Angles and
Units in Astronomy

Announcements

- Homework is due next Thursday (1/25)
- Read Chapter 2 before next Tuesday
- My office hours are on Mondays 10-11am, Thursdays 9-10am or make an appointment for another time
- TA office hours (all in PAIS lobby):

  Wednesday 1-2pm : Dustin Edgeman

  Wednesday 3-4pm : Evan David

  Thursday 9:30-10:30am: Rachel Weller
- Course web page is here:

https://leo.phys.unm.edu/~gbtaylor/astr2110/

How we learn about the Universe

- What do we see?
  - – Observing with telescopes, publishing results
- How does it work? How does it evolve?
  - – Explaining observations with physical laws
- Scientific Method
  - – Predicting. Observing to refine or revise our theory

Basic Physical Measurements

The Metric System
(used by scientists and foreigners)

<u>Mass</u>

1 kilogram (kg) = 1000 grams (g)

28 g = 1 ounce

DEMO: Weight of Mass

If your mass is <u>220 lbs</u>, it's also <u>100 kg</u>.

We tend to use mass and weight interchangeably, but weight depends on gravity.

Distance

1 meter (m) = 100 centimeters (cm)
= 39.4 inches
(slightly longer than a yard - your professor is 1.8 m in height)

1 cm = 0.39 inches

Volume

1 cubic centimeter or 1 cm^3 = 0.06 cubic inches
(about the size of a sugar cube)

Density

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (\text{g / cm}^3)$$

Densities of Substances

Balsa Wood	0.13 g / cm^3
Oak	0.7
Gasoline	0.7
Plastic	0.9-1.1
Water	1.0
Average Rock	2.4
Glass	2.6
Iron	7.9
Lead	11.3
Gold	19.3
Osmium	22.5

DEMO: Sink or Float

Temperature

The Celsius Scale:

DEMO: Hot Wire

$$T(^oC) = 5/9\ [\ T(^oF) - 32\ ^oF\ ]$$

so $32\ ^oF = 0\ ^oC$

$212\ ^oF = 100\ ^oC$

$68\ ^oF = 20\ ^oC$

The Kelvin Scale:

$$T(K) = T(^oC) + 273\ ^oC$$

"Absolute zero" $0\ K = -273\ ^oC$

Powers-of-ten notation

- Astronomy deals with very big and very small numbers – we talk about galaxies AND atoms!
- Example: distance to the Sun is about 150,000,000,000 meters. Inconvenient to write!
- Use "powers-of-ten", or "exponential notation". All the zeros are consolidated into one term consisting of 10 followed by an exponent, written as a superscript. Eg., $150{,}000{,}000{,}000 = 1.5 \times 10^{11}$

Some familiar numbers in powers-of-ten notation:

	prefix
One thousand = 1000 = 10^3	kilo
One million = 1,000,000 = 10^6	mega
One billion = 1,000,000,000 = 10^9	giga
One one-hundredth = 0.01 = 10^{-2}	centi
One one-thousandth = 0.001 = 10^{-3}	milli
One one-millionth = 0.000001= 10^{-6}	micro
One one-billionth= 0.000000001= 10^{-9}	nano

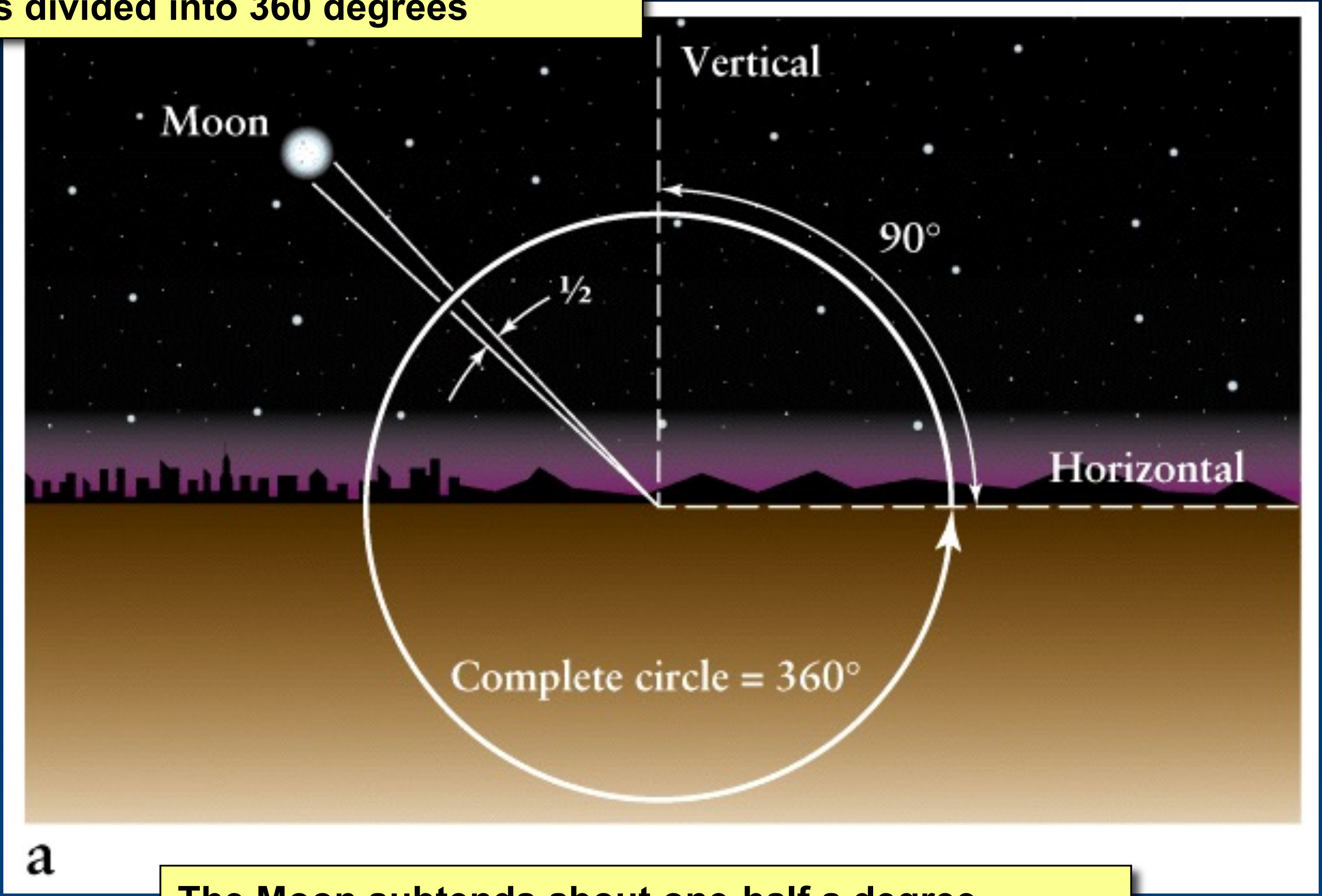
Angles

Astronomers use angular measure to describe:

- the locations of celestial objects on the sky
- the apparent size of an object
- separation between objects
- movement of objects on the sky

(later: to convert to actual sizes, separations, motions, must know distance to object [geometry, or physical understanding])

