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

Indirect search of MeV-scale dark matter by observation of galactic diffuse MeV gamma-rays

Principal Investigator	Kyoto University, Graduate School of Science, Assistant Professor TAKADA Atsushi Researcher Number:90531468
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Purpose and Background of the Research

●Outline of the Research

Dark matter, an important component of the Universe, remains a mystery. Dark matter in the Milky Way has a halo structure and is clustered in the center regions of the galaxy. The main candidates for dark matter are primordial black holes (PBHs), which were formed in the early universe with the mass of an asteroid, and WIMPs, which are elementary, undiscovered particles. Both candidates emit MeV gamma-rays, and their spatial distribution depends on the amount of dark matter. Therefore, we will develop an electron-tracking Compton camera (ETCC), which will provide a large field of view and low noise observations and conduct indirect searches for PBHs and WIMPs from observations of the Galactic Center region using long duration balloons.

●Method

Observations using satellites and balloons have shown that the Milky Way Galaxy has extensive and bright MeV gamma-ray emission (galactic diffuse MeV gamma-ray) and electron-positron annihilation lines. Although observations in the MeV band are expected to provide a probe of nucleosynthesis or chemical evolution, observations in MeV band themselves are difficult and have been limited to other energy bands.

When a MeV gamma-ray collides with an electron, it causes a phenomenon called Compton scattering, in which part of the photon's energy is transferred to the electron and it is recoiled. By measuring the momentum of the recoiling electron and the scattered gamma ray, the direction and energy of the original photon can be obtained from the conservation of momentum law. The MeV gamma-ray telescope based on this principle is the ETCC. The ETCC can completely resolve the direction of the incident gamma rays, which cannot be resolved for each photon using conventional methods, and thus enables the high- sensitive astronomical observations. The ETCC will be loaded on a long-duration balloon in the mid-latitudes of the Southern Hemisphere.

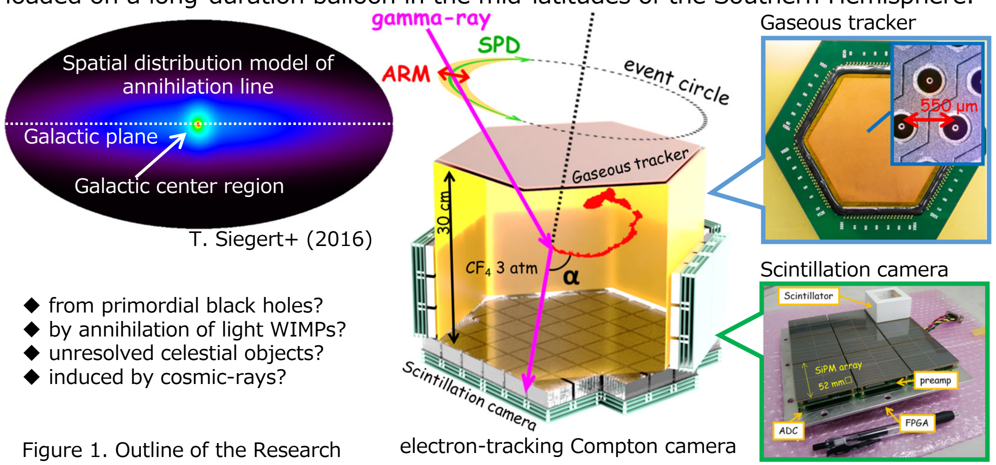

Figure 1. Outline of the Research

●SMILE project

The balloon-based SMILE project is underway to demonstrate gamma-ray observation by the ETCC and to perform MeV-band scientific observations. A balloon experiment (SMILE-I) launched from Sanriku in 2006 for operation test in the space environment and a one-day balloon experiment (SMILE-2+) in Australia in 2018 aimed at demonstrating astronomical observation. In this research, we are promoting scientific observation (SMILE-3).

Figure 2 SMILE-I (Left: preparation for launch, Right: launched balloon)

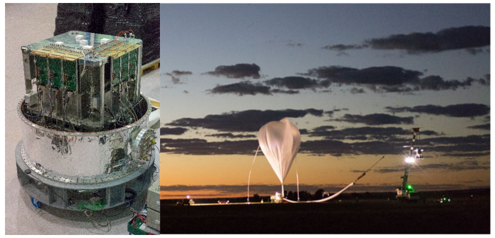

Figure 3 SMILE-2+ (Left: SMILE-2+ ETCC, Right: preparation for launch)

Expected Research Achievements

●Development of the SMILE-3 ETCC

Based on the SMILE-2+ ETCC, we improve the effective area, spatial resolution and energy bandwidth. Increase the effective area by using molecular gases of light elements favourable for Compton scattering. Introduce a machine learning based electron track analysis method to improve the positional accuracy of Compton scattering points and the accuracy of recoil direction determination. While the energy bandwidth of the ETCC is limited by the scintillation detector, two charge readout systems with different gains will be installed.

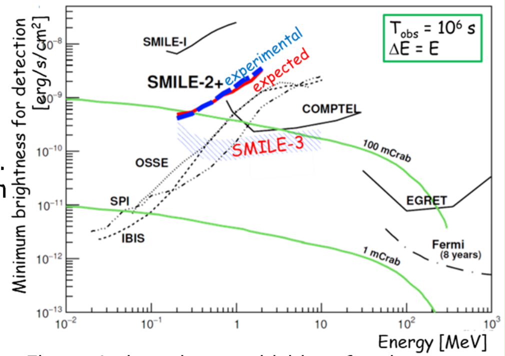

Figure 4. detection sensitivities of various observations

●Investigating origin of galactic diffuse MeV gamma-rays

Observations of the center region of the Milky Way will be made in the mid-latitudes of the Southern Hemisphere using ETCC on board a high-altitude, long-duration balloon. The energy spectrum and spatial distribution of galactic diffuse MeV gamma rays will be used to search for gamma-ray emissions from primordial black holes or WIMP annihilation. If the Milky Way has dark matter-derived MeV gamma-ray emissions, similar emissions can be expected in other galaxies, so we will also approach the existence of PBHs and WIMP annihilations from the energy spectrum of extragalactic diffuse gamma-rays.

●Search for MeV gamma-ray sources

The detection sensitivity targeted by this study exceeds that of COMPTEL, whose observations were completed in 2000. We can therefore expect to search for undiscovered sources, in addition to bright known objects such as the Crab Nebula and the radio galaxy Cen A. ETCC also has a large field of view (120° aperture angle), making it suitable for observing gamma-ray bursts. If sufficient observing time can be secured, ETCC is expected to make significant advances in MeV gamma-ray astronomy.

Homepage Address, etc.	http://www-cr.scphys.kyoto-u.ac.jp/MeV/wiki.cgi https://twitter.com/SMILE2p_ETCC