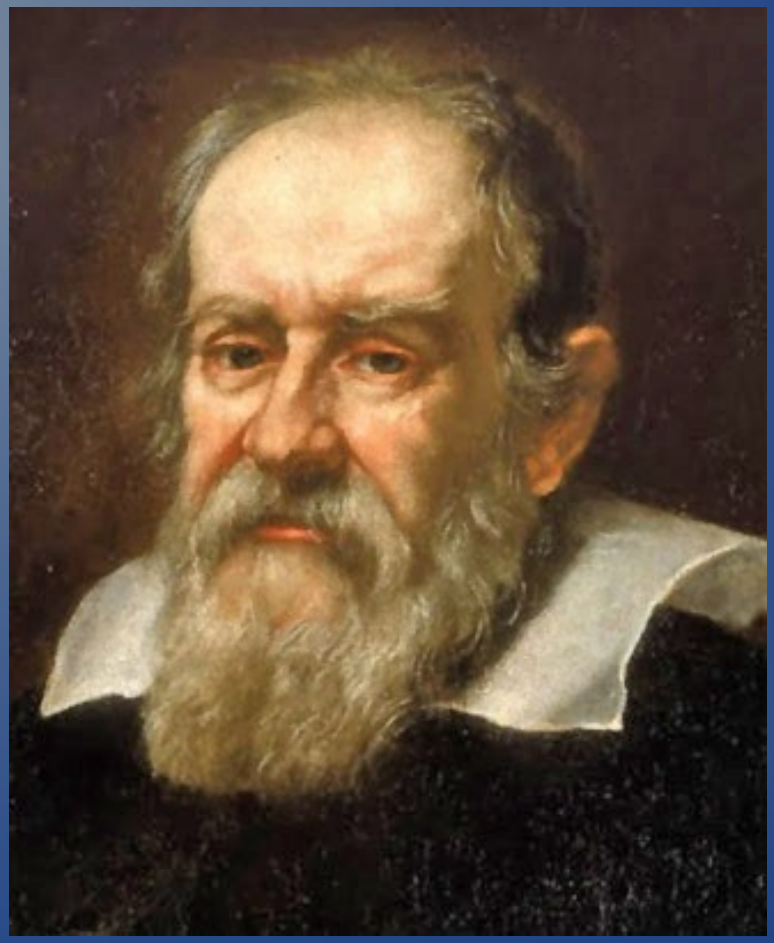
Galileo

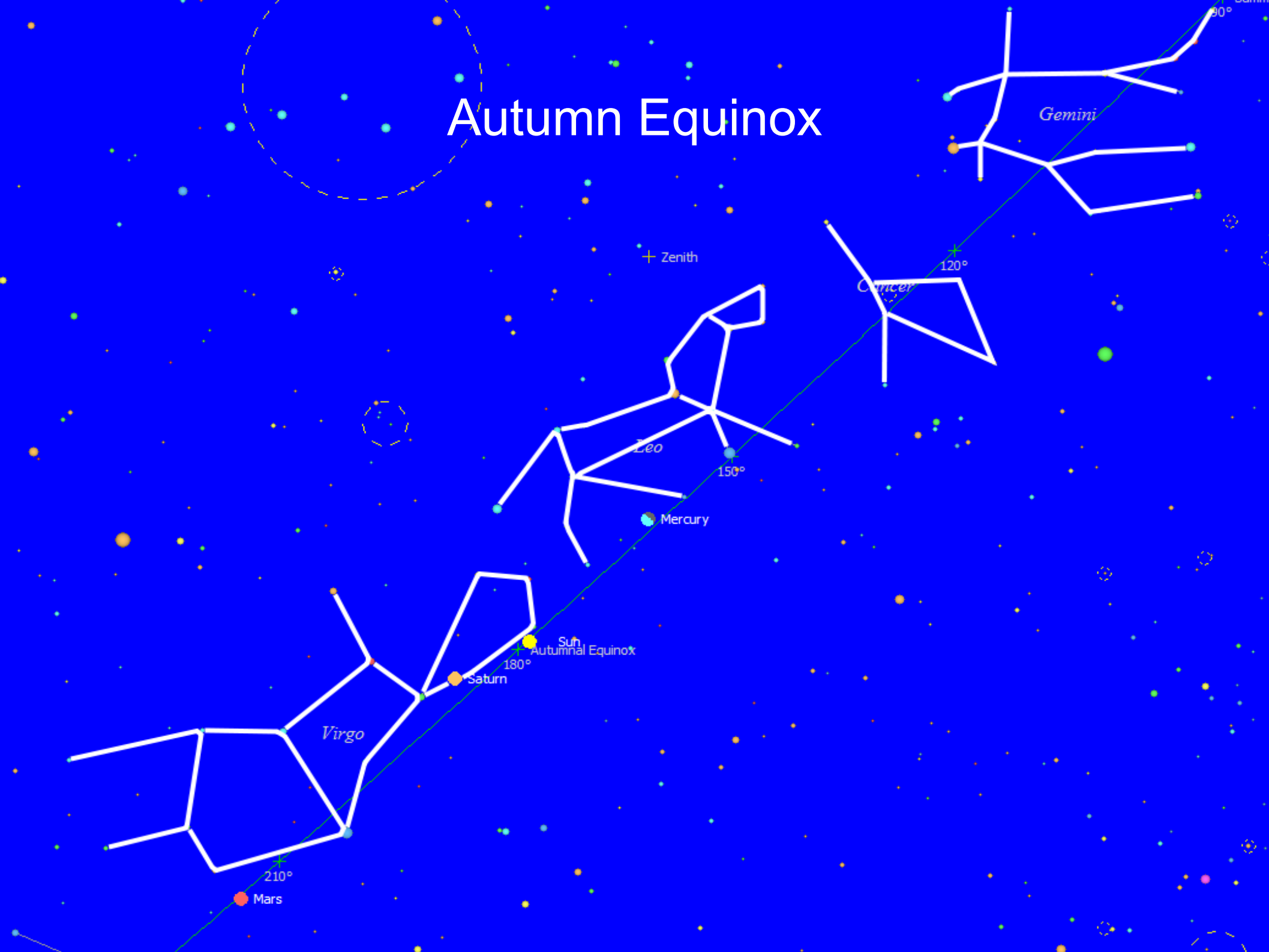
Rude, Arrogant, Almost Entirely Wrong

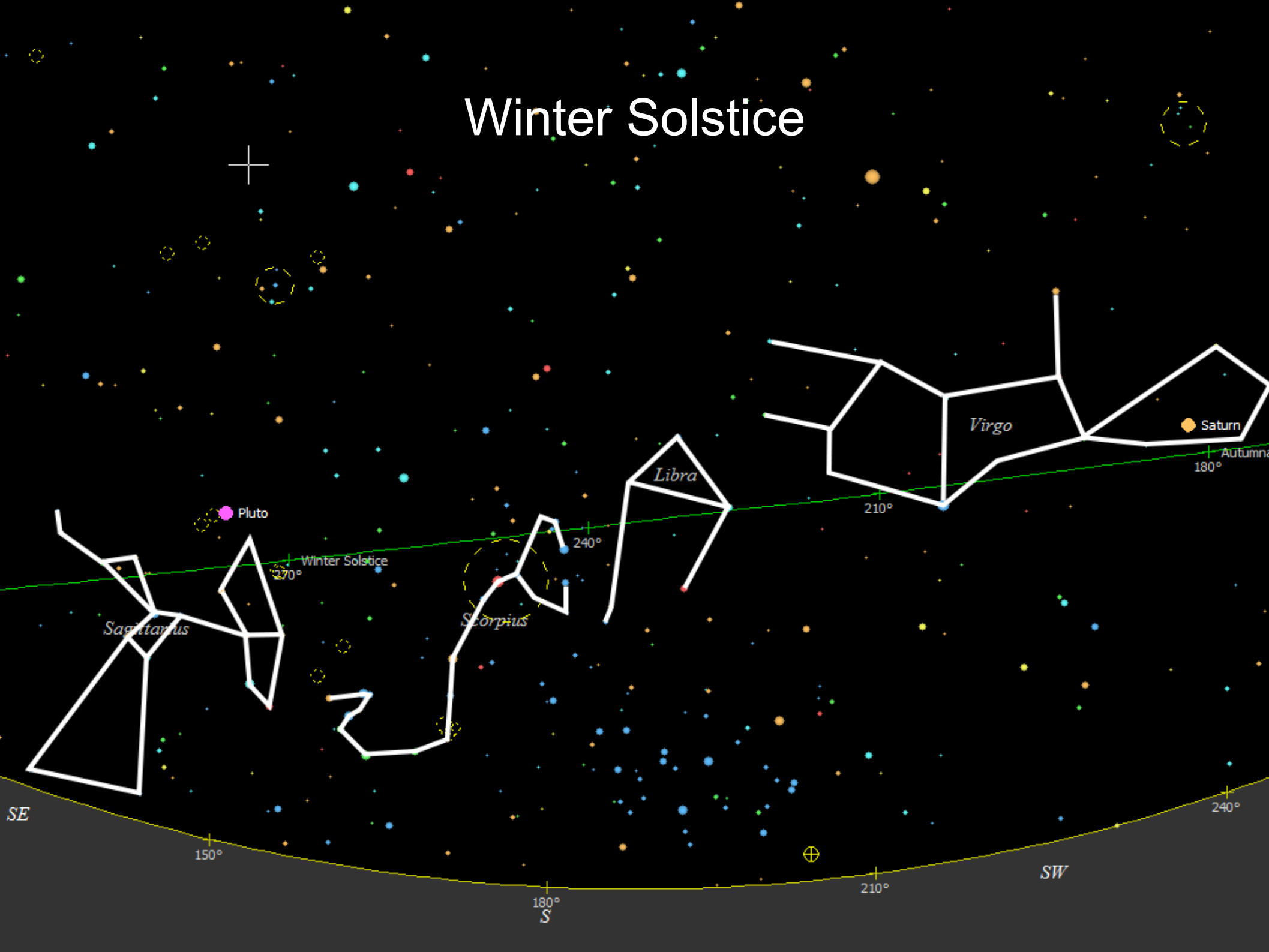


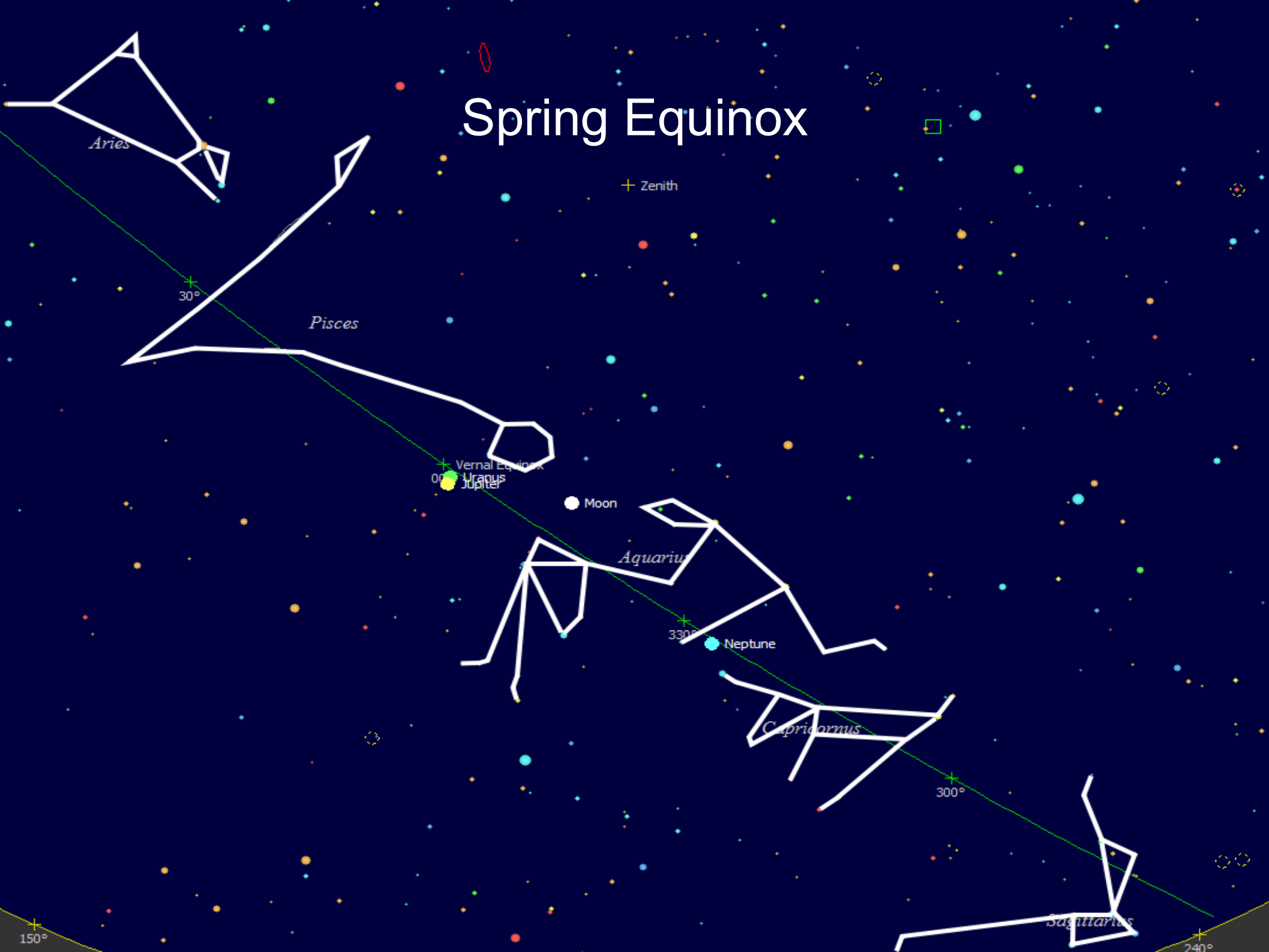
The Amazing Ancients
Patient Observers of the Night Sky

