

# Today

A little more scale...

The Scientific Method

Naked Eye Observations:  
the Appearance of the Sky

# Scientific Notation

- $10^0 = 1$
- $10^1 = 10$
- $10^2 = 100$
- ...
- $10^6 = 1,000,000$
- similarly...
- $10^{-1} = 0.1$
- $10^{-6} = 0.000001$

Units important!

$1 \text{ g cm}^{-3} = 1,000 \text{ kg m}^{-3}$   
density of water

$5.5 \text{ g cm}^{-3}$   
average density of the Earth

$10^{-29} \text{ cm}^{-3}$   
approximate average density  
of the universe

# Definition: **Light-Year**

- The **distance** light can travel in one year.
- About 10 trillion kilometers (6 trillion miles).  
( $10^{13}$  km)

$$d = c \times t$$

distance = (speed of light) x (travel time)

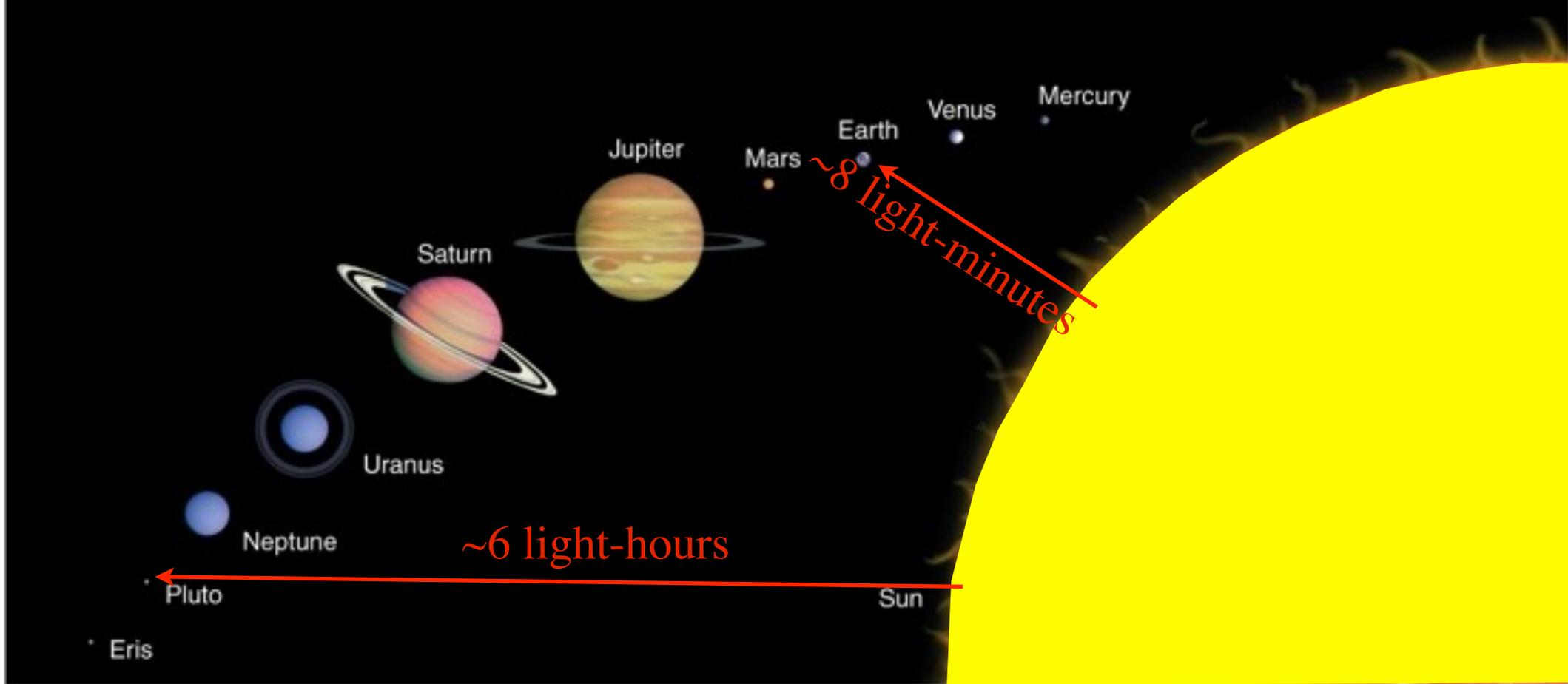
## Light travel time & distance

- Light travels at a finite speed (300,000 km/s).

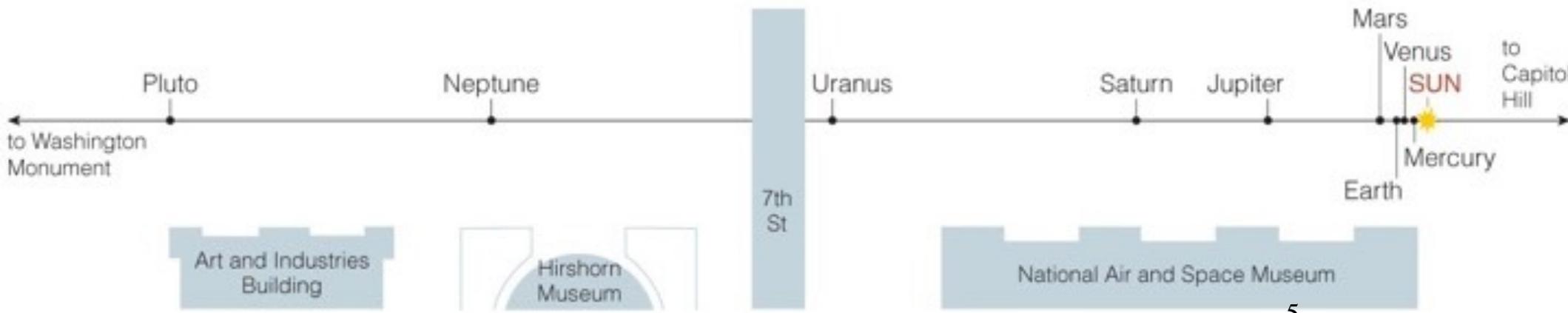
<b>Destination</b>	<b>Light travel time</b>
Moon	1 second
Sun	8 minutes
Sirius	8 years
Andromeda Galaxy	2.5 million years

