

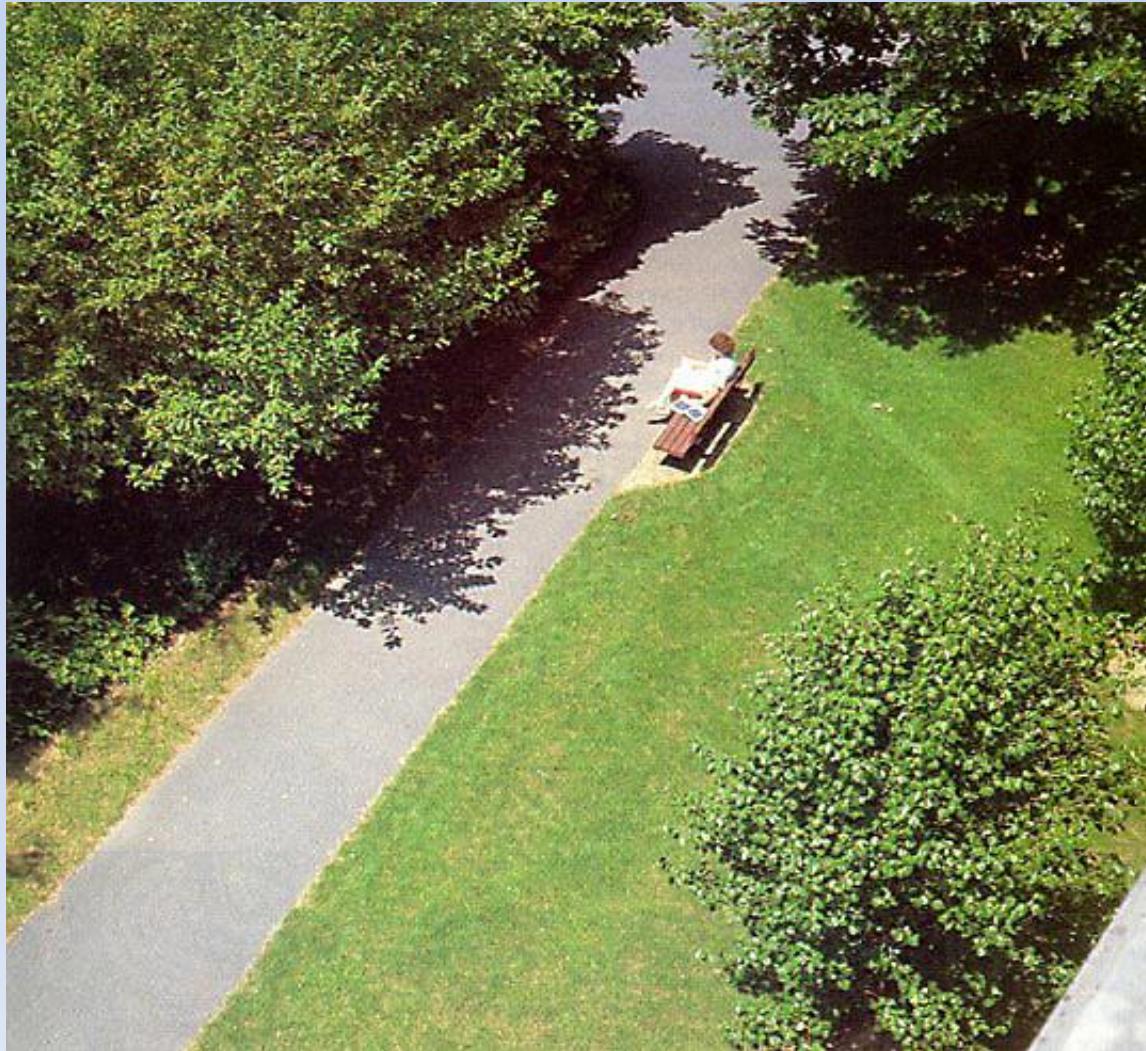
Chapter 1

The universe at different
scales

A quick tour around the universe

- ✓ A quick tour of 13 steps around the whole universe.
- ✓ The scene is widened by 100 times in each step.

Step 1



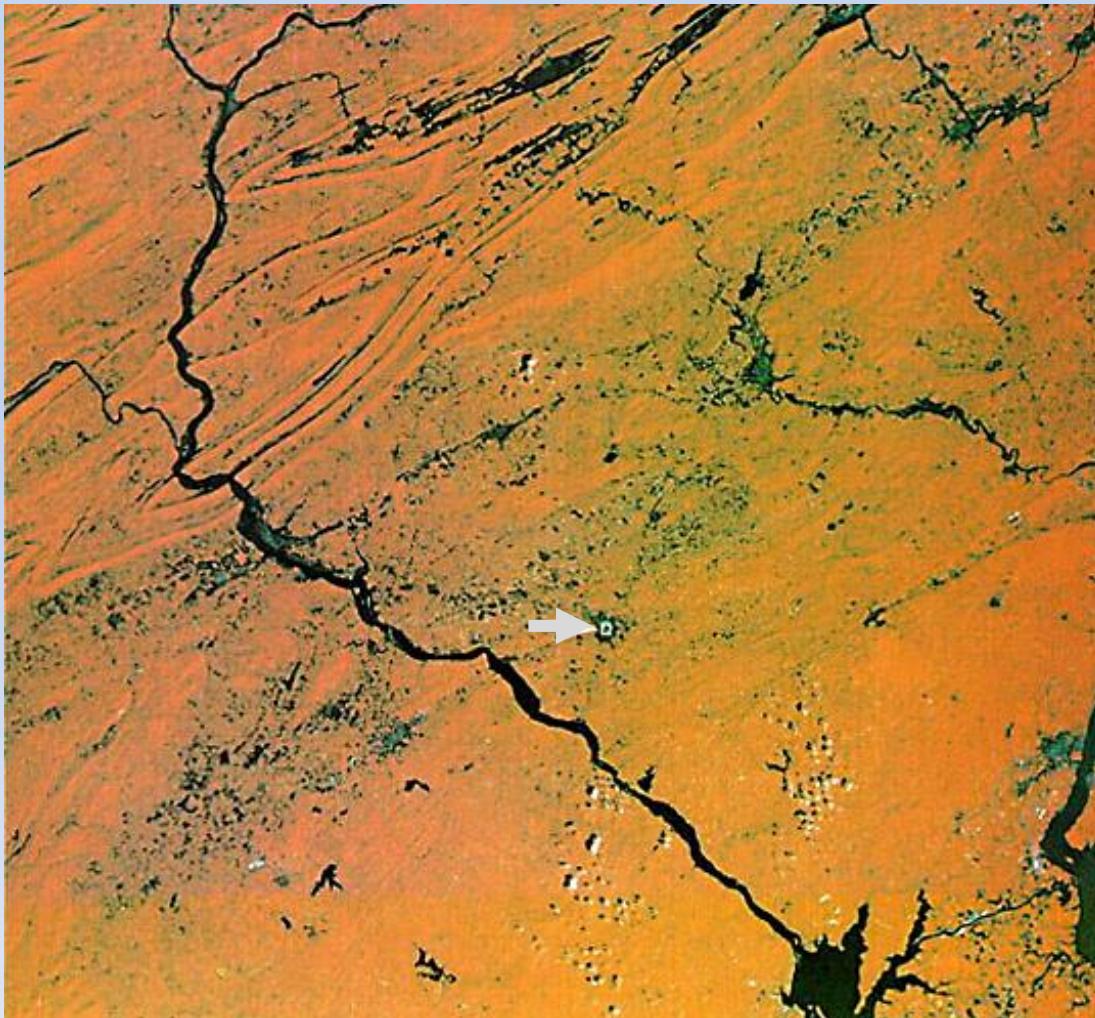
- ✓ 16 m across
- ✓ sizes we are very familiar

