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

Exploring the universe before the Hot Big-Bang with the world's largest superconducting sensor array

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Project Information	Project Number : 25H00403 Keywords : Cosmic Microwave Background, Cosmic inflation, Superconducting sensor, Primordial Gravitational wave	Project Period (FY) : 2025-2029

Purpose and Background of the Research

●Outline of the Research

The universe was in an extremely hot and dense state in its early stages, a phase known as the Big Bang. However, what caused this hot Big Bang remains unresolved. A leading explanation is the Inflation Hypothesis, which proposes that space underwent rapid exponential expansion beforehand. While compelling, definitive evidence—primordial gravitational waves (PGWs) from quantum fluctuations in spacetime—remains undetected. PGWs imprint curl-like patterns, known as B-modes, in the polarization of the cosmic microwave background (CMB). The measurement of B-modes is the most promising method for searching for PGWs.

Our research enhances the sensitivity of the Simons Observatory (SO) in Chile through a novel approach. By searching for B-modes within the range predicted by leading inflationary models, we aim to shed light on how the universe began (Fig. 1).

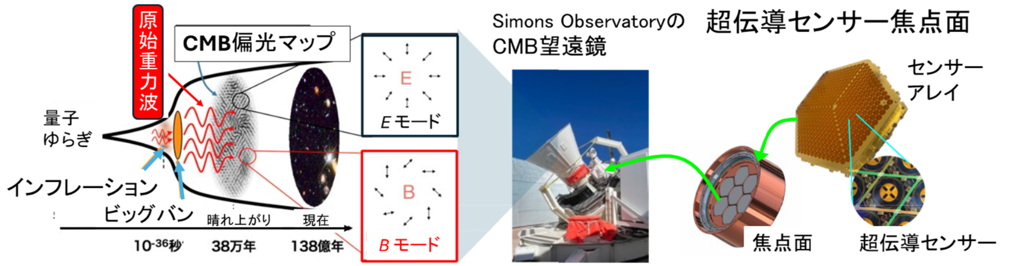

Figure.1 Overview of this research. This study aims to detect PGW through CMB B-mode. Since the expected signal is extremely faint, SO equips with a large array of superconducting TES sensors in order to achieve this groundbreaking discovery.

●Simons Observatory

In this study, CMB observations are conducted at the Simons Observatory (SO), located in Chile's Atacama Desert. SO utilizes two types of telescopes: the Small Aperture Telescope (SAT) and the Large Aperture Telescope (LAT). The SAT is specialized for detecting B-modes. We are actively involved in developing a new SAT (J-SAT) aimed at enhancing sensitivity, enabling the world's most precise search for PGWs.

●Foreground Separation

Detecting PGW requires distinguishing the B-mode signal from foreground emissions. This research utilizes multi-frequency observations at the Simons Observatory, including newly added 220 GHz and 280 GHz bands to separate dust emissions. However, the low-frequency bands (30 GHz and 40 GHz), essential for removing synchrotron emissions, are still under development. Accelerating their deployment is crucial, and this study aims to help achieve that goal.

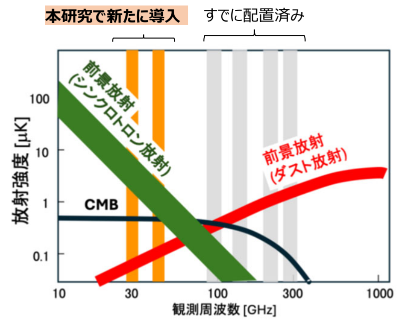

Figure3. CMB and Foreground

●Sky emulator (New idea)

For the TES sensors used in observations to achieve their expected sensitivity, the bias voltage must be adjusted according to the atmospheric thermal radiation environment at the observation site. This study utilizes the "Sky Emulator" (Figure 4) to enable optimization in the laboratory, minimizing the setup period at the observation site. This approach allows for faster acquisition of low-frequency observation data, significantly improving efficiency.

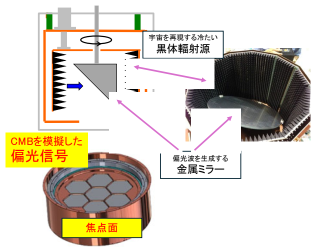

Figure4. Overview of 'sky emulator'

Expected Research Achievements

●Realizing the World's Largest TES Sensor Focal Plane

The world's largest superconducting sensor focal plane provides the most reliable path to achieving unprecedented statistical precision.

In particular, implementing a low-frequency focal plane—crucial for separating foreground emissions—will complement the existing sensor arrays and help ensure the target sensitivity is achieved.

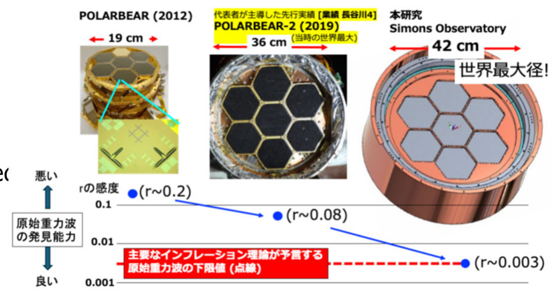

Figure 5. The ability to detect primordial gravitational waves improves with the size of the superconducting sensor focal plane.

●Most Sensitive Search for PGW

With the above approach, we aim to detect primordial gravitational waves down to r ~ 0.003, enabling rigorous testing of major inflation models. A detection would provide key insights into the energy scale of inflation and quantum gravity, while a non-detection would refine future research directions by ruling out leading models.

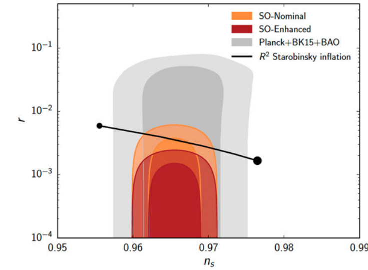

Figure 6. Expected sensitivity for the search for primordial gravitational waves.

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