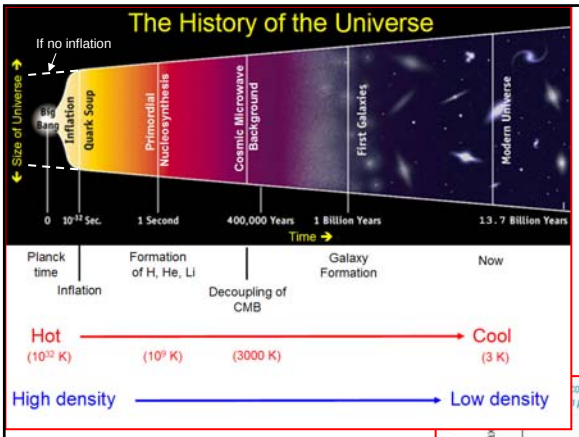
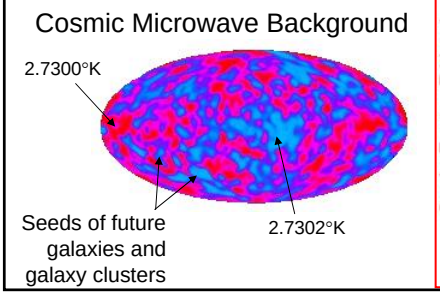
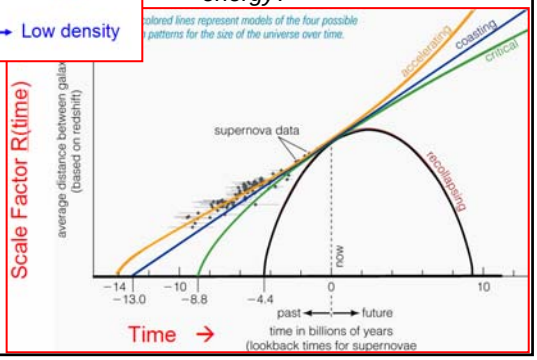


Three Problems for "Big Bang" Cosmology:

1. *Where did structure in CMB come from?*
2. Horizon problem – *how did all parts of universe know how to have same temperature and density?*
3. Flatness problem – *why did initial matter density so exactly balance initial kinetic energy?*

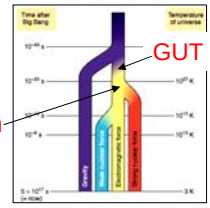




The solution: Inflation

(probably)

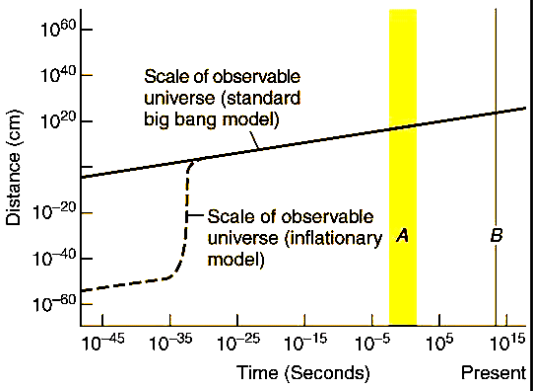
(maybe)



Extremely rapid expansion of universe

- due to release of energy in "phase change".
- like ice to water.

Universe became 10^{30} times larger within 10^{-36} seconds.

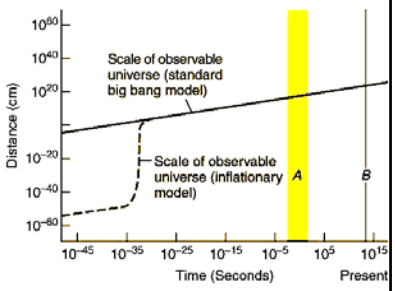


[See Section 17.3]

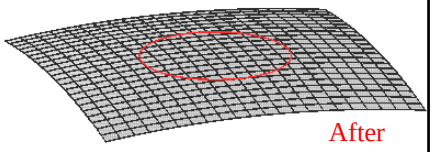
1,000,000,000,000,000,000,000,000,000,000

What does inflation predict for geometry of present universe?

