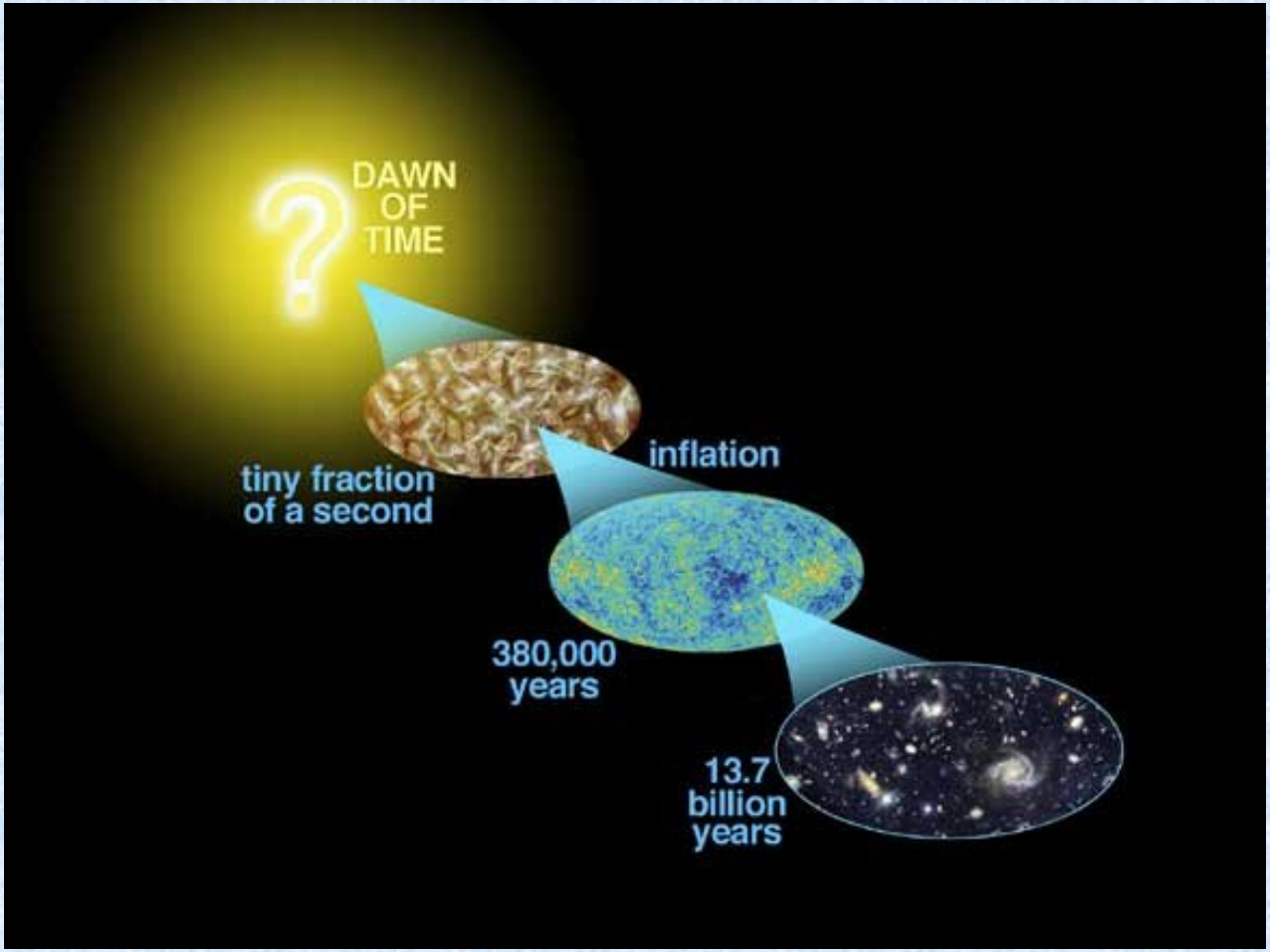
Physics 133: Extragalactic Astronomy ad Cosmology



