

# Today's topics

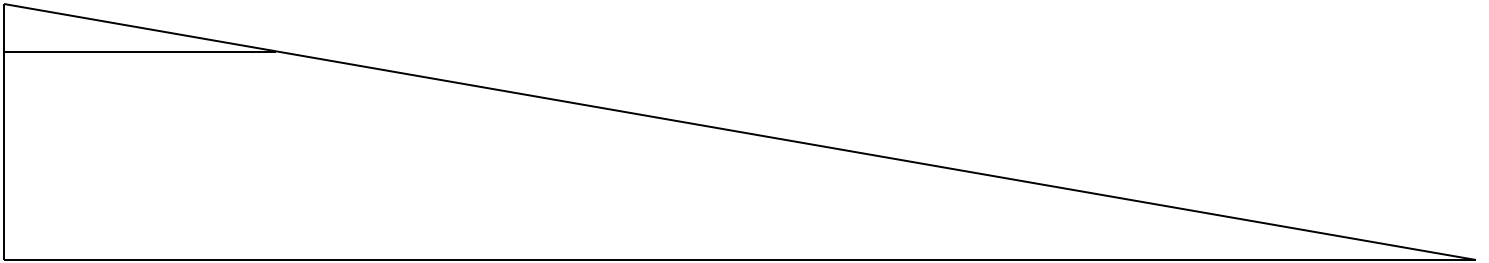
- How to measure distances
- How to measure sizes
- How big is the Universe?

Which is evidence in favor of a sun-centered model of the solar system?

- A) Retrograde motion of planets.
- B) Venus is never more than 47 degrees from the Sun.
- C) Venus is never seen in opposition.
- D) Venus goes through the same set of phases as the Moon.

How can you measure the distance to  
an object you can't reach?

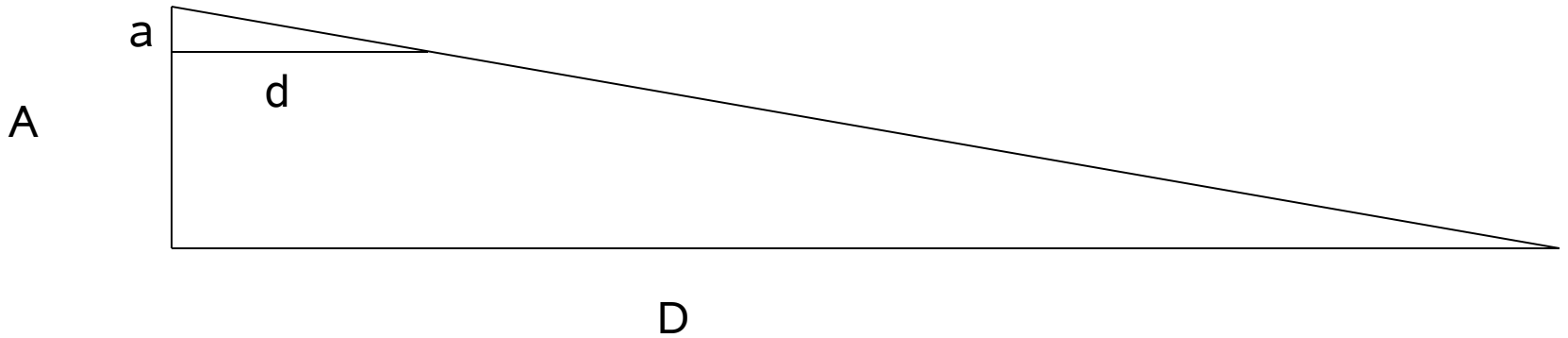
# Triangles



The small triangle has the same shape as the large one.

By measuring the two sides of the small triangle and the short side of the big triangle, we can calculate the length of the long side of the big triangle.

