Cosmic Distances

- How to measure distances
- Primary distance indicators
- Secondary and tertiary distance indicators
- Recession of galaxies
- Expansion of the Universe

Which is **not** true of elliptical galaxies?

A) Their stars orbit in many different directions
B) They have large concentrations of gas
C) Some are formed in galaxy collisions
D) The contain mainly older stars

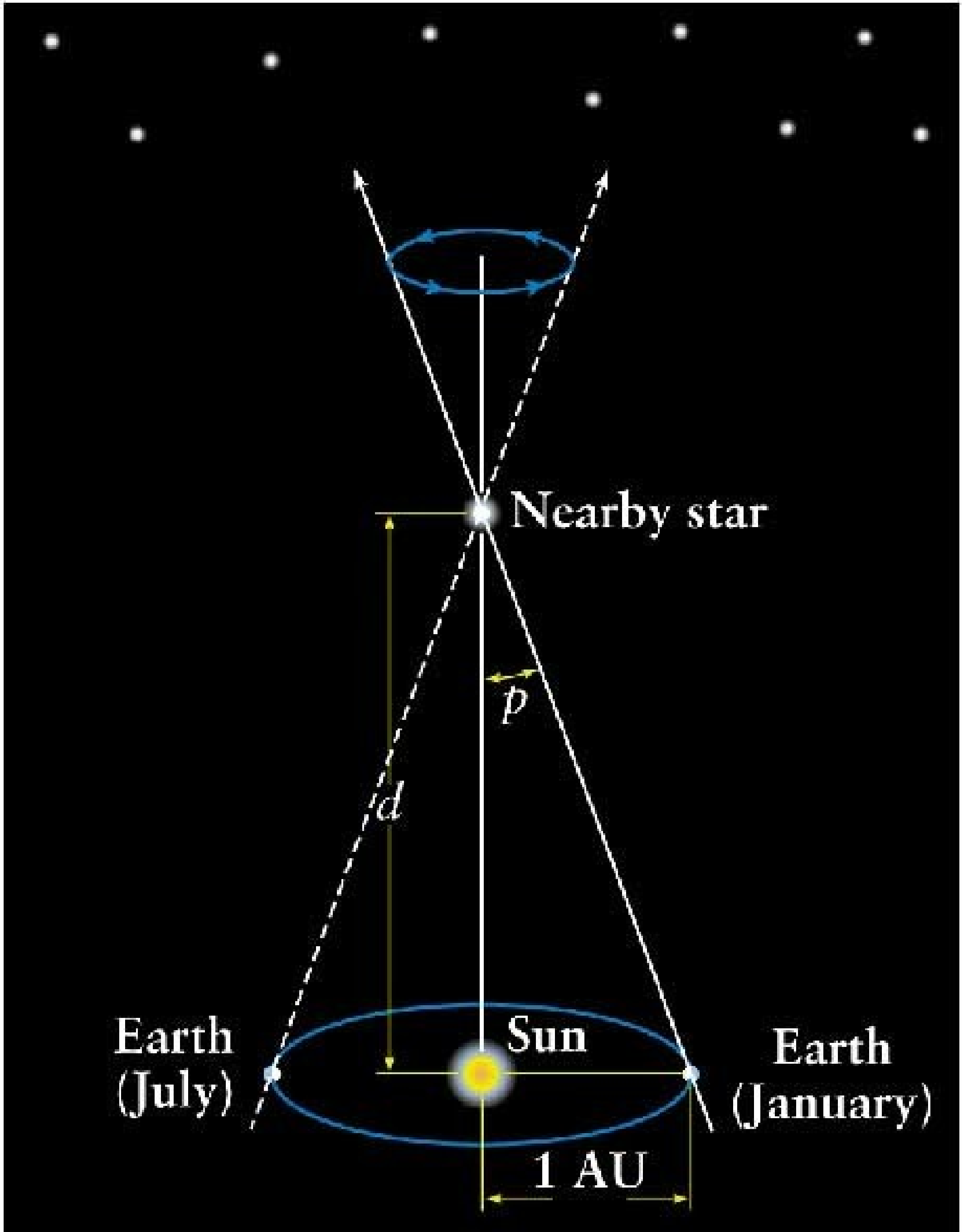
Which is **not** true of galaxy collisions?

A) They can randomize stellar orbits

B) They were more common in the early universe

C) They occur only between small galaxies

D) They lead to star formation



a

Stellar Parallax

As the 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

Stellar Parallax

- Most accurate parallax measurements are from the European Space Agency's Hipparcos mission.

