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

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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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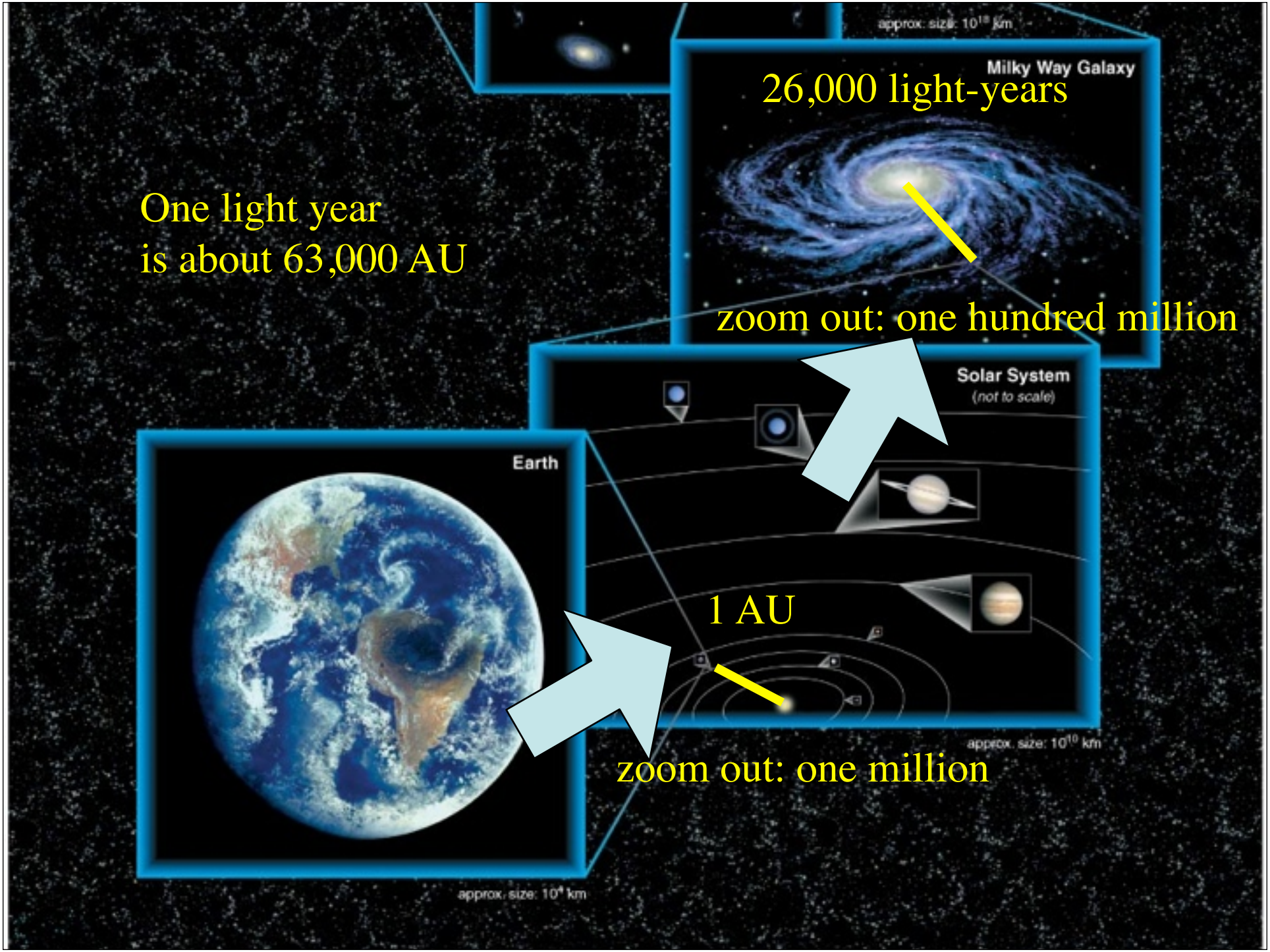
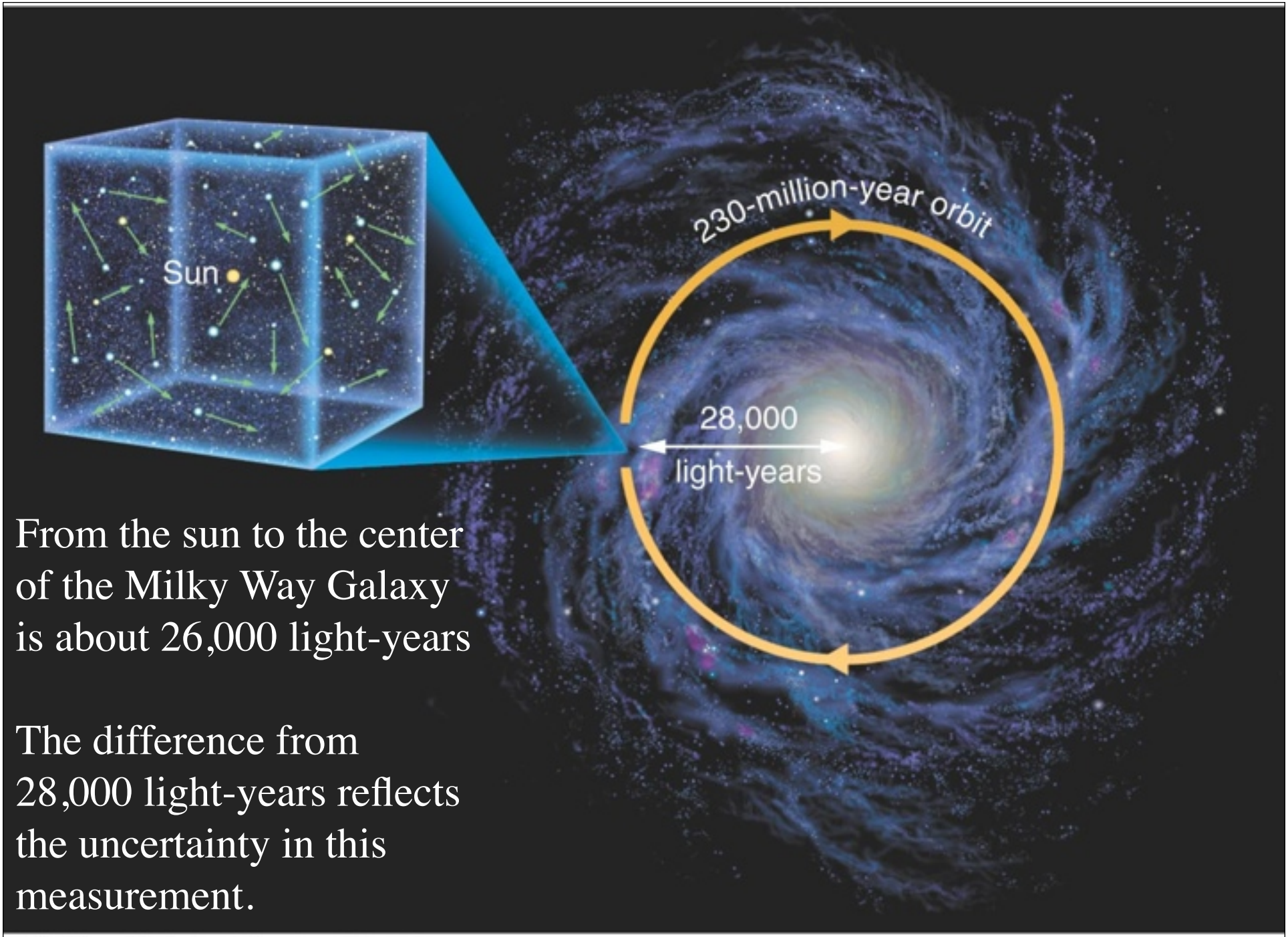

Milky Way Galaxy
26,000 light-years
One light year
is about 63,000 AU
zoom out: one hundred million
Solar System
(not to scale)
Earth
1 AU
zoom out: one million



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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Question of Scale

Which of the following is in **increasing** order of size?