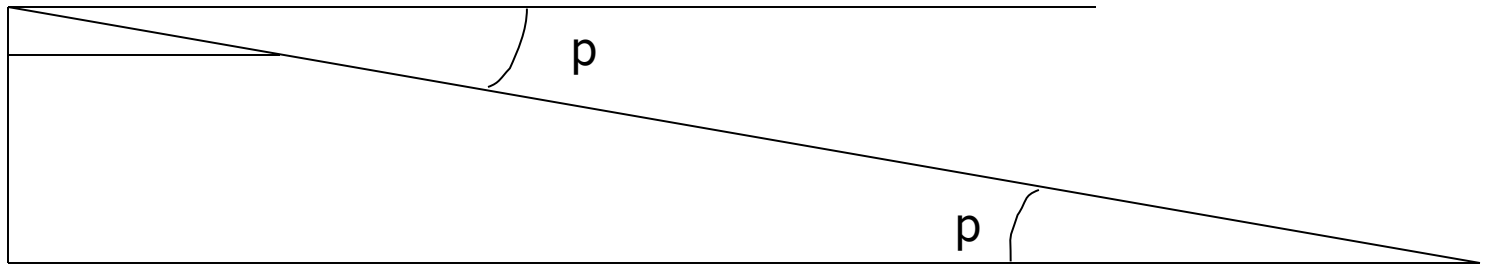
# Measuring distance



$$\frac{D}{A} = \frac{d}{a}$$

$$D = A \frac{d}{a}$$

# So, how can we measure the distance to stars?



Take two telescopes some distance apart and observe the same star.

Measure the tilt between the two telescopes – this sets all the angles for the triangles.

Then we can find the distance to the star from the distance between the telescopes and the angle of the tilt.

# So, how can we measure the distance to stars?

- We want to use the largest distance we can for the short side of the big triangle
- What is the largest distance we can get between the two telescopes (if both of them have to be on Earth – no spacecraft).

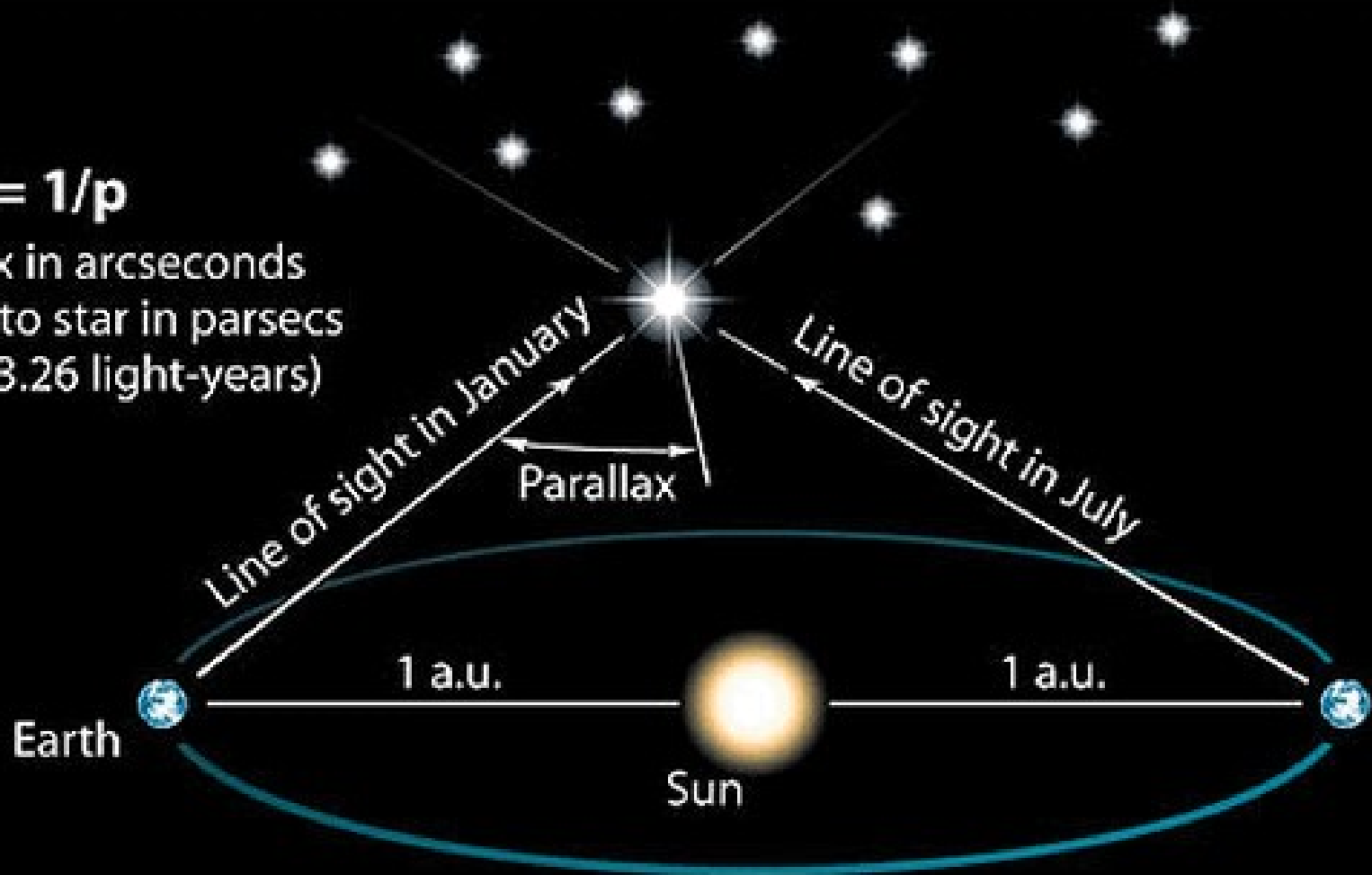
# So, how can we measure the distance to stars?