- Thus, we see objects as they were in the past:

*The farther away we look in distance,  
the further back we look in time.*

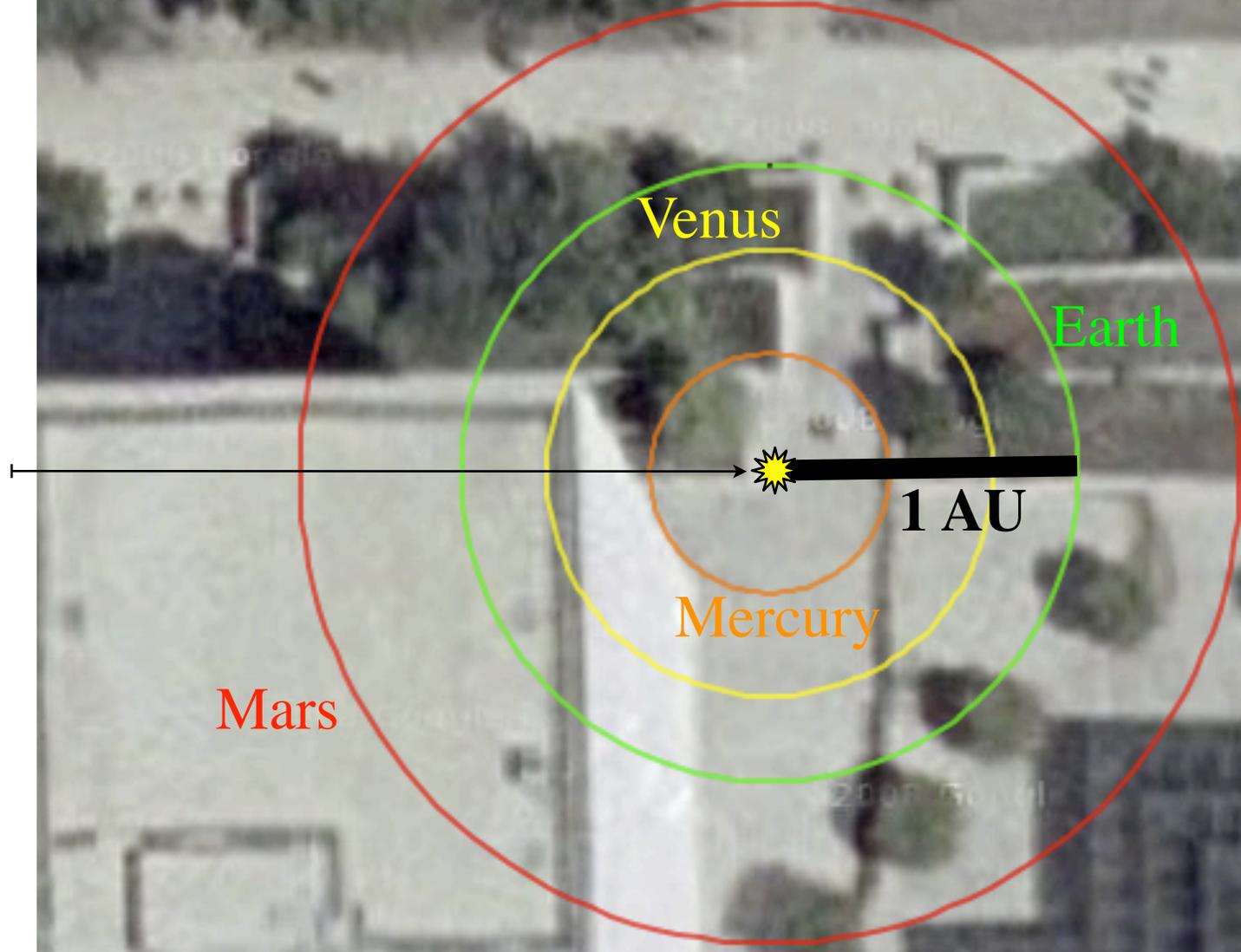


a This painting shows the Sun, the planets, and the two largest known "dwarf planets."  
 (Distances are not to scale in this painting.)