A. Galaxy, Earth, Solar System, Universe

B. Earth, Solar System, Galaxy, Universe

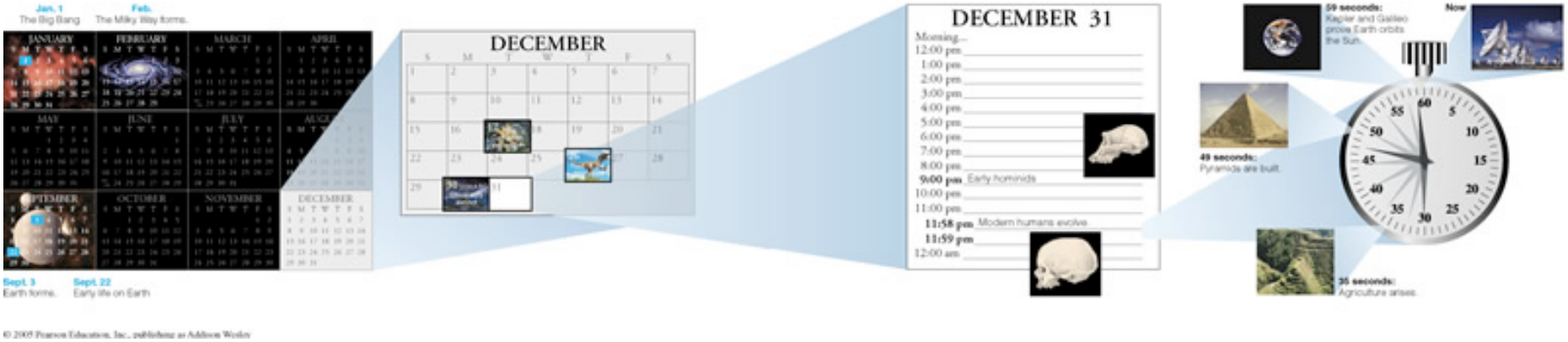
C. Solar System, Universe, Galaxy, Earth

D. Universe, Earth, Galaxy, Solar System

E. I don't know

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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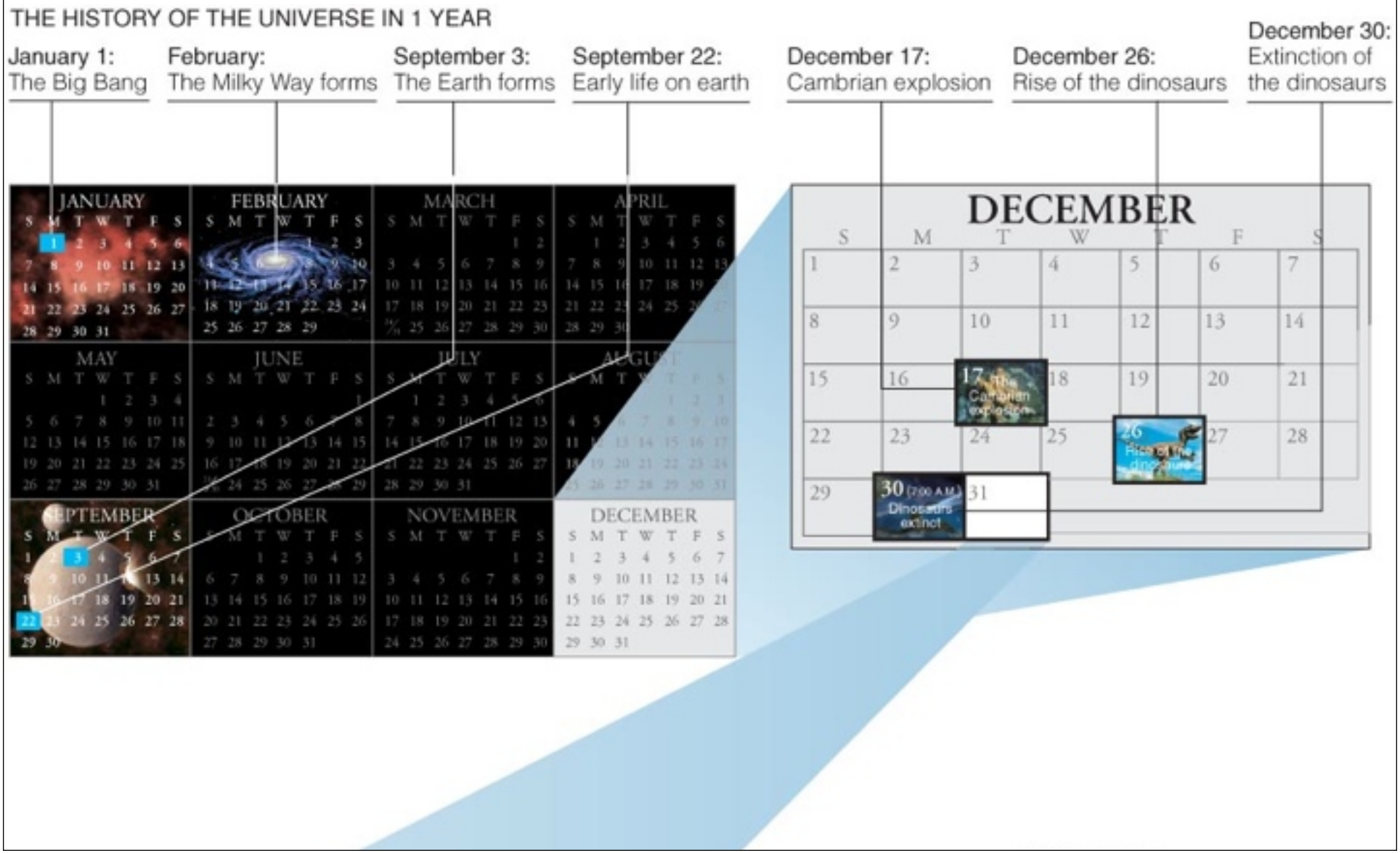
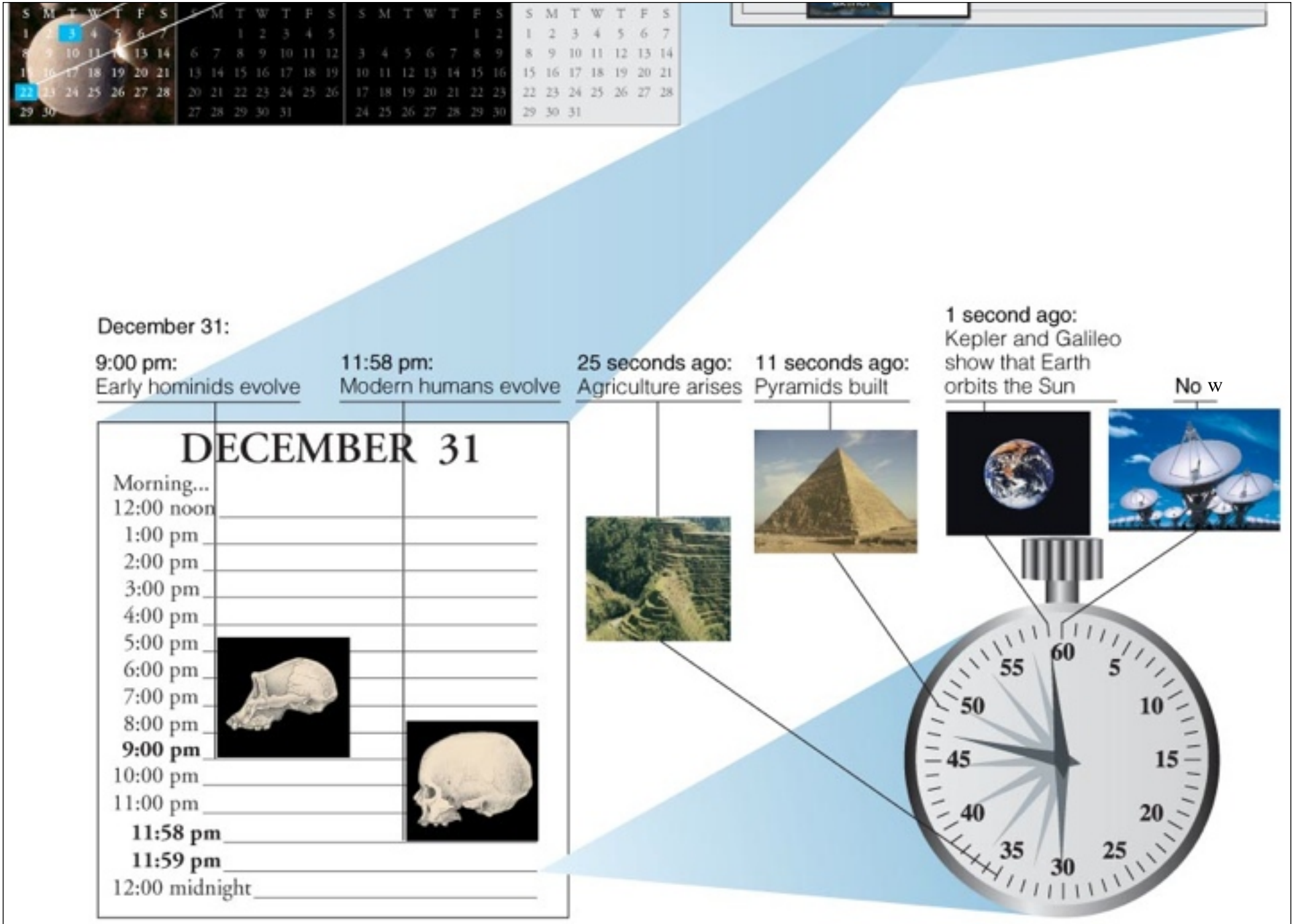