- The largest distance is not by placing the two telescopes at opposite ends of the Earth.
- Instead, we can use one telescope and just let the earth move.



$$d = 1/p$$

$p$  = parallax in arcseconds  
 $d$  = distance to star in parsecs  
(1 parsec = 3.26 light-years)



A.U. = Astronomical Unit = distance from Earth to Sun

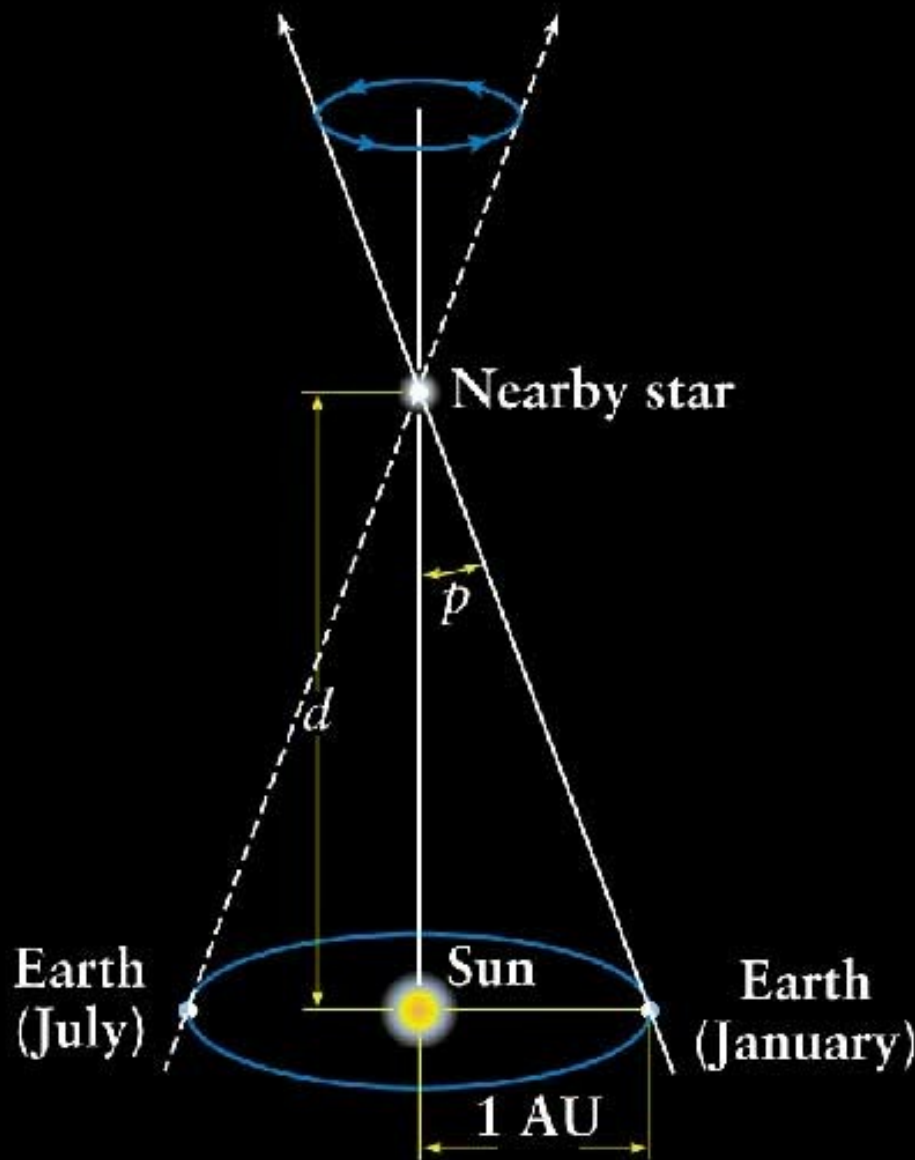
## Stellar Parallax

As Earth moves from one side of the Sun to the other, a nearby star will seem to change its position relative to the distant background stars.

$$d = 1 / p$$

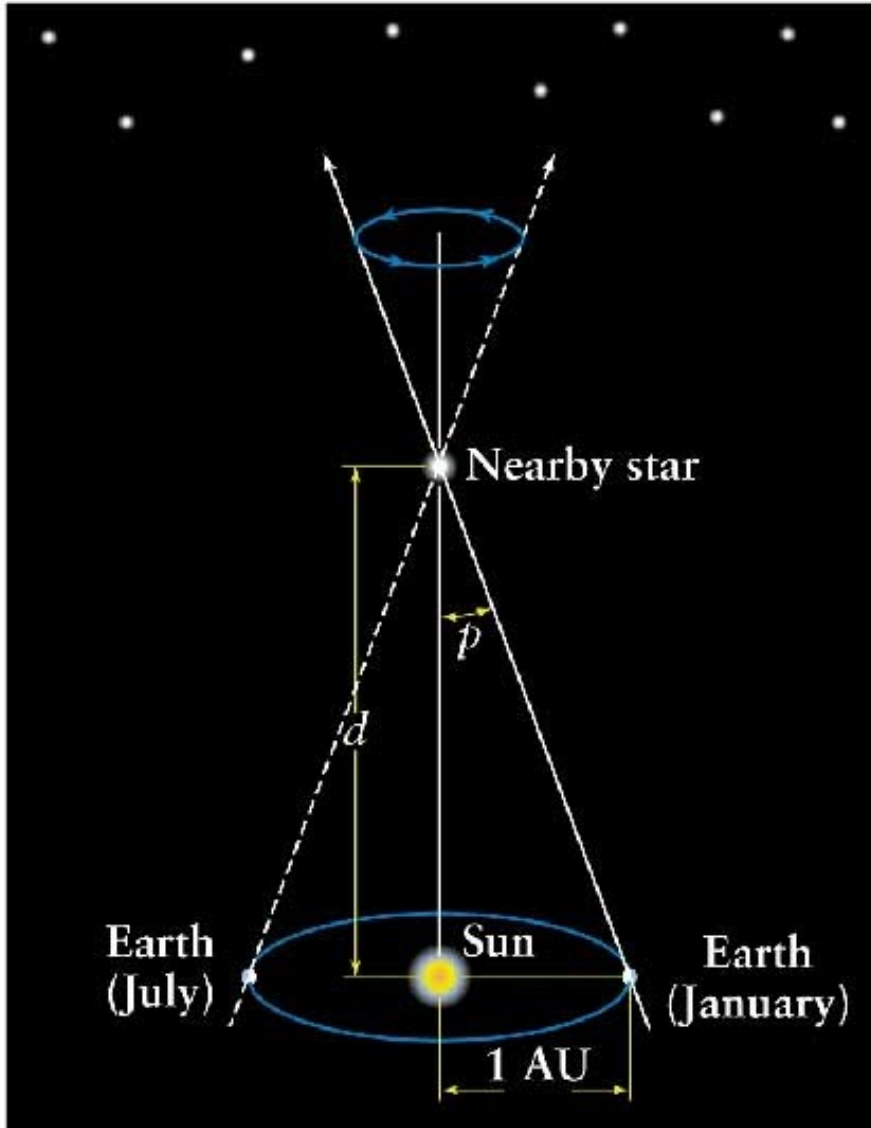
$d$  = distance to nearby star in parsecs