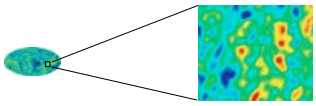
Universe became 10^{30} times larger within 10^{-36} seconds.



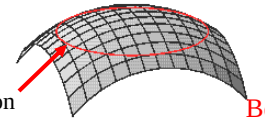
- Predicts a flat universe
- Solves horizon problem.
- Expands quantum fluctuations to create seeds of galaxies.



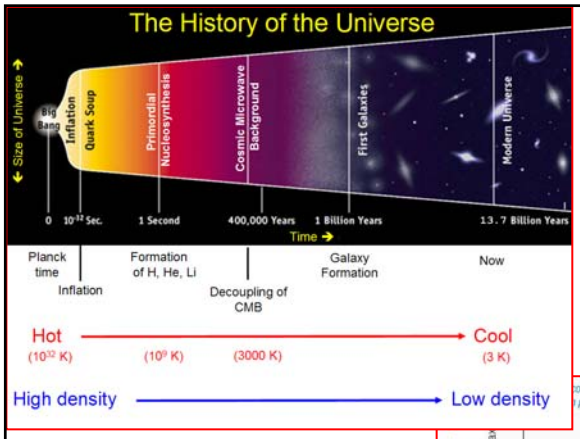
After Inflation



Red circle = horizon

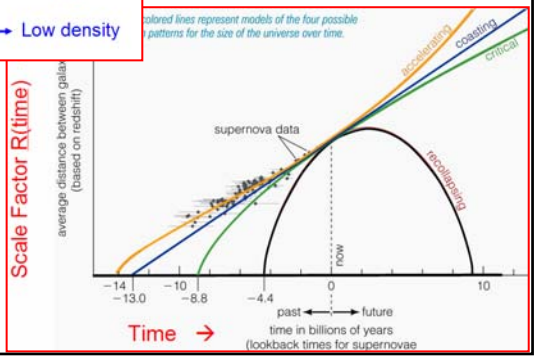


Before Inflation



IT WILL EXPAND FOREVER

(or at least almost forever)



The End of the Universe

Continued expansion, forever… (we think).

- 10^{10} yrs. Current age of universe.
- 10^{14} yrs. Stars use up last nuclear fuel.
- 10^{14} – 10^{37} yrs. Degenerate Era
  - 88% white dwarfs, 10% brown dwarfs, 2% neutron stars + black holes.

wild speculation

- 10^{37} – 10^{100} yrs: Black Hole Era
  - Degenerate stars have disappeared through proton decay (maybe)
  - Dark matter annihilated (??????)
  - Only black holes left, but they also evaporate.
- After 10^{100} yrs: Dark Era
  - Essentially nothing left except hugely redshifted CMB photons.

(See *Sky & Telescope* magazine, August 1998)

What's outside the Universe?

NOT ON THE FINAL

- Other universes, not intersecting with our Universe??
- Some magic numbers:
  - At t = 1 second, our Universe defined by:
    - Ratios of
      - Energy Density. Matter:Kinetic-energy:Cosmolgical-constant-energy.
      - Numbers of particles. Photons:Normal-matter:Dark-matter
    - Amplitude of density fluctuations ~ 10^{-5}
  - Imprinted by Planck Time: ratios of physical constants.
    - Example: electrostatic force 10^{36} x stronger than gravitational force.
  - Different values in other universes?
- ***Anthropic Principle***: our particular universe is suitable for us to live in because otherwise we would not be alive to know about it.

Final Exam

- 3PM Wednesday, in this room.
- Sit in assigned rows, as usual.
- Bring photo-ID
- 51 questions, 1/3 cumulative, 2/3 over material since Midterm 3.

- Study guide for final is on the web
  - + use study guides for Midterms 1-3

- Homework Set 8 is due tonight.

- Rate this course: http://rateyourclass.msu.edu

My Office Hours (BPS 3270):
Today 12:30-2PM
Tu 2-3PM
Or by appointment