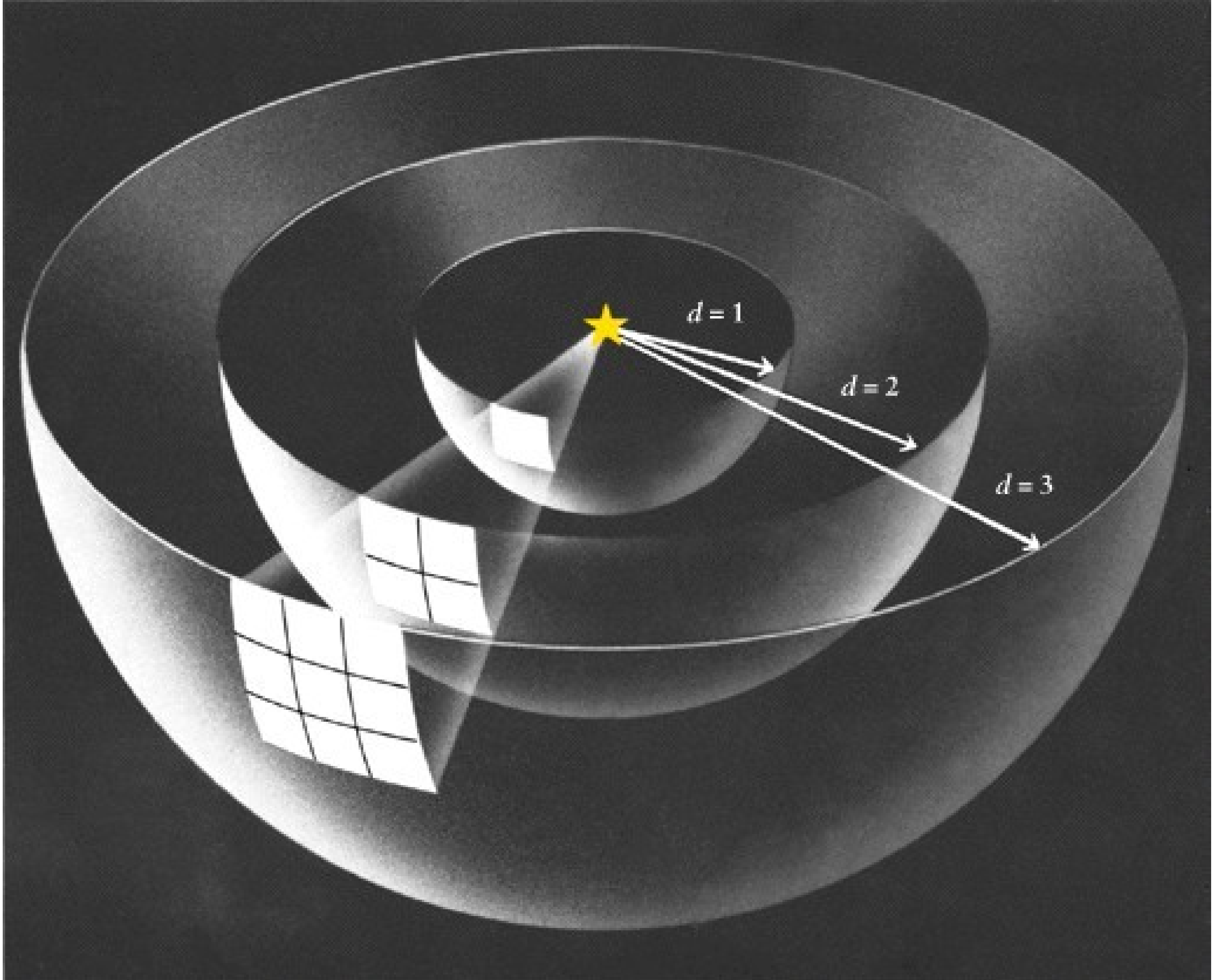
- Hipparcos could measure parallax as small as 0.001 arcseconds or distances as large as 1000 pc.

- How to find distance to objects farther than 1000 pc?

Flux and Luminosity

- Flux decreases as we get farther from the star – like 1/distance^2
- Mathematically, if we have two stars A and B

$$\frac{\text{Flux}_A}{\text{Flux}_B} = \frac{\text{Luminosity}_A}{\text{Luminosity}_B}\left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$



d = 1
d = 2
d = 3

Standard Candles

$$\text{Luminosity}_A = \text{Luminosity}_B$$

$$\frac{\text{Flux}_A}{\text{Flux}_B} = \frac{\text{Luminosity}_A}{\text{Luminosity}_B}\left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$

$$\frac{\text{Flux}_A}{\text{Flux}_B} = \left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$

$$\frac{\text{Distance}_B}{\text{Distance}_A} = \sqrt{\frac{\text{Flux}_A}{\text{Flux}_B}}$$

