The Science of Astronomy (Chapter 3)

The Orbits of the Planets

Does the Earth go around the Sun or does the Sun go around Earth?

Based on Chapter 3

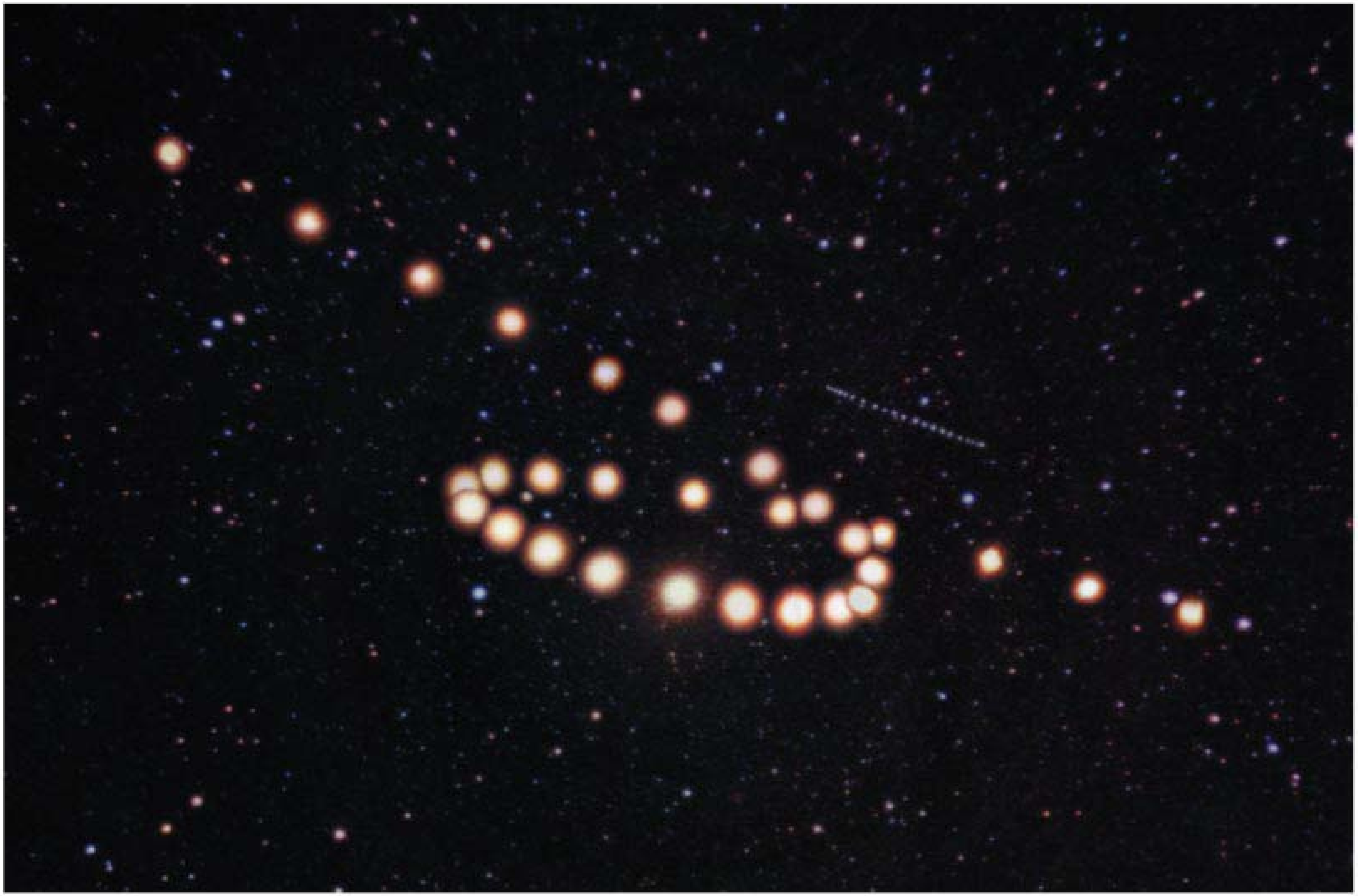
- This material will be useful for understanding Chapters 4, 5, 7, and 8 on “Why does the Earth go around the Sun?”, “Momentum, energy, and matter”, “Our planetary system”, and “Formation of the solar system”
- Chapters 1 and 2 on “The structure and size of the universe” and “Years, seasons, and months” will be useful for understanding this chapter

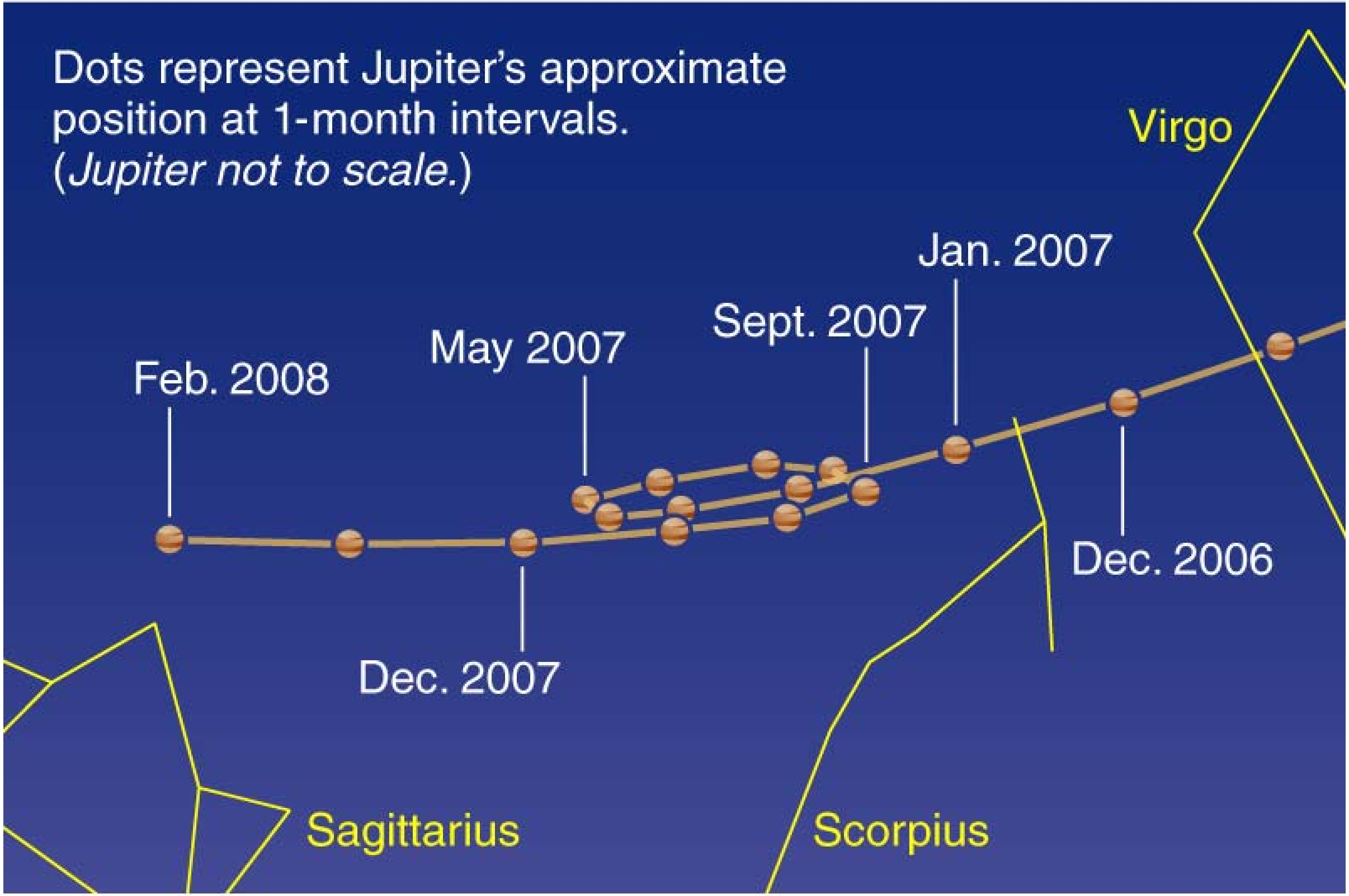
Goals for Learning

- Why are planets unusual in the night sky?
- What did people used to think about the motion of the Sun and Earth?
- Why did ideas about the motion of the Sun and Earth change?
- What laws describe the motion of planets?

Contents of the sky

- Sun (daily and annual patterns)
- Moon (daily and “moon”thly patterns)
- Stars (daily and annual patterns)
- Sun and Moon move through constellations in regular patterns
- Planets (daily patterns, but other unusual behaviour)




Dots represent Jupiter's approximate position at 1-month intervals. (*Jupiter not to scale.*)
Virgo
Jan. 2007
Sept. 2007
May 2007
Feb. 2008
Dec. 2006
Dec. 2007
Sagittarius
Scorpius

