Lecture 23: Four cosmic puzzles

The cosmic jigsaw
Four puzzles...

Reading: Chapter 16 of text (inflation)

I: THE FLATNESS PROBLEM

Universe with a flat geometry is a very special case...
- $\Omega_M = 1$ (for standard models)
- $\Omega_M + \Omega_\Lambda = 1$ (for models with Dark Energy)

Our universe is almost flat...
- We measure $\Omega_M$ approximately 0.3
- CBR results suggest that $\Omega_M + \Omega_\Lambda = 1 \pm 0.01$

Why are we so close to this special case?
In fact, problem is much worse...

- If $\Omega \neq 1$, then value changes with cosmic time...
  - If $\Omega > 1$, then it grows larger and larger
  - If $\Omega < 1$, then it grows smaller and smaller

If the universe is approximately flat now, it had to be very, very flat at early times...
- $\Omega \approx 1$ now means $\Omega$ ($t = 1s$) differed from 1 by less than $10^{-16}$!!
- At the Planck’s time, $\Omega$ differed from 1 by less than $10^{-60}$!!
- So, very special conditions were needed in the early universe to give approximate flatness now.
- If the Universe were not nearly flat, we would not be here...
  - If $\Omega$ had been much above 1, it would have recollapsed very early before making galaxies
  - If $\Omega$ had been much below 1, it would have expanded so rapidly that structures would not have formed
- This requires a lot of fine tuning!
- It is known as the flatness problem
II: THE HORIZON PROBLEM

Concept of the particle horizon:

- The sphere surrounding a given point (e.g., the Earth) which is causally connected to that point.

Consider 3 locations in space; A, B and C.

- Let’s draw their particle horizons...

So, in this example, A and B are causally connected to each other. But C is not causally connected to either A or B.
Consider the “epoch of recombination” when the observable CMB was formed
- Occurred ~400,000 yrs after big-bang
- At that time, particle horizon would be roughly $10^6$ light years across.
- This size-scale at the redshift of decoupling ($z = 1100$) corresponds to an angle of about $1^\circ$ on the sky...
- So, patches of the CMB that are separated by more than 1 degree should not have been in causal contact at the time of decoupling
- This gives the horizon problem...

There were thousands of causally-disconnected regions on sky at the time of last scattering
- How does the CBR “know” that it has to be so uniform across the sky?!
III : THE STRUCTURE PROBLEM

- Structure in the universe (galaxies, clusters of galaxies etc.) came from inhomogeneities in the early universe
- We see those same inhomogeneities in the CBR maps...

How did those inhomogeneities get there?
Why are they just the right magnitude and size to produce the structures we see today?
How is it possible to have the same kind of inhomogeneities spread throughout the whole universe, despite the lack of causal contact between different parts of the early universe?
- CMB is statistically the same in all directions
- Galaxies, etc., that formed are similar in properties, on opposite sides of the Universe
- This is the structure problem.
IV : THE RELIC PROBLEM

- Analogy: consider the cooling of a liquid (e.g., water)
- Once liquid reaches freezing point...
  - Freezing does not occur smoothly and uniformly
  - Freezing starts at certain locations, and the crystals start growing.
  - When crystals eventually merge to form the solid, there will be dislocations where the individual crystals meet...
  - The process of freezing is called a “phase transition” (matter changing from one phase to another).

Dislocations in steel
Beer crystals (Bud)...

http://www.microscopy.fsu.edu/beershots/beerphotos.html

The atomic structure...
What does this have to do with the Universe?

“Quantum fields” related to particles and forces in the very early universe can undergo phase transitions (i.e., they “freeze”).

As Universe cools...

- The temperature falls to the point where certain phase transitions can occur
- Phase transitions will start at particular points in space and grow at light speed
- Can get “dislocations” produced in the universe as a result of different regions meeting

This would produce exotic structure called topological defects...

- Domain walls (2-d sheet-like structures)
- Cosmic Strings (1-d string-like structures)
- None of these structures have been seen in the observable universe (good limits from CBR data - strings would gravitationally lens the background)

GUTs predict exotic particles produced at these domain walls in the early Universe

- Look like magnetic monopoles
- Never yet detected... and they don’t reveal their presence in any observed phenomena. Limits are very good. These objects have to be very very very rare.

The absence of monopoles (and other relics predicted by particle physics theories) is called the relic problem