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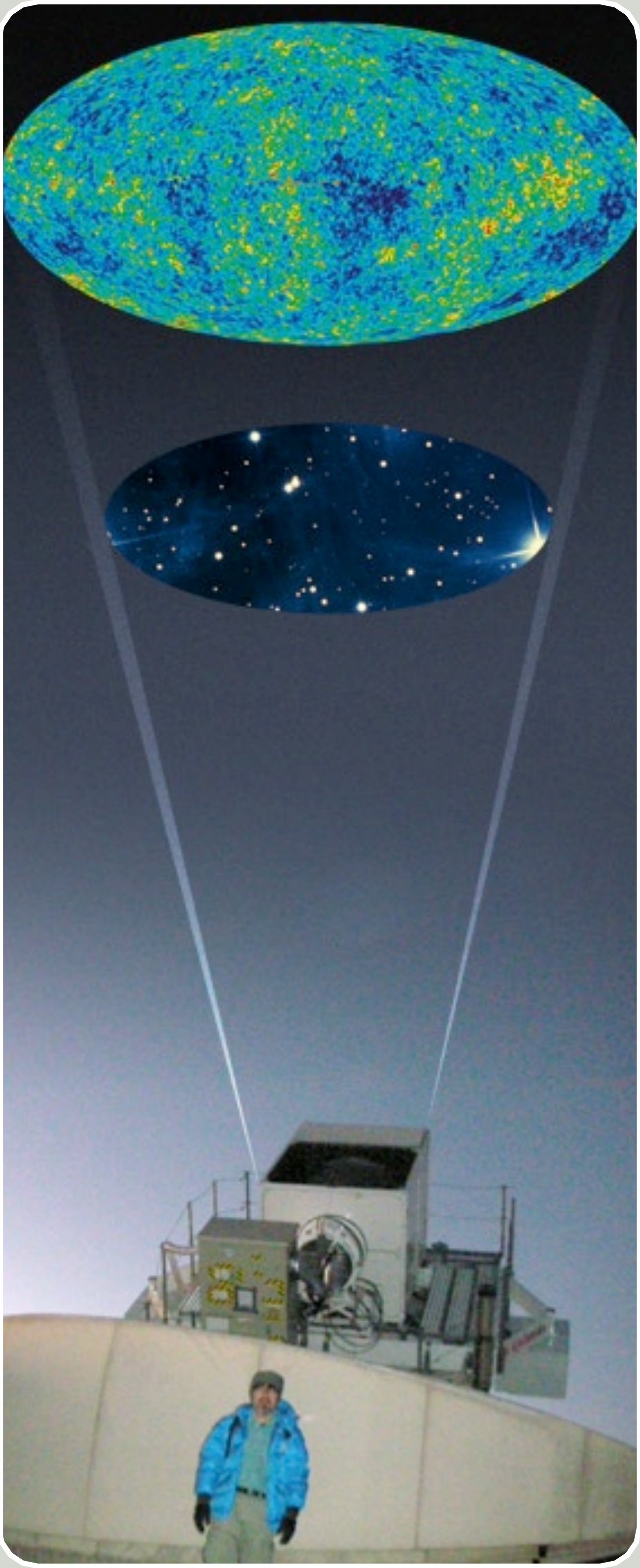
FEATURE STORY



KEK’s new cosmic connection

[Cosmic Microwave Background, Primordial Gravitational Wave]

The newly established Cosmic Microwave Background (CMB) project is KEK's new cosmic connection. Read on to learn what high energy physics community can do to probe primordial gravitational waves from the early universe.

Here is something to think about: if you were unexpectedly confined to a hospital for several weeks, unable to go to work, how would you spend your time? When this happened to Professor Masashi Hazumi of KEK, he chose to connect high energy physics with the cosmos.

Hazumi is a high energy physicist, the kind of person who works with atom smashers. The advancement of our technology has pushed the frontiers of high energy physics, allowing scientists like him probe the origin of matter and the mysteries of the universe. However, as an expert in the field, Hazumi knows that there are limits to what we can do with accelerator technology. For example, we will not be able to engineer particle collisions with energy of more than some tens of TeV in an accelerator at least in the near future. To explore physics beyond this energy, scientists need to use other methods.

The leader of KEK CMB group Prof. Masashi Hazumi of KEK sitting in front of the QUIET telescope in the Atacama desert in Chile.