THE HISTORY OF THE UNIVERSE IN 1 YEAR
January 1:
The Big Bang
February:
The Milky Way forms
September 3:
The Earth forms
September 22:
Early life on earth
December 17:
Cambrian explosion
December 26:
Rise of the dinosaurs
December 30:
Extinction of
the dinosaurs
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
DECEMBER
S M T W T F S
1 2 3 4 5 6 7
8 9 10 11 12 13 14
15 16 17 18 19 20 21
22 23 24 25 26 27 28
29 30 31
17
26
30 (7:00 A.M.)
Dinosaurs extinct



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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

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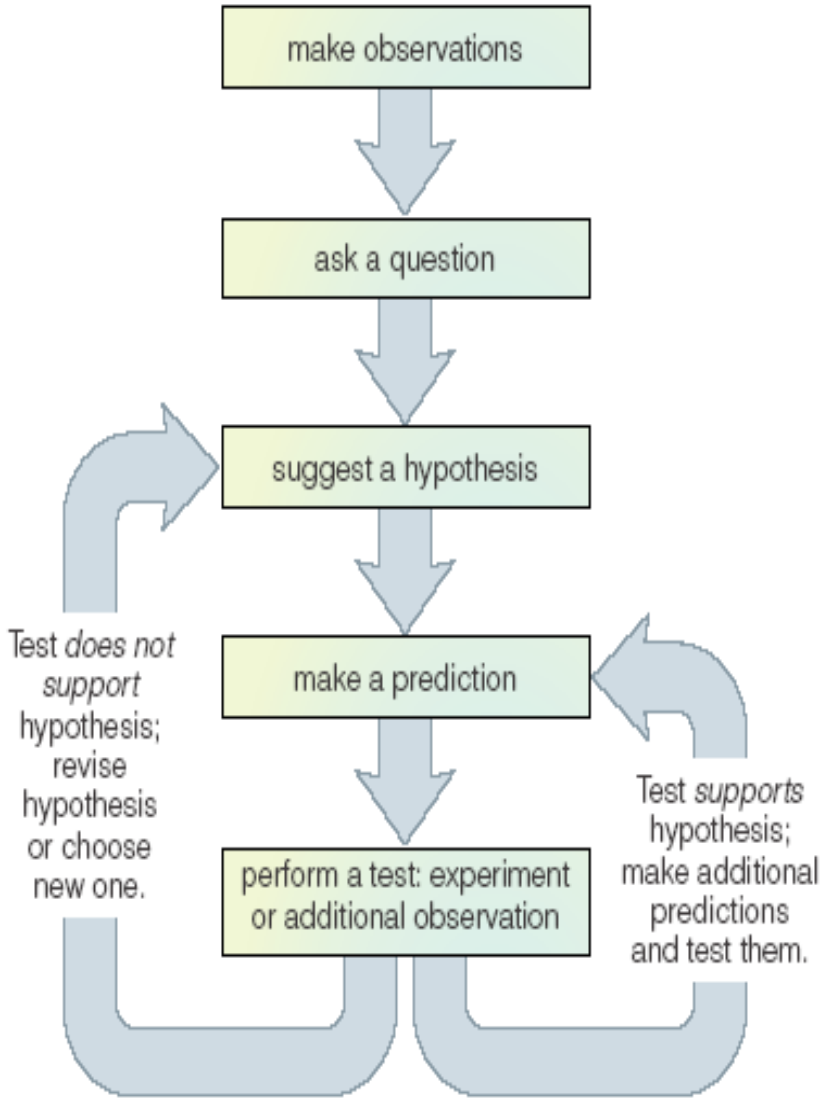
The Scientific Method

A few necessary ASSUMPTIONS:

- There exists an objective, knowable Reality
- 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



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<u>The idealized scientific method:</u>

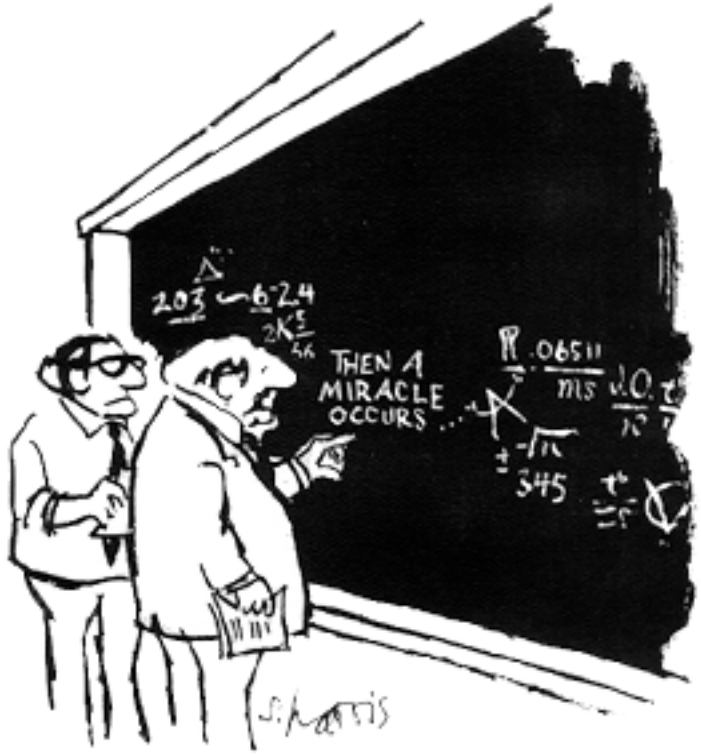
- Based on proposing and testing hypotheses
- **hypothesis** = educated guess

(text, chapter 3.4)

Hallmarks of Science: #1

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

(Divine intervention could be arbitrary and unknowable, hence cannot be used in a scientific model)



"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 “Ockham’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.

The falsifiability requirement

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Scientific Hypotheses

Which of these is a scientific hypothesis?