- Paths of the planets on VoyagerSkyGazer

Planets are Unusual

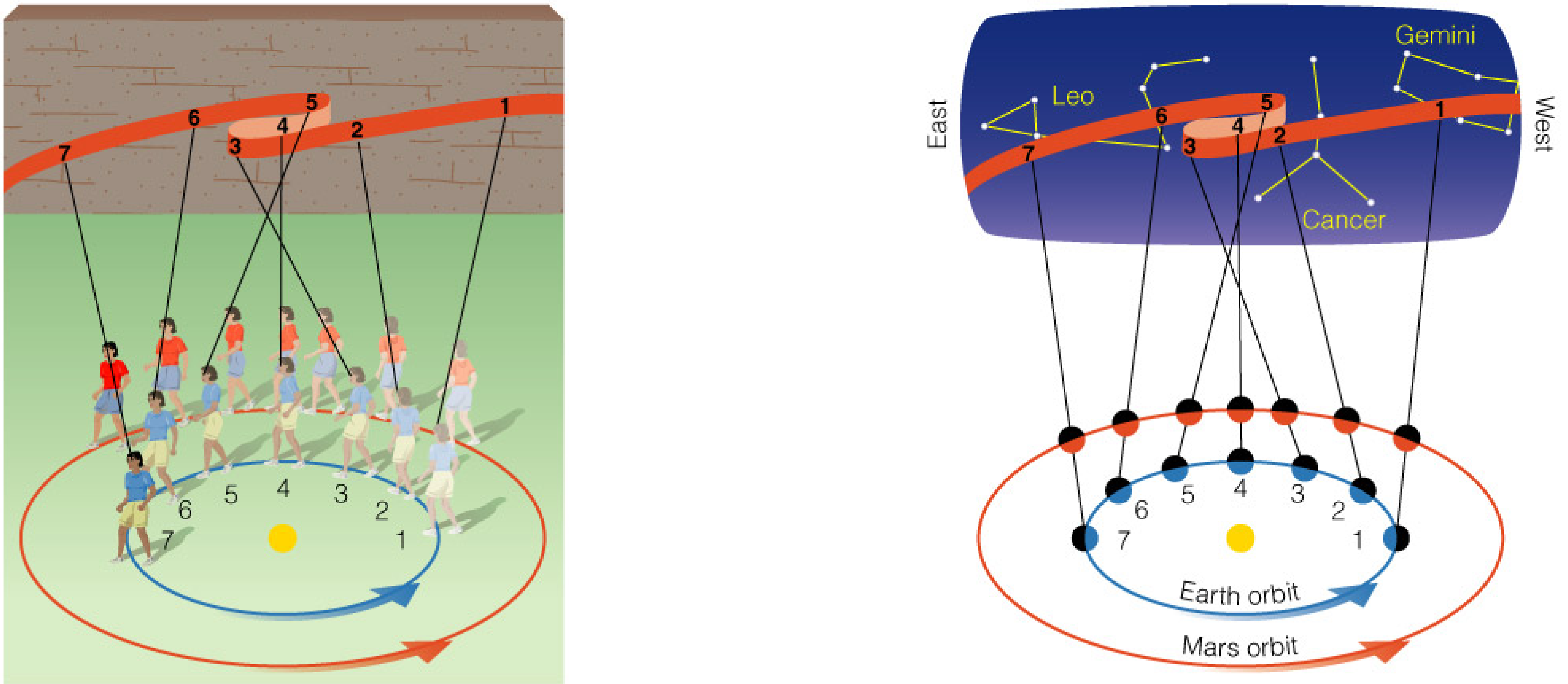
- Sun and Moon move eastward relative to the stars at fixed speed and have fixed brightness
- Planets usually move eastward relative to the stars, but sometimes move westward (retrograde) instead. Their speeds and brightnesses also change.

Explaining Retrograde Motion

- Everything goes around the Earth
  - Planets move in complicated series of circles-upon-circles, suggested by Ptolemy.

- Everything goes around the Sun
  - Planets and Earth go around Sun, Moon goes around Earth

•Interactive Figure 3.15 Ptolemy

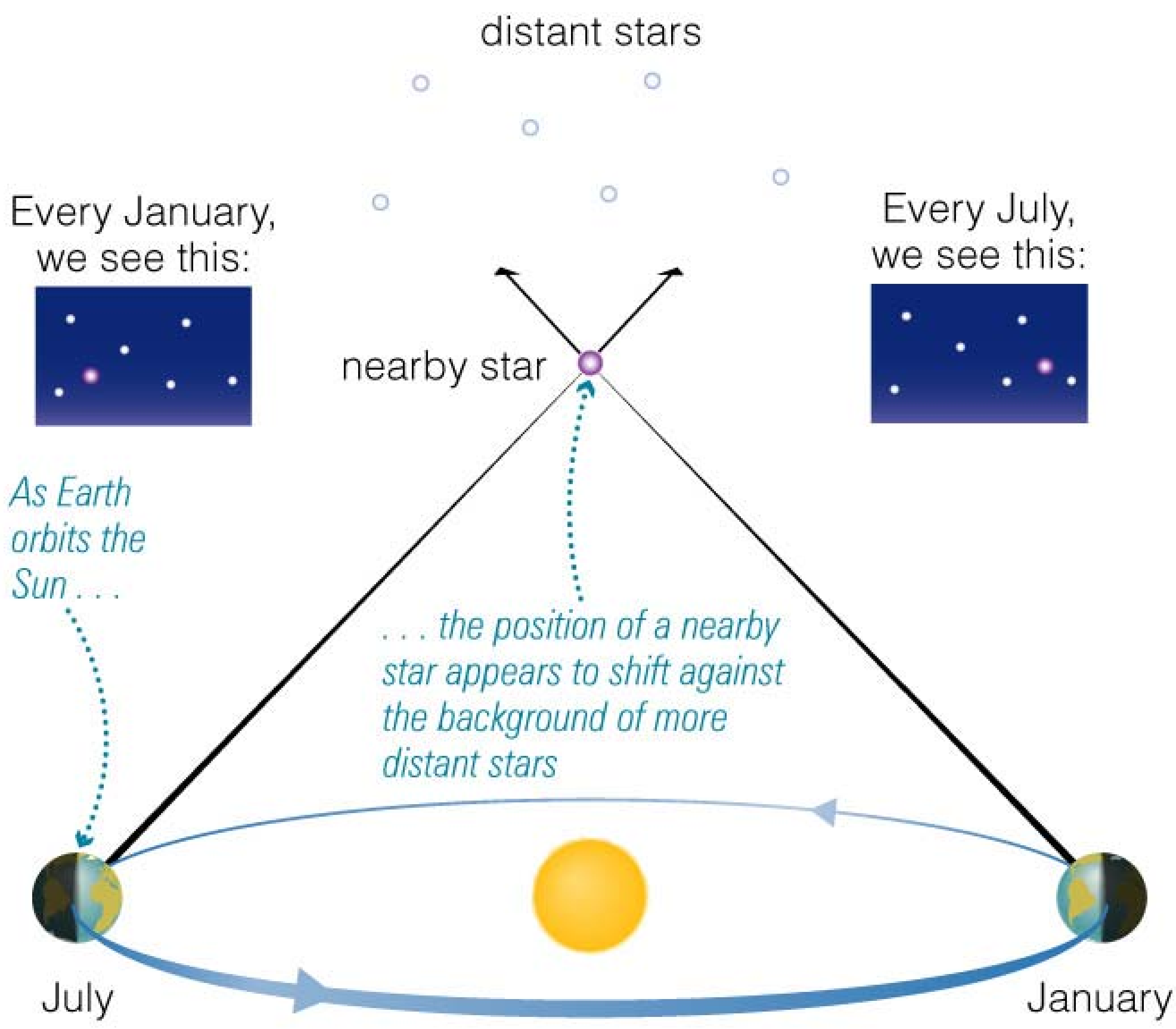


Explanation of retrograde motion if Earth and the planets orbit the Sun

Consequences of Each Choice

- Everything goes around the Earth
  - We are the centre of the universe
  - Do not expect to see stellar parallax
- Everything goes around the Sun
  - We are not the centre of the universe
  - Expect to see stellar parallax
  - Why does the Moon go around the Earth as the Earth goes around the Sun?

- Are the Sun, Moon, and planets made of the same stuff as Earth or of something else, something perfect and supernatural?


distant stars
Every January,
we see this:
Every July,
we see this:
nearby star
As Earth
orbits the
Sun . . .
. . . the position of a nearby
star appears to shift against
the background of more
distant stars
July
January

The Greek Consensus

- Retrograde motion can be explained by epicycles, it’s not a problem
- We can’t see stellar parallax
  - Either the stars are VERY far away
  - Or everything must orbit the Earth
- The stars can’t be VERY far away, so everything orbits the Earth
- These ideas were used to make reasonably successful predictions of the positions of the planets for over a thousand years

Making Predictions with the Earth-Centred Model

- Make lots of observations of the planets over many years
- Use the observations and the structure of Ptolemy's Earth-centred model to predict positions in the future

- These predictions are accurate at first, but inaccurate after 100 years or so.
- Make a new series of observations and generate new predictions of planetary positions.

- Repeat every few hundred years

Nicholas Copernicus (1473-1543)

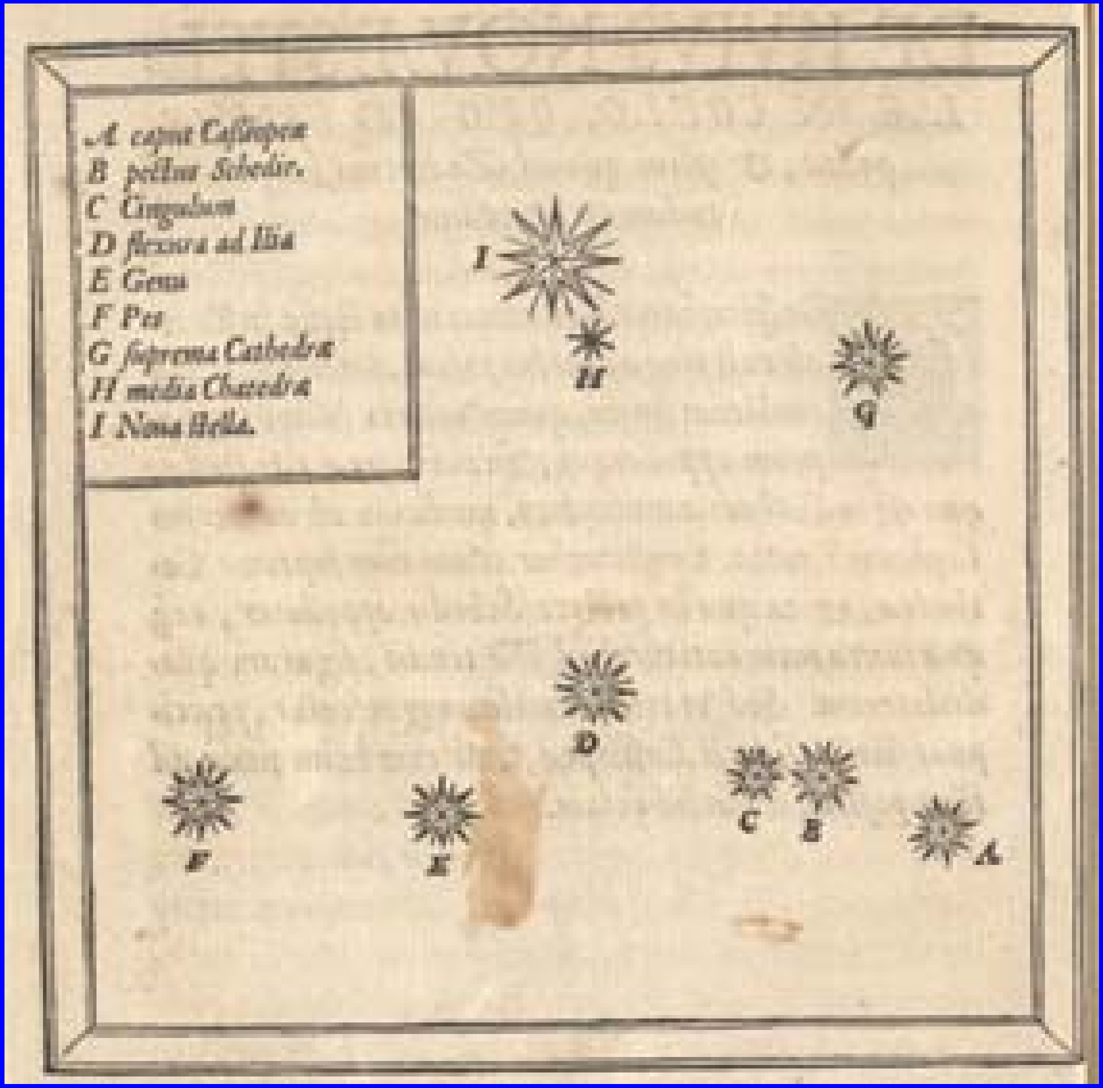
Nicholas Copernicus (1473-1543)

