Fate of the Universe

November 25, 2002

1) Fate of the Universe
2) Shape of the Universe
3) Large Scale Structure

Final Exam will be held in Ruby Diamond Auditorium

NOTE THIS!!!

not UPL

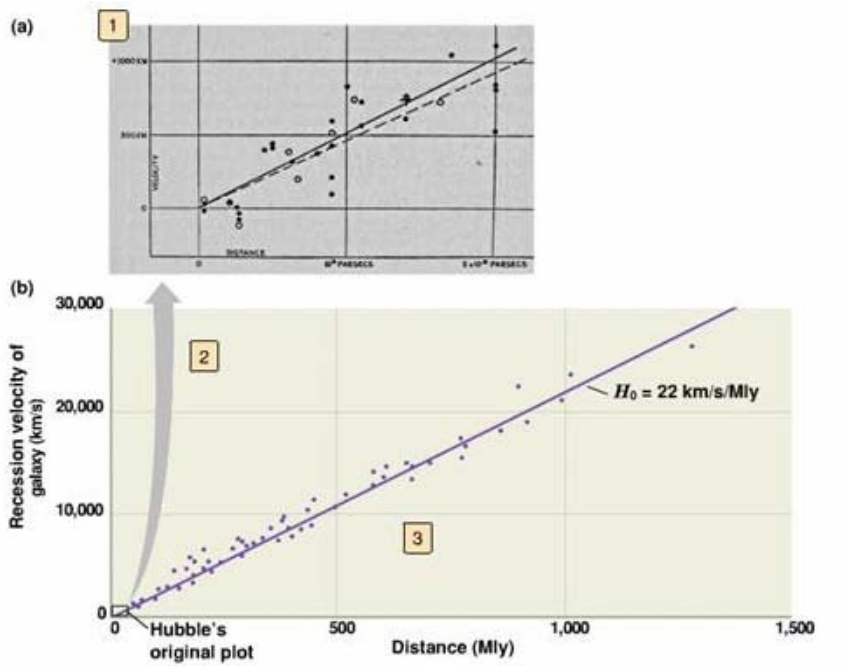
Dec. 11, 2002 10am-noon

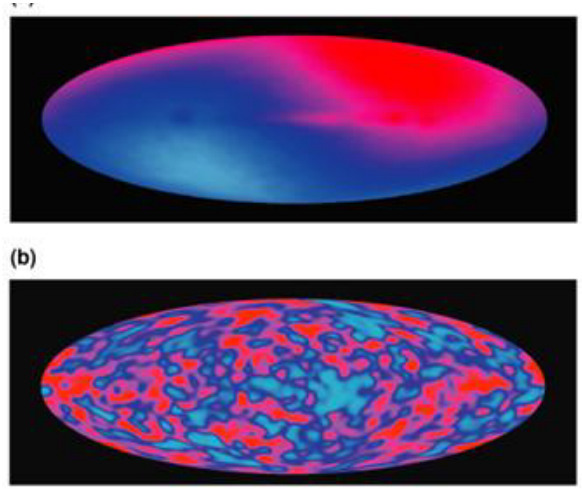
Review

- Hubble's Law
  - redshift

$$v = H_0 \times d$$

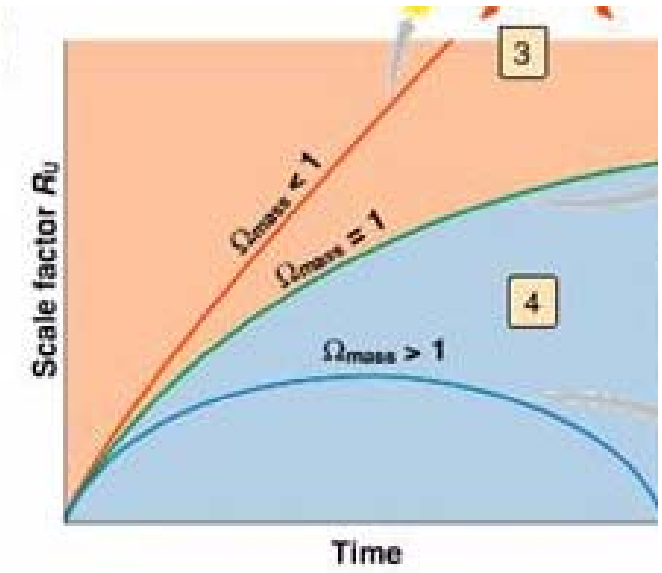
- Expanding Universe
  - examples
  - Big Bang
  - age of the Universe
  - cosmic microwave background
- Fate of the Universe





