Thesis Summary

Deep Morphological and Spectral Studies of Supernova Remnant CTB 37A with *Fermi*-LAT

（*Fermi* ガンマ衛星 LAT による超新星残骸 CTB 37A の形状とスペクトルの詳細研究）

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Despite intensive studies of the non-thermal emission from many supernova remnants (SNRs) and recent observational evidence on the origin of cosmic rays (CRs) from three SNRs associated with molecular clouds (IC 443, W44, and W51C) by *Fermi*-LAT, the contribution of the Galactic candidates on the total CR budget and nature of the high energy emission toward these objects remain still elusive.

As my Ph.D. thesis, I have worked on one of the poorly studied Galactic SNRs, CTB 37A, with *Fermi*-LAT data. The middle-aged SNR CTB 37A is known to interact with several dense molecular clouds through the detection of shocked H_2 and OH 1720 maser emission. Radio and X-ray observations of the SNR confirm a mixed-morphology classification of the remnant. The TeV γ-ray source HESS J1714-385 and the X-ray source CXOU J171419.8-383023 are both offset to the west from the geometric center of the remnant and are embedded within its extended radio shell. However, it is still not clear whether the TeV γ -ray emission originates in the SNR or the putative pulsar wind nebula.

To answer the key question on the nature of γ-ray emission toward the remnant, I have carried out detailed analyses on the morphology and spectrum of the source, which are crucial for distinguishing between hadronic and leptonic scenarios. In this work, I used eight years of *Fermi*-LAT Pass 8 data, with an improved point spread function and an increased acceptance, to perform detailed morphological and spectral studies of the γ-ray emission toward CTB 37A from 200 MeV to 200 GeV. The best-fit of the source extension is obtained for a very compact Gaussian model with a significance of 5.75σ and a 68% containment radius of $0.116° \pm 0.014°_{\rm stat} \pm 0.017°_{\rm sys}$ above 1 GeV, which is larger than the TeV emission size. The remnant has the smallest extension compared with the other SNRs in the GeV band previously studied in the first SNR Catalog of the LAT collaboration. The energy spectrum is modeled as a LogParabola, resulting in a spectral index of $\alpha = 1.92 \pm 0.19$ at 1 GeV and curvature of $\beta = 0.18 \pm 0.05$, which becomes softer than the TeV spectrum above 10 GeV.

Based on the spatial and spectral characteristics, I proposed the possibility of a new composite candidate to explain the broadband emission toward the CTB 37A system and to elucidate the nature of the GeV-TeV emission. Recently, an energetic pulsar (t_c = 18.9 kyr) hiding inside the CTB 37A system was discovered in a blind search by P. M. Saz Parkinson et al. [1], which approved the proposed scenario on the composite class of the SNR.

The SNR properties, including a dynamical age of 6000 yr, are derived assuming the Sedov phase. To explain the multi-wavelength spectrum of the remnant, I generated a model using an analytical approach [2], based on a steady-state particle transport equation. In a more detailed treatment, contribution of particles in both the blast wave and the radiative shocks are taken into account. From the multi-wavelength modeling of emission toward the remnant, it is concluded that the non-thermal radio and GeV emission is mostly due to the re-acceleration of the pre-existing CRs by radiative shocks in the adjacent clouds. Furthermore, the observational data allow us to constrain the total kinetic energy transferred to the trapped CRs in the clouds.

[1] Saz Parkinson, P. M., et al., 2018, the 8th International Fermi Symposium
[2] Uchiyama, Y., et al., 2010, Astrophys. J. 723, L122