- He liked the simple explanation of retrograde motion offered by the Sun-centred model
- He also used a Sun-centred model to relate the known periods of the planets to their relative distances from the Sun, something not possible with the Ptolemy model
- But how could you test these predicted distances?
- Copernicus proposed that the planets go in circles-upon-circles around the Sun. Just going around in circles didn't work.
- His predicted planet positions were no better than Ptolemy's

Tycho Brahe (1546-1601)

Tycho Brahe (1546-1601)

- Both Ptolemy's Earth-centred model and Copernicus's Sun-centred model fitted existing observations equally well.
- Tycho decided to make better observations so that these theories could be tested
- He observed the planets for over thirty years. Without a telescope, he used his naked eye to make observations accurate to better than 1/60 of one degree, or one arcminute.
  - (Full Moon = 30 arc-minutes)
- He was never able to make either model fit his incredibly accurate data


A caput Cassiopeæ
B pectus Schedir.
C Cingulum
D flexura ad Ilia
E Genu
F Pes
G suprema Cathedræ
H media Chathedræ
I Noua stella.
I
H
G
D
F
E
C
B
A

The perfection of the heavens – Supernova

- In 1572 Tycho saw a new star in the night sky. It was as bright as Jupiter, soon became as bright as Venus, and even became bright enough to see during the day for two weeks. As it dimmed, it went from white to yellow to orange to red. It was visible in the night sky for over one year

- Tycho saw a supernova, an exploding star, and used its parallax to show that it was much further away than the Moon – the heavens changed

The perfection of the heavens – Comets

- Comets were known long before Tycho
- Atmospheric phenomena, not heavenly

- Tycho used parallax (again) to show that comets are far away in the heavens
- The heavens change

Johannes Kepler (1571-1630)

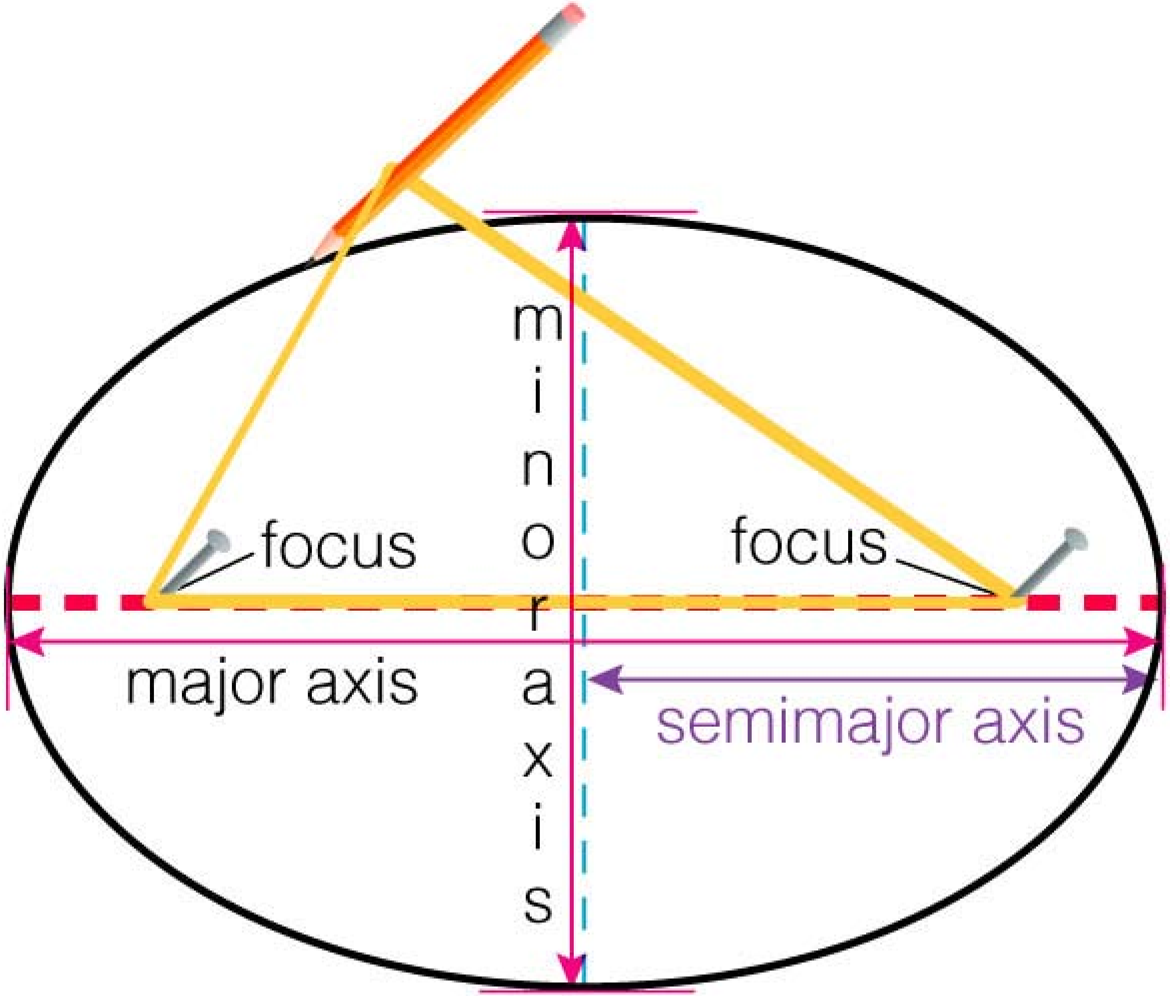
Johannes Kepler (1571-1630)

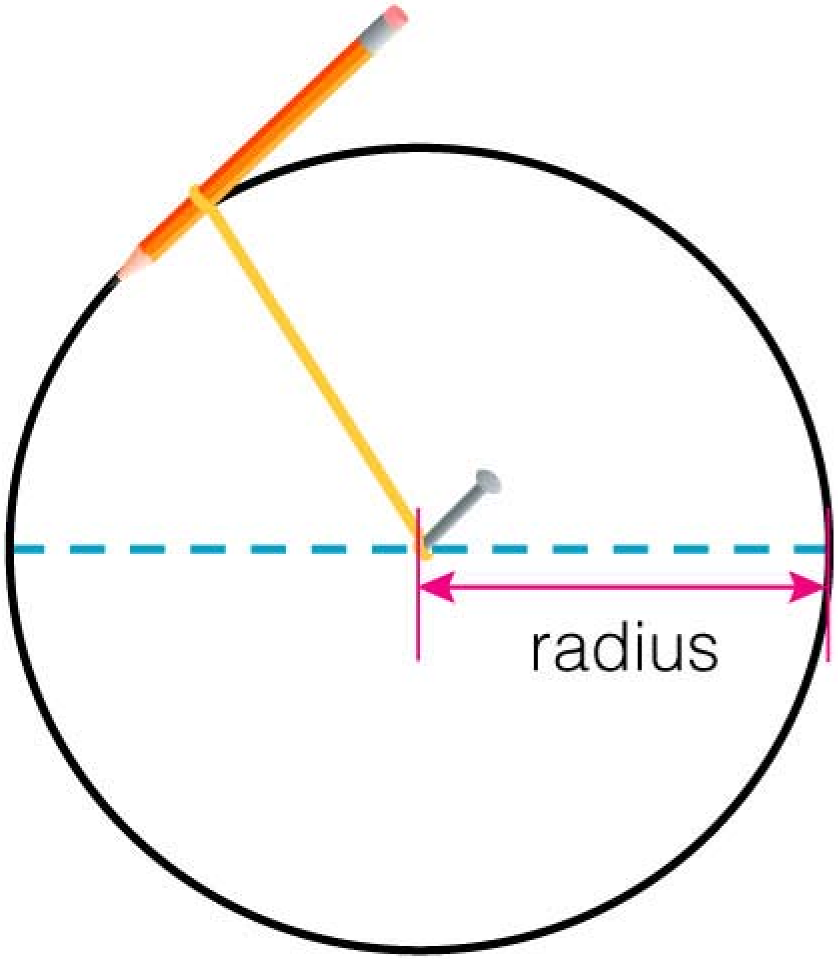
- He worked with Tycho’s data to find a model that worked. Mars was particularly difficult.
- Should he assume that there were some mistakes in Tycho’s data and adapt an existing model or should he trust the data and work towards a new model?
- He trusted Tycho’s data
- After years of effort, Kepler proposed three laws of planetary motion

Kepler's First Law

- The orbit of each planet around the Sun is an ellipse. The Sun is at one focus. Nothing is at the other focus.

- What is an ellipse? What is the focus of an ellipse?