A circle is divided into 360 degrees

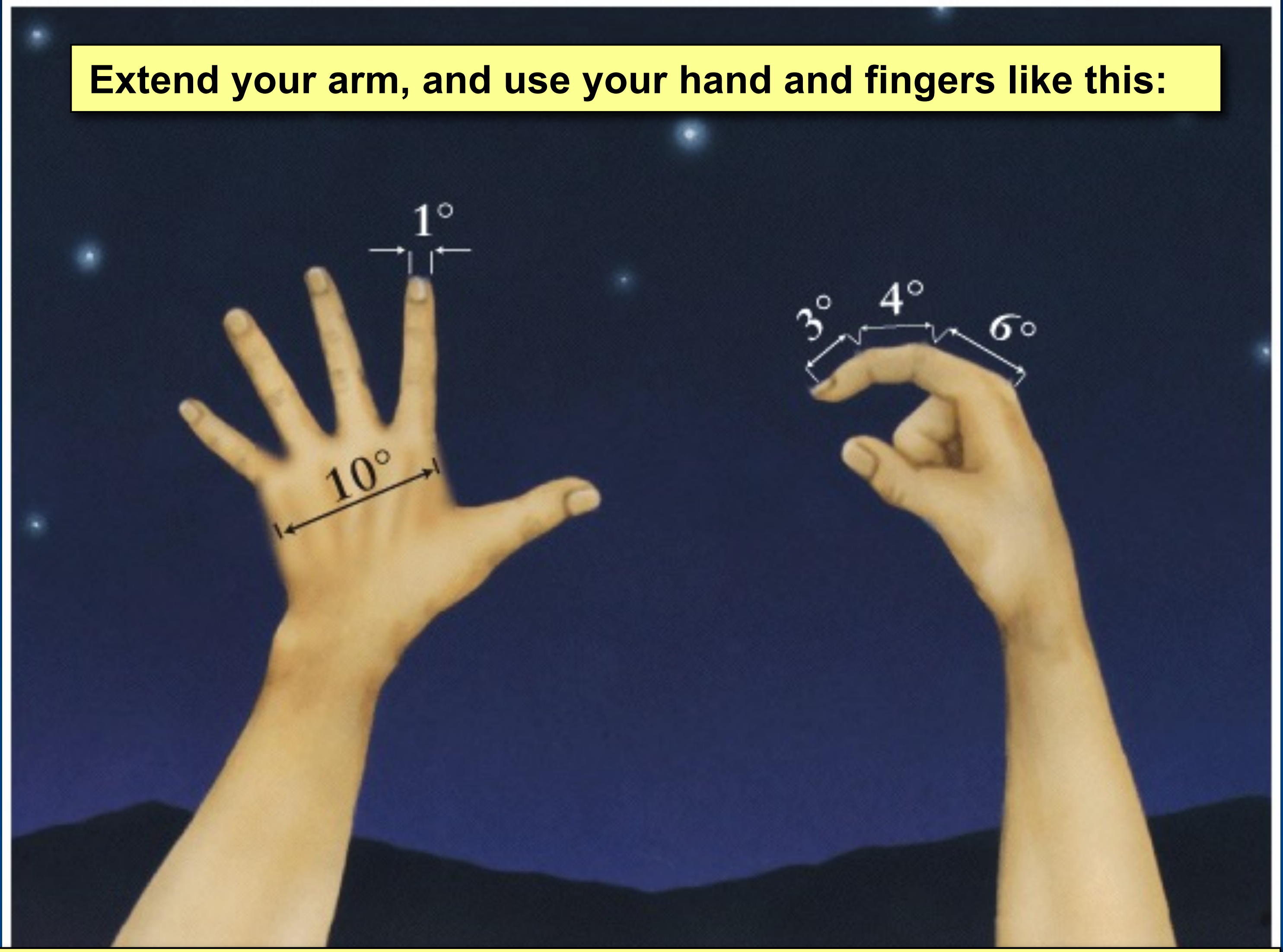


The Moon subtends about one-half a degree

Another way of saying this: the Moon has an angular diameter of one-half a degree

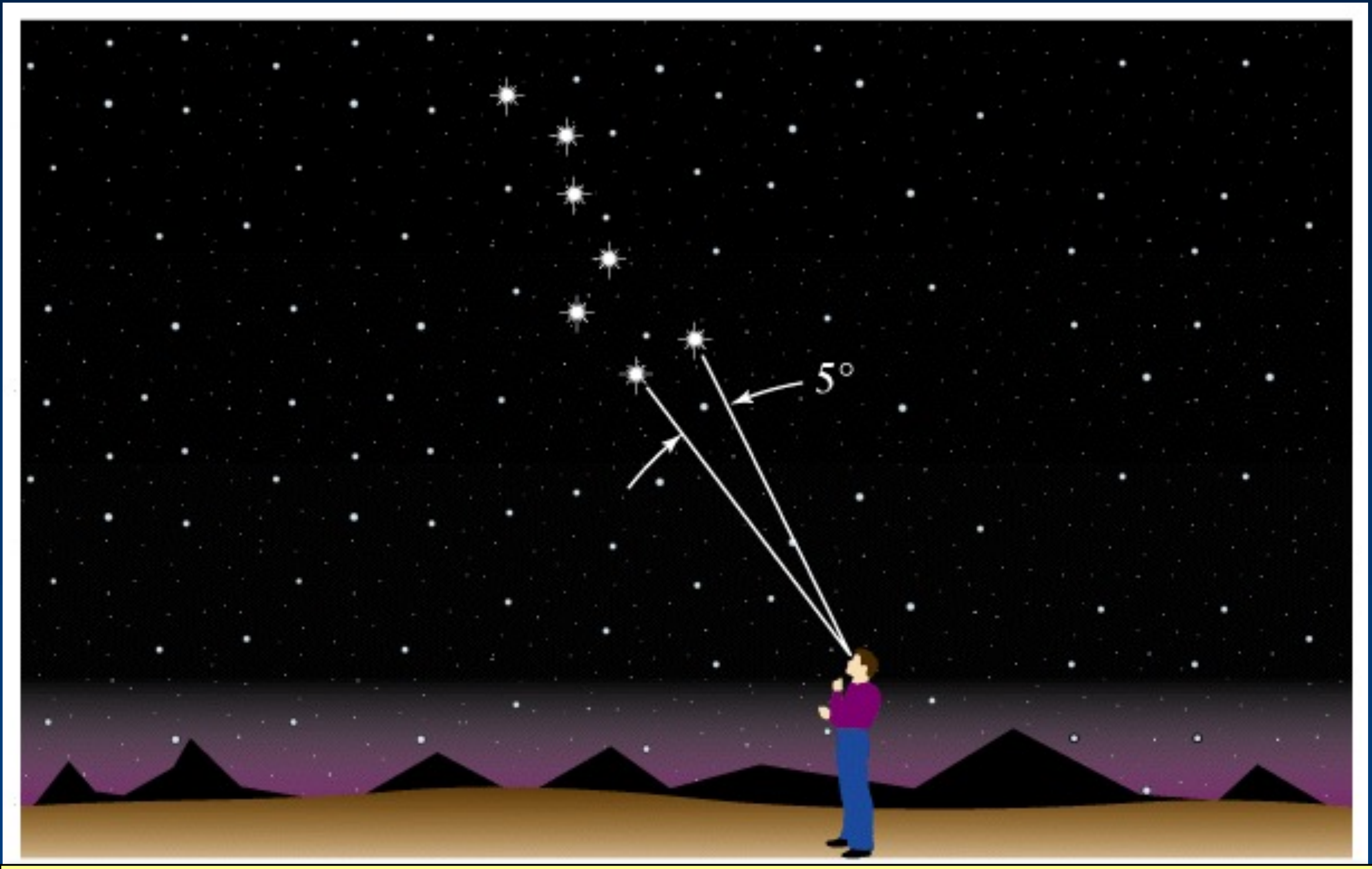
How to estimate angles

Extend your arm, and use your hand and fingers like this:



Is this what you expected for the Moon's angular diameter?

Example of angular separation: the “pointer stars” in the Big Dipper



Question: how many full Moons could you fit across the stars of the Big Dipper?

How do we express smaller angles?

We subdivide the degree into 60 arcminutes

(a.k.a. minutes of arc):

1° = 60 arcmin = 60'

An arcminute is split into 60 arcseconds

(a.k.a. seconds of arc):

1' = 60 arcsec = 60"

Note: we also need much smaller angles than this in astronomy! An arcsec is split into 1000 milli-arcsec

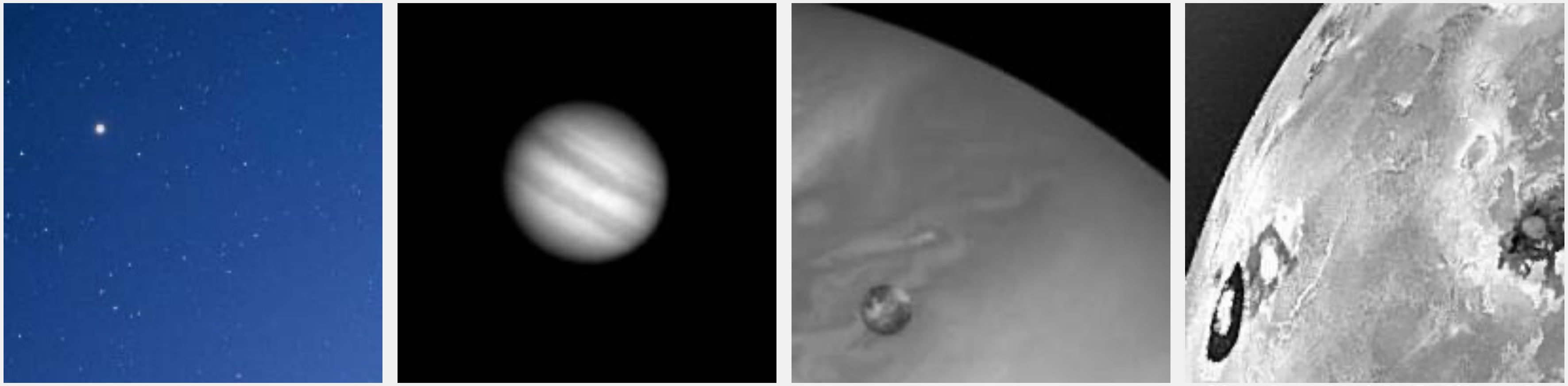
THE QUEST FOR RESOLUTION

Resolution = Observing wavelength / Telescope diameter

Angular Resolution	**Optical (5000A)**		**Radio (4cm)**	
	Diameter	**Instrument**	**Diameter**	**Instrument**
1′	**2mm**	**Eye**	**140m**	**GBT+**
1″	**10cm**	**Amateur Telescope**	**8km**	**VLA-B**
0.″05	**2m**	**HST**	**160km**	**MERLIN**
0.″001	**100m**	**Interferometer**	**8200km**	**VLBI**