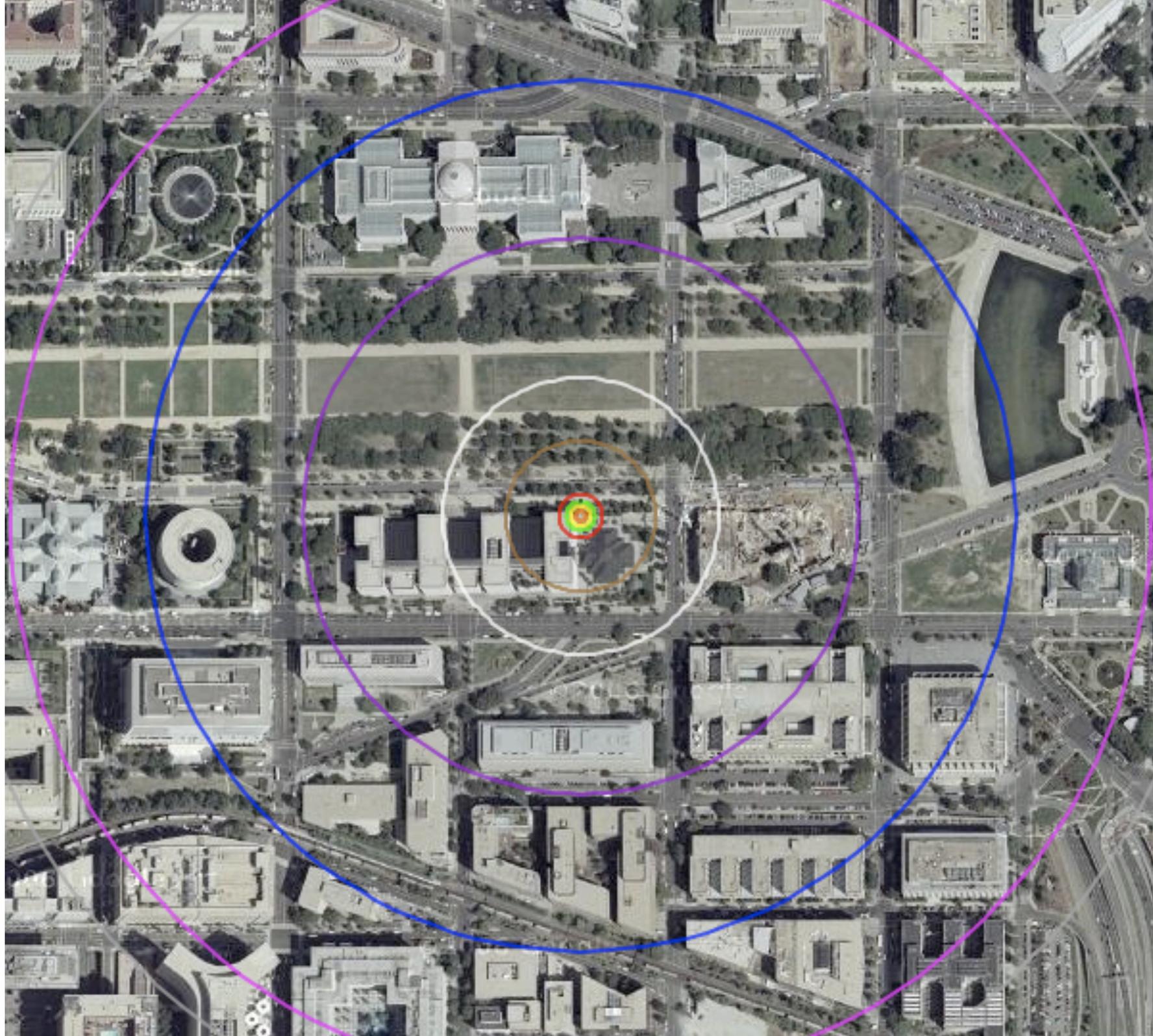
b This map shows the locations of the Sun and planets in the Voyage model; the distance from the Sun to Pluto is about 600 meters (1/3 mile). Planets are lined up in the model, but in reality each planet