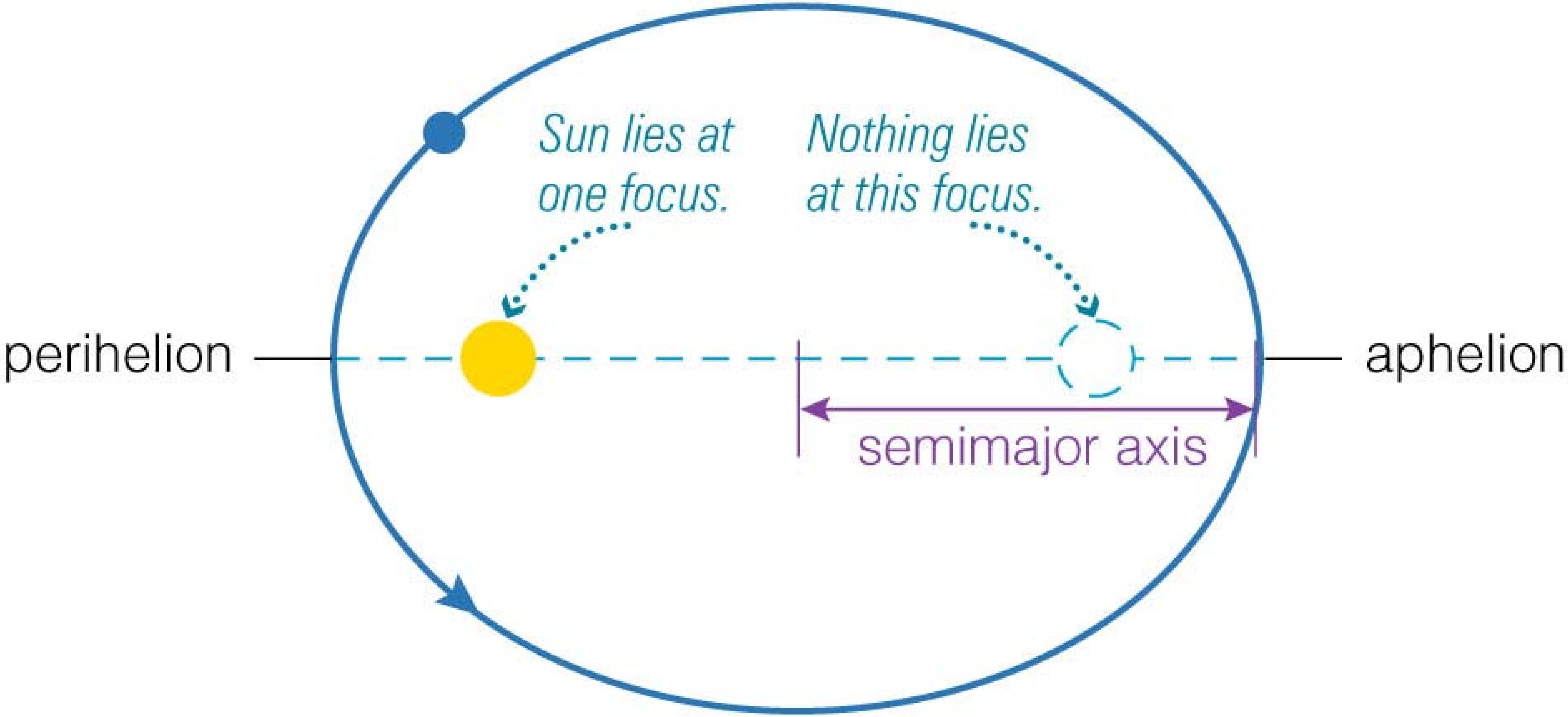

focus
focus
minor axis
major axis
semimajor axis

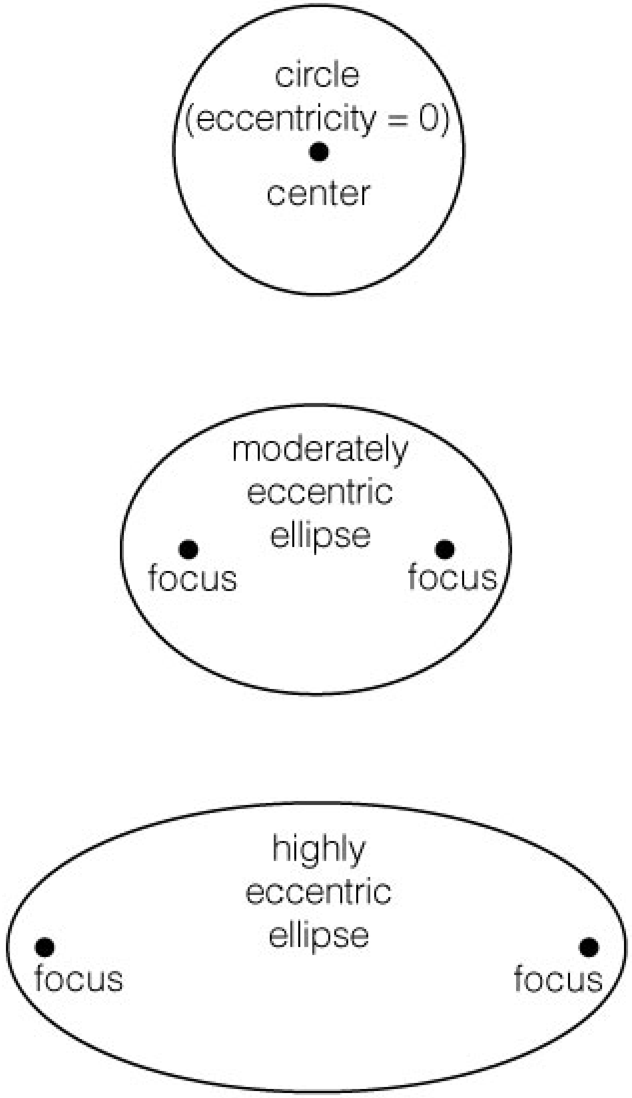


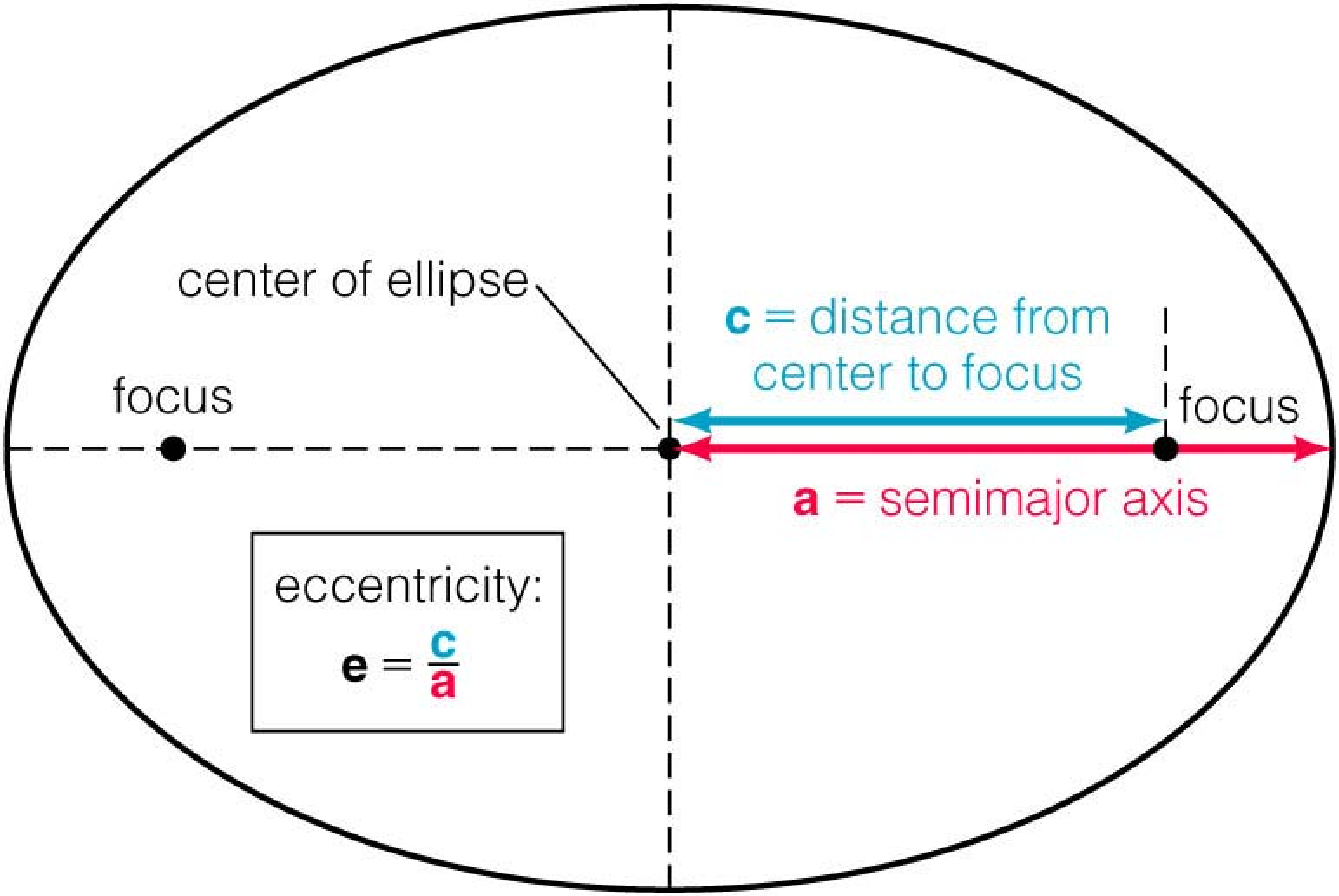
A circle is a special case of an ellipse

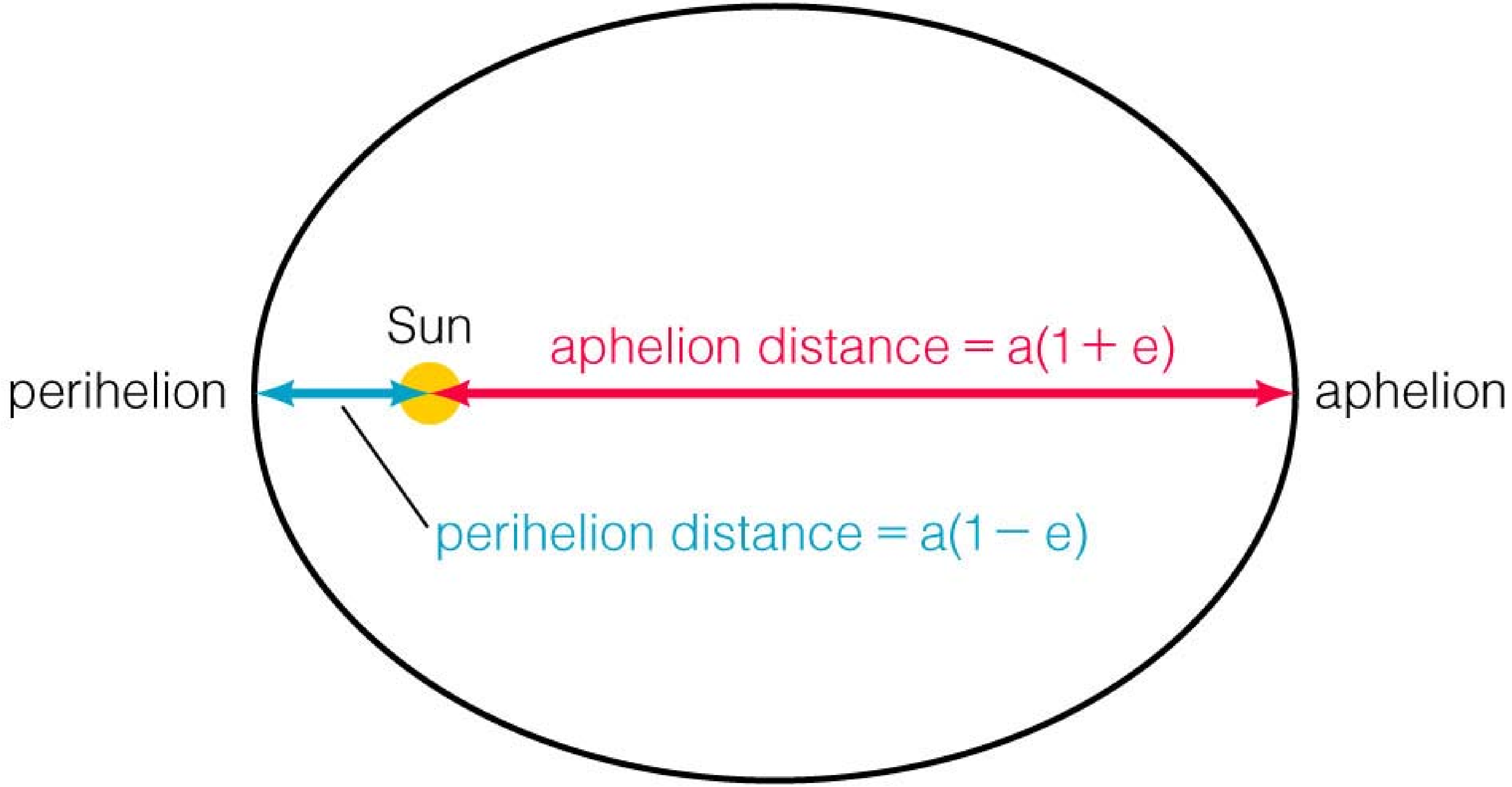
An ellipse has two foci
(foci = plural of focus)