Lecture 6; January 27 2014

Previously

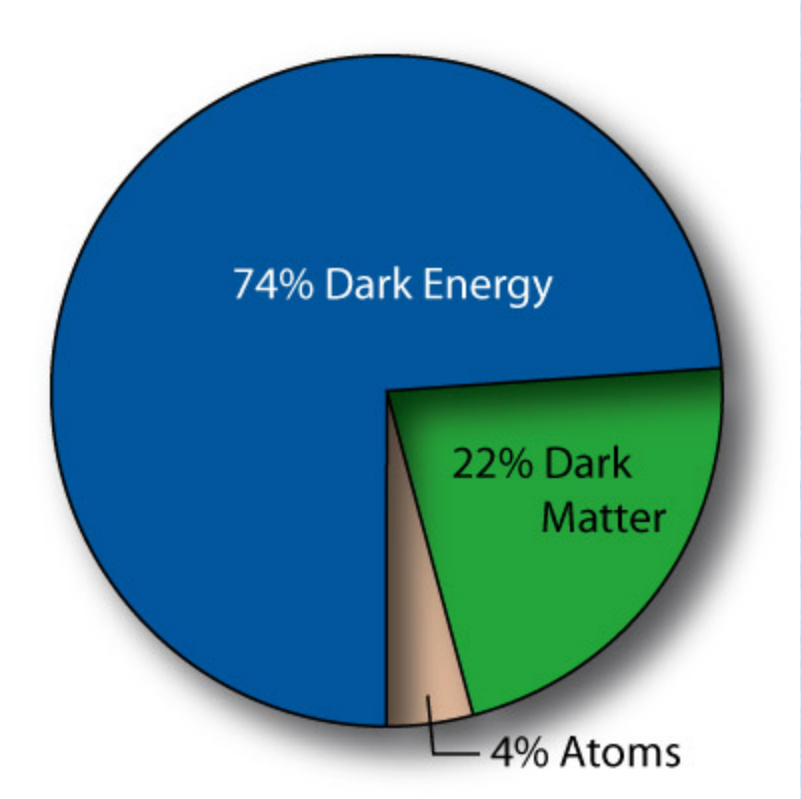
- Friedmann Equation describes the evolution of a(t) depending on content and geometry of the universe.
- Fluid equations describe the evolution of the content of the universe with a(t).
- The cosmological constant or dark energy is an extra term in Friedmann Equation and can induce acceleration. Currently supported by observations.

Outline:

- What kind of Universe do we live in?
- Modeling the Universe. Single component:
  - Curvature only
  - "Flat" universe
  - Matter only
  - Radiation only
  - Lambda only

What kind of Universe?

- We have a framework
- Let's compute properties of the Universe as a function of cosmological parameters
- Comparison with observations will tell us the answer



What kind of Universe? Evolution of energy density

- **What is the connection between a(t) and ε(t) for any constant w?**
- **[Black board]**

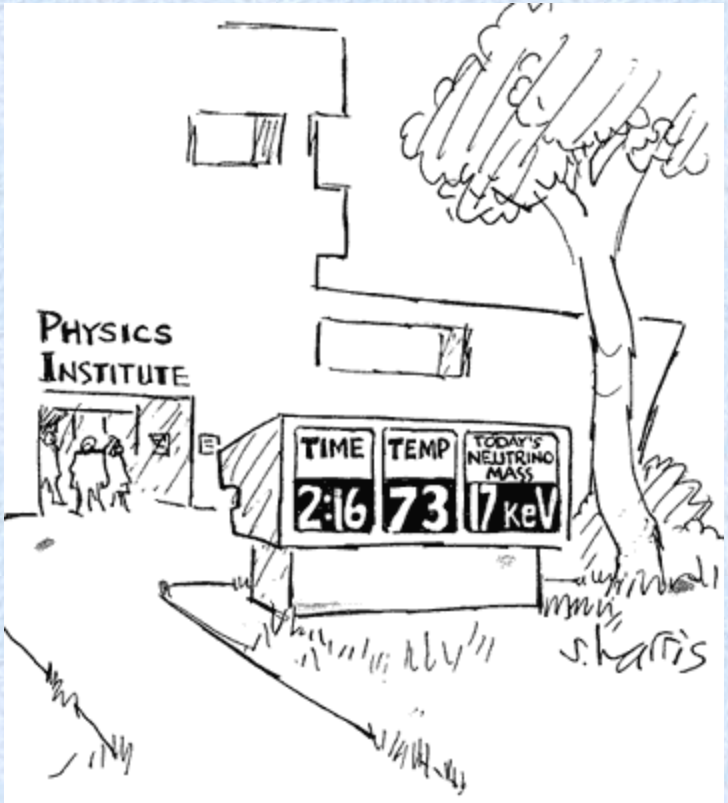
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\epsilon - \frac{\kappa c^2}{R_0^2 a^2}$$

