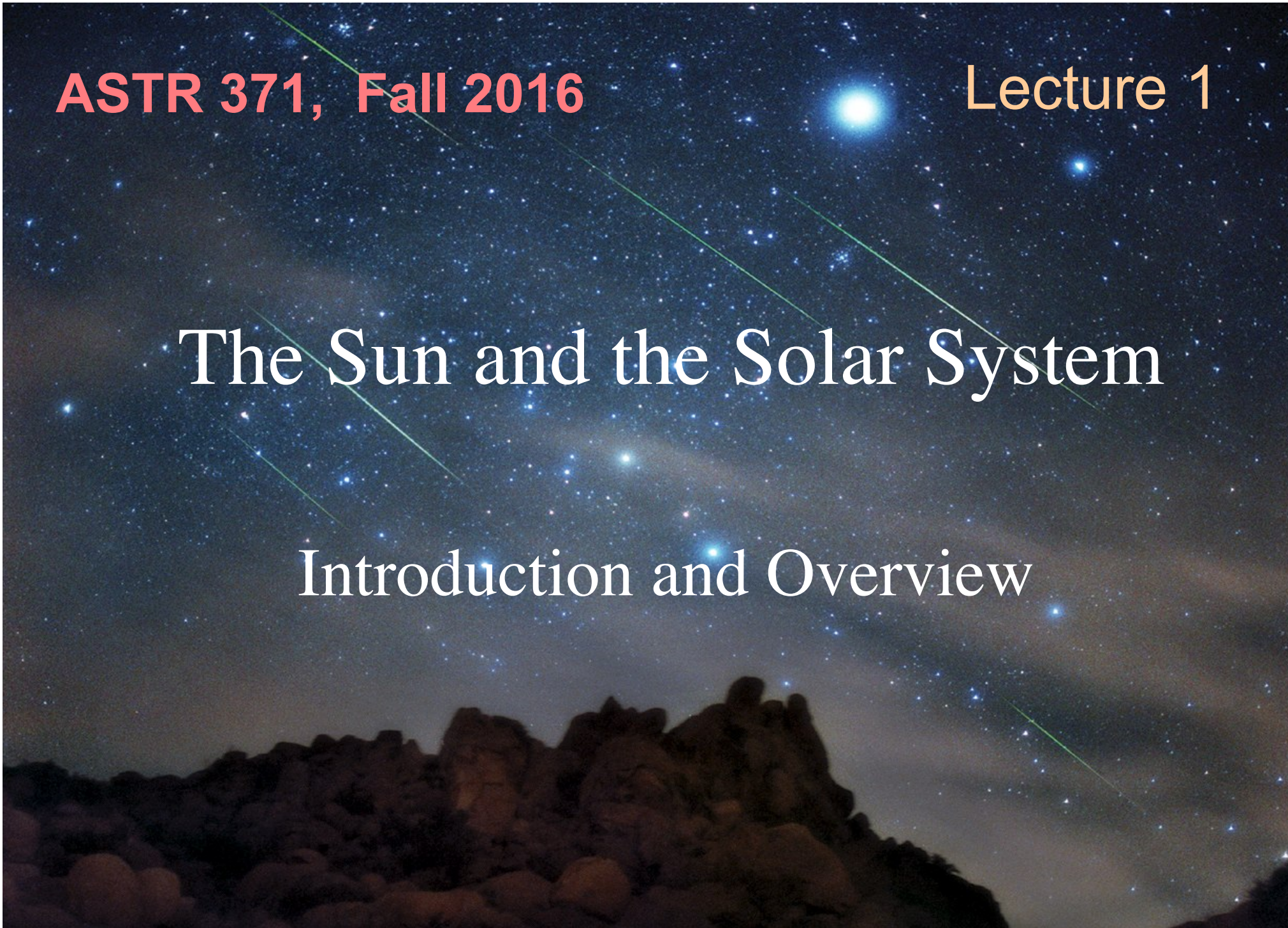


**ASTR 371, Fall 2016**

**Lecture 1**

# The Sun and the Solar System

Introduction and Overview



# Homework

Due September 7, Wed.

FK Chap 1, Questions 3, 16, 24, 38

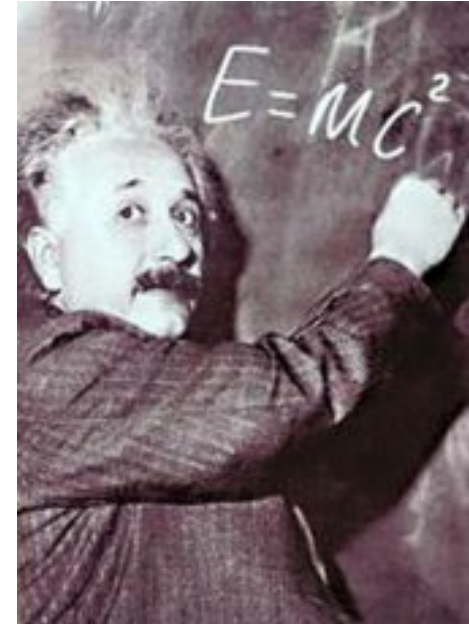
A1: (a) use data of the diameter and average distance of the Sun and Moon, find the angular size (**in units of arcsecond and in degree**) of the Sun and the Moon viewed from the Earth. The Sun's data are given at Table 16-1 (pp. 434), and the Moon's data are given at Table 10-1 (pp. 257).