Standard Candles

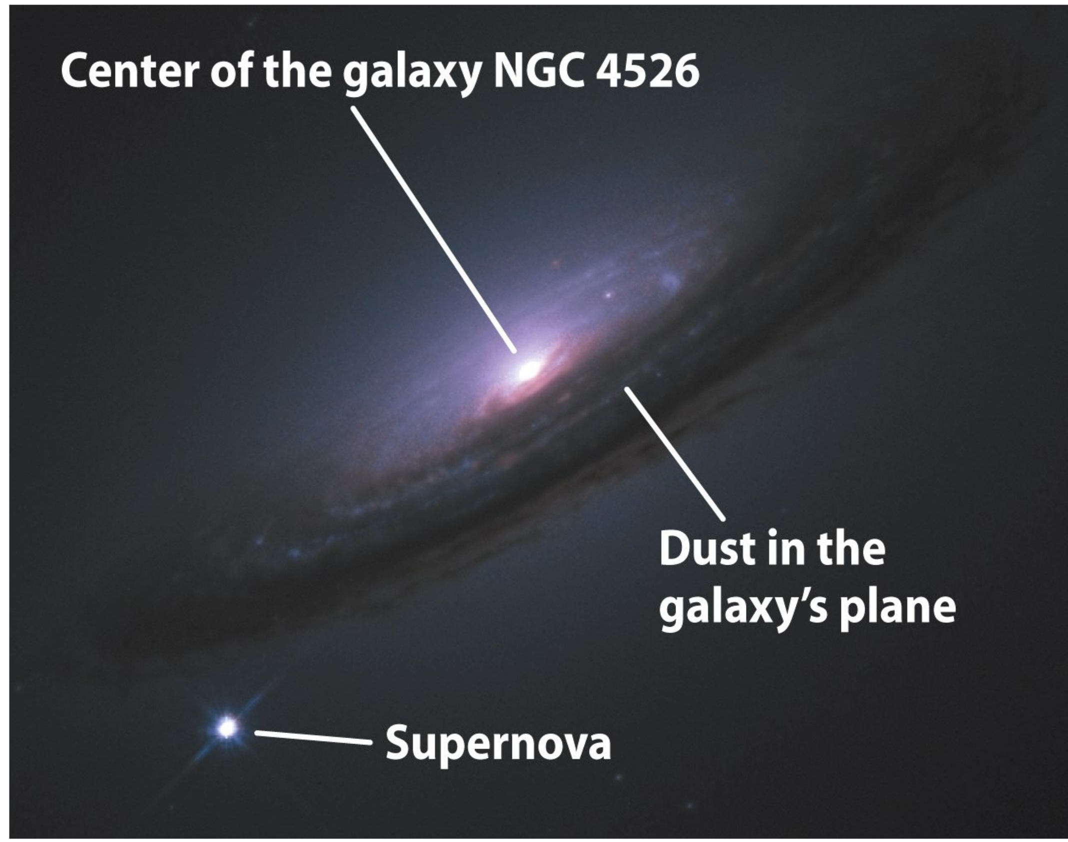
1. Measure the distance to star A to be 200 pc.
2. Measure the flux of star A.
3. Measure the flux of star B, which is known to have the same luminosity as star A, to be lower by a factor of 1600 (or the flux of A is 1600 times the flux of B).
4. Find the distance to star B.

$$\frac{\text{Distance}_B}{\text{Distance}_A} = \sqrt{\frac{\text{Flux}_A}{\text{Flux}_B}} \qquad \frac{\text{Distance}_B}{200\text{ pc}} = \sqrt{\frac{1600}{1}}$$

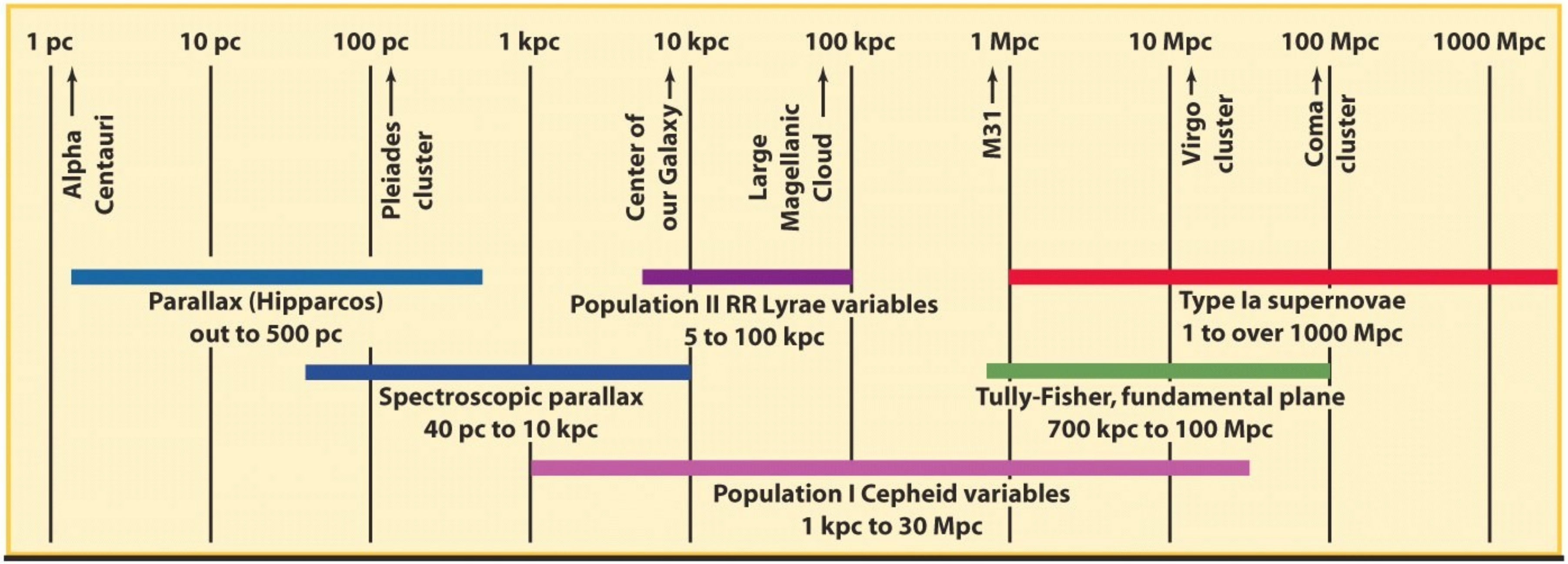
$$\text{Distance}_B = 40 \times 200\text{ pc} = 8000\text{ pc}$$

