Reminders

1. Online Quiz Chapter 15 Due Tuesday at 11:59PM
2. Midterm 3 Friday Nov 20
Cosmology Part I
Hubble Discovered Expansion of the Universe using Cepheid Variables
Redshift: Measure Velocity Using Doppler Shift
When galaxies interact stars don’t collide because

(a) stars are tiny compared to the average distance between them
(b) gravity is too weak
(c) there are not enough stars
(d) stars do collide
Clicker Question

When galaxies interact the thing that interacts is:

(a) stars
(b) gas
(c) dark matter
(d) everything
Clicker Question

Dark matter is

(a) truly dark, it doesn’t emit light
(b) something completely different than ordinary matter
(c) likely a light super-symmetric particle like a sneutrino
(d) interacts only by gravity
(e) all of the above
Hubble’s Law

- Hubble Law

\[ v = H_0d \]

\[ H_0 = 73 \pm 5 \text{ km/s/Mpc} \]

- Observational evidence for expansion of the universe

- Redshift: \( z \)

\[ z = \frac{\delta \lambda}{\lambda} \approx \frac{v}{c} (v \ll c) \]
Hubble’s Data

![Graph showing Hubble's law with a linear relationship between distance (Mpc) and velocity (km/s).]
Modern Hubble Diagram

Source: NASA
Hubble’s Constant: (from Supernovae), Age of the universe

\[ H_0 \sim 70 \text{km/s/Mpc} \]

Age of the Universe

\[ d = vt \]

Hubble’s Law

\[ v = H_0 d \]
or

\[ d = v \left( \frac{1}{H_0} \right) \]

Thus \( T_{\text{age}} \sim \frac{1}{H_0} \)!
Hubble Expansion is like a race