$$\dot{\epsilon} + 3\frac{\dot{a}}{a}(\epsilon + P) = 0$$

$$P = w\epsilon$$

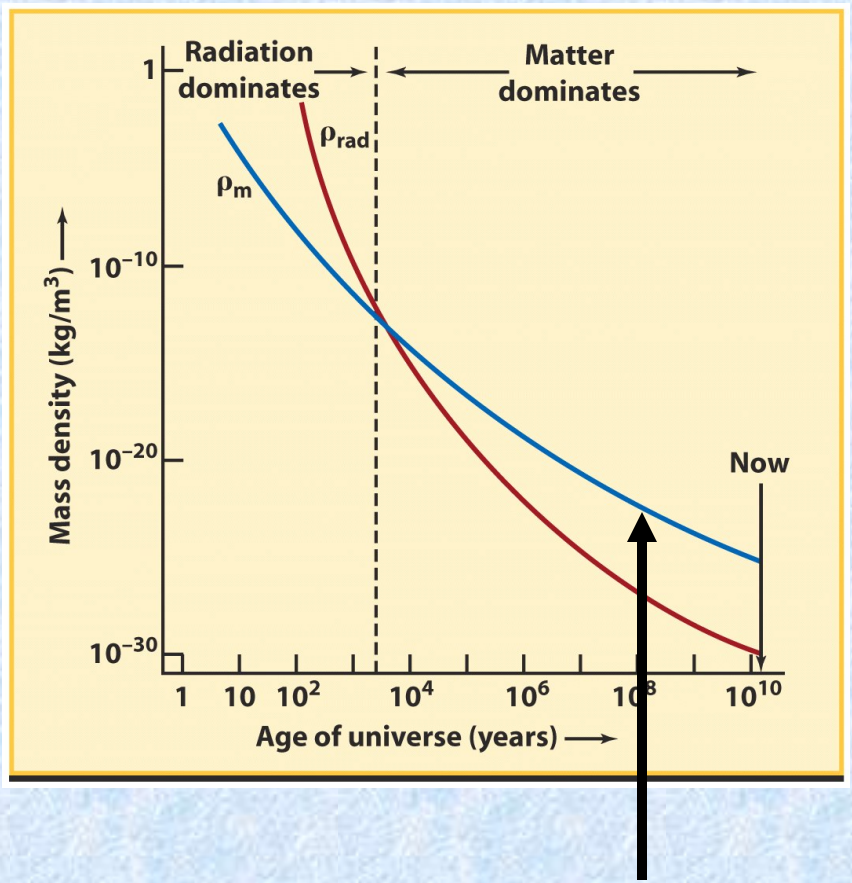
What kind of Universe? Photons and neutrinos

- **CMB photons dominate over other photons. Ωγ~5 10e-5**
- **Neutrinos are relativistic and almost as abundant as CMB. Neutrino background Ων = 0.681 Ωγ.**
- **[Black board]**



What kind of Universe? Who rules?

