Astronomy and the Universe

- **Goals:**
  - To understand the methods scientists use to study astrophysical problems.
  - To understand how studying the stars, and galaxies tells us about how the universe was created.
  - To use angles to measure size and distance.
- **Scientific method**
  - Foundations of modern astronomy are built on the laws of physics.
  - With only one view of the universe we must assume that these laws hold <u>everywhere</u> (we cannot experiment).
  - Scientific method is built on observation, logic and skepticism.

Scientific Method

Hypothesis → (Implications / Tests) → **Model** → (Body of / Hypotheses) → **Theory**

Gather data Form a Theory Test the Theory

Careful design
Understand errors

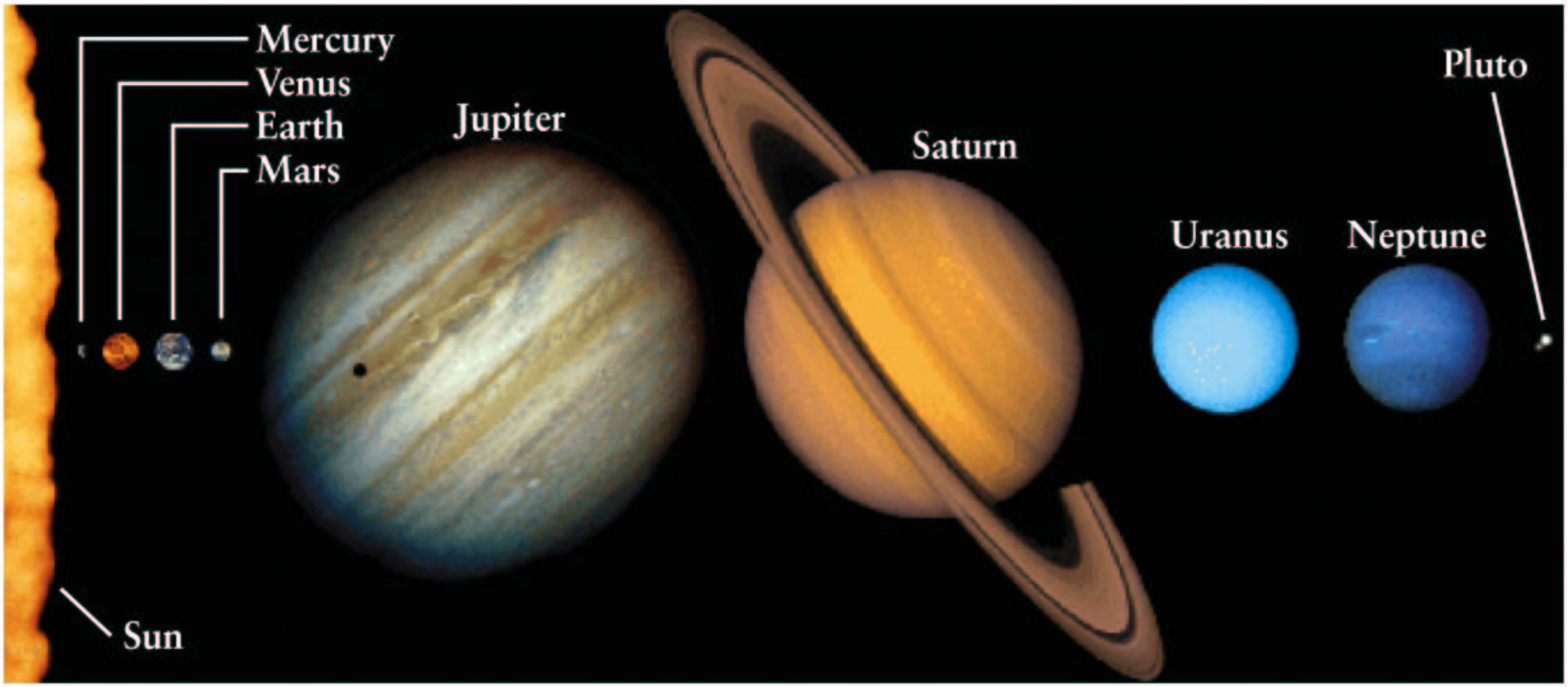
Reproduce observations

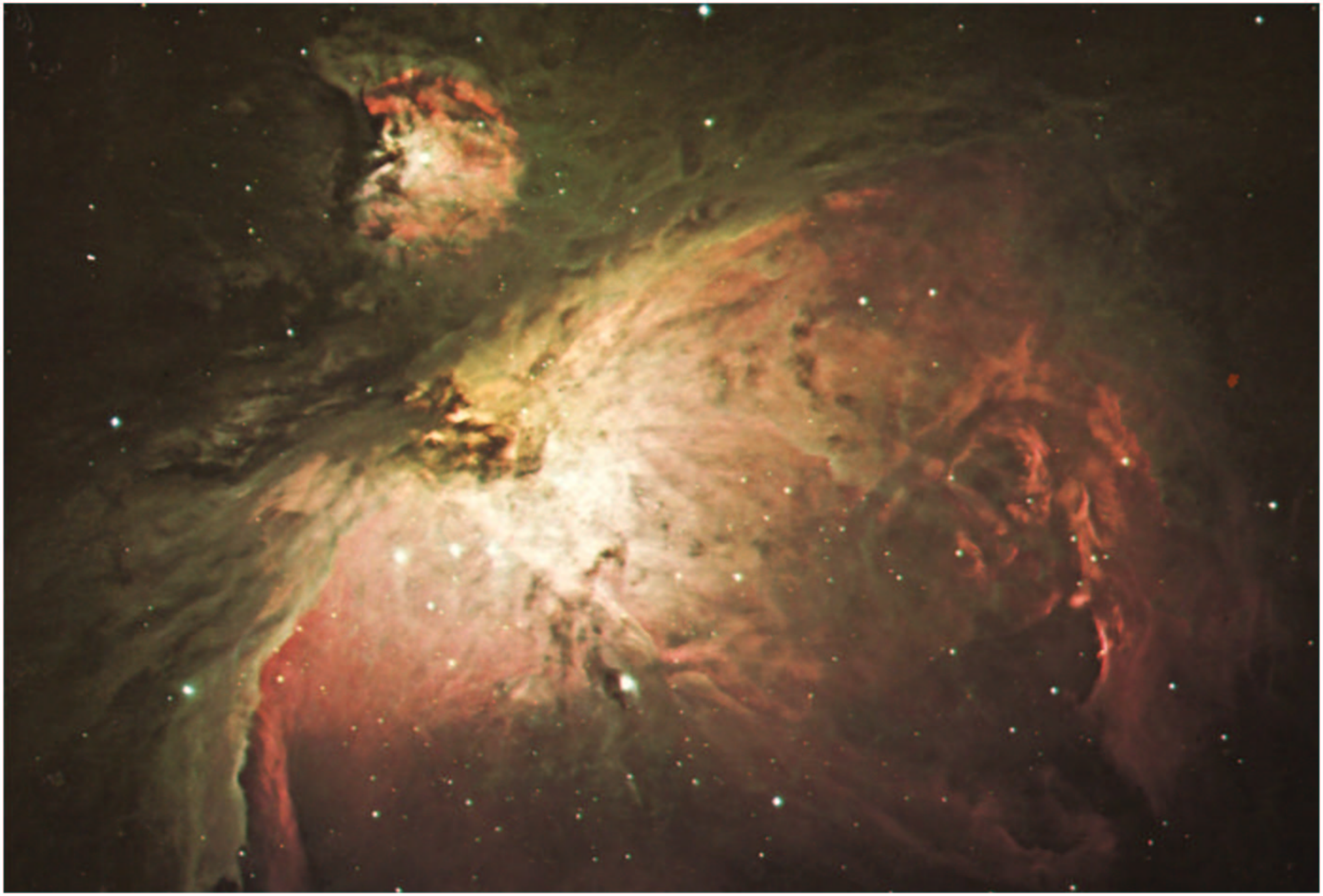
Controlled experiments

No theory is irrefutable. All theories must be able to make predictions and must hold for all valid observations (e.g. general Relativity).

Scientific Method

- **Hypothesis vs theory**
  - Common usage hypothesis = theory
  - In science theory = law.
  - Theory provides understanding of facts.
- **Developing new theories**
  - We rely on new tools, techniques and data.
  - We can now study objects from the x-rays through to radio waves.
  - Each probe different physical aspects
  - Combined they can provide theories for how the universe formed and evolves.


Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
Sun

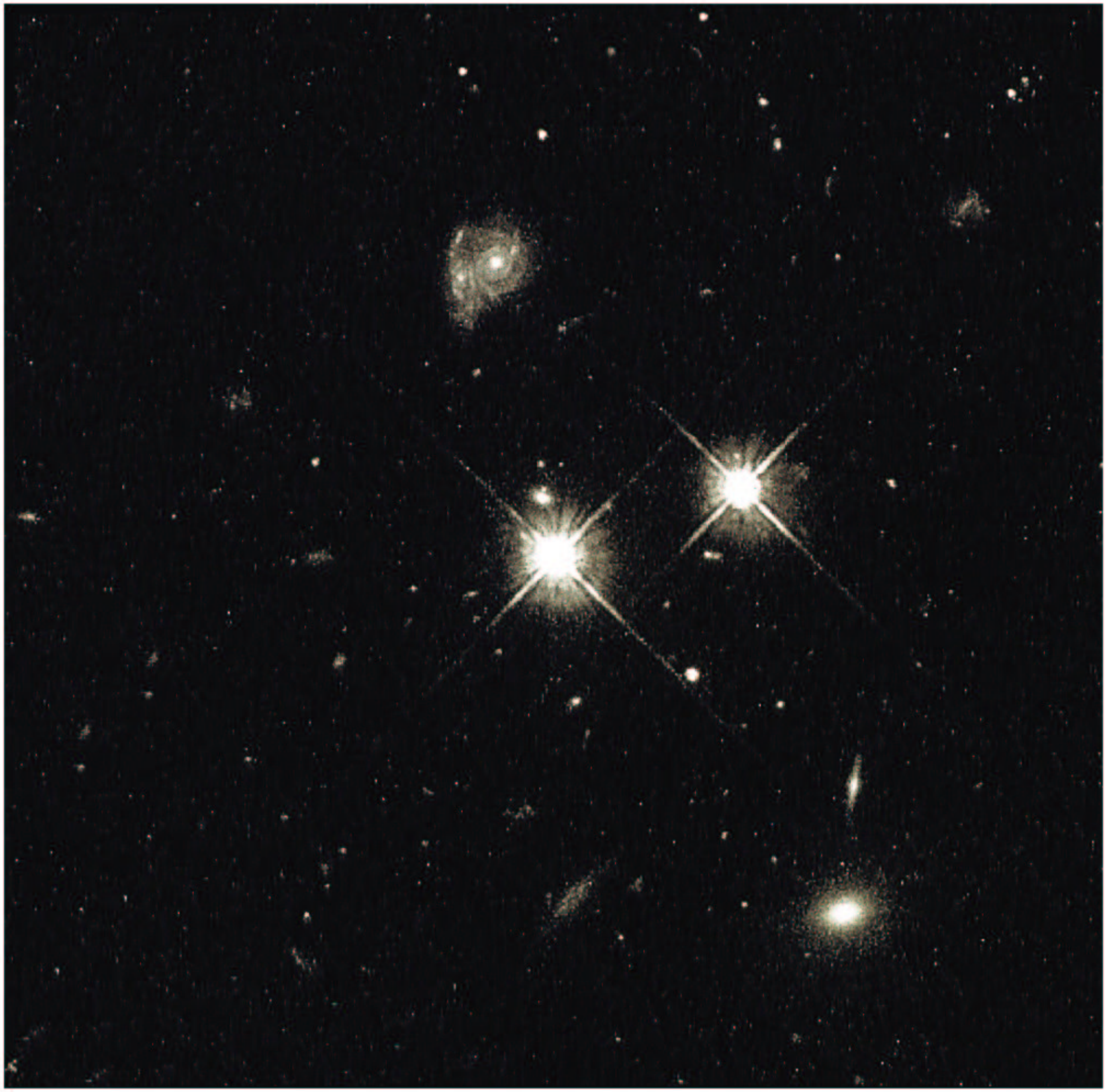


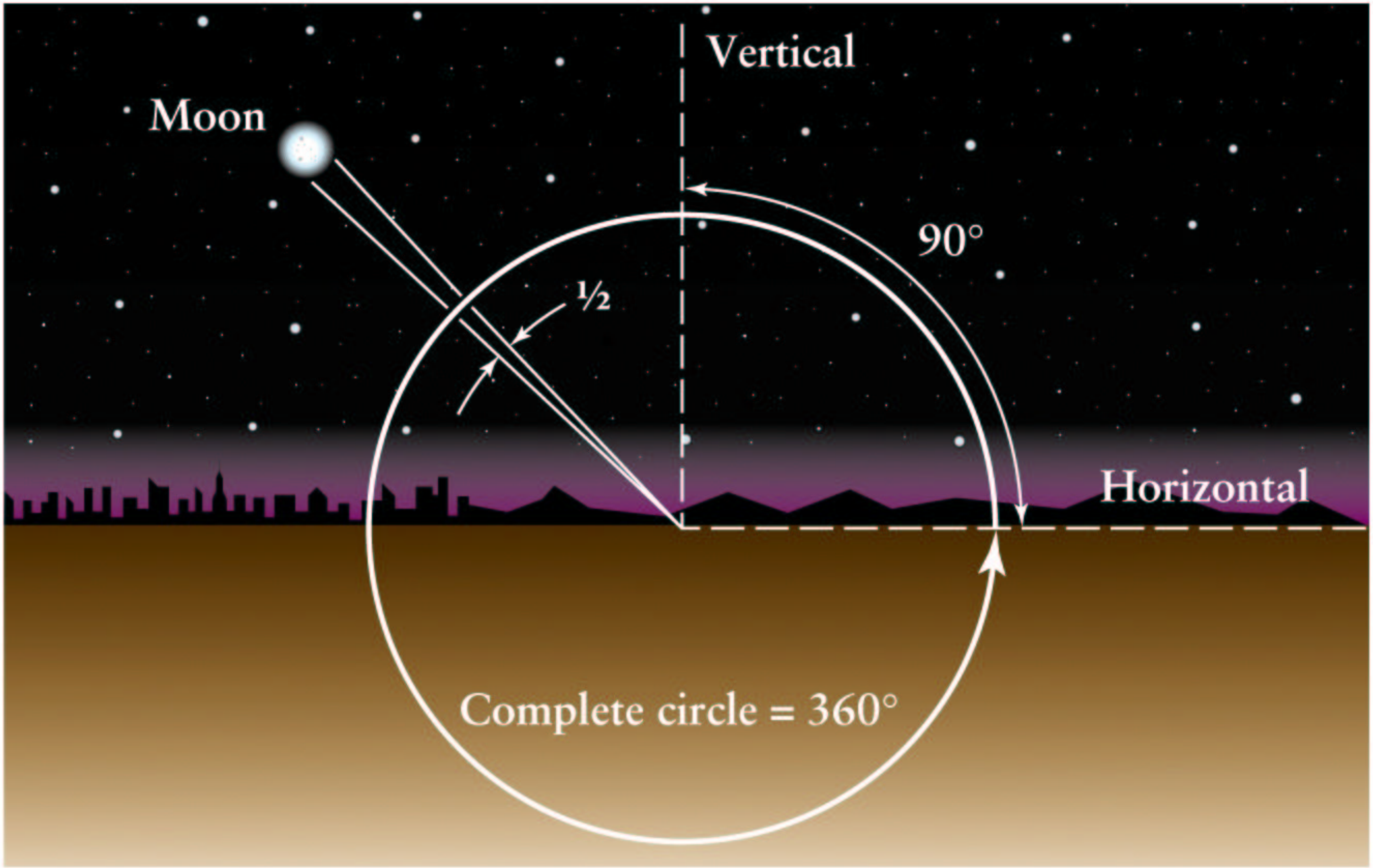
Studying the stars

- We have only one experiment
  - Our own Galaxy contains hundreds of billions of stars. All with different ages, compositions and histories.
  - By studying the statistical and physical properties we can learn how they form, age and die.
- Our own sun will eventually die
  - Hydrogen is converted to Helium releasing energy (nuclear fusion - e.g. nuclear bombs).
    - $T_{surface}$= 5500 ^{o}C (10,000 F)
    - T_{center}= 1.5x10^{6} ^{o}C
    - Diameter = 1.39x10^{6} km
  - Eventually the hydrogen will be used up and the sun will begin to die.

Observing Galaxies

- Stars are not formed in isolation
  - Grouped in galaxies
  - >100 billion stars/galaxy
  - >100s millions of galaxies
- Galaxies can be observed to great distances.
  - Most distant galaxies are at redshifts > 5 (70,000,000,000 light years away).
  - The distribution of galaxies tells us about how they were formed and how old is the Universe (15 billion years).
- Fascinating new objects
  - Quasars (quasi-stellar objects) are star-like but radiate with the energy of >100 galaxies.
  - Even more energetic sources (Gamma-ray bursters).

