Today

A little more scale…

The Scientific Method

Naked Eye Observations:
the Appearance of the Sky

The "student set" for Smartwork5 is 40700, which is labeled CWRU_ASTR201_Fall207.
Add yourself to this set after you sign in and you should be able to see the electronic portion of the homework assignments.

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!

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

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

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

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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)

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Light travel time & distance

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

Destination	Light travel time
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.

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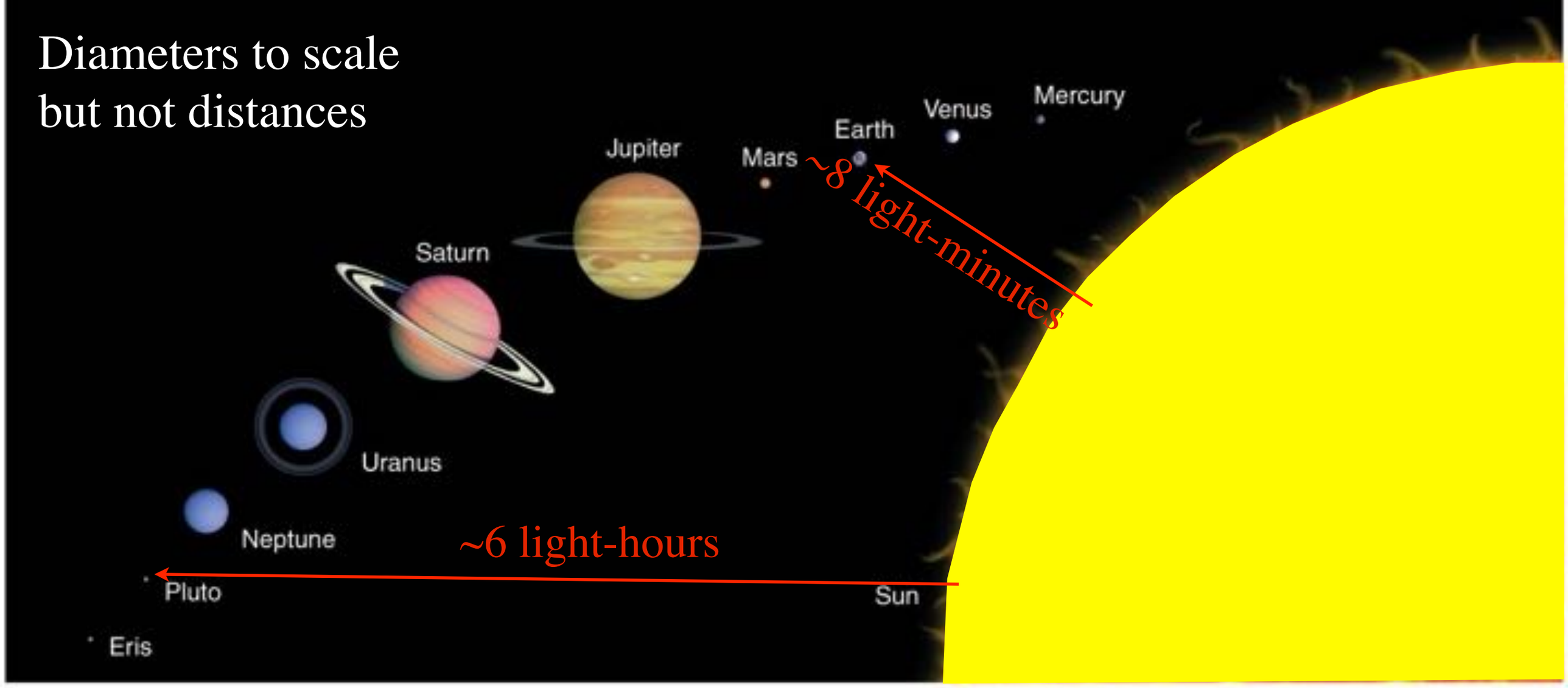
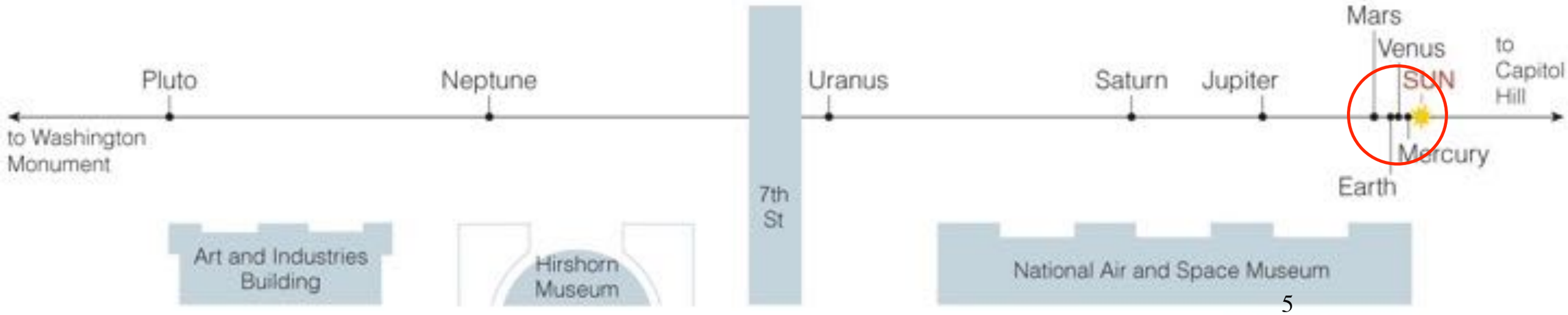
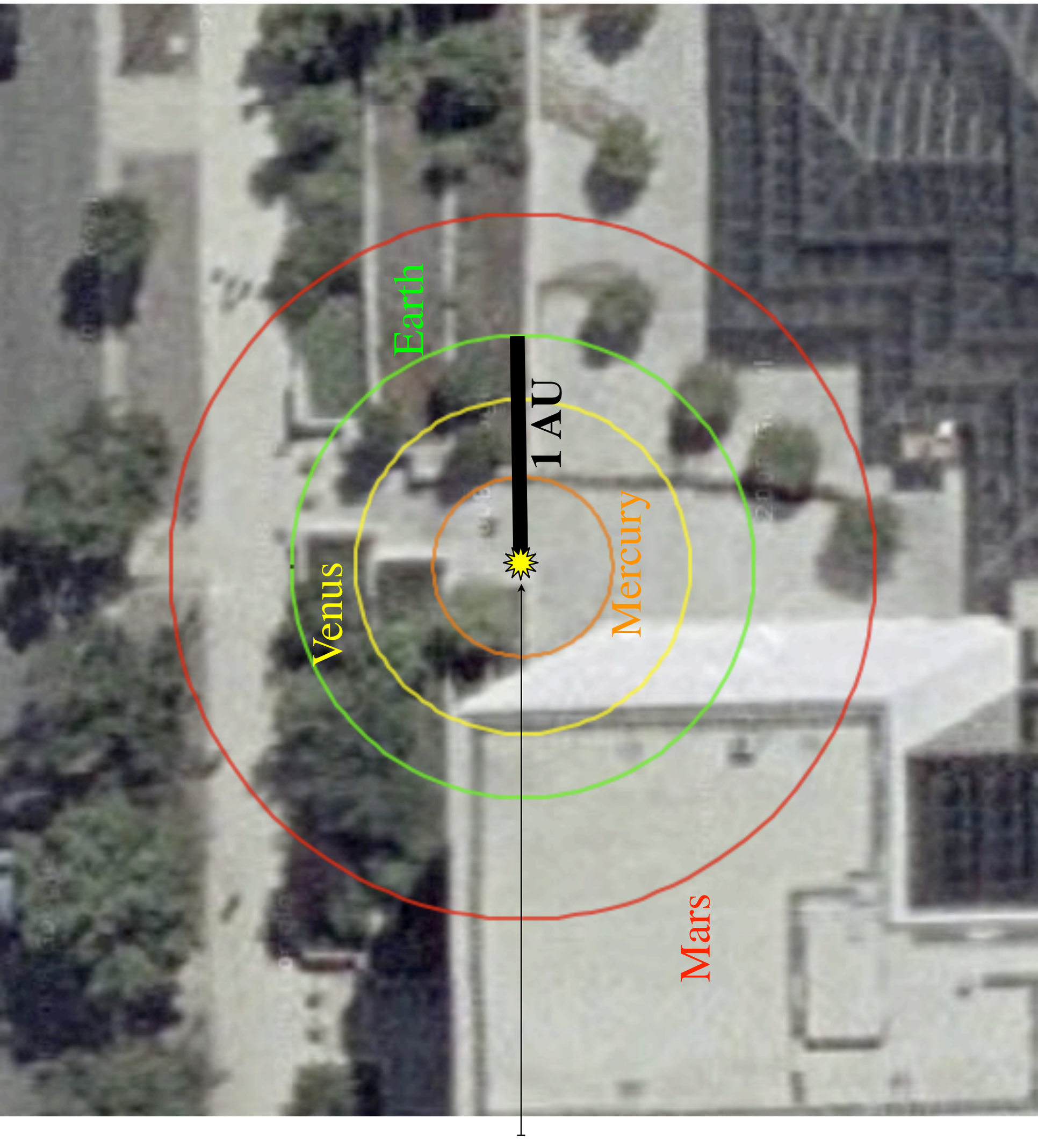
Diameters to scale
but not distances