Atmosphere gives 1" limit without corrections which are easiest in radio

Jupiter and Io as seen from Earth



1 arcmin **1 arcsec** **0.05 arcsec** **0.001 arcsec**

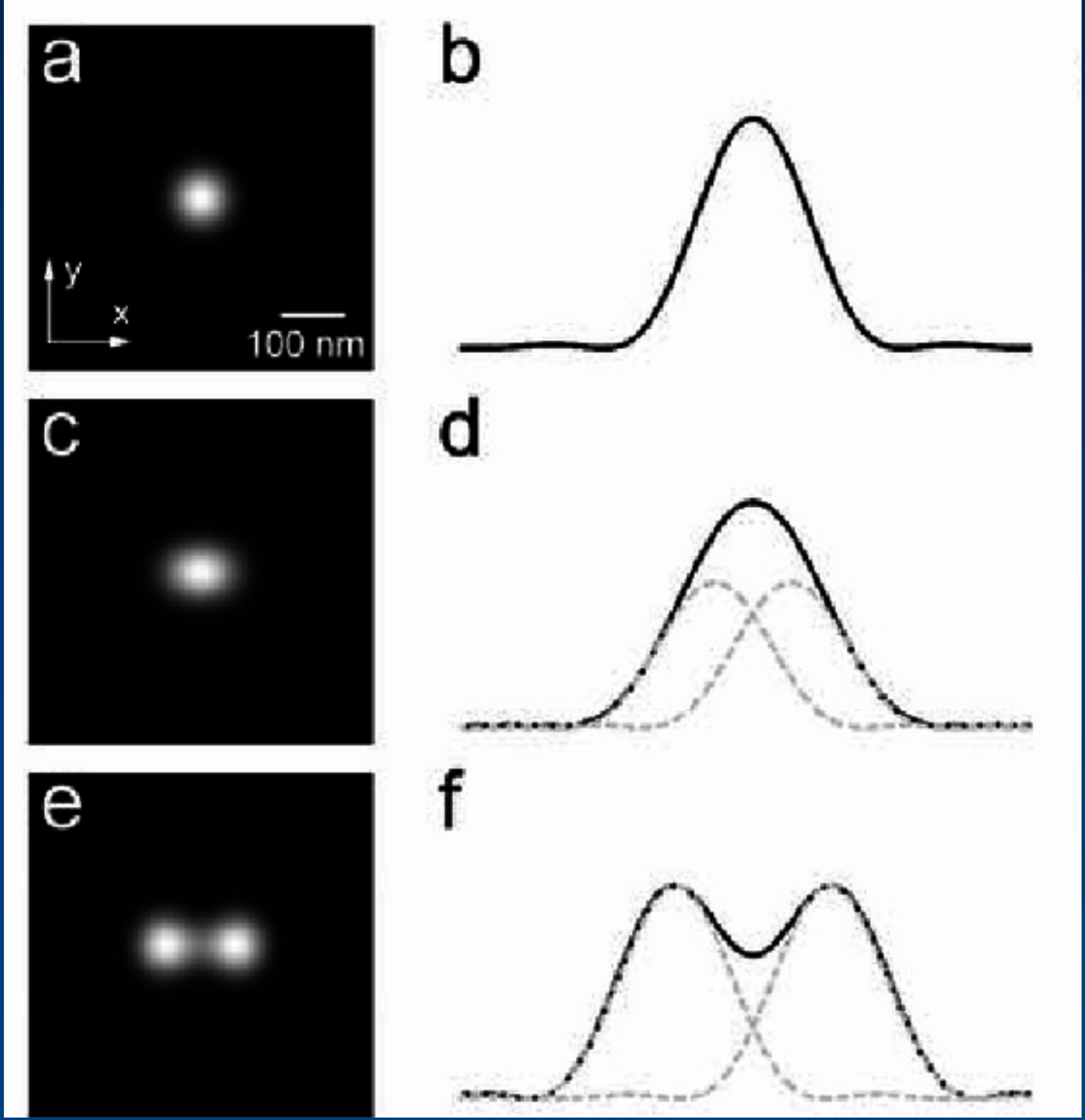
Simulated with Galileo photo

THE QUEST FOR RESOLUTION

Diffraction limit:

$\theta = 1.22\ \lambda/D$

θ = resolution
λ = wavelength
D = Diameter of telescope



The small-angle formula

Relation between angular size, physical size, and distance to an object:

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

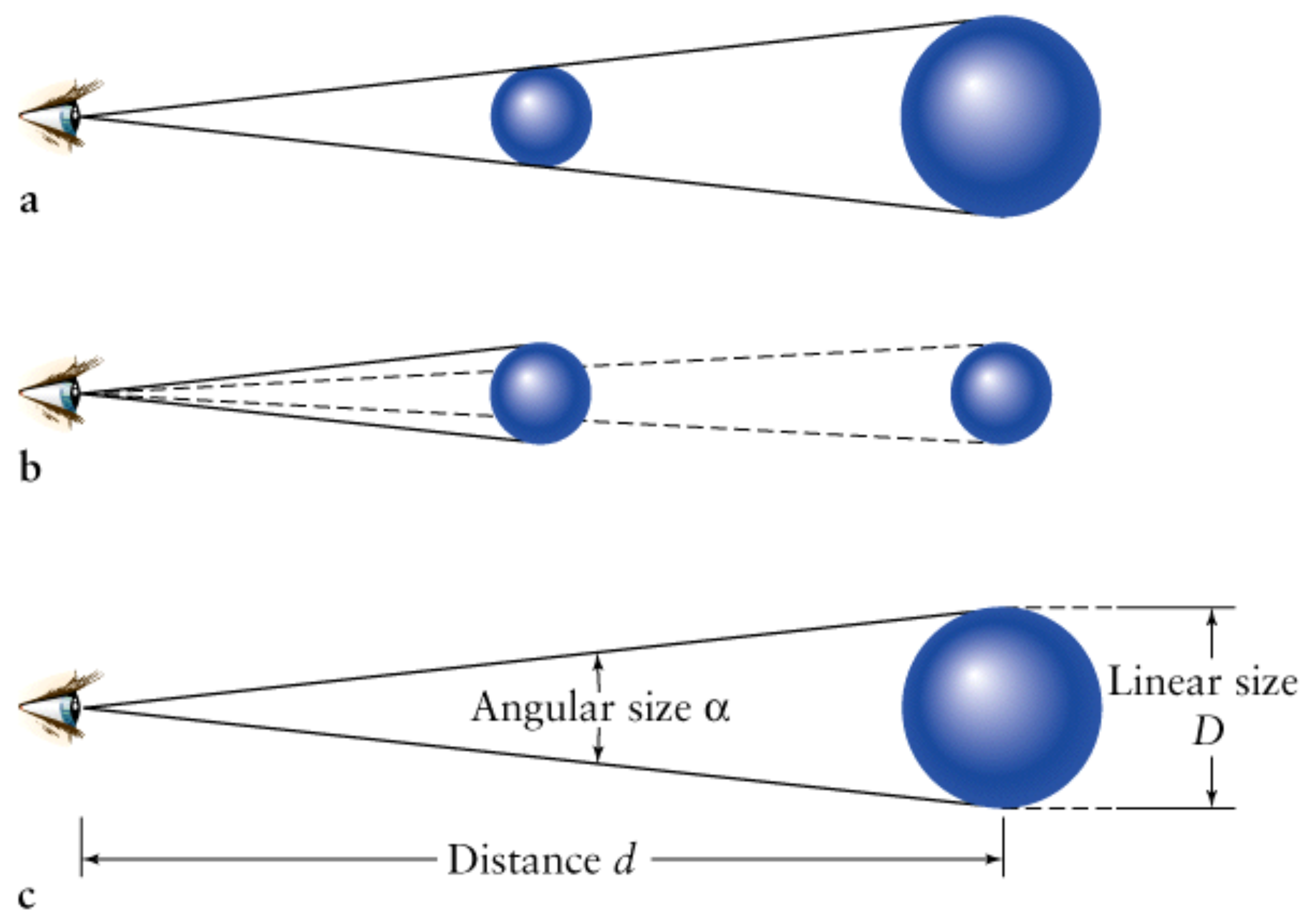
where

D = linear size of an object

α = angular size of the object (in arcsec)

d = distance to the object (in same units as D)

The same idea in pictures: the angular size depends on the physical, linear size AND on the distance to the object.



