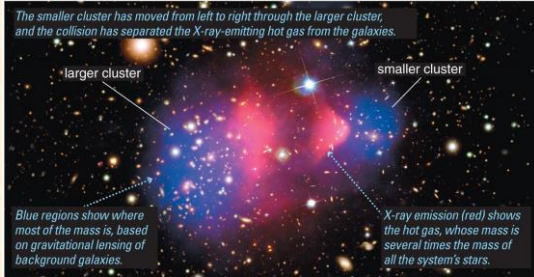


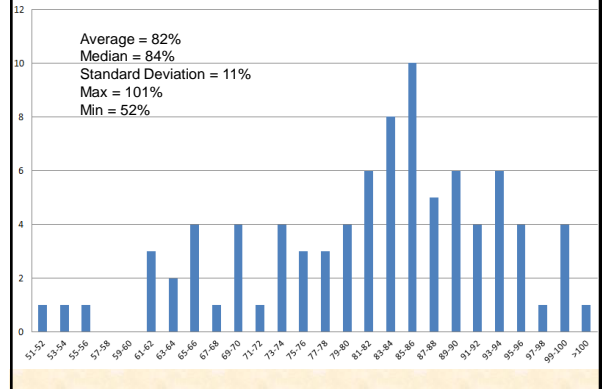
ASTR 1020: Stars & Galaxies

November 22, 2013

- Reading for Dec. 2: Chapter 23, section 23.4.
- *Mastering Astronomy* Homework due on Dec. 6: *The Fate of the Universe*



Exam 3 Distribution



Astronomy in the News: Nuclear fusion laser-beam experiment yields surprising results

Brian Bitterfeld



The experimental chamber in which the proton-boron fusion reactions were produced.

Reading Clicker Question: Dark Matter is inferred to exist because

- a) We see lots of dark patches in the sky
- b) It explains how the expansion of the universe can be accelerating
- c) We can observe its gravitational influence on visible matter

Clicker Question: Dark Matter is inferred to exist because

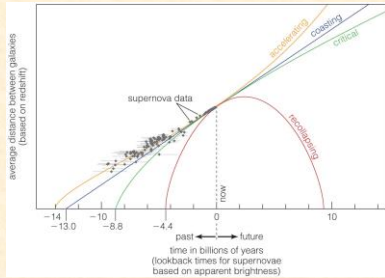
- a) We see lots of dark patches in the sky
- b) It explains how the expansion of the universe can be accelerating
- c) **We can observe its gravitational influence on visible matter**

Today

- Chapter 23, Section 23.4: *Dark Matter and the fate of the Universe.*
- After Fall Break: *Dark Energy.*

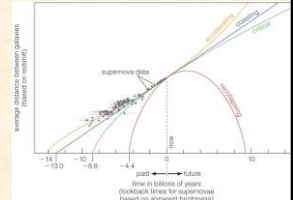
Dark Matter and the Fate of the Universe

- Expansion begins with the Big Bang
- Several different models for Past and Future



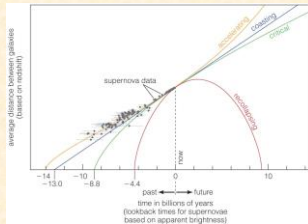
Important Diagram

- "Average distance between galaxies"
= $1 / \text{expansion factor}$
= $1 / (1+z)$
- NOW is fixed in time ($z=0$)
- Hubble constant NOW sets the slope of the line = how fast the universe is expanding NOW



Big Bang= when distance is zero;
 $z=\infty$

- But the expansion rate is not necessarily constant for all time....
- Gravity will SLOW expansion rate \rightarrow deceleration
- Different models for different amounts of dark matter

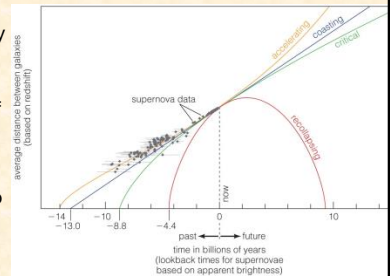


Model Universes: Recollapsing Universe

Dark matter density is greater than "critical density"
($\sim 10^{-29}$ grams/cc = a few atoms in a closet)

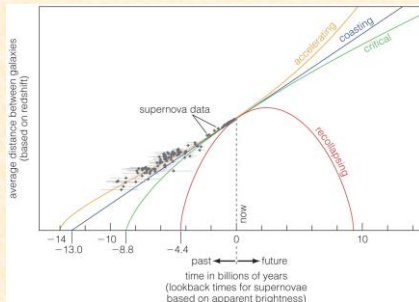
Expansion will stop in the future, will collapse

Oscillation?



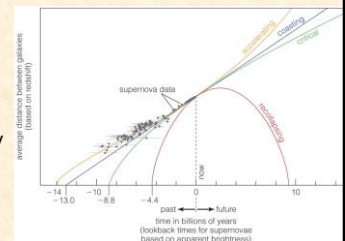
Critical Universe

- Density = critical density
- No dark energy
- Will expand forever, but just barely



Coasting (or Open) Universe

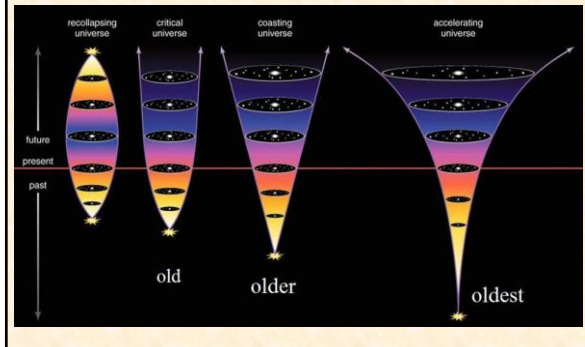
- Has always expanded at the same rate (no deceleration from gravity!)
- No dark energy & density < critical density
- Age of universe is $1/H_0$



What is the fate of the Universe?

- **Recollapse:** crushing heat, destruction of all matter, ?rebirth?
- **Eternal expansion:** cold, galaxies dimming
 - star formation slowing
 - everything winds up as a brown dwarf, black dwarf, neutron star or black hole

After the break: An Accelerating Universe & Dark Energy



Happy Thanksgiving!

