論文内容の要旨

論文題目

Observational study of very-high energy particle acceleration in transient objects with the Ashra detector

Ashraを用いた突発天体における超高エネルギー粒子加速の観測的研究

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Astronomy has developed with observations using photons of various wavelength, from radio to gamma rays, which is called 'multi-wavelength astronomy'. However, in the beginning of the 21th century, it faces on a turning point toward 'multi-particle astronomy', with particles other than photon, such as neutrinos and gravitational waves. They can be strong tools to reveal the origin of high-energy universe. In particular, neutrinos can serve as a key to the mechanism of the particle acceleration, which is an open question since decades ago.

The Ashra (All-sky Survey High Resolution Air-shower detector) Experiment is a project that aims to catch signals from transient objects with air light, to open the door to the multi-particle astronomy. It can detect with trigger, very-high-energy gamma rays, ultra-high-energy cosmic rays, and very-high-energy neutrinos, as well as UV light without trigger. The detector is a type with fixed optics, which has a wide field of view of 42 degrees in diameter and a high angular resolution of several arc-minutes. It is most suitable for the monitoring observation for transient objects.

We have designed an observation at the site on Mauna Loa on Hawaii Island, to study neutrino emissions from transient objects, and to confirm the performance of the trigger system of the Ashra detector. The principle of the trigger system had been tested in an observation for gamma rays, carried out in 2004 on Haleakala on Maui Island. We have planned to use the trigger system to the observation in 2008, while the other components are the same as the final design of the Ashra detector. For this observation we have adopted the earth-skimming tau neutrino detection technique, with which the Earth's rock is used as a target for neutrino interaction while the atmosphere is used as a detector. We have simulated neutrino signals detected as Cherenkov radiation from air-showers generated by tau leptons emerging from Mauna Kea, a mountain close to our site. The detector was calibrated with various ways in advance.

During the observation time, conditions must be monitored to keep stable observation and data quality. We have achieved high observation efficiency with operation schemes and Slow Control System neatly designed for monitoring surroundings. Also, as another condition for observation, background light of the sky and Mauna Kea have been observed in advance. As a result, during the observation from September to December in 2008, we observed a gamma-ray burst (GRB), GRB081203A, in a period before and after its occurrence. Also we observed 13 GRBs after their occurrence, and 32 active galactic nuclei (AGN).

The obtained data were analyzed. In order to estimate the sensitivity we calculated the physics function for signal and noise, and detector function for both. The physics function for signal is source models. We focuses on neutrino emissions from GRBs and AGN. The physics function for noise is background fake events. In principle, the earth-skimming neutrino detection technique is free from background cosmic rays, thanks to the screening effect of the Earth's rock. We have studied the screening effect of Mauna Kea and make sure the absence of the background events. As a consequence, the largest background source is Cherenkov radiations from muons that interact with the detector itself. We have simulated and removed the fake events carefully.

We have not discovered any neutrino emission above 10^{15}eV (PeV) up to about 10^{18}eV (EeV), and set upper limits to the fluence and flux of source models, related to the mechanism for the particle acceleration in transient objects. For GRB precursor, we set a limit $E\Phi(E) < 8.3 \cdot 10^{-8}$ [cm^{-2}], assuming a spectrum extended up to 5 EeV. For GRB late prompt, the obtained limit is $E^2\Phi(E) < 6.2$ [erg cm^{-2}]. For GRB afterglow, the limit leads $E^2\Phi(E) < 26$ [erg cm^{-2}]. Furthermore, neutrino emission from AGN is studied. The limit for diffuse flux is about 2 orders of magnitude larger than that by other experiments. In addition, we set an upper limit, $E^{1.4}\Phi(E) < 6.5 \cdot 10^{-13}$[$cm^{-2}$ s^{-1} $PeV^{0.4}$], based on a source model assuming proton synchrotron emission. Though this limit corresponds to a diffuse flux rejected by experiments, it is still meaningful as a limit for point source, which is not affected by the source distribution in the universe. All the above limits are derived with 90% confidence level, including systematic errors.

This is one of the first experiments that searched for astrophysical neutrinos by the earth-skimming tau neutrino detection technique. These results demonstrate the strength of our detector. For future neutrino experiments, pointing accuracy in PeV region is important to localize transient objects, as well as it is of importance to extend sensitive region of air monitoring toward lower energies. The results in this thesis reveals the strength of our detector, and hence we expect the Ashra detector as a candidate to realize 'multi-particle astronomy', which is necessary for us to understand the particle acceleration in the universe.