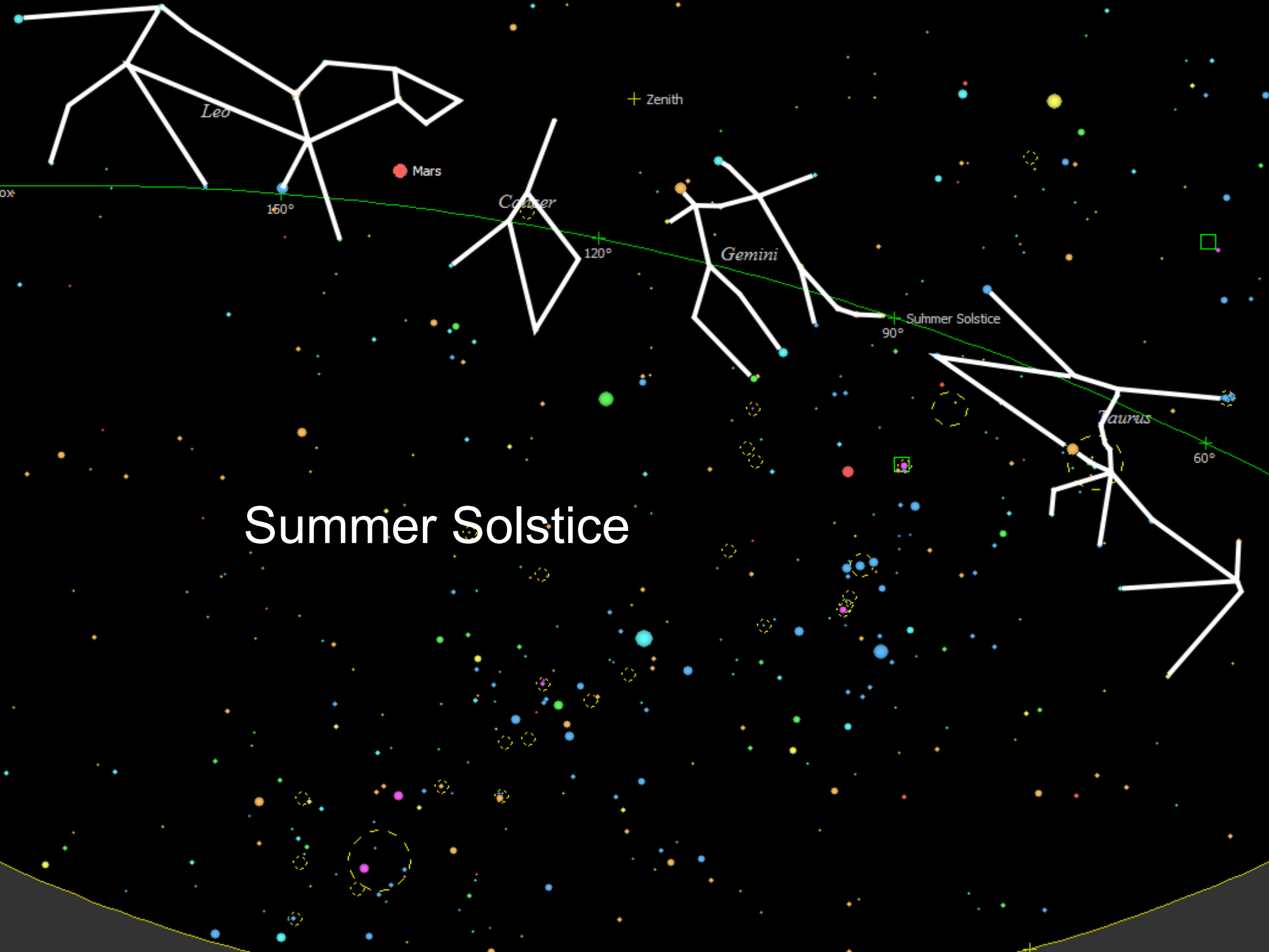
- Created mental maps of the stars in the sky.
- Imagined pictures to help chart the stars (constellations--especially the 12 constellations of the Zodiac).
- Noticed five (5!) “stars” that wandered around, unlike all of the rest.
- The great superstition of astrology: *“Our fate was determined by the location of the planets at the hour of our birth.”*

Autumn Equinox



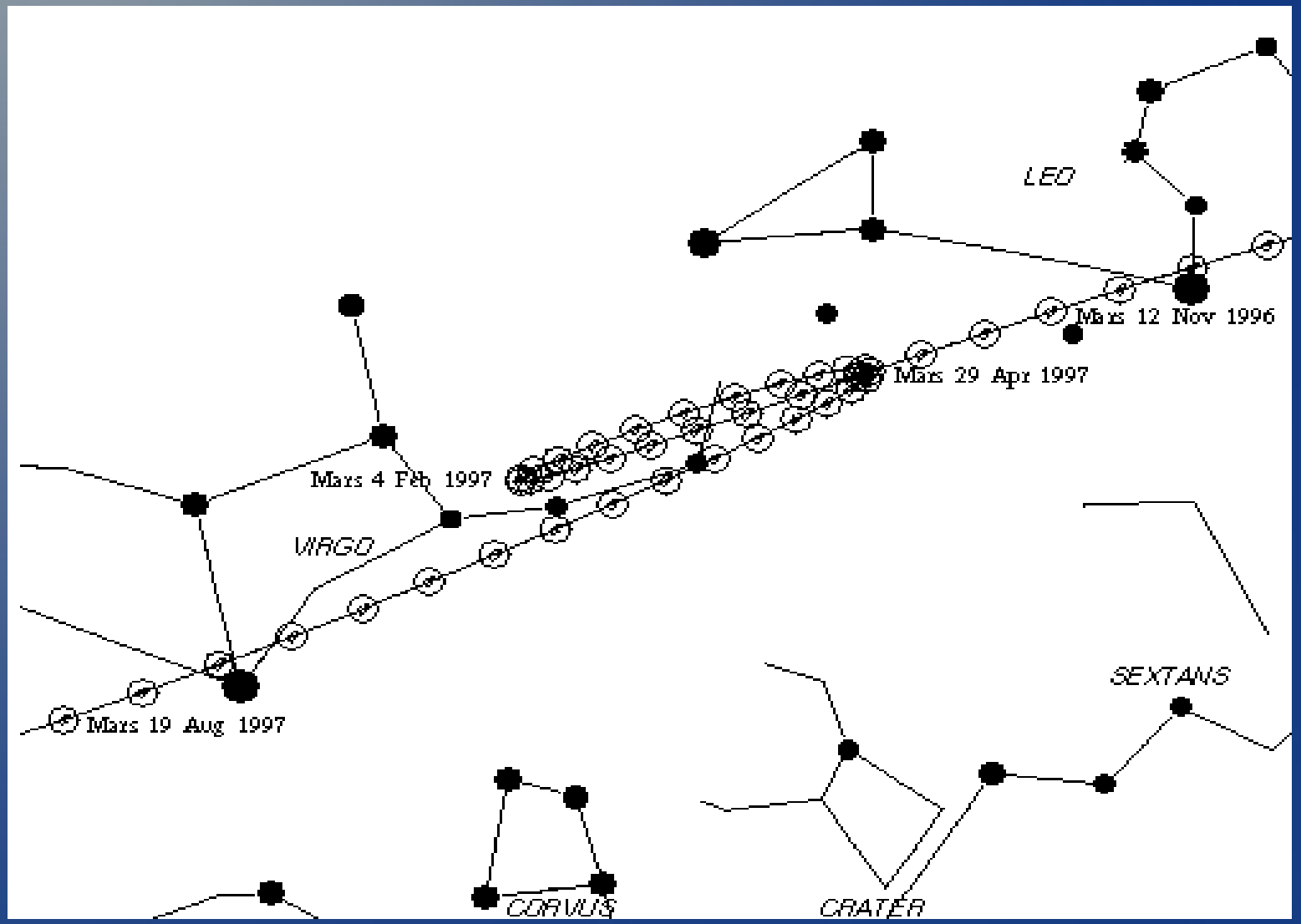

Winter Solstice
Pluto
Winter Solstice
270°
Sagittarius
Scorpius
240°
Libra
210°
Virgo
Saturn
180°
Autumna
SE
150°
180°
S
210°
SW
240°


Spring Equinox
Aries
Zenith
30°
Pisces
Vernal Equinox
Uranus
Jupiter
Moon
Aquarius
330°
Neptune
Capricornus
300°
Sagittarius
150°
240°

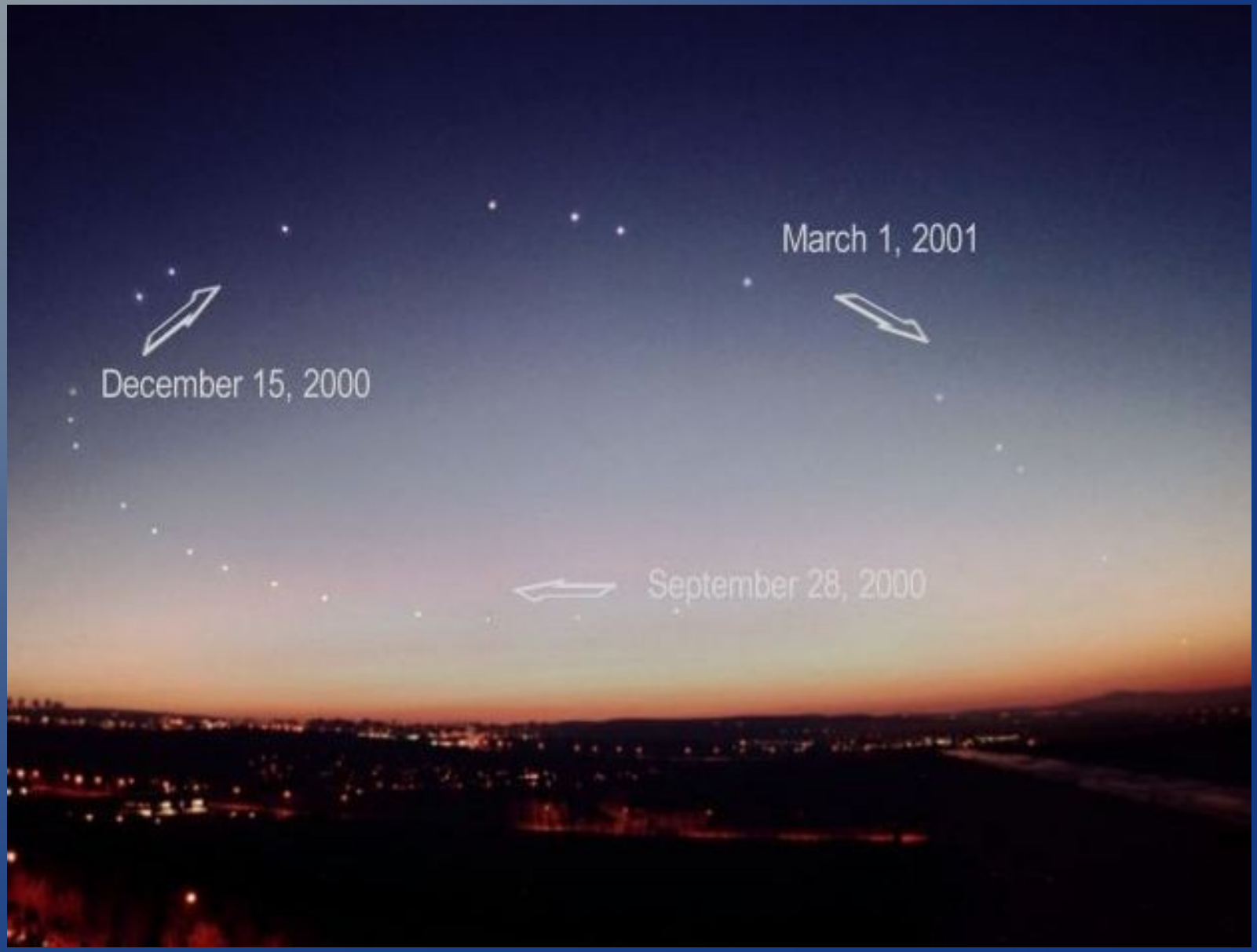


Summer Solstice

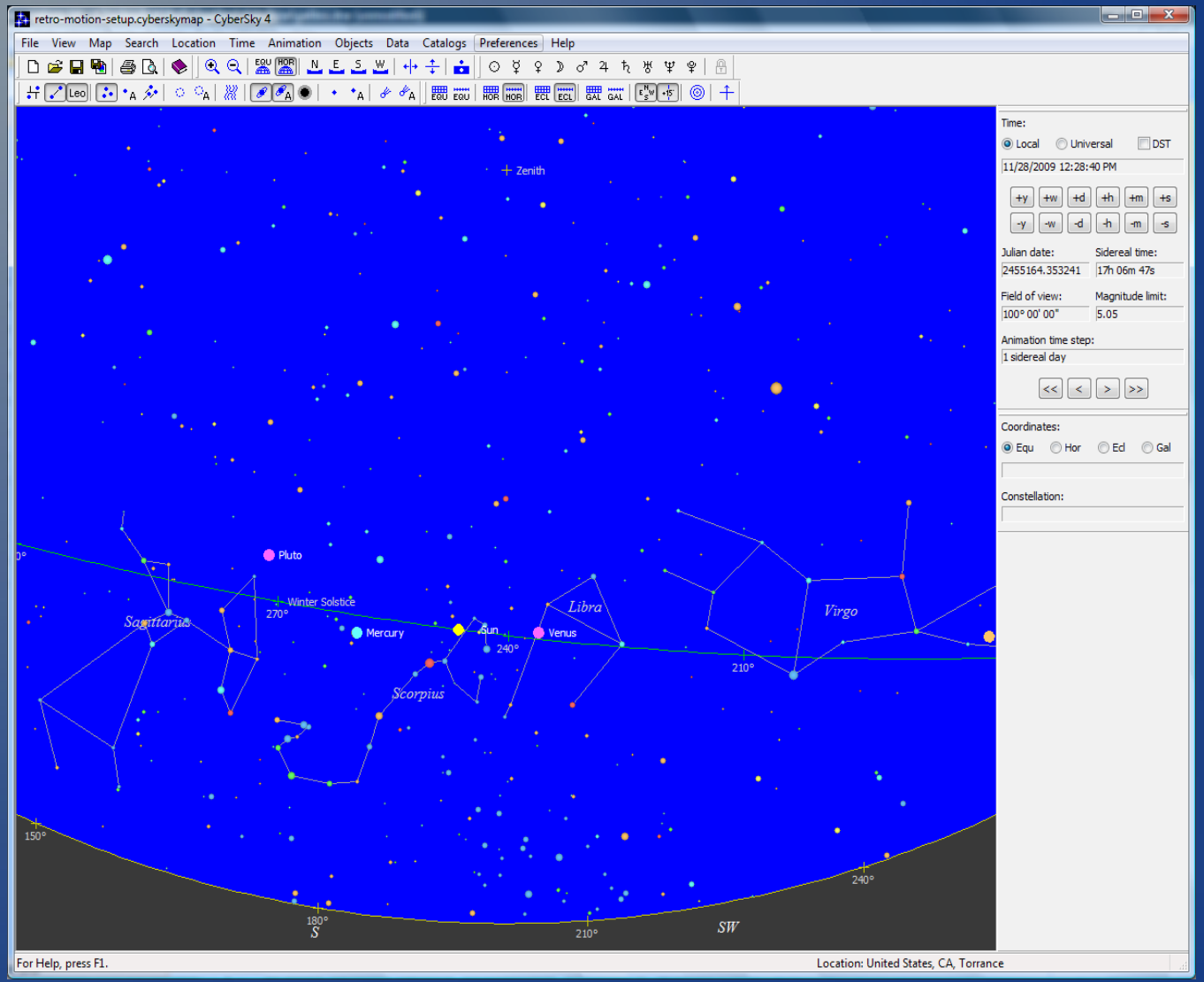
Retrograde Motion



Venus: Jewel of the Sky



Cybersky
http://www.cybersky.com/

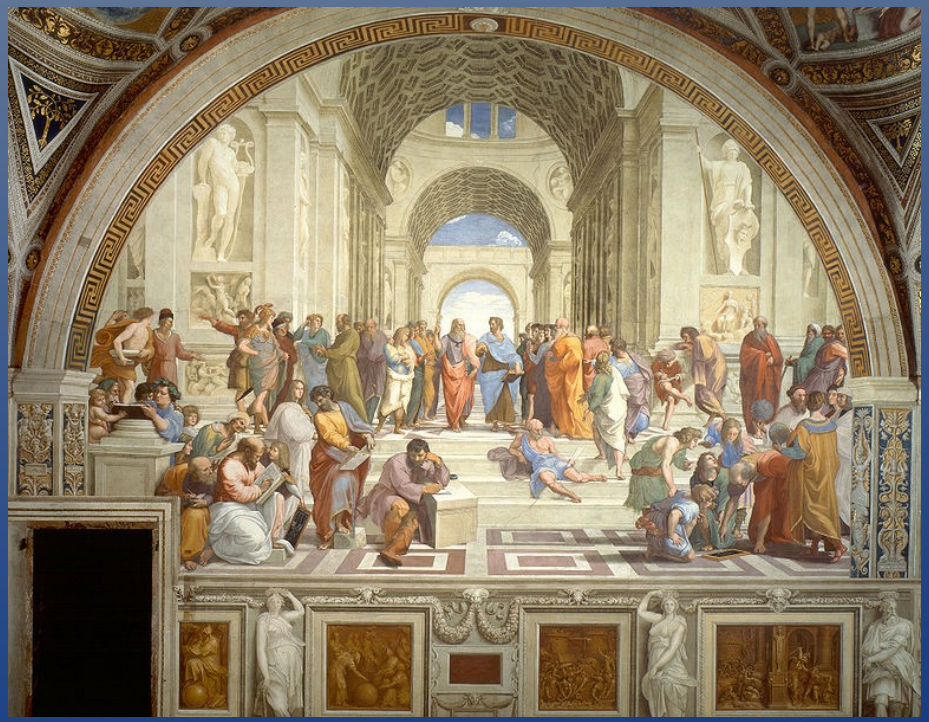


History of Astronomy
Crying for a Vision

Observations (data): Everything in the sky, except for the five planets, moves in perfect circles at a uniform rate.