Distances to galaxies

Standard candles, such as Cepheid variables, the most luminous supergiants, globular clusters, H II regions, and supernovae in a galaxy, are used in estimating intergalactic distances.



The Distance Ladder



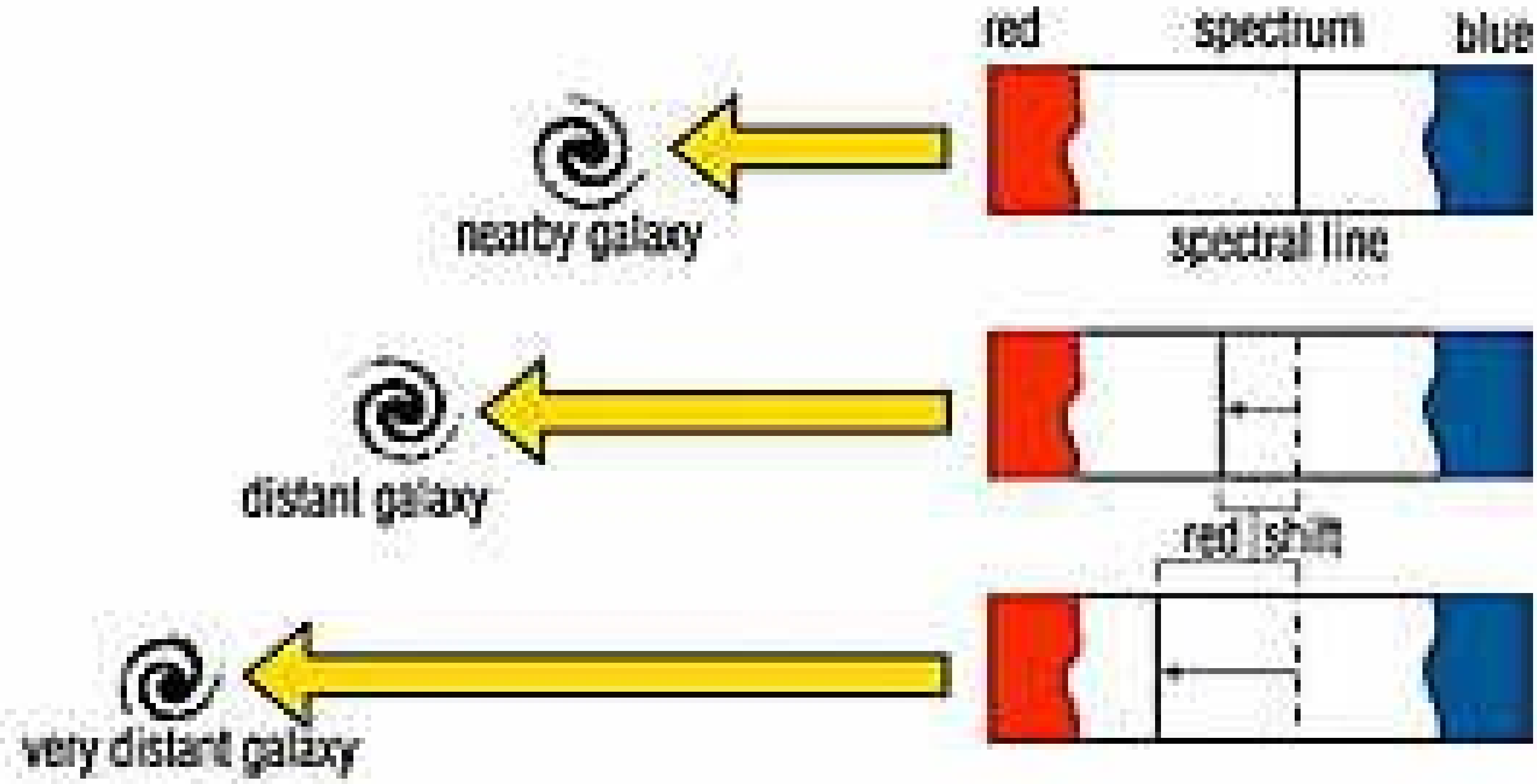
- Each stage in the ladder overlaps the previous and next
- Cepheid distances are critical
- Tully-Fisher, fundamental plane apply to whole galaxies
- Supernova are now the best estimators at large distances

A Cepheid variable star is 900 times dimmer but has the same period as another Cepheid which is 100 pc away. How far is it?

