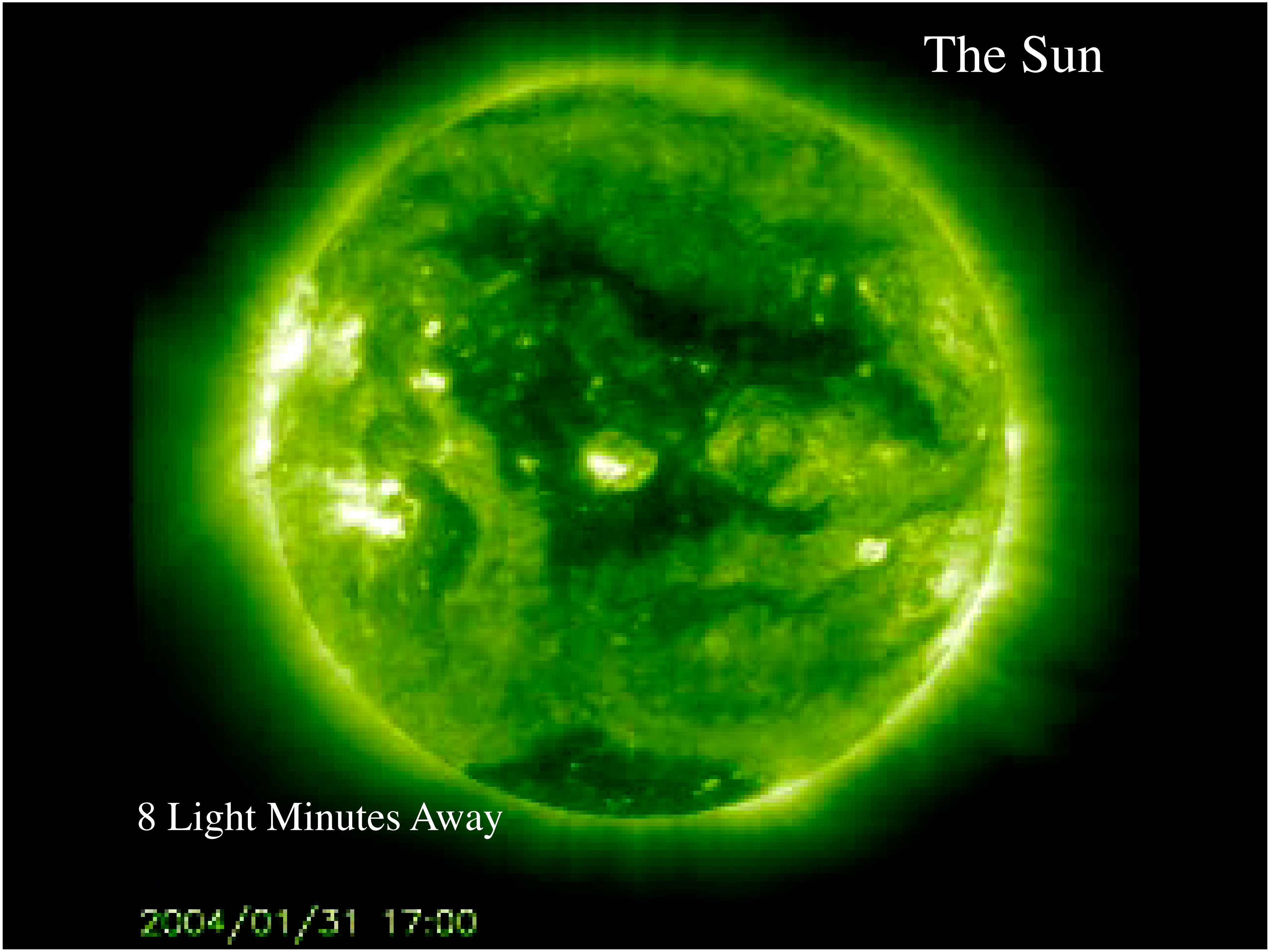
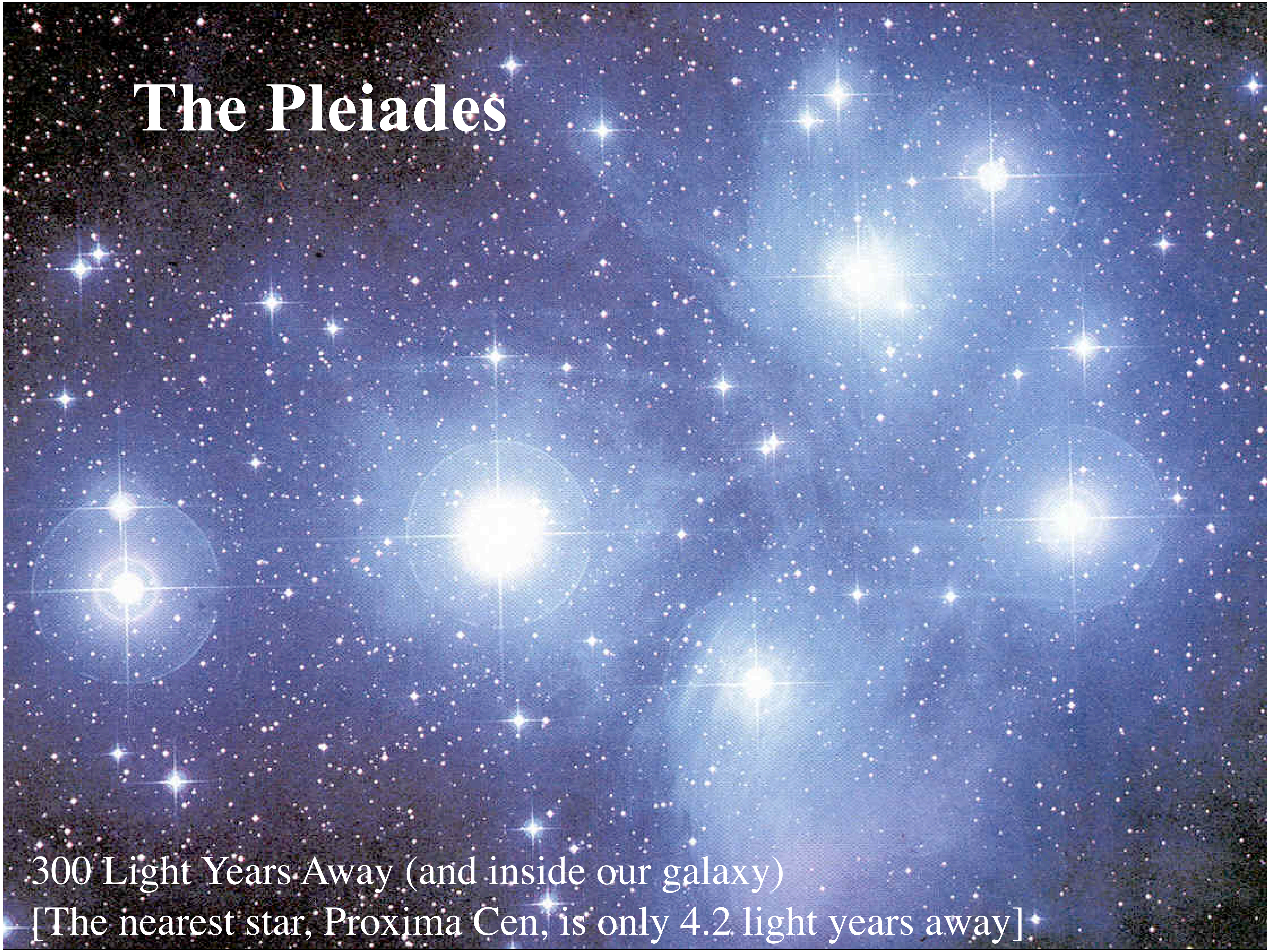
