MODELS OF THE UNIVERSE

1. From Static to Expanding Universes
   • 1917: Einstein and a finite static model
e de Sitter and an empty expanding model
   • 1922: Friedmann and a dynamic universe
   • 1929: Hubble and the Expansion
   • 1931: Lemaître and the Primeval Atom

2. The Big Bang Model
   • 1948: Steady-State universe
   • 1948: The BB model
   • 1965: Confirmation of BB model
   • Limitations of the BB model
• 1917: Einstein applies GR to universe as a whole
  GEOMETRY = MATTER/ENERGY
  **cosmological principle**: universe same anywhere
  Tries static model: unstable, so add “cosmological constant”

\[
\rho = \frac{\text{energy}}{\text{volume}} = \text{const.} \ (\text{energy density})
\]

• 1917: de Sitter proposes model only with \( \Lambda \) (cosm. const.)
  rapid expansion, but empty cosmos...

• 1922: Friedmann -- Universe is dynamic \( \Rightarrow \rho(t) \)
  Universe can change in time (no \( \Lambda \) required)
  What is its geometry? Open or closed? And its fate?
  \( \Rightarrow \) it depends on its energy density \( \rho \)
It all depends on “critical density”, $\rho_{\text{critical}} = 10^{-29}\text{g/cm}^3$ (about 1 atom of H per cube of 0.5 meter side)

Open: $\rho < \rho_{\text{critical}}$

Critical: $\rho = \rho_{\text{critical}}$

Closed: $\rho > \rho_{\text{critical}}$
1929: Hubble discovers expansion finally some data to guide theory!!
Hubble’s expansion law: \( R(t) = H \ V(t) \), \( H \) is Hubble’s const.

Far away galaxies are receding with velocity proportional to distance!!

* but problems with age...

1931: Lemaître proposes the “Primeval Atom” model
2. The Big Bang Model

- 1948: Steady-state model: Hoyle, Bondi and Gold uncomfortable with “origin” problem
  ➡ “perfect cosmological principle”: universe always same
  (but…violation of energy conservation!)

- 1948: George Gamow: Universe was hot and dense in the “beginning”, filled with PRIMORDIAL SOUP
  Primordial soup = photons, protons, neutrons, electrons, neutrinos

PREDICTIONS:
1) existence of “cosmic microwave background radiation”
2) abundances of light nuclei (H, D, He, Li)

➡ Universe starts simple!! And then structures emerge as it expands and cools
1. “initial conditions”, $t \sim 0.01$ sec  
2. “Nucleosynthesis”, $0.01\text{ sec} < t < 3\text{ min.}$  
3. “Decoupling”, $t \sim 300,000$ years  

What about before $t \sim 0.01$ sec? Invoke particle physics...