(b) when the Moon is at apogee, what is the angular size of the Moon? If the Moon is lined up with the Sun, what phenomenon will be observed by an observer on Earth?



# 1.1 Astronomy is a physical science

To understand the universe, astronomers employ **scientific methods** to test **hypothesis**, build **models** and **theories**, and uncover the **laws of physics**.



What physics will we learn from the Sun, planets, and satellites?

Advances in astrophysics benefit from, as well as contribute to, new understandings of fundamental physical rules and technology development.

- (a) celestial objects being laboratories to test physical rules.

Ex.1: astronomical proofs of general relativity.

- (b) development in observing technologies

Ex.2: Hubble Space Telescope

- (c) high speed computers used to \*simulate\* astrophysical processes on extreme time-spatial scales and with extreme physical conditions



Ex.2: Hubble Space Telescope observes the Universe outside the Earth's atmosphere.

HST has uncovered the dimmest stars in globular star clusters.

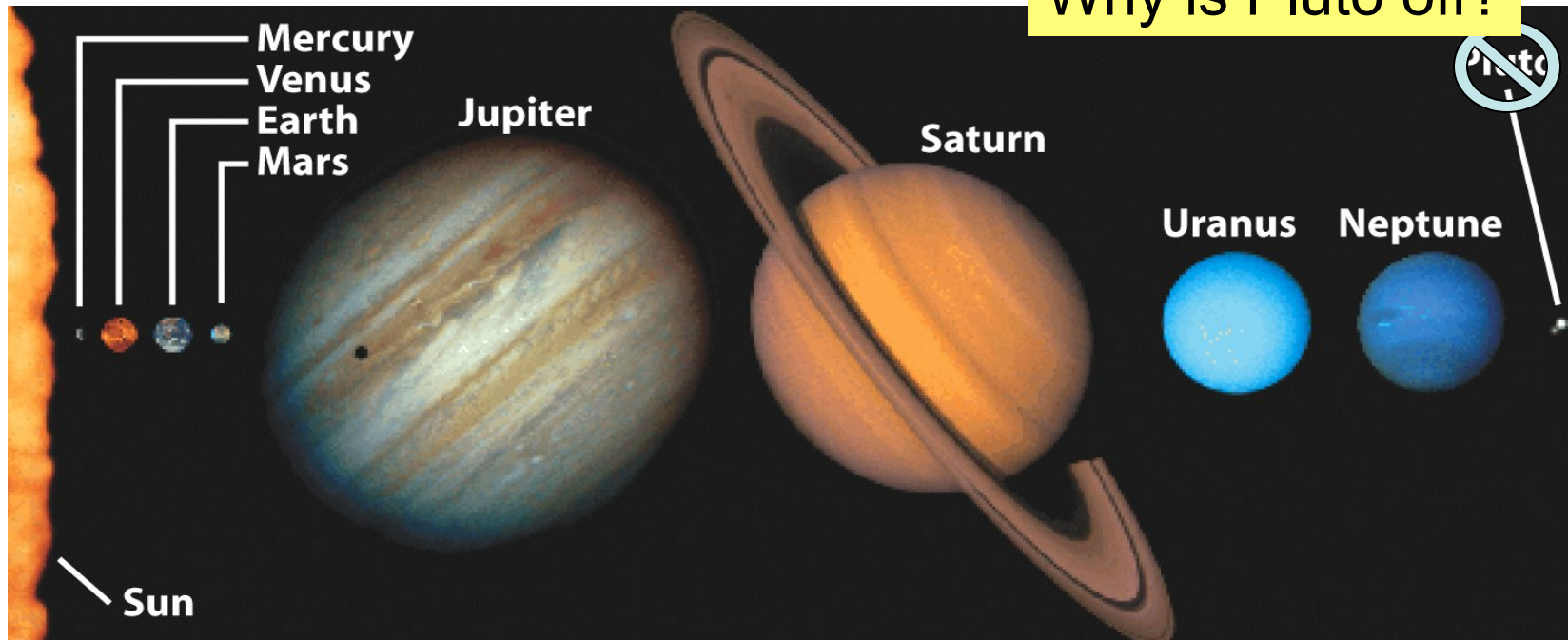




# 1.2 the Solar System

By exploring the planets, astronomers uncover clues about the formation of the solar system.

Why is Pluto off?