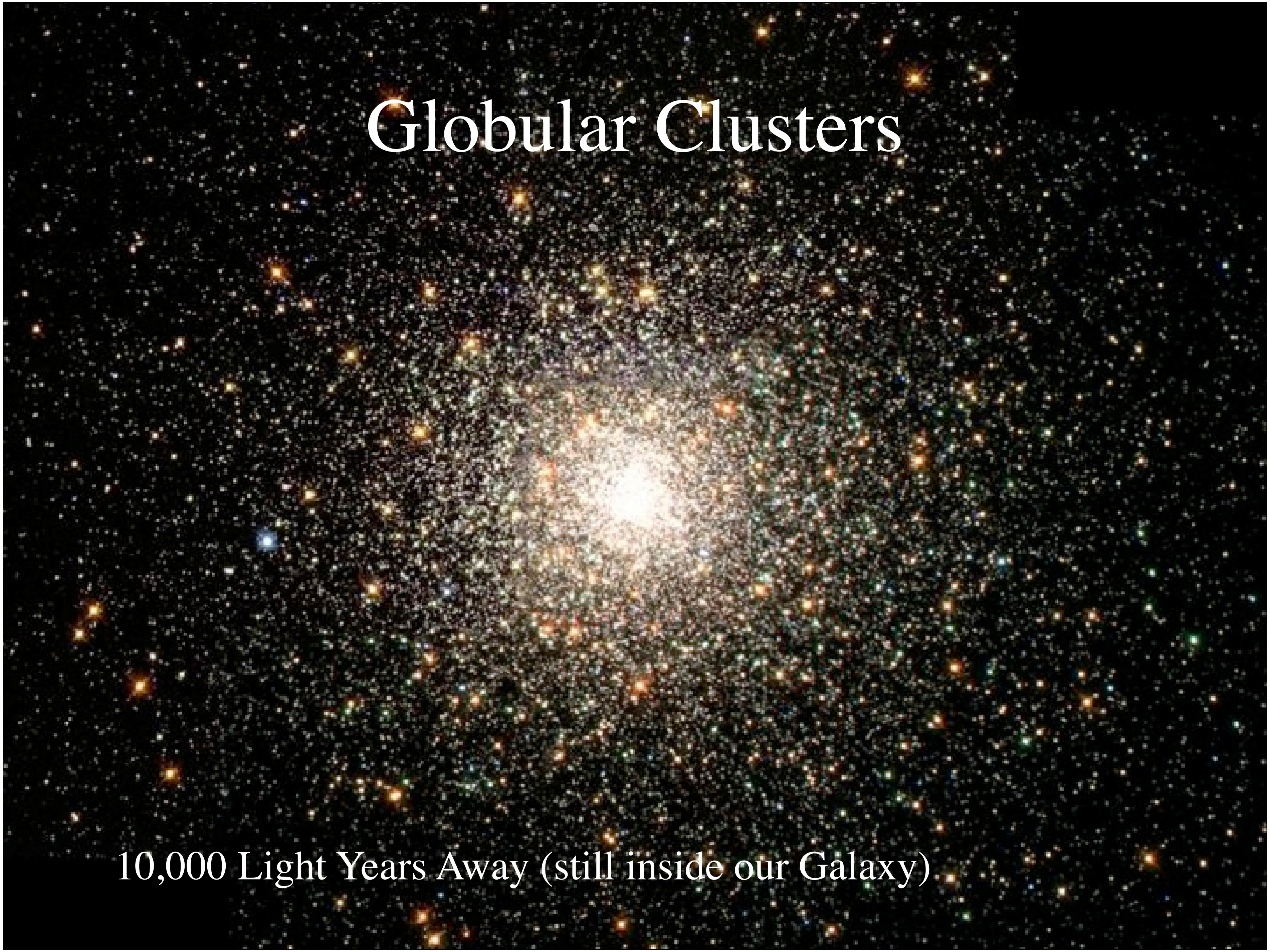
How High Is the Sky?

