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Lecture 23
The Fate of the Universe

Reading: Chapter 22

What will happen in the future…

- Using laws of physics and the state of the universe we know, we can make *predictions* for what will happen in the future.

- Two kinds of predictions
  - Immediate predictions: orbits of Moon, planets etc. Eclipses. Comets.
  - Long-term predictions: the fate of Sun, the fate of our Galaxy, the fate of our Universe, etc.

The fate of the Sun

- 3 to 4 billions years from now
  - The Sun will approach a red giant and get brighter
  - Earth will be doomed to a runaway green-house effect. Oceans boiled away
  - When the Sun becomes a red giant, it becomes 100 times larger in radius
  - Earth's temperature exceeds 1,000K
  - The solar prominences might lap at Earth's surface
  - Ejecta from the Sun (planetary nebula) will propagate through past Pluto into interstellar space
  - The Sun we know will die --- there will remain a white dwarf (no explosion).

The fate of our Galaxy

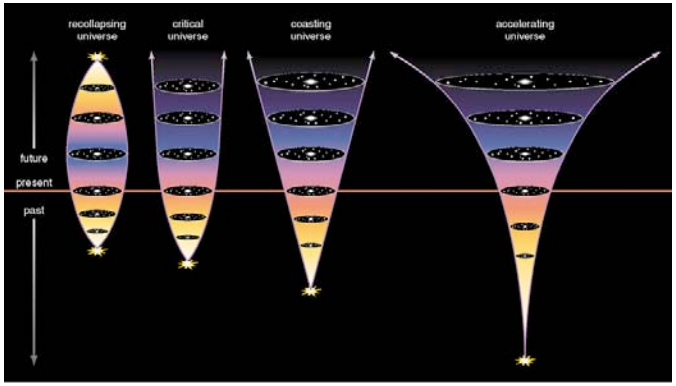
- Our neighborhood, Andromeda galaxy, is approaching us at the speed of 130 km/s.
- Our Galaxy will collide with Andromeda in 4 billion years! (roughly at the time when the Sun becomes a white dwarf).

The fate of large scale structure

- Evolution of the large scale structure critically depends on matter density of the universe.
  - The structure keeps developing if matter density is larger than or equal to the critical density.
    - Larger and larger clusters of galaxies continue to form
  - The structure stops growing and "freezes out"
    - Clusters of galaxies no longer form at late times
    - The appearance of the universe does not change much except the expansion of the universe.

The fate of the Universe

- The evolution of the entire universe depends on energy content (matter and dark energy)

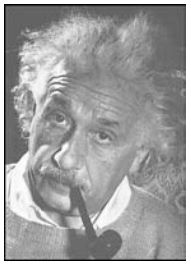


Accelerating Universe

- Imagine you throw a ball upwards.
  - Because of graviational pull, speed of the ball will slow down (decelerate), eventually stop, and will come back down to you.
  - Ever-expanding universe is such that the ball will slow down but never comes back to you, as gravity is not strong enough to pull it back down.
  - Accelerating universe is more strange --- the ball will accelerate: it will go upwards faster and faster! This is the effect of dark energy, acting somewhat like anti-gravity.

Einstein's Biggest Blunder?

- Einstein believed that the Universe must be "static" (not expanding or collapsing) purely for his philosophical reasons.
- On the other hand, his theory of General Relativity told him that the universe would collapse immediately!
- He had to stop the universe from collapsing -- therefore, he inserted the so-called Einstein's "***cosmological constant***" (a kind of dark energy) to balance gravity.
- Shortly after, Hubble discovered the expansion of the universe
  - the universe has not collapsed yet because of the expansion. (Analogy of a ball)
  - Einstein immediately accepted the observational fact and withdrawn his cosmological constant, calling it his "biggeest blunder"
- About 80 years later, dark energy was re-discovered, and its weirdness bothers cosmologists!



Future Night Sky -- Horizon

- We have learned that we can observe only a part of the entire universe, as speed of light is finite.
  - It takes time for photons to come to our sight
- In other words, we can see more and more of the universe as time goes by.
  - Or, **"horizon size" grows in time.**
- However, this is not always true!

Acceleration blocks our sight

- Accelerated expansion means that the universe expands faster and faster.
- Horizon is roughly given by the boundary at which the expansion reaches speed of light.
- If the expansion slows down (decelerates), then this boundary gets larger.
- On the other hand, if the expansion accelerates, this boundary gets SMALLER.
  - We will see less and less of the universe as time goes by!

Future: Hell for Astronomers

Not to mention that it woud be hell for everyone anyway… (Remember Earth will be boiled away in *only* 4 billions years!)

100 billion yeas later

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