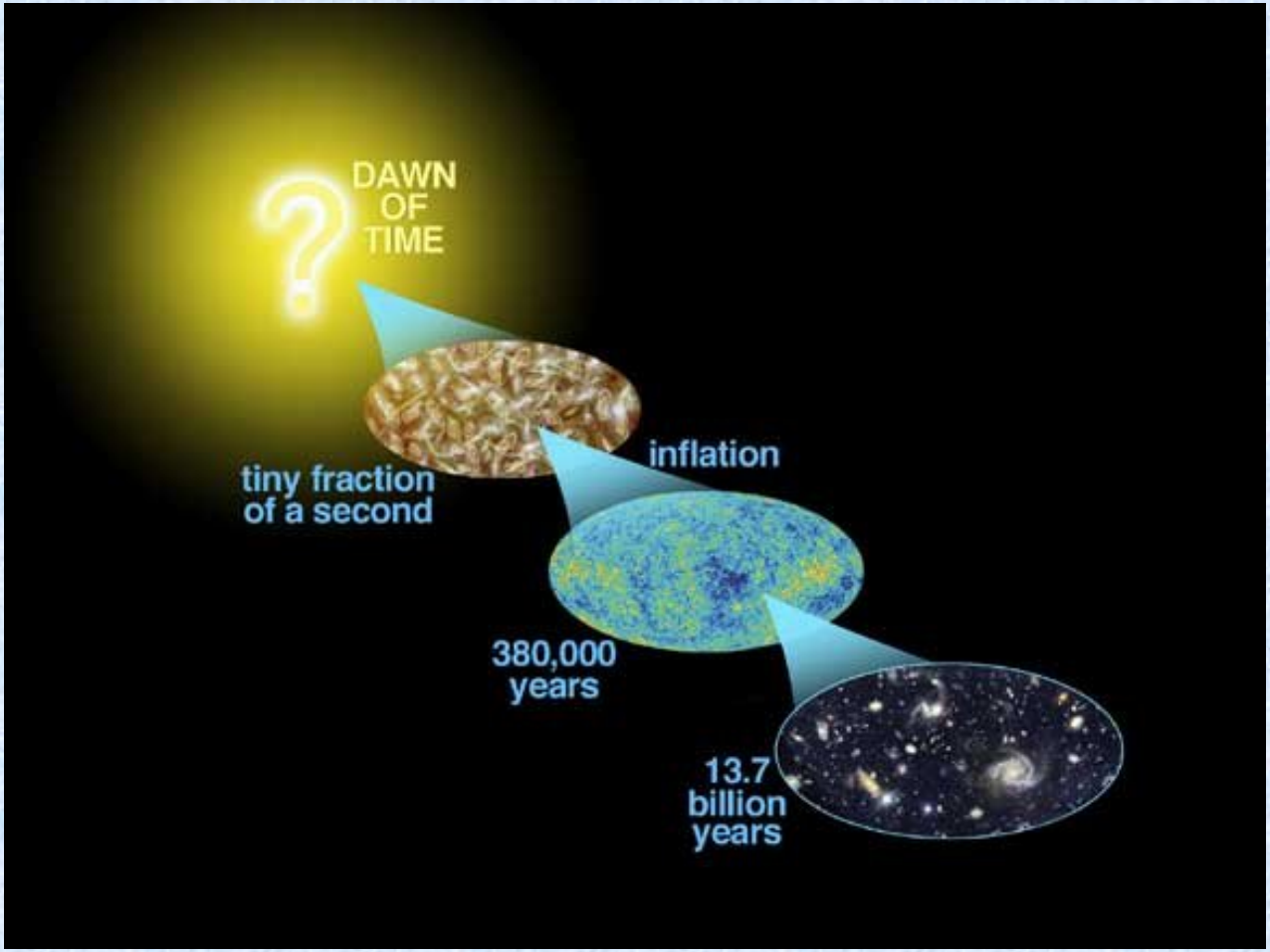
Physics 133: Extragalactic Astronomy ad Cosmology



Lecture 5; January 22 2014

Previously

- The universe is a 4 dimensional manifold as in General Relativity
- The universe is homogeneous and isotropic
- This implies that space and time can be "separated" so that we can define a cosmic time t
- There are only three possible geometries for the universe. Their metric is the Robertson-Walker metric
- In the RW non-static universe redshift is a measure of distance.
- The dynamics of the Universe is described by Friedmann Equation; Newtonian analog.

