論文の内容の要旨

Search for High-Energy Gamma Ray Line emission from Dark Matter annihilation in the Galactic Center (銀河中心領域における暗黒物質対消滅からの高エネルギーガンマ線ライン放射の探索)

氏　名　稲　田　知　大

It is widely believed that about 25 % of mass-energy in the universe can be explained by dark matter. Dark matter is expected a new fundamental particle at GeV - TeV energies beyond the standard model of particle physics. Weakly Interacting Massive Particle (WIMP) is one of the most famous candidates for dark matter. WIMP is searched in several ways such as direct detection experiments at detectors in the underground, collider experiments and indirect dark matter searches with cosmic rays. Direct detection experiments and collider experiments have searched for a long time. However, a discovery has not been reported yet. Considering current situations, the next frontier for dark matter search is the TeV-scale. Indirect dark matter searches with gamma rays give us the chance to search for heavy dark matter particles at TeV energies which are difficult to reach with the direct detection technique and collider experiments. We focused on the search for the gamma-ray line emission from dark matter annihilation because it provides a clear signal compared with other astrophysical backgrounds. As an observational target, we chose the Galactic Center of the Milky Way. The Galactic Center of the Milky Way is the most promising target for the dark matter search with gamma rays because it is believed to contain an extremely high density of dark matter.

The MAGIC telescopes located on the Canary island of La Palma, Spain, are sensitive to gamma rays from 50 GeV to 50 TeV and have observed the Galactic Center for 6 years. The Galactic Center is visible at La Palma from zenith angles of 57 degrees, which is the minimum. In observations at large zenith

angles, the collection area for gamma rays at TeV energies increases in proportional to approximately $1/\cos^2\theta$ where θ is the zenith angles. However, compared to the observation at low zenith angles, the Cherenkov light is absorbed more by the atmosphere in the observation at large zenith angles because of the thickness of the atmosphere. Also, The Cherenkov light density on ground becomes dim because the Cherenkov light is spread over a large area. Those effects increase the energy threshold and systematics for energy estimation. We developed an analysis technique optimized for spectral line search and evaluated their systematics. The line emission search from dark matter annihilation was performed with 6 years datasets for the Galactic Center. We could not find a significant excess. Hence, We computed 95 % confidence level (C.L.) upper limits on annihilation cross-section for 45 dark matter masses (from 800 GeV to 50 TeV) with the Einasto profile, assuming that the branching ratio of $\chi\chi \to \gamma\gamma$ channel is 100 %. Most of the obtained limits in this work mark the most constraining in the TeV dark matter masses range (e.g., $1.2 \times 10^{-27}\mathrm{cm}^3\ \mathrm{s}^{-1}$ at ~3 TeV and $2.0 \times 10^{-27}\mathrm{cm}^3\ \mathrm{s}^{-1}$ at ~10 TeV) for the $\chi\chi \to \gamma\gamma$ channel.

We have worked for the Cherenkov Telescope Array (CTA) for future studies, which is the next generation ground-based observatory for gamma-ray astronomy at very-high-energies. CTA will cover a wide energy range, 20 GeV - 300 TeV by three types of telescopes whose diameters are different. CTA will consist of two observatories (one in the north in Spain, the other one in the south in Chile) for full sky coverage. We have developed for optical instruments of the Large-Sized Telescope (CTA-LST). CTA-LST is the largest among the telescopes of CTA, and CTA-LST is designed to cover the lowest energy range. CTA-LST will be built with 4 telescopes for both northern and southern observatories. Now the first CTA-LST has constructed in the same observatory of MAGIC. The shape of the primary mirror of CTA-LST is parabolic, and the primary mirror consists of 198 segmented mirrors. Each segmented mirror has a spherical curvature which has a different focal length. We arranged them to match the curvature on the dish to exploit the best performance of a telescope after 949 mirrors production for four CTA-LSTs. We estimated with ray-trace simulation that our arrangement of mirrors expected about 30 % smaller spot size of the telescope than one layout sample, which the mirror position is randomized. We installed mirrors following our arrangement and measured the spot size of the first CTA-LST. In the end, we confirmed that the measured value is consistent with the expected value.

This thesis has three parts : Overview, Dark Matter Search in the Galactic Center and technical activities for CTA-LST. In the overview part, we introduce the field of high-energy astrophysics with very high-energy gamma rays in Chapter 1. We explain the dark matter paradigm to solve the dark matter quest and how to search candidates in Chapter 2. We describe imaging atmospheric Cherenkov telescopes, MAGIC and CTA from both physical and instrumental points of view in Chapter 3. In the Dark Matter Search in the Galactic Center part, we introduce the indirect dark matter search with gamma-ray and mention the motivation of the line search in Chapter 4. we describe the Galactic Center observation with the MAGIC telescopes and the analysis method optimized for the Galactic Center in Chapter 5 and represent the likelihood analysis dedicated for the line emission search and results and discussions in Chapter 6. In the technical activities for CTA-LST part, we describe the brief introduction to the optics for CTA-LST in Chapter 7. We explain the measurement and production of the segmented mirror of the CTA-LST in Chapter 8. We represent how the telescope was constructed and its commissioning in Chapter 9. In the end, we conclude this thesis and mention the future prospects in Chapter 10. .