Step 2



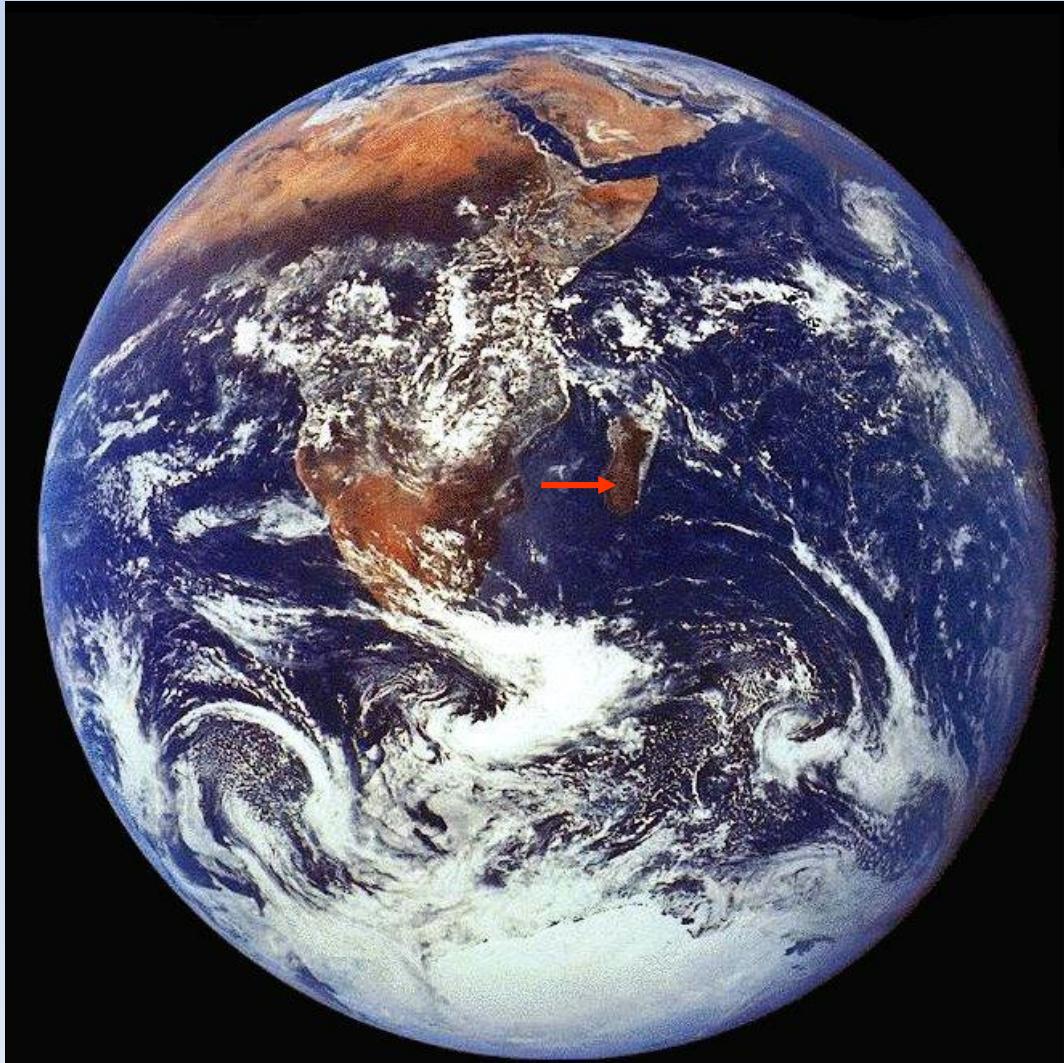
- ✓ A city of 1600 m across
 - ✓ Metric prefixes:
 $k = 1,000$,
 $M = 1,000,000$
e.g., $1600 \text{ m} = 1.6 \text{ km}$
 - ✓ Scientific notation
 $10^5 = 100,000$,
 $10^{-3} = 0.001$
e.g., $45,000 = 4.5 \times 10^4$,
 $0.000062 = 6.2 \times 10^{-5}$
- $$1600 \text{ m} = 1.6 \text{ km}$$
- $$= 1.6 \times 10^3 \text{ m}$$

Step 3



- ✓ infrared photo taken from an artificial satellite
- ✓ 1.6×10^5 m across
- ✓ H.K. ≈ 100 km
 $= 10^5$ m

Step 4



- ✓ Our Earth
- ✓ 1.6×10^7 m across
- ✓ Earth diameter
 $\approx 1.3 \times 10^4$ km
 $= 1.3 \times 10^7$ m

By Apollo 17 in Dec 1972

Step 5



- ✓ The Moon appears
 - ✓ 1.6×10^9 m across
 - ✓ Moon orbit
 $\approx 3.8 \times 10^8$ m
- Moon radius \approx
1/4 Earth radius



The Moon's radius ≈
1/4 of the Earth's;
rocky satellite



The Earth's diameter ≈ 6400 km

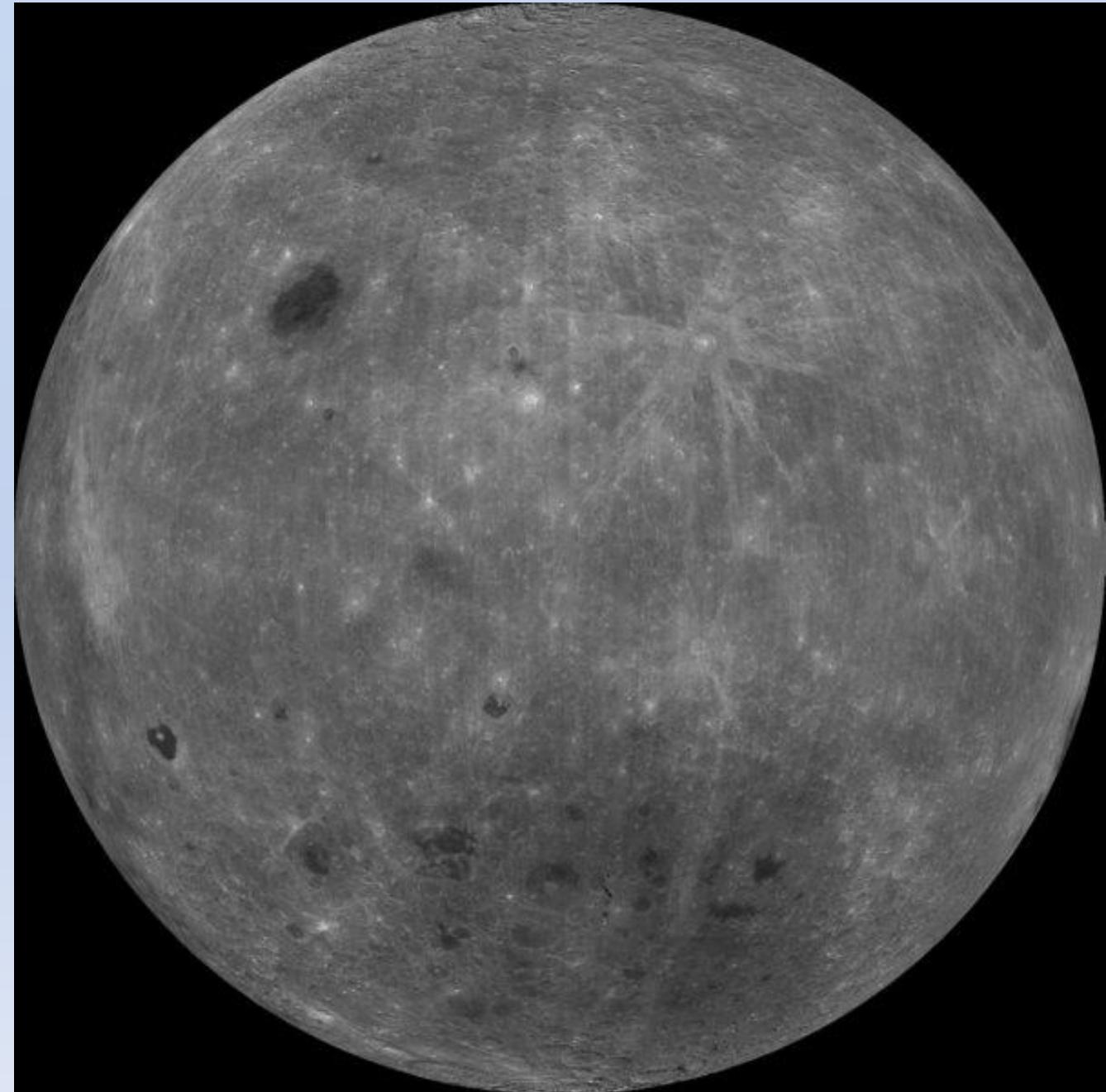


*It revolves around
the Earth once
about 27 days*



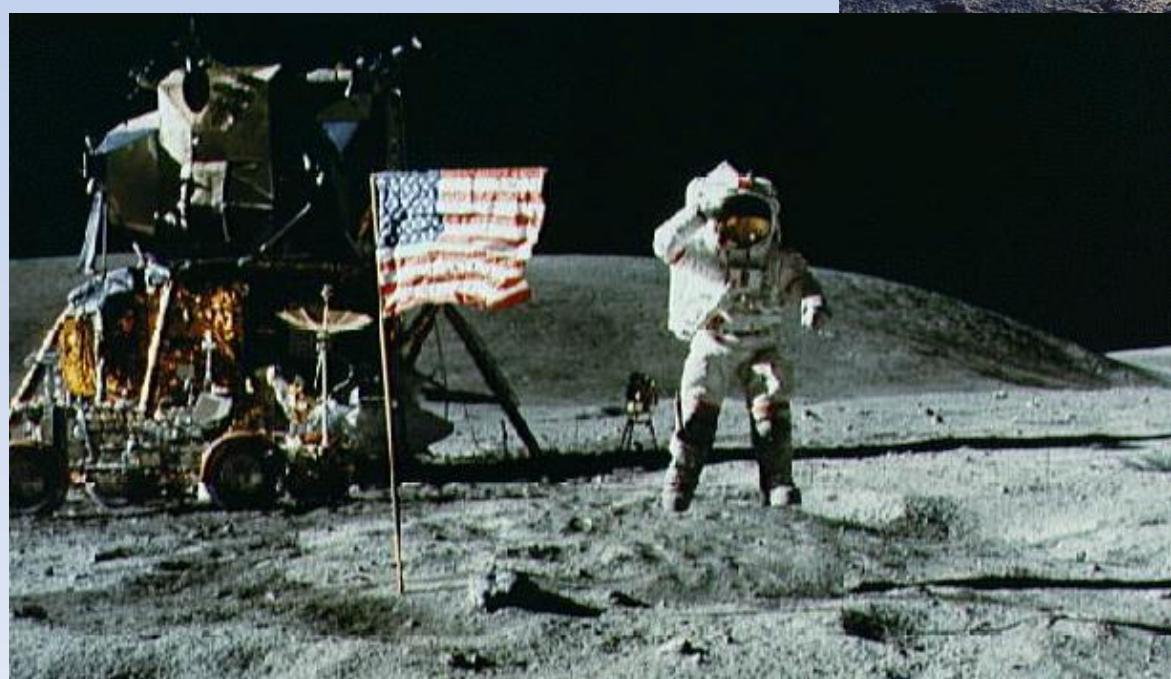
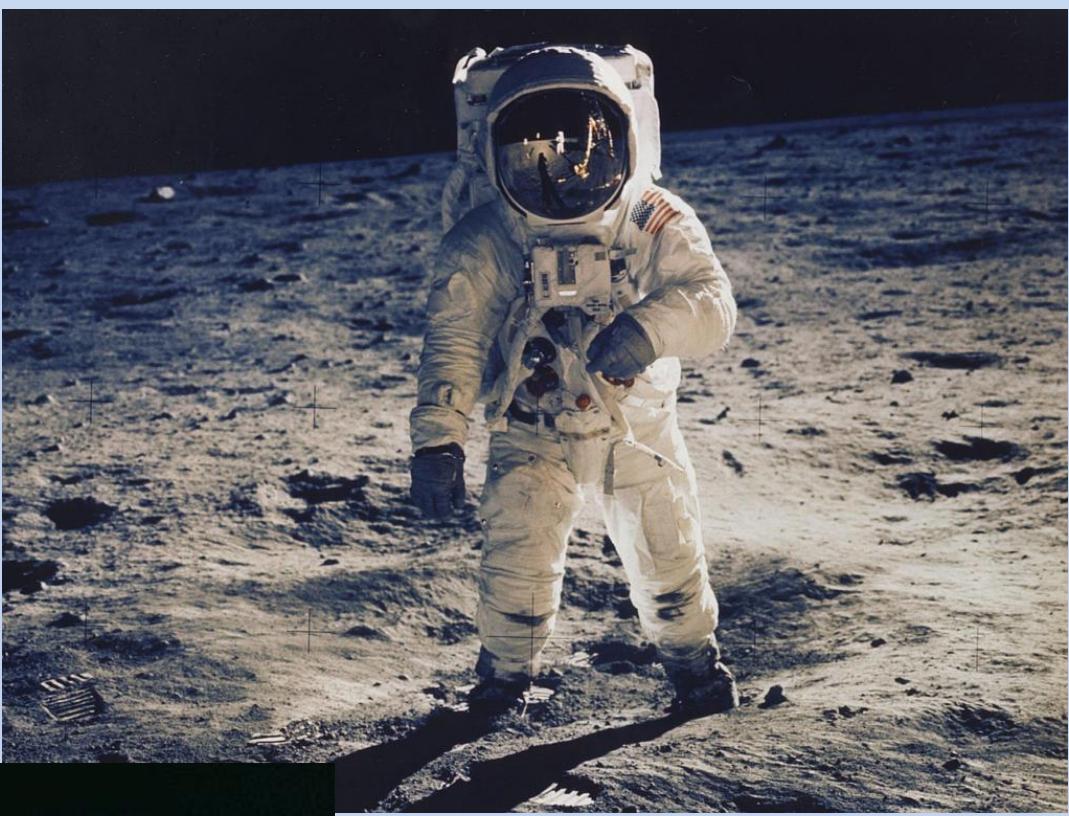
The Moon's near side

