning*** typically moves from general truths to specific conclusions. It opens with an expansive explanation (statements known or believed to be true) and continues with predictions for specific observations supporting it. Top down reasoning.

Both

- Induction - observations lead to hypothesis lead to testing lead to theories
- Deduction - mathematical laws lead to experiments to confirm or deny
- AS long as both are falsifiable who cares.
- BEWARE - starting with conclusions and only seeking certain answers is not science, subjective validation is garbage

Pseudoscience

Pseudoscience is a claim, belief, or practice which is presented as scientific, but does not adhere to a valid scientific method, lacks supporting evidence or plausibility, cannot be reliably tested, or otherwise lacks scientific status.[1] Pseudoscience is often characterized by the use of vague, exaggerated or unprovable claims, an over-reliance on confirmation rather than rigorous attempts at refutation, a lack of openness to evaluation by other experts, and a general absence of systematic processes to rationally develop theories.

http://www.dhmo.org/facts.html

Pseudoscience

- Exaggerated/Grandiose Claims
- Non-falsifiable claims
- Secrecy
- Reverse of burden of proof
- Assertion that claims not shown to be false must be true
- Over reliance on anecdotal evidence/ correlation/ testimony
- Lack of scientific scrutiny
- Absence of progress
- Lack of self-correction
- Personalization - attacks of critics
- Use of misleading language
- Lack of reproducibility
- Failure to understand basic proven science
- Conflicts with observed reality

Why is astrology not a science?

How is astrology different from astronomy?

- Astronomy is a science focused on learning about how stars, planets, and other celestial objects work.

- Astrology is a search for hidden influences on human lives based on the positions of planets and stars in the sky.

A hypothesis to test today:

The positions of the planets (astrology) can serve as a useful guide to everyday life

Theoretical idea why: The planets are large and important and move in complex ways. These mirror our complex lives.

Maybe there are magnetic fields or other unknown forces (gravitational?) that are exerted on us.

Astrological Time Twins

- A study involving 2,101 people born in London during 3–9 March 1958.
  - They were born on average 4.8 minutes apart,
  - Astrology had predicted 'really exceptional similarities of life and temperament'.

- Measurements at ages 11, 16 and 23 provided test scores for IQ, reading and arithmetic; teacher and parent ratings of behavior such as anxiety, aggressiveness and sociability; self-ratings of ability such as art, music and sports; and various others such as occupation, accident proneness and marital status;

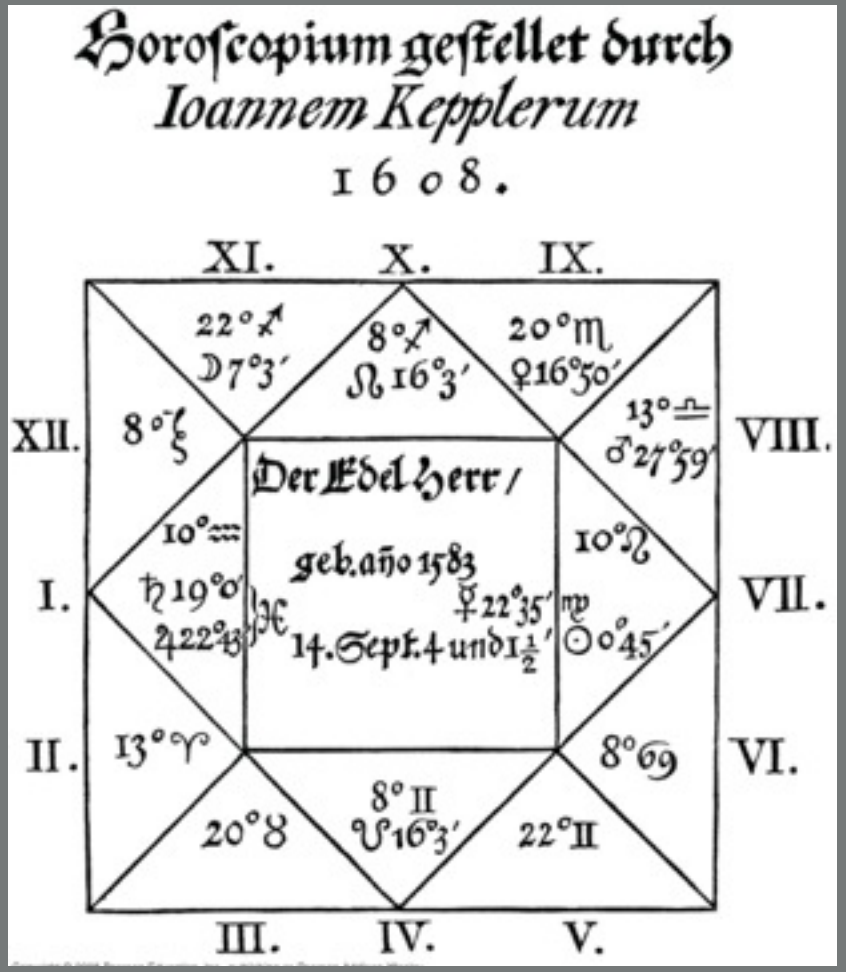
No correlation was found!

- The correlation was 0.00 ± 0.03!!!
  - It disconfirmed the idea of Sun Signs (2,101 Pisces evidently had few similarities!)

- The above result is just one example, many other similar tests have been done.
  - (Eysenck and Nias, 1982; Culver and Ianna, 1984; Dean, Mather and Kelly, 1996; Martens and Trachet, 1998; Dean et al., 2002).

Astrology has been shown to have no scientific validity

- Scientific tests have shown that astrological predictions are no more accurate than we should expect from pure chance.



Psuedo Science

- http://www.quackwatch.com/01QuackeryRelatedTopics/pseudo.html
- http://www.snopes.com/
- http://en.wikipedia.org/wiki/List_of_topics_characterized_as_pseudoscience