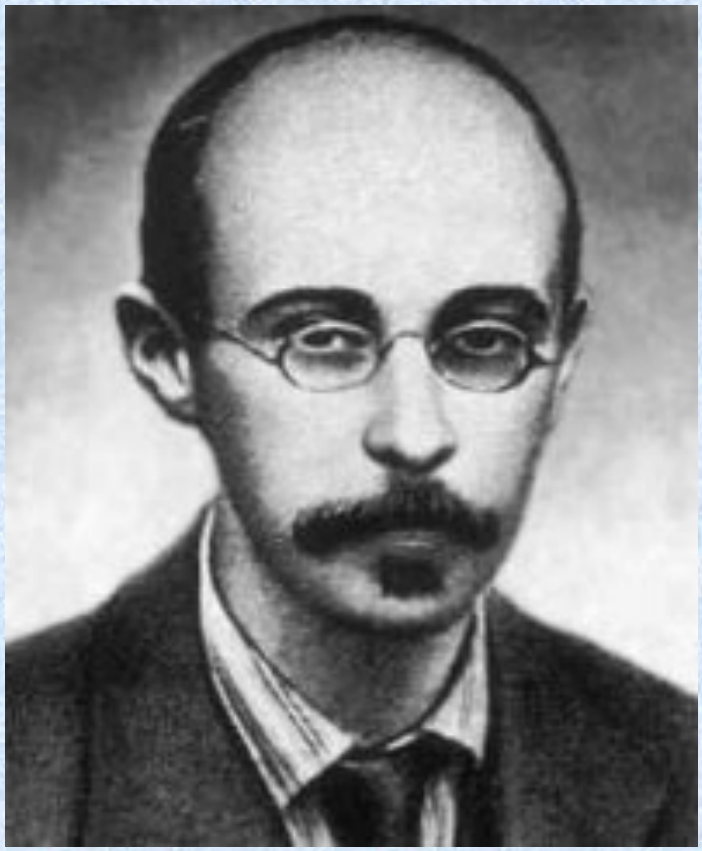
Outline:

Dynamics of the Universe:

- Friedmann Equation
- Fluid Equation
- Acceleration Equation
- Equation of State
- Cosmological Constant

Dynamics of the Universe. Friedmann Equation

- **Limitations of Newtonian analog:**
  - **Newtonian**
  - **What's outside the sphere?**
  - **Inhomogeneous. Isotropic**
- **Friedmann Equation (1922) is the correct form with energy instead of mass and curvature instead of internal energy [Blackboard]**



1888 - 1925

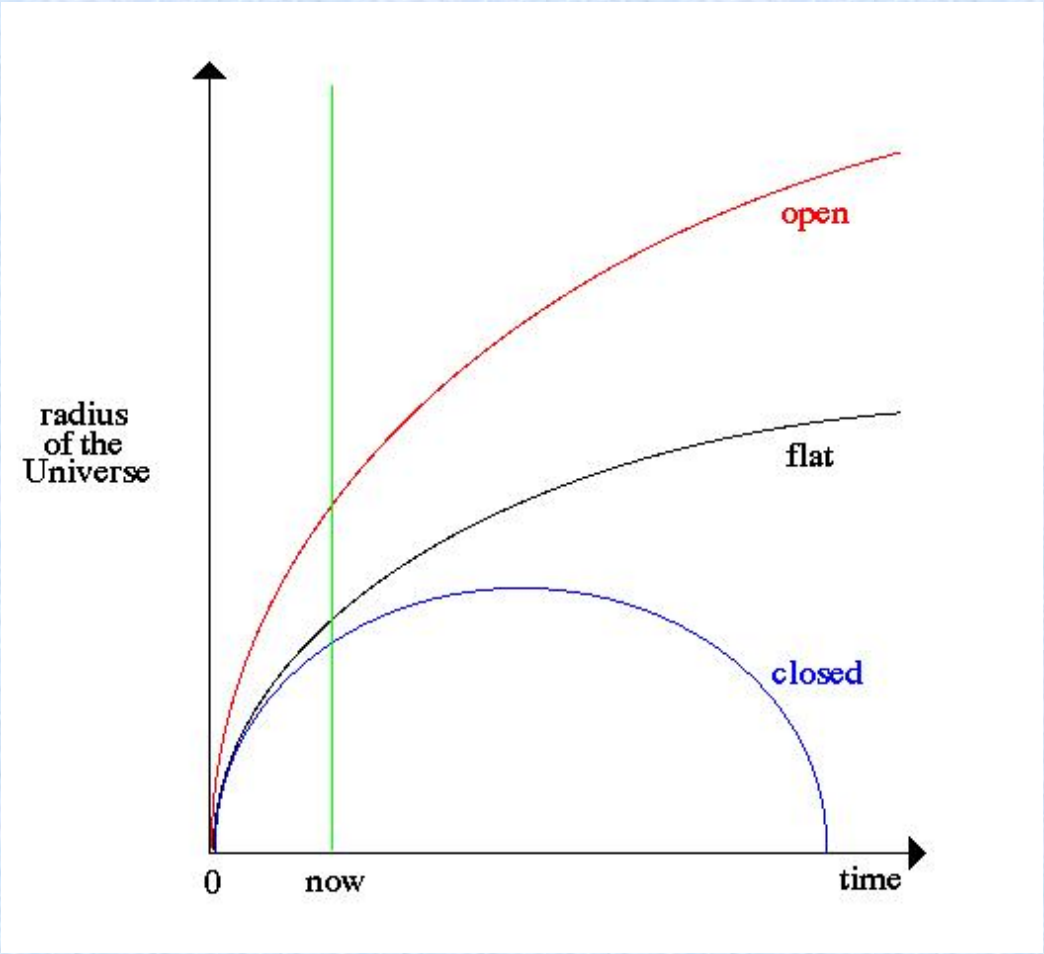
Dynamics of the Universe. "Fluid" equation