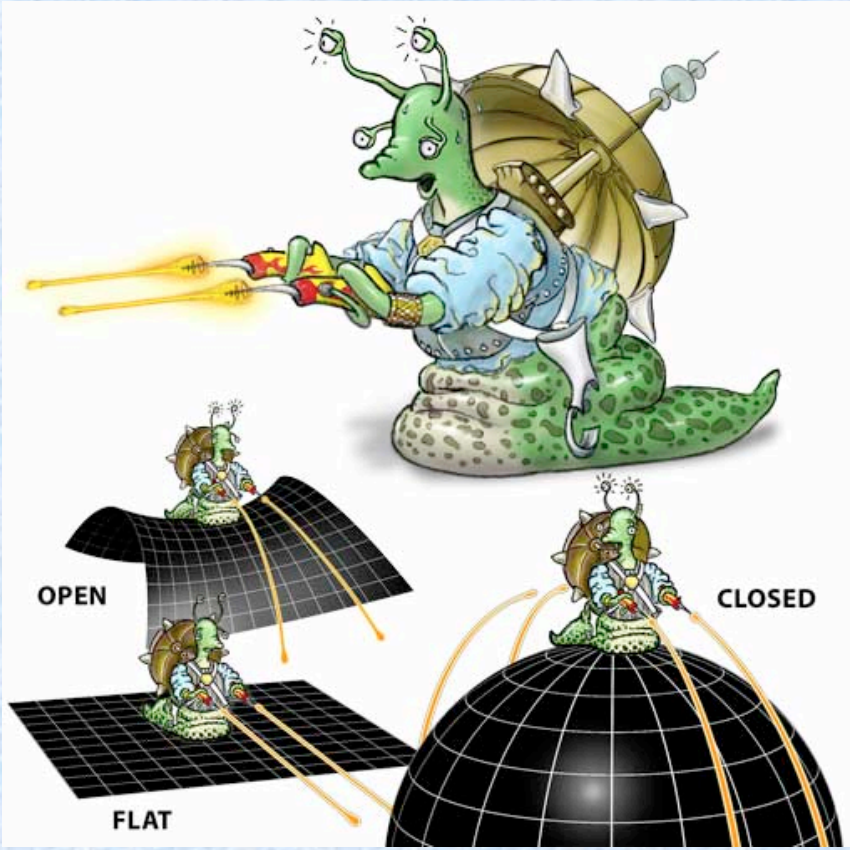
- **Depending on w, energy density evolves at different rates**
- **The dominant species changes with time**
- **[Black board]**