Distances to scale:

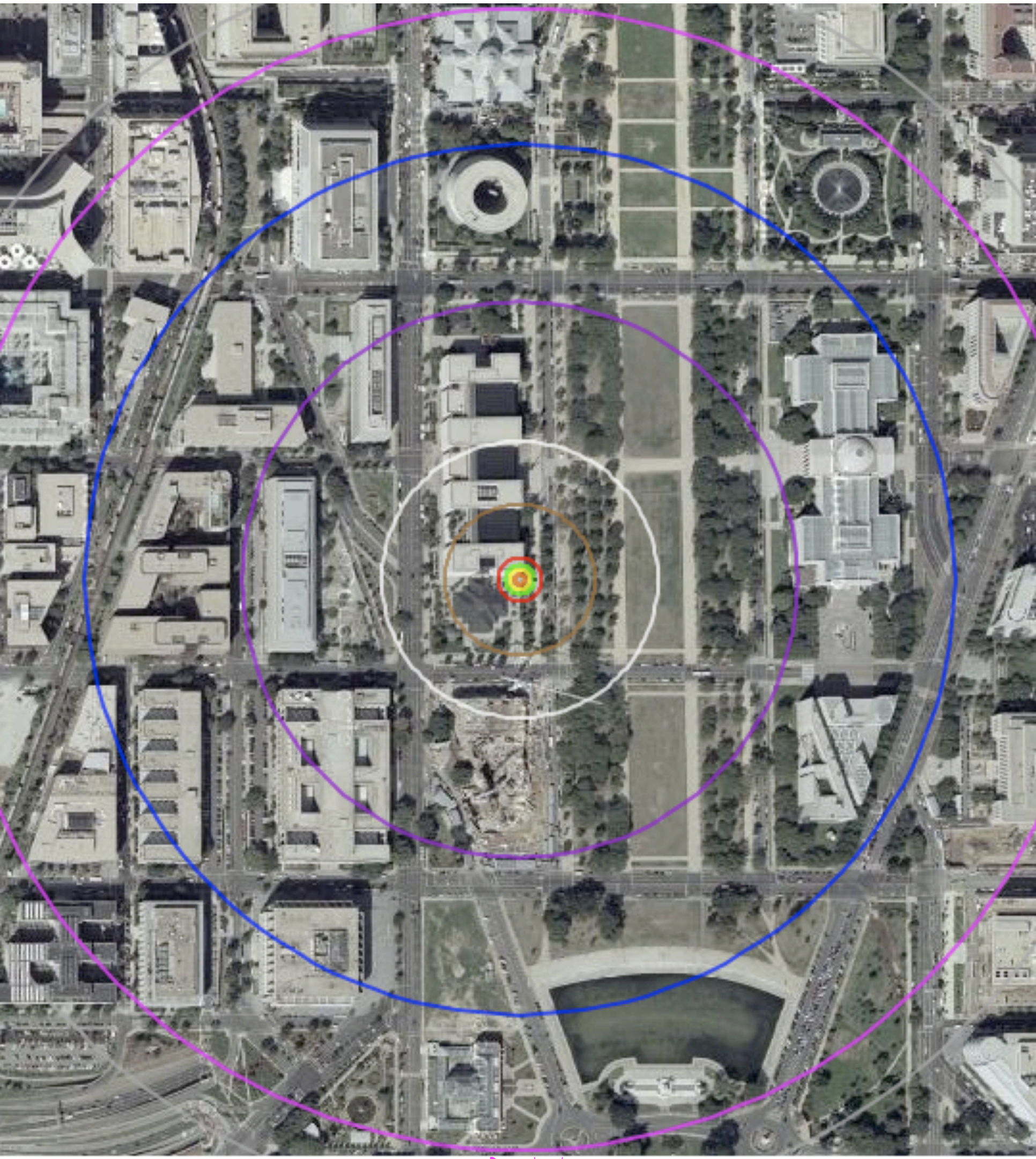


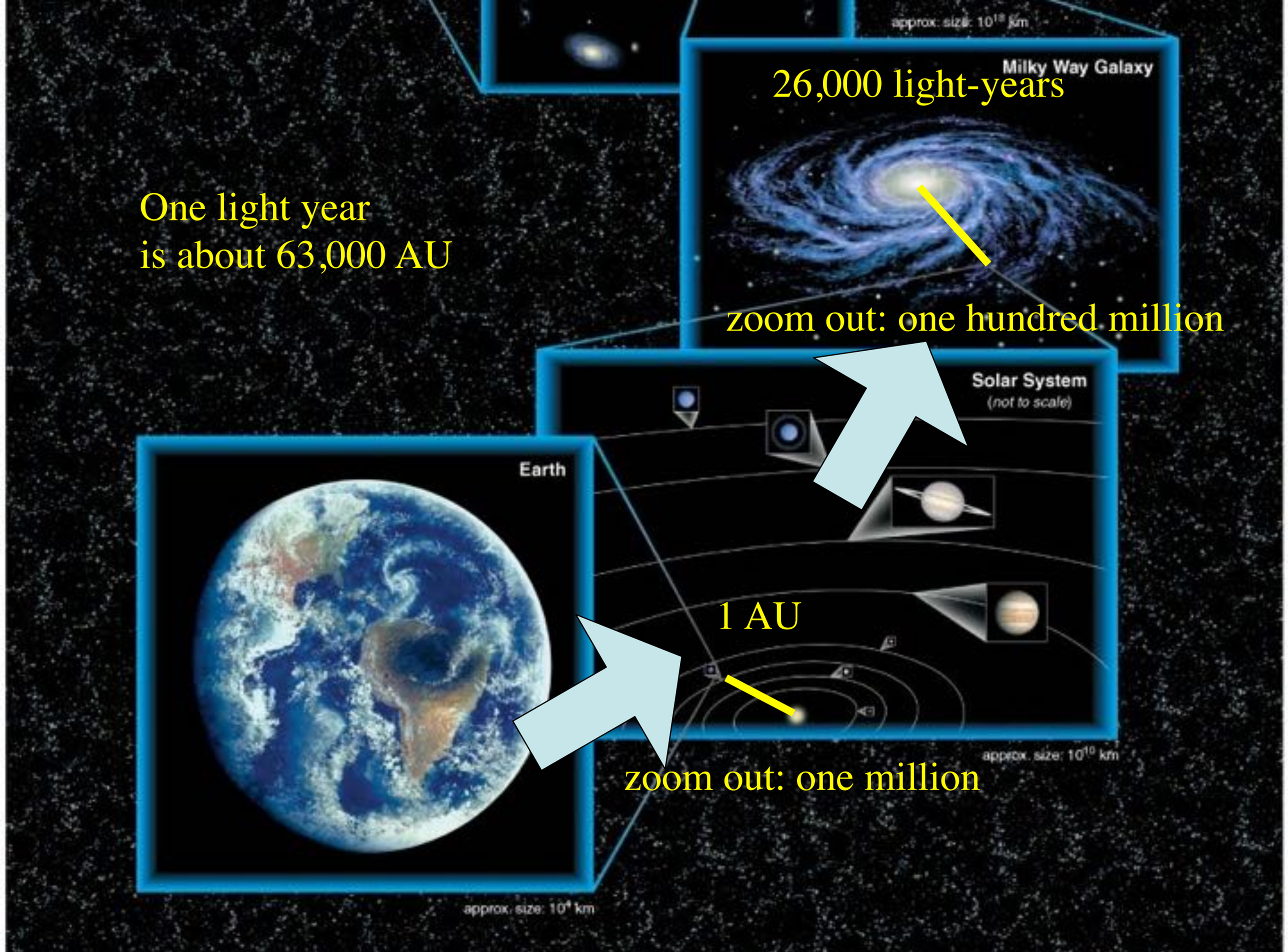
AU = Astronomical Unit



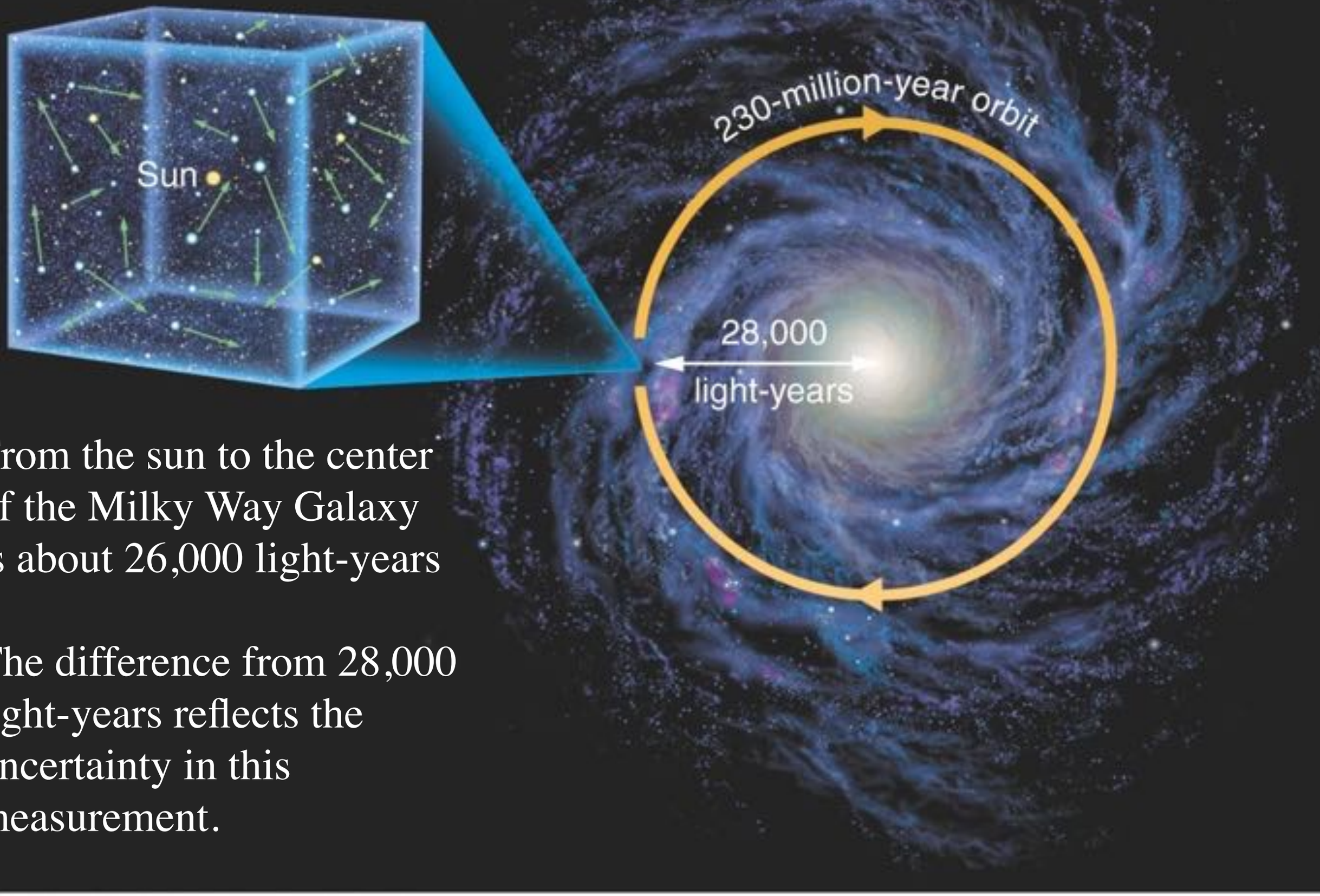
The sun is 13 cm in diameter on this scale

To same scale





26,000 light-years
Milky Way Galaxy
One light year
is about 63,000 AU
zoom out: one hundred million
Solar System
(not to scale)
Earth
1 AU
zoom out: one million
approx. size: 10^10 km
approx. size: 10^4 km



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.