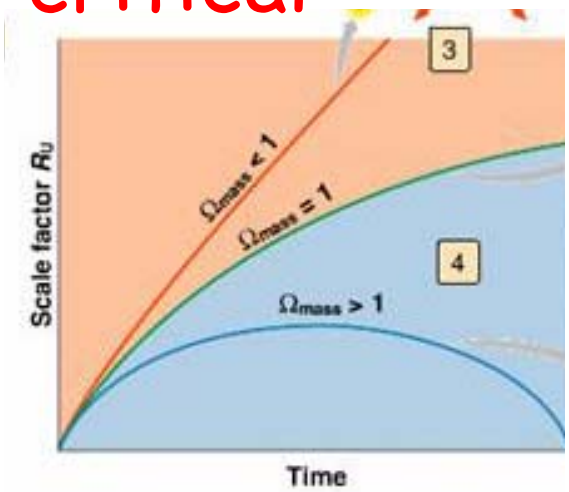
Fate of the Universe

- The Universe is expanding
- But gravity should be pulling it back in
- So what should the Universe's fate be:
  - Continue expanding forever
  - Have expansion keep getting slower forever
  - Expansion stops and eventually Universe collapses upon itself
- These possibilities are called
  - open universe
  - flat universe
  - closed universe

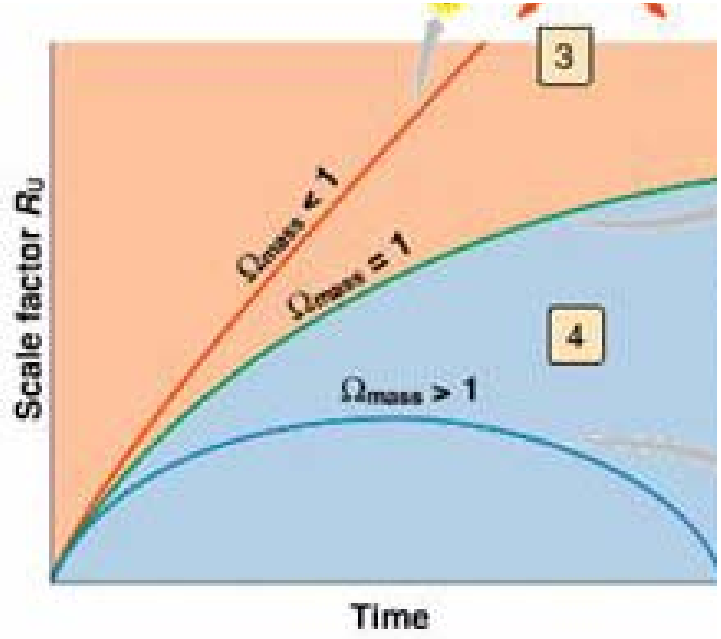


Enough Matter?

- The amount of matter in the Universe helps determine its fate
  - if there is enough mass, gravity wins
  - given H_0 = 22 km/(s MLY), critical mass density is 8×10^{-27} kg/m^3
- define Ω_{MASS} as the actual density of mass in the Universe divided by the critical density
  - $\Omega_{MASS} < 1$ is an open universe
  - $\Omega_{MASS} = 1$ is a flat universe
  - $\Omega_{MASS} > 1$ is a closed universe



