論文の内容の要旨

The Extreme Universe and Multi-Wavelength Sky Probed by TeV Gamma-Ray Observations: Pulsar TeV Halos, Radio Emission from Quiescent Galaxies, and Black-Hole Jets

(TeV ガンマ線観測で探る極限宇宙と多波長の空：パルサーTeV ハロー、非星形成銀河の電波放射、ブラックホール・ジェット)

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Observations of very-high-energy gamma-rays are important in finding powerful particle accelerators in the galaxy and probing their nature. Recent progress in TeV gamma-ray astrophysics has lead to new discoveries. This thesis studies their theoretical implications, focusing on the following four topics:

(1) HAWC observations have identified a new morphological source class, TeV halos, powered by high-energy electrons and positrons that have escaped from the PWN but remain trapped in a larger region where diffusion is slow. Many theoretical properties of TeV halos remain mysterious, but empirical arguments suggest that they are ubiquitous. We theoretically quantify the importance of TeV halos in existing and future observations by HAWC, H.E.S.S., and CTA, by performing population modeling of TeV halos. We find that TeV halos can potentially explain a sizable fraction of TeV gamma-ray sources in the Galaxy. We also find that unresolved halos can make significant contribution to the diffuse TeV gamma-ray emission from the Galactic disk. Further, we show that future observations of TeV halos are useful to constrain the statistical properties of pulsars at birth.

(2) HAWC data also show marginal evidence for the gamma-ray emission around recycled/millisecond pulsars, which would indicate that they efficiently produce cosmic-ray electrons. These electrons can produce synchrotron radiation by interacting with the galactic magnetic field, contributing to the radio luminosity. We show that this emission can dominate the radio luminosities of massive quiescent galaxies. This scenario is in line with recent observations that found a peculiar radio excess in galaxies with high stellar masses and low star-formation rates. We show that MSP-based models provide significantly improved fit to the data over the SNR-only models.We discuss the implications for the radio-FIR correlation, the observation of radio excesses in nearby galaxies, and local electron and positron observations.

(3) HAWC has reported the detection of > 20 TeV gamma-rays from X-ray knots in the jets of the Galactic microquasar SS433. We construct a model of particle acceleration, cooling, and transport in the astrophysical jets to study the physics implication of this detection. Our model can account for the radio, X-ray, and VHE

emission from this object. However, the GeV emission remain unexplained with the knot models, suggesting that it is originated from different regions/mechanisms. We find that the acceleration process should be efficient, which could be realized by diffusive shock acceleration close to the Bohm limit. This suggests that the jets of SS433 can accelerate protons beyond a PeV. Future hard X-ray and MeV gamma-ray observations can critically test our models.

(4) H.E.S.S. recently reported that the very-high-energy gamma-ray emission from Centaurus A is extended along the jet direction beyond a kiloparsec from the core. This kiloparsec-jet has also been intensively studied in X-rays, which has identified two notable features: bright diffuse emission and many compact knots. We use this new observation to constrain the physical conditions of the kiloparsec jet and study the origin of the nonthermal emission. We show that the diffuse jet is weakly magnetized and energetically dominated by thermal particles. We then propose that knots are the sites of both amplified magnetic field and particle (re)acceleration, but the magnetic field energy is sufficiently weak, such that particles in the knots are in the slow cooling regime. We show that the entire kiloparsec-scale diffuse emission could be powered by particles that are accelerated at and escaped from knots.