- ✓ rocky satellite
- ✓ shows phases as orbiting the Earth

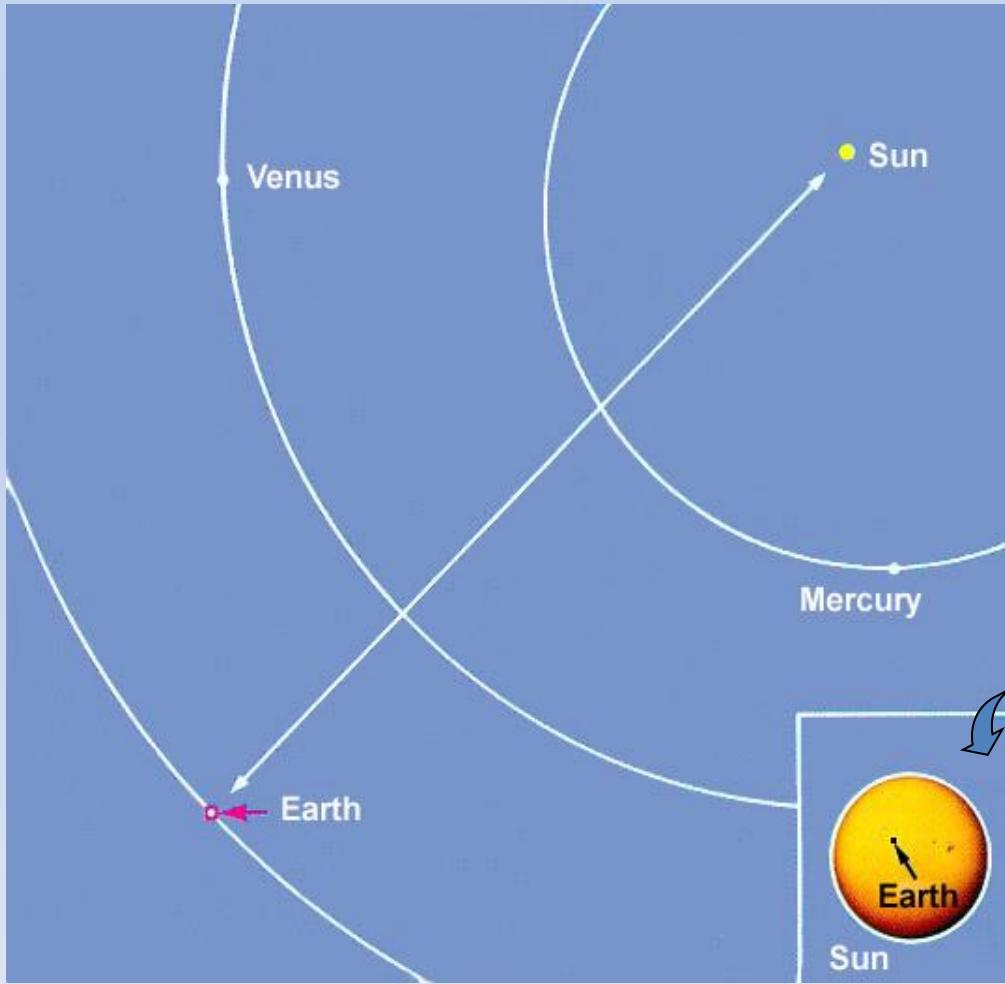


The Moon's near side was first photographed by the Soviet probe Luna 3 in 1959

*inaccurately called the "dark side" of the Moon

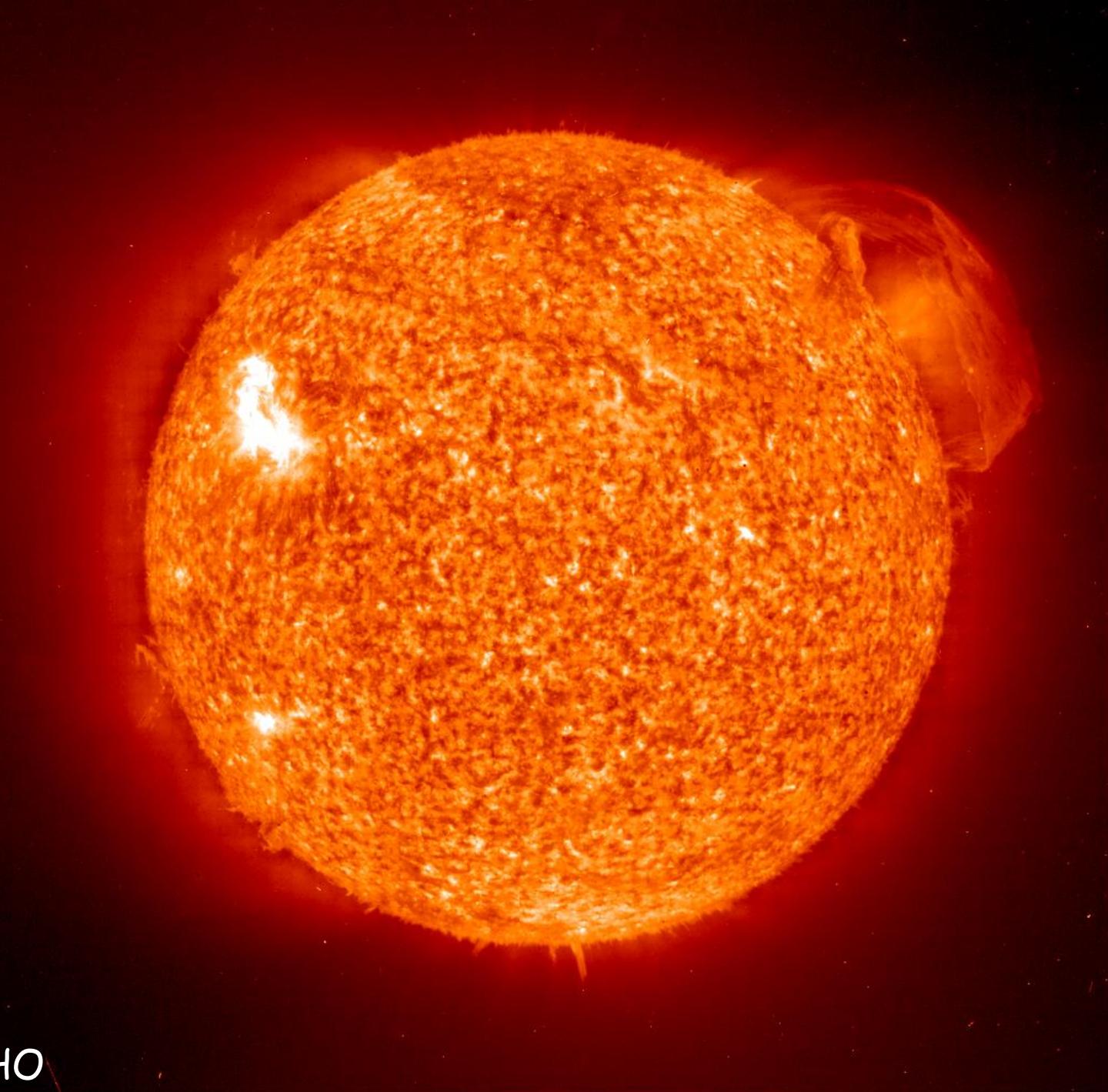


Step 6



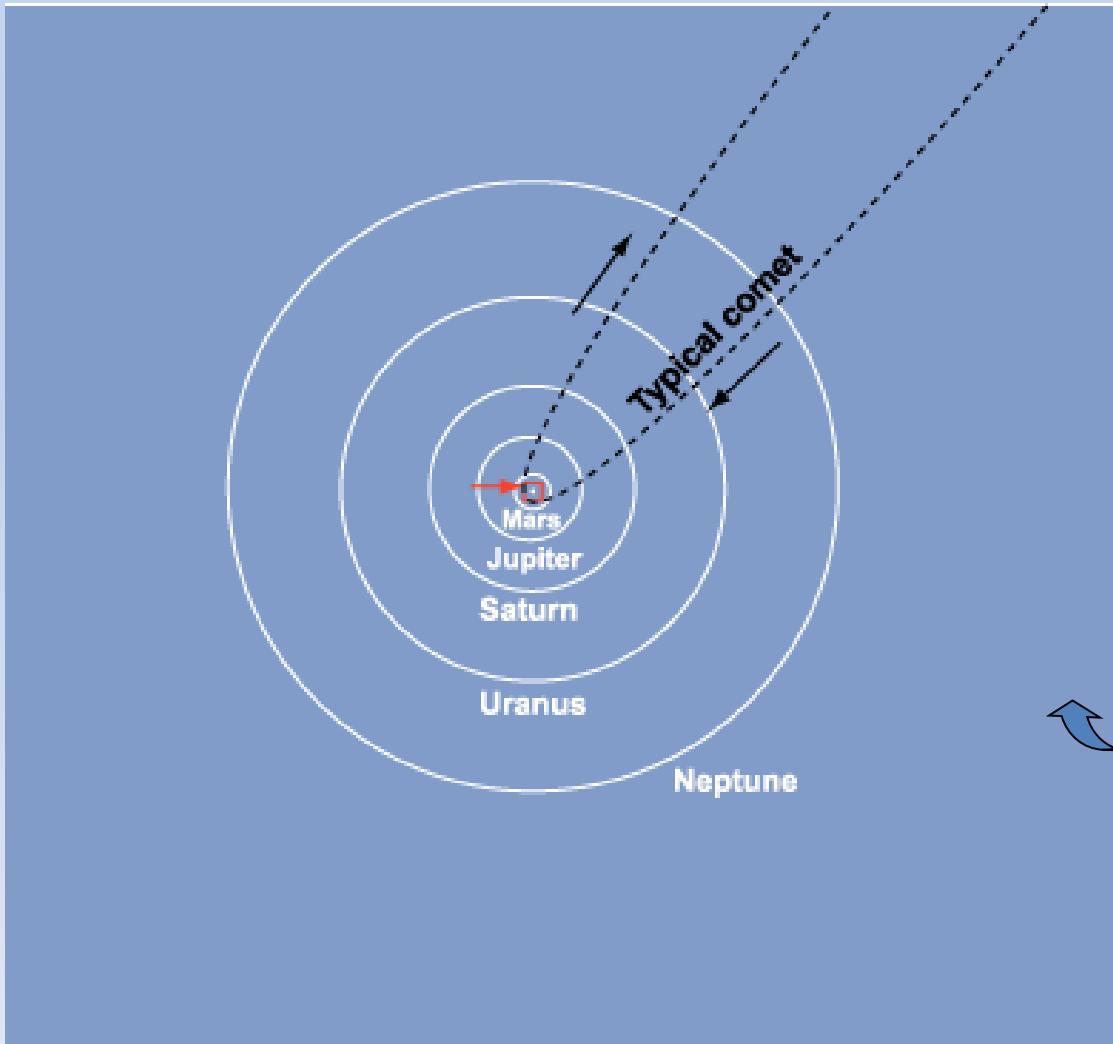
- ✓ The Sun appears
- ✓ 1.6×10^{11} m across
- ✓ average distance between the Earth and the Sun
 $\approx 1.5 \times 10^{11}$ m
= 1 AU

The Sun reduced to a table tennis ball, the Earth becomes a grain of salt 4 m away



By SOHO

Step 7



- ✓ The Entire Solar System
 - ✓ 1.6×10^{13} m across
 - ✓ The Solar System spans about 60 AU
- all planets (except Mercury) are in almost circular orbits



- ✓ The Sun reduced to a table tennis ball, Jupiter (largest planet) becomes an apple seed 20 m away
- ✓ Solar System spans 230m (in diameter)