If you move the two foci together,
then the ellipse becomes a circle


Sun lies at one focus.
Nothing lies at this focus.
perihelion
aphelion
semimajor axis


circle
(eccentricity = 0)
center
moderately
eccentric
ellipse
focus
focus
highly
eccentric
ellipse
focus
focus


center of ellipse
c = distance from center to focus
focus
focus
a = semimajor axis
eccentricity:
e = c/a


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

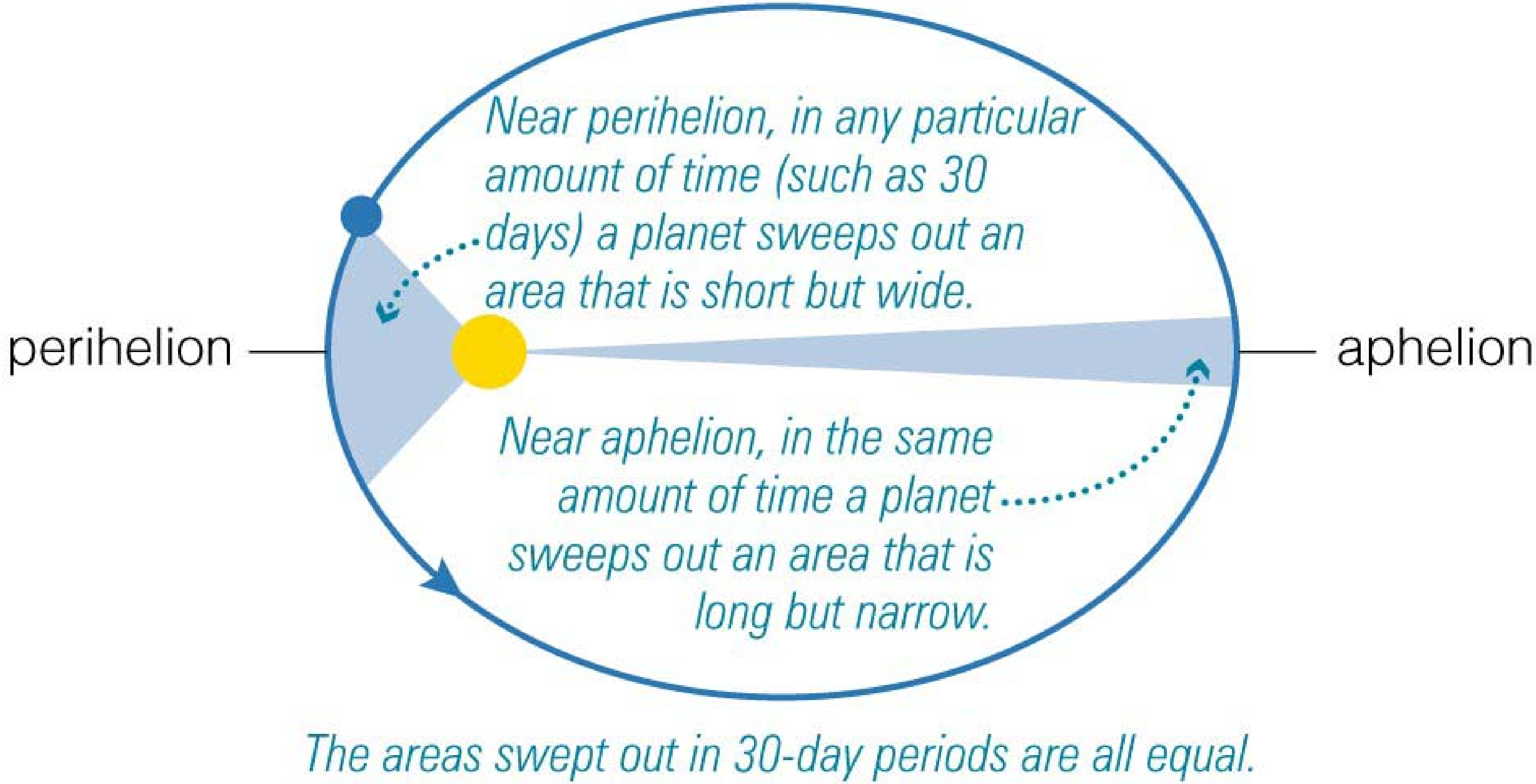
Ellipse Summary

- Perihelion = Closest to Sun
- Aphelion = Furthest from Sun
- Semi-major axis (a) = Average of Perihelion and Aphelion distances
- Perihelion = a(1-e)
- Aphelion = a(1+e)

- Circle has e=0

Kepler’s Second Law

- As a planet moves around its orbit, it sweeps out equal areas in equal times


Near perihelion, in any particular amount of time (such as 30 days) a planet sweeps out an area that is short but wide.
perihelion
aphelion
Near aphelion, in the same amount of time a planet sweeps out an area that is long but narrow.
The areas swept out in 30-day periods are all equal.