Bob Rutledge


The Sun
8 Light Minutes Away
2004/01/31 17:00


The Pleiades
300 Light Years Away (and inside our galaxy)
[The nearest star, Proxima Cen, is only 4.2 light years away]

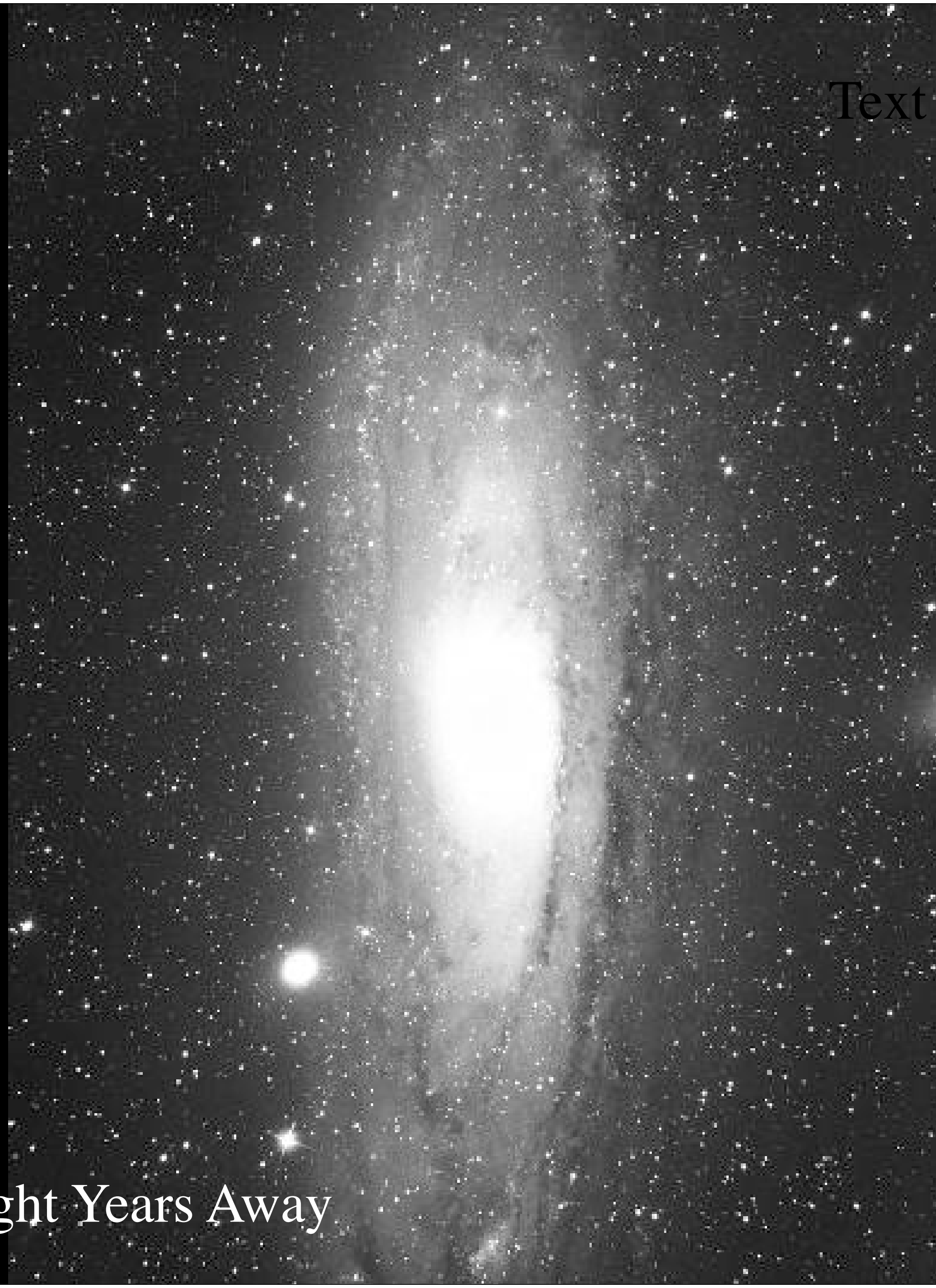
Globular Clusters



10,000 Light Years Away (still inside our Galaxy)