While in the hospital, instead of filling in the blanks of Sudoku grids, Hazumi pondered this kind of ultra-high energy physics, the kind that just can't be done in an accelerator on Earth. There were many interesting topics: X-ray astronomy, black holes, dark energy, dark matter, gravitational wave detection with interferometers, muons, neutrinos, etc. He listed the pros and cons for each of those fields as they came to his mind, and picked the field that looked most promising.

“The cosmic microwave background project, or CMB project, appeals to me because in it we look directly into the primordial cosmos,” says Hazumi.

The epoch of last scattering

The cosmic microwave background (CMB) is microwave radiation coming from outer space. The radiation is a relic of the early days of our universe, when the universe became cool enough to form atoms. Up to this point, the universe was opaque because the ubiquitous free electrons absorbed and scattered photons. When those electrons became bound to protons, the universe became transparent to electromagnetic radiation—light. The radiation from that time is still around today in the form of the CMB. The map of CMB radiation provided a proof for this era, which was predicted in the big bang theory. Many astrophysicists believe that the map of CMB radiation is one of the biggest discoveries of the century.

The universe became transparent to light about 380,000 years after the big bang.

Now, 380,000 years sound pretty much insignificant compared to the age of the universe, which the present cosmological observations yield at about 13.7 billion years. Knowing this age however, is not enough for particle physicists like Hazumi. He and his fellow physicists believe that the universe became explorable by particle physics experiments around 10^{-11}seconds into its existence. The interesting thing about the CMB physics is that it can actually probe the time even before that.

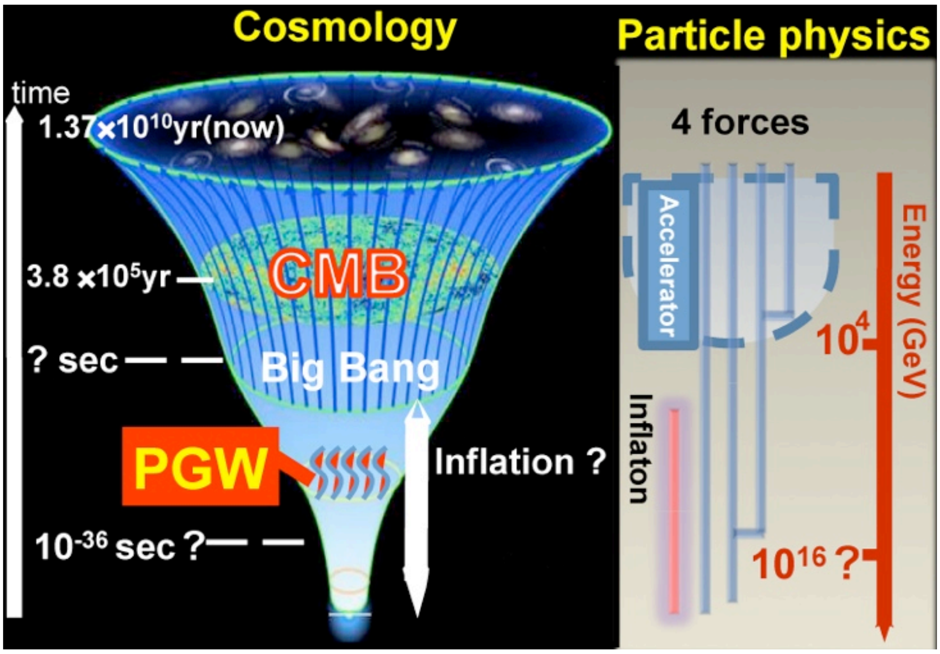
Cosmic inflation and primordial gravitational waves

“There are three things you can measure in the CMB radiation: intensity, wavelength, and polarization,” explains Hazumi. “CMB polarization offers the best chance to date of detecting very exciting feature called primordial gravitational waves generated during the cosmic inflation.”