Worksheet 1

Lunar laser ranging gives roundtrip time 2.56 seconds. Use this and the fact that the moon is 30 arcminutes in angular diameter to calculate the distance to the Moon (in km), its physical diameter (in km) and the size of the smallest crater you could see by eye (in km).

Units in astronomy

Astronomers use the normal metric system and powers-of-ten notation, plus a few “special” units.

Metric system: (mks or cgs)

distances in m, or cm

masses in kg, or g

time in s

temperature in ° C or K

(astronomers do also tend to use units which are well-matched to an object or parameter, eg. km, g, Gyr, nm…)

In astronomy, we deal with:

1. Vast distances

- Radius of Earth = 6400 km = 6.4×10^8 cm

- Distance to Sun = 1.5×10^{13} cm = 23500 Earth radii = 1 Astronomical Unit (AU)

- Distance to next nearest star (Proxima Centauri): 270,000 AU = 4.3 "light years" (light year: distance light travels in one year, 9.5×10^{12} km. Speed of light $c = 3 \times 10^8$ m/sec)

- Size of Milky Way Galaxy: about 100,000 light years

- Distance to nearest cluster of galaxies (Virgo Cluster): 5×10^7 light years

2. Huge masses:

- Mass of Earth = 6×10^{24} kg = 6×10^{27} g = 1 M_{Earth}
  (or 6000 billion billion tons)

- Mass of Sun = 2×10^{30} kg = 2×10^{33} g = 1 M_{Sun}
  = 1 "Solar Mass"
  = 333,000 M_{Earth}

- Mass of Milky Way galaxy: more than 10^{11} M_{Sun}

- Mass of a typical cluster of galaxies: about 10^{15} M_{Sun}

3. Long ages and times:

- Age of Earth and Solar System: 4.5 billion years
  = 4.5 x 10^9 years

- Lifetime of stars: about 10^6 - 10^{12} years

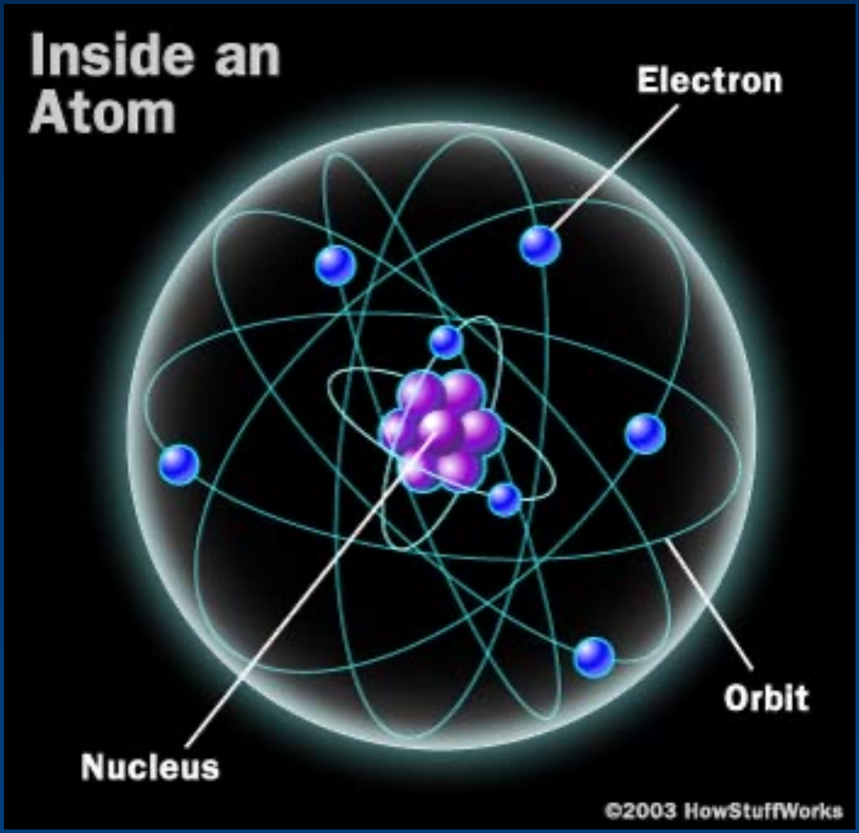
-Age of universe: 13.8 x 10^9 years

4. Very high and low temperatures:

- An interstellar "molecular cloud":
  T =10 K

- Center of Sun:
  T = 1.5 x 10^7 K

Size estimate



Atom:

10^{-8} m

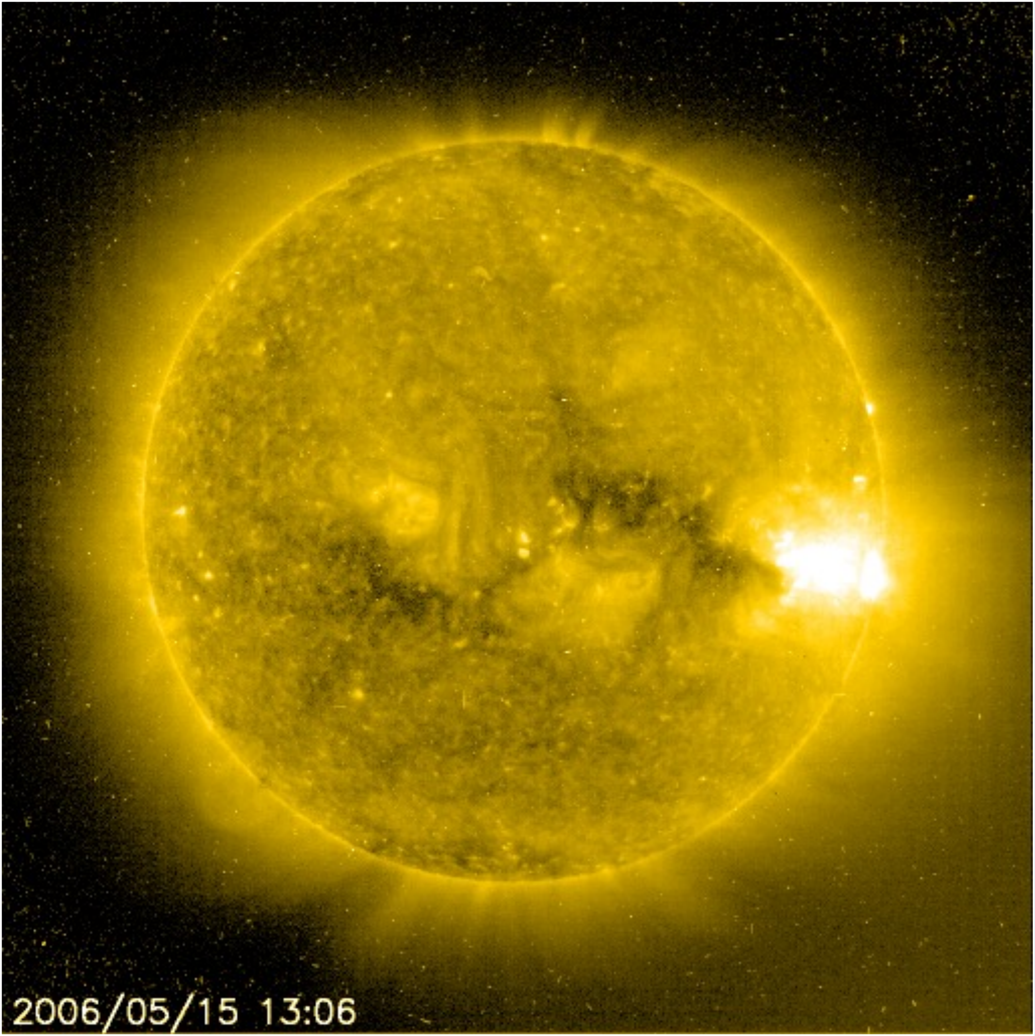
Size estimate

Child:
10^0 m

Size estimate

Earth:
10^7 m

Size estimate

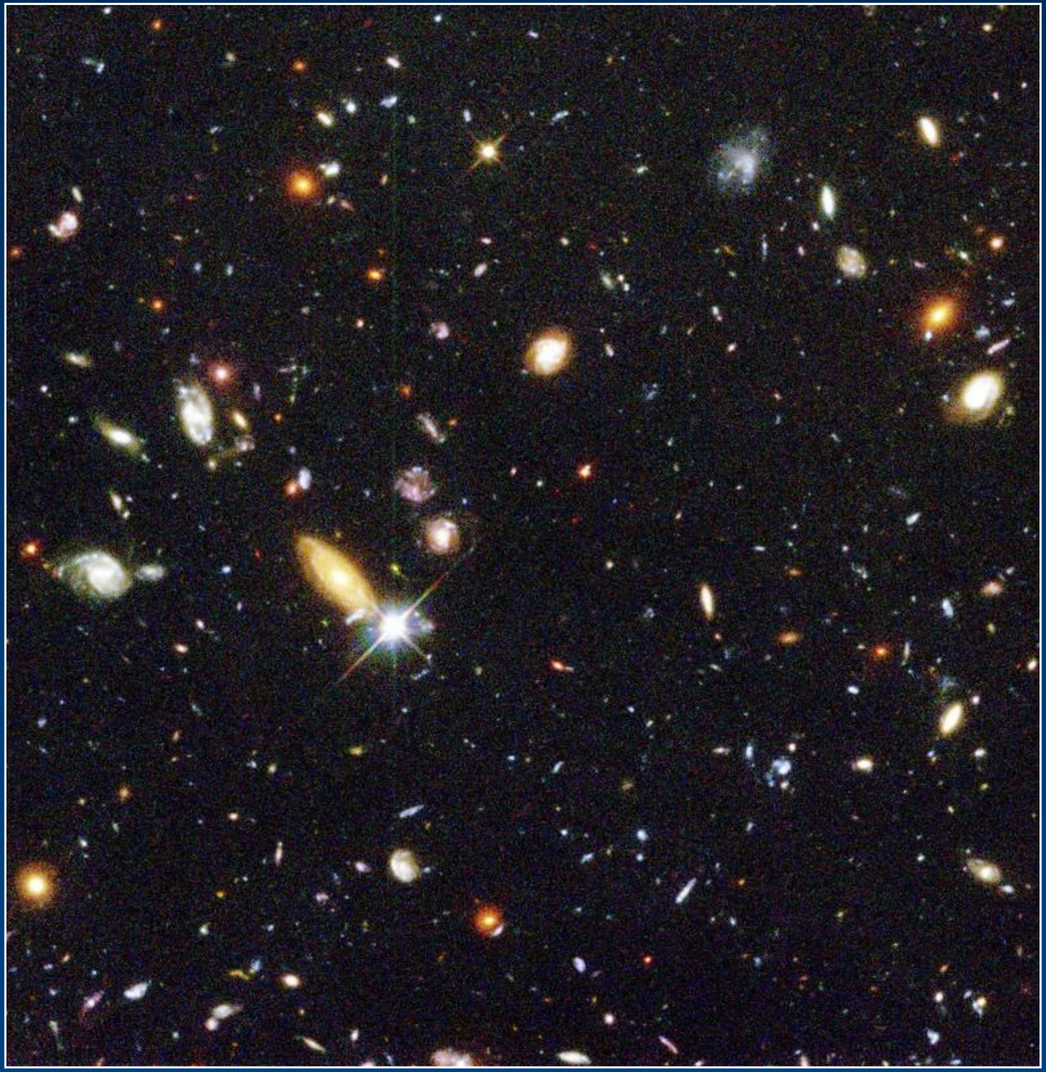


Sun:
10^9 m

Size estimate

Galaxy:
10^{21} m

Size estimate



The visible
Universe:
10^{26} m

Special distance unit: light-year

- A light-year is the distance light travels in one year. Speed of light is 3 x 10^8 m/s. In one year, light travels about 9.5×10^{15} m.

NB: a distance, not a time!

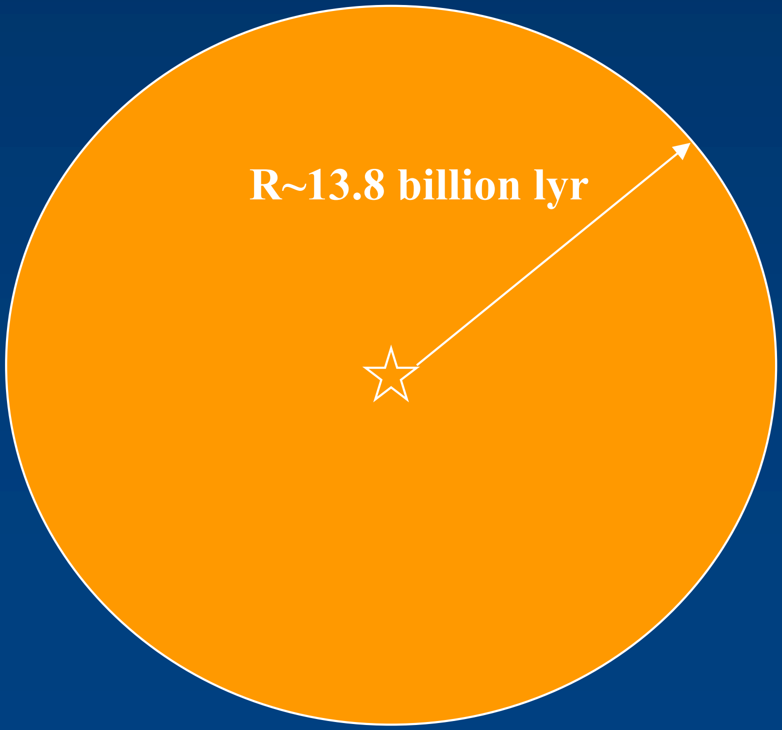
- Example: light takes 4.22 years to travel from Proxima Centauri, the nearest star beyond the solar system

  => Proxima Centauri is 4.22 light-years away.

- Hence we see this star as it was 4.22 years ago.

The observable Universe

- If the Universe is 13.8 Gyr old, we cannot know about objects for which the light would have had to travel more than 13.8 billion light-years to get to us (those signals have not yet had enough time to reach us)



…all objects whose light had to travel less than 13.8 billion light-years.

The Astronomical Unit (AU)

1 Astronomical Unit = 1 AU = the average distance between the Earth and the Sun = 1.496×10^8 km

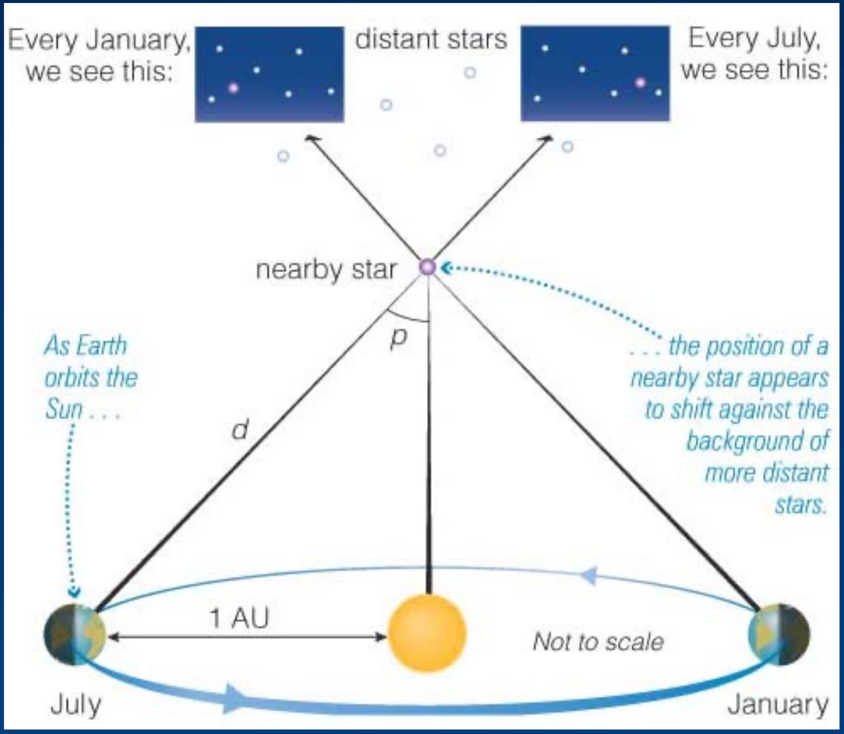
Why? It's convenient for interplanetary distances!

Example: The average distance between Jupiter and the Sun is 5.2 AU. Isn't that simpler than 7.8×10^8 km ?

The parsec

- Short for "parallax of one second of arc"
- It is the distance to a star which has a "trigonometric parallax" of 1", when observed at two opposite positions in the orbit of the Earth around the Sun, taken 6 months apart.
- If the trigonometric parallax is p, then d(pc) = 1/p(arcsec)

Note: diagram not to scale!