A truly scientific question was posed by the ancients:

What the @#$% is going on up there?
Why **do we see what we see?**



Bernard J.F. Lonergan, SJ:

- Data
- Questions
- Insight ("Aha! Eureka! I've found it!")
- Judgment. *Not all insights are sound.*

Mythology

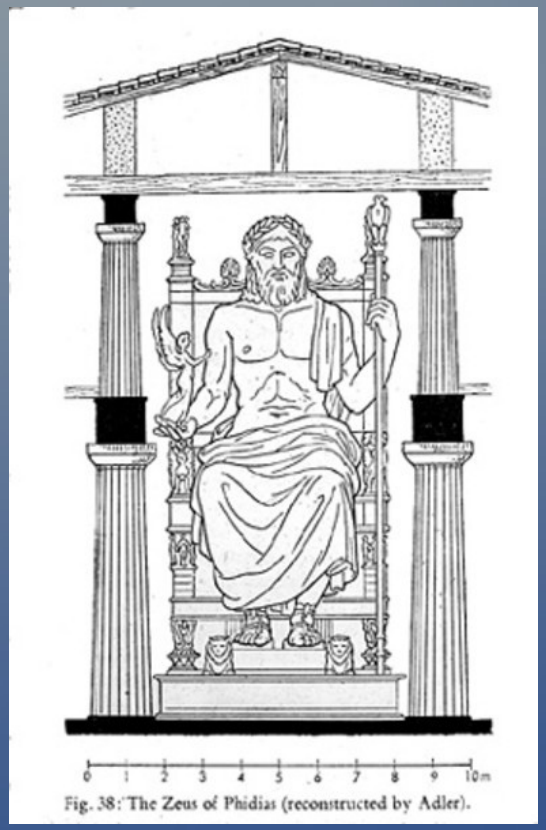


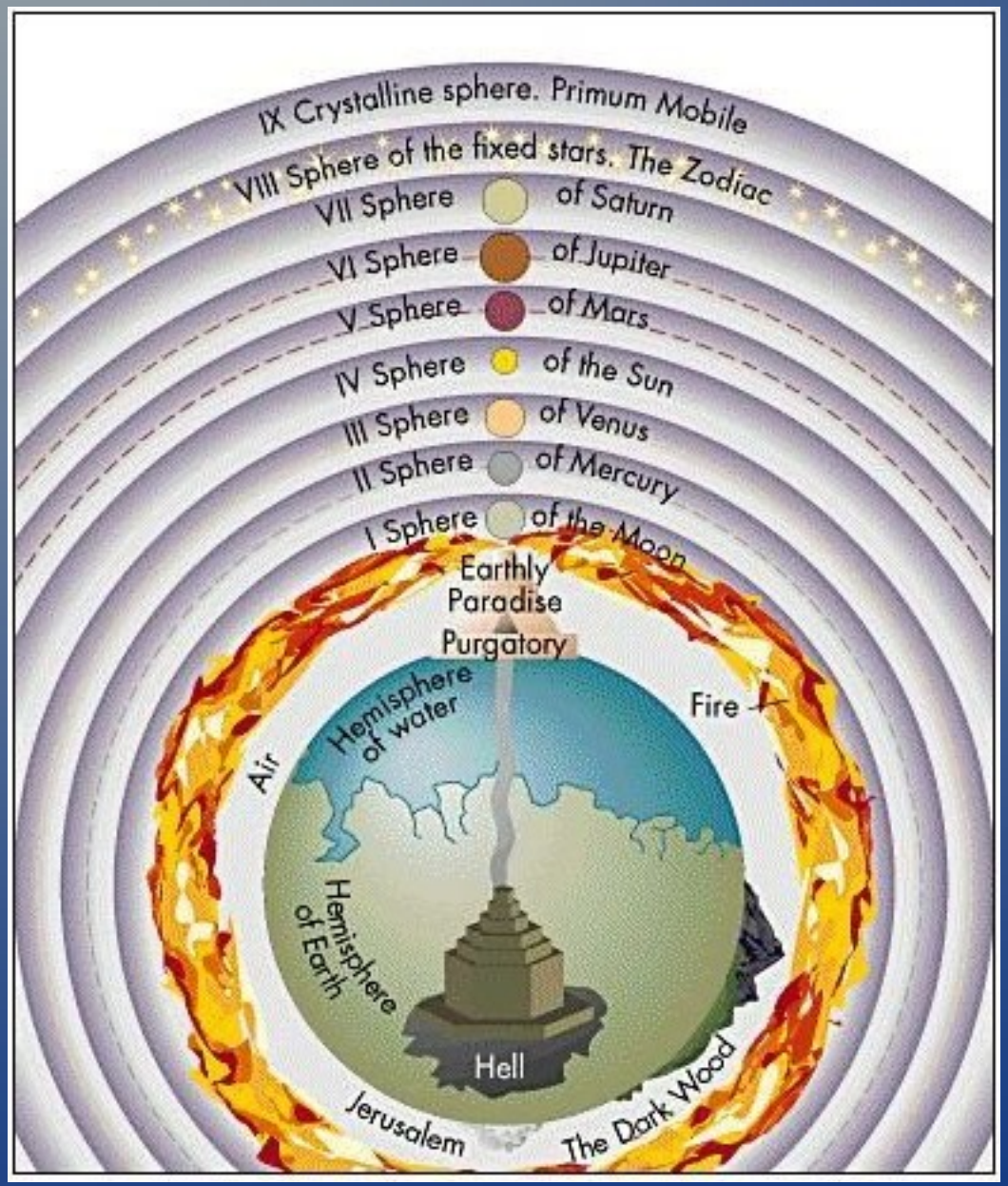
Fig. 38: The Zeus of Phidias (reconstructed by Adler).

Each planet is a divinity, the property of a divinity, or the home of a divinity. The gods and goddesses like to hang out witheach other and sometimes have trouble leaving the house after a party.

The wandering behavior is purely arbitrary. “The gods must be crazy!”

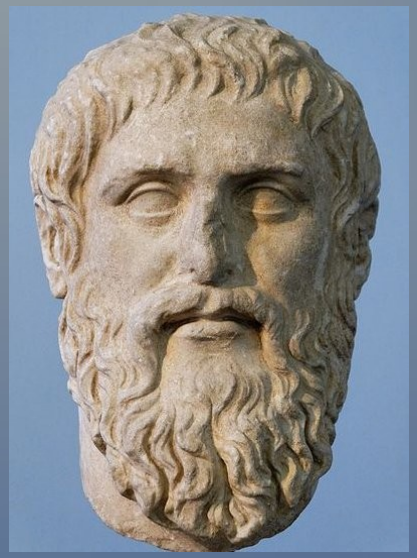
- Artemis: Goddess of the moon.
- Mercury: Messenger-God, thief, prankster.
- Venus: Goddess of love.
- Apollo (Helios): God of the sun.
- Mars: God of War.
- Jupiter (= Greek Zeus): King of the Gods, sky, thunder
- Saturn: God of agriculture, justice, and strength.

Theory of the Celestial Spheres



- Best is above. GOD is the "Primum Mobile."
- Worst is below.
- Not a privilege to be at the center!
- Everything below the sphere of the moon is imperfect (changing).
- Everything above is perfect (unchanging).
- *Our idea of "center stage" has nothing to do with the ancient worldview!*

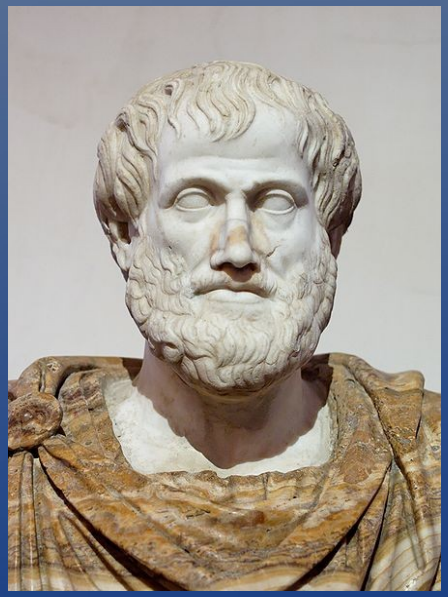
The Philosophers



Plato (427-347 BC)

Assumptions that correspond to sense impressions:

- Everything in the heavens moves in perfect circles.
- Everything in the heavens moves at its own steady pace.



Aristotle (384-322 BC)

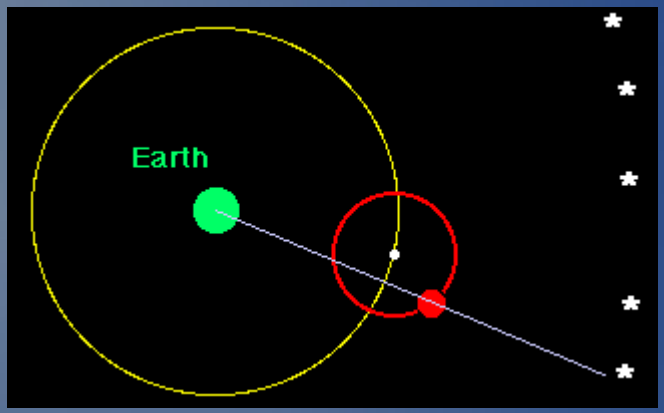
Everything above the orbit of the moon is perfect (unchanging); everything below the orbit of the moon is imperfect (changing all the time).

Ptolemy
The father of astronomy (~150 BC)

Hypothesis (theory, view, interpretation): The planets must be traveling at uniform velocity in perfect circles; they must have circular orbits (epicycles) that themselves are in circular orbits (cycles).

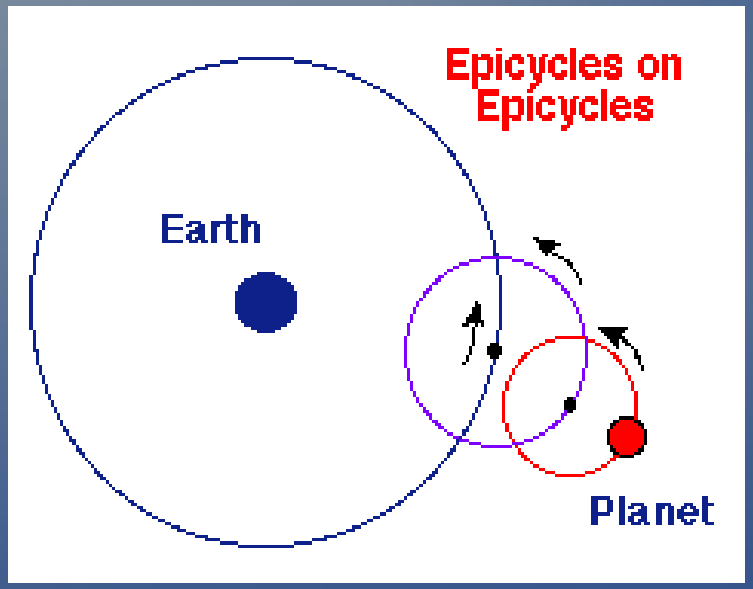
Corollary of the hypothesis: What we perceive with our eyes is an optical illusion. The planets are not behaving randomly; they do not stop, reverse direction, stop, and reverse direction again. In reality, they only go forward and obey the same laws as all other heavenly bodies: *they travel in perfectly circular orbits at a uniform rate.*