- The star we call the Sun and all the celestial bodies that orbit the Sun
  - including Earth
  - the other seven planets
  - all their various moons
  - smaller bodies such as asteroids and comets



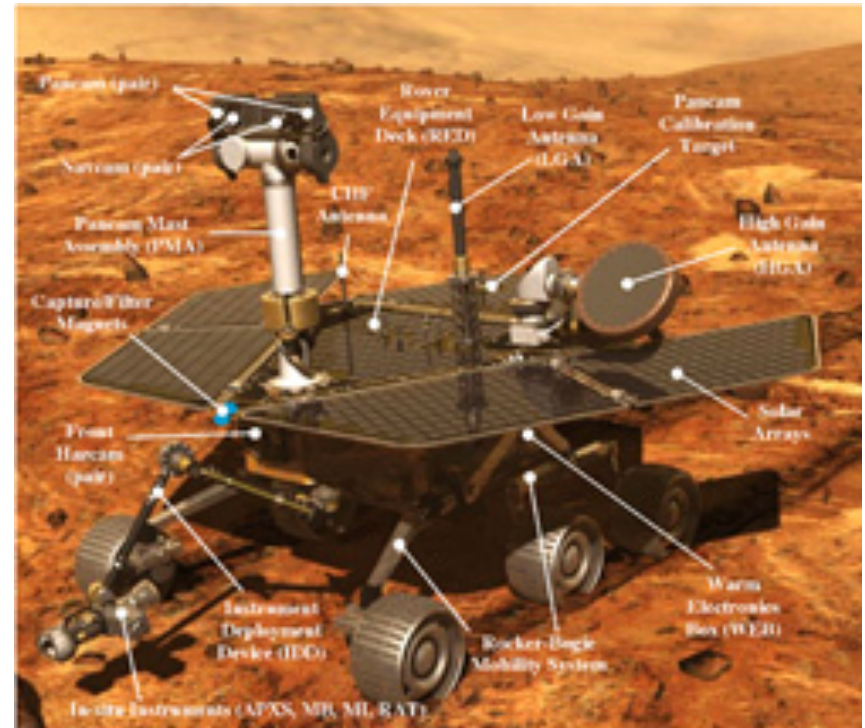
We will learn the motion, structure, atmosphere, magnetic field of the Sun, planets, and satellites, and how to observe them.

We will learn how to explain them -- gravity, energy, and nature of light.

We will learn why our planet, the Earth, hosts life.

Our spacecrafts have visited all planets.

Ex. 3: Mars Rover: our Robot geologist on Mars.

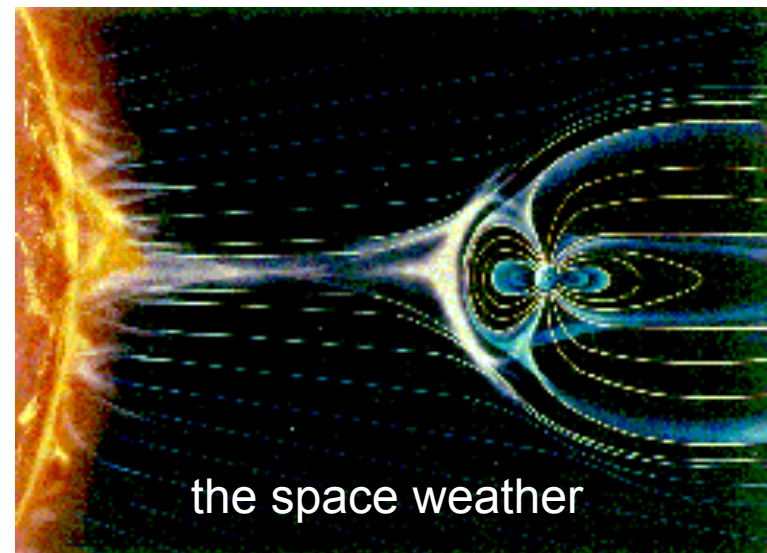


Spirit uncovered soils that have had a salty chemistry indicating the former presence of water. Spirit took this false-color image on June 1, 2006 (NASA/JPL)