- ✓ in the Solar System, asteroids between Mars & Jupiter; icy comets around the Sun in elongated orbits



Classification of planets and other bodies in the Solar System into three categories, namely, planet, dwarf planet (矮行星) and small solar system bodies as proposed by the International Astronomical Union's (國際天文聯合會) in 2006.

Step 8

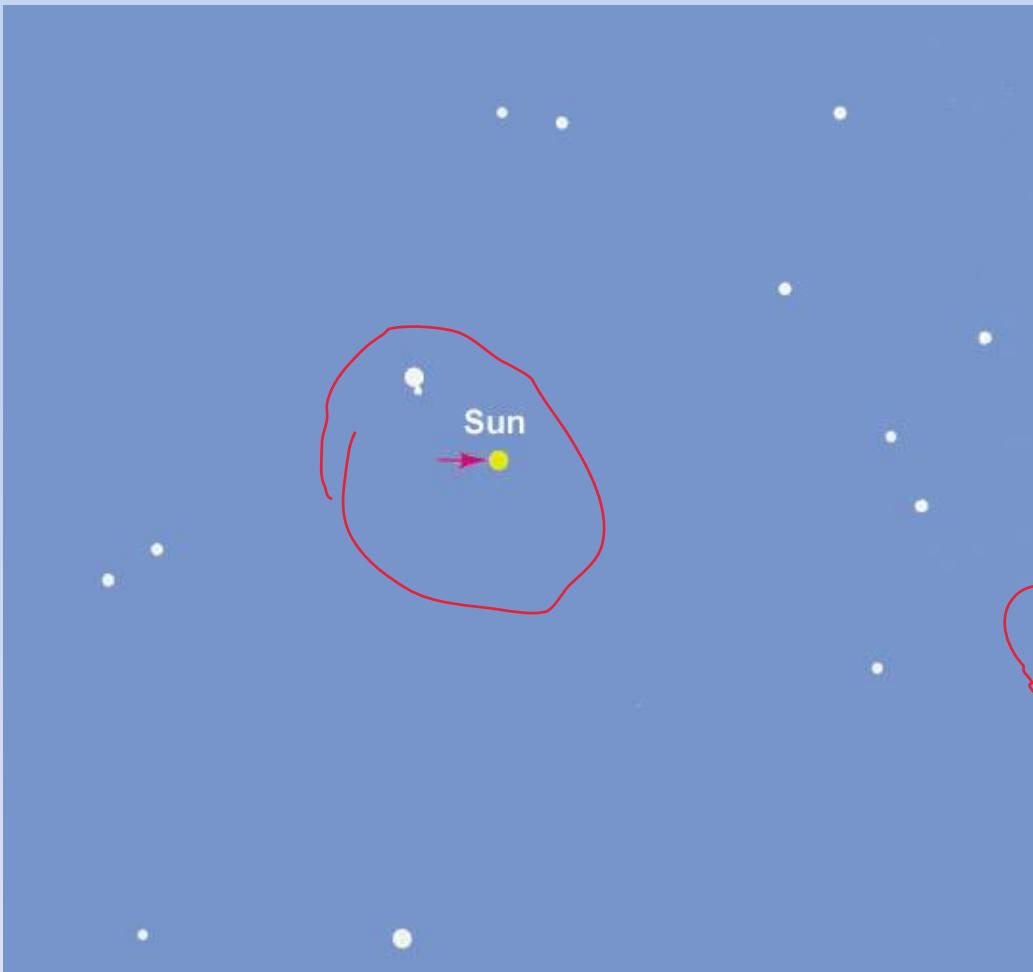


✓ 1.6×10^{15} m across
 $\approx 1.1 \times 10^4$ AU

✓ The Entire Solar System becomes a bright dot

✓ no star observed except the Sun

Step 9



✓ $1.6 \times 10^{17} \text{ m}$ across
 $\approx 1.1 \times 10^6 \text{ AU}$

✓ nearest star
observed: Proxima
Centauri (半人馬座毗鄰
星) 4.2 ly away

✓ Light year, ly (光年):
distance traveled by
light in vacuum in one
year,

$$1 \text{ ly} \approx 6.32 \times 10^4 \text{ AU}$$
$$\approx 9.5 \times 10^{15} \text{ m}$$

✓ $1.6 \times 10^{17} \text{ m}$
 $\approx 1.1 \times 10^6 \text{ AU}$
 $\approx 17 \text{ ly}$