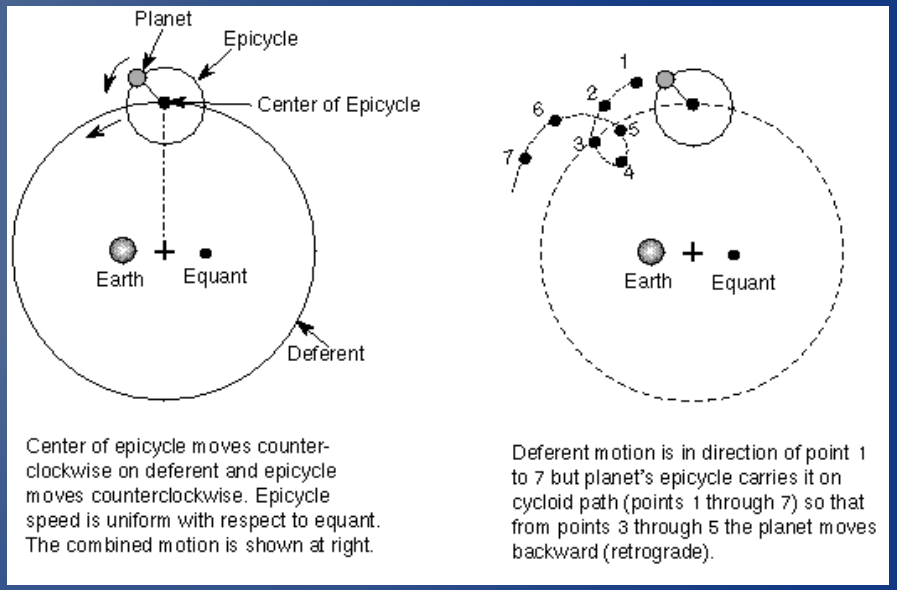
Cycles and Epicycles



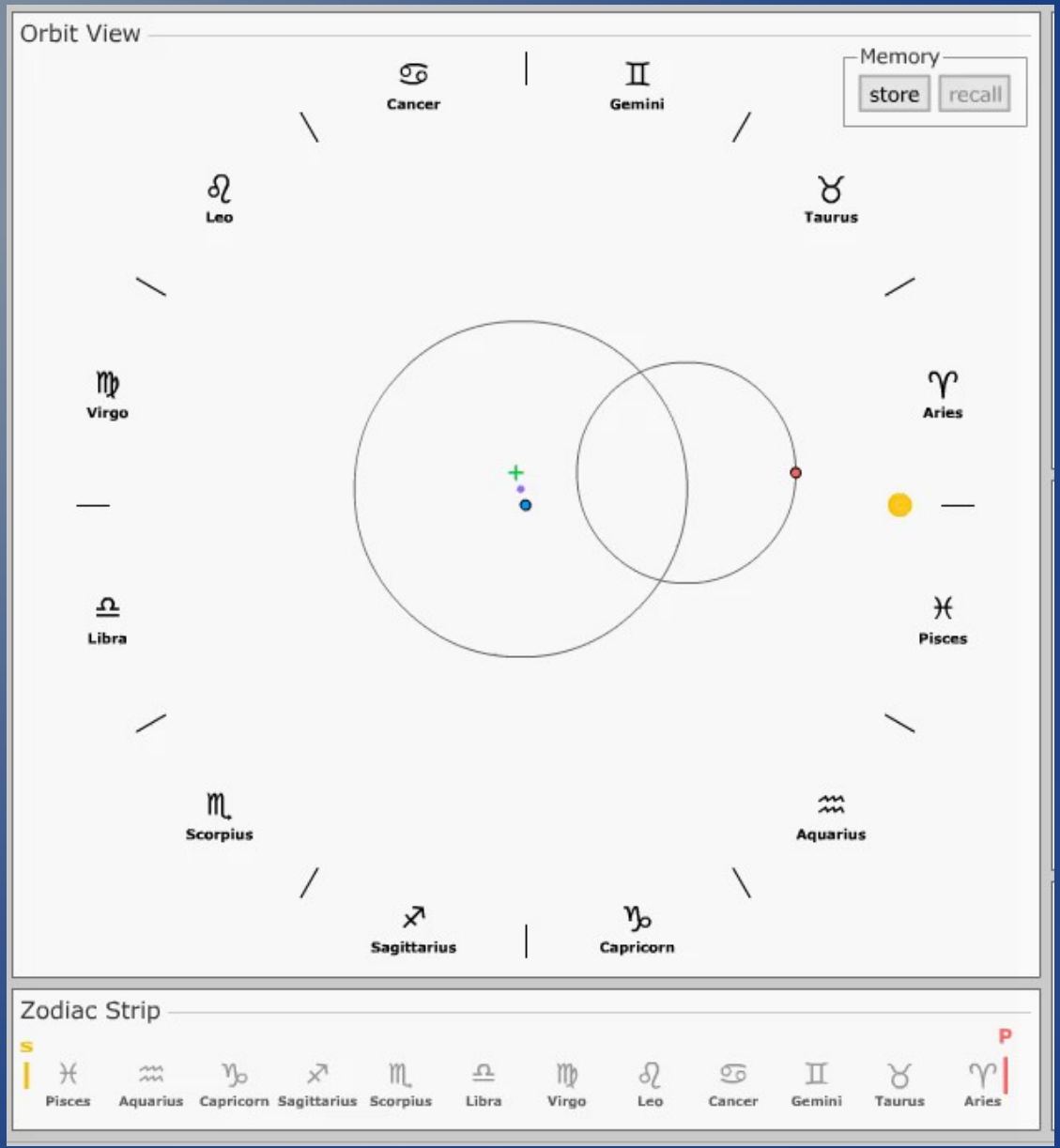
Correspondence with Observations

An improvable approximation

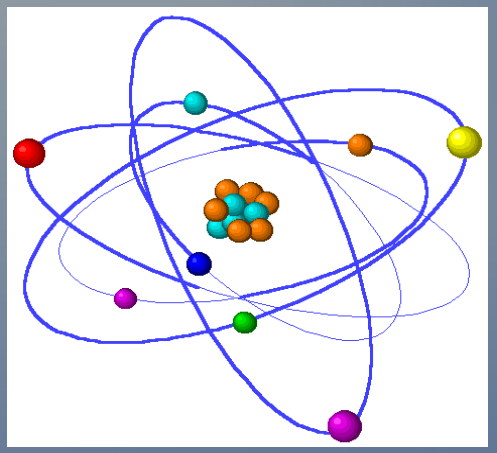


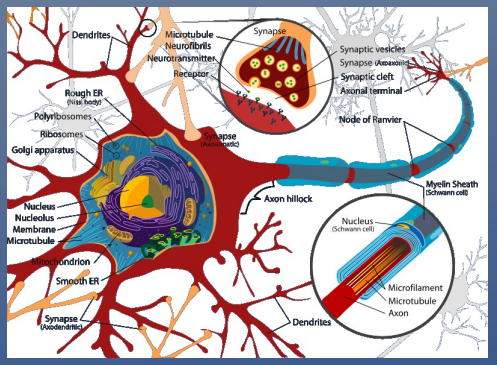


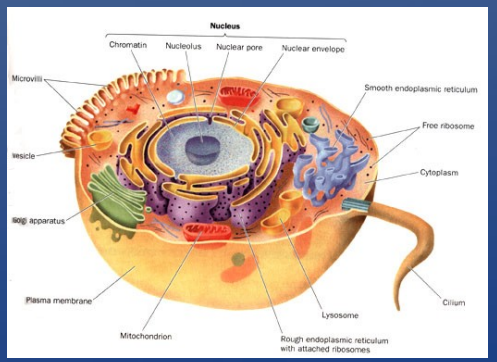
Efforts to make the predictions of the model correspond to observations--to match the theory to the data--led to modifications of the model.


Orbit View
Memory
store
recall
Cancer
Gemini
Leo
Taurus
Virgo
Aries
Libra
Pisces
Scorpius
Aquarius
Sagittarius
Capricorn
Zodiac Strip
S
P
Pisces
Aquarius
Capricorn
Sagittarius
Scorpius
Libra
Virgo
Leo
Cancer
Gemini
Taurus
Aries

Science discredits impressions



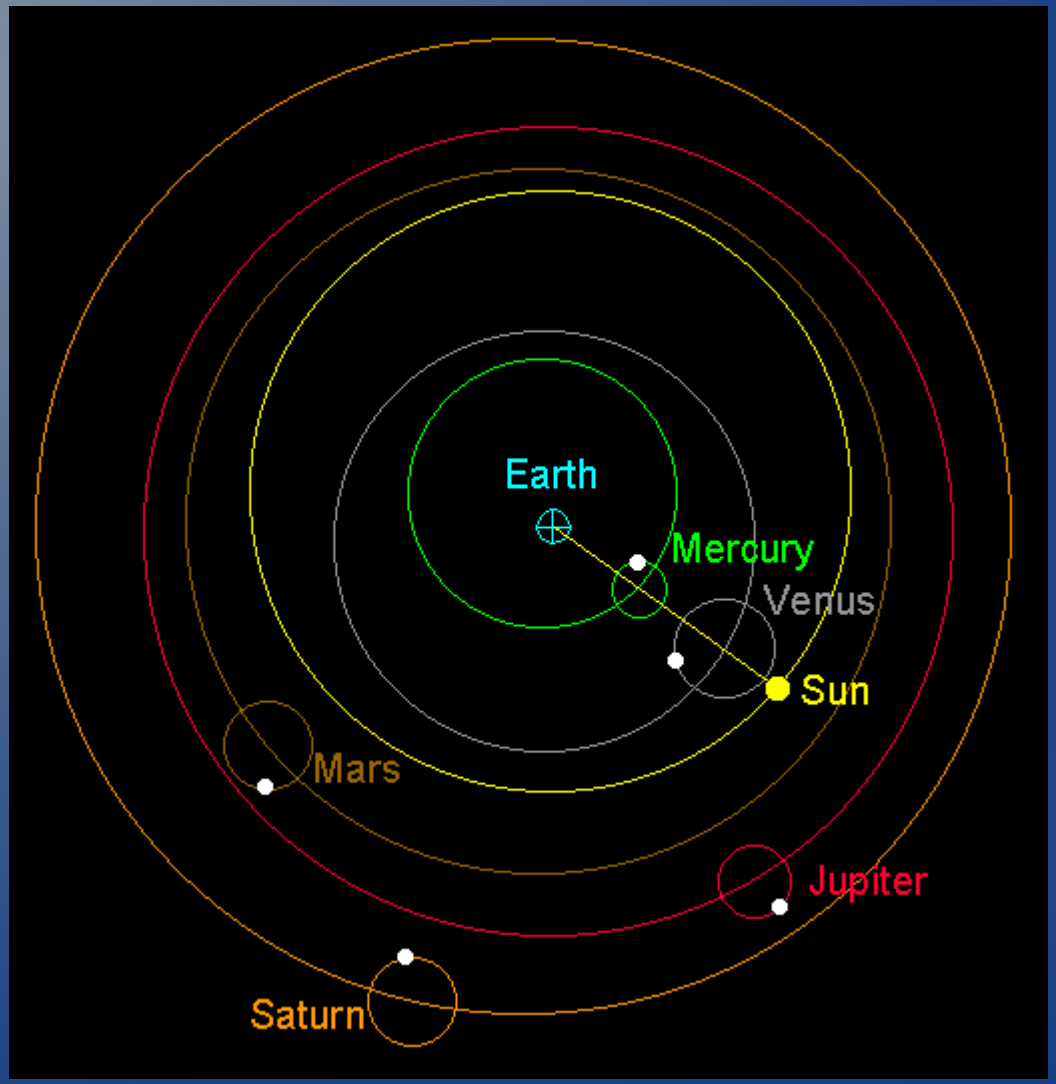




- The planets only *appear* to reverse course; in reality, they travel forward at all times.
- The table in front of you only appears to be solid; in reality, it is made up of molecules that are made up of atoms that are made up of protons, neutrons, and electrons. The table is mostly empty space!
- Protons and neutrons only appear to be solid particles; in reality, they are composed of quarks and other elementary particles.
- Cells only appear to be simple gelatinous bricks; in reality, they are astonishingly complex bio-chemical factories composed of thousands of intricate parts and processes.

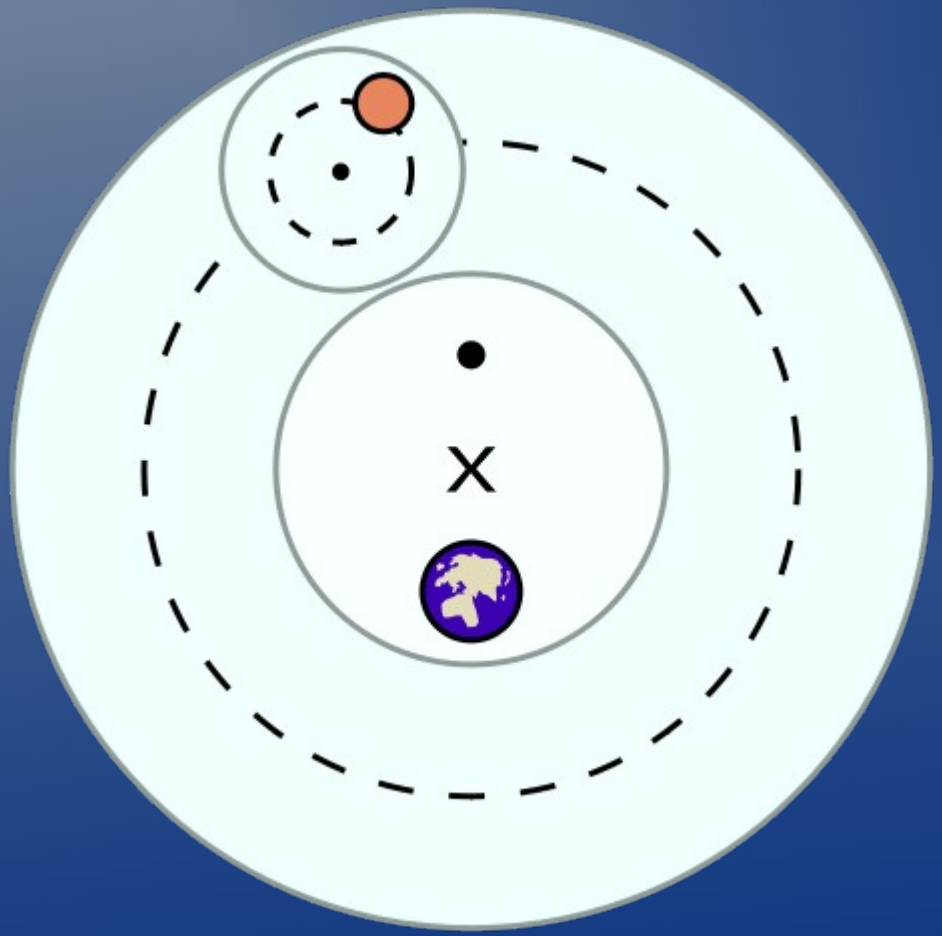
Ptolemaic Solar System

So ugly only a mother could love it.



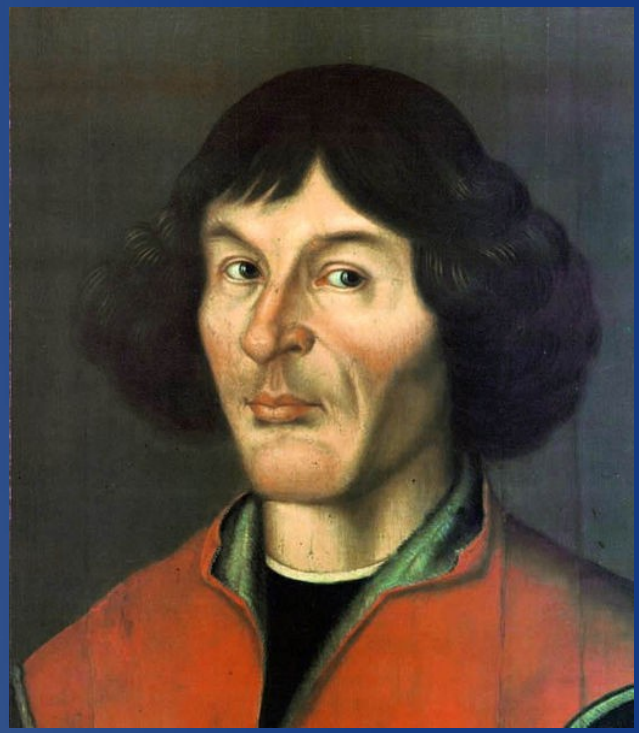
OK, Ptolemy, but why do the planets move that way?

"That's just the way things are, son."



Nicholas Copernicus (1543)
Geometric Genius

- A Roman Catholic cleric (possibly a priest; certainly celibate and a member of religious community).
- Not the first to ask the question, “What if the sun is at the center of planetary motions?” Some Greeks beat him to that punch by about 17 centuries or so.
- Copernicus argued that if the sun is at the center, then:
  - we can calculate the size of the planetary orbits;
  - we can calculate the length of time for each planet’s orbit around the sun.
- Martin Luther condemned Copernicus immediately; the Catholic Church did not oppose teaching heliocentrism until after Galileo made a stink about it *~90 years later*.