# 1.3 Our Star: the Sun

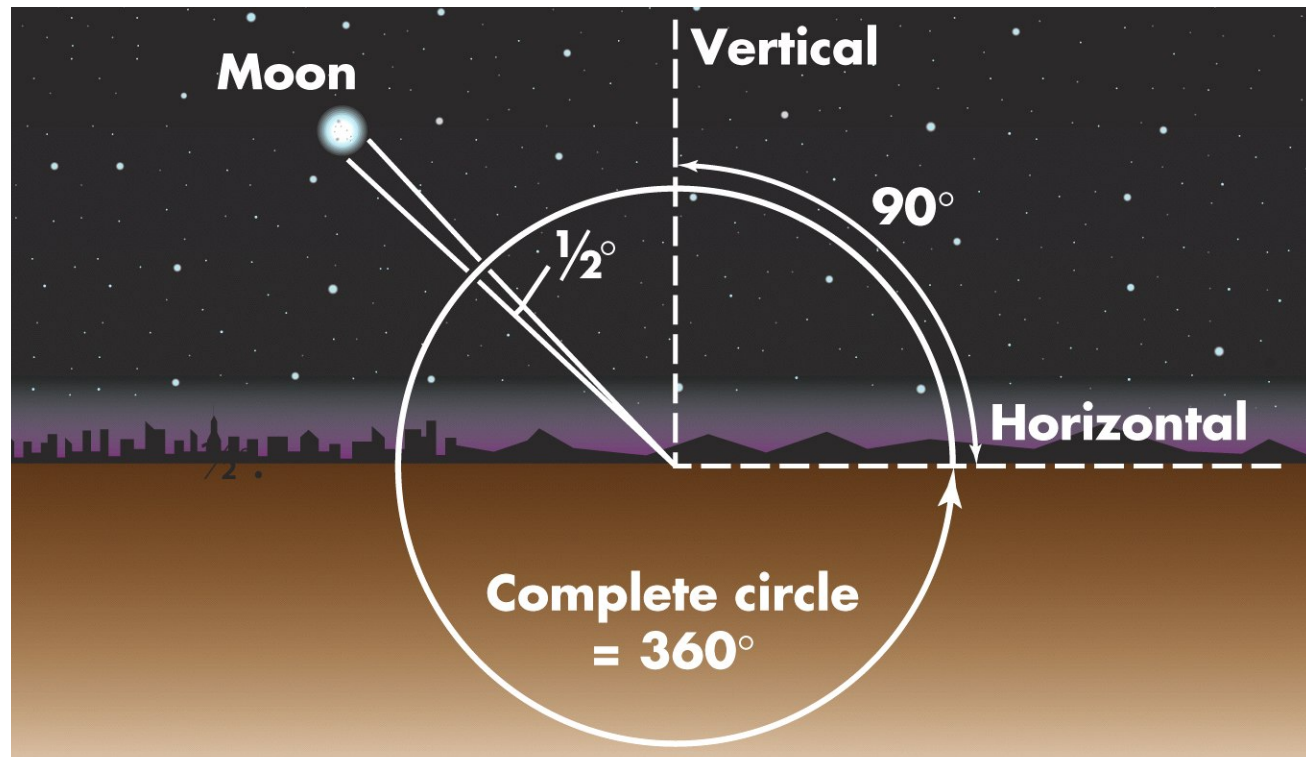
## Why study the Sun?



How far and how big?



## 1.4 Size and Distance of an Object



- Astronomers use **angular measure** to describe the apparent size of a celestial object—what fraction of the sky that object seems to cover.
- If you draw lines from your eye to two edges of the Moon, the angle between the lines is the **angular size** of the Moon.



### Basic units of angular measurements:

$$1^{\circ} \text{ (degree)} = 60' \text{ (arcminute)}$$

$$1' \text{ (arcminute)} = 60'' \text{ (arcsecond)}$$

$$1 \text{ radian} = 360^{\circ}/(2\pi) = 57.2958^{\circ} = 206265''$$

Ex.4a: the size of the Moon: the **angular diameter** (or **angular size**) of the Moon is  $0.5^\circ$  or the Moon subtends an angle of  $0.5^\circ$ .

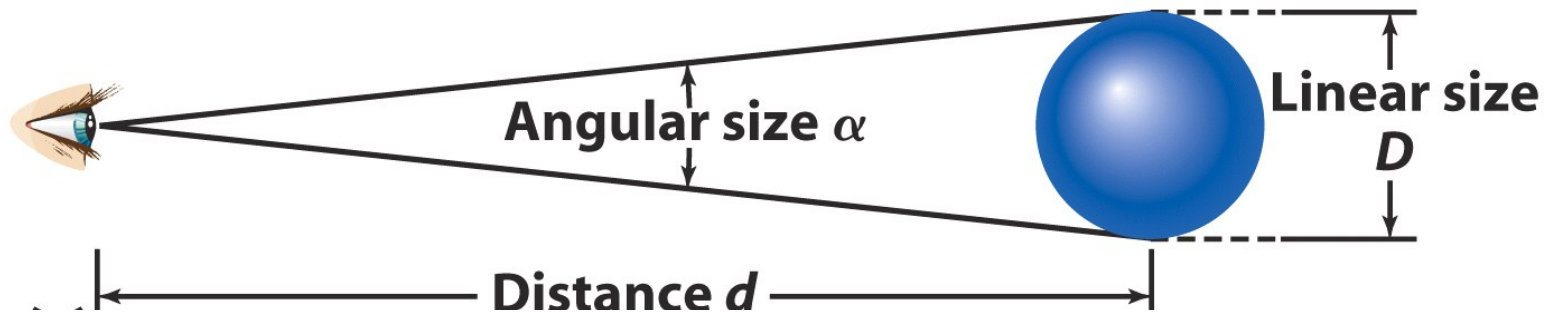
Ex.4b: the angular diameter of the Sun as of 2016 August 29 is about  $1900''$ . How does it compare with the Moon?

