Cosmology

• The contents of the Universe
• Einstein’s greatest blunder
• Accelerating Universe
• Dark energy
How was the review?

A) Great!
B) Useful
C) OK
D) Could have been better
E) Useless
Contents of the Universe

• Normal matter
  – Stars
  – hot gas
  – anything made of atoms

• Total is 4% of $\rho_c$
Rotation curve of Milky Way

Sun’s velocity is about 220 km/sec

Sun’s velocity should be only 160 km/sec

Difference is contributed by the dark matter halo.

Visible matter only

Distance from Center (kpc)

Rotation Velocity (km/sec)
Mass of the Milky Way

Enclosed Mass for Milky Way

- Disk
- Dark Matter
- Bulge
- Total

Enclosed Mass (billion solar masses) vs. Distance from Center (kpc)
Dark Matter

• Dark – it doesn’t produce light (any kind)
• Does have mass, produces gravity
• Nature is unknown

• Most likely it is elementary particles
Contents of the Universe

- Normal matter is 4% of $\rho_c$
- Dark matter is 23% of $\rho_c$
- Total of normal and dark matter is $\Omega_M = 0.3$

- But, we need 100% of $\rho_c$
- Remainder, 73%, is dark energy $\Omega_\Lambda = 0.7$
Contents of the Universe
What produced the photons that we see as the 3 degree cosmic background radiation?

A) Neutrinos
B) Hot gas
C) Stars
D) Formation of helium nuclei
When did the universe first become transparent?

A) 1 year after the big bang
B) $10^3$ years after the big bang
C) $10^6$ years after the big bang
D) $10^9$ years after the big bang
E) $10^{12}$ years after the big bang
Einstein and Cosmology

• After Einstein wrote down the equations for General Relativity, he made a model of the Universe and found that the Universe had to be either expanding or contracting.

• He introduced a new term, the cosmological constant or $\Lambda$, in his equations representing a energy field which could create antigravity to allow a static model.

• After Hubble found the expansion of the Universe, Einstein called $\Lambda$ his greatest blunder.
Cosmological Constant

• Quantum physics predicts that some energy fields that act like $\Lambda$.

• One such field is the one thought to cause the rapid expansion of the Universe during inflation.

• Another such field appears to be operating today.
Matter slows down expansion
SN2002dd in the Hubble Deep Field North

WFPC2 1995

ACS+WFPC2 2002
Expansion is speeding up
Expansion is slowing down
Accelerating Universe

• Hubble expansion appears to be accelerating

• Normal matter cannot cause acceleration, only deceleration of expansion

• Dark energy is required
  – may be cosmological constant
  – may be something else
  – major current problem in astronomy