1 pc = 3.1×10^{16} m

= 206,265 AU

= 3.3 light years

Han Solo says he did the Kessel run in less than 12 pc.

Whaaat???

Astrometry of PMS stars

Loinard, Mioduszewski, Rodriguez, et al., 2005, ApJ, 619, 179.

HDE 283572

Proper motion

26.42 milliarcsec/yr

v = 16.9 km/s

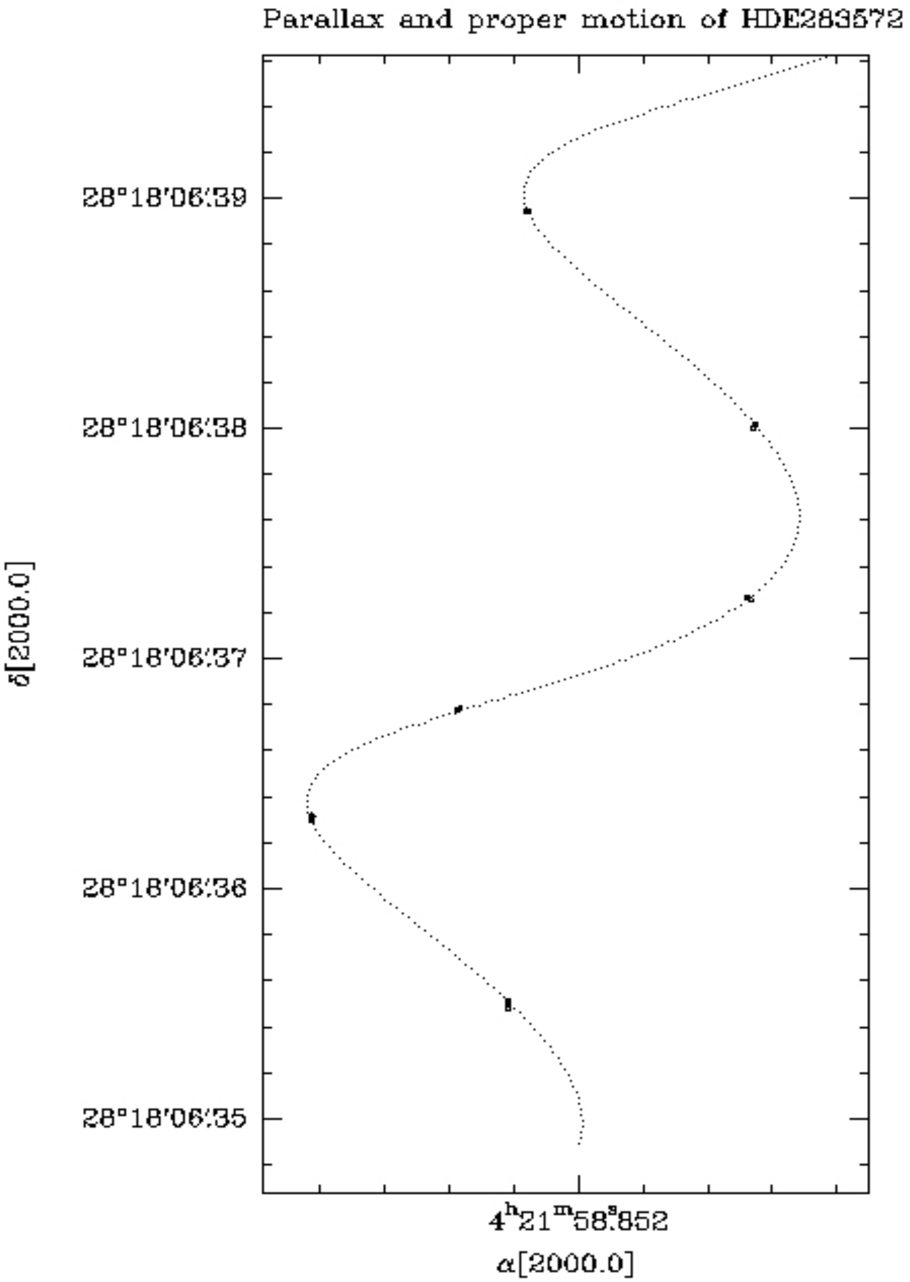
Parallax:

7.794 milliarcsec

Distance

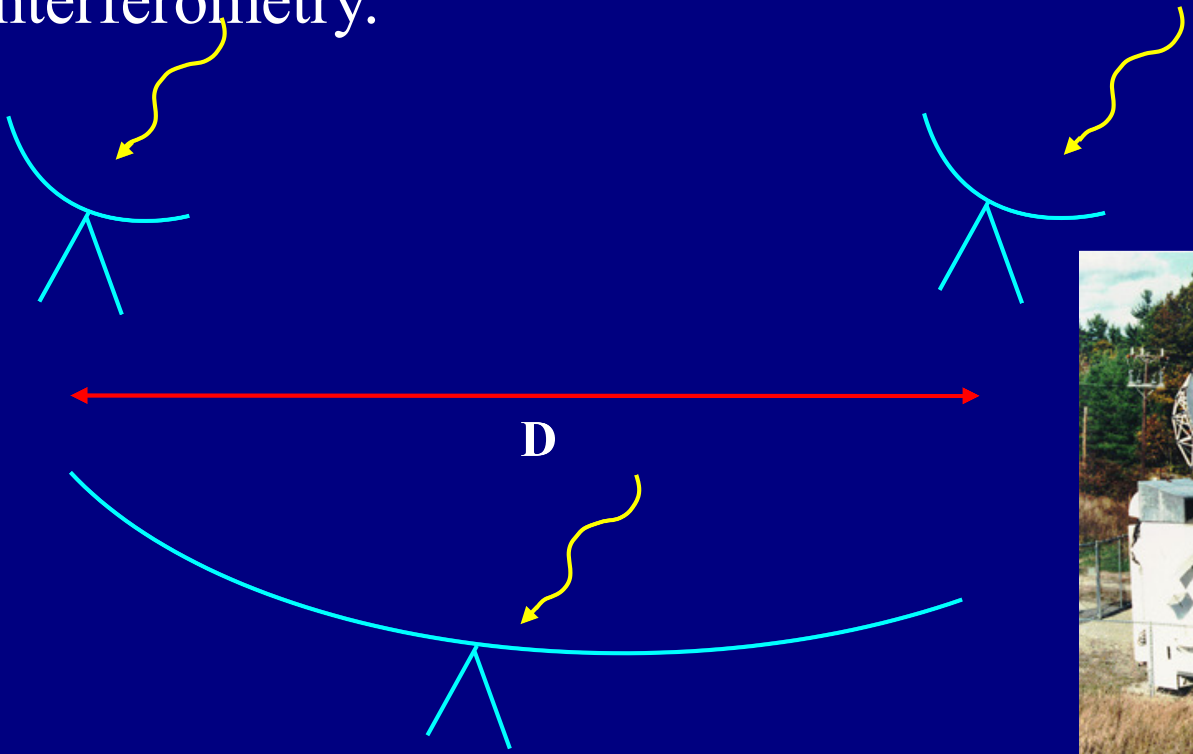
128.3 parsecs

0.5% accuracy



Interferometry

A technique to get improved angular resolution using an array of telescopes. Most common in radio, but also limited optical interferometry.



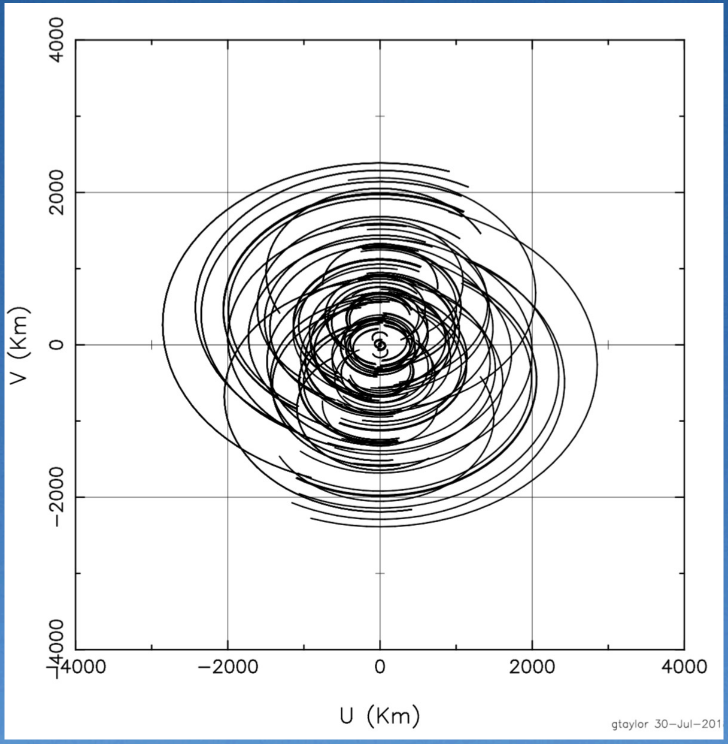
Consider two dishes with separation D vs. one dish of diameter D. By combining the radio waves from the two dishes, the achieved angular resolution is the same as the large dish.

