Lec 1: 01/19/2010

Introduction:

The subject of Cosmology is the universe at large scales (galaxies, clusters of galaxies, superclusters, and eventually the entire universe).

There are fundamental questions arising from observation of structures of different size:

(1) What does the universe look like at large scales?

(2) How did the structure form and evolve in time?

(3) How big is the observable part of the universe?

(4) How old is the universe?

Can we address these questions within a consistent model based on laws of physics that we know?

Cosmology as a "physical science" requires precise measurements from observation.

The influx of high quality data, made possible by advances in technology, has turned Cosmology into an "experimental subject" where we can now talk about error bars in a meaningful way. One often hears that we have entered the era of "Precision Cosmology".

Observational milestones that have played crucial role in leading to modern cosmology.

— Expansion of the universe (Hubble, 1920's). This is one of the observational pillars of "Big-Bang Cosmology". In an expanding universe further means older, smaller and hotter. Following it back in time (by using Einstein theory of general relativity) it turns out that the universe was very small and hot at early times. At sufficiently early moments, the temperature was so high that all matter disintegrated into the elementary particles (the most fundamental constituents) $\xrightarrow[\text{space connection}]{\text{inner space-outer}}$ Lab for fundamenta physics.

So, the early universe was much simpler to describe: a bath of elementary particles in thermal equilibrium with an expanding background.

- Cosmic Microwave Background (1960's, 1990's, 2000's).

This is another observational pillar of the big-bang cosmology. The universe is filled with background photons that have a blackbody spectrum. The temperature currently is 2.7°, and this photon see is very isotropic (at the level of 1 in

10^5). The CMB is the holy grail of modern cosmology and can be used to extract informatio about fundamental physics.

- Primordial abundance of light elements (1970's, calculations made in 1940's). This is the third observational pillar of the **big-bang** cosmology. Light elements are synthesized in the early universe (~75% Hydrogen, ~25% Helium-4, negligible amounts of Deutrium, Helium-3 and Lithium-7).

- Missing matter in the Universe (1930's, 1960's & 1970's). Rotation curves of galaxies indicate that more matter than the shining one is needed. There are now various pieces of evidence that support the existence of "Dark Matter".

- Supernova observations at high redshift (1990's).

The luminosity vs redshift of type Ia supernova at $z \sim 1$ indicated that the universe has undergone accelerated expansion recently. This requires a new component in the energy budget of the universe coined as "Dark Energy".

We now have a "Standard Model of Cosmology" that is consistent with all observation (by large) and describes the evolution of the universe based on a few parameters. According to it the universe is ~13.7 billion years old, ~10,000 Mpc large (the observable part), and 96% of its content at current time is dark.

Challenges for fundamental physics:

Dark matter? Dark energy? What caused small anisotropy?

It turns out that the interesting things that we observe in the universe can be considered as relics from early times (Dark Matter, CMB, Primordial light elements, initial anisotropy). In most of the time, the expanding universe is a thermodynamical system that is in equilibrium. There are certain moments when certain reactions go out of equilibrium (because of the expansion). The reactions then freeze out and henceforth some relics will be subject to expansion.