Ex.4c: the angular size of the Moon is approximately the same as a car of 2-meter long viewed at the distance of 200 meters away.

Ex.4d:  $1^\circ$  is the angular size of your finger an arm's length away.

Q: does it make sense?

# Angular size vs linear size - small-angle formula



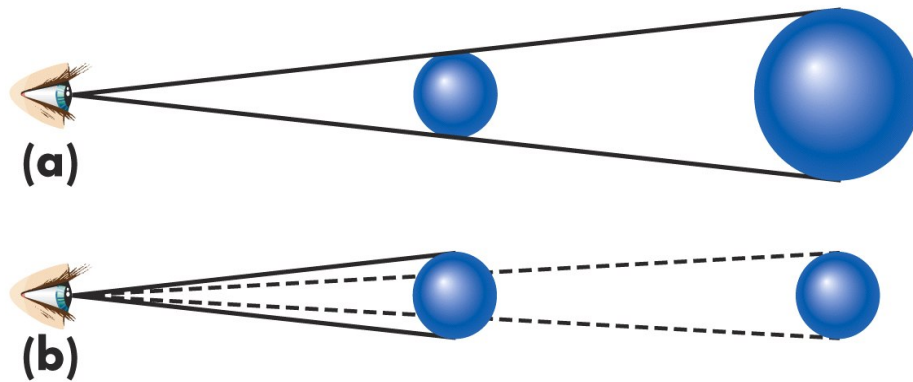
$D$  = linear size of the object

$d$  = distance to the object

$\alpha$  = angular size of the object  
(in arcsec)

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





- $\alpha \sim 1/d$ : same object: the farther away, the **smaller(?!)**
- $D \sim d$ : different objects of the **same size(?!)**, the farther away, the **larger(?!)**

Q: the Sun's distance from Earth is about 400 times the Moon's distance. How large is the Sun compared with the Moon?

Ex.5: On July 26, 2003, Jupiter was 943 million kilometers from Earth and had an angular diameter of  $0.5'$ . Using the small-angle formula, determine Jupiter's actual diameter.

$$D = \frac{0.5 \times 60'' \times 943 \times 10^6 \text{ km}}{206265} = 137 \times 10^3 \text{ km}$$

Q: what's the angular size of the Earth viewed from Jupiter?

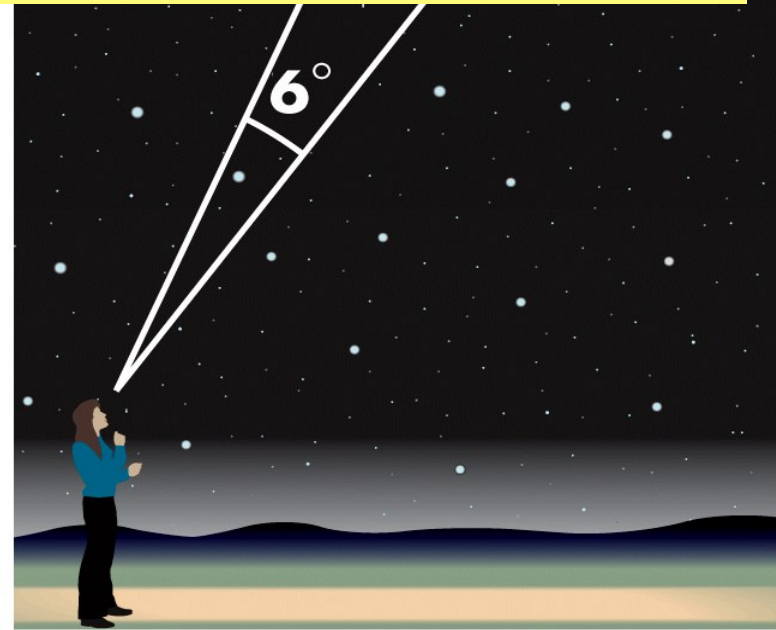
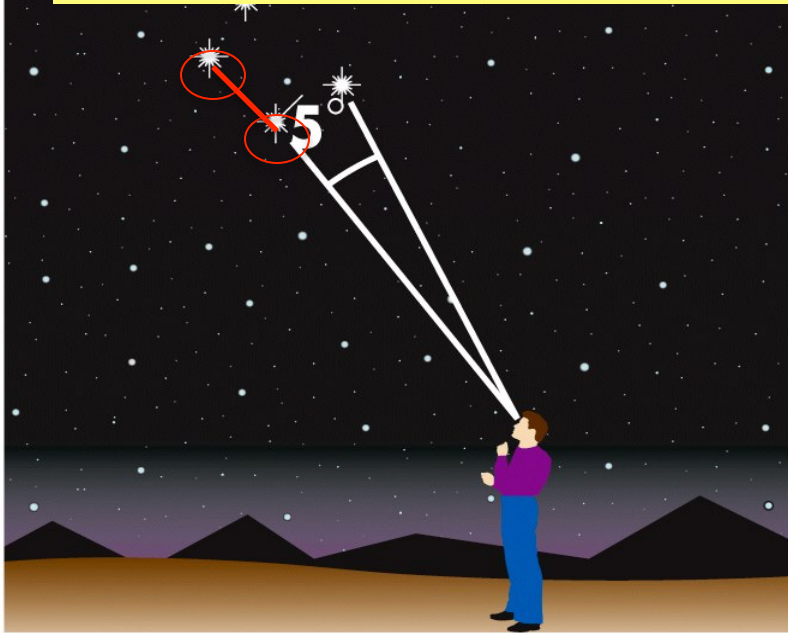
Ex.6: Under excellent conditions, a telescope on earth can see details with an angular size as small as  $1''$ . What's the greatest distance at which you could see details as small as 1.7m using the telescope?