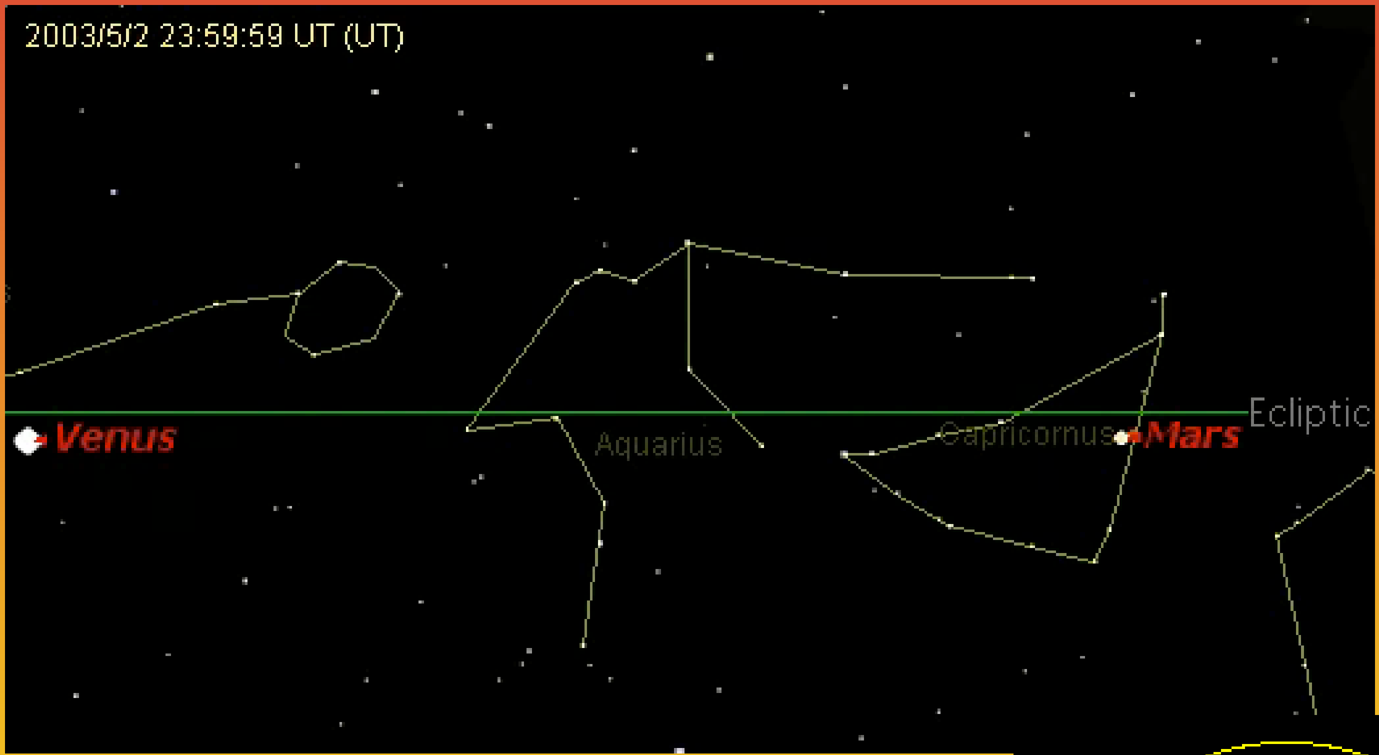

Not Our Galaxy,
but looks a lot like it!
Us
24,000 Light Years


100 Million Light Years Away



2.4 Million Light Years Away

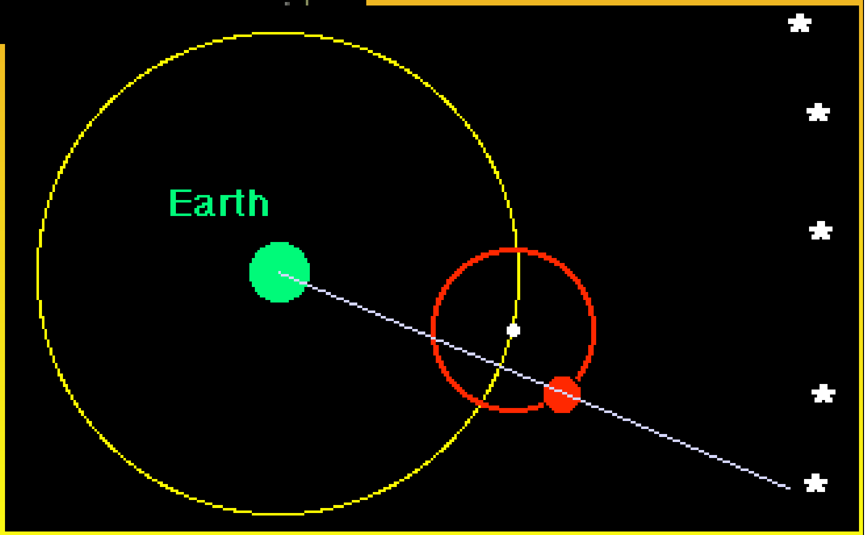
The “Wanderers” (Planets) and Epicycles



Source: exporatorium.edu

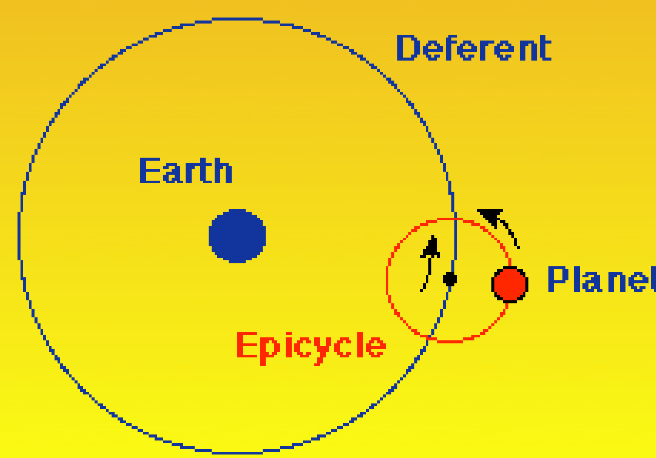
This is what Mars looks like as you track its motion across the sky!

The Ptolemaic system was based on uniform motion (constant velocity) around perfect circles.

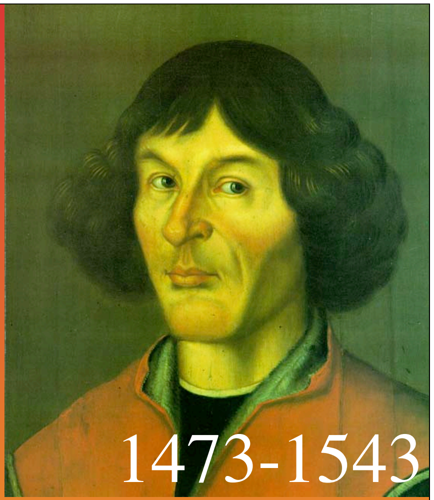


The Ptolemaic Universe (140 AD): The Earth is at the Center

- The earth was the center of the Universe. It did not move or rotate.
- The stars were on a distant, uniformly rotating sphere.
- The planets ("wanderers") and the sun were each on spheres which rotated about the earth.
- The planets move in "epicycles" -- additional rotations about a fixed point on the sphere as it moved around the earth.

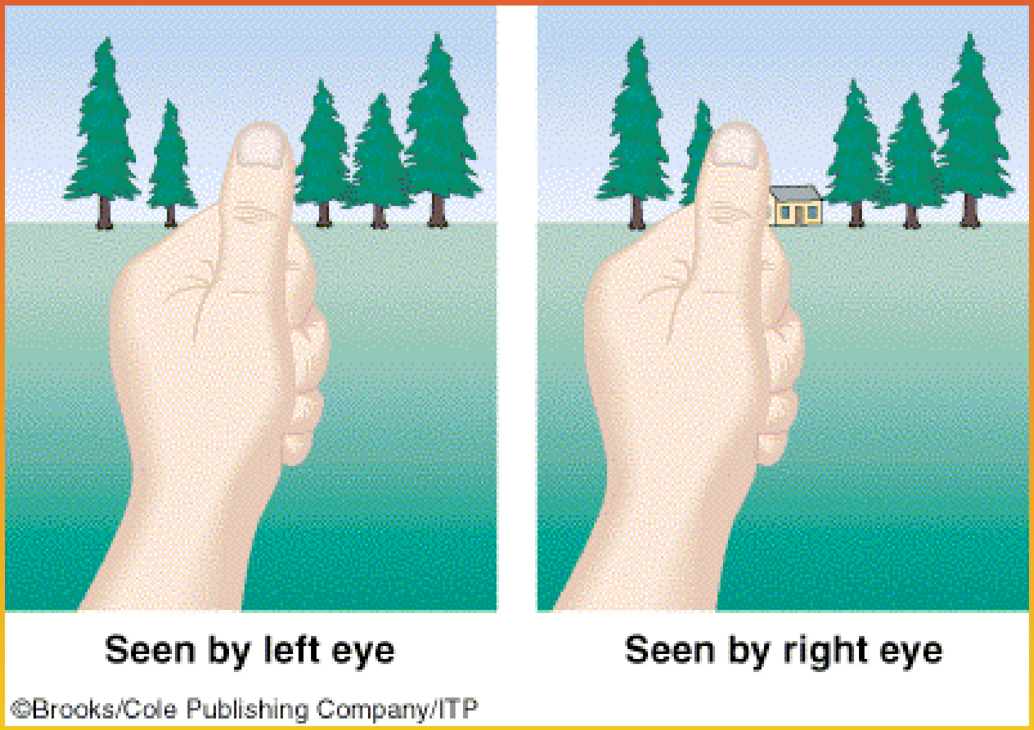


The Copernican Revolution (1543)



- Copernicus suggested: everything moves in circles around the sun.
- It was not embraced; it still required epicycles, and there
- Also: if the earth is moving, why do we not see the stars shift in parallax?

