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

1888 - 1925
Dynamics of the Universe.

“Fluid” equation

- We have 1 equation and two functions $a(t)$ and $\varepsilon(t)$
- 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.
- 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!