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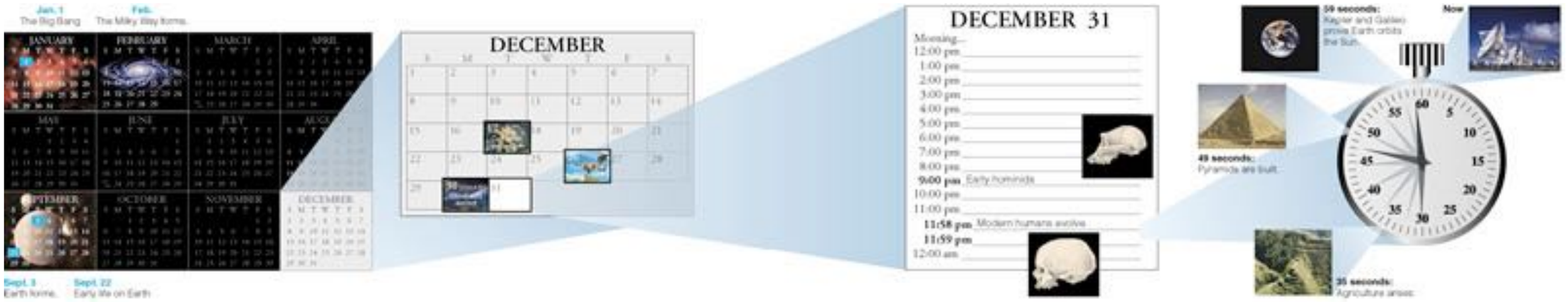
Space is Huge; Time is Deep: The Universe is Ancient

- 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.

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THE HISTORY OF THE UNIVERSE IN 1 YEAR