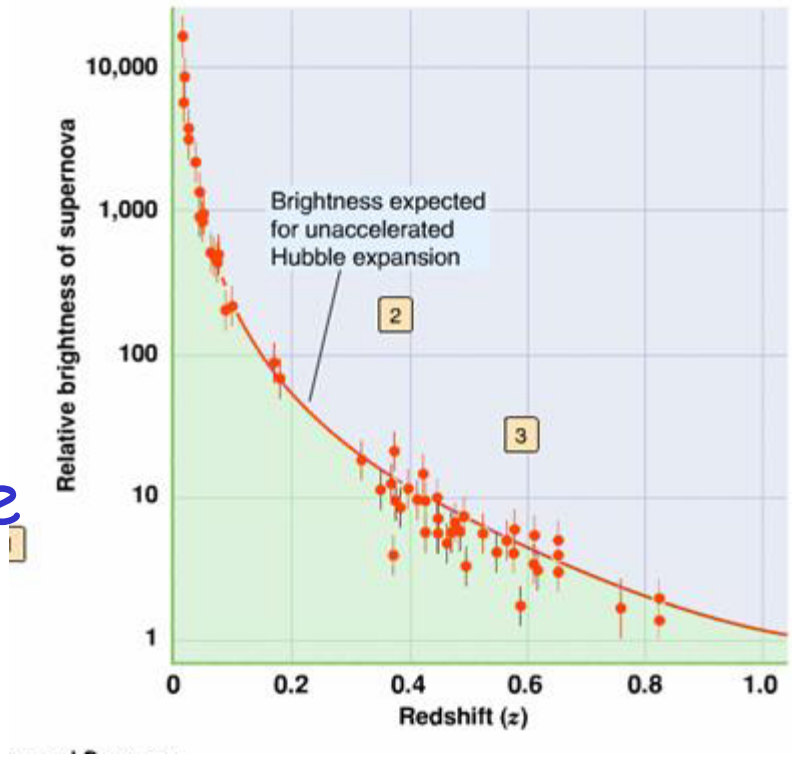
Enough Matter?



- Visible matter
  - only 2% of critical density
  - $\Omega_{MASS} = 0.02$
- Dark matter in galaxies
  - about 10 times as much
  - $\Omega_{MASS} = 0.2$
- Dark matter between galaxies
  - raises total to 30% of critical density
  - $\Omega_{MASS} = 0.3$
- We do not observe enough matter to cause the Universe to be closed
- But it's not the end of the story

Is the Expansion Slowing Down?

- Use Type 1a supernovae
  - a standard candle
  - use brightness to determine distance
  - use redshift to determine distance
  - compare distances
  - data lies below prediction
- Answer: The rate of expansion is speeding up!

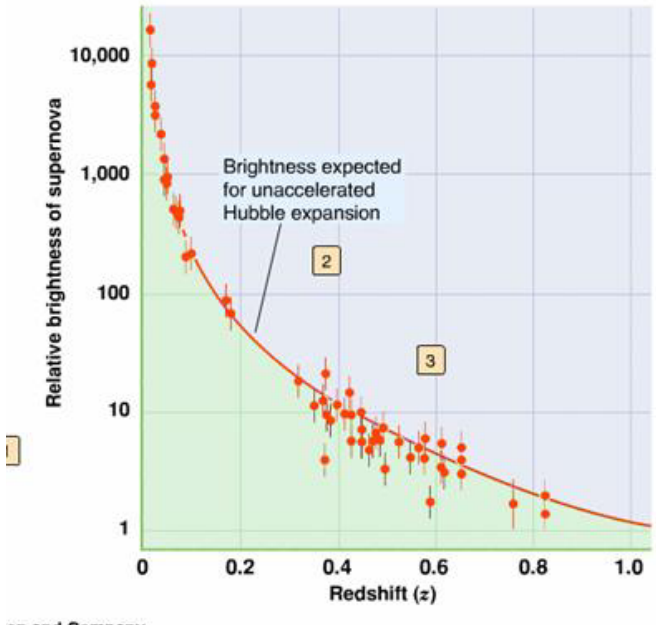


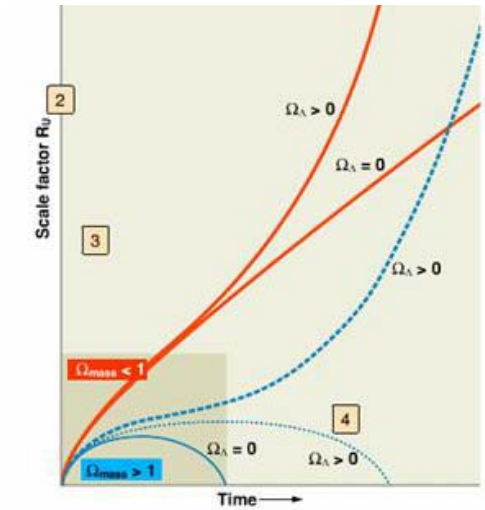
Einstein's "Greatest Blunder"