A) 100 pc
B) 3000 pc
C) 90,000 pc
D) Really far

Doppler effect for light

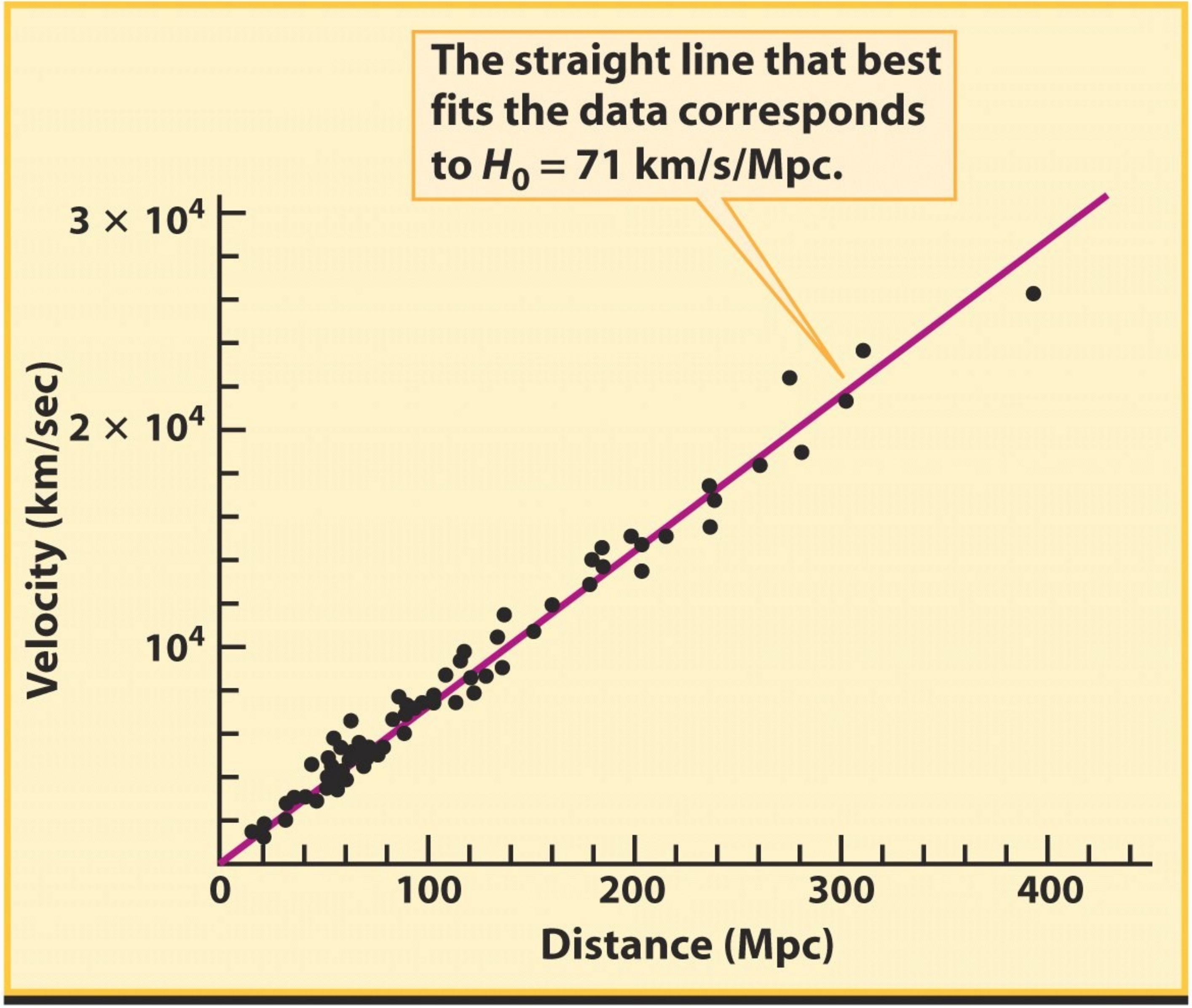
Light from distant galaxies is redshifted



Distances and velocities of galaxies

- If you measure the distances to a large set of galaxies and also measure the speed of the galaxies using the redshift, what do you find?

Hubble expansion $v = H_0 d$



What would be the recession speed of a galaxy at a distance of 7 Mpc?

A) 0.1 km/s

B) 10 km/s

C) 245 km/s

D) 490 km/s

E) 980 km/s

$\text{Speed} = H_0 \times \text{distance}$ $\quad H_0 = 70$ km/s/Mpc

What would be the recession speed of a galaxy at a distance of 14 Mpc?