The sun is 13 cm in diameter on this scale



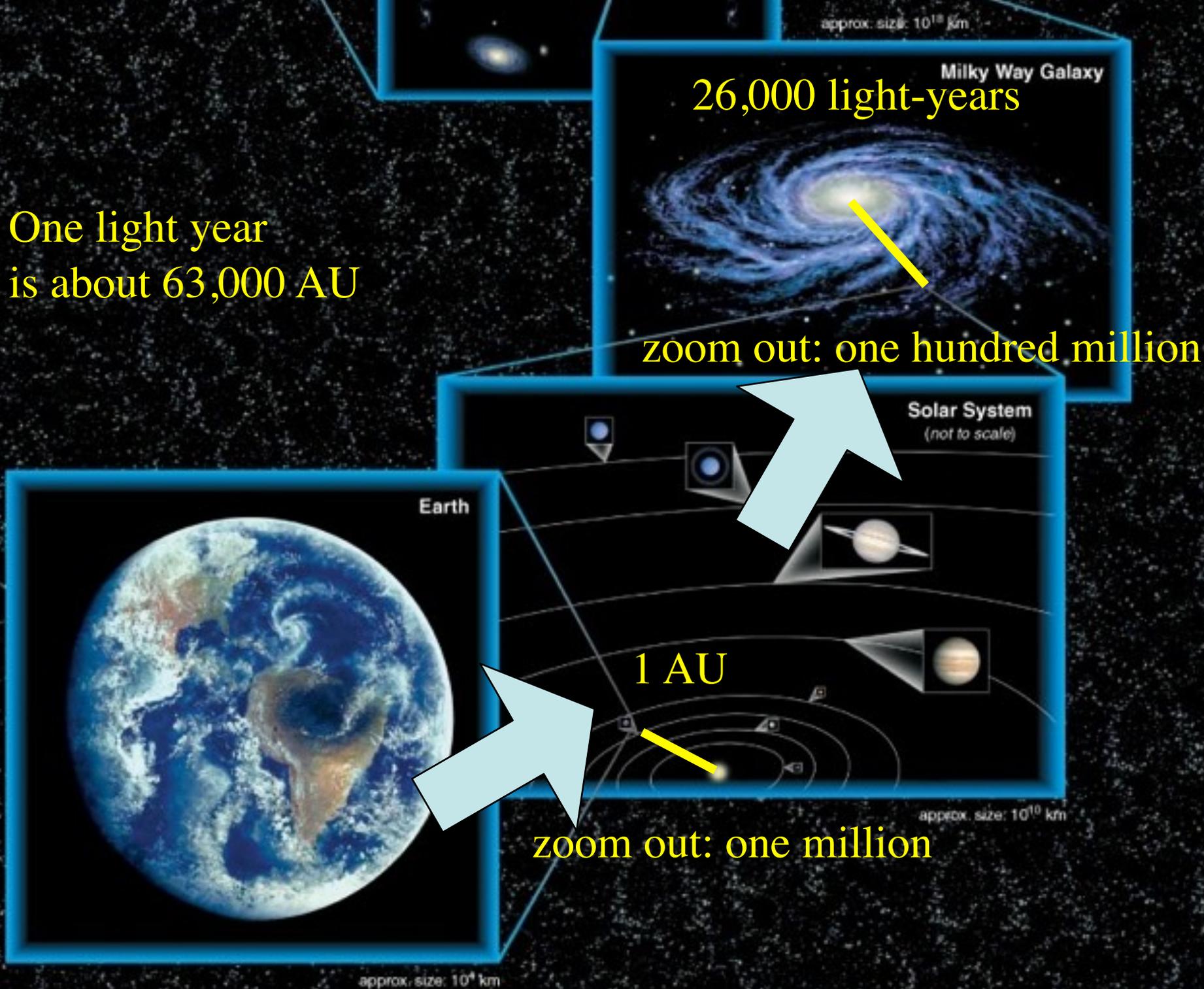
AU = Astronomical Unit

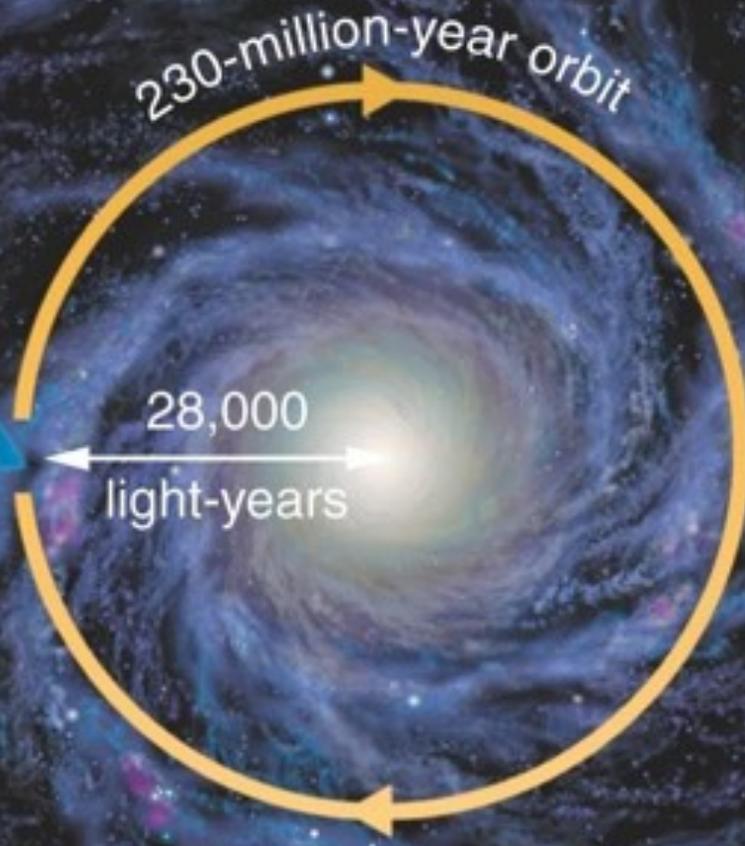
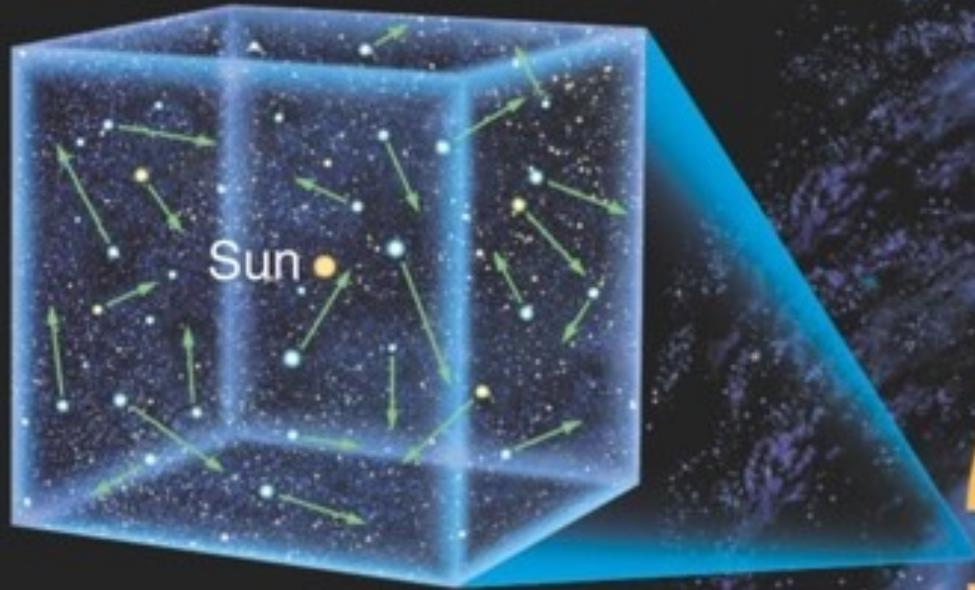
To same scale



Pluto  
40 AU

One light year  
is about 63,000 AU



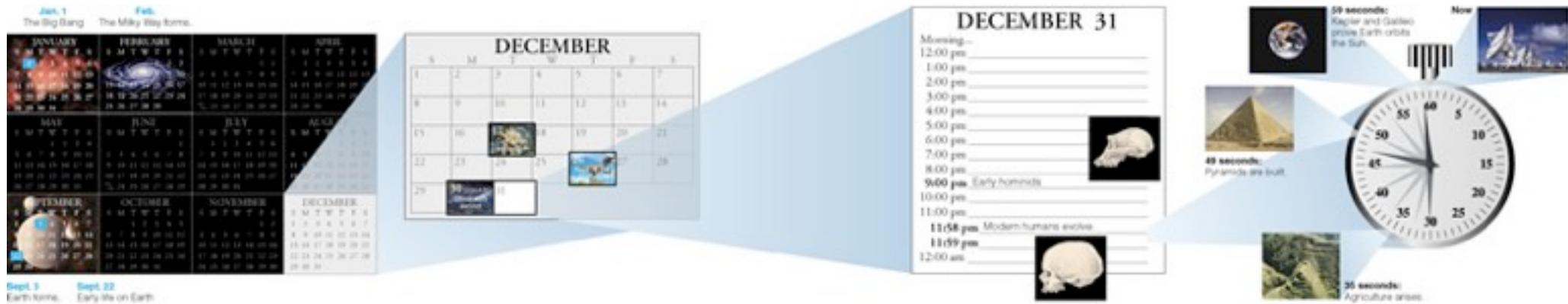


From the sun to the center of the Milky Way Galaxy is about 26,000 light-years

The difference from 28,000 light-years reflects the uncertainty in this measurement.

# Space is Huge; Time is Deep: The Universe is Ancient

- The Cosmic Calendar: A scale on which we compress the history of the universe into 1 year.