Step 10

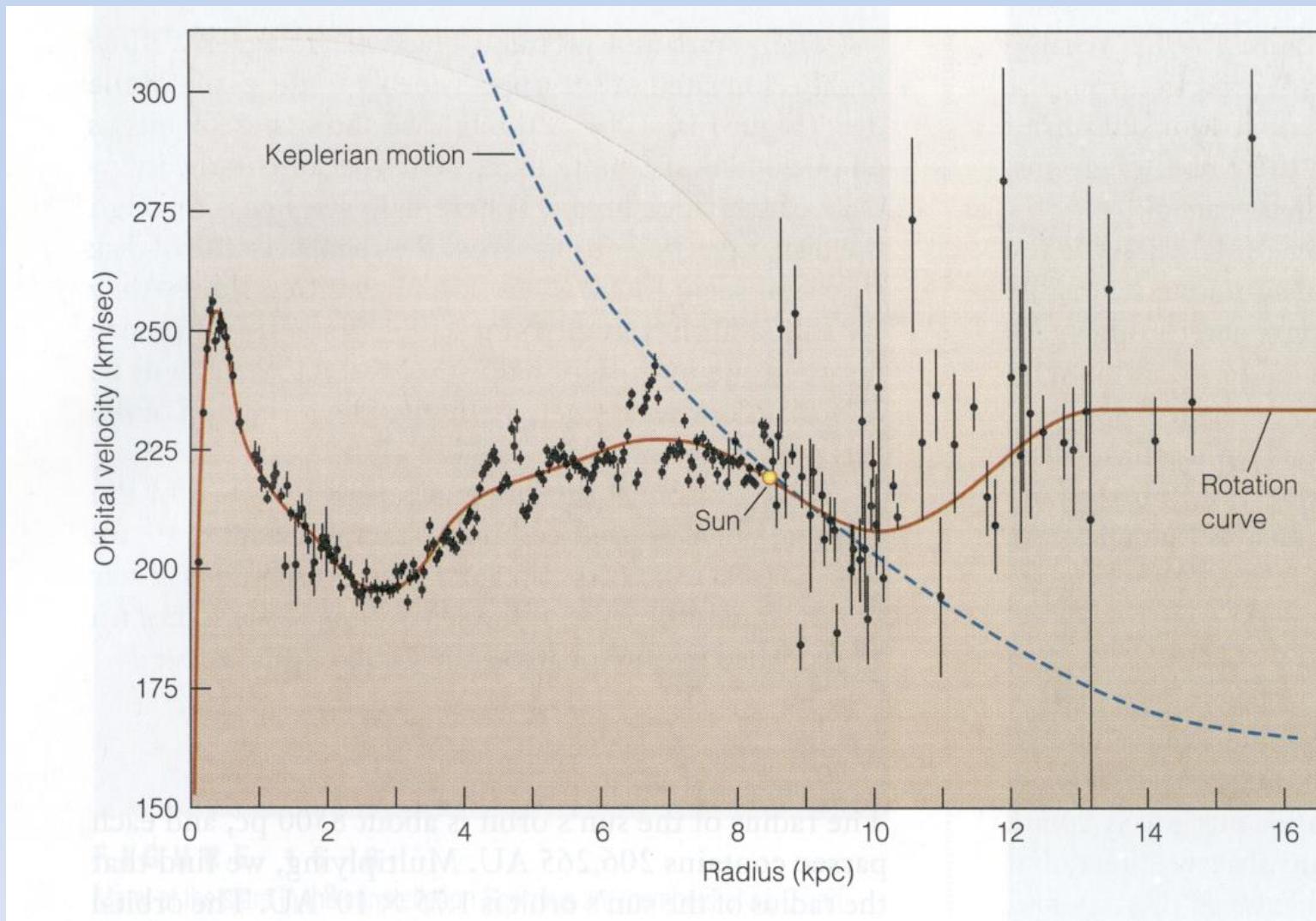


- ✓ 1.6×10^{19} m across
 $\approx 1.7 \times 10^3$ ly
- ✓ stars not scattered randomly
- ✓ all shine by nuclear energy generated in the cores

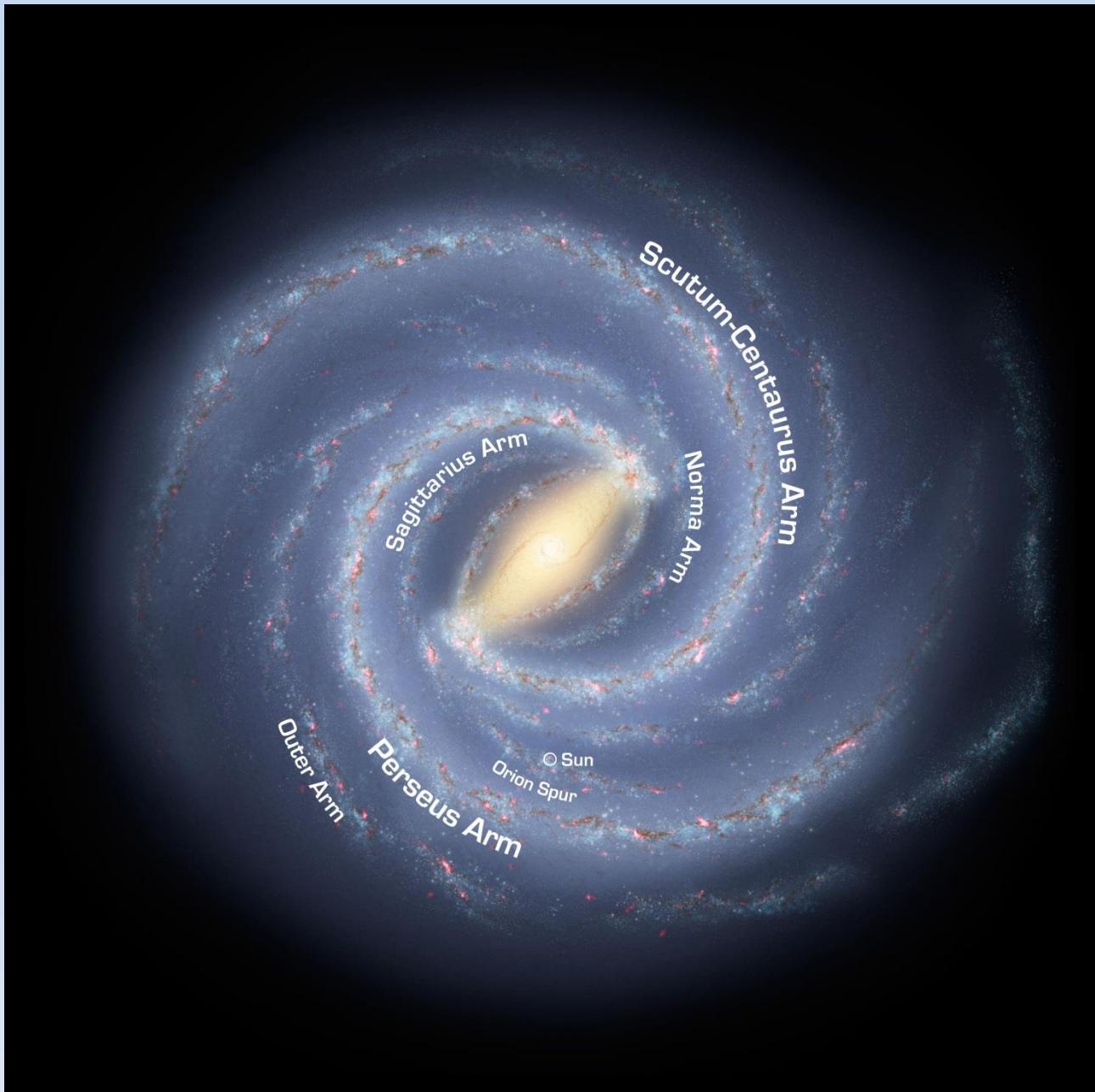
Step 11



- ✓ Milky Way Galaxy appears
- ✓ 1.6×10^{21} m across
 $\approx 1.7 \times 10^5$ ly
- ✓ about 100 billion
(1千億) stars