$p$  = parallax angle of that star in arcseconds



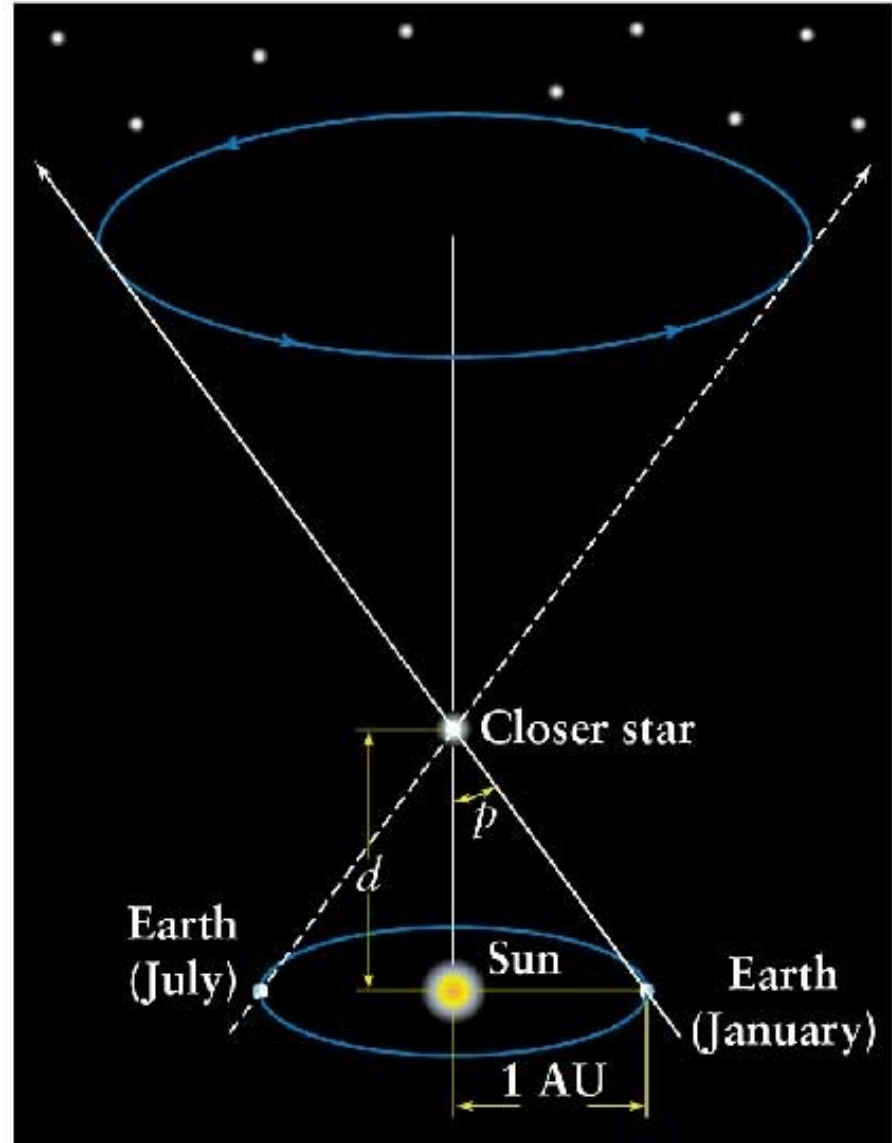
# Parallax of your thumb

- Look at the person sitting next to you or some nearby object.
- Look through your right eye and put your thumb 6 inches in front of your eye, then line up your thumb with the other person's nose.
- Now switch between your left and right eyes? Does your thumb stay lined up with the person's nose?
- Now repeat the procedure with your thumb 12 inches from your nose. Does your thumb appear to move more or less (relative to the person's face)?



a

Farther star – smaller parallax



b

Closer star – larger parallax

## Example: Using parallax to determine distance

The bright star Vega has a measured parallax of 0.1 arcsec ( $p = 0.1''$ )

This means that Vega appears to move from  $+0.1''$  to  $-0.1''$  with respect to distant stars over a year's observation

$$D(\text{pc}) = 1/p('') = 1/0.1 = 10 \text{ pc}$$

Vega is 10 pc (parsec) from Earth  
(remember: 1 pc = 3.26 light years)

The parallax of the star Vega is 0.1 arcseconds.  
On which planet would the parallax be larger than 0.1 arcsec?

A) Venus

B) Mars

C) Parallax doesn't depend on planet

D) None of the other answers is correct

# Sizes of Astronomical Objects

- How can we measure the sizes of astronomical objects?
- The same way that we measure distances – using triangles