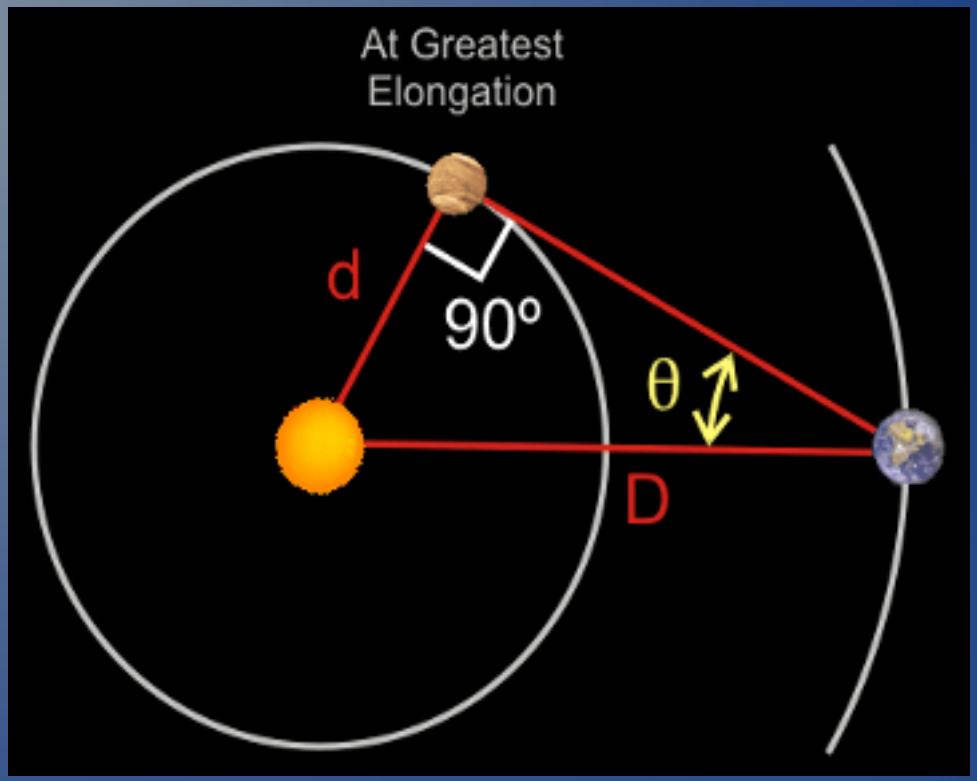


Angles and Triangles

Elongation: observed angle between sun and a planet

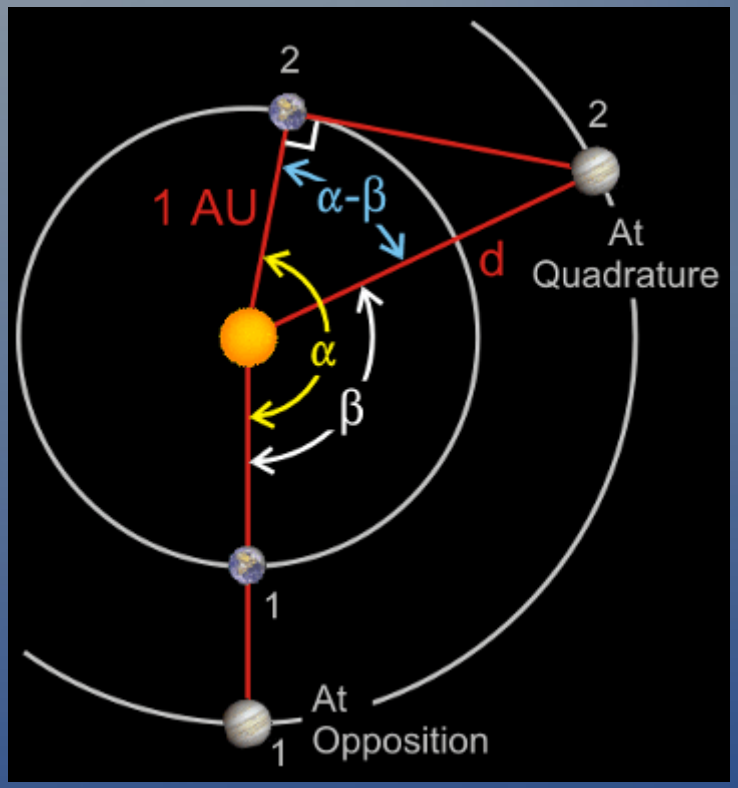
http://astro.unl.edu/naap/ssm/modeling2.html

Interior planets
Mercury and Venus



D = Sun to earth = 1 Astronomical Unit
Θ = Greatest elongation observed
d = D sin Θ = planet's distance from sun

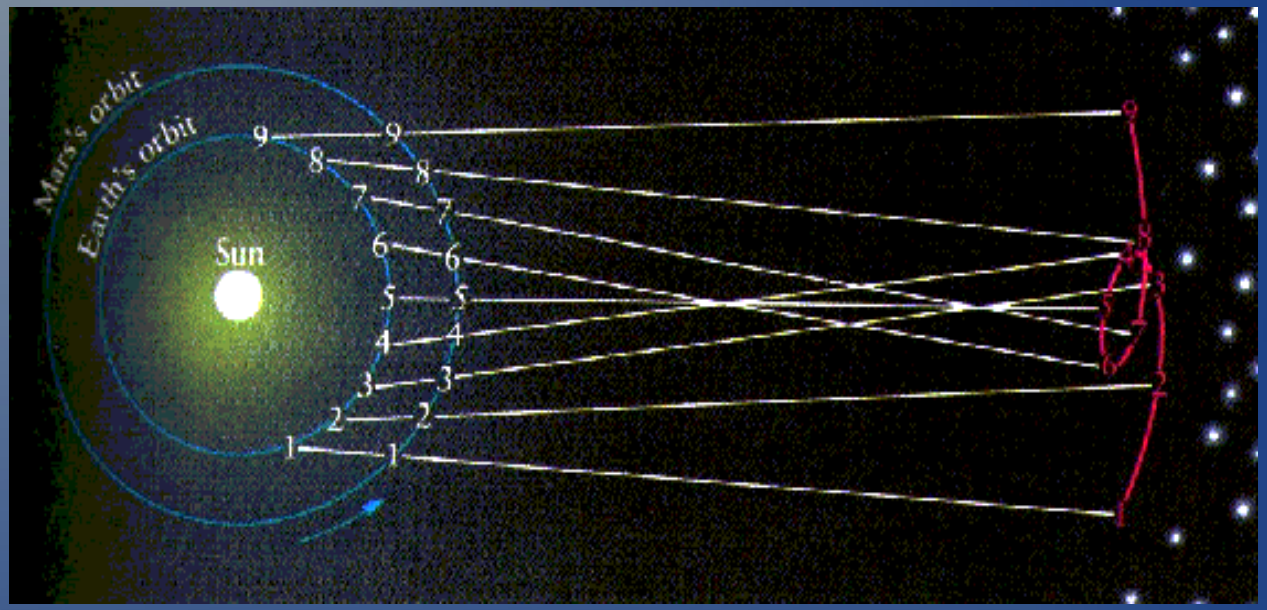
Exterior Planets
Mars, Jupiter, Saturn



- **Opposition**: sun, earth, planet all in straight line with each other.
- **Quadrature**: sun to earth to planet forms right angle.
- By measuring the time it takes to go from opposition to quadrature, we can calcuate **α** for the earth and **ß** for the planet.
- **α - ß** gives us one angle of the right triangle at quadrature.
- d = 1/cos(**α- ß**)

Retrograde Motion Explained

As the earth overtakes and speeds past Mars, it looks to us as though Mars comes to a stop, then reverses course.



It's just an optical illusion!
We can't trust our eyes.
We must trust *theory*.

A New Way of Seeing Things

East

West

Beautiful! But ...

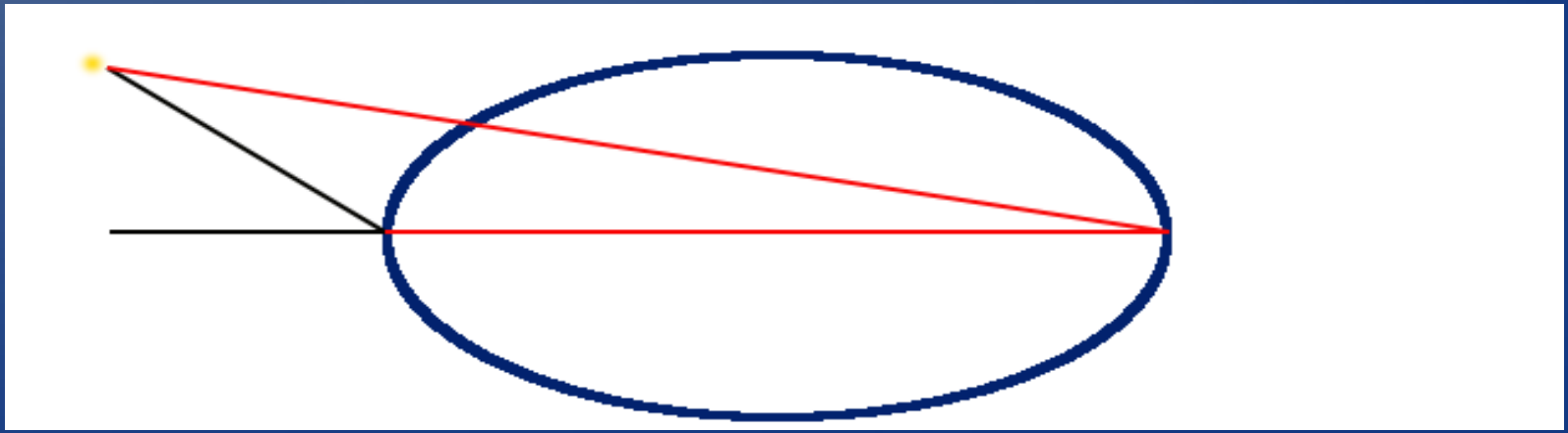
... it was a system so ugly that only a mother could love it.

Copernicus kept the Platonic assumptions about circular orbits and uniform velocity.

Therefore, his system needed more cycles and epicycles than the Ptolemaic system and was less accurate at matching predictions to observations!

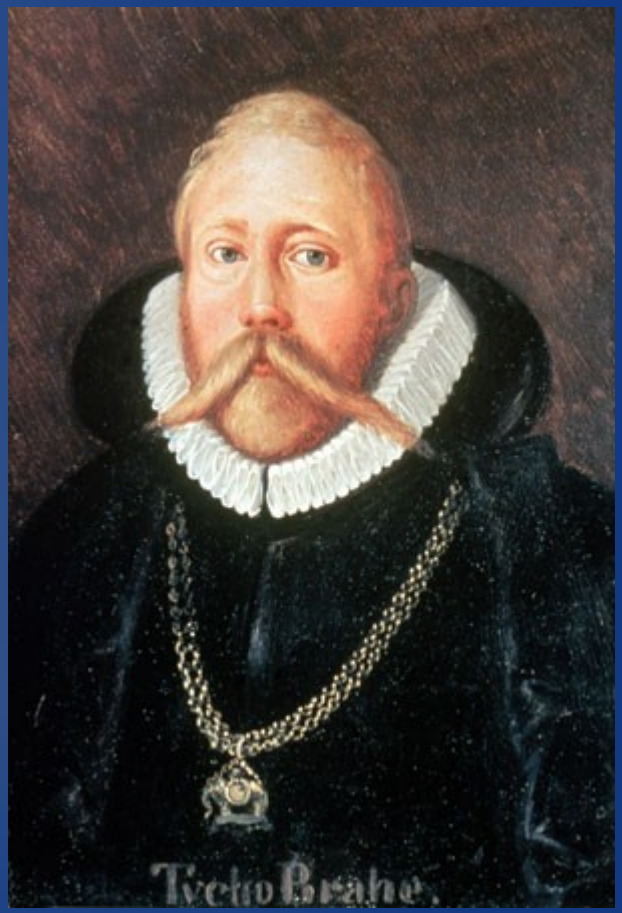
The Case against Copernicus

- We don't feel as though we are traveling at ~700 mph around the axis of the earth (at the equator, it's about 1000 mph).
- We don't feel as though we are traveling at ~66,000 miles per hour around the sun. [584,040,000 miles per year / 8,760 hours per year = 66,703 mph].
- If from one year to the next, we were 186,000,000 miles closer to the other side of the galaxy, *we should be able to observe stellar parallax*.
- Common sense says, "We're standing still and everything else is moving around us."



Tycho Brahe (1546-1601)
The Great Observer

- Constructed the largest and most accurate instruments for making astronomical observations.
- Motivated by money--he was astrologer to royalty.
- Recorded the motions of Mars for 25 years!
- Theorized that Mercury and Venus orbited the sun (halfway to heliocentric system).
- Others had made the same guess before him--he had much better data to back up his argument.
- Believed that the absence of stellar parallax proved that heliocentrism was false.

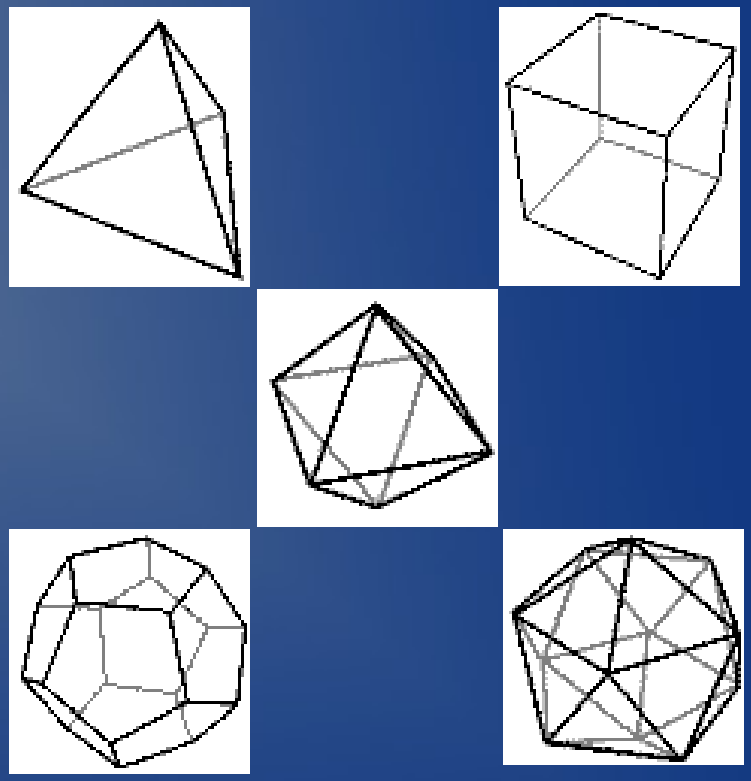


Johannes Kepler (1571-1630)
Mystic, Thief (?), Mathematician, Scientist

Geometric Fact

There are five Platonic solids:

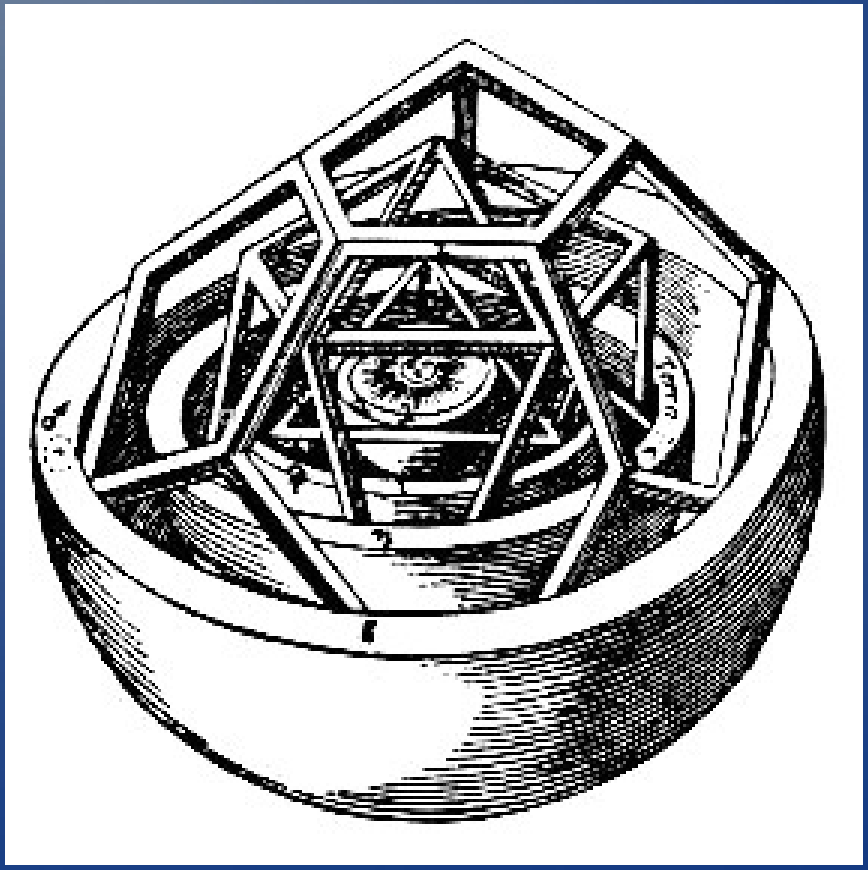
- tetrahedron (4)
- cube (6)
- octohedron (8)
- dodecahedron (12)
- icosahedron (20)

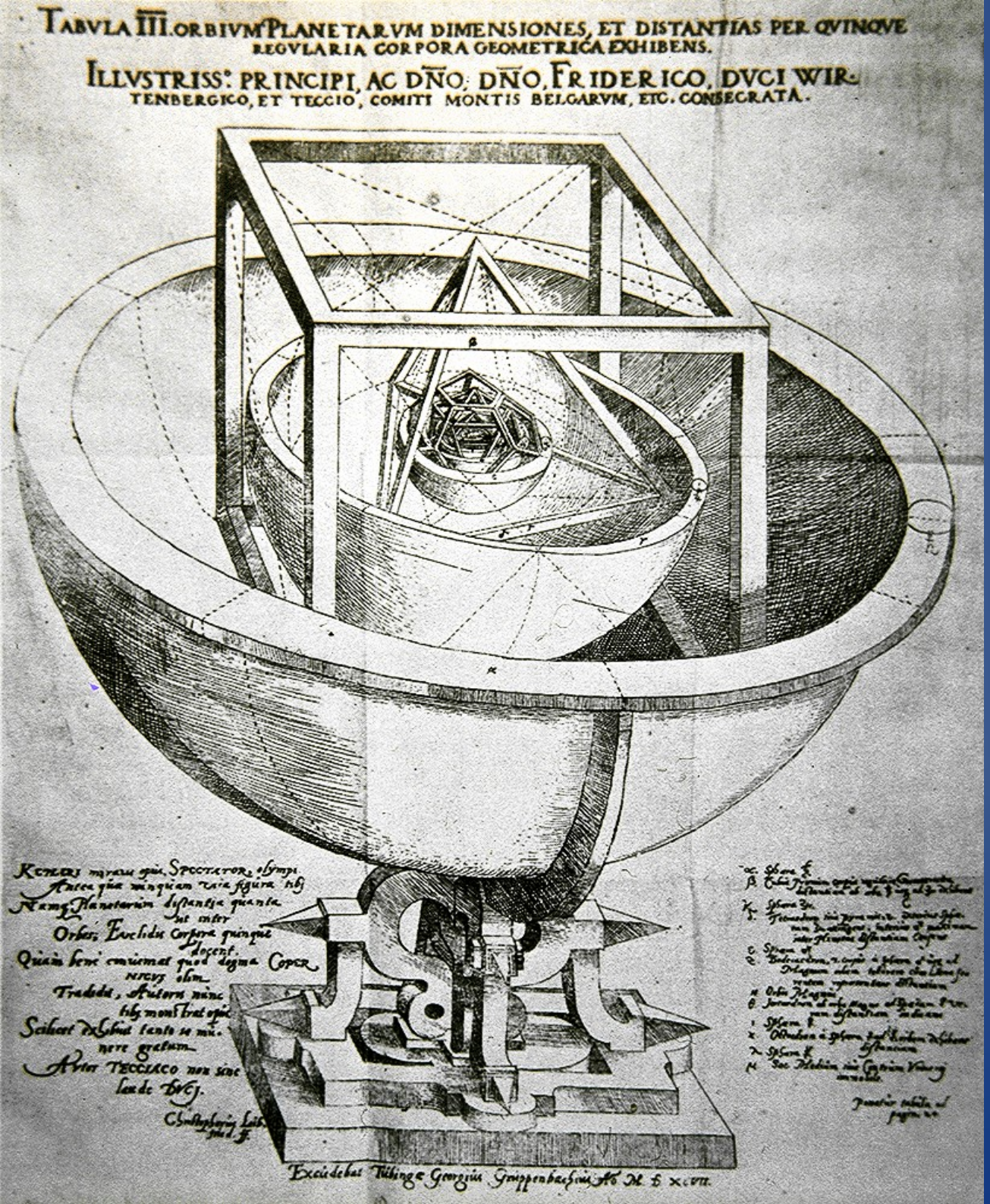


Mystical Inuition

Perhaps the five Platonic solids explain the relative size of the orbits of the five planets!

Mysterium Cosmographicum (1600)





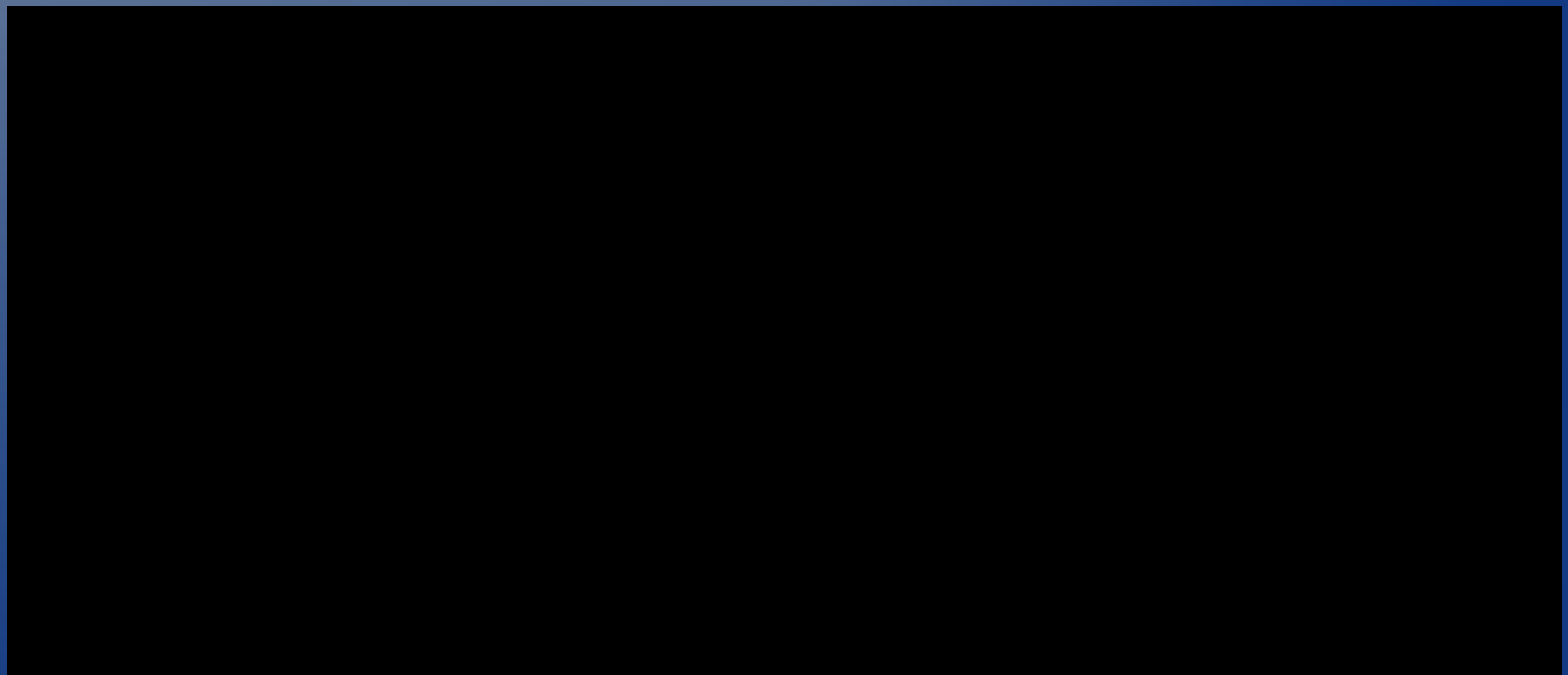
Spheres inscribed
within solids
inscribed
within spheres
inscribed
within solids!

Kepler got his model to come within 5% of the relative sizes of the planetary orbits!

The Good Thief (and Scientist!)

According to Tycho Brahe's heirs, Kepler stole Tycho's data on Mars.

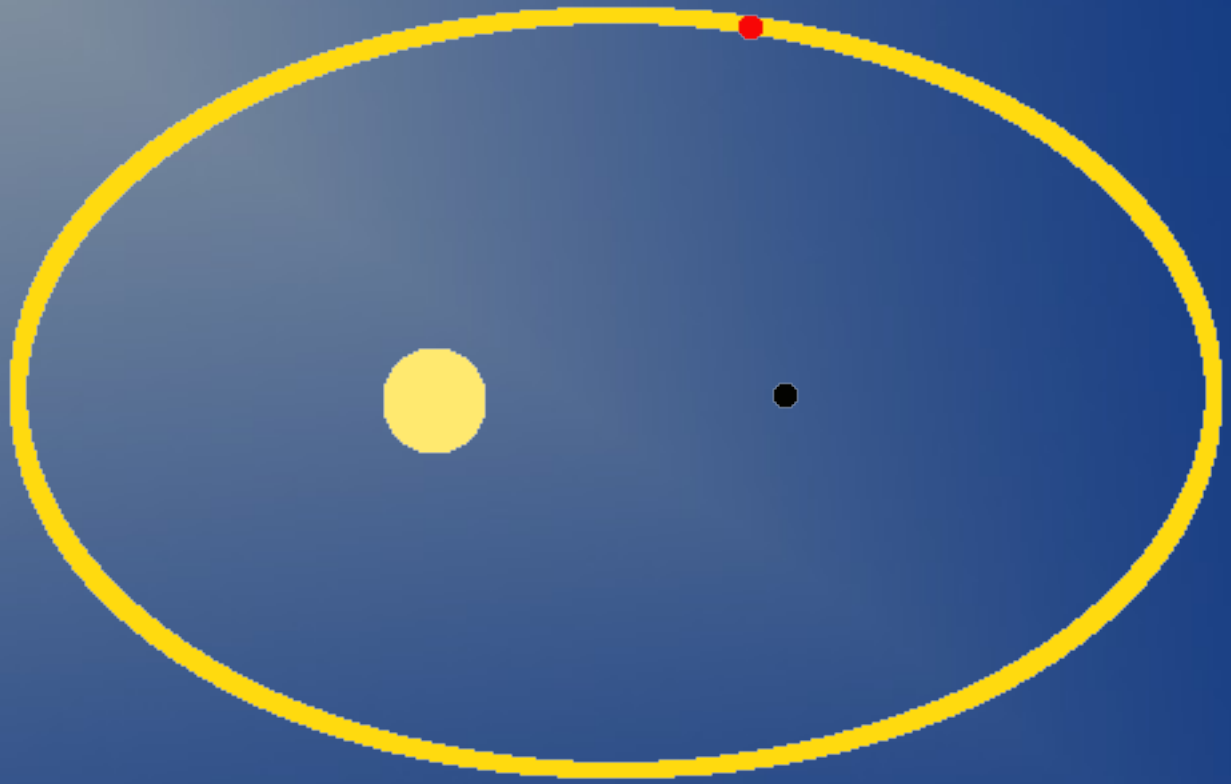
The courts ultimately allowed Kepler to publish his work based on Tycho's data.



“Follow the evidence where it leads.”

- Kepler abandoned his much-loved theory of Platonic solids because it could not be made to fit Tycho’s observations.
- Kepler spent two years calculating Mar’s orbit according to the Ptolemaic system, using an equant. He got the model to match the data to within the limits of the precision of Tycho’s instruments, but he was not satisfied.
- He then developed two separate proofs that orbits are ellipses that have one focus at the center of the sun (First Law of Planetary motion). He didn’t like his conclusion the first time around--ellipses seemed to be “imperfect.”
- After starting from scratch and inventing a new method of interpreting the data, he came to the same conclusion.

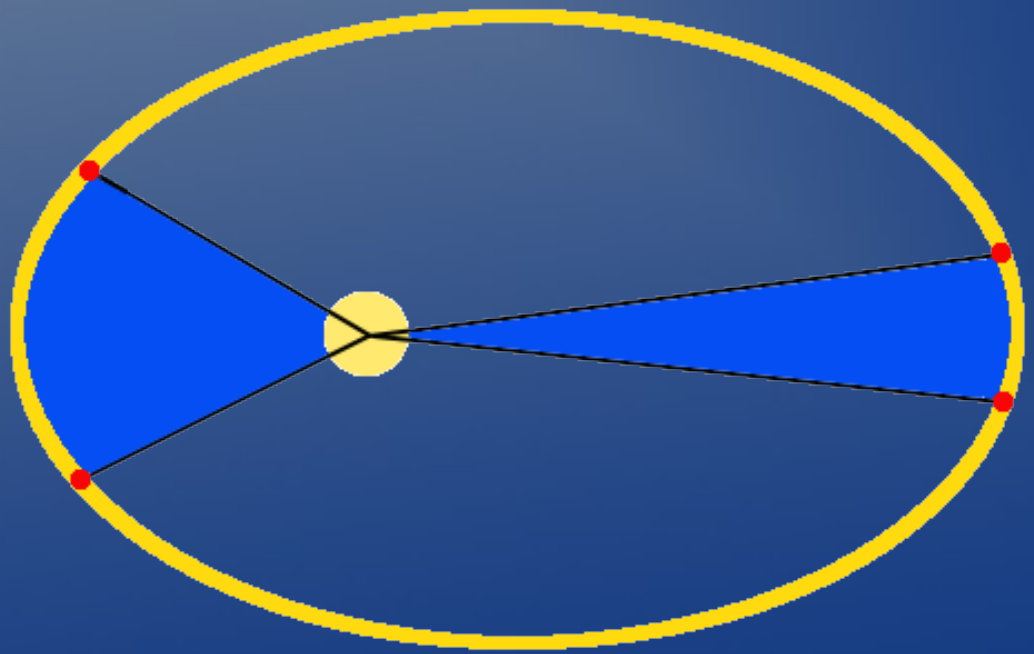
Kepler's First Law of Planetary Motion



Kepler's Second Law

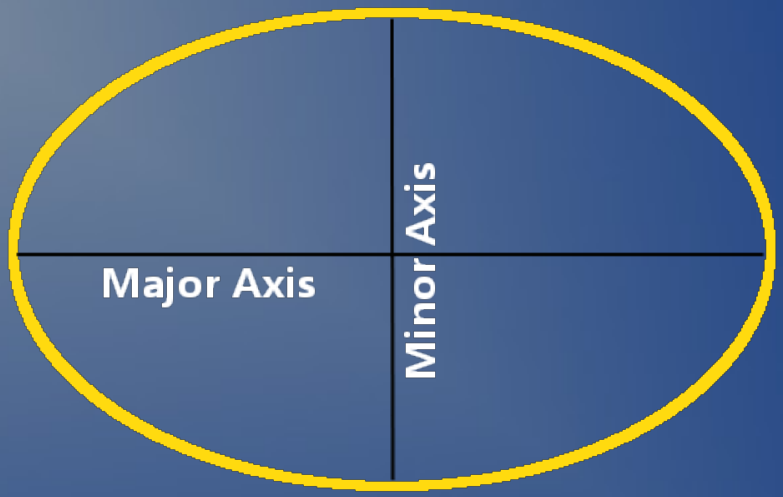
The radian between the planet and the focus in the sun sweeps out equal areas in equal times.