January 1: The Big Bang

February: The Milky Way forms

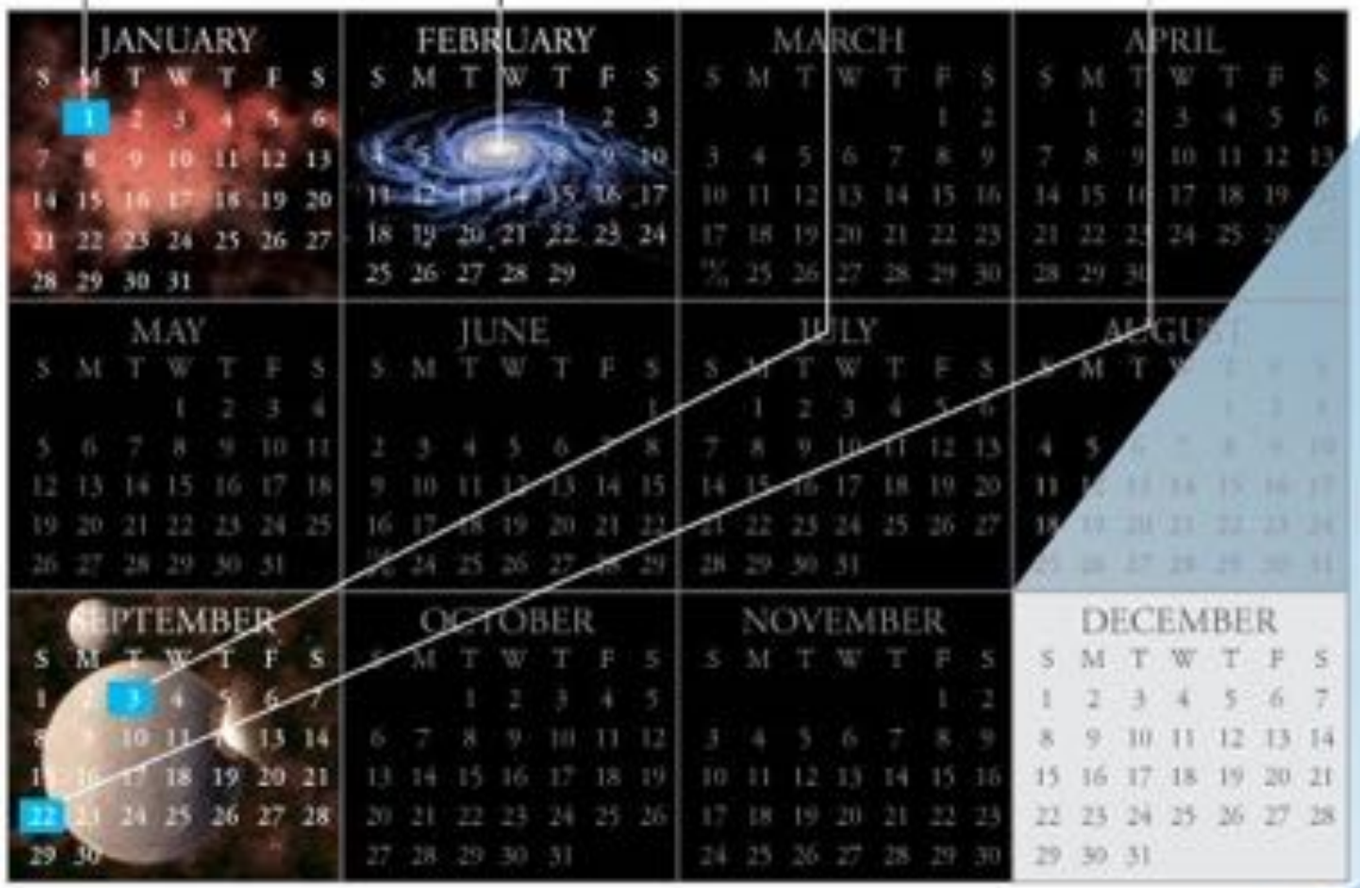
September 3: The Earth forms

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

No w

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

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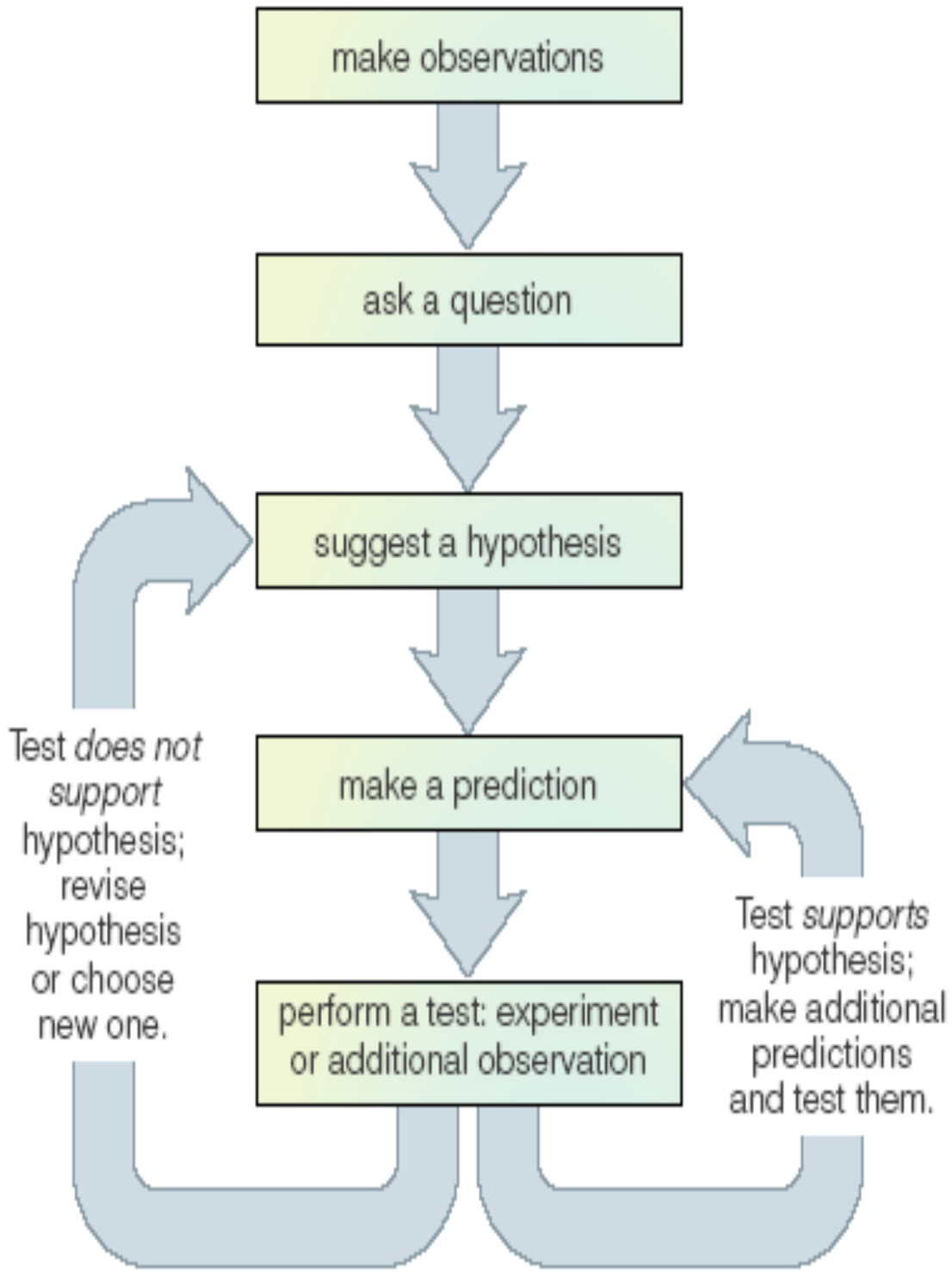
Astronomy covers, well, astronomical scales:

- 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



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The idealized scientific method:

- Based on proposing and testing hypotheses

Facts are the results of observation or measurement.

A scientific hypothesis is an idea that leads to testable or falsifiable predictions.

A theory is a well-developed group of ideas that is tied to known physical laws and makes testable predictions.