- Einstein believed in a static Universe
  - pre-Hubble
- Equations of general relativity showed any Universe containing matter could not be static
- So, Einstein inserted a "fudge-factor" to balance the equation
  - called the cosmological constant (Ω_Λ)
  - opposes gravity (necessary to be static)
- After Hubble, Einstein called this his greatest blunder
  - should have predict Universe was expanding or contracting

Redshift Doesn't Match

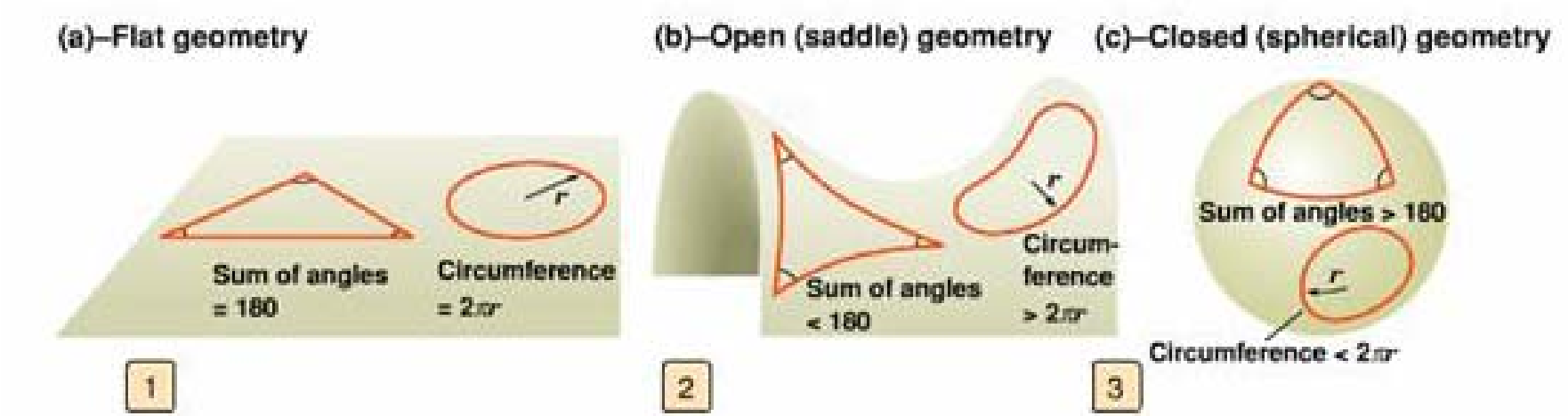
- Redshifts of Type Ia supernovae don't completely match expectation
  - points tend to lie below the line
- This can be explained by the expansion of the Universe *speeding up*





