論文の内容の要旨

Advancement of Millimeter-wave Polarization Modulator and Millimeter-wave Polarization Oscillation Search for Ultralight Dark Matter

（ミリ波偏光変調器の進展と
ミリ波偏光振動観測による超軽量暗黒物質の探索）

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In this dissertation, we present two primary research products that improve the prospects for the millimeter-wave science. First, we present new polarization modulator using a cryogenic continuously rotating half-wave plate (CHWP) for the cosmic microwave background (CMB) polarization experiment, the small aperture telescopes (SATs) of the Simons Observatory (SO). The SATs of SO will precisely measure the large angular scale CMB power spectrum and search for the signal of the primordial tensor perturbation, which could be driven by the rapid expansion of the early universe called inflation. The CHWP modulator is a powerful tool for the CMB polarization measurements at large angular scale by mitigating the atmospheric $1/f$ noise and the instrumental polarization. Our CHWP modulator is the largest of its kind, and this work advances the methodology for characterization, and introduces techniques for efficient operation. The three CHWP modulators we built and evaluated are being deployed to Chilean observation site and expected to start scientific observations from 2024. This development contributes not only to the SO project, but also to the design of future experiments such as CMB-S4. Second, we describe a search for the ultralight dark matter. The ultralight pseudo-scalar field that couples to photons through the Chern-Simons term, the axion-like particle (ALP), is a candidate for the dark matter and induces an oscillation of polarization angle of linearly polarized light traveling through the ALP background. We searched for the axion-like polarization oscillation of the Crab Nebula observed for the purpose of the polarization angle calibration by the CMB polarization experiment, the POLARBEAR experiment. This work advanced the methodologies for the calibration of polarization angle and the understanding of the systematic errors, and provided the tightest constraints to our knowledge of the polarization oscillation amplitude of the Crab Nebula on a time scale of one hour to one year. A hint of polarization oscillation signal was found on a time scale of about 60 days. The possibility of the residual systematics or the intrinsic variability of the Crab Nebula has been considered, resulting in no clear evidence for either of them. Interpreting this as an ALP signal leads to significant tension with other constraints. Future measurements with more statistics will give more conclusive understanding for it. In summary, this dissertation presents significant advances in the instrumentation, methodology, and science exploitation of the millimeter-wave polarimetry.