A) 0.1 km/s

B) 10 km/s

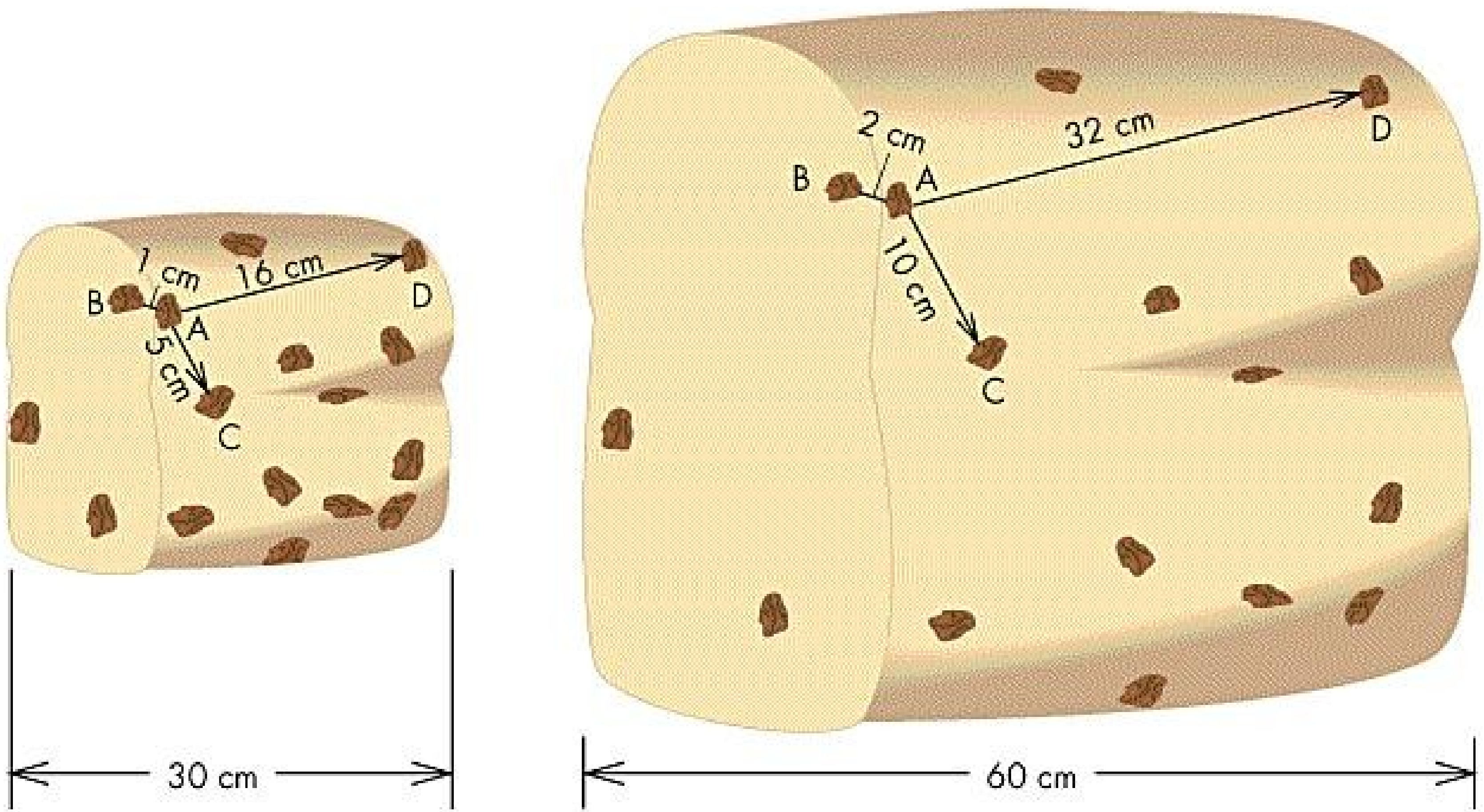
C) 245 km/s

D) 490 km/s

E) 980 km/s

$\text{Speed} = H_0 \times \text{distance}$ $H_0 = 70$ km/s/Mpc

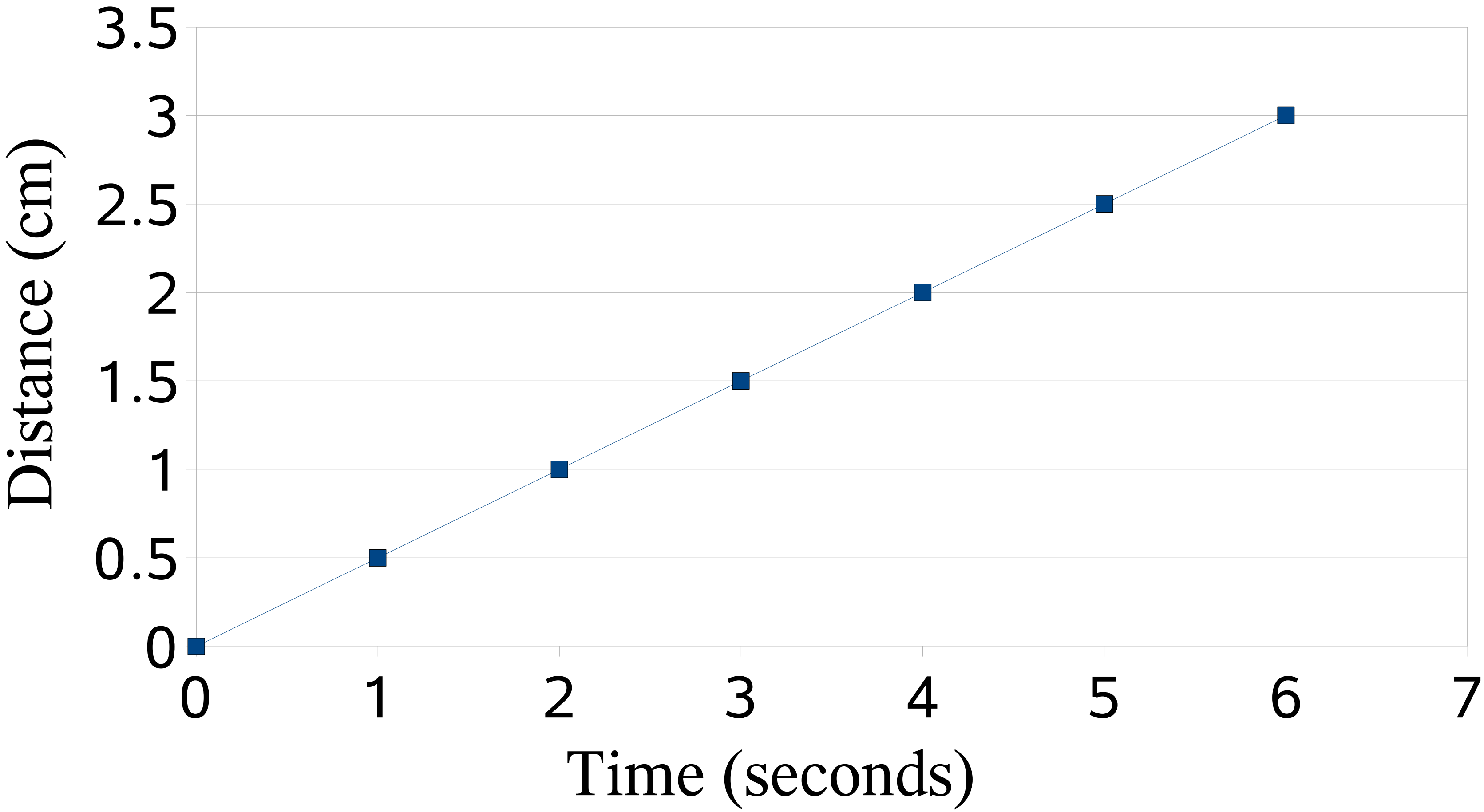
Expansion of the Universe



