【Grant-in-Aid for Specially Promoted Research】

Formation Processes of Heavy Elements in the Early Universe Elucidated by Superconducting Nanoelectronics, Large-Scale Numerical Simulations, and Data Science

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Project Information	Project Number : 24H00004	Project Period (FY) : 2024-2028
	Keywords : Line intensity mapping, integrated superconducting spectroscopy, sparse modeling, deep learning, submillimeter-wave	

Purpose and Background of the Research

●Outline of the Research

Understanding the star-forming activity throughout the 13.8 billion-year history of the universe, along with the physical processes that govern it, is crucial for unveiling the origins of heavy elements and materials, which were formed within stars and constitute the world and life. The James Webb Space Telescope (JWST) has now discovered galaxies in the early Universe, mere hundreds of millions of years after the Big Bang, in the visible to mid-infrared wavelengths. Sub/millimeter-wave observations are essential for detecting star formation obscured by solid particles of heavy elements, i.e., 'dust'. There has been significant progress in observing individually detectable bright galaxies using ALMA. However, studying dust-enshrouded star formation in fainter, and thus more numerous galaxies remains a formidable challenge, even with ALMA.

●Purpose: obscured star-formation and heavy element productions via [CII] LIM

We propose to conduct the "line intensity mapping" (LIM) observations targeting the ionized carbon emission [CII] 158μm line. LIM measures the integral amount of energy emitted by the spectral lines of galaxies averaged in the spatial and depth (redshift) directions. Thus one can assess the contributions from faint and numerous galaxies that are difficult to detect individually (Figure 1). We develop the superconducting imaging spectrograph TIFUUN (Figure 2) and data-scientific methods to separate the atmospheric emission (Figure 3) and contaminating foreground lines. We will quantify the dust-obscured star formation and clarify the formation and accumulation of heavy elements in the first 2 billion years of the Universe by detecting the [CII] LIM signals.

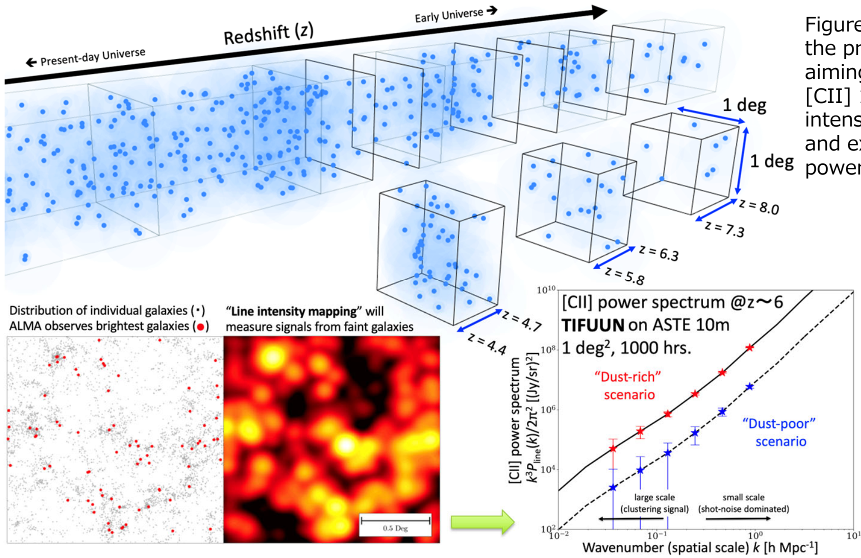

Figure 1. Overview of the proposed study aiming at conducting [CII] 158μm line intensity mapping and expected [CII] power spectra

●Sub/millimeter-wave imaging spectrograph TIFUUN

We have proposed and demonstrated the integrated superconducting spectrometer (ISS) technology by detecting astronomical signals using DESHIMA on ASTE. We will develop the **T**erahertz **I**ntegral **F**ield **U**nits with **U**niversal **N**anotechnology **TIFUUN** based on the success of ISS technology (Figure 2). Eventually it will bring a huge leap (~3 orders of magnitude in the mapping speed) from the existing LIM observations.

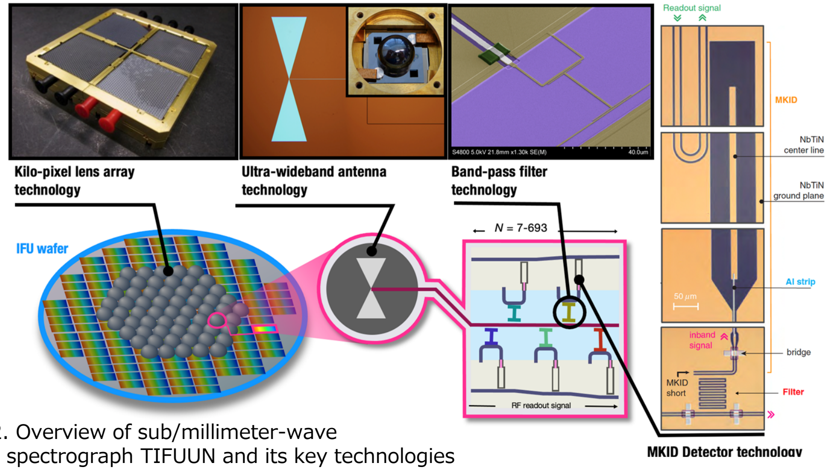

Figure 2. Overview of sub/millimeter-wave imaging spectrograph TIFUUN and its key technologies

●Data-scientific methods for observations and LIM data analysis

It is essential to implement efficient techniques to remove atmospheric emission and contaminating foreground signals by exploiting data-scientific methods. We have successfully developed methods to extract astronomical signals in sub/millimeter-wave position-switching observations (Figure 3) and to separate foreground emission lines from the LIM observations. These will be applied to 3D LIM analysis.

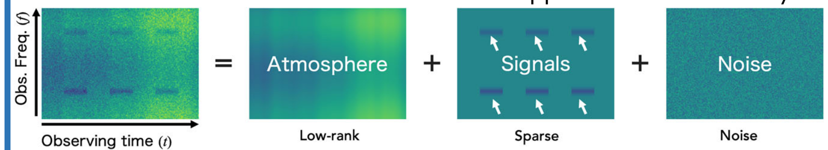

Figure 3. Decomposing astronomical signals and atmospheric emission using the Sparse modeling.

Expected Research Achievements

●5 pillars of this research

(1) Development of TIFUUN, (2) Development of Data-scientific methods for observations and data analysis, (3) Theoretical investigation of sub/millimeter-wave line intensity mapping, (4) Deployment, commissioning, and science operation of TIFUUN on the Atacama Submillimeter Telescope Experiment ASTE, (5) Quantification of obscured star formation and elucidation of heavy element production and accumulation processes by combining LIM and ALMA/JWST observations.

●Expected breakthrough and impact on the public

The combination of the large-format imaging spectrograph TIFUUN and data-scientific approaches to exploit it will drastically accelerate the implementation of sub/millimeter-wave LIM. The insights gained will not be limited to the field of galaxy formation and evolution, but will also lead to new developments in heavy element production, and even in cosmology. Elucidating the origin of carbon, a key element in our body and life, will have a significant impact on the public by stimulating scientific interest.

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