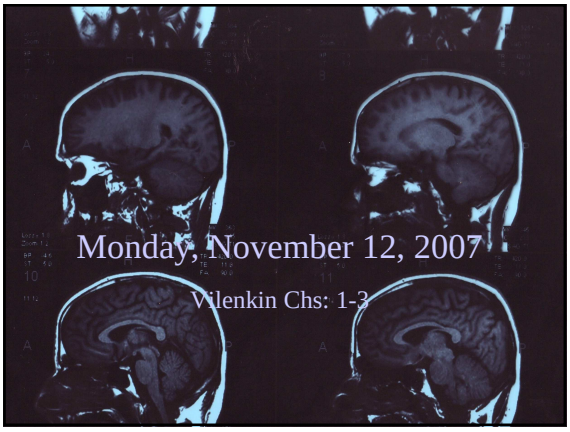


Agenda

- Announce:
  - No Class on Thursday
  - Read Chs 4-6
- Handback/discuss tests
- Chs. 1-3

Vilenkin's *Many Worlds in One*

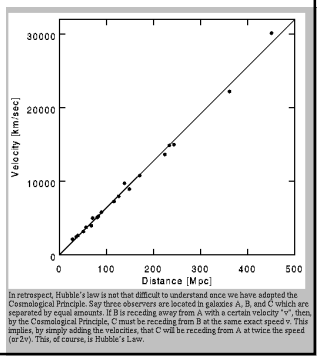
- Cosmology—study of the large scale structure of the Universe
- What constitutes "large scale"?
- How is this different than material in Thorne's book? Ford's book?
- How are all three books similar?

The Big Bang (Theory)

- Features of the theory
  - Universe has been expanding from some smaller region (not into anything!)
  - Was very hot and cools as it expands
  - Primordial nucleosynthesis

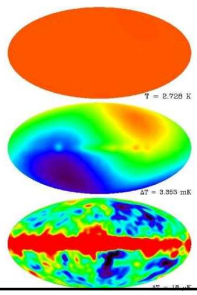
Big Bang Evidence #1

- Hubble's observation of the expansion of galaxies
  - Why not stars?
  - Are we at the center?
  - What's expanding?



Big Bang Evidence #2

- CMBR—Cosmic Microwave Background Radiation
  - Hugely isotropic radiation associated with the Universe (what does this mean?)
  - Indicative of a very cold temperature of the Universe of 2.73 Kelvin (how so?)



If you're still not convinced…

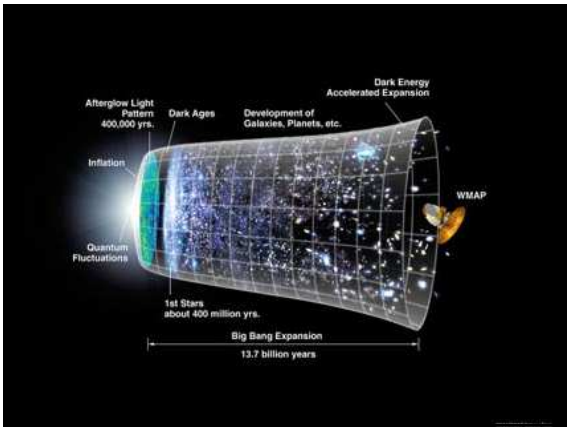
- All the astrophysics we do which relies on Big Bang…..**Works!**
- That's what we said about relativity and quantum mechanics
- Again, it's not that we wish to brainwash you…we'd desperately want to find stuff that does **not** work!

What Banged?

- The big bang theory doesn't attempt to explain what banged, how, or why
- Free to insert God, philosophy, etc here
- Not particularly clear how far science, even in principle, take us

Guth's Proposal

- Substance w/ special properties
  - Causes gravity to be repulsive (not a new force)
  - Density always remains the same
    - Doesn't decrease w/ expansion
    - Increasing strength with increasing volume
- Energy comes from increasingly negative gravitational energy
- Termed *Inflation*



Inflation

- Universe began
  - very small
  - Chunk of this "repulsive gravity stuff"
- Expanded very quickly for a short time
- Repulsive stuff decayed away producing lots of hot particles
- Universe continued expanding (not so fast) and cooling and that's what we observe now

Einstein & Cosmology

- Study a very simple Universe
  - Homogenous—unform density
  - Isotropic—looks same in all directions
  - Static (why?)—doesn't change in time
- No solution for such assumptions
- Stuff wants to attract other stuff
- Decides his equations must be changed…

Einstein's Biggest Blunder

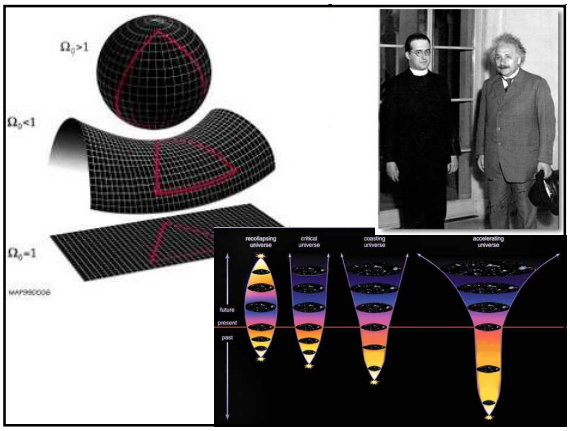
- How could he change equations?
  - Needed to maintain "reference frame invariance"
  - Constant speed of light
- Only freedom was to introduce *cosmological constant*
  - Energy of empty space
  - Strange stuff: Negative pressure (tension)

Nature of Vacuum Energy

- Constant (in space and time) energy density and tension
- Can't see effect of tension or energy density because it's everywhere
- Except for its gravitational effect
- Tension so great overcomes its energy density to produce "anti-gravity"
- Can produce a static universe where vacuum energy balances attraction of the rest of the Universe

Friedmann's Universe(s)

- Assume:
  - Homogenous
  - Isotropic
  - Closed (but not static)
- Universe expands (bigger sphere)
- Then contracts (smaller sphere)
- Big Bang and Big Crunch are singular



Do you prefer eternal Universe or singular beginning?

- The problem with an eternal universe:
  - Eventual heat death…everything reaches same temperature (thermal equilibrium)
  - Entropy increases in a closed system (2nd law)
- So if Universe has existed forever, then we should be in state of maximum entropy…we don't so Universe not eternal
- The problem with a 13.7 billion year old Universe:
  - Why did it start then?
  - How was it homogenous and isotropic?
  - etc

The Competitor: The Steady State Theory

- Universe remains essentially the same (steady state)
- Universe expands (as per Hubble)
- Matter continually gets created in voids left by expansion
- Failure of energy conservation comparably to creation of Universe at Big Bang
- However, observations show differences long ago…universe didn't look same billions of years ago