Well-established theories (e.g., Darwin's theory of evolution, Einstein's theory of relativity) have passed many tests and are widely accepted

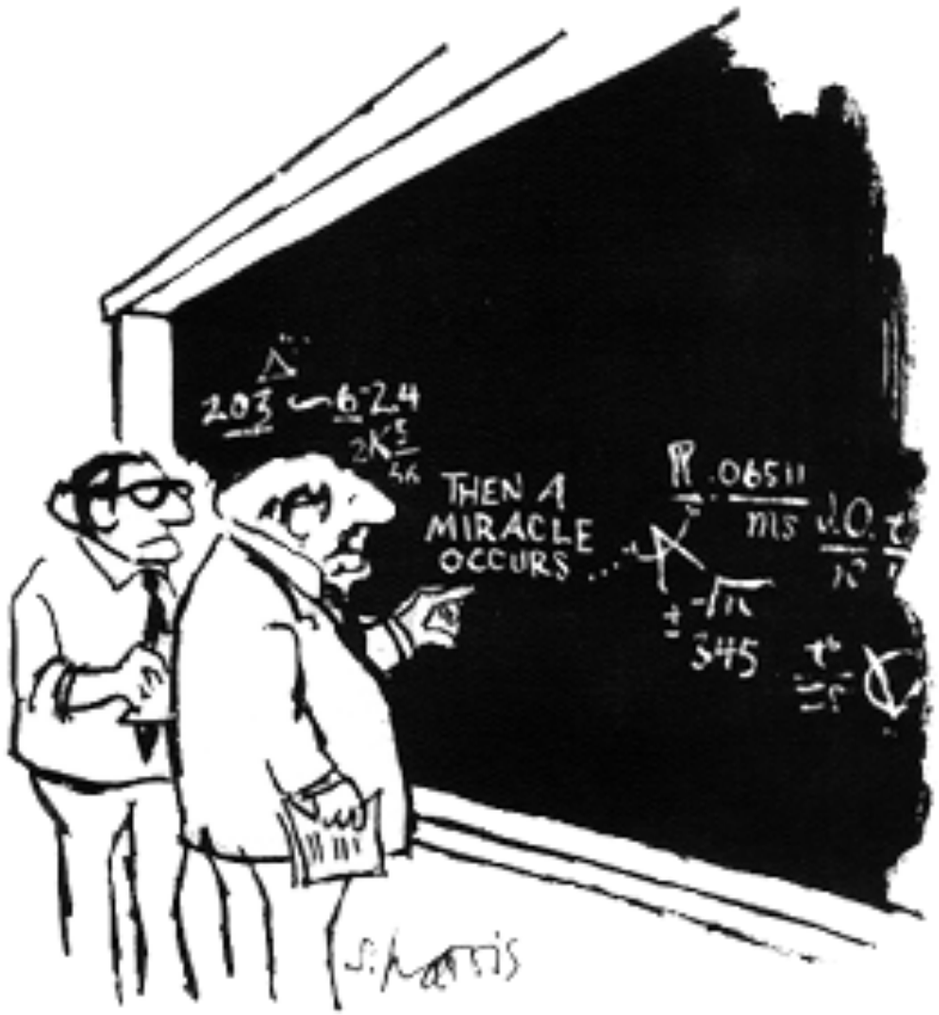
but theories remain subject to revision or rejection if they fail to explain new tests.

Hallmarks of Science: #1

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

(A scientific model cannot include divine intervention.)

No magic!



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

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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”

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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.

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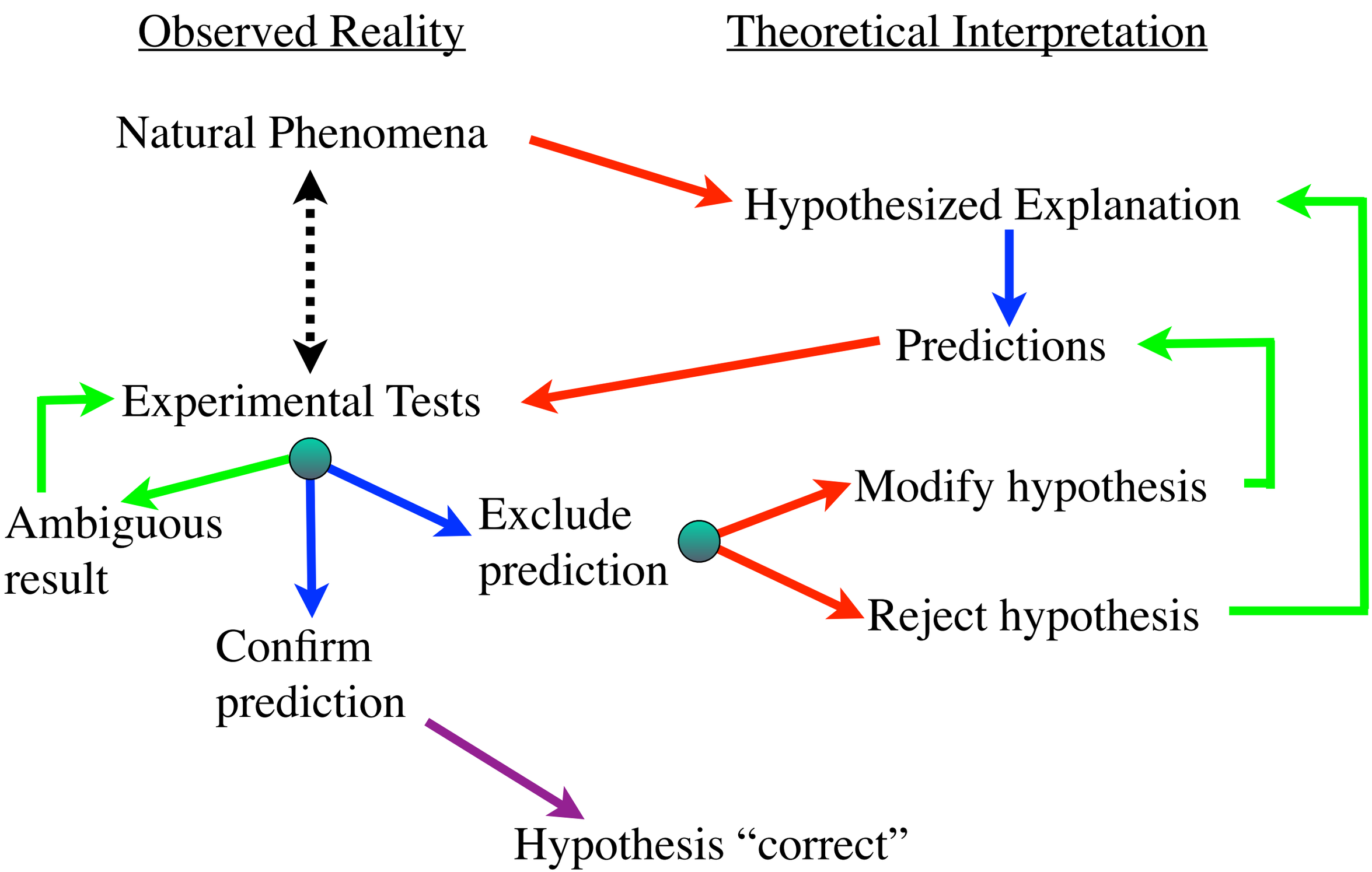
Hypothesis Testing