A. The undetectable Flying Spaghetti Monster is in this room

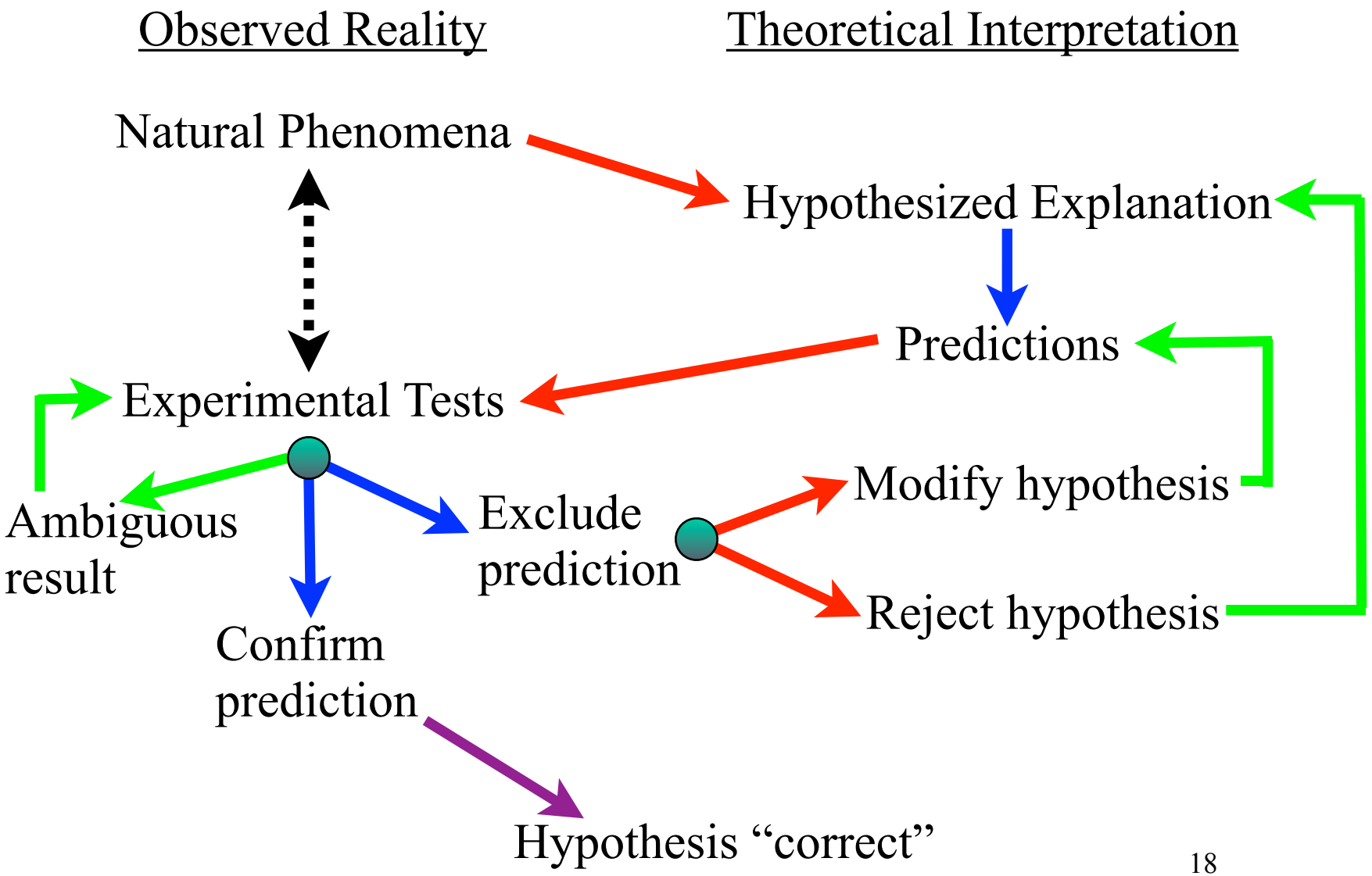
B. A given mathematical conjecture is true

C. Newtonian gravity works on all scales

D. Maryland fans are better-looking than Duke fans

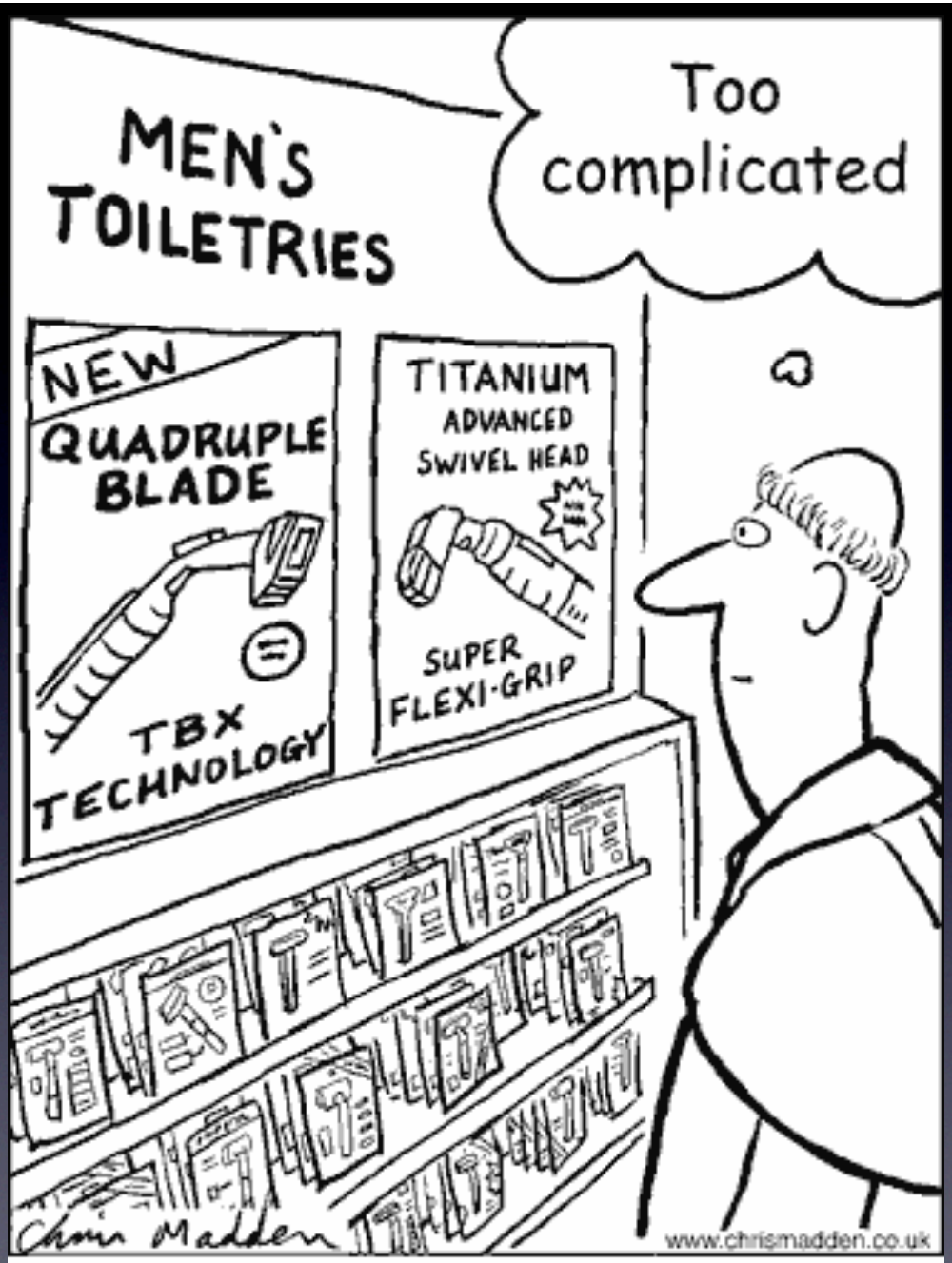
E. I don't know

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 (Ockham'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.