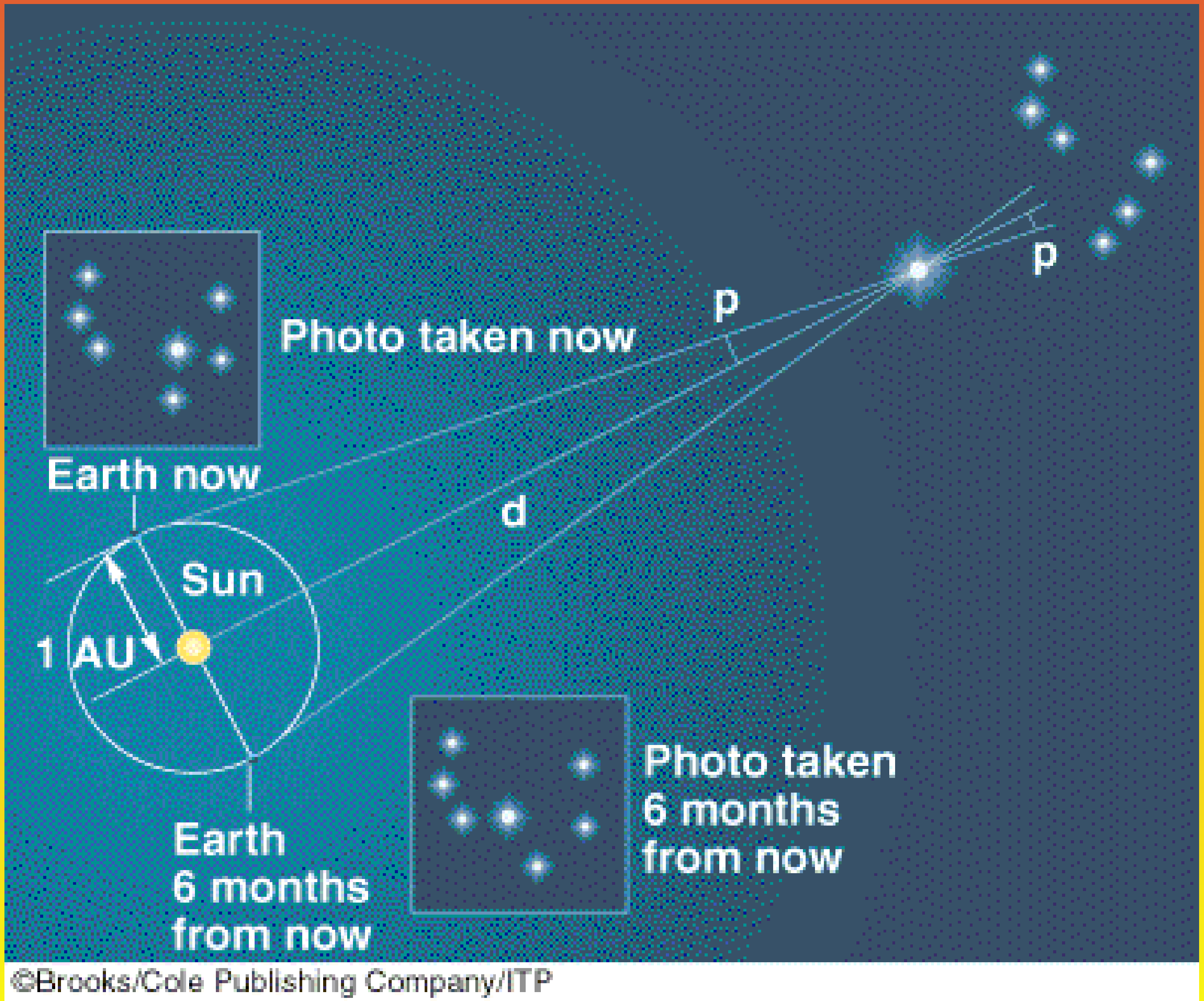
What is Parallax?



Parallax is the apparent "shift" of a foreground object relative to background objects, due to observing from two different positions.

Parallax is the first step to measuring the distances to everything in the universe - nearby planets, nearby stars.

Parallax (cont).

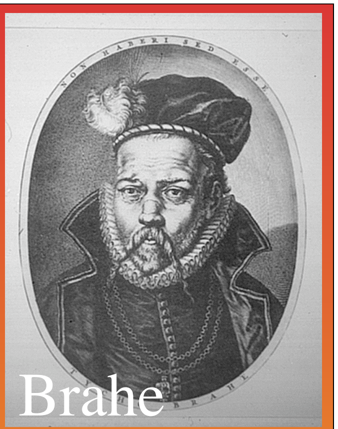


Parallax is used to measure the distance to nearby stars in units of Earth-Sun Distance (called "Astronomical Units" or AUs).

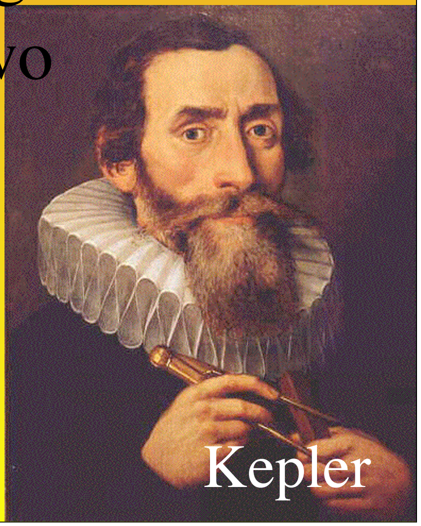
Parallax (cont).

- At Copernicus' time, no parallax had been measured, with a limit of <1 arcmin. What limit does this place on the distance to the stars?
  - Convert 1 arcmin to radians (2.9×10^{-4} radians)
  - D > 1 AU/ 2.9×10^{-4} radians = 3400 AU. That's a big universe!
  - But how big is 1 AU? They didn't know.

The Copernican Revolution (cont.)



- Tycho Brahe (1546-1601) made careful observations of the positions of the planets as they moved through the sky.
- Brahe's student Johannes Kepler, following Brahe's death, analyzed these observations, and found the planet's orbits can be described as moving through ellipses (not circles) with the sun at one of the two focii.