Kepler's Third Law

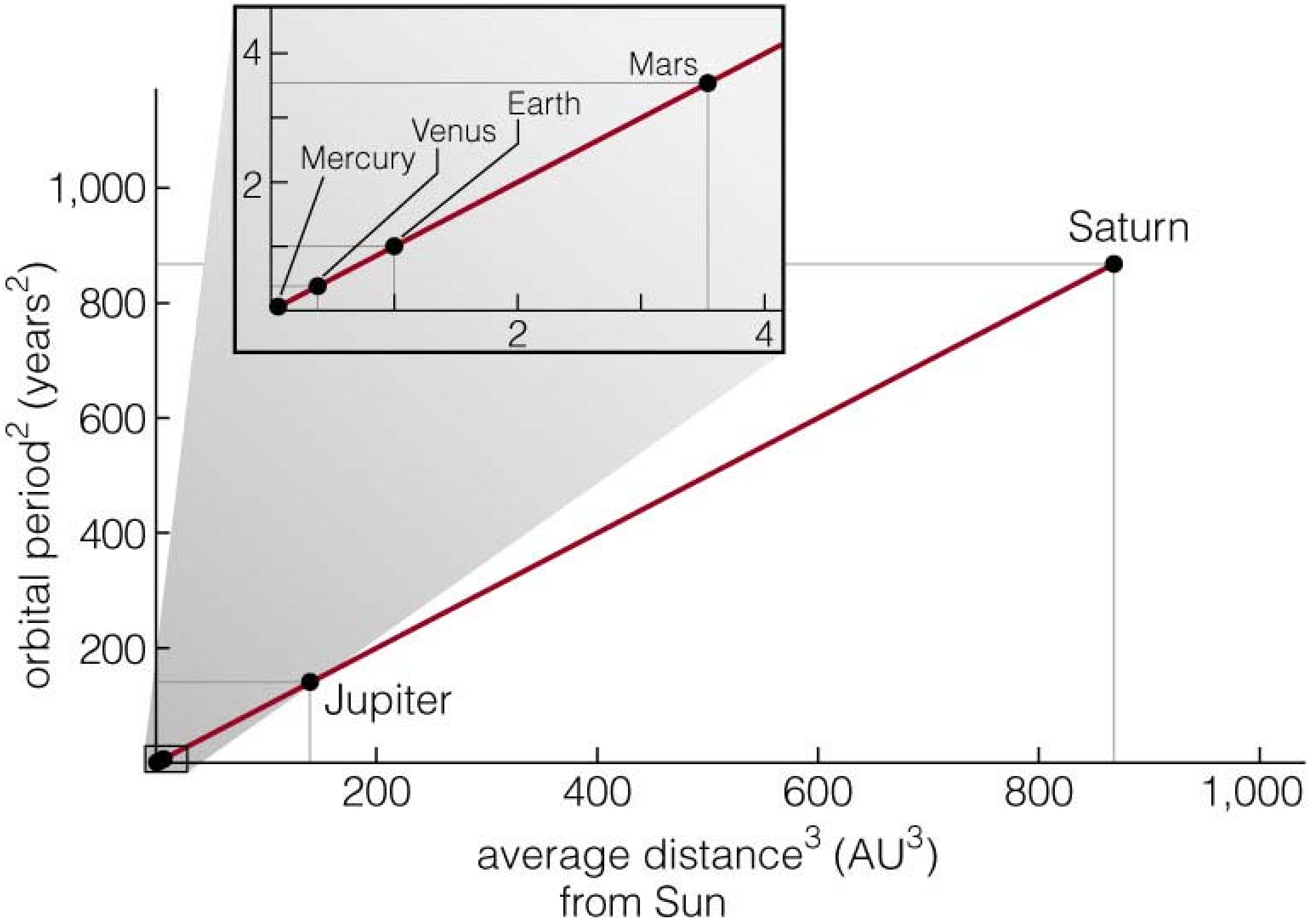
- $p^2 = a^3$

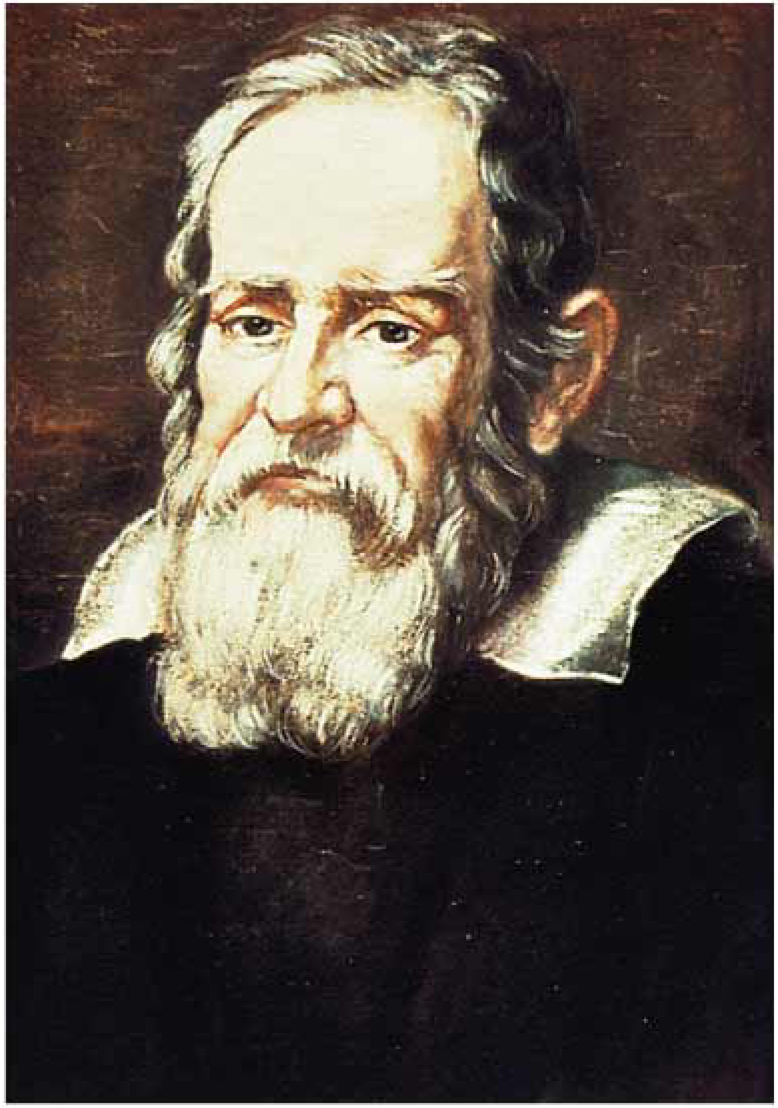
- p is the orbital period in years
- a is the semi-major axis in astronomical units (AU)
- The Earth is 1 AU from the Sun

STOP!

- Activity – Verify Kepler's Third Law

	a / AU	$(a/AU)^3$	p / yrs	$(p / yrs)^2$
Mercury	0.4	0.06	0.24	0.06
Venus	0.7	0.36	0.62	0.36
Earth	1.0	1.0	1.0	1.0
Mars	1.5	3.4	1.88	3.4


Mars
Earth
Venus
Mercury
4
2
2
4
1,000
800
600
400
200
orbital period^2 (years^2)
Saturn
Jupiter
200
400
600
800
1,000
average distance^3 (AU^3)
from Sun



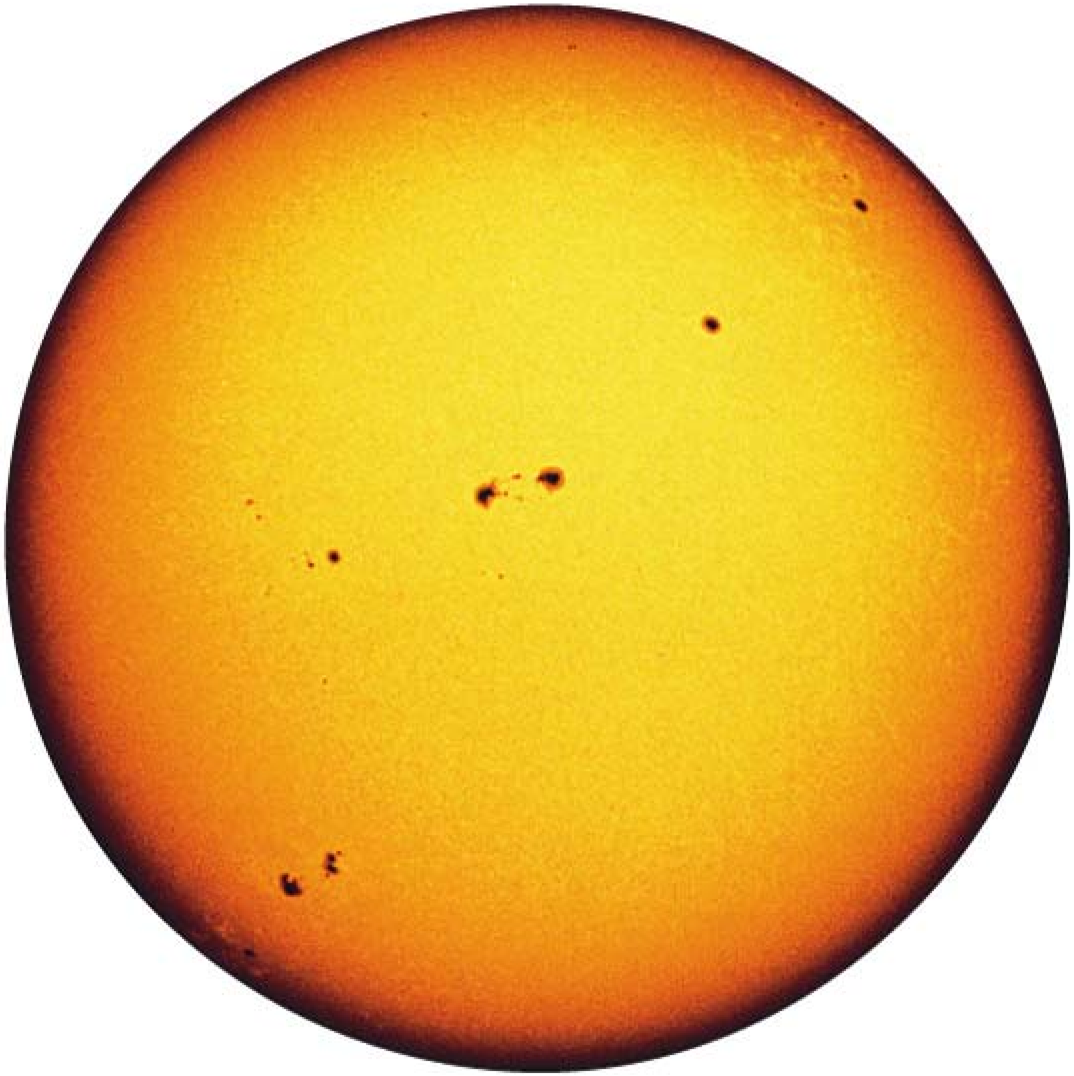
Galileo Galilei (1564-1642)

Galileo Galilei (1564-1642)

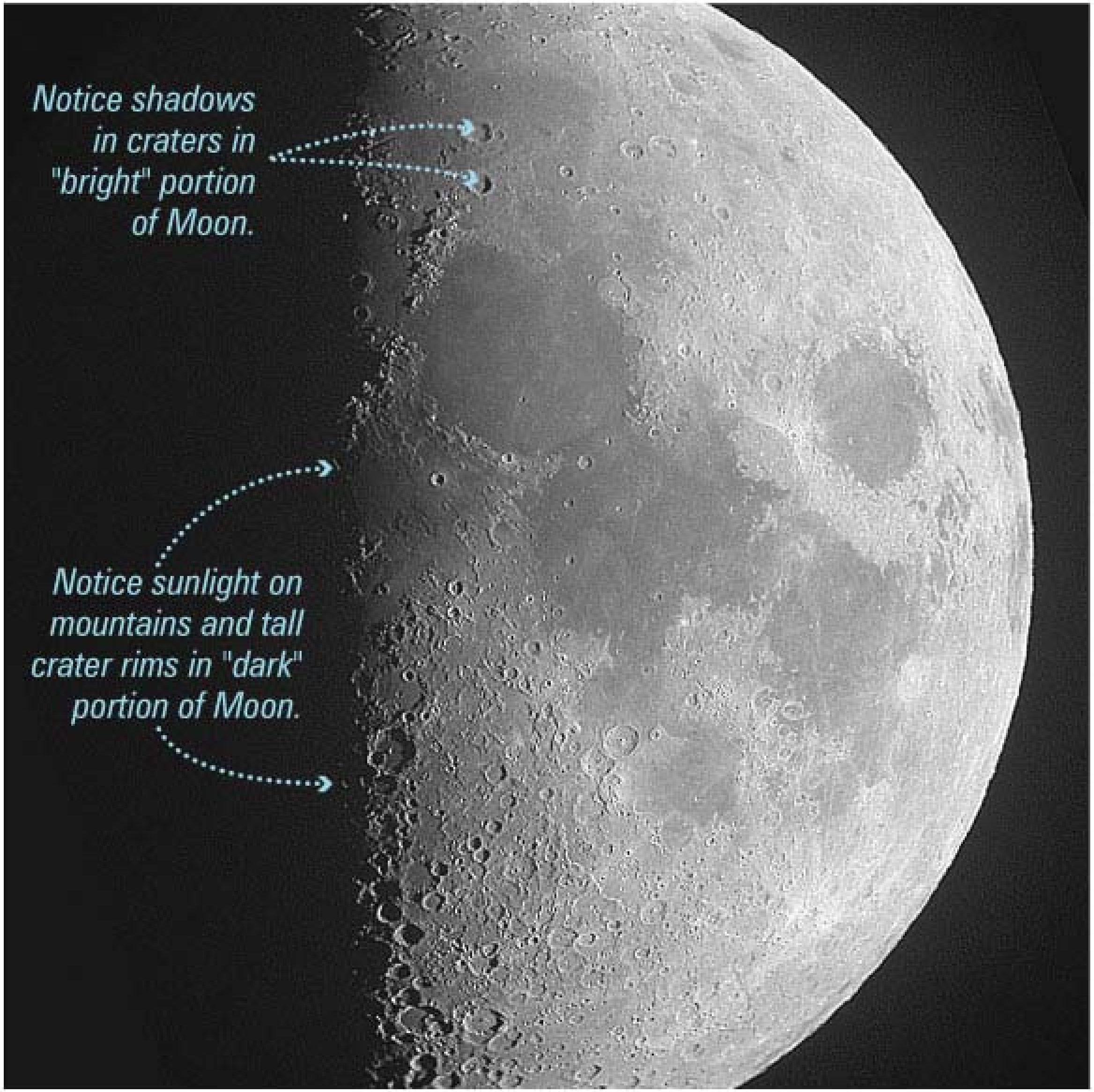
- Active at the same time as Kepler
- Used experiments to test and develop hypotheses
- His focus on experiments, rather than the Greek ideal of philosophical arguments, is the main characteristic of what we think of as science today
- He demolished the idea of the perfection of the heavens and made it possible for scientists to imagine physical laws applying equally here on Earth and in the heavens