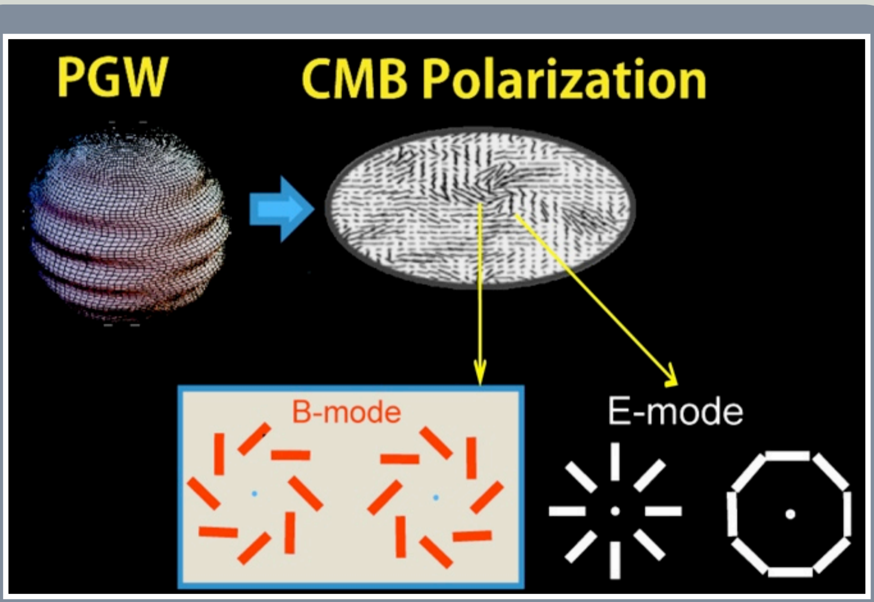
Cosmologists believe that at around 10^{-36} seconds after the birth, the universe began an expansion by a factor of 10^{26} that lasted for very small fractions of a second. This theory is called the inflationary scenario, and elegantly resolves many of the puzzles of the big bang.

For example, the CMB radiation appears nearly homogeneous and isotropic, with intensity fluctuations of only one part in 100,000. However, these tiny fluctuations are incredibly important, and are related to the matter and energy distribution—the large-scale structure—of our observable universe. By theorizing a rapid expansion of the space in very short period of time, cosmologists are able to explain the smallness of these variations. If such an enormous expansion had not occurred, the universe would have been entirely heterogeneous and anisotropic, unable to form the large-scale structure we see today.

It was in this brief inflationary epoch that graviton-antigraviton pairs were created from the quantum vacuum. In a universe which was not expanding rapidly, those graviton-antigraviton pairs would quickly recombine and



Cosmology and particle physics. Primordial gravitational waves (PGW) are relics of the inflation epoch observed in the cosmic microwave background (CMB) radiation by means of polarization measurement. (Ref. Theoretical Astrophysics Group Department, The University of Tokyo:http://utapen4.phys.s.u-tokyo.ac.jp/~sato/)



Primordial gravitational waves give the divergence-free B component in the CMB polarization.

annihilate. However, in a rapidly expanding universe, the gravitons and antigravitons were split far apart in tiny fractions of a second. They were split apart before they had a chance to annihilate back again into vacuum. Hazumi says, “We currently have no means to create detectable gravitons in a machine. In a way, the early universe is our machine for producing primordial gravitons.”

The graviton is a particle hypothesized to explain gravitational force in quantum field theory, and acts as a field as well. Cosmologists believe that the enormous expansion of space during the inflation gave rise to fluctuations in the fabric of spacetime creating ripples across the universe. These ripples are called primordial gravitational waves, and they can be detected in the CMB polarization.

Polarization of CMB radiation

The CMB radiation is a result of radiation scattered from the last free electrons, before the universe became transparent 380,000 years after its birth. There are two ways that the CMB radiation can become polarized. The first is anisotropic primordial radiation. When radiation of the same intensity was incident from all directions on an electron, there would be no net polarization in the scattered radiation, and the CMB would be unpolarized. However, distinct intensity anisotropy was discovered by the COBE satellite in 1992 and has precisely been measured by the WMAP satellite. If the intensity of the CMB is anisotropic today, then the primordial radiation incident on the electrons was also anisotropic, which means that the CMB radiation we see today would be polarized. This CMB polarization pattern due to intensity anisotropy can further be deformed by gravitational waves that stretch and shrink the metric of space.

Dr. Osamu Tajima (right) of KEK is deploying the W-band receiver system at the observing site in Chile. Tajima is currently a two-year visiting fellow at University of Chicago, working together with the Chicago team (center and left).