$$d = \frac{206265 D}{\alpha} = \frac{206265 \times 1.7 \text{ m}}{1}$$
$$= 3.5 \times 10^5 \text{ m} = 3.5 \times 10^2 \text{ km}$$

Q: how about a quarter coin?



Q: if the Sun is at the eastern Horizon and the Moon at the western Horizon, what's the angular distance between them?



If you draw lines from your eye to each of two stars, the angle between the lines is the **angular distance** between the two stars.

**Note:** here we refer to the **distance projected to the surface of an imaginary celestial sphere centered at the observer**, as if the two objects were in this same spherical surface.

Q: does the radius of this sphere matter?



# Units of Distance (d!) in Astronomy

- **Astronomical Unit (AU)**

- One AU is the average distance between Earth and the Sun = distance of light traveled in 500s
- $1.496 \times 10^8$  km or 92.96 million miles

- **Light Year (ly)**

- One ly is the distance light can travel in one year at a speed of about  $3 \times 10^5$  km/s or 186,000 miles/s
- $1 \text{ ly} = 9.46 \times 10^{12}$  km or 63,240 AU

- **Parsec (pc)**

- the distance at which 1 AU subtends an angle of 1 arcsec
- $1 \text{ pc} = 3.09 \times 10^{13} \text{ km} = 3.26 \text{ ly}$

Ex. 7: the distance of planets to the Sun in units of AU.

Mercury:	0.4
Venus:	0.7
Earth:	1
Mars:	1.5
Jupiter:	5
Saturn:	10
Uranus:	20
Neptune:	30
(Pluto:	40)

$$P^2 = a^3 \quad (\text{Kepler's law})$$

$P$  : orbital period in year.

$a$  : radius of orbit in AU.

Ex. 8: Proxima Centauri, the second closest star to Earth, is at the distance of 4.2 ly. If its diameter is 0.15 that of the Sun, what is its angular size as observed on Earth?

$$D_{star} = \frac{\alpha_{star} d_{star}}{206265}, \quad D_{sun} = \frac{\alpha_{sun} d_{sun}}{206265}$$

$$\frac{D_{star}}{D_{sun}} = \frac{\alpha_{star} d_{star}}{\alpha_{sun} d_{sun}}, \quad \alpha_{star} = \alpha_{sun} \frac{D_{star}}{D_{sun}} \frac{d_{sun}}{d_{star}}$$

$$\alpha_{star} = \alpha_{sun} \times 0.15 \times \frac{500}{4.2 \times 365 \times 24 \times 60 \times 60} = 0.001''$$

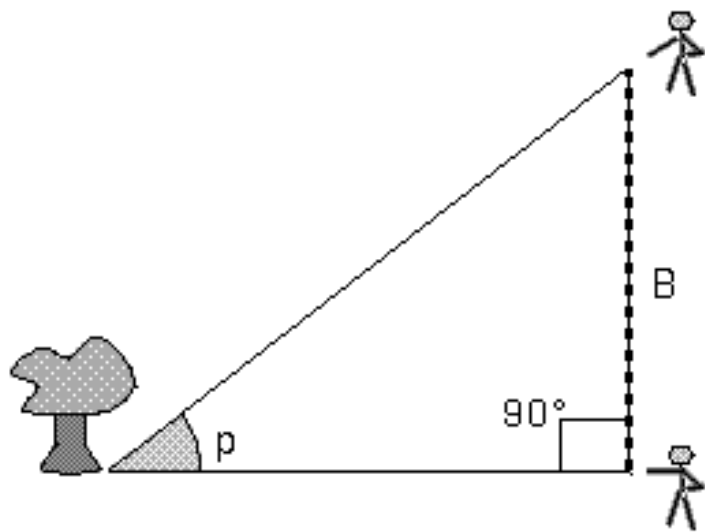


Advanced techniques, such as adaptive optics, interferometry, space telescopes etc, are often needed to directly measure the angular size of celestial objects. With the knowledge of distance, we can know the linear size of the objects.