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

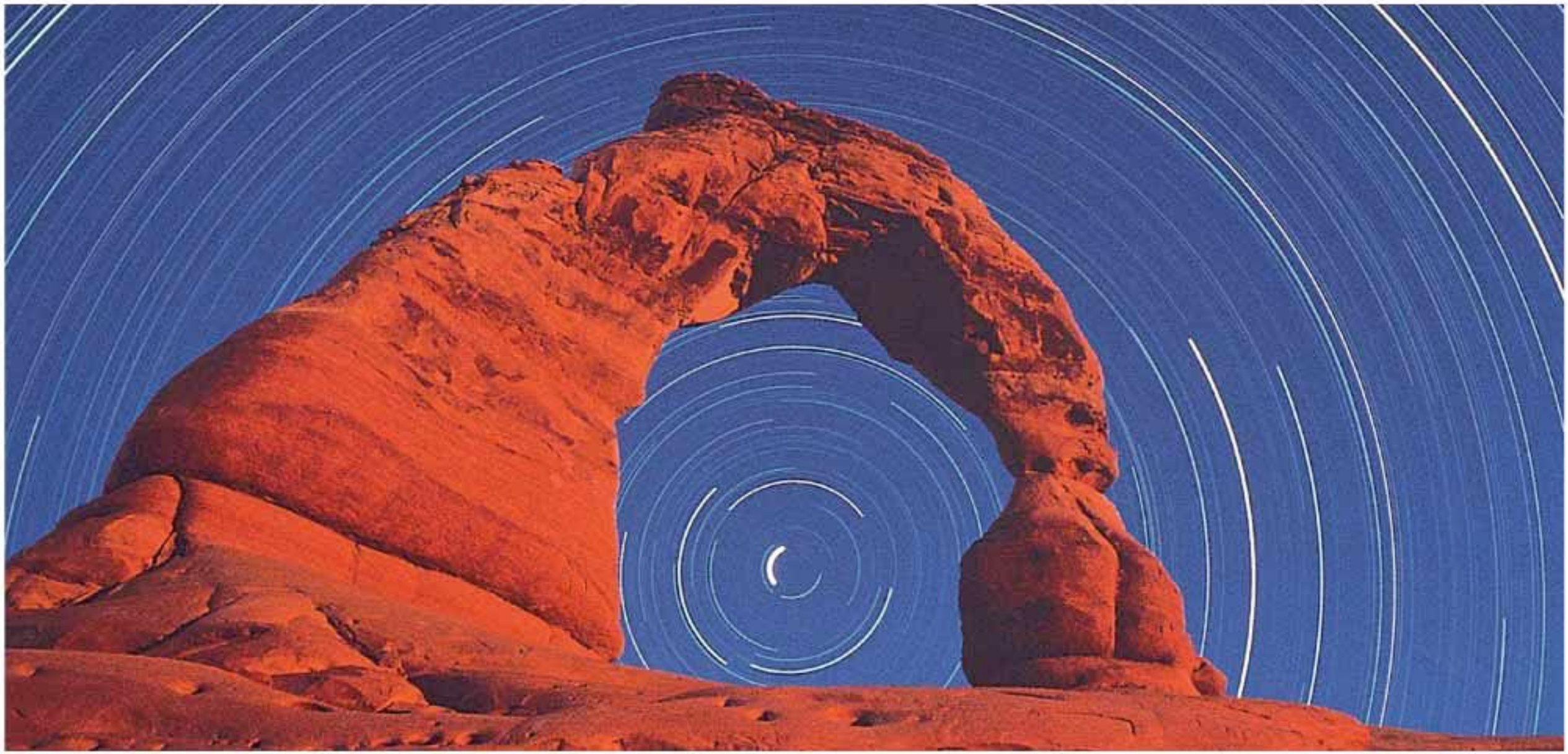
e.g., Newton's constant:

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

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



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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?

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