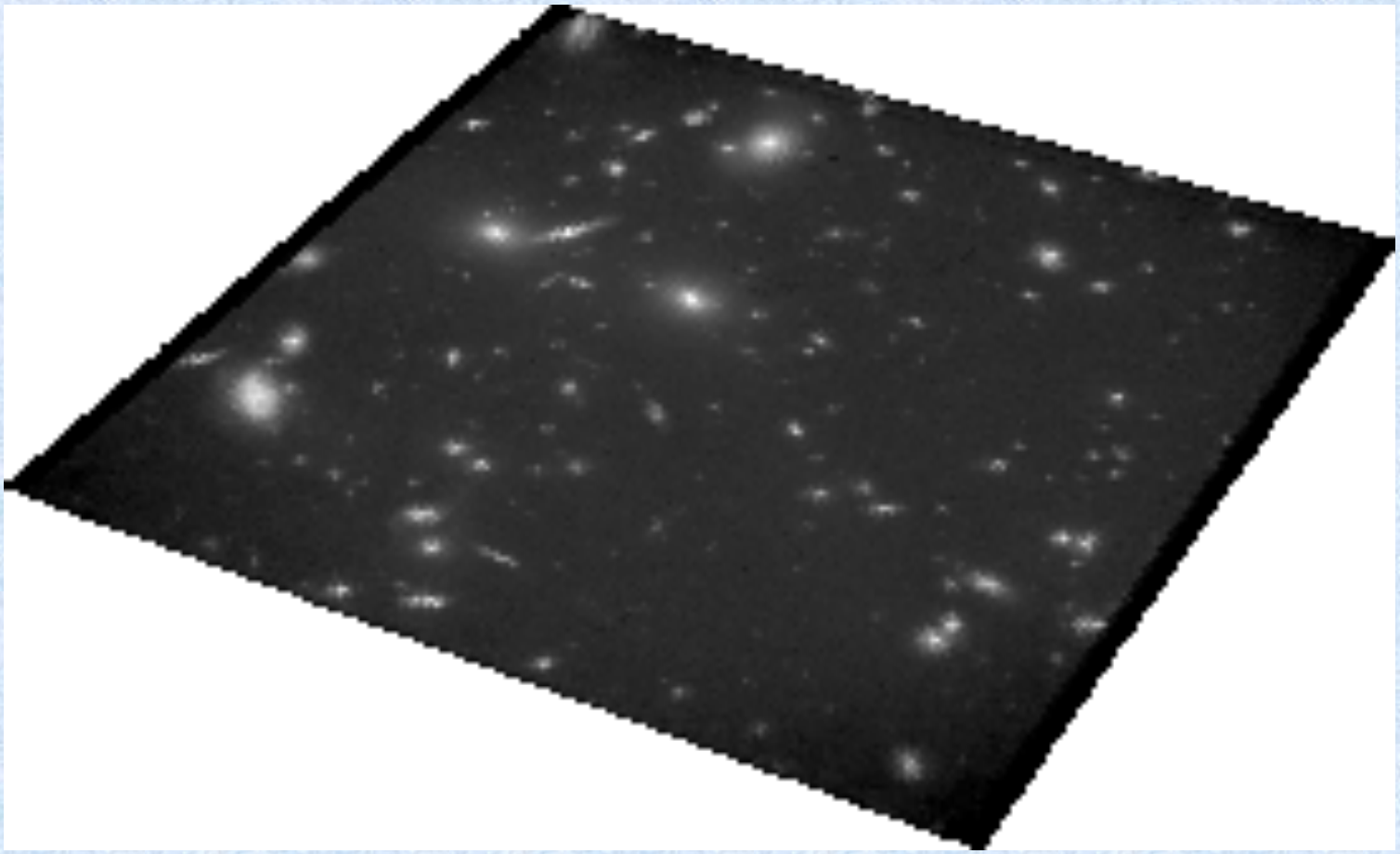
COSMOLOGICAL CONSTANT

Single component Universes. Curvature only

- Let's start simple… an empty Universe..
- And let's solve the Friedmann Equation..
- [Black board]



Single component Universes.
"Flat" Universe with a single "fluid"



Is this right?

What kind of Universe?
Matter only

- We know there are massive particles in the Universe.
- What about a Universe made only of massive particles?
- This is known as the Einstein-de Sitter Universe
- [Black board]

What kind of Universe? Radiation only

- **Horizon=Hubble Length**
- **[Black board]**

What kind of Universe?
Radiation only and the "singularity"

- **The early universe is effective radiation dominated…**
- **Let's see what happens when we go back to the "beginning of time"**
- **[Black board]**

Single component Universes.
Λ only

- **What happens for a pure cosmological constant?**
- **The universe expands exponentially**
- **Infinitely old**
- **Infinite horizons**
- **[Black board]**

Summary

- What kind of Universe do we live in? What's the content and hence kinematics of the Universe?
- Photons and neutrinos are given by the CMB. How about the rest?
- Different species dominate at different times
- Special cases. Single component Universes

Single component Universes. Summary. I

- Curvature only:
  - a(t) linear in time
  - t0H0=1
  - Horizon infinite
- Flat with w:
  - a(t) scales as t to the power of 2/(3+3w)
  - t0H0=2/3(1+w)
  - Horizon can be finite

Single component Universes. Summary. II

- Matter only:
  - a(t) scales as t to the power of 2/3
  - t0H0=2/3
  - Horizon finite
- Radiation only:
  - a(t) scales as t to the power of 1/2
  - t0H0=1/2
  - Horizon finite

Single component Universes. Summary. III

- Λ only:
  - a(t) exponential in t
  - Infinite Age
  - Infinite horizon

The End

See you on Wednesday!