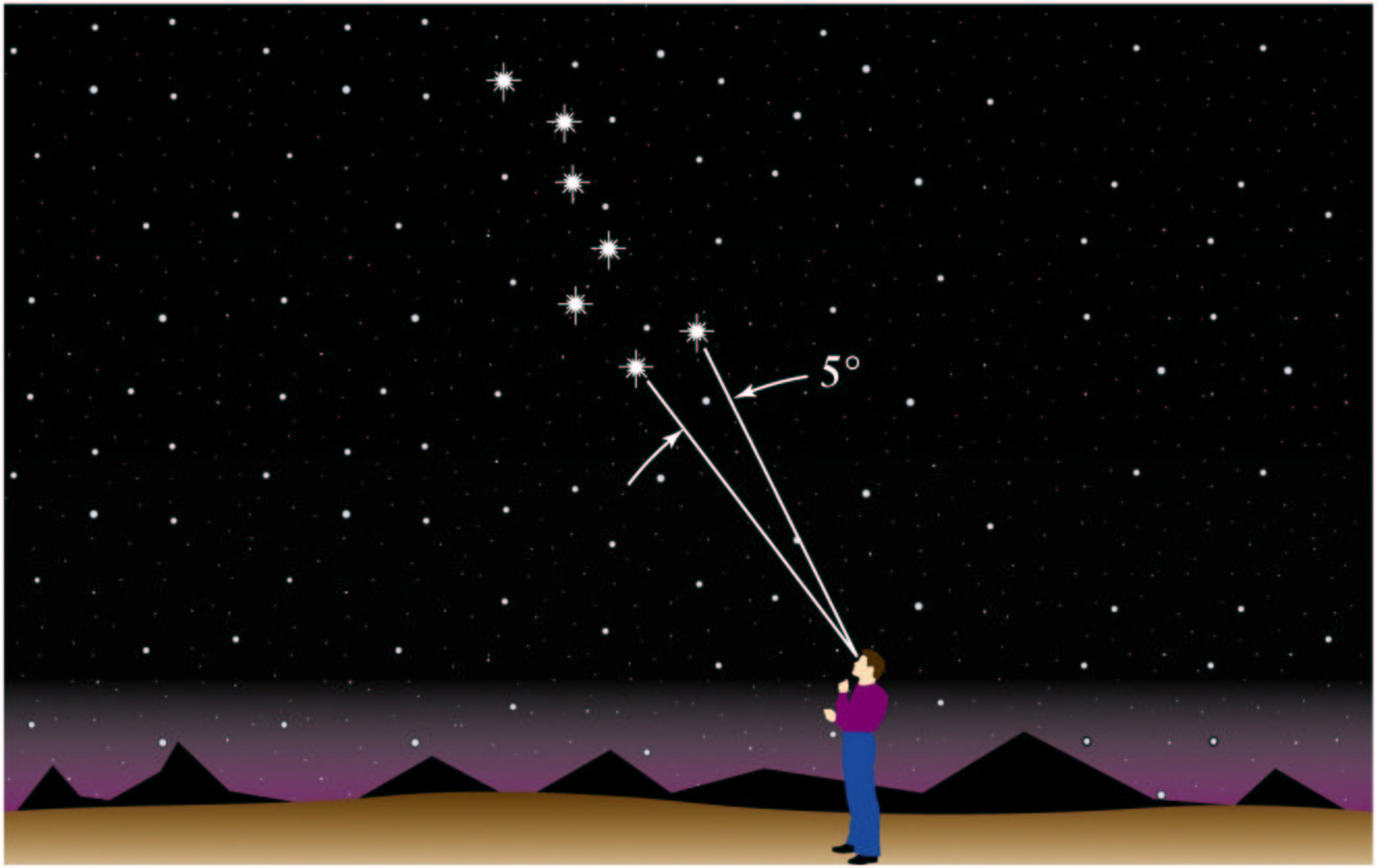




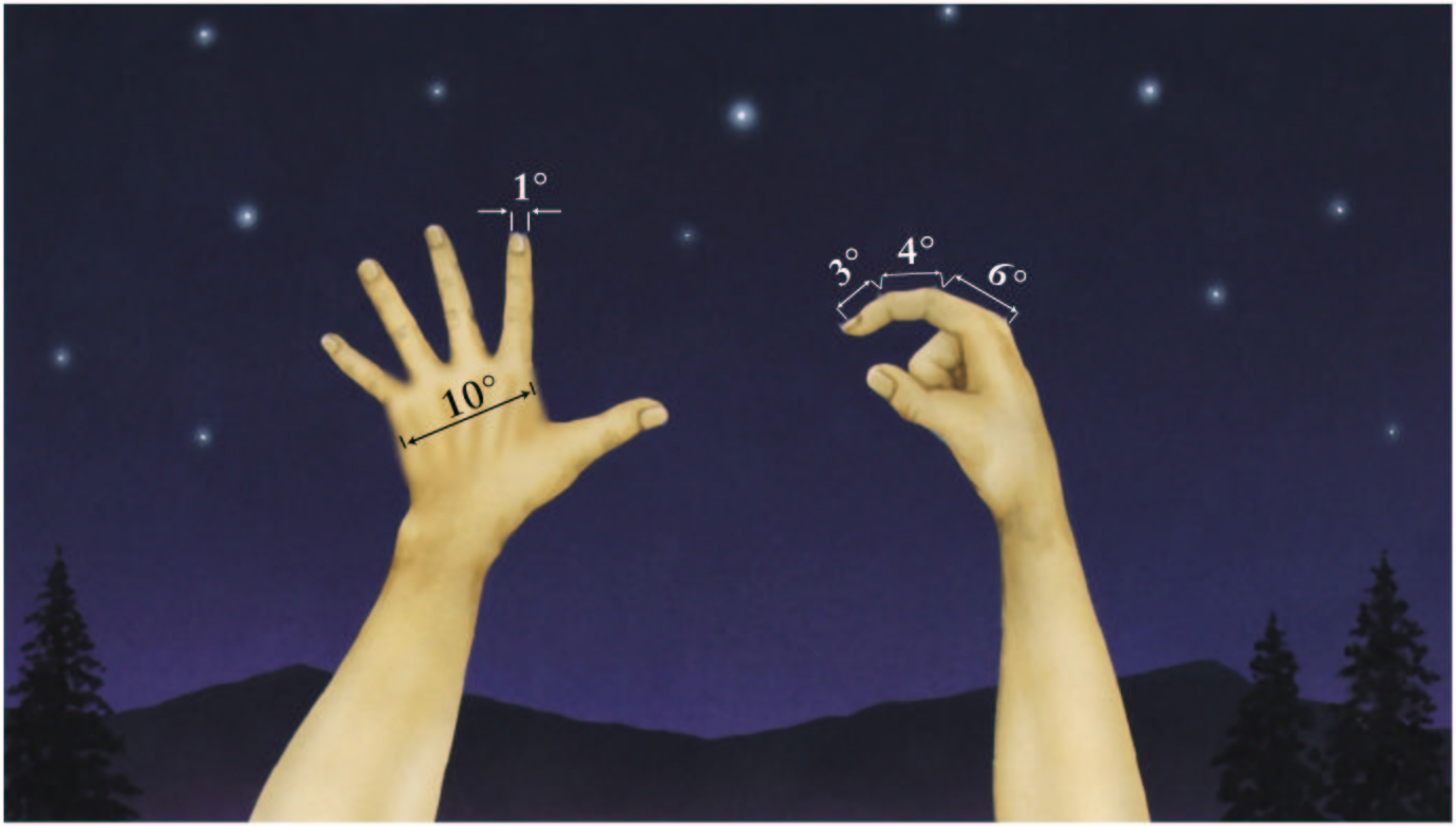
a

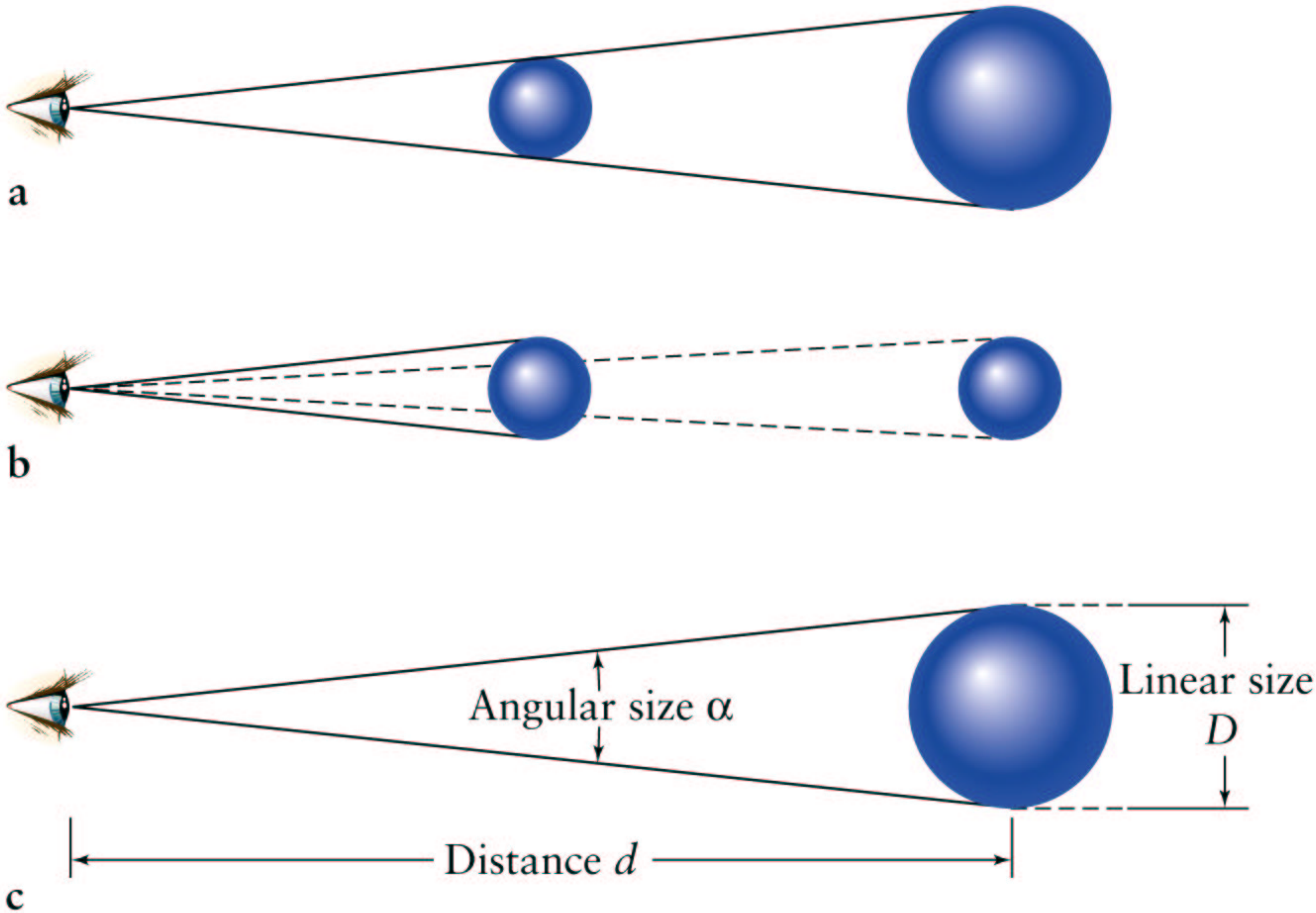
Angles in Astronomy

- **We cant measure linear size**
  - Stars and galaxies appear as if on the surface of a sphere.
  - Angles measure the apparent separation and sizes of objects.
- **Definitions**
  - There are 360^o (degrees) in a circle
    - 1^o = 60 arcminutes = 60’
    - 1’ = 60 arcseconds = 60’’
  - Alternatively in radians
    - $360^o = 2\pi$ radians
    - 1 radian = 57.296 degrees
- **Rules of “thumb”**
  - Size of the moon = 0.5^o
  - Tip of your thumb (arms length) 4^o
  - Ursa Major (big dipper) $\alpha - \beta = 5^o$



b


1°
10°
3°
4°
6°


a
b
Angular size α
Linear size
D
Distance d
c

Small Angle Approximation

- Size, angle and distance are related

$$D = \frac{\alpha\, d}{206265}$$

D: linear size
d: distance
α: angular size (arcseconds)

- 206265: There are 360º or 2π radians in a circle
- Relation between size and angle
  - For a fixed size - further away (smaller)
  - For a fixed distance - larger object larger angle
- Note objects with the same angular size may have different linear sizes (due to distance).

Small Angle Approximation

- Example 1: Space Telescope
  - How far could the space telescope see a dime (1.5cm) ?
    - The telescope can resolve objects 0.1 arcsecs in size

$$1.5\text{ cm} = \frac{0.1\text{ arcsec} \quad \text{x} \; d}{206265}$$

distance = 3093975cm = 31 km (20 miles)

- Example 2: Man on the moon
  - How big an angle would a man on the moon project.
    - A basketball player 2m tall.

$$\alpha = \frac{206265 \text{ x } 2\text{m}}{384{,}000{,}000\text{m}}$$

α= 0.00107 arcsec

    - Much smaller than we can resolve

- How well does your eye resolve?