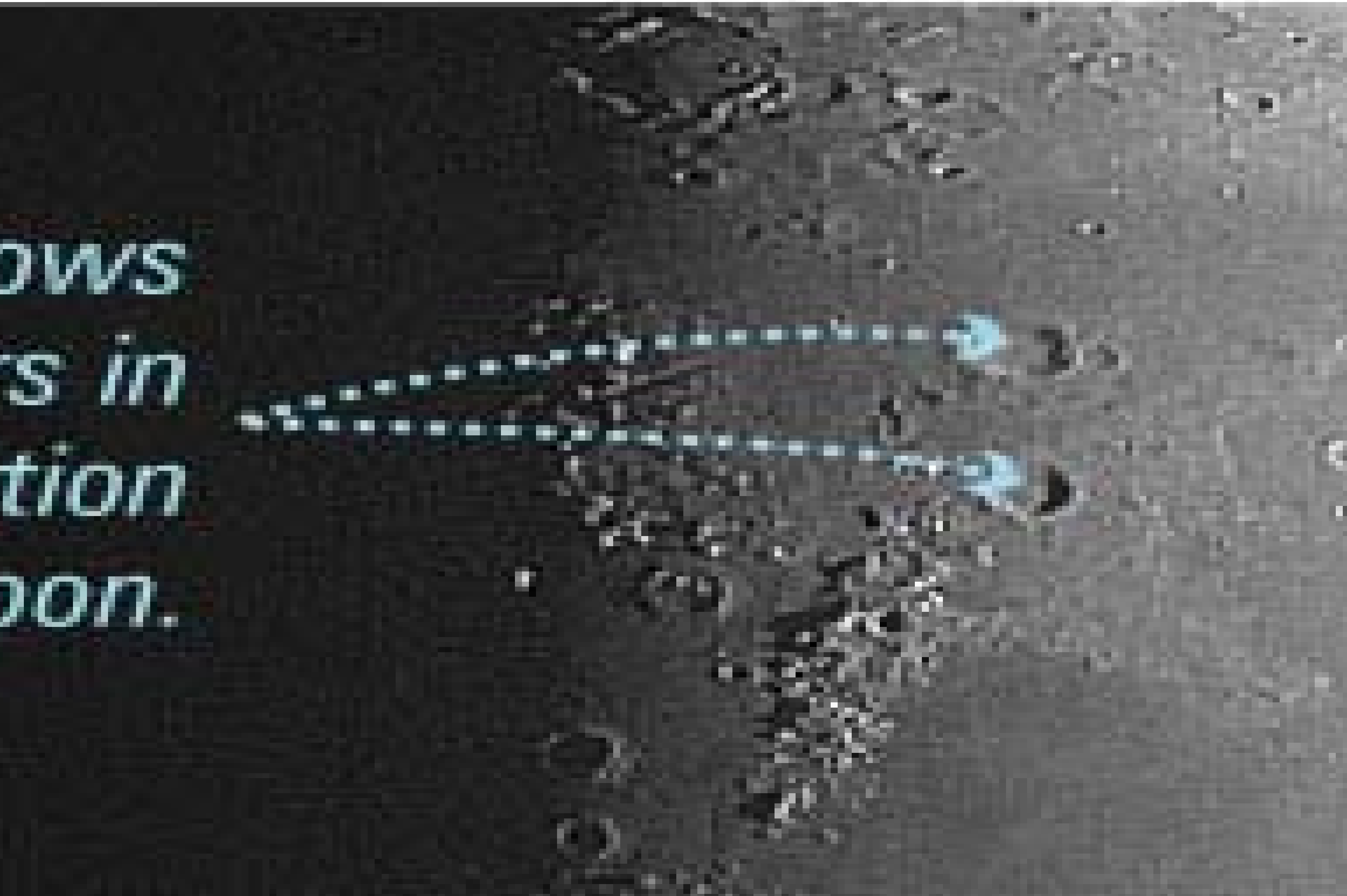
Galileo's Discoveries with the Telecope

- Imperfections on the Sun (sunspots)
- Mountains and valleys on the Moon
- Four moons orbiting Jupiter
- Phases of Venus (like the phases of the Moon)

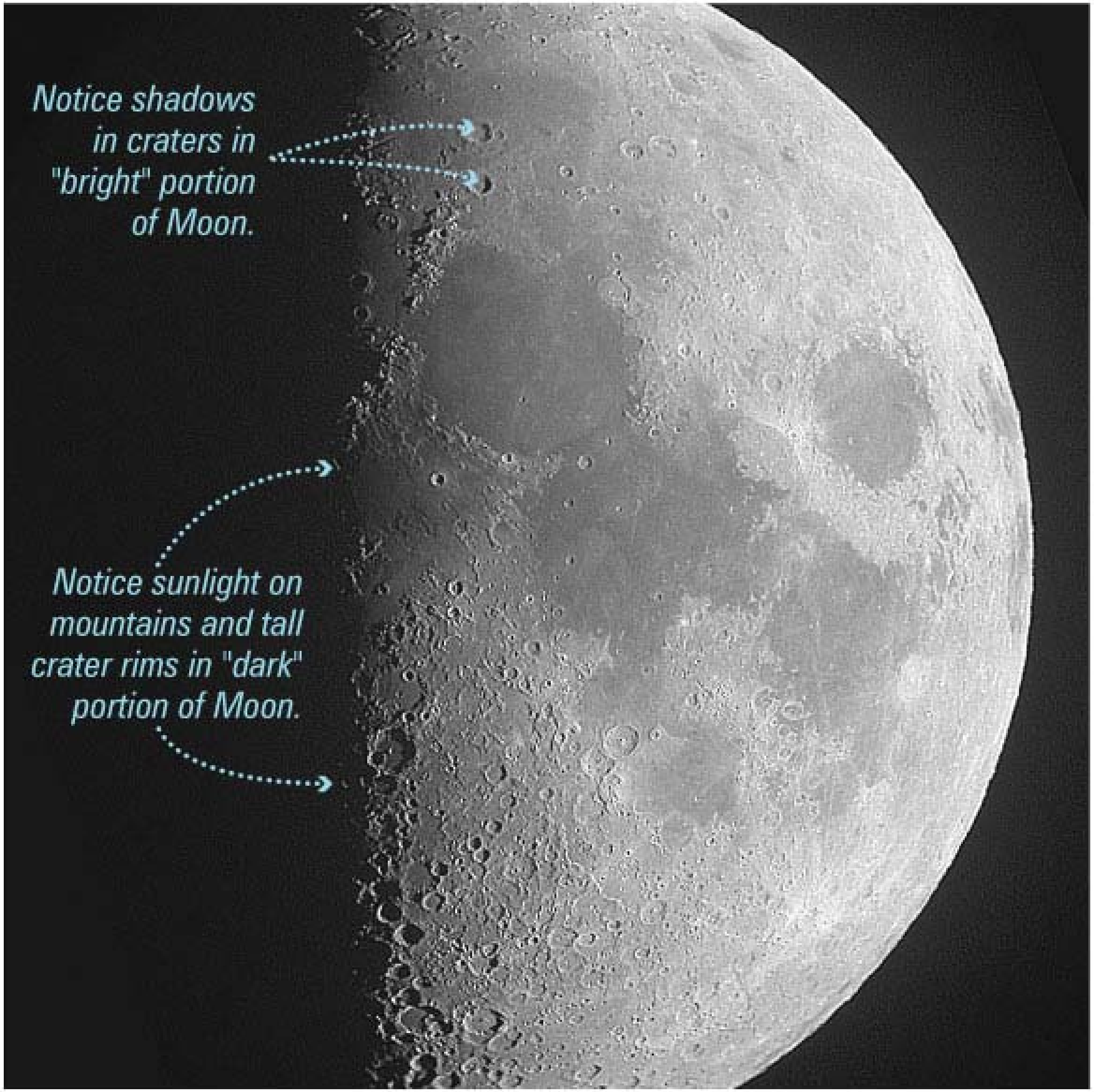


Sunspots


Notice shadows
in craters in
"bright" portion
of Moon.
Notice sunlight on
mountains and tall
crater rims in "dark"
portion of Moon.

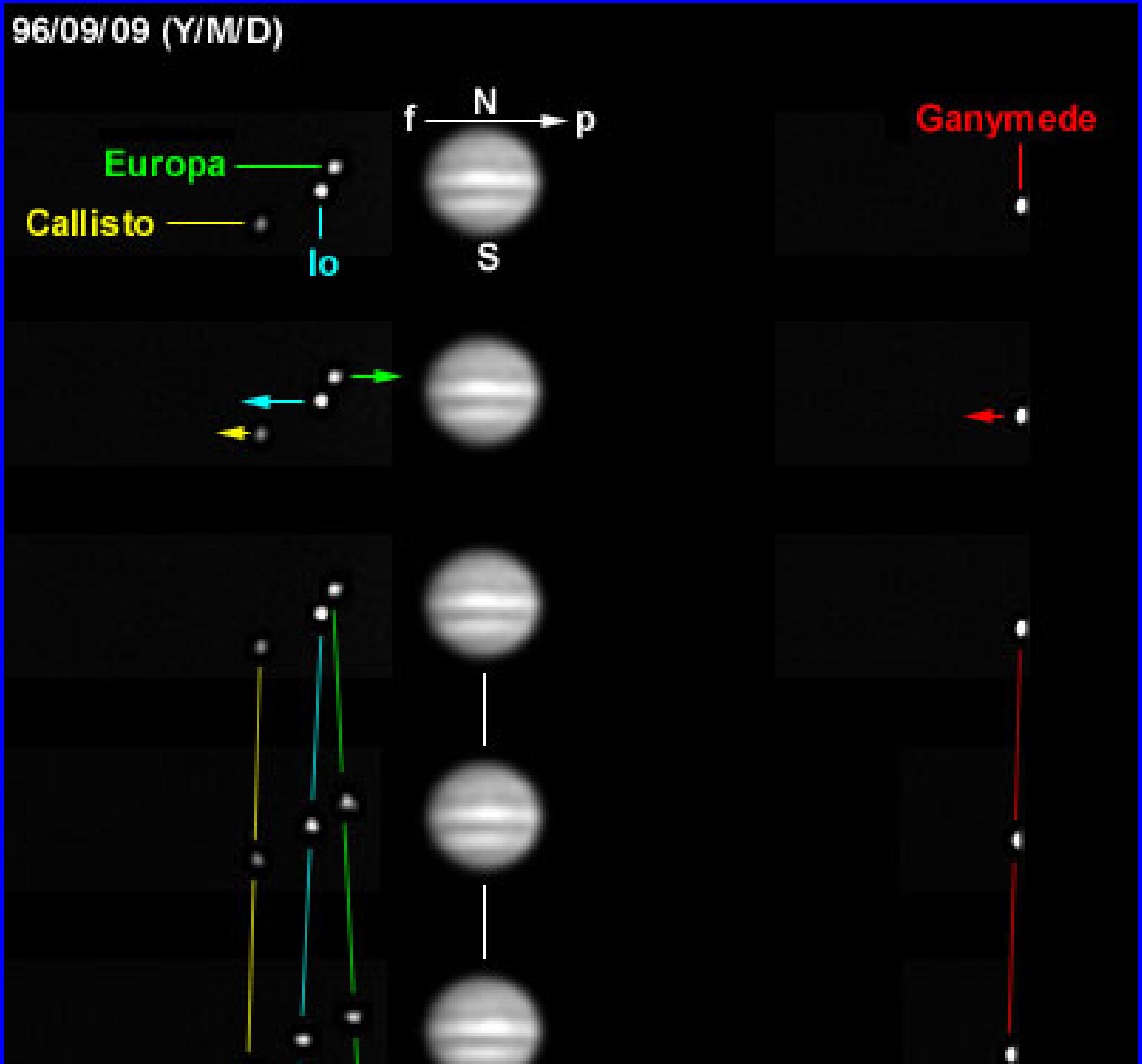

ows
s in
tion
oon.

ms in "dark"
on of Moon.