The velocity of a planet (or comet) changes continually from a maximum at the perihelion to a minimum at the aphelion!



Kepler's Third Law

The square of the orbital period of a planet is equal to to the cube of the semi-major axis of its orbit.

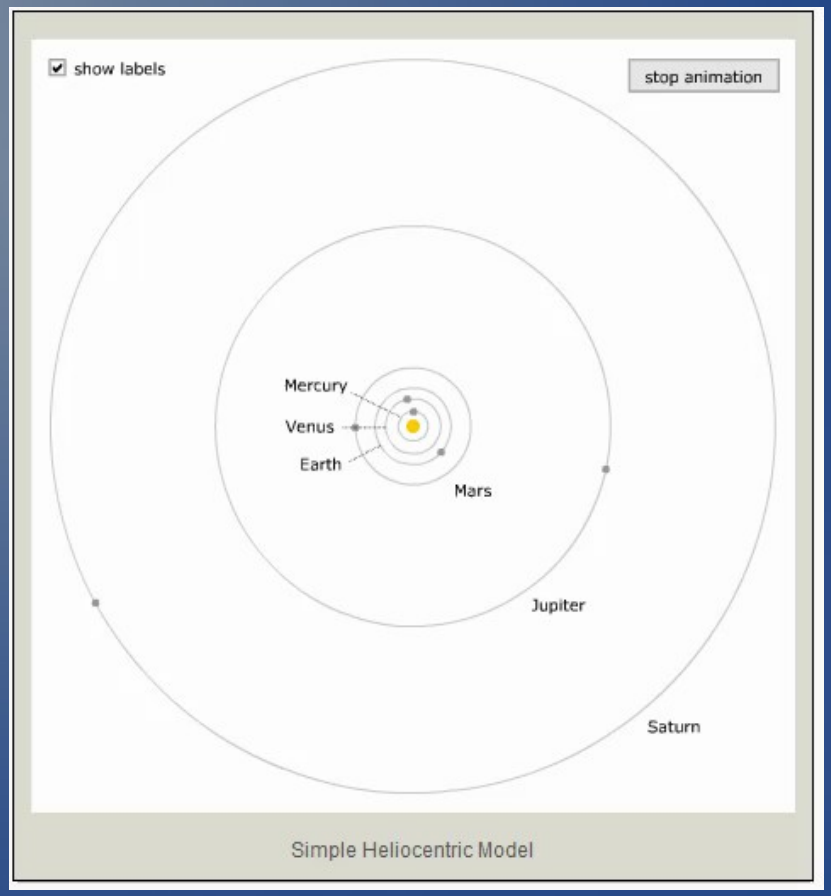


The bigger the orbit, the more slowly the planet travels around it.

Kepler showed that there was a beautiful harmony to the size of orbits and the length of an orbital period.

This was not the Platonic beauty he first sought, but it is awesome in its own right!

Closer, faster; further, slower

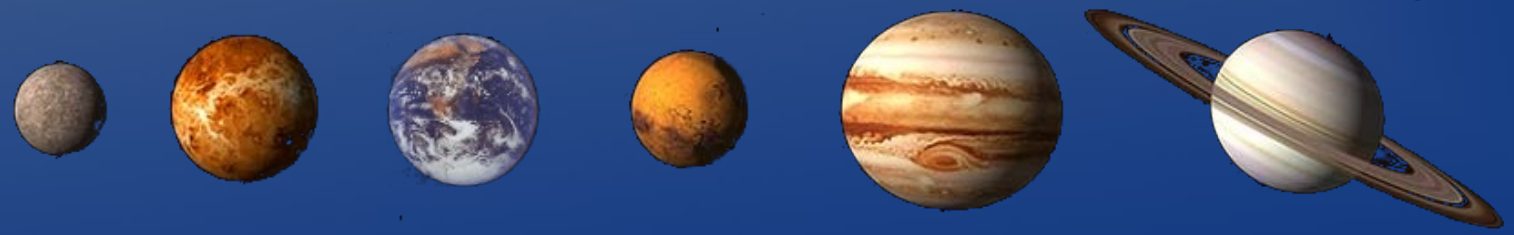


The Greeks were right!

There is a uniformity in nature. The planets are law-abiding citizens of the universe, not wild and crazy gods and goddesses.

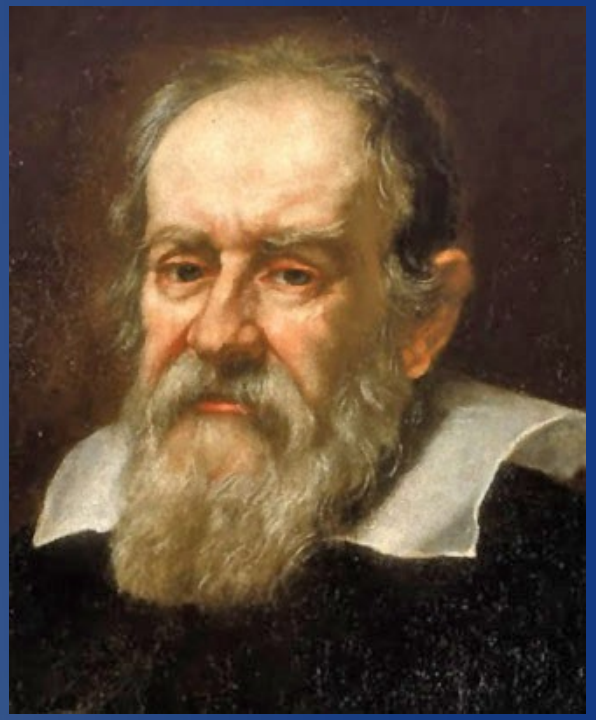
The Greeks were wrong!

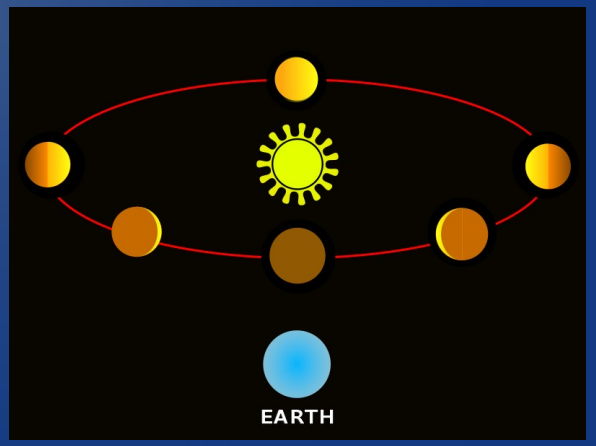
The planets do not move at uniform speed in perfect circles. The planets are all obeying some other law that causes them to have *the same kind of orbits.*



Galileo Galilei (1564-1642)
A Genius and a Jerk

- Studied Copernican system under Jesuits.
- Performed masterful experiments on motion.
- Improved the telescope and pointed it at the heavens (1609).
  - Found mountains on the moon (it was therefore not a perfect sphere).
  - Observed the phases of Venus (confirming Tycho's half-heliocentric system--evidence that Venus orbits the sun, not the earth).
  - Identified four moons of Jupiter--an absolutely amazing feat of observation!
  - Saw sunspots that suggested the sun rotated on its axis.
  - Showed that the Milky Way was composed of individual stars.
- Honored in Rome in 1611 for his telescopic observations. *Galileo was a superstar!*

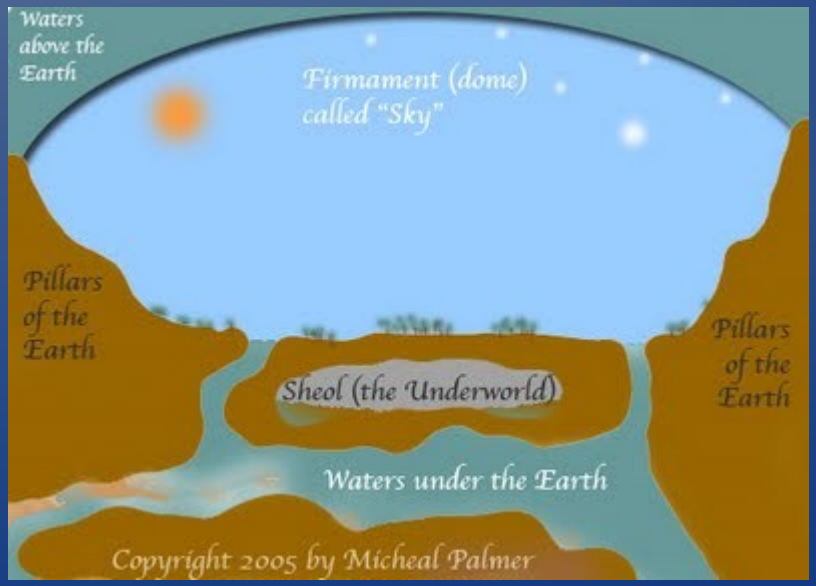




The First Trial of Galileo

Galileo started publishing Scripture studies in 1614.

- "'Sun, stand thou still at Gibeon' ... and the sun stood still" (Joshua 10:12).
- "The world is established; it shall never be moved" (Ps 93:1).
- "Thou didst set the earth on its foundations, so that it should never be shaken" (Ps 104:5).
- "The sun rises and the sun goes down, and hastens to the place where it rises" (Eccl 1:5).

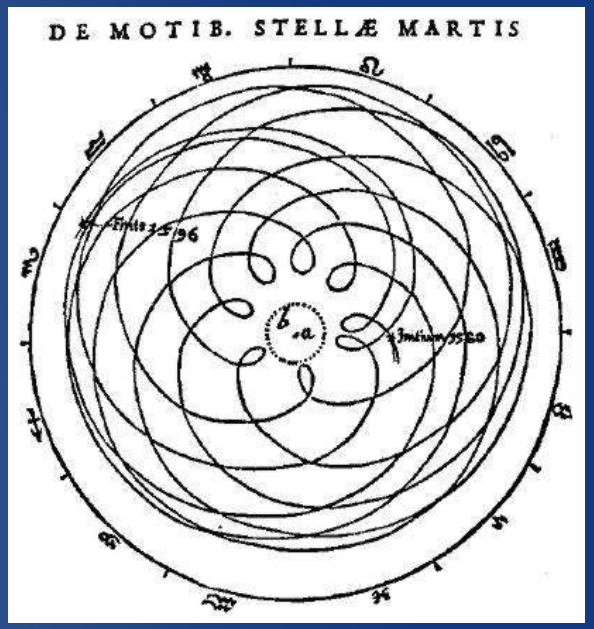


“He willed to make them Christians ...”

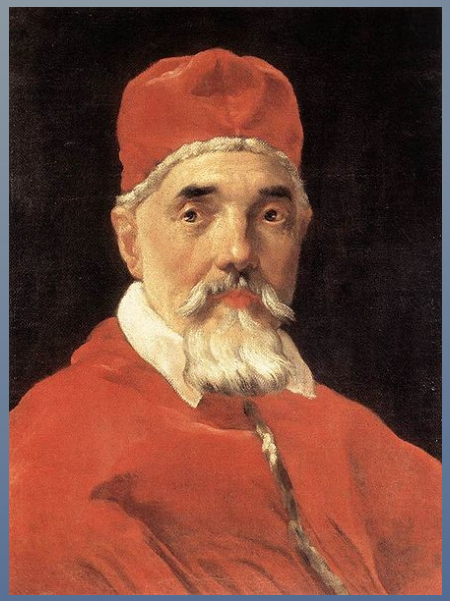
"Galileo pointed out correctly that both St. Augustine (354-430 AD) and St. Thomas Aquinas (1225-1274) taught that the sacred writers in no way meant to teach a system of astronomy. St. Augustine wrote that 'One does not read in the Gospel that the Lord said: I will send you the Paraclete who will teach you about the course of the sun and moon. **For He willed to make them Christians, not mathematicians**'" (George Sim Johnston).

Galileo vs. the Pope
A Contest of Manhood and Honor

- In 1611, Maffeo Cardinal Barberini had participated in honoring Galileo in Rome.
- Barberini became Pope Urban VIII in 1623 (d. 1644). Galileo dedicated *The Assayer* (1623) to him and the Pope was pleased to be so honored.
- When the Pope heard that Galileo was writing a new book on the solar system (*Dialogue on the Two Chief World Systems*, 1630) , he asked Galileo to include his own theory about science in the book.
- *Galileo put the pope's theory in the mouth of Simplicio, the dunderhead who never gets anything right in the Dialogue.*
- The pope was not amused. Although Galileo had scrupulously obeyed the Church's rules for publication, the Pope had him brought up on trumped-up charges.



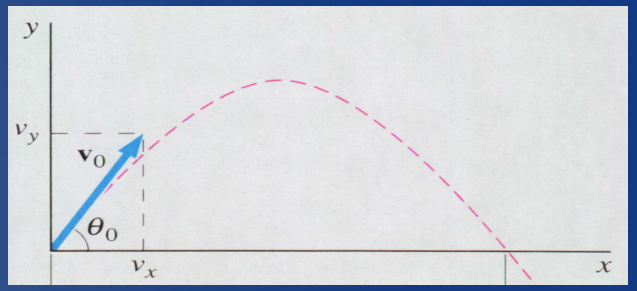
The Condemnation of 1633



- The Pope's henchmen pushed through a condemnation of Galileo based on a statement which differed from what Galileo had been instructed to do in 1616; it's not clear whether the more stringent statement was a forgery or a letter that had never been delivered to Galileo.
- Galileo spent the rest of his life (1633-1642) under "house arrest," living in his own home in Florence for most of those years.
- The group that the Pope used to get revenge on Galileo did not have the authority to make an ex cathedra decree and it was definitely NOT a council of the Church; their support for the geocentric system was their opinion, not a dogma of the Church.
- The church allowed Copernicanism to be taught (quietly) as a working hypothesis, not as a fact that had been established.