- We have 1 equation and two functions a(t) and ε(t)
- What is the connection between the two?
- Adiabatic expansion
- [Black board]

Dynamics of the Universe. Acceleration equation

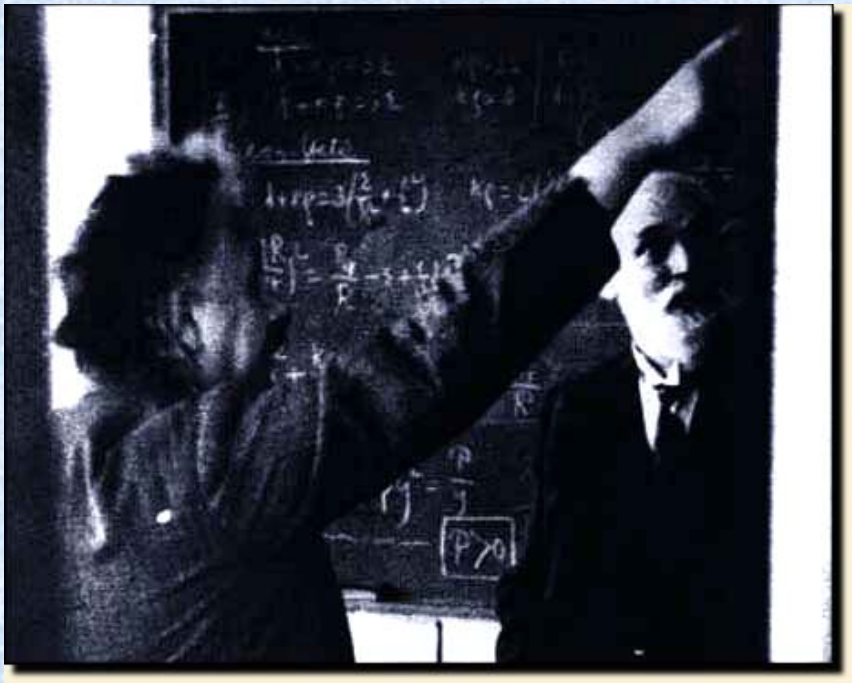
- **Another convenient form (not independent) is the equation of motion with the second derivative**
- **[Black board]**
- **Examples of Equation of state [blackboard]**

Fate of the universe in curvature + mass models



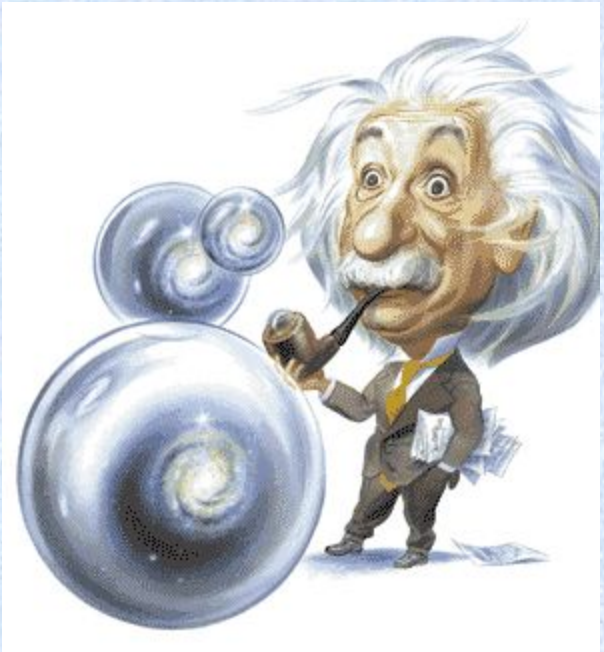
The cosmological constant

- Soon after the completion of general relativity (1916) people used it to describe the universe.
- However, with only matter there was no way to obtain a static solution, which at that time was the prejudice.
- Einstein added the cosmological constant to his equations to find a static solution…
- [Blackboard]



The cosmological constant

- Unfortunately the static solution is unstable
- And, when Hubble announced his discovery of the expansion, unnecessary
- So the cosmological constant remained on the outskirts of cosmology for a long time…
- Now it's back!



Cosmological constant or dark energy?

- Nowadays people prefer to talk in terms of dark energy, instead of cosmological constant.
- The classic cosmological constant is a modification of Einstein's equation [Black board]
- Dark energy is interpreted as something with negative pressure filling space
- Is it some sort of vacuum energy?
- We really don't know…

Dynamics of the Universe. Summary

- 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.

The End

See you on monday!