The Very Long Baseline Array

If we want even higher angular resolution:

Operated by the National Radio Astronomy Observatory (NRAO) in Socorro, NM

LWA Swarm Concept



- Goal of 3 existing full stations (●) plus ~10 LWA mini stations (●), baselines up to 2500 km for resolution 0.5” at 80 MHz with 5 mJy sensitivity
- Cost is ~$5M including 1 year of operations

The Sky at Night

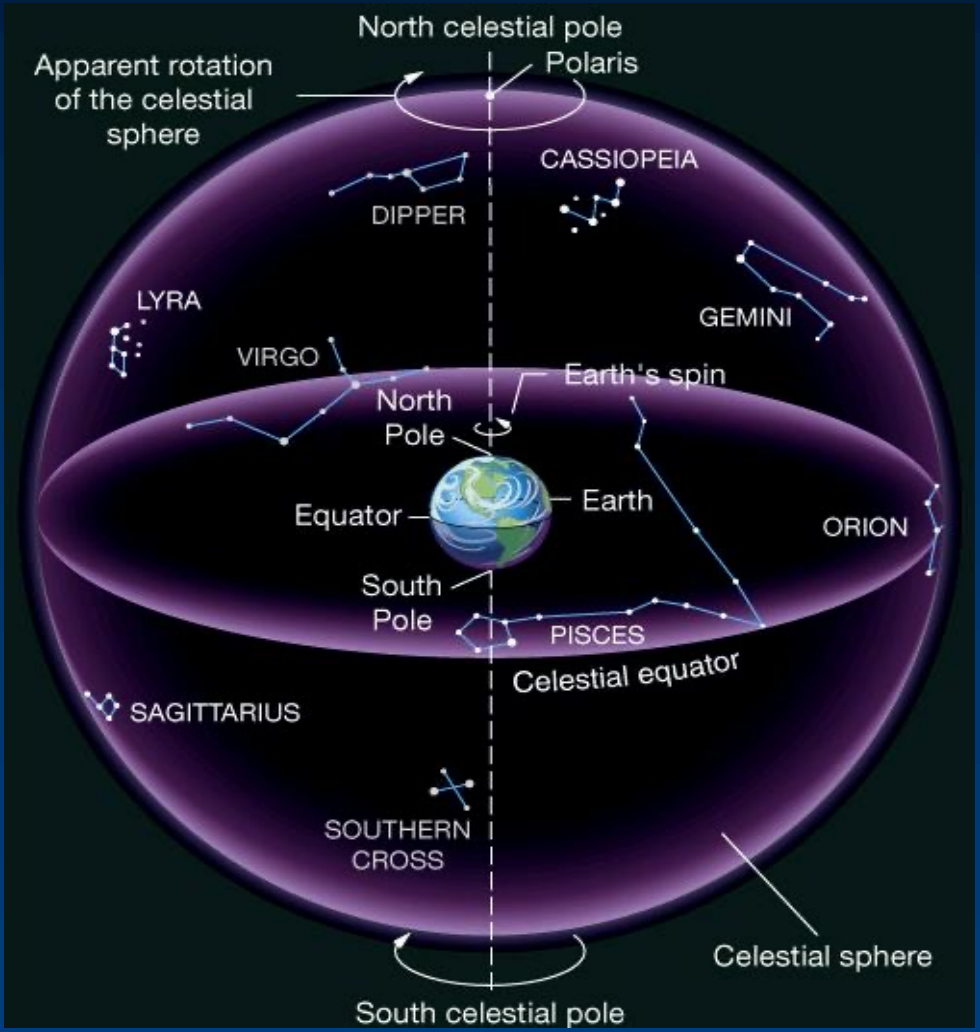
What do we see?

The Moon
Planets
Perhaps a meteor shower, comet, or other rare event
Stars - about 3000 visible
Patterns of stars - constellations
    88 of them
    Useful for finding our way around the sky,
    navigating the oceans
Satellites, airplanes, clouds, lightning, light pollution ...

The Celestial Sphere

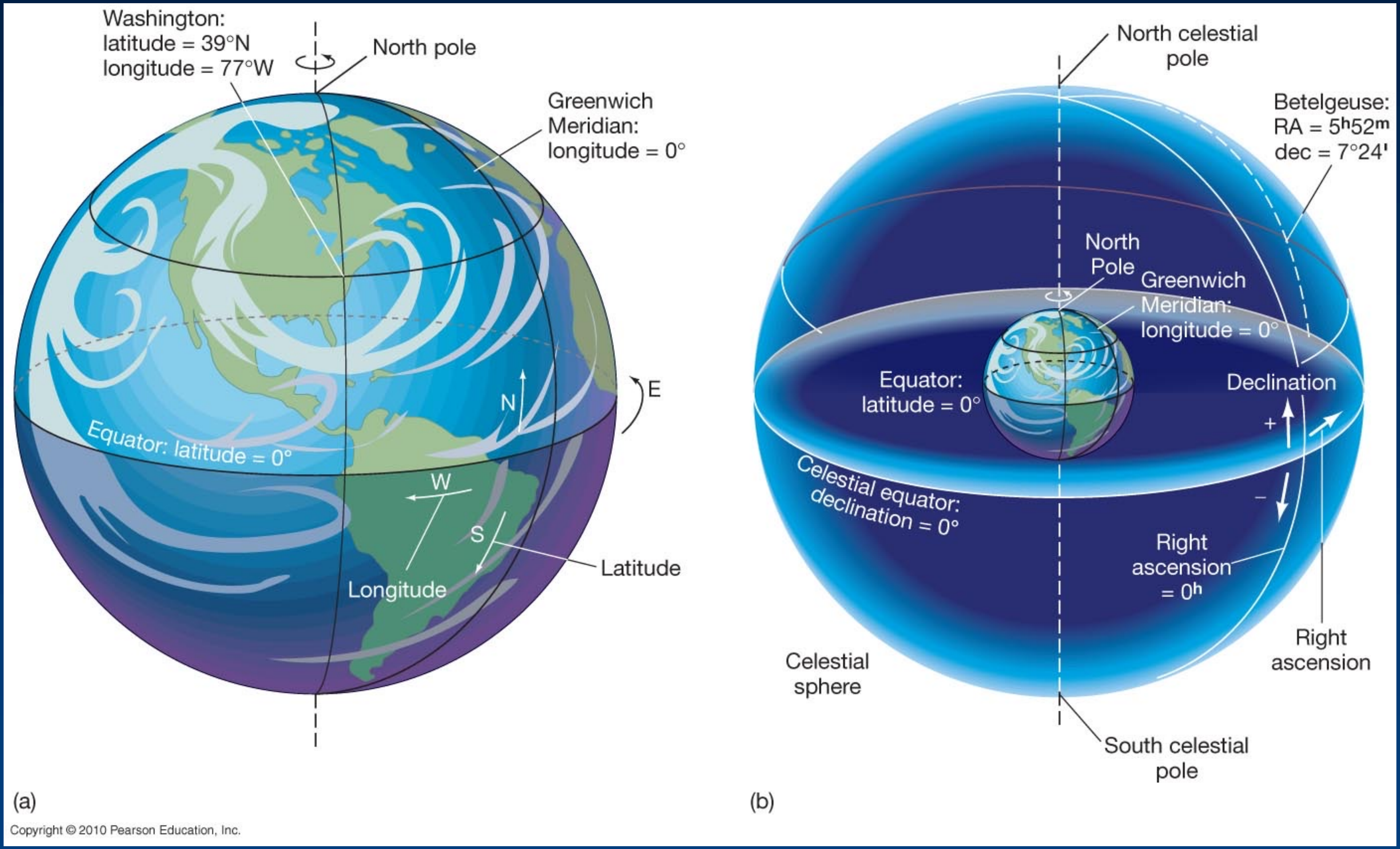
An ancient concept, as if all objects at same distance.

But to find things on sky, don't need to know their distance, so still useful today.