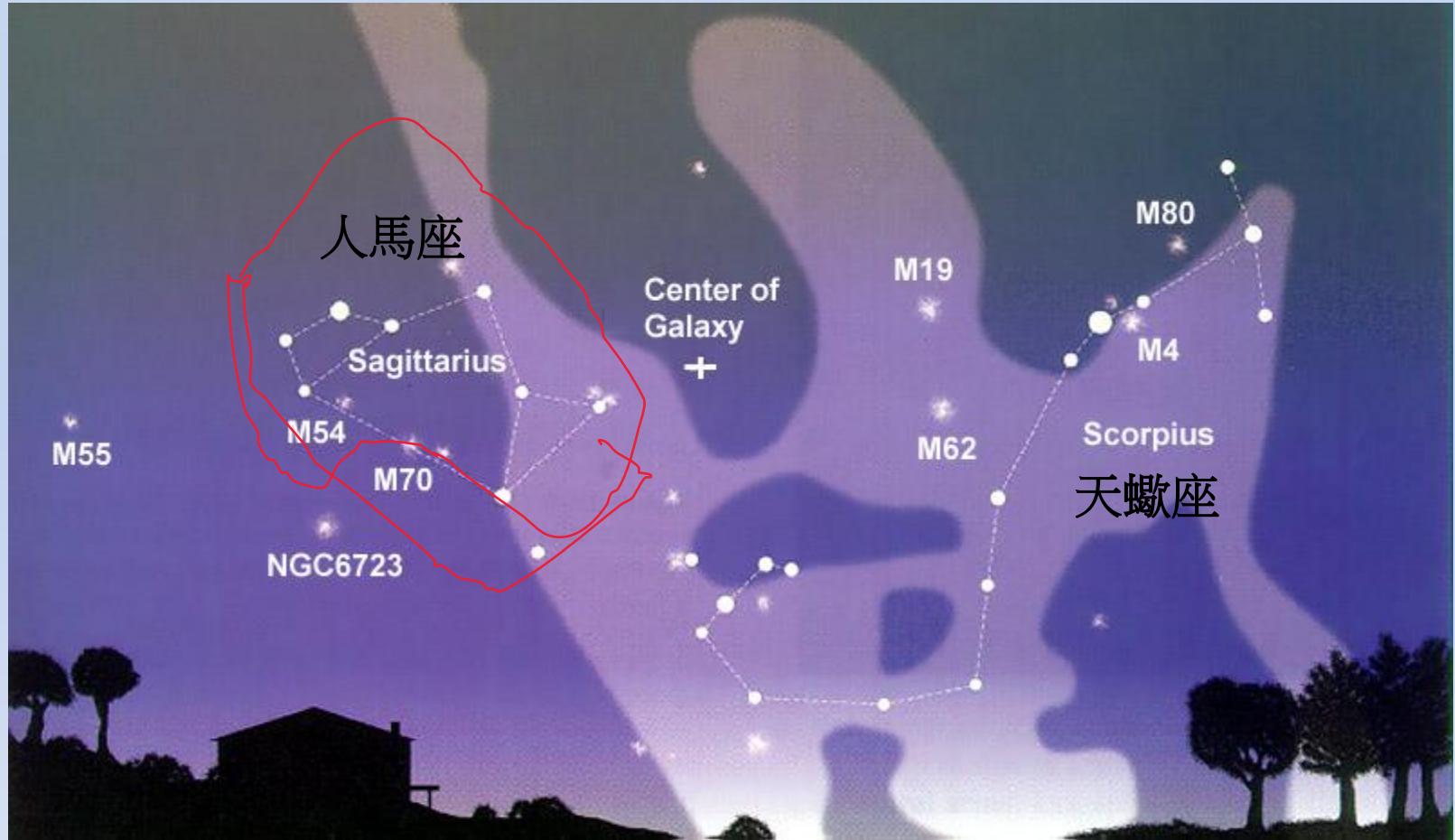


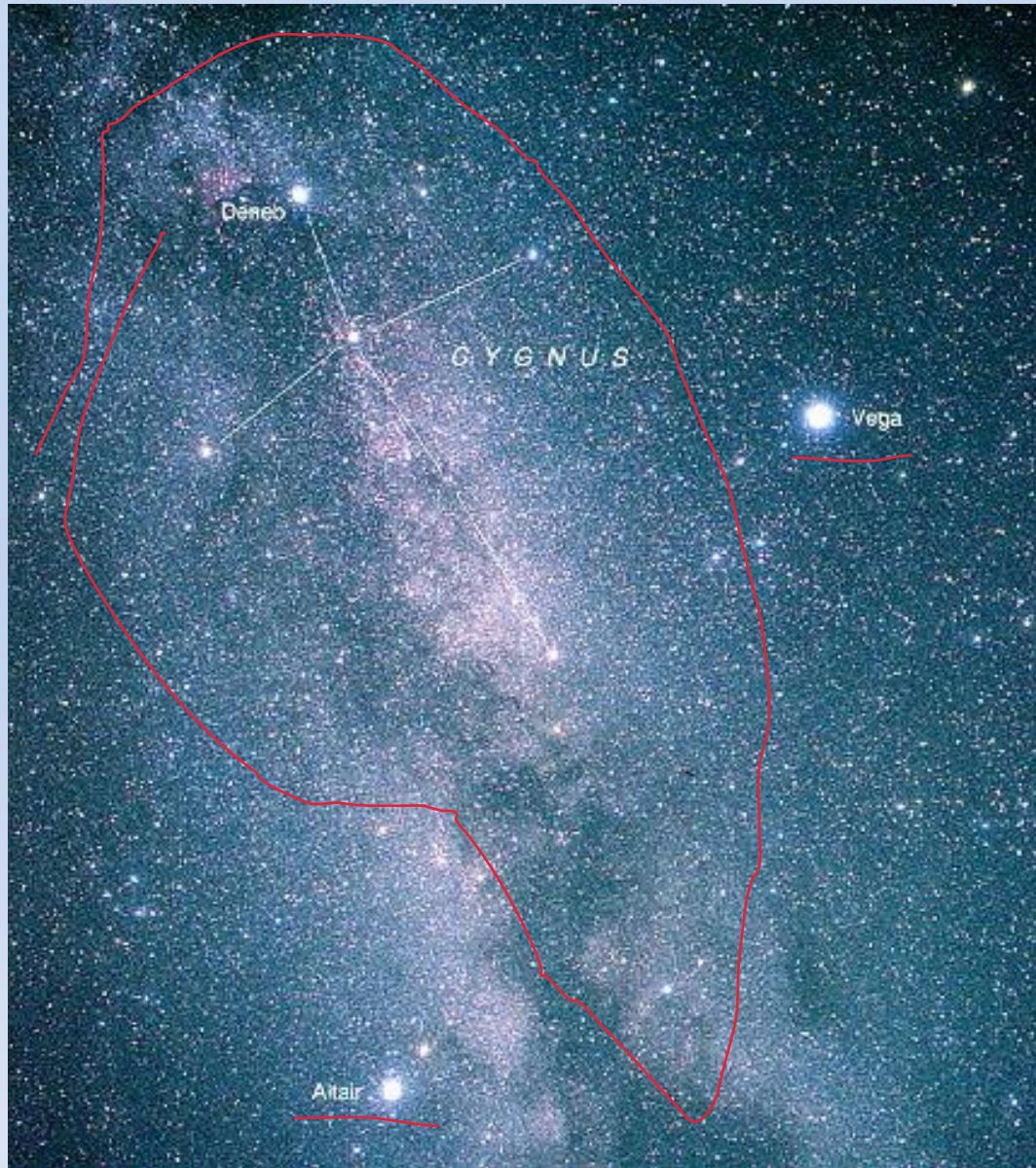
How fast does the Solar System move?



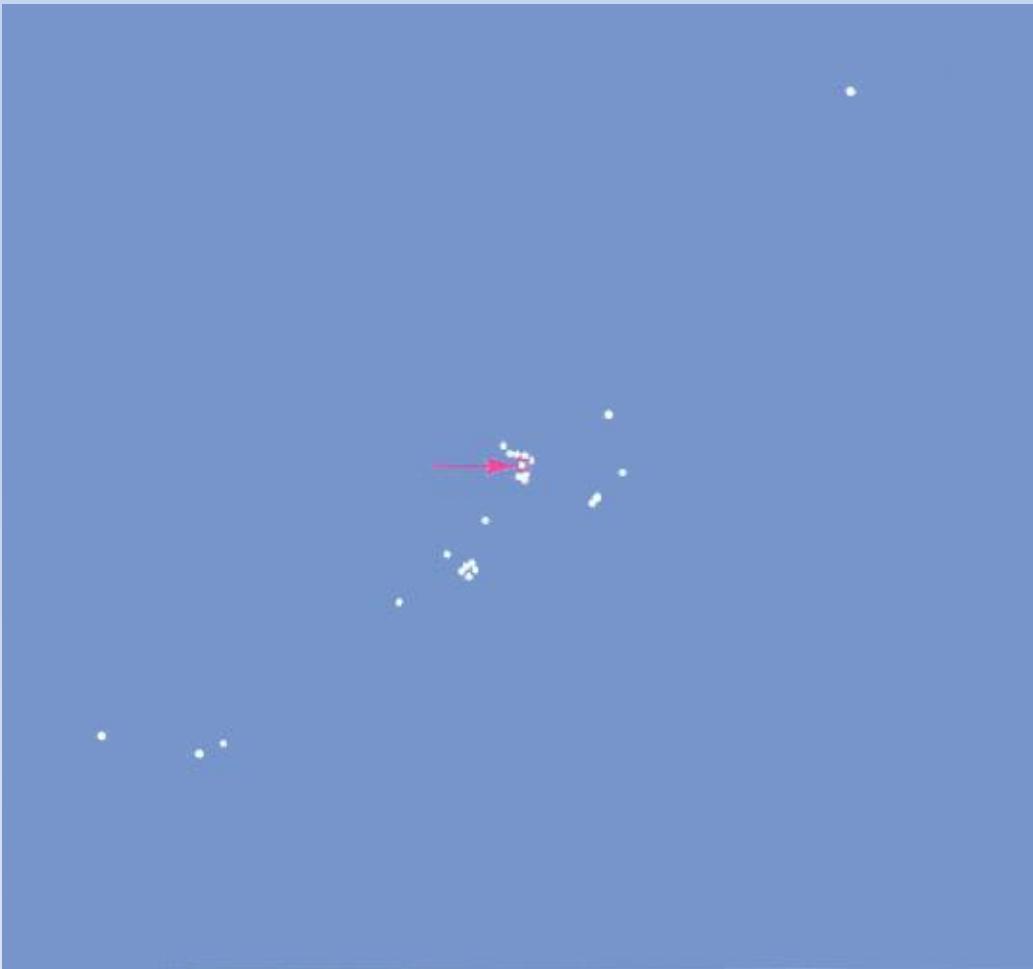
Credit: NASA/JPL-Caltech

- ✓ Spiral structure
- ✓ all stars undergo a complete life cycle: *protostars, main-sequence stars, giants, and finally white dwarfs, neutron stars or black hole*