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The Universe is about 14 billion years old, so at this scale, 1 month represents a little more than 1 billion years.

# THE HISTORY OF THE UNIVERSE IN 1 YEAR

January 1: The Big Bang  
 February: The Milky Way forms  
 September 3: The Earth forms  
 September 22: Early life on earth

December 17: Cambrian explosion  
 December 26: Rise of the dinosaurs  
 December 30: Extinction of the dinosaurs





December 31:

9:00 pm:  
Early hominids evolve

11:58 pm:  
Modern humans evolve

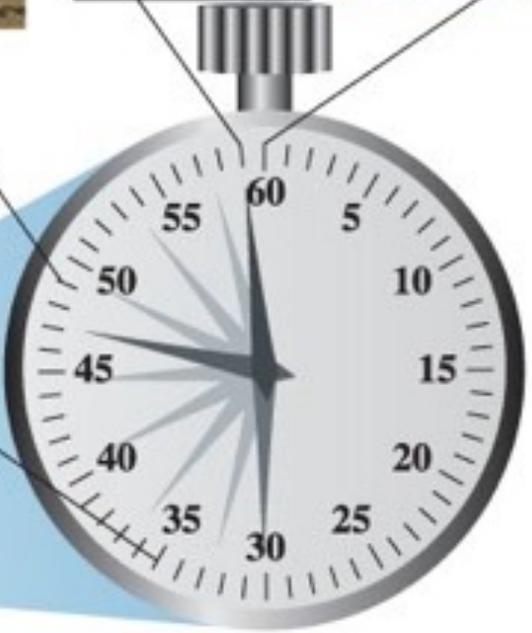
25 seconds ago:  
Agriculture arises

11 seconds ago:  
Pyramids built

1 second ago:  
Kepler and Galileo  
show that Earth  
orbits the Sun

Now

DECEMBER 31	
Morning...	
12:00 noon	
1:00 pm	
2:00 pm	
3:00 pm	
4:00 pm	
5:00 pm	
6:00 pm	
7:00 pm	
8:00 pm	
9:00 pm	
10:00 pm	
11:00 pm	
11:58 pm	
11:59 pm	
12:00 midnight	



# Astronomy covers, well, astronomical scales:

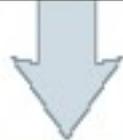
- The Universe is MUCH larger than
    - Galaxies which are MUCH larger than
      - Stars which are MUCH larger than
        - Planets which are MUCH larger than
          - » Moons, comets, and asteroids, which are MUCH larger than
            - PEOPLE
- The Universe is incredibly ancient
  - but does have a finite age

# The Scientific Method

## A few necessary ASSUMPTIONS:

- There exists an objective, knowable Reality
  - or at least an inter-subjective reality upon which independent observers can agree
- Reality is governed by physical processes that can be described by a set of rules
  - The “Laws of Nature”
- The Laws of Nature are accessible to human knowledge through experimentation
- The Laws of Nature are universal
  - The rules don’t change arbitrarily
  - God doesn’t cheat