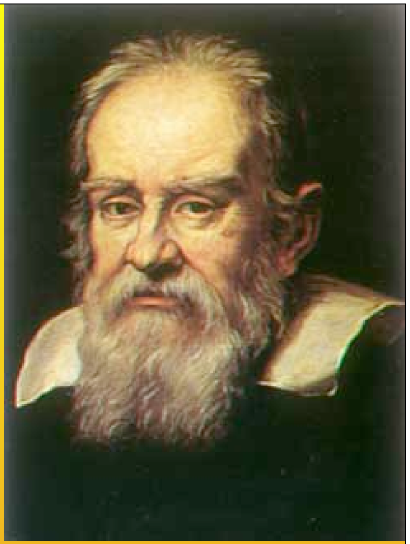
Kepler’s Three Laws (1609 and 1619)

1. The planets move about the Sun, tracing ellipses.
2. The orbits sweep out an equal area in equal amounts of time.
3. The amount of time (P) it takes for a planet to go around the sun is related to its distance from the sun (a) as:

$$P^2 \propto a^3$$

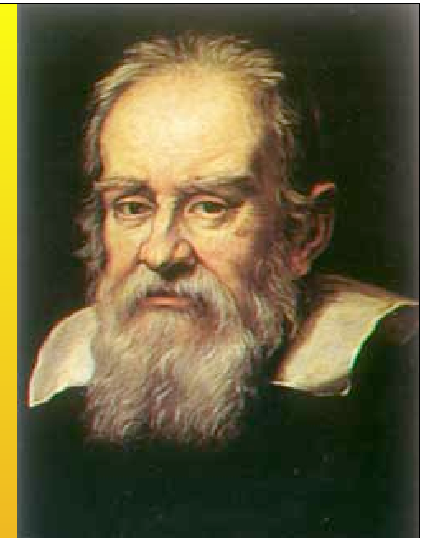
First Astronomer to successfully predict a Transit of Venus! (1631)

Galileo Galilei (1564-1642)



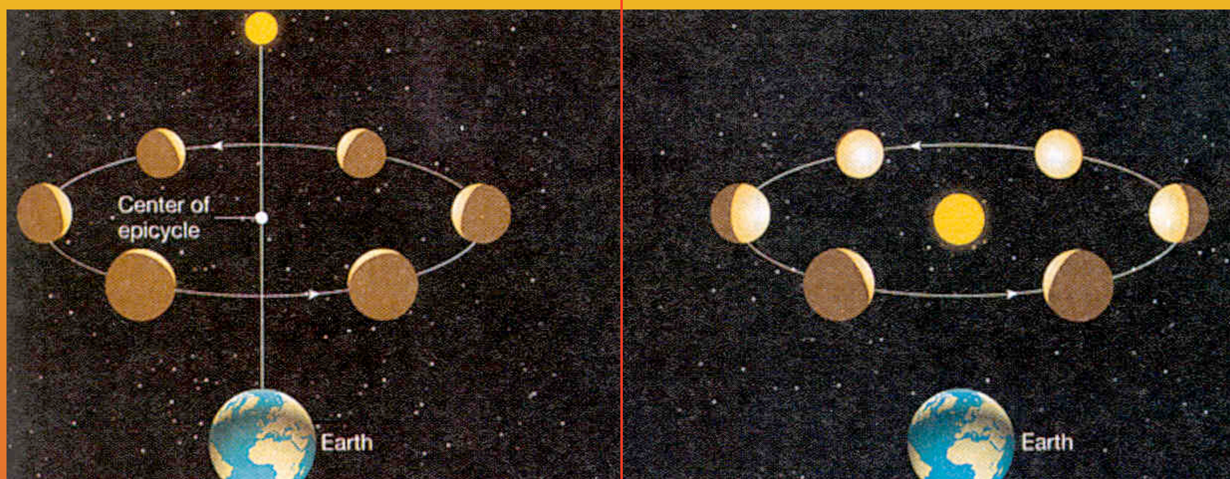
- The telescope was first discovered, not by Galileo, but by Dutch eyeglass makers, to magnify distant objects.
- Immediately put to *VERY IMPORTANT USE*.
- Galileo turned the telescope toward the heavens.

What Galileo did with the Telescope (1610)



Ptolemy predicts..

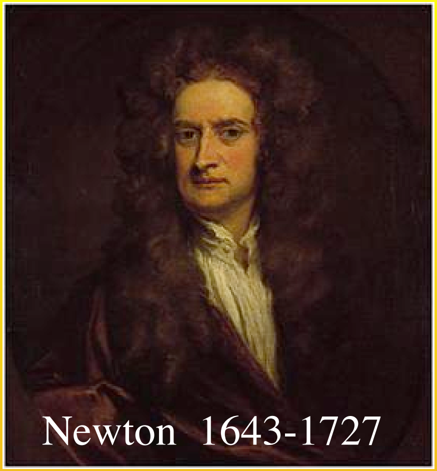
Copernicus predicts, and Galileo saw!



This observation ended the idea geo-centric universe of Ptolemy.

The Sun is the Center of the Solar System!

Newton's Law of Gravitation
(1687)

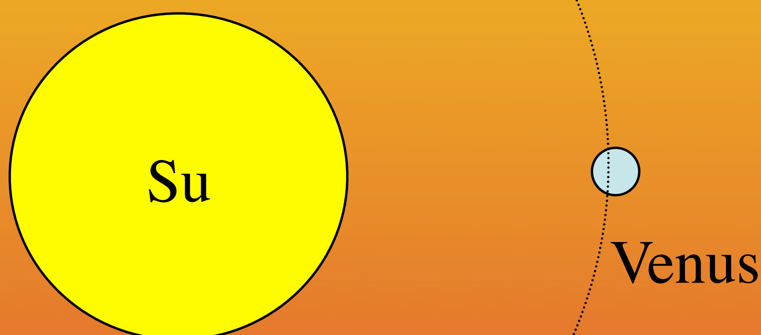


$$F = \frac{GMm}{r^2}$$

From Newton's Law of Gravitation, Newton's Second Law of Motion, you can derive Kepler's Third Law!