Powers of Ten and Exponents

- Astronomy is a subject of extremes
  - we study the largest objects in the Universe (galaxies and clusters).
  - we study the smallest objects (atoms and X-ray wavelengths).
- Scientific Notation
  - Large Numbers

$$10^0 = 1 \Rightarrow 1$$
$$10^1 = 10 \Rightarrow 10$$
$$10^2 = 100 \Rightarrow 10x10$$
$$10^3 = 1000 \Rightarrow 10x10x10$$

  - Small numbers

$$10^0 = 1 \Rightarrow 1$$
$$10^{-1} = 0.1 \Rightarrow \frac{1}{10}$$
$$10^{-2} = 0.01 \Rightarrow \frac{1}{10x10}$$
$$10^{-3} = 0.001 \Rightarrow \frac{1}{10x10x10}$$

Powers of Ten and Exponents

- **Examples:**
  - Distance to the moon
    - 384,000,000m = 3.84×10^8m
  - Diameter of a hydrogen atom
    - 1.1×10^{-10}m
- **Arithmetic with exponents**
  - Multiplying numbers = add exponents
    - $100 \times 1000 = 10^2 \times 10^3 = 10^5$
  - Dividing by 10^n = multiplying by 10^{-n}

$$10^{-1} = \frac{1}{10}$$

$$10^{-n} = \frac{1}{10^n}$$

$$\frac{1.3 \times 10^2 \times 2.5 \times 10^4}{1.4 \times 10^3} = \frac{1.3 \times 2.5}{1.4} \times 10^2 \times 10^4 \times 10^{-3}$$

$$= 2.32 \times 10^3$$

  - Exponents and numbers can be treated separately

Astronomical Distances

- Many units of distance, mass, time
  - Standard system is SI (Systeme International)

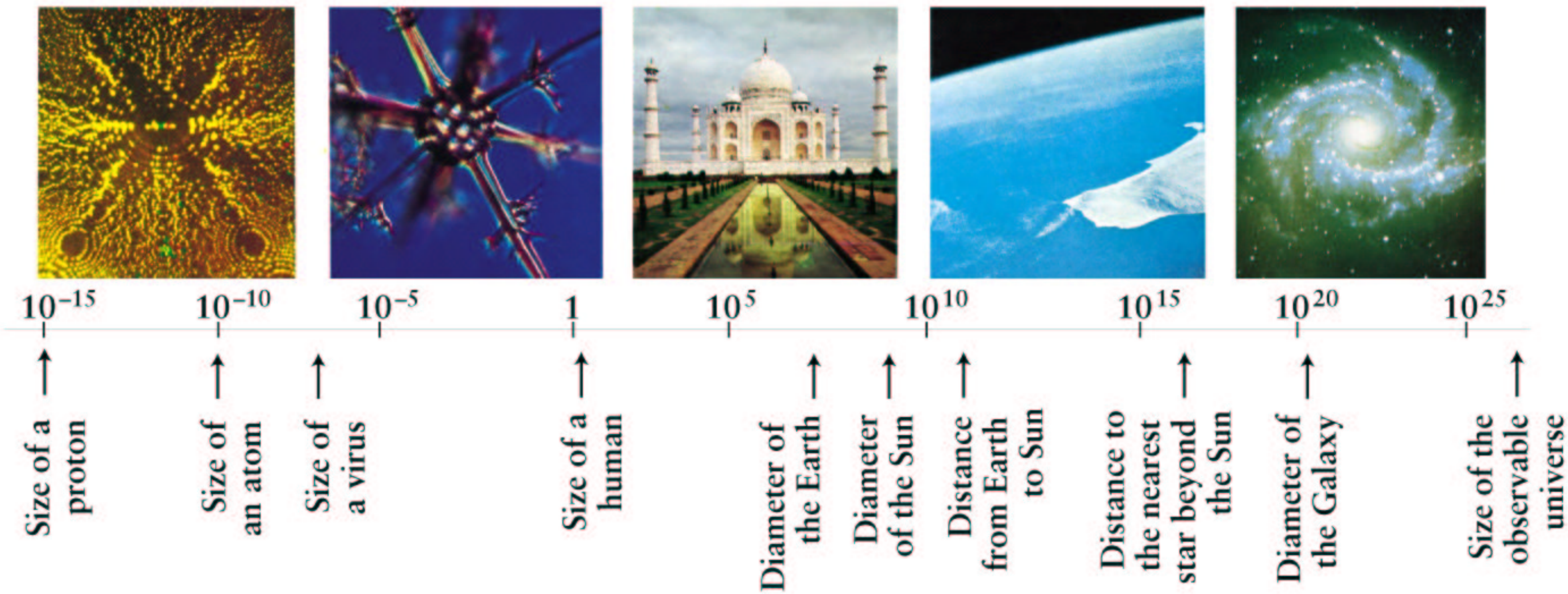
	S.I.	cgs	Imperial
Length	m	cm	ft
Mass	kg	gm	lb
Time	s	s	s
Temperature	K	K	F

  - T(Kelvins) = T(Celsius) + 273.15
- Combing exponents and SI
  - exponents can be included with these measures.