A Raisin bread dough before rising

B Raisin bread dough after rising

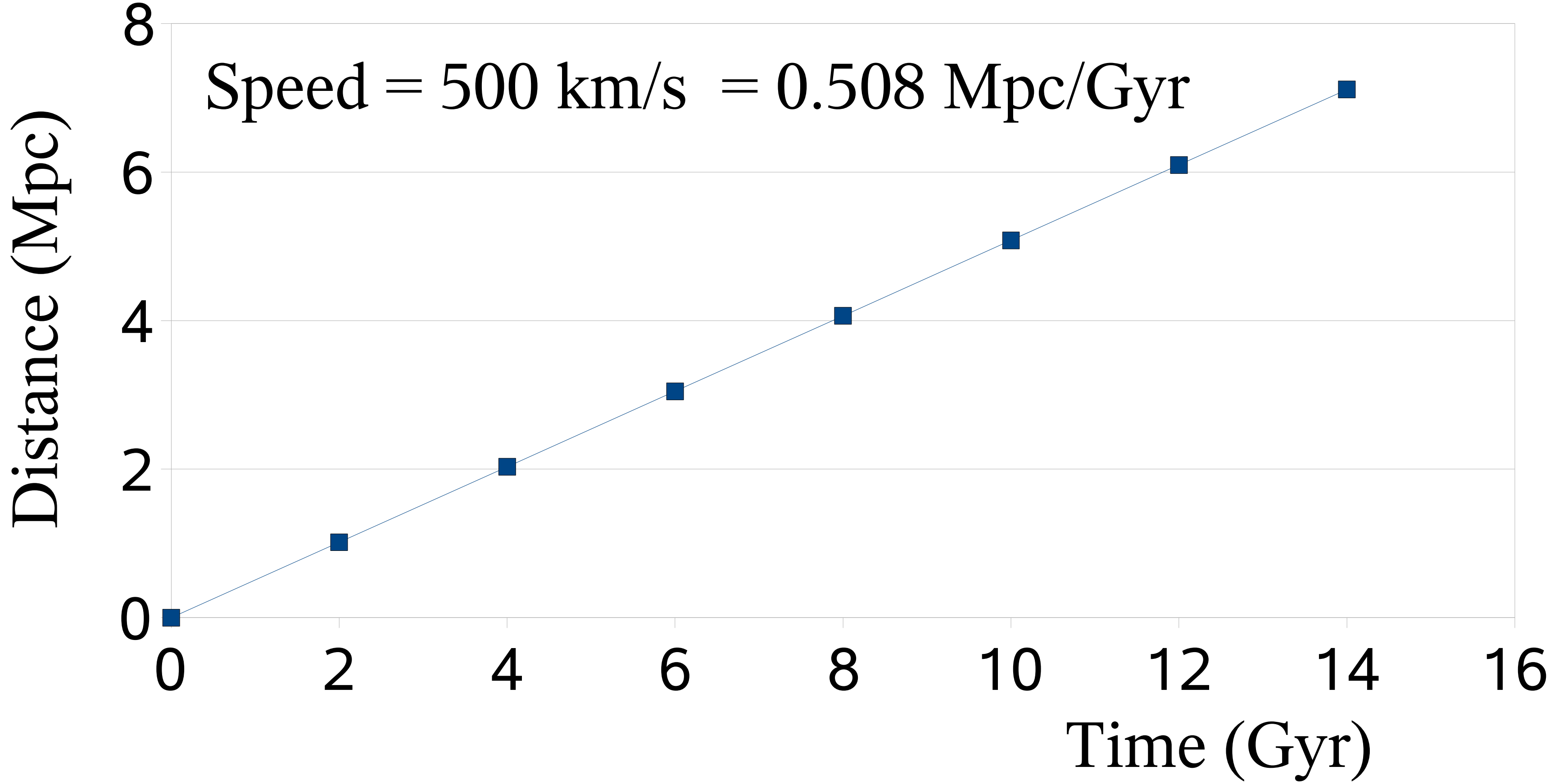
Motion at constant speed



distance = velocity × time   velocity = 0.5 cm/s

time = distance / velocity = 3 cm/(0.5 cm/s) = 6 s

Receding galaxy