$$P^2 \propto a^3$$

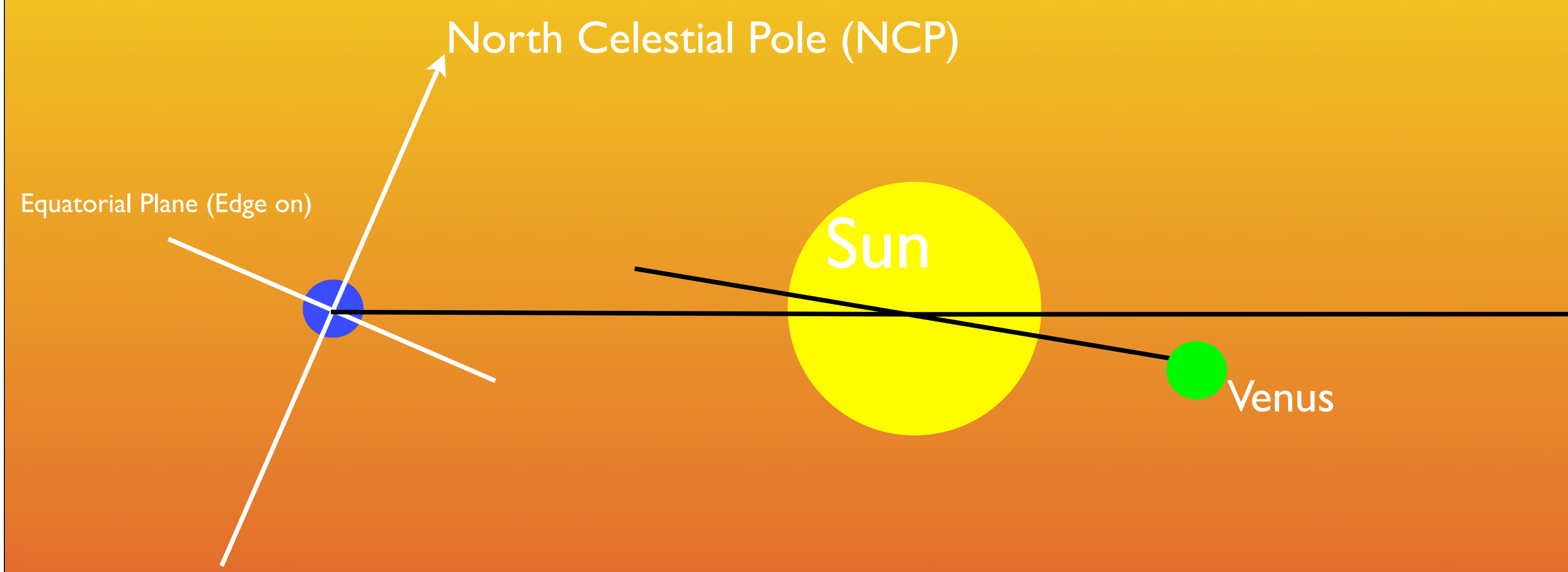
The Accurate Measurement of the Astronomical Unit (Earth-Sun Distance)

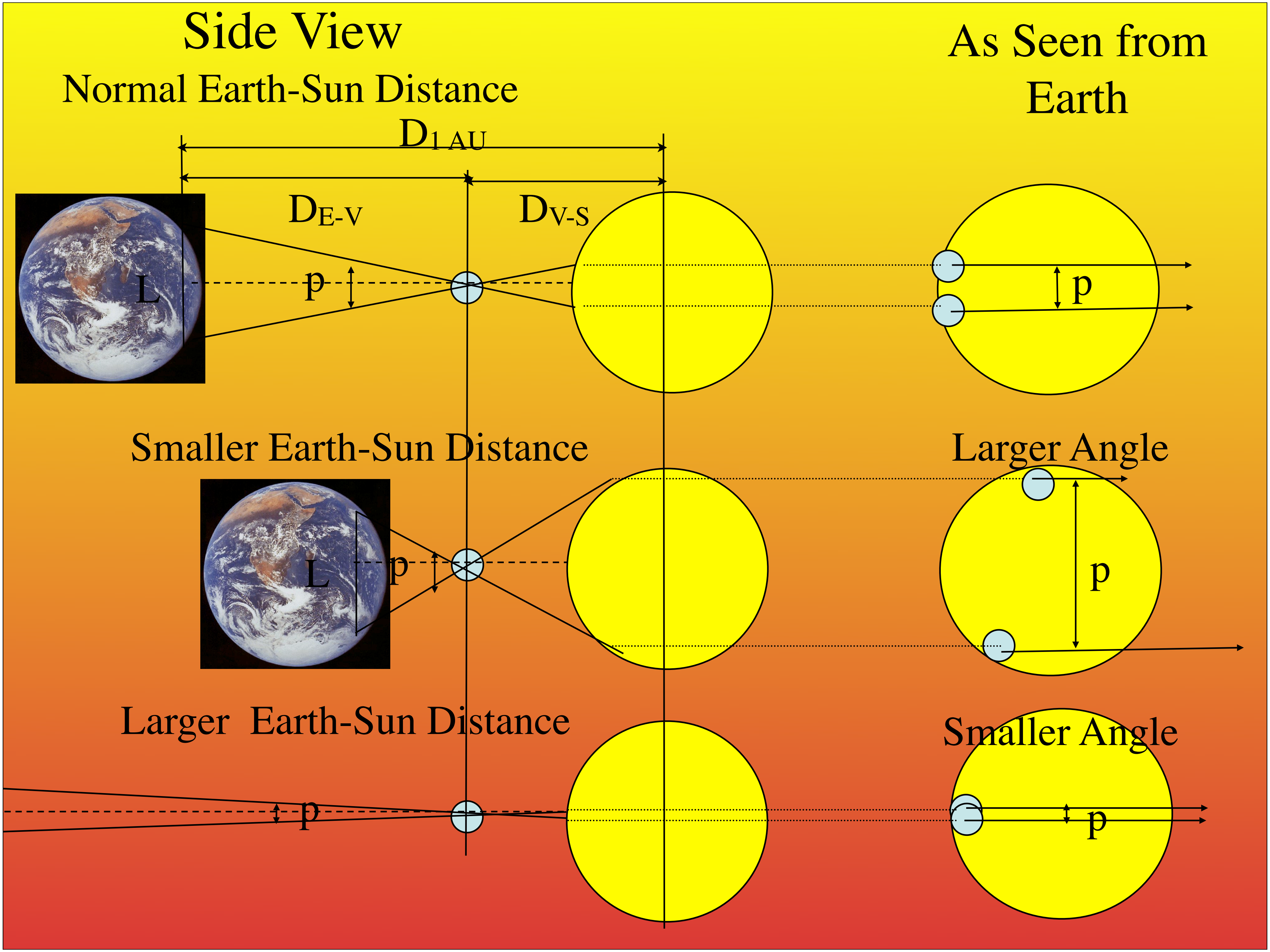


- Edmund Halley pointed out (1716) that Venus, viewed from Earth, sometimes moves across the sun -- a “transit”.

- Viewed from two different latitudes, the angles of transit can be measured.

Transits of Venus are Rare, because the orbit of Venus is not in the same plane as the orbit of earth.