Galileo's Laws of Motion

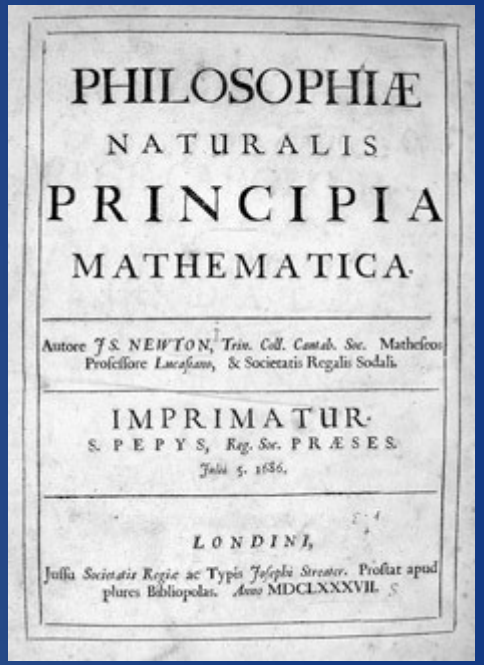
Discourses on Two New Sciences (1638)



- The two new sciences dealt with:
  - Strength of materials
  - Motion
- The basic experiments were completed by 1604.
- While under house arrest, Galileo wrote up the results of his research. Lamentably, the Inquisition would not allow this study to be published in Catholic territory.
- The most notable results:
  - The path of a projectile is a parabola.
  - All bodies are accelerated at the same rate in a vacuum, regardless of mass.
  - The rate of acceleration is proportional to the square of the time that passes. Galileo measured the rate of acceleration on earth: 32' (9.8 m) per second per second.

The Triumph of Heliocentrism

- 1687: Newton's *Philosophiae Naturalis Principia Mathematica* showed how the concept of gravity, coupled with Galileo's laws of motion, explains Kepler's ellipses (GG +54).
- Newton's laws of motion:
  - Every body in motion or at rest tends to stay in motion or at rest unless a force acts on it.
  - Force is measured as mass times acceleration.
    - $F = ma$
    - $F_{gravity} = G\, m_1\, m_2 / d^2$
      (explains Kepler's laws!)
- For every action there is an equal and opposite reaction.


PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S. NEWTON*, Trin. Coll. Cantab. Soc. Matheseos Professore Lucasiano, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, Reg. Soc. PRÆSES.
Julii 5. 1686.

LONDINI,
Justu Societatis Regiæ ac Typis Josephi Streater. Prostat apud plures Bibliopolas. Anno MDCLXXXVII.

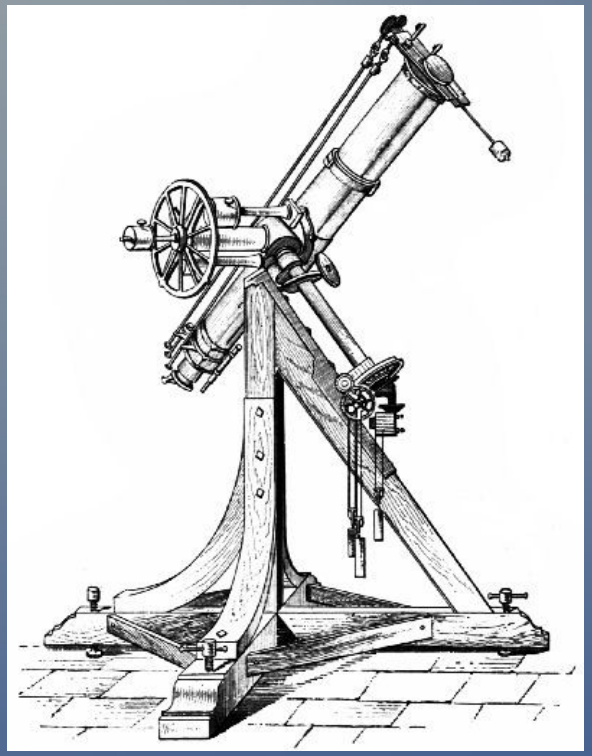
So, Sir Newton, why do the planets move that way?

"Because the force of gravity varies inversely with the distance between two bodies."

Yeah, but why does gravity act that way?

"Because that's the way things are, son."

The Evidence Clinches the Case



- **1728**: First evidence of the motion of the earth gleaned by Bradley's work on the slant of light falling from the stars (GG +95).
- **1741**: Benedict XIV told the Holy Office to grant an imprimatur to the first edition of the Complete Works of Galileo. This means that Catholics were permitted to discuss Galileo's theories publicly (GG +108).
- **1820**: Based on Italian evidence of rotation and orbit (1792-1806), Catholics were allowed to teach Copernicanism as a fact rather than as a working hypothesis (GG +187).
- **1838**: Measurement of stellar parallax by Friedrich Bessel confirmed that the earth orbits around the sun (G+205).
- **1851**: Foucault's pendulum demonstrated the rotation of the earth around its axis (GG +218).

The Legend of St. Galileo
Proto-martyr of the Church of Science

People who accuse the Church of hating science act as if Galileo knew and defended ***the Kepler-Newton model***: elliptical orbits and constantly changing velocities caused by the force of gravity.

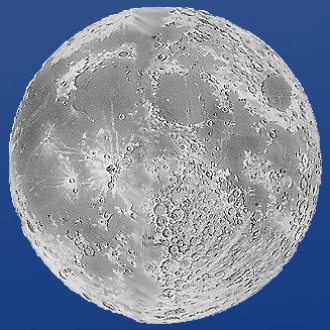
What Galileo Got Right

Unproven beliefs (good conjectures):

- The sun is at the center of the planetary system, not the earth.
- The earth does rotate on its axis.

Telescopic observations:

- Venus orbits the sun, not the earth.
- The moon is not a perfect sphere.
- Jupiter has moons that orbit around it.



What Galileo Got Wrong

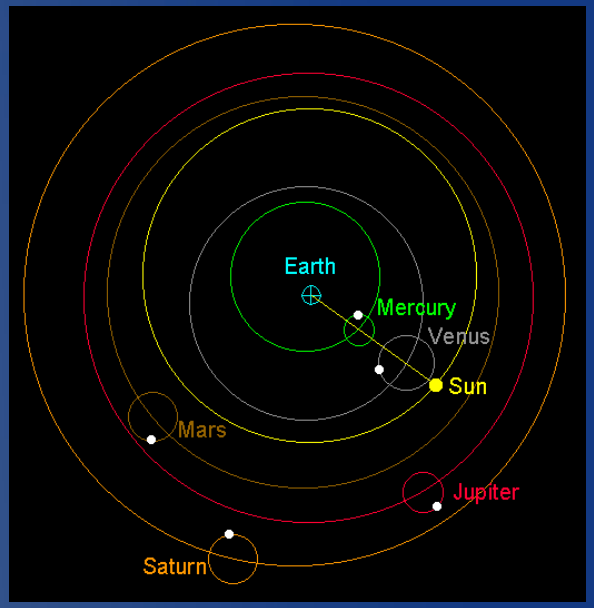
- Defended Copernicus' inaccurate, Platonic system: circular orbits, uniform motion, cycles and epicycles.
- Refused to answer Kepler's letters about his findings; he either never read Kepler's work, couldn't understand it, or chose to ignore it.
- Added no new observations to establish the motion of the earth around the sun.
- Made his case for heliocentrism based on the motion of the tides (rejected then and now as false; Kepler conjectured that the moon caused the tides).

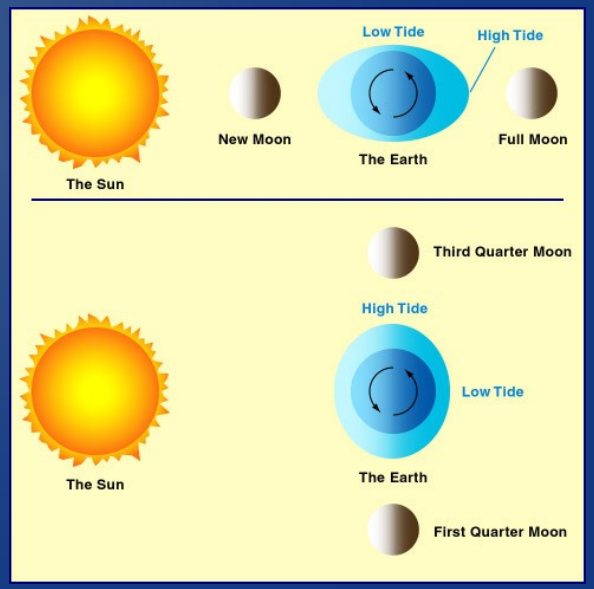
In Defense of Galileo

A failed theory is nothing to be ashamed of

Science is all about testing hypotheses. You can't decide how to test a theory until you have a theory to test.

- **Ptolemy's theory of planetary motion** was wrong--thunderously wrong!--but it was a testable hypothesis. It taught astronomers to seek explanations for observations and to match predictions to data.
- **Copernicus' theory of planetary motion** was not as wrong as Ptolemy. He got the location of the sun right, measured the size of the orbits in Astronomical Units, and calculated the periods of the planetary orbits.
- **Galileo's theory of the tides** was wrong, but it was right for him to guess that they might tell us something about the motion of the earth. After Newton discovered the law of gravity, it was clear that the gravitational pull of the sun and moon as the earth rotates on its axis is the true cause of high and low tides.





Astronomy Scorecard

- Who used mathematics to describe planetary motion?
  - Copernicus
  - Kepler
  - Newton
- What was Galileo's greatest contribution to answering the ancient question about planetary motion?
  - His 1604 studies on the nature of motion (published in 1638).
- Who applied Galileo's insights about motion to explain the planetary system?
  - Newton
- What convincing evidence did Galileo offer to support the heliocentric hypothesis?
  - None!
- Why should the Church have accepted heliocentrism as a fact in Galileo's time?
  - Because it was proved to be true ~200 years later?
  - Because St. Galileo the Great said so?

The Errors of the Pope

- His pet theory of science--that perhaps God wanted to deceive us about the nature of the universe--was, in fact, dunderheaded. Only a few Biblical fundamentalists would defend that idea (e.g., God put dinosaur bones into the rocks to fool us when He created the universe 6000 years ago--but the dinosaurs were never living animals).
- The Church had the right to ask Galileo not to do exegesis and theology; it did not have the right to control Galileo's work in science.
- Galileo had followed the rules for publishing a controversial work. His fidelity should not have been called into question.
- The pope should have asked for a debate about the status of the question instead of bullying Galileo.

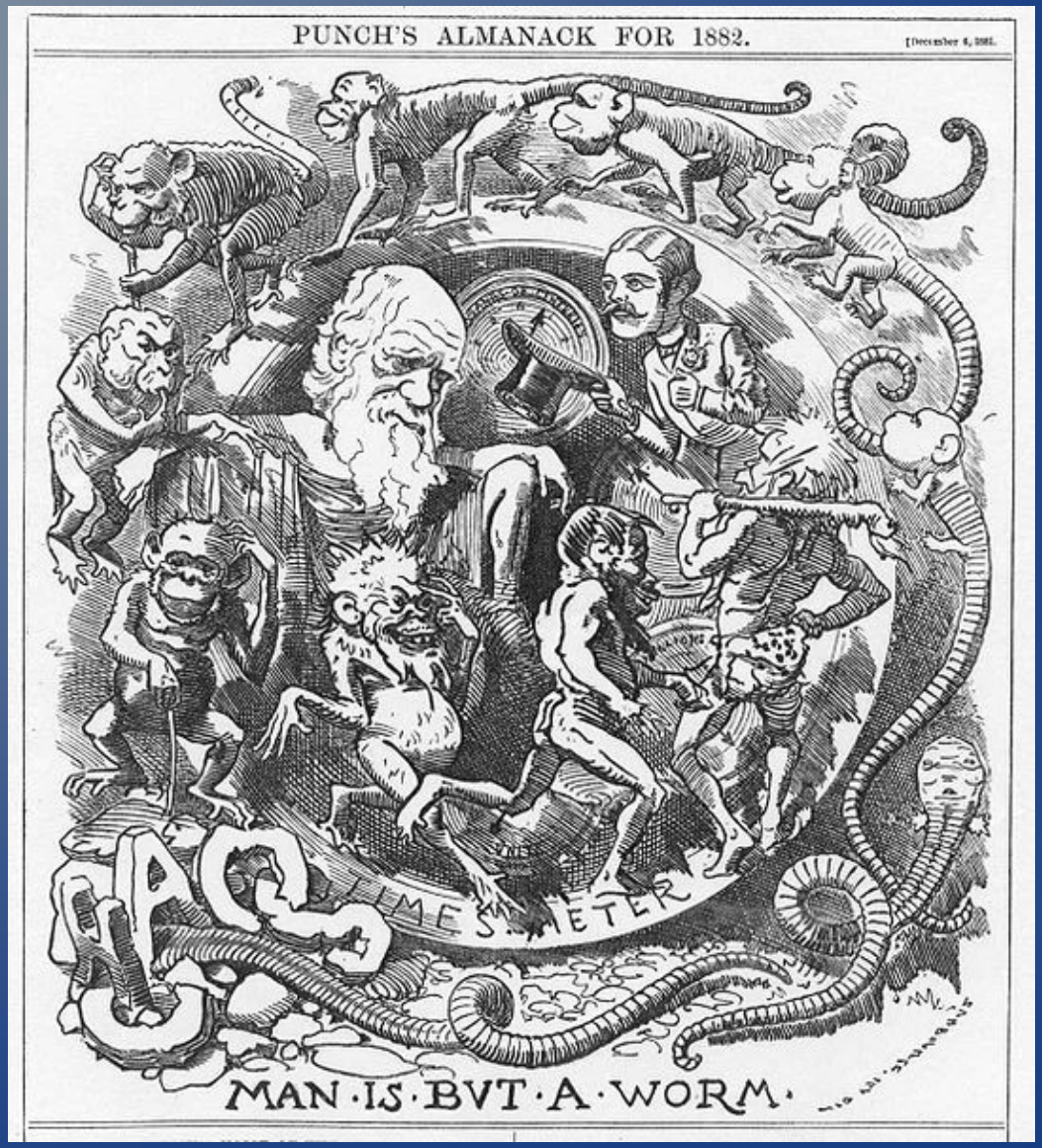
The Church is not opposed to science

It is opposed to false interpretations and the misuse of science. The Church did not reject other elements of Galileo's scientific research (as opposed to his Scriptural exegesis):

- Improvement of the telescope (1609): optics.
- Telescopic discoveries (1610).
- Experiments with motion:
  - uniform acceleration of falling
  - bodies, inertia, parabolic
  - trajectories, etc.
- Belief that mathematics is the language of science (*The Assayer,* 1623, dedicated to Pope Urban VII (Barberini!).

The Next Galileo Affair

Evolution: fact or faith?



When I consider thy heavens, the work of thy hands,
the moon and the stars, which thou hast ordained;
What is man, that thou art mindful of him?
and the son of man, that thou visitest him?
For thou hast made him
a little lower than the angels,
and hast crowned him with glory and honour.

Psalm 8:4-6

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This slideshow is essentially a first draft.

I need to give credit for the various components of it.

Wednesday, December 16, 2009

http://moleski.net