The radius of stars may be measured indirectly by luminosity, the radiation energy rate (next week):

$$L = 4\pi R^2 \sigma T^4 \quad (\text{Joule s}^{-1})$$

Ex. 9: parallax: measuring the different angular position of a remote object from two different locations on Earth.



The farther away,  
the smaller the  
angle  $p$ .

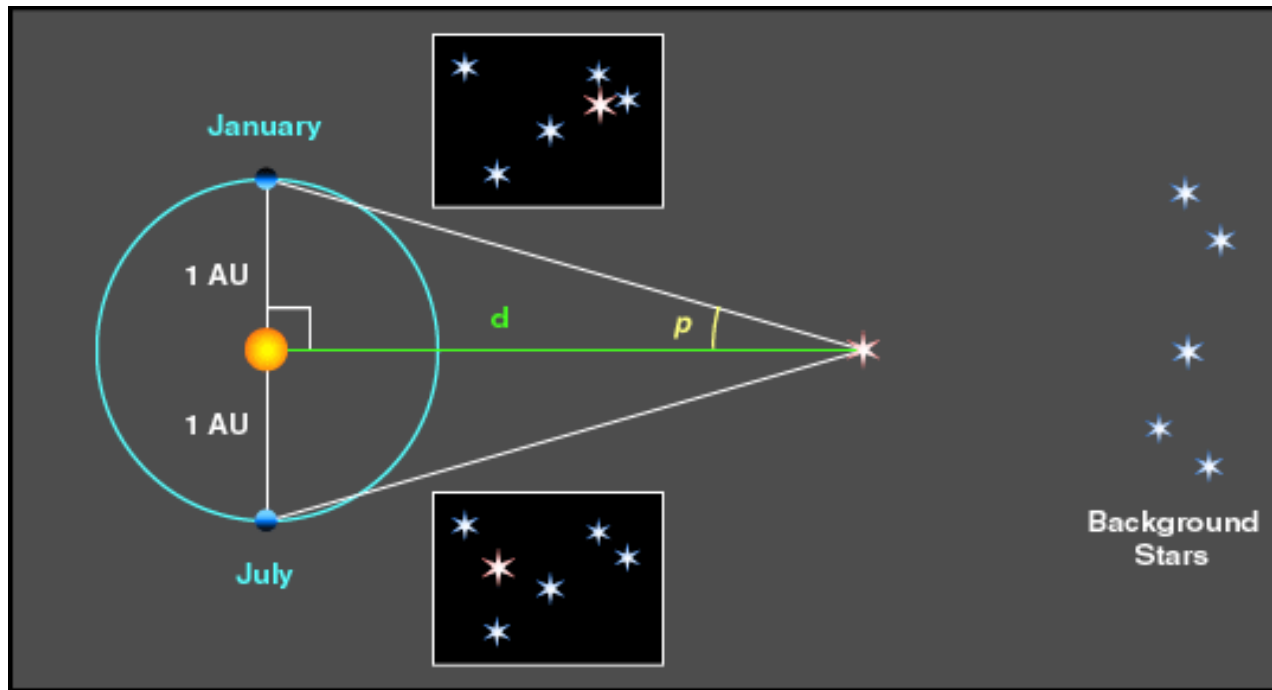
The distance  $d$  is determined by the **baseline length  $B$**  and angle  $p$  (**parallax**) as:

$$d = B / \tan(p)$$

or simply:

$$d = B / p \quad \text{when } d \gg B$$

The scale of solar system was first determined by **trigonometric parallax**. A greater distance ( $d$ ) can be determined with a longer baseline ( $B$ ).



**Annual Parallax:** observing a celestial object 6 months apart,  $B$  becomes the Sun-Earth distance, i.e., 1 AU.

**Parsec (Parallax arcsec)**, or pc, is an astronomical distance units. 1 pc is the distance of an object whose parallax is 1 arcsec;  $1\text{pc} = 3.26\text{ ly}$ .