Ockham chooses a razor

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

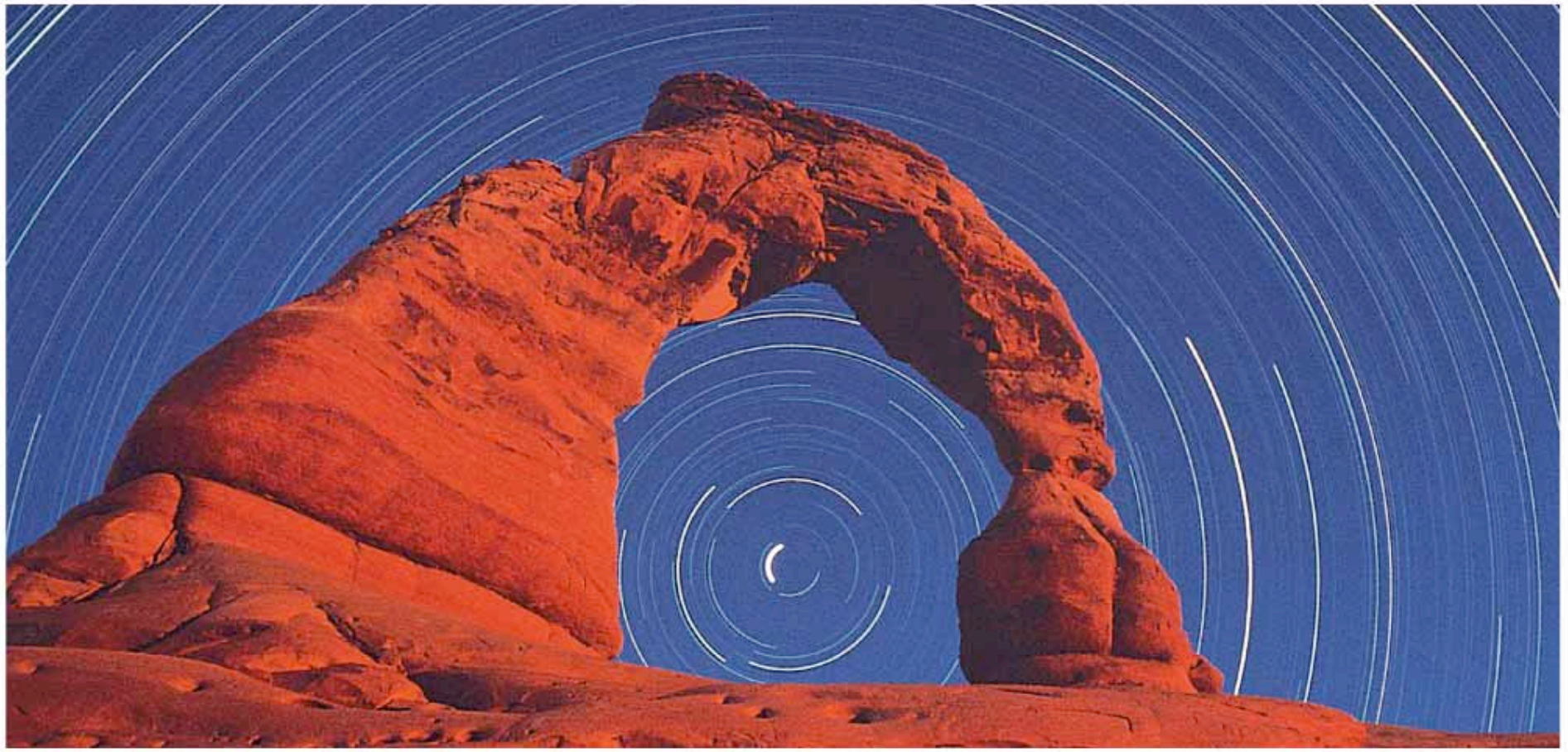
e.g., Newton's constant:

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

the distance to the center of the Milky Way

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

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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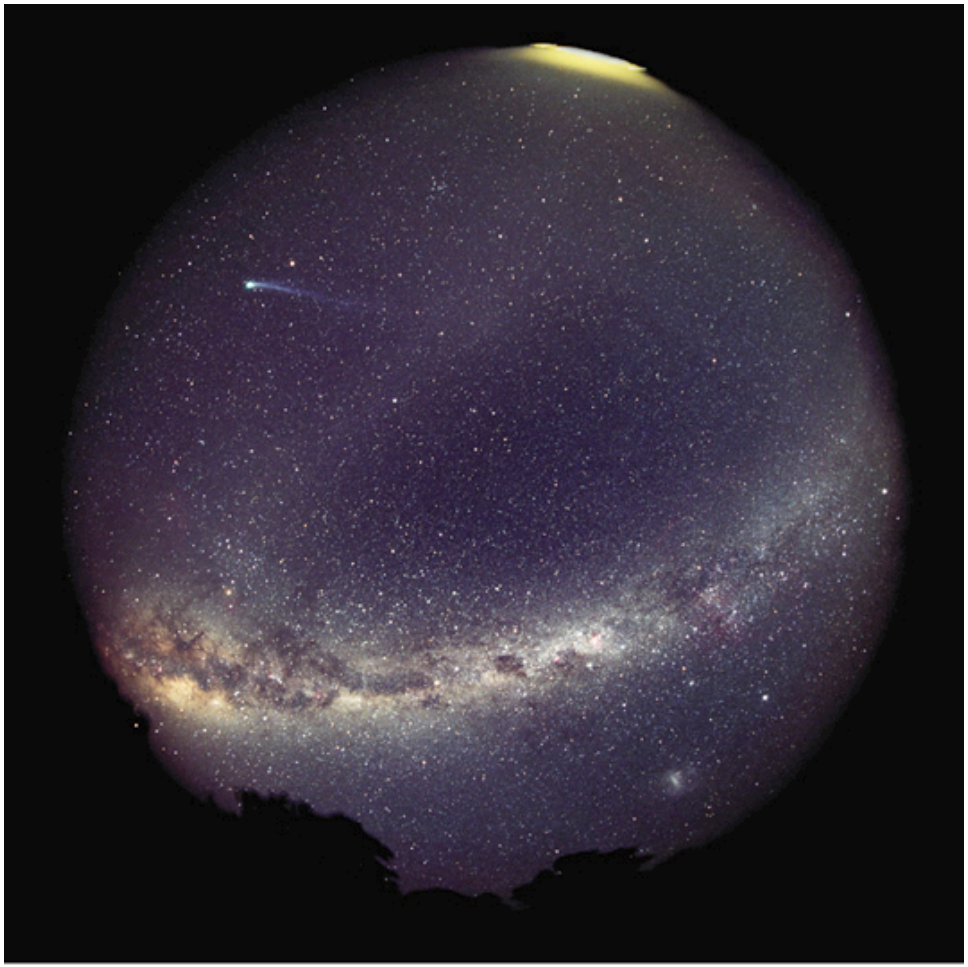
What does the universe look like from Earth?

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



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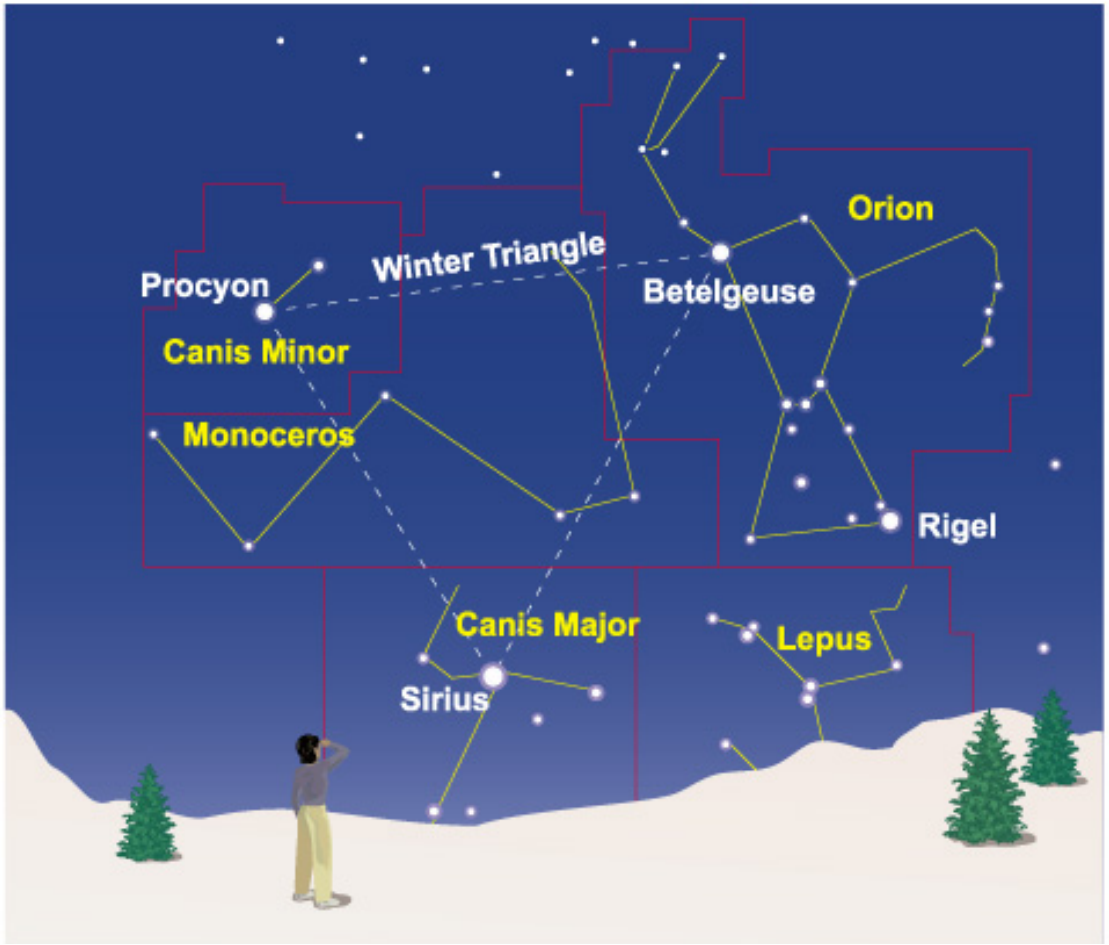
Constellations

A constellation is a *region* of the sky.