Side View
Normal Earth-Sun Distance
D1 AU
DE-V
DV-S
L
p
As Seen from Earth
p
Smaller Earth-Sun Distance
L
p
Larger Angle
p
Larger Earth-Sun Distance
p
Smaller Angle
p

Coming Transit of Venus

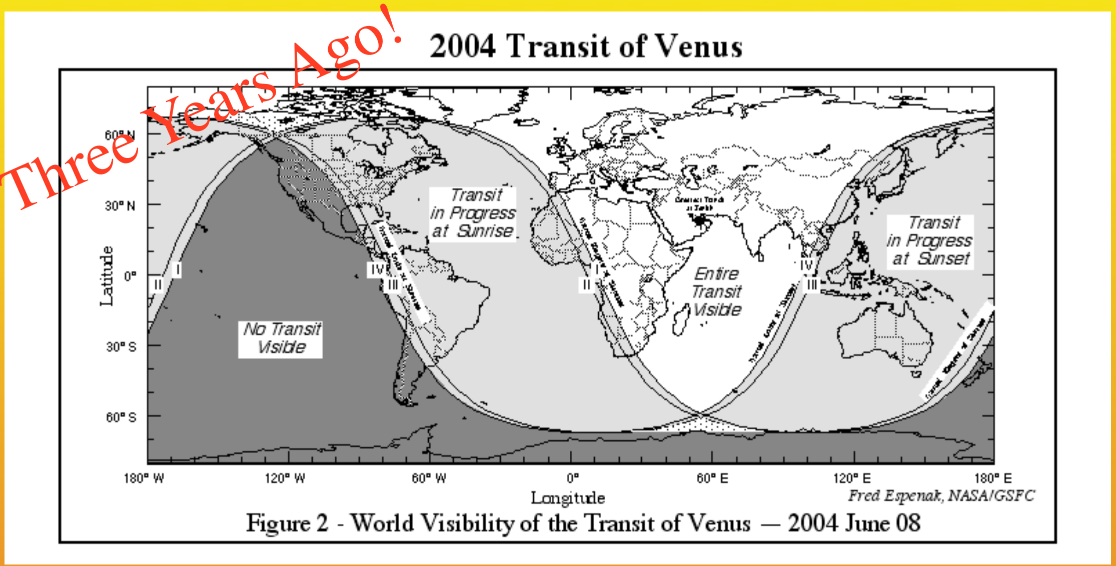


Figure 2 - World Visibility of the Transit of Venus — 2004 June 08

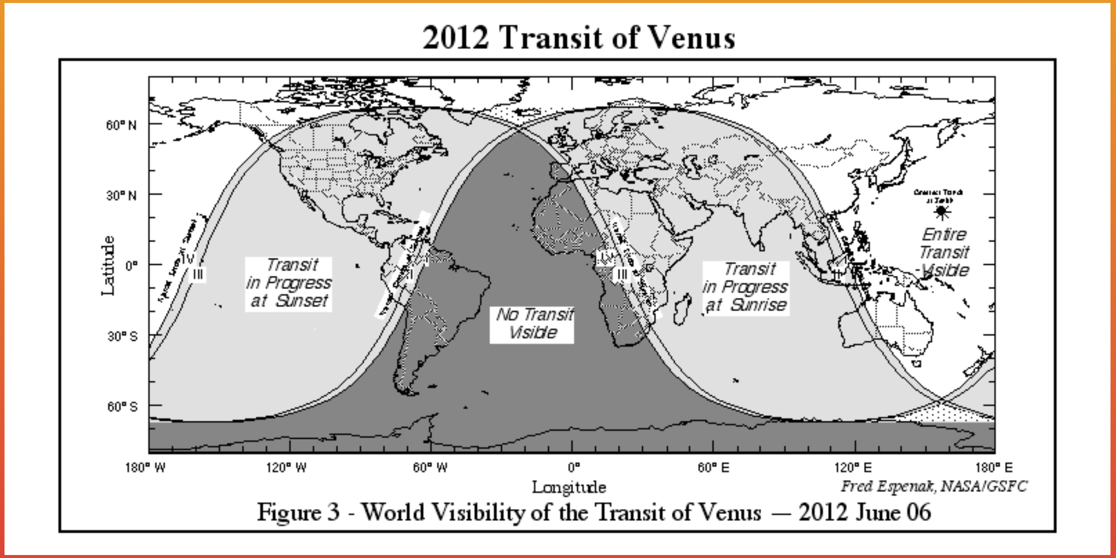


Figure 3 - World Visibility of the Transit of Venus — 2012 June 06

Transits since

Halley's Proposal:

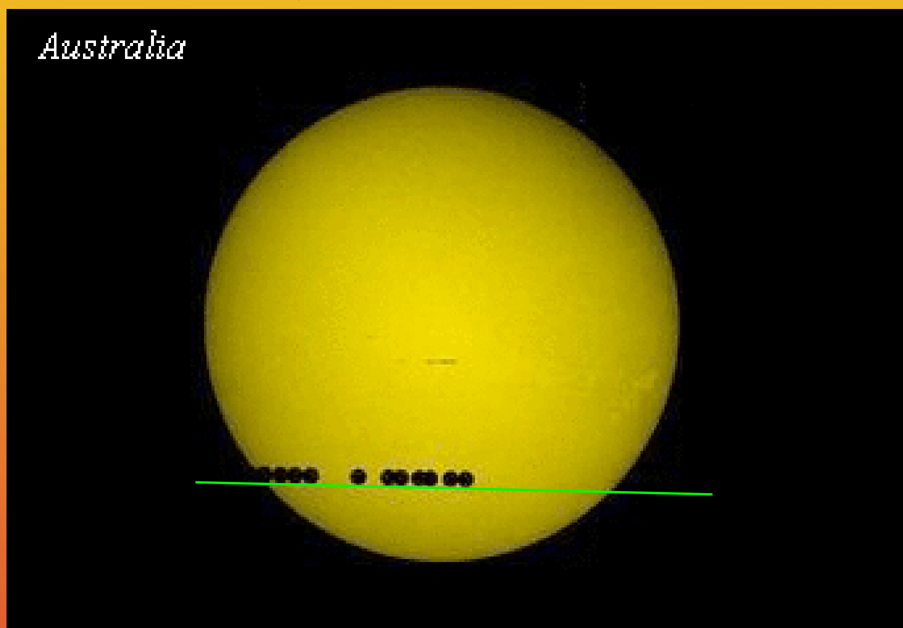
1761, 1769

1874, 1882

2004, 2012

June 8, 2004
Venus Transit of the Sun

- Parallax Effect: Sonderborg, Denmark vs. Exmouth, NW Australia



Credits: Astronomy Group Sonderborg; Learmonth Solar Observatory

Time Lapse Video (x100)

Learning the Size of the Astronomical Unit

- Copernicus (1473-1543): The Sun is the center of the Solar System
- Kepler (1571-1630): Observed that $P^2 \propto a^3$
- Galileo (1654-1542): Established through observation that the Sun is the center of the Solar System.
- Newton (1643-1727): Kepler's 3rd law comes from Gravity (1687)!
- Halley (d1742): Proposed (1716) using parallax measurements of Venus to measure the Earth-Sun distance.
- Transit of Venus observed (1761)
- Transit of Venus observed (1769)
  - these "pairs" of transits only occur ever ~100 yrs. The next pair was 1874, 1882 -- and the observations failed!

Thank You!