If precisely measured, the polarization map should look like a bunch of tiny bars on the sky (see image). Each bar gives the direction of the polarization of CMB radiation in that part of the sky. Interestingly, primordial gravitational waves produce curl patterns in this map. This is called ‘divergence-free’ or B-mode, in analogy with the magnetic field. On the other hand, without the primordial gravitational waves, primordial intensity anisotropy produces star-shaped patterns in the map, where bars point directly out from or tangent to a circle around a single point. This is called ‘curl-free’ or E-mode, in analogy with electric field.

“The CMB map we have today mainly shows the intensity of the radiation,” says Hazumi. “For polarization, if measured precisely, we have much richer information with the angle and the length of the bars, which correspond to the direction and the strength of polarization.”

QUIET, POLARBeaR, and LiteBIRD

In 2007, Hazumi received official approval from the KEK director general to start research and development for his new projects: the Q/U Imaging Experiment (QUIET) and the Polarization of Background Radiation experiment (POLARBeaR). QUIET and POLARBeaR are collaborations of 14 and 9 organizations, respectively, from US, Europe and Japan. The KEK CMB group is the first group from Japan to ever join a CMB polarization project.

Despite its importance, CMB science had previously been neglected in Japan. This was unusual as many major high energy organizations world-wide had started such research decades before. “There are, however, increasing number of interested individuals and groups in universities and research institutions in Japan,” says Hazumi.

QUIET and POLARBeaR are both ground-based CMB telescopes located (or to be

Eri Yaginuma (left) and Akie Shimizu (right) are graduate students at Sokendai University. Yaginuma studies effective ways to scan the sky using LiteBIRD, and Shimizu studies the power spectrum analysis for POLARBeaR.

located) in the Atacama desert in Chile at an altitude of 5,000 meters. Both telescopes measure the polarization of CMB radiation, but they do so for different frequencies. While QUITE works at 40 and 90 GHz, POLARBear works at the higher frequencies of 90, 150, and 220 GHz. These frequencies are carefully chosen to distinguish CMB background radiation from other foreground radiation.

QUIET is currently in phase I, in which the team is observing using 100 receiver modules. QUIET will be upgraded to employ ten times more receivers in 2012 to greatly enhance the sensitivity. POLARBeaR telescope is currently under construction, and will start taking measurement next year. During the QUIET phase II run, scientists at QUIET and POLARBeaR plan to conduct joint measurements, taking data from the same patches of the sky simultaneously.

“With the combined analysis, we will be able to remove the foreground signals more effectively,” says Hazumi. “The joint project will provide the highest sensitivity in ground-based CMB projects for the coming decade.”

Hazumi also established a working group for a next-generation satellite CMB project, Light satellite for the studies of B-mode polarization and Inflation from CMB Radiation Detection (LiteBIRD). “If we could find the primordial gravitational waves using ground-based telescopes, the next step would be to launch a satellite dedicated for B mode precision measurement to identify a correct model of inflation. Our approach is to design a light-weight satellite so that it can be launched as soon as possible” he says. The LiteBIRD working group, proposed by the KEK CMB group was approved by JAXA in 2008, and is now composed of more than 30 scientists from 11 organizations in Japan and the US.

New era, new people

Hazumi's project was entirely new to the high energy physics community both at KEK and in Japan. However, he was confident that he could pull it off for three reasons. First, the high energy physics community at KEK is already an excellent source of knowledge and technologies suitable for astrophysics experiment. Second, Japanese industries have already proved themselves to be good producers of the types of devices used in astrophysics research. Third, the timing was ripe for Japanese academia to enter the field of experimental cosmology.

The KEK CMB group now has nine full-time staff and students, and eight part-time staffs. In addition, the collaboration has attracted international partners.

Hazumi says, “The most important thing is people. I am especially optimistic because this new field seems to attract many young, brilliant researchers not only at KEK but also in Japan.” Hazumi and his team are trying to find fundamental rules of the universe that should be simple and short. “The list of researchers is very encouraging, and tells me that CMB physics is an exciting, growing field. It tells me that people are interested in fundamental and grand questions about the cosmos.” The discovery of primordial gravitational wave will be a ground breaking discovery in cosmology, and also in particle physics.

Hiroki Watanabe is a graduate student at Sokendai University. He says he enjoys the project because creating detectors and equipments for astrophysics experiment was what he always wished to do.

Related Link:
[Cosmic Background Radiation (Japanese)](#)

[KEK CMB Group (Japanese)](#)

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