88 constellations fill the entire sky.



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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.

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Thought Question

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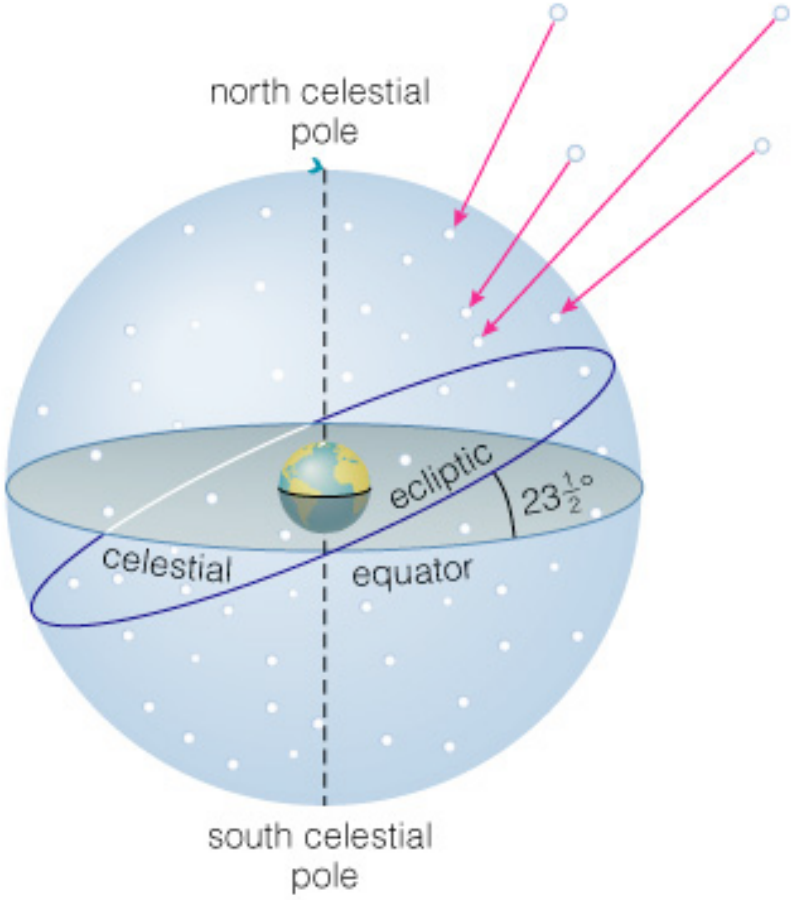
The Celestial Sphere



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

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

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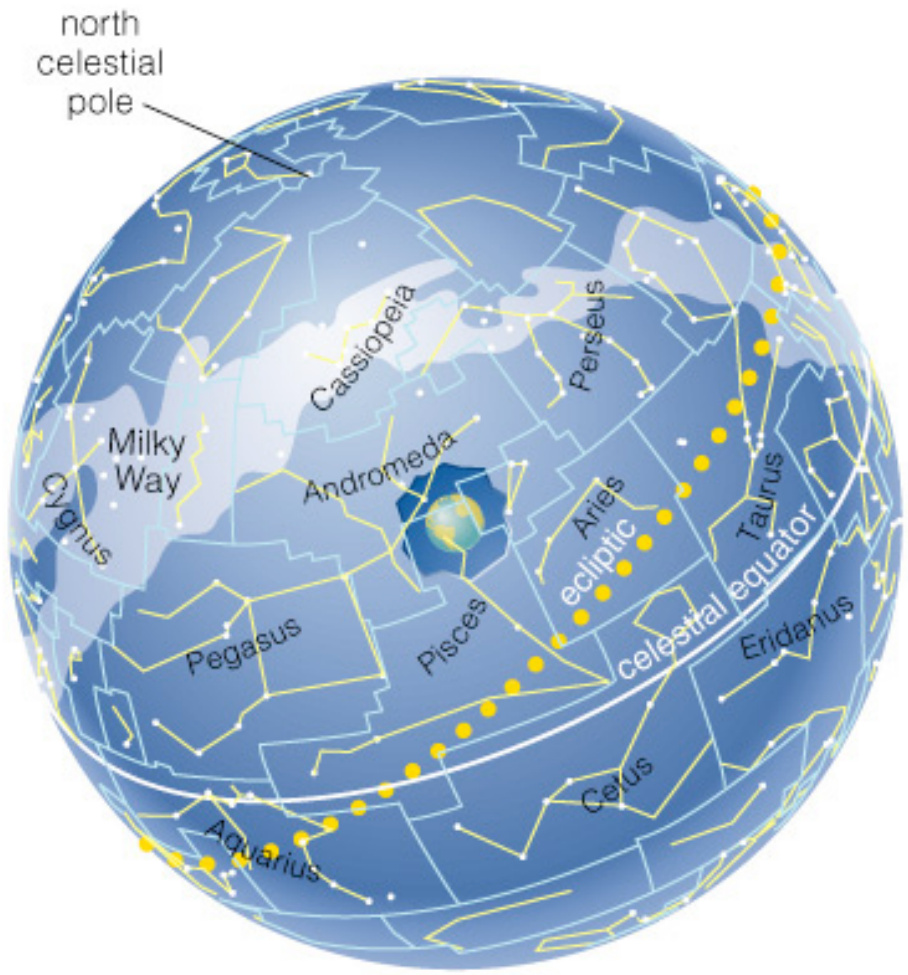
The Celestial Sphere



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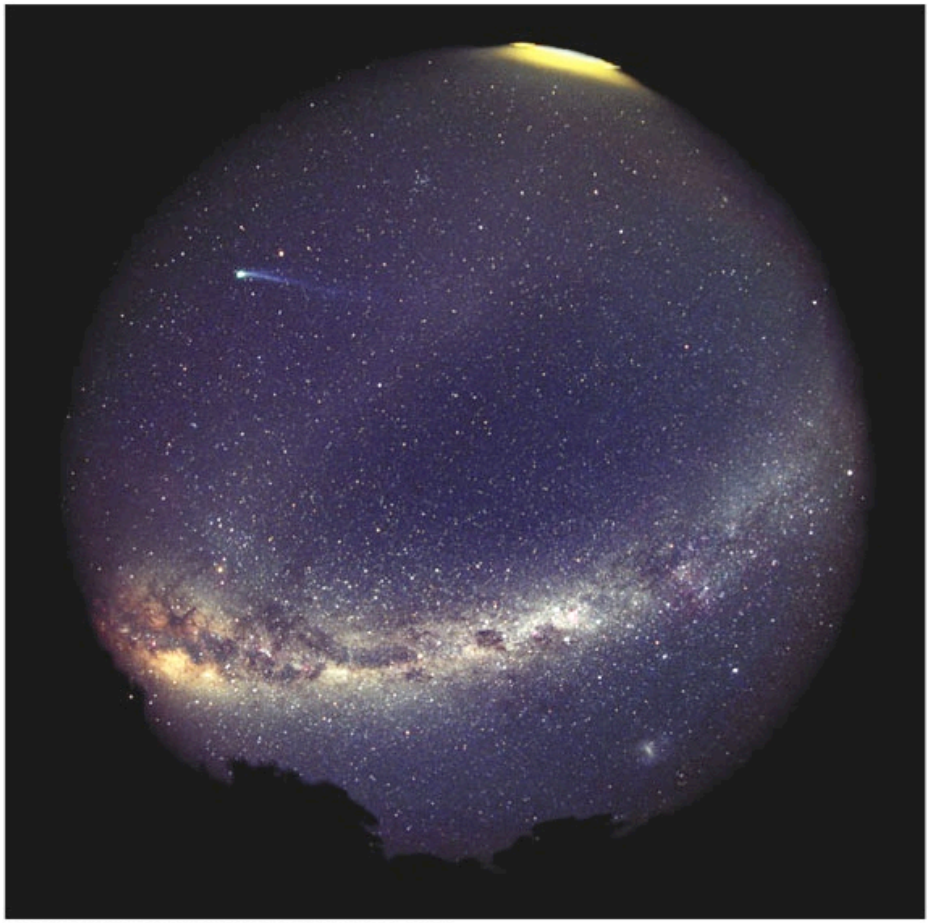
The 88 official constellations cover the celestial sphere.