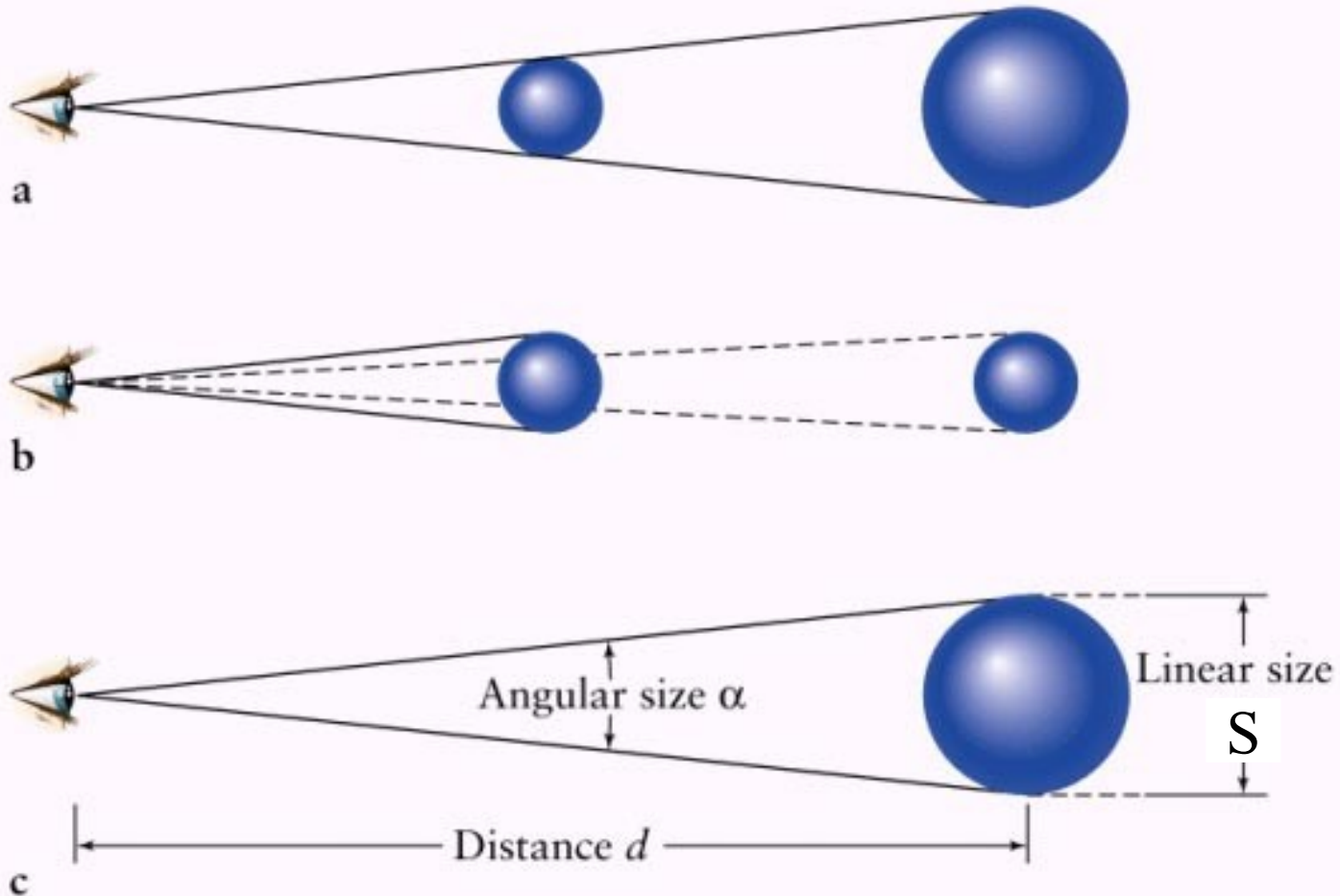
# The Small-Angle Formula

$$S = \frac{\alpha \cdot d}{206265}$$

$S$  = linear size of object

$\alpha$  = angular size of object  
(in arcseconds)

$d$  = distance to the object





*Example:* On November 28, 2000, the planet Jupiter was 609 million kilometers from Earth and had an angular diameter of 48.6". Using the small-angle formula, determine Jupiter's actual diameter.

$$S = 48.6'' \times 609,000,000 \text{ km} / 206265 = 143,000 \text{ km}$$

## The Small-Angle Formula

$$S = \frac{\alpha \cdot d}{206265}$$

$S$  = linear size of object

$\alpha$  = angular size of object  
(in arcseconds)

$d$  = distance to the object

An object is 2000 m away and has an angular size of 1". How big is it?

- A) Size of a grain of salt
- B) Size of the finger nail on your pinky
- C) Height of a person
- D) Length of the Titanic
- E) No clue

$$S = \frac{\alpha \cdot d}{206265}$$

# How big is the Universe?

- Greeks (up about 100 B.C.)
  - Earth at Center (except for Aristarchus)
  - Universe extends to ‘sphere of Saturn’, largest measured distance is from Earth to Sun at several million miles
- Renaissance (1500-1650)
  - Sun at Center
  - Universe extends to ‘distant stars’ with inferred distance of about 100 billion miles, largest measured distance is from Sun to Saturn at about 1 billion miles

# How big is the Universe?

- Parallax to stars
  - First parallax measured in 1838 to star 61 Cygni of 0.3 arcseconds for a distance of 11 ly =  $7 \times 10^{13}$  miles.
- Distance to center of Milky Way
  - from globular clusters 50,000 ly (1915)
- Distance to Andromeda nebula
  - from Cepheids 2,000,000 ly (1923)
  - (really 2,500,000 ly)

# How big is the Universe?

- Distance to first discovered quasar 3C 273 (supermassive black hole)
  - from redshift  $2 \times 10^9$  light years (1960)
- Distance to early Universe
  - from cosmic background radiation  $1.4 \times 10^{10}$  light years (1965)