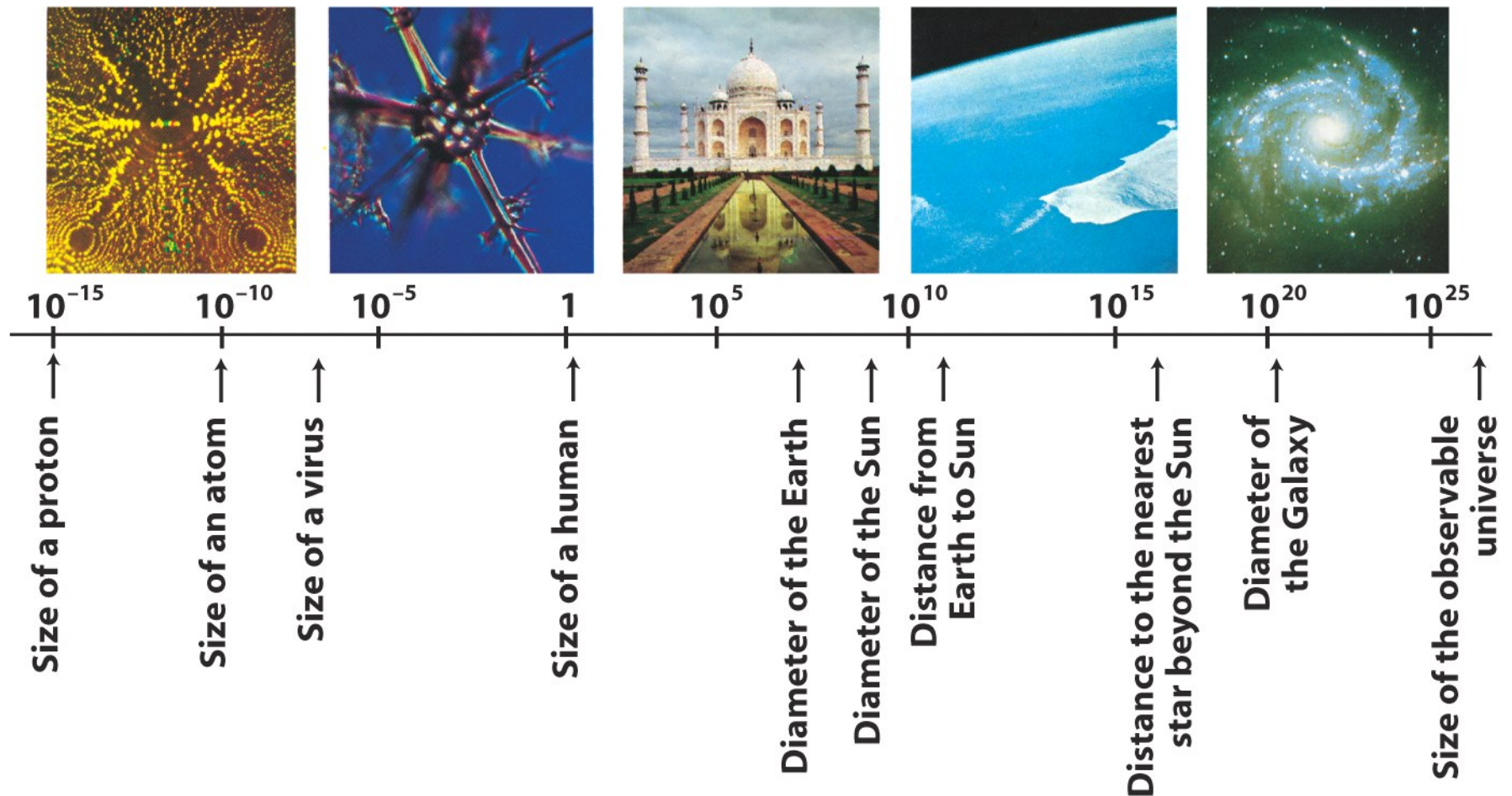
Q: what is the parallax of Proxima Centauri?

# Telescope resolving power

- Ground-based telescopes can resolve up to  $0.01''$ .
- The Hipparcos satellite launched in 1989 can measure  $p$  approaching  $0.001''$ , or the stellar distance up to  $1000 \text{ pc} = 1 \text{ kpc}$ .
- The center of our Milky Way Galaxy is  $8 \text{ kpc}$ . So stellar parallax is useful only for neighborhood stars ( $<30\text{-}500 \text{ pc}$ ).
- VLBA interferometer technology can measure the distance of up to  $10 \text{ kpc}$ .

# 1.5 Powers-of-10 Notation

Powers-of-ten notation is a useful shorthand system for writing numbers





# Common Prefixes

Factor		Name	Symbol
(billion)	$10^9$	Giga-	G
(million)	$10^6$	Mega-	M
(thousand)	$10^3$	kilo-	k
(hundredth)	$10^{-2}$	centi-	c
(thousandth)	$10^{-3}$	milli-	m
(millionth)	$10^{-6}$	micro-	$\mu$
(billionth)	$10^{-9}$	nano-	n

## Key words

- angle
- angular diameter (angular size)
- angular measure
- arcminute
- arcsecond
- degree ( $^{\circ}$ )
- distance - astronomical unit (AU)
- exponent
- laws of physics
- model
- powers-of-ten notation
- small angle formula
- theory

# Summary:

- To understand the universe, astronomers use the laws of physics to construct testable theories and models to explain observations and predict new phenomena.
- Astronomers study planets to learn the formation of the solar system.
- Astronomers study the Sun to learn the structure and evolution of stars and sun-earth connection (climate and space weather).
- Astronomers use angular measurements to denote the apparent size and distance of celestial objects.