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.

The Milky Way



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A band of light that makes a circle around the celestial sphere.

What is it?

Our view into the plane of our galaxy.

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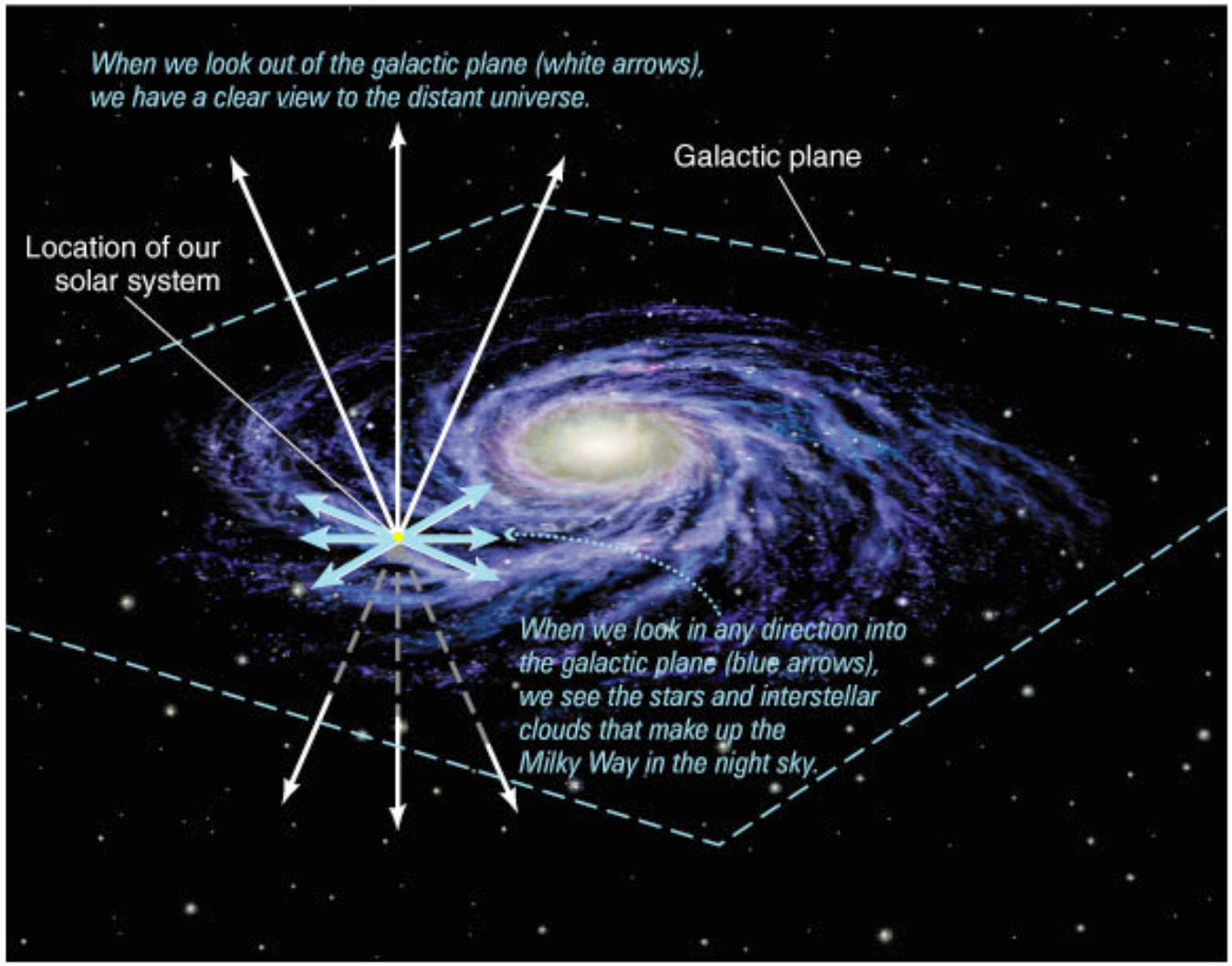
The Milky Way



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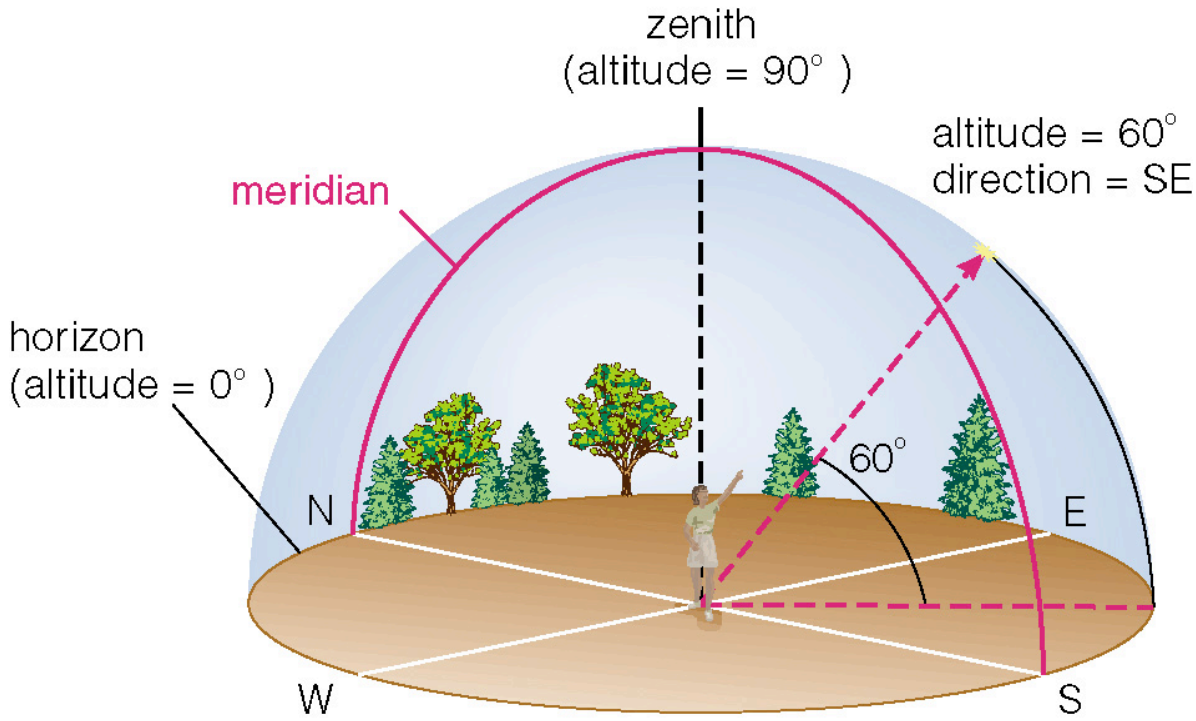
The Local Sky

An object's **altitude** (above horizon) and **direction** (along horizon) specify its location in your local sky.



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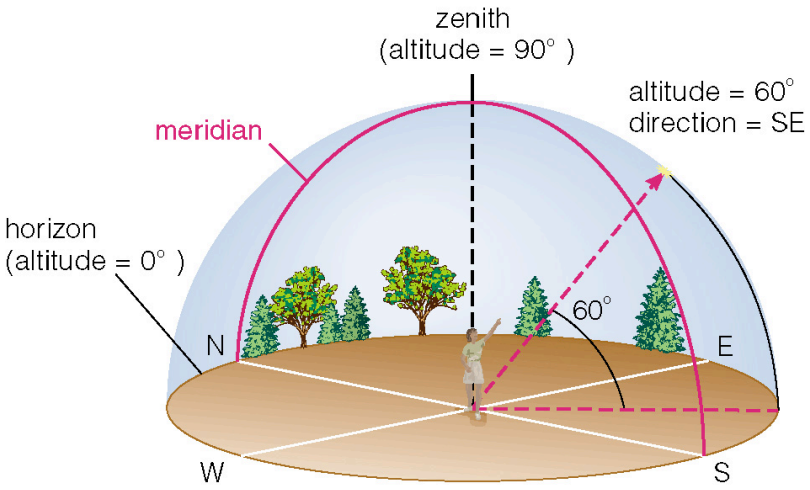
The Local Sky