Features:
- Does not rotate with Earth
- Poles, Equator
- Coordinate System

The Celestial Sphere



latitude and longitude **Declination and Right Ascension**

Declination: +90 (north pole) to -90 (south pole)
Right Ascension: 0 to 24 hours (1 hour = 15 degrees)

The "Solar Day" and the "Sidereal Day"

Solar Day

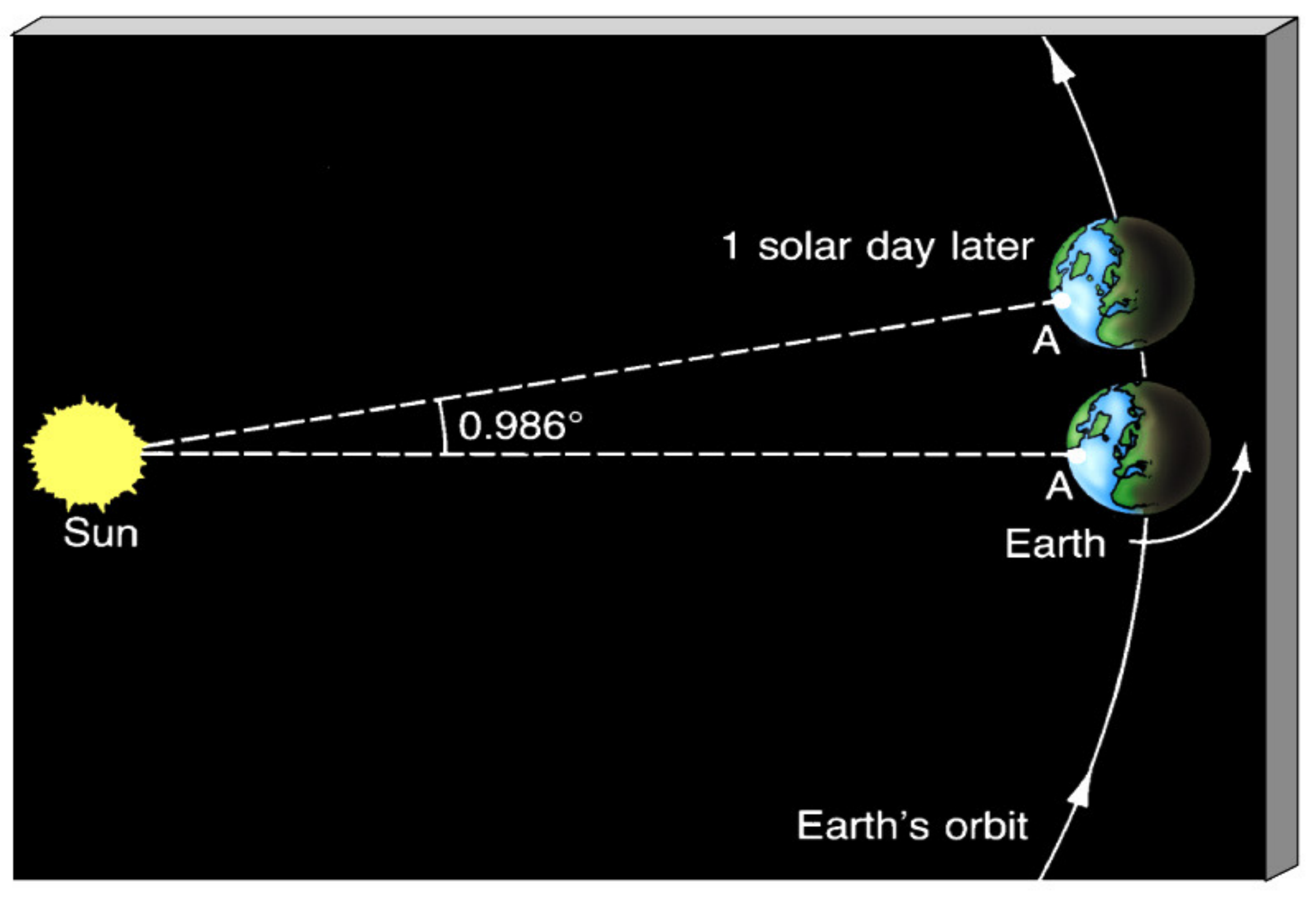
How long it takes for the Sun to return to the same position in the sky (24 hours).

Sidereal Day

How long it takes for the Earth to rotate 360^o on its axis.

These are not the same!

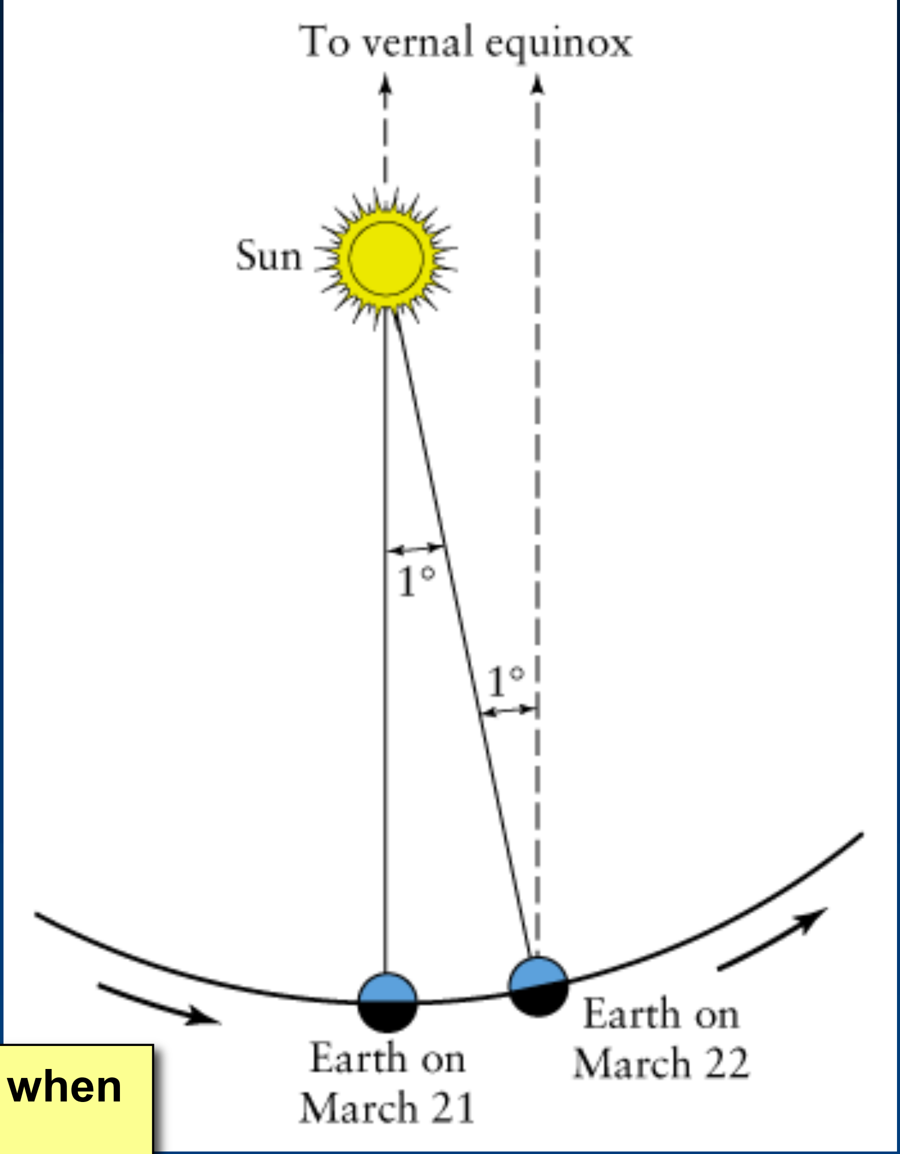
One solar day later, the Earth has rotated slightly more than 360º
A solar day is longer than a sidereal day by 3.9 minutes
(24 hours vs. 23 hours 56 minutes 4.091 seconds)



Solar time and sidereal time are different because the Earth is not only rotating, but also revolving around the Sun.

The Earth turns 360° in one sidereal day, but must turn a bit more in a solar day because it's moved in its orbit a little while revolving.

The difference is about 3.9 minutes, in the sense that a solar day is 24 hours while a sidereal day is 23 hours, 56 minutes, 4.091 seconds.



Useful fact for observing: sidereal time zero is when vernal equinox crosses meridian. Happens at midday on March 21 or midnight on Sept 22. This is also time when an object with RA=0^h crosses meridian. So in general an object crosses the meridian when the sidereal time is equal to its RA. And sidereal time=solar time on midnight, Sept 22

Observatories use sidereal clocks!

What Time is it Anyway?

IAT: International Atomic Time

UTC: Coordinated Universal Time

MDT: Mountain Daylight Time

LST: Local Sidereal Time

This class will end at:

19:15:00 UTC = 12:15:00 MDT = 19:59:12 LST