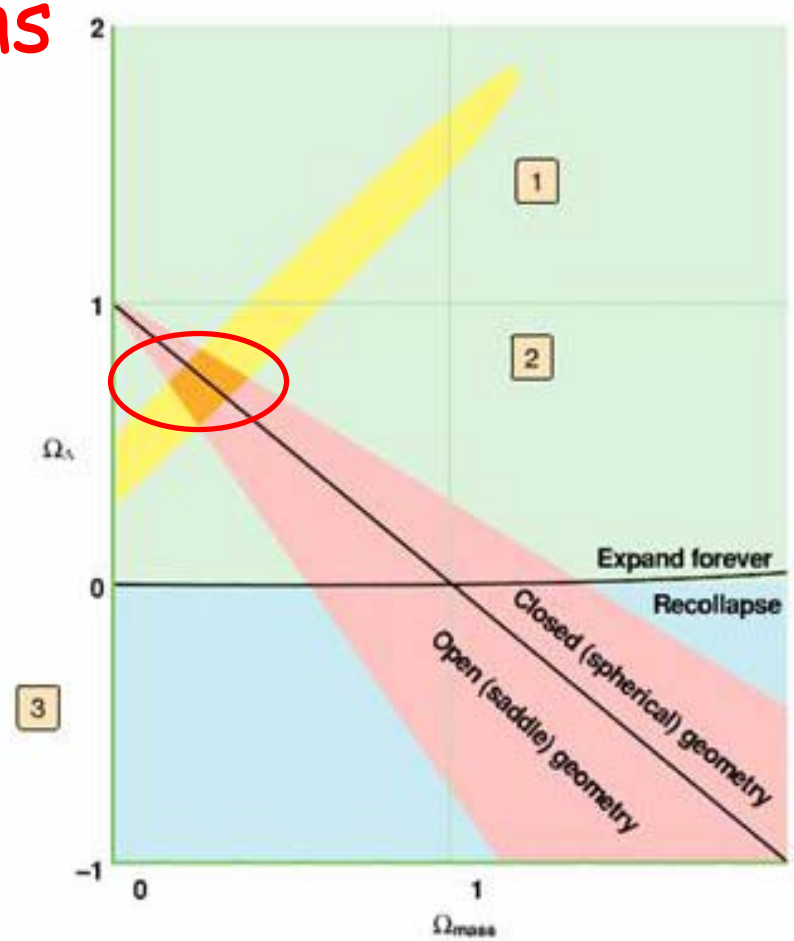
Shape of the Universe

- The Universe has a shape
  - determined by $\Omega_{MASS} + \Omega_{\Delta}$
  - $\Omega_{MASS} + \Omega_{\Delta} < 1$ (saddle)
  - $\Omega_{MASS} + \Omega_{\Delta} = 1$ (flat)
  - $\Omega_{MASS} + \Omega_{\Delta} > 1$ (spherical)
  - determines how we see the Universe behave

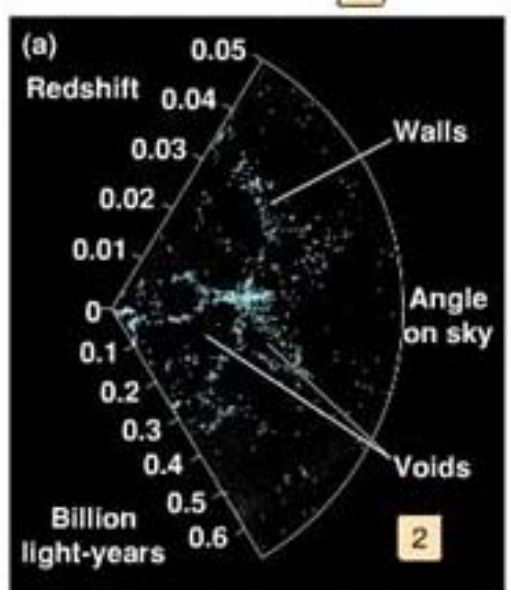


$\Omega_{MASS} + \Omega_{\Delta} = 1$?

- The Universe appears flat
- Data gives shaded regions
  - supernovae
  - CMB
  - movement of globular clusters and galaxies
- Currently favored:
  - $\Omega_{MASS} \sim 0.3$
  - $\Omega_{\Delta} \sim 0.7$



Bigger Structure



- Structure bigger than galaxies
- Galaxy groups
  - 2-30 galaxies
  - Local Group – contains the Milky Way
- Galaxy clusters
  - 100s of galaxies
- Superclusters
  - groups and clusters combined
- The Universe is filled with large scale structure
  - "walls" and "filaments"

Formation of Structure

- (early in the Universe)
- Normal matter was spread fairly evenly
  - due to interactions and radiation
- Dark matter was not smoothly
  - clumps remained
- Expansion spread things out
  - but gravity held large clumps of dark matter together
- Dark matter attracted normal matter
  - source of galaxies and structure