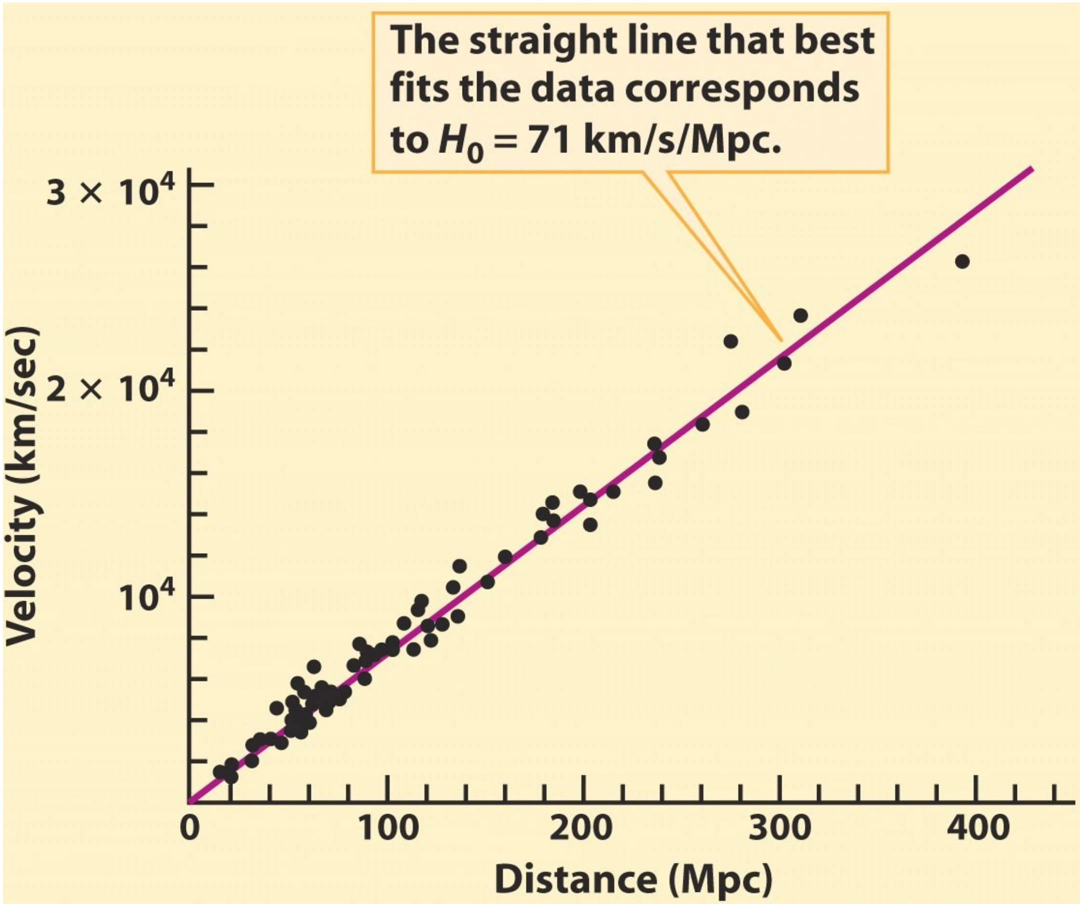


When were galaxies in the same place?

time = distance / velocity

= 7 Mpc/(0.508 Mpc/Gyr) = 13.8 Gyr ago

Hubble expansion $v = H_0 d$



Time = distance/velocity

= $d/H_0 d$

= $1/H_0$

= 1/(71 km/s/Mpc)

= 13.8 Gyr