LECTURE 1: THE BRIEF HISTORY OF THE UNIVERSE

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1. The Big Bang

Cosmology is a study of space and time of the Universe. According to our understanding today, the Universe started from a "Big Bang", a singularity of space-time, which can be described by neither Einstein's general relativity (GR) which is applicable to large scale structure of space-time with the presence of gravity, nor the quantum theory, which is designed to study the microscopic scales. The unification of GR and quantum field theory may do the job, but unfortunately such a theory has not been established (some attempts to do so including the string/M theory, and the loop quantum theories).

2. The cosmic inflation

After the big bang, the Universe was expanding **exponentially** for an extremely short period of time, which lasted from 10^{-36} seconds after the big bang, to sometime between 10^{-33} and 10^{-32} s. This era is called the cosmic inflation.

During inflation, the expansion of the Universe was accelerating, which was driven by the *inflaton*. The mechanism of inflation was invented by Alan Guth (MIT), Andrei Linde (Standford) and Paul Steinhardt (Princeton), to solve the problems of the cosmic isotropy, flatness, cosmic horizon and the non-existence of the magnetic monopoles.

3. The radiation dominated era

In the early Universe, the energy was in a form of radiation, which means that the primary component of the early universe was photons and neutrinos. These stuff dominated the Universe until 60 k years after the Big Bang, when the amount of matter (stuff that presureless) and radiation are almost the same.

During this period of time, the the expansion of the Universe was decelerating.

4. The CMB

In the early Universe, the temperature was so high that photons were tightly coupled to electrons via the Thomson scattering, which in turn are tightly coupled to baryons by Coulomb interactions. Due to these processes, the Universe was opac, as the photons couldn't travel freely to us today. This means that whatever instrument we use to probe the early Universe, there exists an intrinsic limit that we can see, which is what we call the last-scattering surface (it literally means the last moment that the photons interacted with baryons).

As the Universe cools down, these processes couldn't happen anymore, at about 380 kyrs after the Big Bang, which is roughly at redshift $z \sim 1100$. At this very moment, the photons were set free!!

The wavelength of these photons are in the microwave bands, so the background radiation due to these photons is called the Cosmic Microwave Background radiation (CMB). The CMB is one of the most important cosmic probes for the history of expansion and structure growth of the Universe, and recent CMB probes include the Planck and WMAP satellites. China is building a ground-based CMB instrument in Tibet to probe the B-mode polarization of the CMB photons, which is key to searching for the primordial gravity waves.

5. The matter-dominated era

After the CMB epoch, the Universe is so cool that matter (dark matter and baryons) starts to dominate the Universe. So from the CMB to very recent (at $z \sim 1$), the Universe was dominated by matter.

During the matter dominated era, the the expansion of the Universe was still decelerating. According to a recent study published in 2018 [3], at around 250 million years after the Big Bang, the first stars formed and ignited the dark Universe!! The stars then form galaxies, clusters and larger structures, which can be used to probe the history of the Universe!

6. Now: the dark energy-dominated era

In 1998, two groups of people independently discovered the accelerating expansion of the Universe, using supernovae type Ia (SNe Ia) (a Nobel prize was awarded for this in 2011). This was very surprising, as it contradicts Einstein's theory of gravity, which asserts that the expansion of spacetime can only be slowed down due to the attractive nature of gravity.

The cosmic acceleration means that either there is unknown energy component, dubbed dark energy, in the Universe which offers a repulsive force, or that Einstein's theory of gravity may break down on cosmic scales, which is referred to as modified gravity.

Homework

Read Chapter 1 of [1], and references therein.

References

[1] Dodelson, S. 2003, Modern cosmology / Scott Dodelson. Amsterdam (Netherlands): Academic Press. ISBN 0-12-219141-2, 2003, XIII + 440 p.
[2] Peacock, J. A. 1999, Cosmological Physics, by John A. Peacock, pp. 704. ISBN 052141072X. Cambridge, UK: Cambridge University Press, January 1999., 704
[3] Hashimoto, T., Laporte, N., Mawatari, K., et al. 2018, Nature, 557, 392