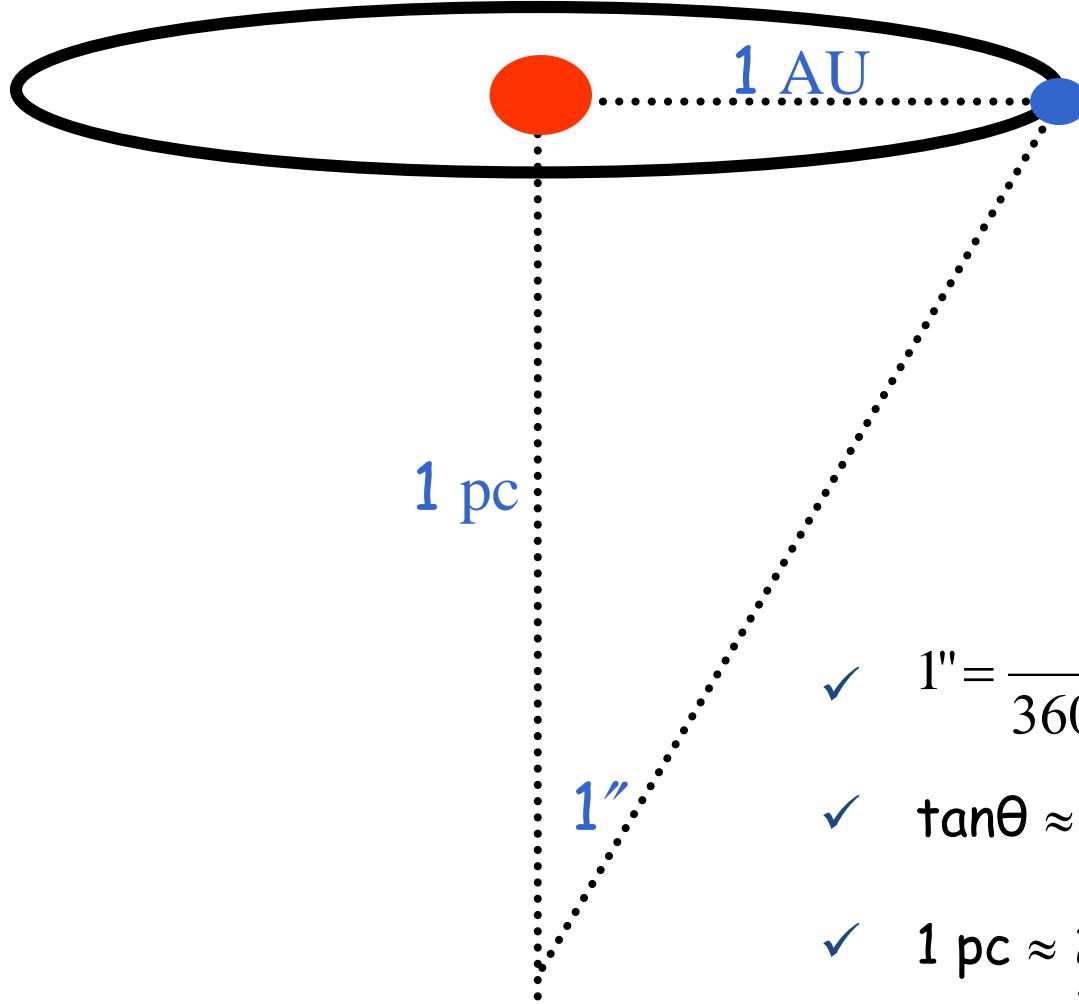




Step 12



- ✓ 1.6×10^{23} m across
 $\approx 1.7 \times 10^7$ ly
- ✓ The Milky Way Galaxy becomes a dot
- ✓ Galaxies not scattered randomly, tend to form clusters
- ✓ our galaxy cluster:
Local Group ~ several dozen galaxies in diameter around 6 Mly
- ✓ Parsec, pc
1 pc ≈ 3.26 ly

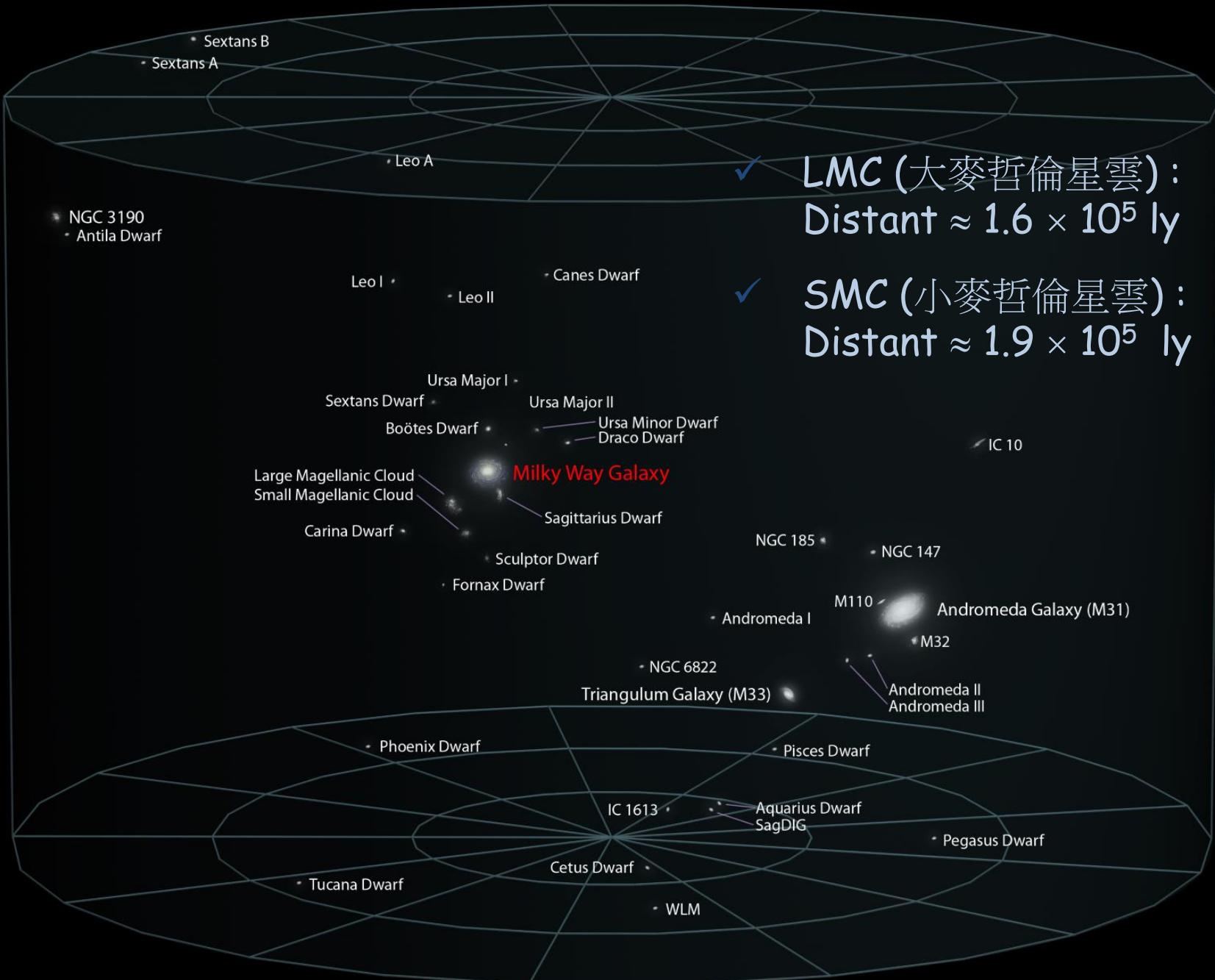


✓ $1'' = \frac{2\pi}{360 \times 60 \times 60} \text{ rad}$

✓ $\tan\theta \approx \theta = 1 \text{ AU} / 1 \text{ pc}$

✓ $1 \text{ pc} \approx 2.1 \times 10^5 \text{ AU}$
 $\approx 3.26 \text{ ly}$

not in scale



Credit: Adam Evans; Wikimedia Commons

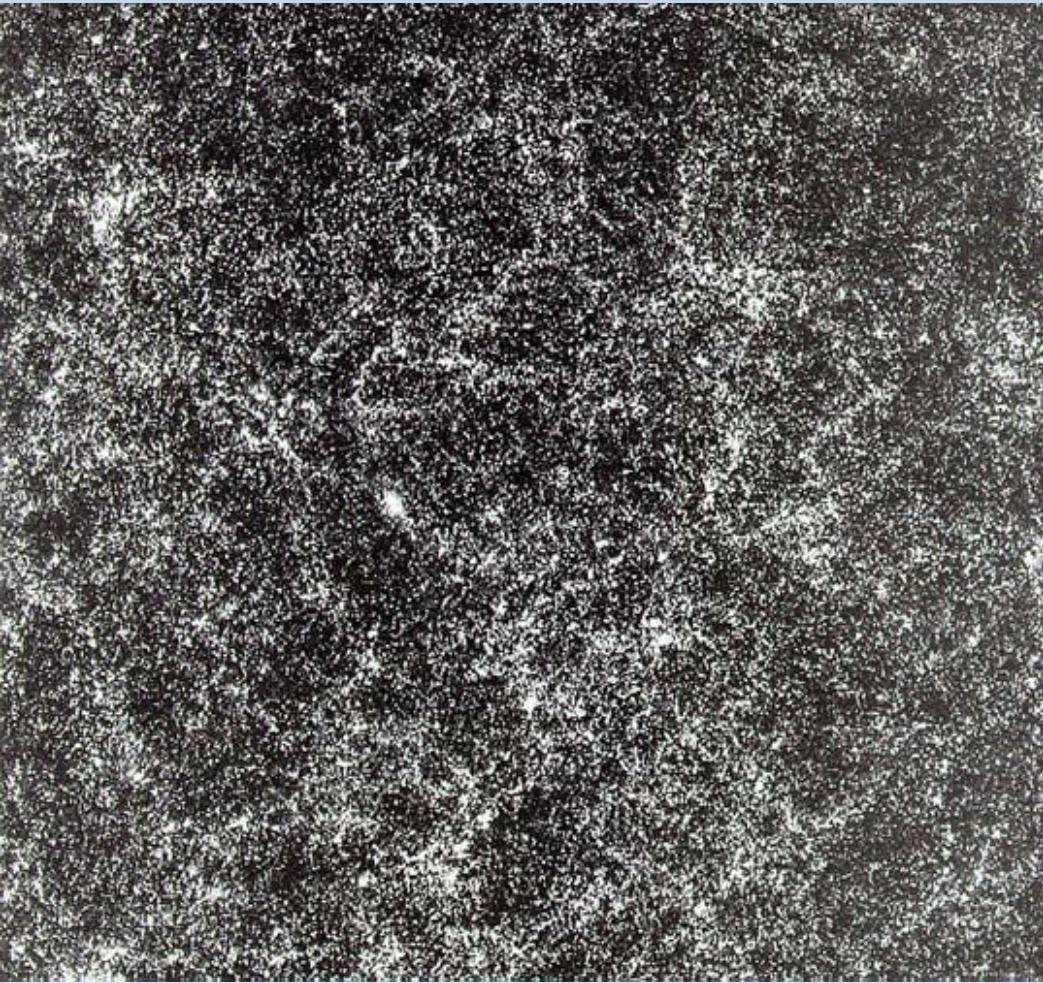


M31 Andromeda Galaxy (仙女座星系)

