“How do we solve the mysteries of the early universe?”

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Do you know in which field three scientists won the 2019 Nobel Prize in physics? The prize rewards “new perspectives on our place in the universe”: new understanding of the universe’s structure and history, and the first discovery of an exoplanet orbiting a solar-type star. Nevertheless, much is still unknown about “the early universe”. Everyone may wonder how the universe began and how it evolved. These are fundamental questions for humanity and many scientists are trying to reveal their mysteries.

The modern story of the universe has only been known for the last hundred years. The universe had been regarded as stationary and eternal, but in the 1920s some scientists suggested that distant galaxies are moving away from us. Hubble, one of them, observed the redshift of distant galaxies and implied that the universe is expanding. In the mid-20th century the Big Bang theory was proposed as a theory for explaining this observation. The model describes how the universe expanded from an initial state of extremely high density and high temperature. In the model the early universe was full of a compact, hot and opaque particle soup in which light particles, photons, just bounced around.

As the universe expanded and the temperature of it dropped to about 3,000 deg C, electrons and protons became bound to form electrically neutral hydrogen atoms. Then, photons began to move freely and light was able to travel through the cosmos. This light has a wavelength of a few millimeters because of the expansion of the universe. In 1964, Penzias and Wilson (1978 Novel Prize in Physics) first detected this microwave light from everywhere in space and its spectrum was consistent with that of a blackbody radiation. James Peebles, one of the last year’s Novel Prize in Physics laureates, calculated this microwave background radiation theoretically based on the Big Bang theory and predicted that the temperature of the radiation is about 2.7 K, about -270 deg C. Since the theory and experiment matched well in this way, the Big Bang theory has been regarded as a powerful theory for explaining the expanding universe, although it doesn’t explain why the temperature in the universe is almost uniform.

As a theory which explains the uniformity of the temperature, “inflation” theory is supported by many scientists. The inflation theory, a theory of exponential expansion of space in the early universe, was introduced in the early 1980s and explained how regions which apparently could not have been in contact with each other have the same temperature. Inflation is also a mechanism for generating primordial perturbations over the smooth universe. Inflation predicts that quantum-mechanical perturbations of the scalar field in the very early universe are produced and grow large-scale structure and anisotropy in the late universe. In addition, inflation also predicts that fluctuations in the tensor field produce “primordial” gravitational waves, which is related to the energy scale of the early potential field. It is true that the inflation theory explains the evolution of the early universe, but it has not yet been confirmed by some observations.

More precise measurement of the cosmic microwave background (CMB) radiation may be the important key to confirm the inflation theory, just as Penzias and Wilson’s measurement implied the Big Bang theory. There are ground-based CMB experiments and satellite CMB experiments. For example, in 1989 NASA launched COBE satellite which made two major advances: high-precision spectrum measurements of CMB temperature, 2.7 K, and discovery of the anisotropies in the CMB temperature at a level of about 10 micro K. WMAP satellite in 2000s and Planck satellite in 2010s measured the anisotropy of CMB temperature precisely and also the anisotropy of CMB polarization. Polarization is defined by the direction which the electromagnetic waves of CMB photons oscillate. The signal of polarization is much smaller than that of temperature, but has much information about cosmology, including inflation. Now many scientists are developing the next-generation ground-based experiments to measure fluctuations of CMB polarization at an unprecedented sensitivity. I’m involved in one of the ground-based experiments, “Simons Observatory”, which are under construction and will start observation in 2021.

One of the science goals of Simons Observatory is to search for evidence of inflation by observing the CMB polarization. According to the inflation theory, primordial gravitational waves create a “B-mode” pattern which is the odd parity component of CMB polarization, while density perturbations do not create B-mode polarization. Therefore, observing B-mode polarization in degree scales leads to the discovery of the primordial gravitational waves, which results in proof of the inflation theory. Furthermore, if the gravitational waves can be detected, we can predict the energy scale in which inflation occurred, which coincidently matches that of the Grand Unified Theory, a model in which the electromagnetic, weak, and strong interactions are merged into a single force. Furthermore, it is a big step towards the final goal of modern physics beyond cosmology: the unification of gravity and quantum theory.

Investigating the origin of the universe and the evolution of the universe is a significance activity which attracts not only scientists but also all people. It may not be long before the confirmation of the inflation theory changes our conceptions of the world.

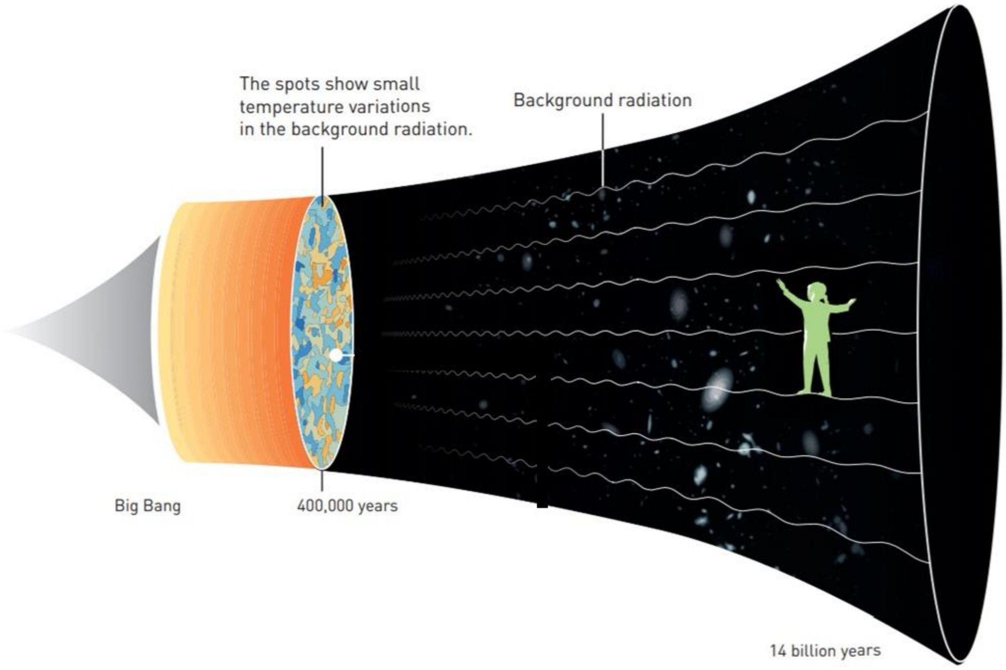

Fig 1: The cartoon of cosmic microwave background radiation after the Big Bang [1].

(Source: Johan Jarnestad/The Royal Swedish Academy of Sciences)

Reference

[1] The Nobel Prize in Physics 2019 Popular Information, Retrieved June 8, 2020, from https://www.nobelprize.org/prizes/physics/2019/popular-information/