Last time: Cosmology II - Testing the Big Bang
• Testing the Big Bang - synthesis of the elements (helium in particular)
• remnant radiation produces a cosmic microwave background
• small density fluctuations needed to make galaxy clusters were present in the very early universe
• an “Inflation” epoch is needed to make the post-Big Bang expanding universe look like what we see today

Today: Cosmology III - Inflation and the Accelerating Universe
• Testing Inflation - requires \( \Omega = 1.000 \) but ordinary matter isn’t enough
• Inflation requires there to be “non-baryonic” dark matter
• dark matter can seed formation of large structures - the Cosmic Web
• at early times, the Universe was expanding slower than we thought
• Dark Matter (~25%) + Dark Energy (~70%) + ordinary matter (< 5%)
• expansion is now “accelerating” - dark matter joined by dark energy

Inflation - a solution to the uniformity problem
• \( t \sim 10^{-37} \text{sec} \)
  • gravity repulsive
  • brief accelerated expansion
• before inflation: all points in space could communique
• after inflation: too distant for further contact
  inflation requires \( \Omega_o = 1 \)

• if true:
  • we live in 1 part of an inflated Universe
  • our Universe is FLAT (\( \Omega_o = 1.000000000... \))
• note: from B.B. nucleosynthesis:
  • \( \Omega_o < 0.1 \) for “normal” matter
  • so any \( \Omega > 0.1 \) is in a new, unknown form

Testing Inflation #1: Add up all mass in the Universe

• count up all mass in galaxies
  • include massive dark galaxy halos
  • \( M_{\text{detected}} \rightarrow \Omega_o \sim 0.03 \)
Testing Inflation #1: Add up all mass in the Universe

- count up all mass in galaxies
  - include massive dark galaxy halos
  - $M_{\text{detected}} \rightarrow \Omega_0 \sim 0.03$

- include more “dark matter”
  - galaxy clusters need dark matter to stay together
  - 90% of cluster mass must be dark matter
  - $M_{\text{detected}} \rightarrow \Omega_0 \sim 0.3$

Testing Inflation #2: Hubble law at large distances

- Expansion was faster at earlier times
  - closed (higher density) Universe - much faster
  - open (lower density) Universe - not as fast
  - empty (zero density) Universe - same speed always

- Curvature of Hubble law at large distance $\rightarrow \Omega_0$
  - distant = younger = faster than now
Results of test with Type 1a Supernovae

- expansion in past was **slower** than any prediction
- universe has accelerated compared with expectations
- conclusion: $\Omega$ has a **non-gravity** part
- “dark energy” helping push the expansion (?)
Where we stand today:

We live in a universe that will expand forever.

And:

There is strong evidence that

$$\Omega_0 = 1.00000000... = \Omega_{\text{matter}} + \Omega_{\text{dark energy}} = 0.3 + 0.7$$

and that a "Dark Energy" pervades our Universe

Nobel Prize, 2011
Perlmutter
Schmidt
Riess

http://cosmicweb.uchicago.edu/sims.html
The Cosmic Web

http://cosmicweb.uchicago.edu/sims.html
Testing the Big Bang Idea

- **Big Bang Nucleosynthesis**
  - production of light and heavy elements in the early Universe

- **Remnant radiation from primeval fireball**
  - universal background radiation

- **Origin of Cosmic Structures**
  - formation of galaxies and huge superclusters in an expanding Universe

Other / Alternate Universes

- This may not be the ‘first’ Big Bang, or the only one
- Other Big Bangs - other physics
  - small change in physical constants makes life impossible
  - “The anthropic principle
- If ours is open or flat, we face a cold, dark future death
- If ours is closed, it may get recycled!

The “Oscillating” Universe