10^{-9} = nano = n
10^{-6} = micro = μ
10^{-3} = milli = m
10^{-2} = centi = c
10^{+3} = kilo = k
10^{+6} = mega = M

Astronomical Distances

- **New measures of distance:**
  - Astronomers create units of distance to suit the application.
    - 1 Astronomical Unit = Earth-Sun distance
    - 1AU = 1.496×10^8 km = 93 million miles
    - Distance from Sun to Jupiter
      5.2 AU = 7.779×10^8 km
  - Distances to stars we calculate in light years (time it takes light to travel from point A to point B).
    - Light travels at 3.0×10^5 km/s (180,000 miles/hour).
    - 1 ly = 9.46×10^{12} km = 63,240 AU
    - Light takes 8.3 minutes to reach us from the sun
    - Light Year is a measure of distance NOT time.



10^{-15}
10^{-10}
10^{-5}
1
10^{5}
10^{10}
10^{15}
10^{20}
10^{25}
Size of a proton
Size of an atom
Size of a virus
Size of a human
Diameter of the Earth
Diameter of the Sun
Distance from Earth to Sun
Distance to the nearest star beyond the Sun
Diameter of the Galaxy
Size of the observable universe

Astronomical Distances

- **Scales of the Universe**
  - **Our Solar System**

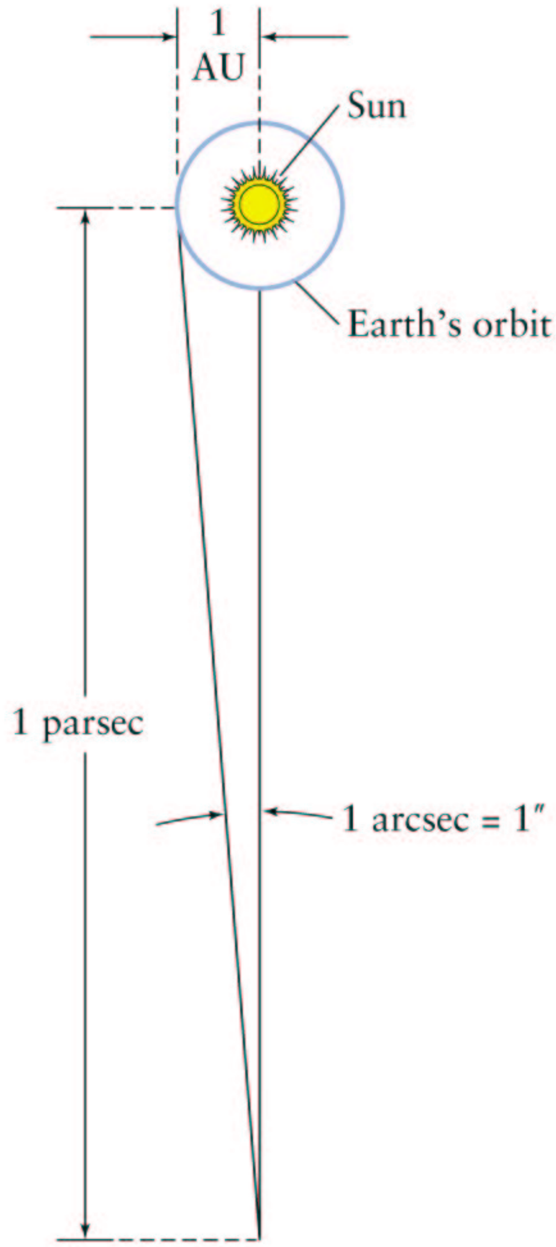
Around the Earth = 0.13 light second
Earth to Moon = 1.3 light seconds
Earth to Sun = 8.3 light minutes
Earth to Jupiter (closest approach) = 35 light minutes
Earth to Pluto = 4 light hours

  - **Distance from the Sun**

Mercury = 0.39 A.U.
Venus = 0.72 A.U.
Earth = 1.0 A.U.
Jupiter = 5.2 A.U.
Pluto = 40 A.U.

Sun to Nearest Star (Proxima Centauri) =4.2 ly
Sun to the Distant Edge of our Galaxy = 1 x 10^5 ly
The Milky Way to most distant known quasar = 1 x 10^{10} ly

  - **Our Milky Way Galaxy**


1
AU
Sun
Earth's orbit
1 parsec
1 arcsec = 1″

Parsecs: Another Measure

- **Measuring large distances**
  - Usually the distances to stars and galaxies are expressed in "parsecs"
  - Imagine looking at the sun from a distant star. The Sun would appear to be separated from the Sun by a small angle. The further away we are from the Sun the smaller the angle.
  - When the angle is 1 arcsec the distance of the star is defined to be one parsec
- **The small angle approximation**

$$D = \frac{\alpha\, d}{206265} \qquad \Rightarrow d = \frac{206265 \text{ x } 1 \text{ AU}}{1 \text{ arcsec}} = 1\text{pc}$$

$$d = 206265 \text{ AU}$$

$$d = 3.09\text{x}10^{13} \text{ km} = 3.26 \text{ ly}$$

  - very large distances we use kilo (10^3) and Mega (10^6) parsecs. The center of our Galaxy is 8 kpc away.