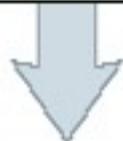
make observations



ask a question



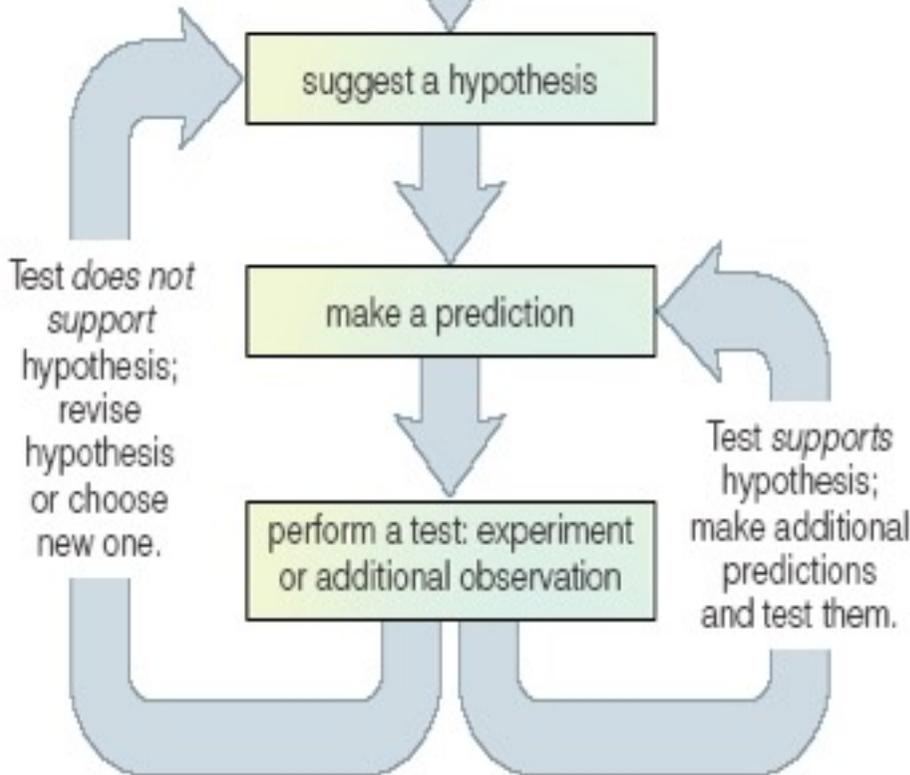
suggest a hypothesis



make a prediction



perform a test: experiment or additional observation



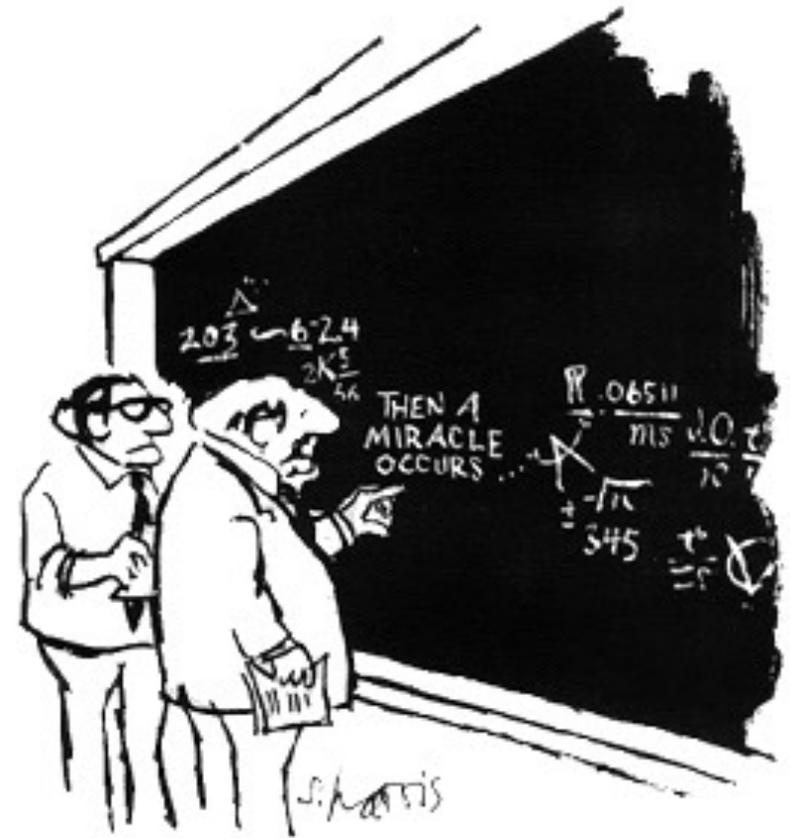
## The idealized scientific method:

- Based on proposing and testing hypotheses
- **hypothesis** = educated guess

# *Hallmarks of Science: #1*

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

(A scientific model cannot include divine intervention.)



"I think you should be more explicit here in step two."

## *Hallmarks of Science: #2*

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

This philosophy of simplicity is often called “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 Principle of Doubt

- Hypotheses can be *rejected* but never completely *confirmed*.
- At best, a theory can be *adequate* for describing a specific set of phenomena.
- Do not trust - verify through experiment.
- Simple theories are preferable to complicated theories (Occam's Razor)
  - Any theory can be made complicated enough to explain anything
  - Elegance and Understanding trump Age and Authority
  - If a theory has its predictions come true, we are obliged to acknowledge its efficacy, even if it means rejecting something we formerly believed.

# Measurement Uncertainty

- No experiment is perfect
- Experimental uncertainty is often the difference between rejecting a hypothesis and an ambiguous result
- It is important to quantify both measurements **AND** their accuracy

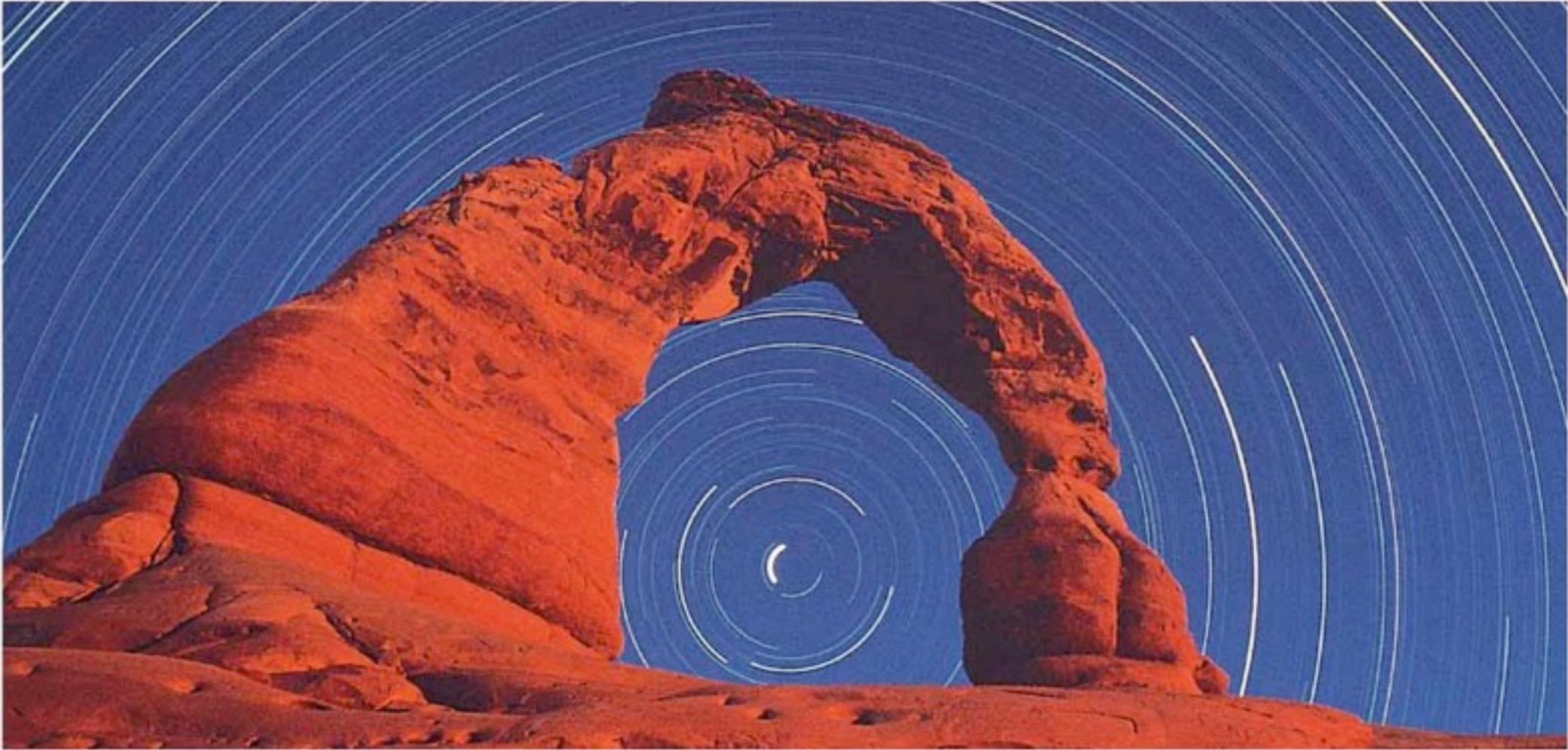
e.g., Newton's constant:

$$G = (6.67428 \pm 0.00067) \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}. \quad (0.01\%)$$

the distance to the center of the Milky Way

$$R_0 = 26,000 \pm 2,000 \text{ light years} \quad (8\%)$$

# The Appearance of the Sky



## 2.1 Patterns in the Night Sky

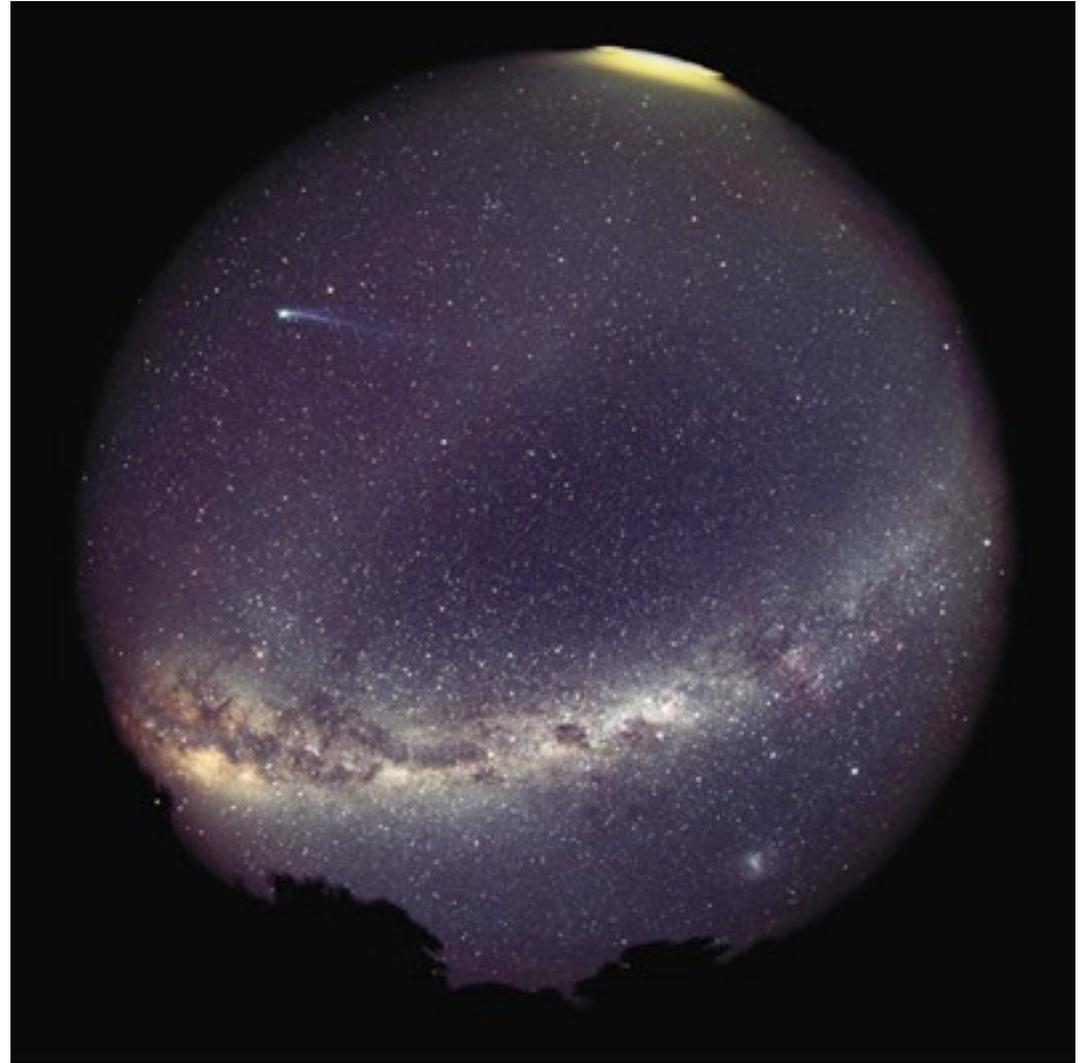
### Our goals for learning:

- What does the universe look like from Earth?
- Why do stars rise and set?
- Why do the constellations we see depend on latitude and time of year?

