【Grant-in-Aid for Scientific Research (S)】

Revealing the high-energy dynamic universe and dark matter with the CTA large-aperture gamma-ray telescopes

Principal Investigator	The University of Tokyo, Institute for Cosmic Ray Research, Professor KUBO Hidetoshi	Researcher Number:40300868
Project Information	Project Number : 23H05430 Keywords : cosmic gamma rays, black hole, cosmic rays, dark matter search	Project Period (FY) : 2023-2027

Purpose and Background of the Research

●Outline of the Research

The major purpose of the research is to elucidate the nature of cosmic high-energy phenomena, cosmic ray origins, and dark matter. First, we will construct the next generation ground-based gamma-ray telescopes (CTA-LST) and improve the gamma-ray detection sensitivity through joint observations with the current telescope MAGIC. Secondly, we will elucidate the mechanisms of radiation and particle acceleration in high-energy objects and the origin of cosmic rays by observing high-energy objects (black hole objects, neutron stars, etc.), and take the follow up observations for gravitational waves and neutrino alerts, with playing a role in the multi-messenger astronomy. In addition, the extragalactic background radiation will be measured from gamma-ray observations to elucidate the history of star formation. Furthermore, we will improve the gamma-ray sensitivity for annihilation cross sections in the 1-10 TeV mass region of the dark matter.

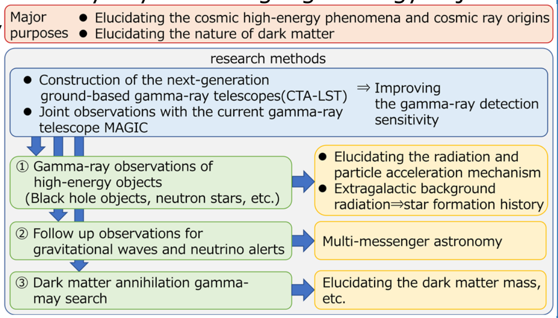

Figure 1. Outline of the Research.

●International Cosmic Gamma-ray Observatory CTA Project

Particles (cosmic rays) reaching 10^{20} electron volts, which far exceed the energy of artificial accelerators, have been flying from space to Earth. Their origin has not been clarified. Gamma-ray emitting objects with giant black holes are the promising candidates for the origin. However, even the radiation mechanism is not fully understood.

Dark matter is said to account for about 30% of the energy composition of the universe. Although searches using artificial accelerators have continued, the nature of dark matter is still unknown. We have been challenging the above questions by observing cosmic gamma rays with energies of tera electron volts (TeV). More than 200 objects have been detected (Fig. 2). For further studies, we are constructing the next-generation ground-based gamma-ray observatory, Cherenkov Telescope Array (CTA) (Fig. 3), located in the northern (Spain) and southern (Chile) hemispheres to observe all sky. More than 1,000 objects are expected to be detected with the CTA observatory. About 120 people from Japan are participating in the CTA project, leading the construction of four 23m aperture large-sized telescopes (LST) with the lowest energy threshold, which can see the distant universe. The first LST telescope was constructed on the island of La Palma in the Canary Islands, Spain (Fig. 4). The scientific observations began in 2021.

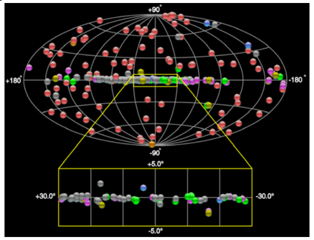

Figure 2. Celestial objects from which gamma rays with energies in the TeV region have been detected. http://tevcat.uchicago.edu/

Figure 3. Construction plan of an array of four CTA Large Sized Telescopes (LST) and two MAGIC telescopes in operation on the island of La Palma, Spain, where this research is based.

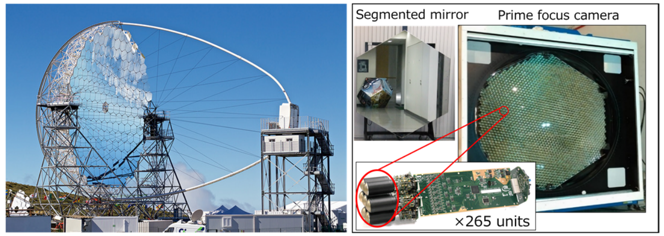

Figure 4. First CTA large sized telescope (CTA-LST) installed on La Palma Island, Spain (left), and a segmented mirror and the prime focus camera (right).

Expected Research Achievements

● Construction and operation of four CTA Large Sized Telescopes (CTA-LSTs)

In parallel with the operation of the first LST (Fig. 4), which has already started scientific observations, we will construct the LST 2-4 and start the operation, then take simultaneous observations and cross-calibration with the MAGIC telescopes.

● Observations of high-energy celestial objects - Toward understanding high energy phenomena and the origin of cosmic rays

[Active Galactic Nuclei (AGN)]

AGN is an object with a giant black hole more than ten million times the solar mass. With observing the flux variations in seconds to minutes by LST (Fig. 5), the contributions of accelerated protons and electrons, the acceleration mechanism and its contribution to the origin of cosmic rays will be clarified.

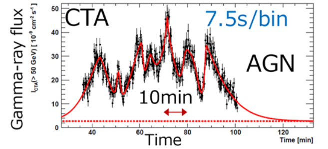

Figure 5. Simulation of the flux variation when an AGN is observed with CTA. DOI:10.1142/10986.

[Gamma-Ray Burst (GRB)]

GRB is an object that emit more energy in seconds than the Sun will emit in its entire lifetime, creating a black hole (Fig. 6). The GRB observation limit by LST extends to about 12 billion light-years away. The LST observations will elucidate the electron acceleration and the contribution of protons to cosmic rays.


Figure 6. Gamma-ray burst. ©ICRR,U.Tokyo/ N.Wakabayashi

[Supernova remnant] and [Neutron star]

are also observed to study the acceleration mechanism and the cosmic ray origin.

[Follow up observations for gravitational waves and neutrino alerts]

CTA-LSTs play an important role in the multi-messenger astronomy.

● Dark Matter Search

We will search for gamma rays produced by the annihilation of dark matter as a candidate WIMP (Weakly Interacting Massive Particles) (Fig. 7). We will observe the central region of the Milky Way Galaxy with LSTs. The LSTs can achieve better sensitivity in the dark matter mass range of 1-10 TeV, which cannot be explored by artificial accelerators (Fig. 7).

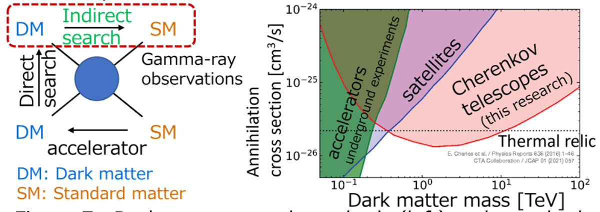

Figure 7. Dark matter search methods (left) and searched areas for annihilation cross section (right).

Homepage Address	CTA http://www.cta-observatory.jp/ MAGIC http://magic.scphys.kyoto-u.ac.jp/