Zenith: The point directly overhead

Horizon: All points 90° away from zenith

Meridian: Line passing through zenith and connecting N and S points on the horizon

Hence AM and PM: the sun before and after the meridian

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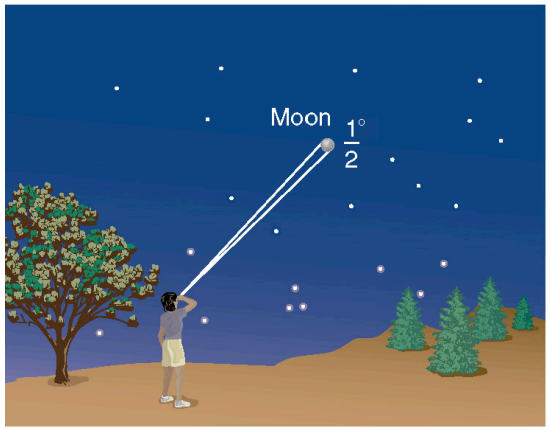
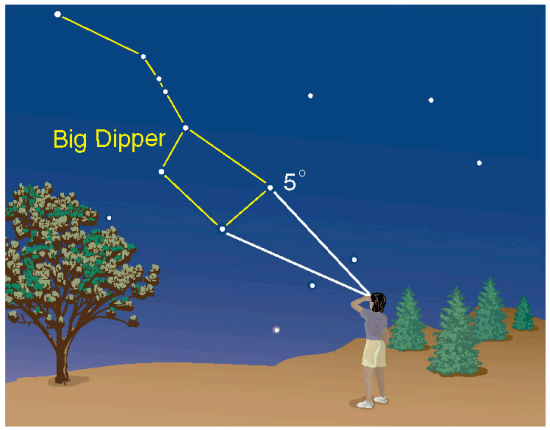
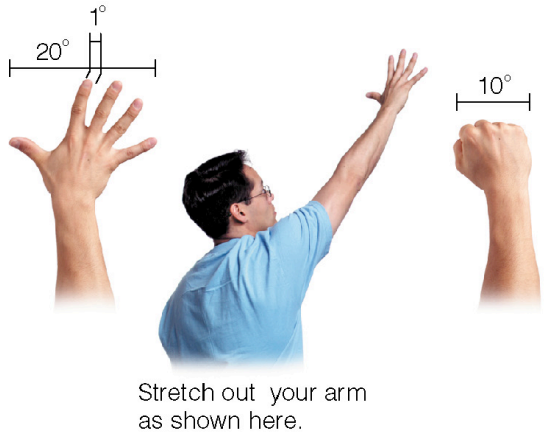
We measure the sky using *angles*







The Celestial Sphere is a projection of the 3D universe onto the 2D sky. We don't know how far a star is just by looking at it (that's the suppressed dimension). What we easily notice is the angular separation between stars - the 2D sky celestial sphere.

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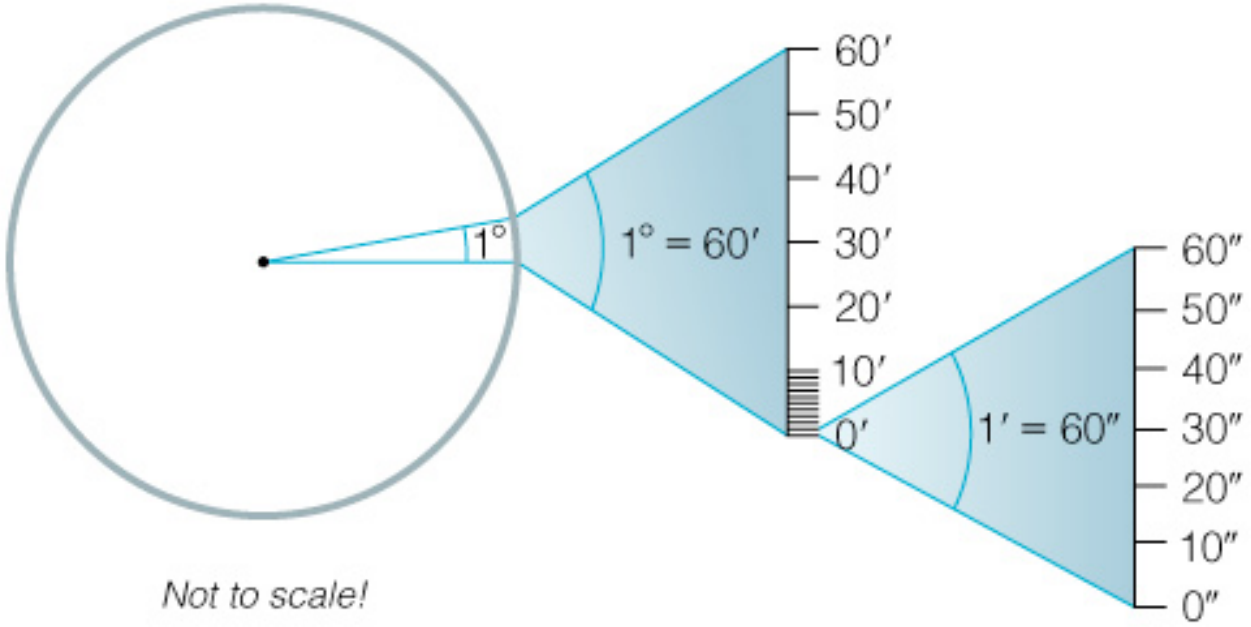
Angular Measurements

- Full circle = 360º
- 1º = 60′ (arcminutes)
- 1′ = 60″ (arcseconds)



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Thought Question

The angular size of your finger at arm's length is about 1°. How many arcseconds is this?

- 60 arcseconds
- 600 arcseconds
- $60 \times 60 = 3{,}600$ arcseconds

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Thought Question

The angular size of your finger at arm's length is about 1°. How many arcseconds is this?

- 60 arcseconds
- 600 arcseconds
- **60 × 60 = 3,600 arcseconds**

1 degree = 60 arcminutes = 60 x (60 arcseconds)

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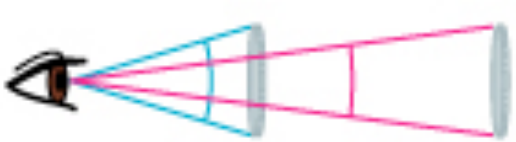
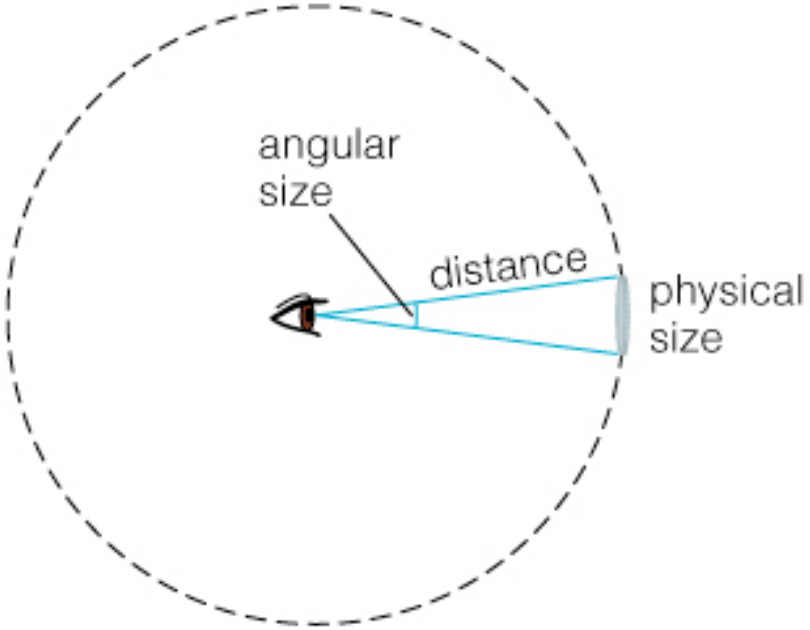
Angular Size

$$\text{angular size} = \text{physical size} \times \frac{360 \text{ degrees}}{2\pi \times \text{distance}}$$



An object's angular size appears smaller if it is farther away.



$$\theta = L/D$$

$$\text{angular size (in radians)} = \frac{\text{physical size}}{\text{distance}}$$

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Summary

- The universe is old as well as big!
- The scientific method favors simplicity and testability
- The night sky appears as a surface, but some apparently near things are actually at much different distances

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