*Launch Stellarium*

# What does the universe look like from Earth?

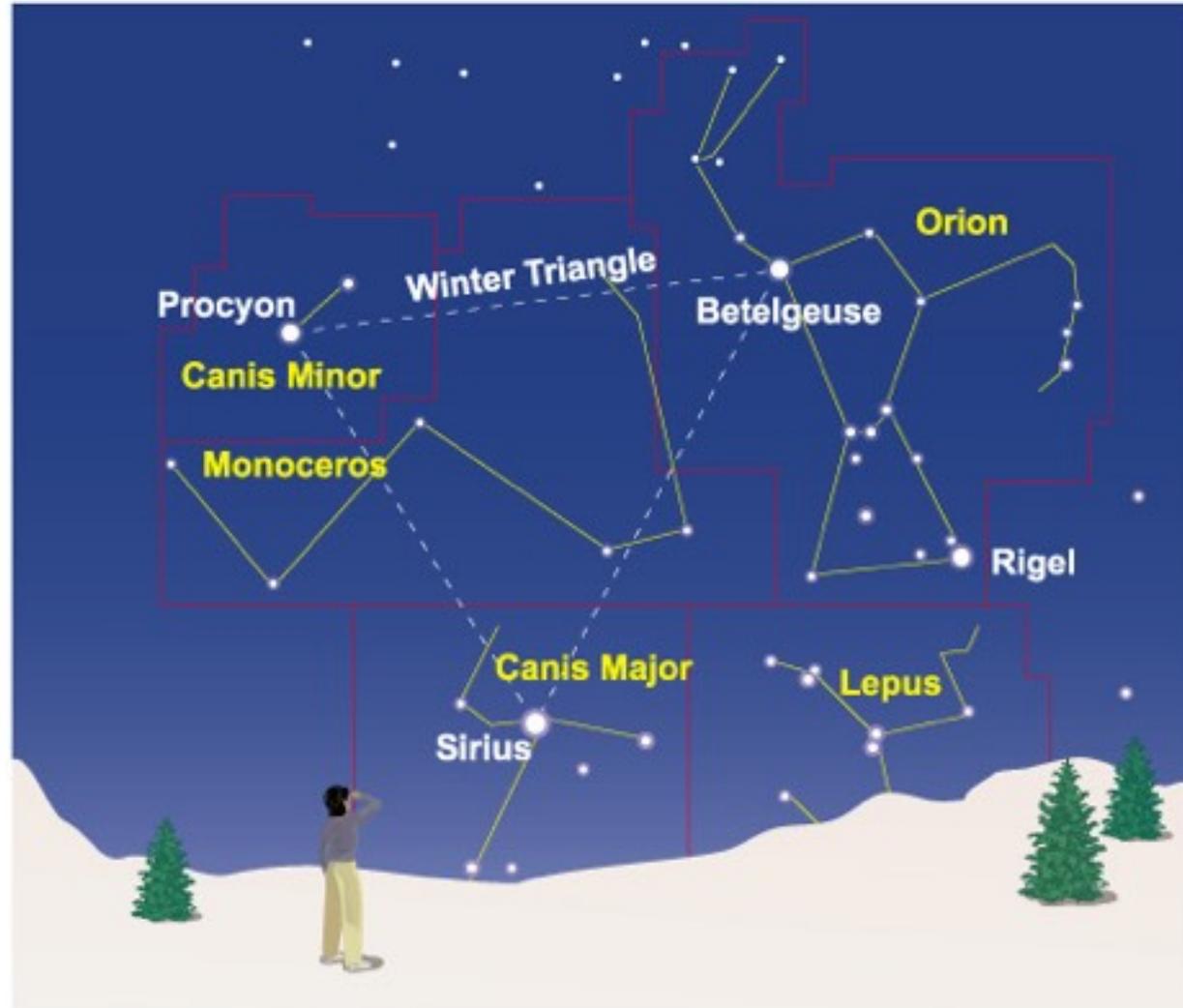
With the naked eye, we can see more than 2,000 stars as well as the Milky Way.



# Constellations

A constellation is a *region* of the sky.

88 constellations fill the entire sky.

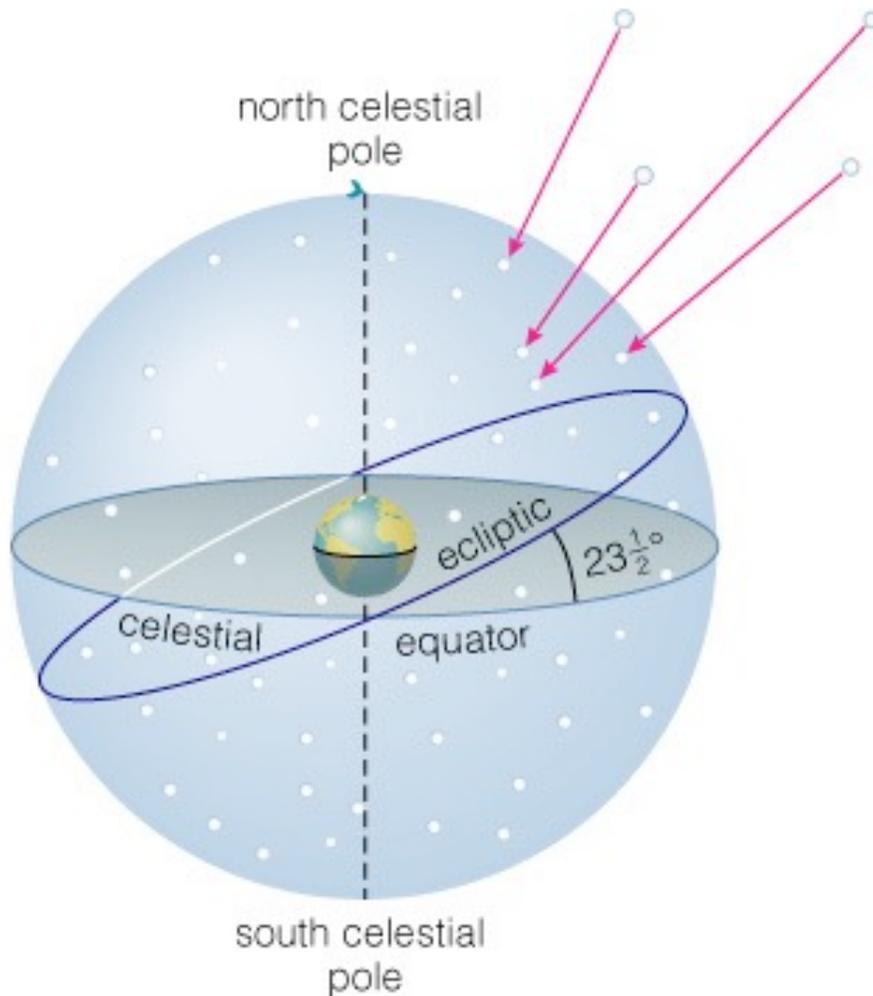


# Thought Question

The brightest stars in a constellation...

- all belong to the same star cluster.
- all lie at about the same distance from Earth.
- **may actually be quite far away from each other.**

# The Celestial Sphere



Stars at different distances all appear to lie on the celestial sphere.

The ecliptic is the Sun's apparent path through the celestial sphere.

# The Celestial Sphere

The 88 official constellations cover the celestial sphere.

The celestial sphere is like a globe of the earth - the 2D surface of a sphere that maps where things are.

BUT we look up at it from the inside rather than down on it from above. East & West get flipped like left and right in a mirror.