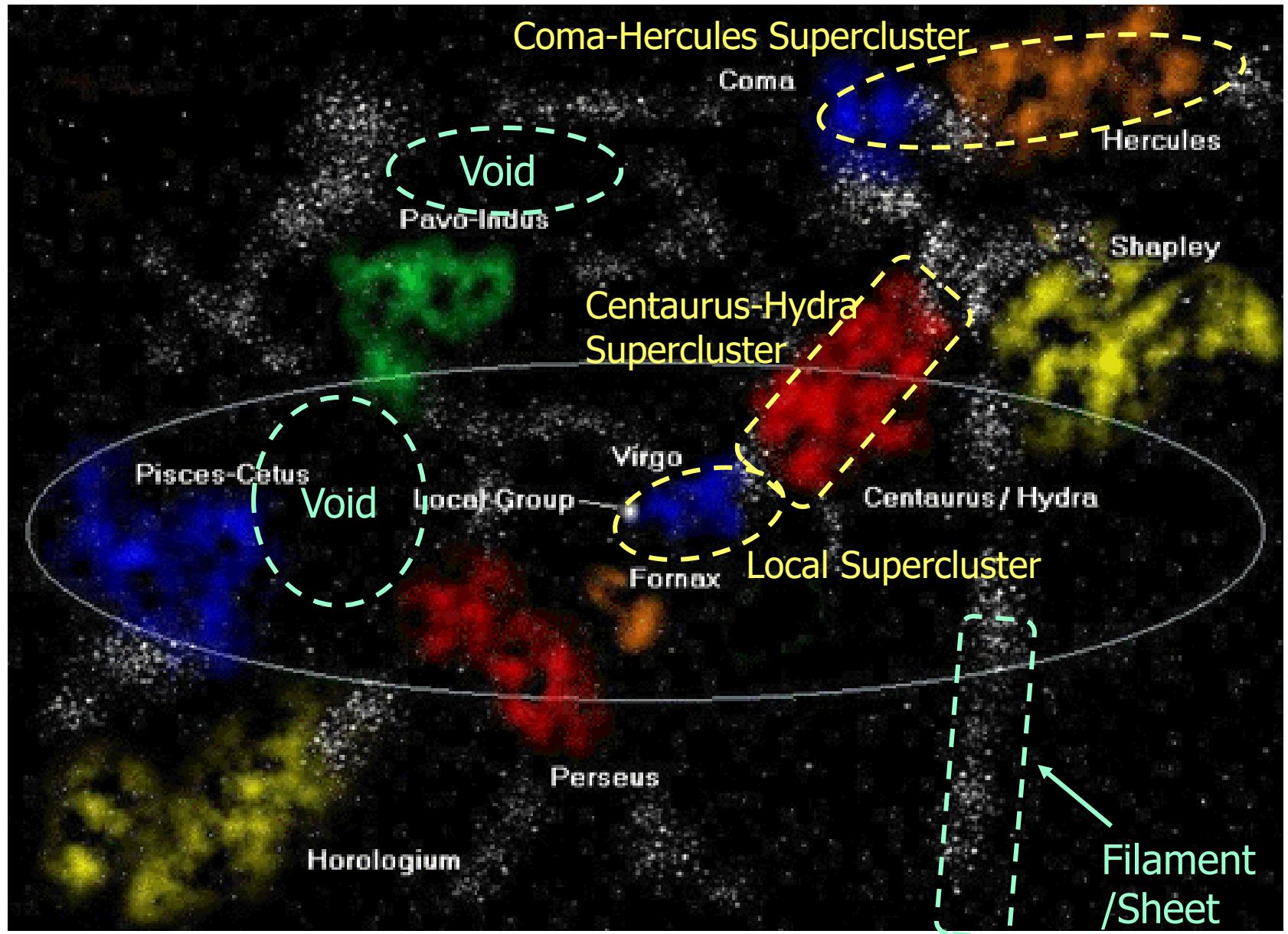


Coma cluster (后髮座星系團): another galaxy cluster
More than 280 Mly from us, more than 1000 galaxies.

Step 13

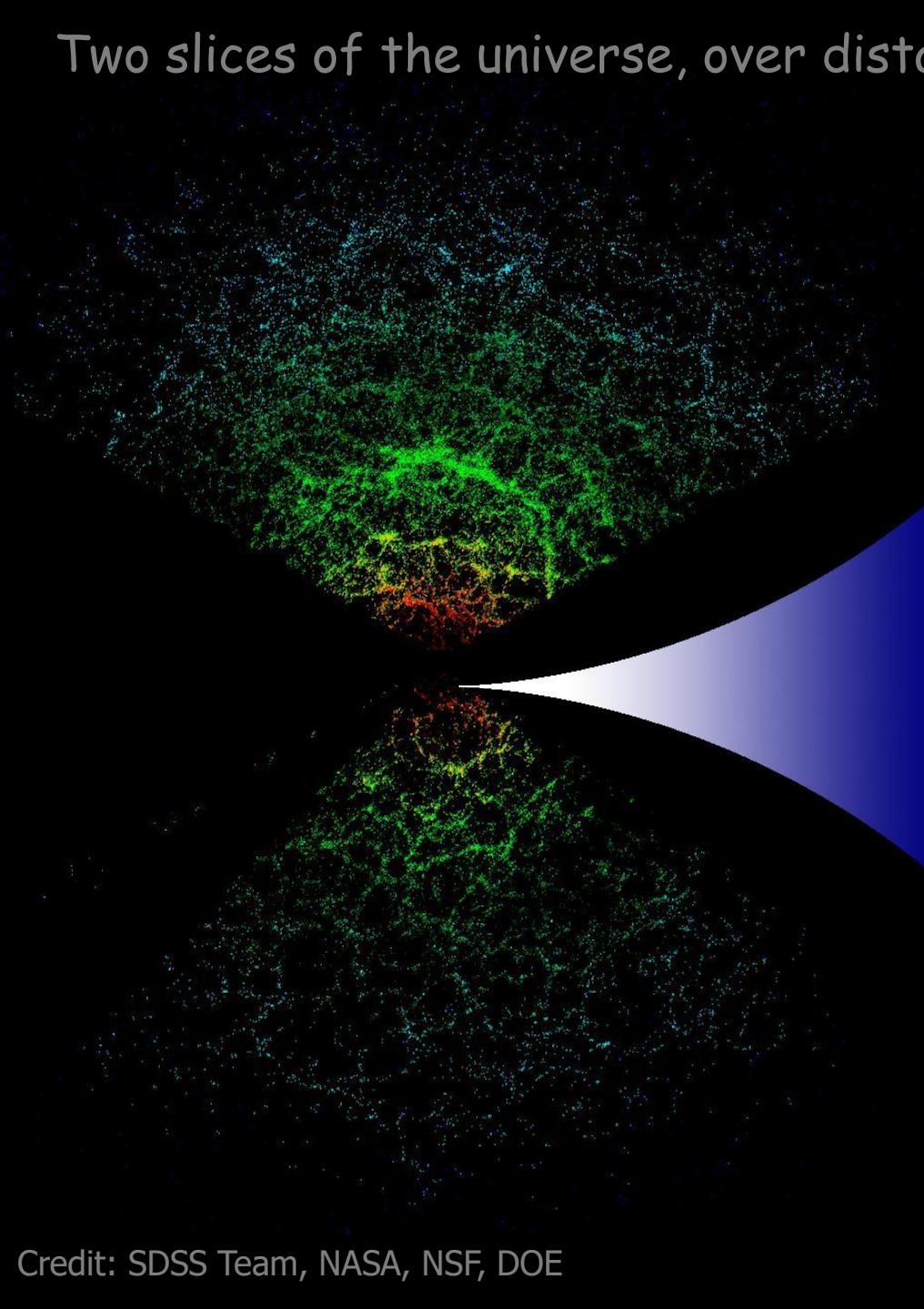


- ✓ Clusters of galaxies group to form superclusters (超星系團).
- ✓ linked to form filaments outlining voids
- ✓ recessing away from each other - indicate an expanding universe



There are structures and patterns.

Two slices of the universe, over distance of billions lightyears across



Distance from a galaxy can be estimated by analyzing its light
(more about it in later chapters)



2.5 m (100 inch) telescope at New Mexico

Powers of Tens



**POWERS
OF TEN**

Finally, how else could we get some feelings about the vastness of the universe?



Credit: NASA; ESA;
and G. Bacon and Z.
Levay, STScI

Are there really so many galaxies?

- a small region of space in the constellation Fornax (天爐座)
- 3.4 arcminutes diagonally (1/10 of a diameter of a full Moon)
- ~10,000 galaxies



Wikipedia, “Hubble Ultra-Deep Field”

Credit: NASA, ESA, G. Illingworth (UCO/Lick and UCSC),
R. Bouwens (UCO/Lick and Leiden U), and the HUDF09
Team



5000 galaxies were found in that small patch of sky!