Notice shadows in craters in "bright" portion of Moon.
Notice sunlight on mountains and tall crater rims in "dark" portion of Moon.

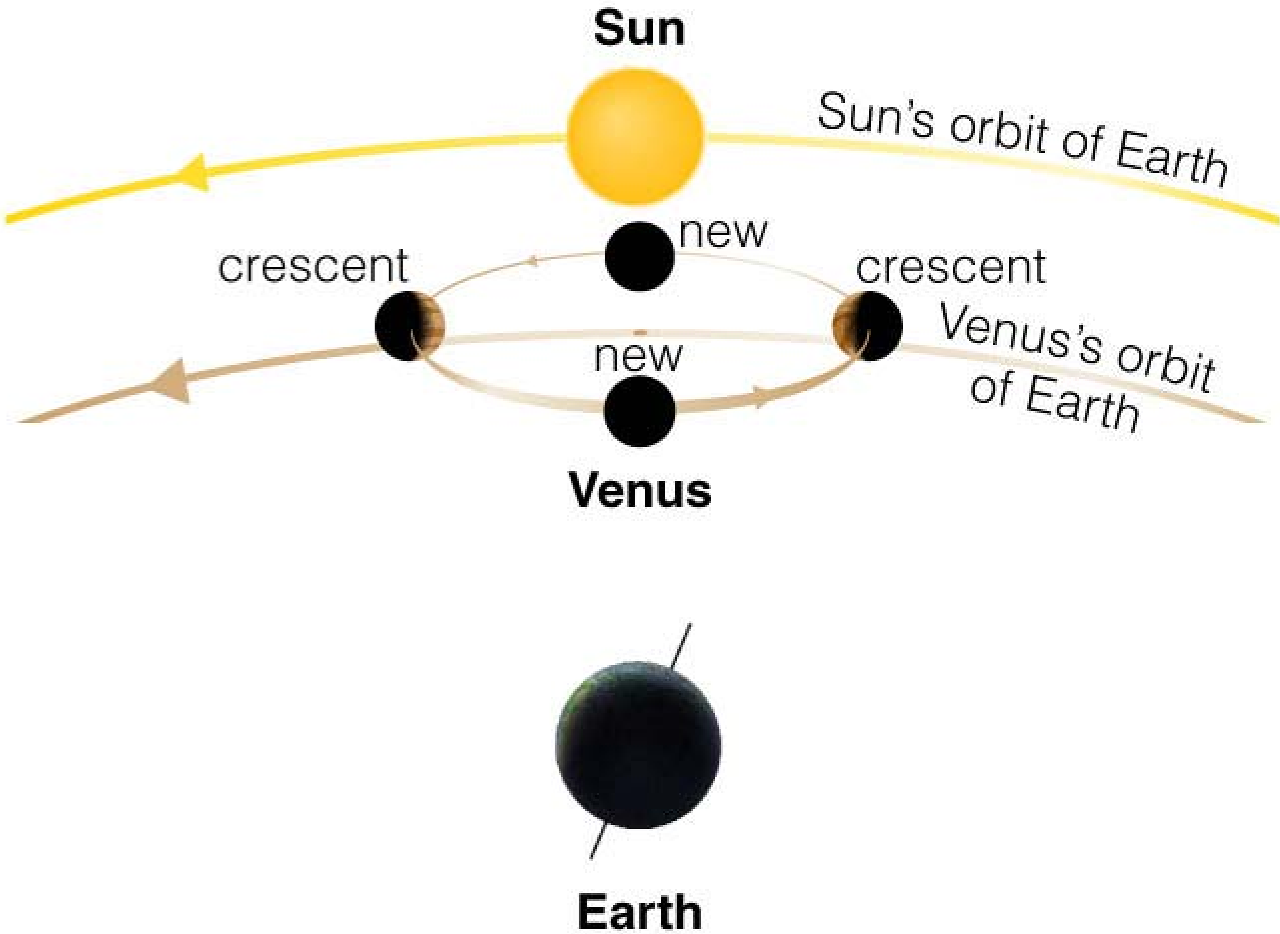
\Documents and Settings\Paul Withers\Desktop\teaching\imagesfromweb\anim_galilean.ht

Open anim_jup_satellites.gif in Windows Media Player

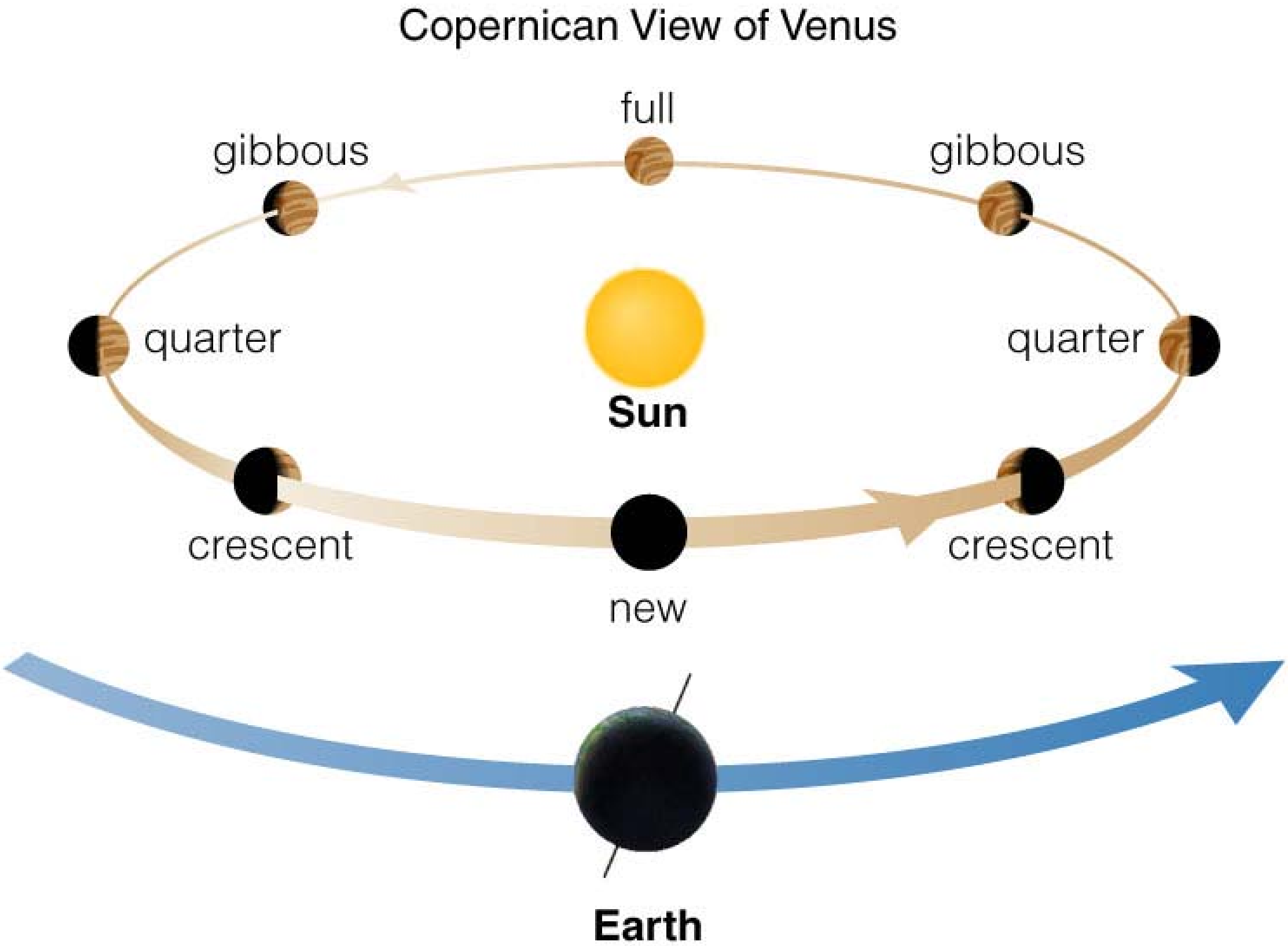


96/09/09 (Y/M/D)
f
N
p
S
Europa
Callisto
Io
Ganymede

Ptolemaic View of Venus



When Venus is close to Sun in the sky, Venus is always new, never full



When Venus is close to Sun in the sky, Venus is sometimes new, sometimes full

Goals for Learning

- Why are planets unusual in the night sky?
- What did people used to think about the motion of the Sun and Earth?
- Why did ideas about the motion of the Sun and Earth change?
- What laws describe the motion of planets?

Goals for Learning

- Why are planets unusual in the night sky?
  - They move against the background stars, sometimes going backwards in retrograde motion

Goals for Learning

- What did people used to think about the motion of the Sun and Earth?
  - In Ptolemy’s model, the Sun and everything else in the solar system orbit around Earth with paths that are described by circles-upon-circles
  - Objects in the heavens were thought to be perfect and unchanging, unlike things on Earth

Goals for Learning

- Why did ideas about the motion of the Sun and Earth change?
  - Predictions from Ptolemy's model (Sun goes around Earth) weren't as good as predictions made by Kepler (Earth goes around Sun)
  - 4 moons orbit Jupiter
  - Venus shows phases inconsistent with Sun going around Earth

Goals for Learning

- What laws describe the motion of planets?
  - Kepler's laws
  - Planets orbit in ellipses with the Sun at one focus
  - Equal areas in equal time
  - $p^2 = a^3$

Picture References

- www.astrosurf.com/cidadao/animations
- http://www.seds.org/~spider/spider/Vars/sn1572.html