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

Galaxy Formation in the Pre-Reionization Era Explored by Far-Infrared Nebular Emission Lines

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Project Information	Project Number : 22H04939　　Project Period (FY) : 2022-2026 Keywords : Radio astronomy, galaxy formation, cosmic reionization, superconducting receiver

Purpose and Background of the Research

●Outline of the Research

In this study, we investigate when massive galaxies emerge and how common they are in *pre-reionization era* (i.e., the age of the universe less than 600 million years), and what physical properties they have, especially by exploiting mm and submm-wave spectroscopic observations of far-infrared spectral lines. For this sake we develop a novel receiver, FINER, for the Large Millimeter Telescope (LMT) in Mexico, which offers the highest sensitivity in the northern hemisphere. With LMT-FINER and ALMA in the northern and southern hemispheres, respectively, we will unambiguously identify dozens of galaxies that are found in pre-reionization era but remain unexplored, allowing us to learn the mechanism that controls formation of galaxies.

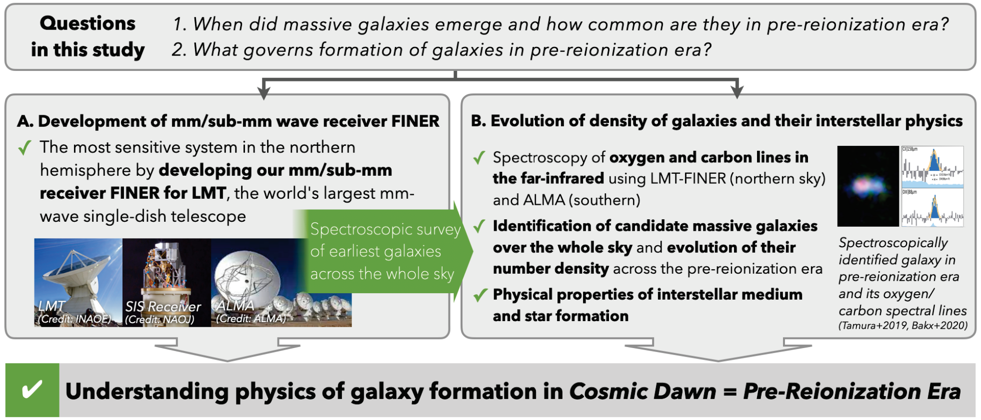

Figure 1. Summary of this research.

●Background and purpose

How and when first stars and galaxies form is one of the most fundamental questions in modern astronomy. The pristine materials in the early universe cooled down 380k years after the Big Bang and became neutral hydrogen gas. When first stars and galaxies are born, however, the hydrogen gas in the intergalactic space is ‘re-ionized’ by ultraviolet photons from the stars. This so-called cosmic reionization is indirect evidence for the birth of the first luminous objects. In recent years, it has been reported that cosmic reionization occurred around 660 million years after the Big Bang, whereas more than 100 galaxy candidates have been found even before the period, meaning that we are likely witnessing the birth of the earliest galaxies in the universe.

In particular, finding *massive* galaxies in the era is difficult but is expected to offer unique information on galaxy formation, because the probability of finding them depends on the cosmic structure formation model. Then, the key questions we are trying to address in this research are when massive galaxies emerge and how common they are in pre-reionization era, as well as what controls growth of them. However, confirming galaxy "candidates" is fairly difficult; in general, identifying an object as a galaxy and determining its physical properties begin with spectroscopy of atomic or molecular spectral lines. But the combination of bright spectral lines and a sensitive instrument that are sufficient for detection of a galaxy even in the furthest universe is very limited.

In this study we aim for a sensitive spectroscopic survey of galaxies in the pre-reionization era using the far-infrared oxygen and carbon nebular lines that are demonstrated to be bright, based on our novel mm and submm-wave receiver, FINER, for Mexico’s Large Millimeter Telescope in addition to existing observatories such as ALMA. We also aim to elucidate their physical properties.

Expected Research Achievements

●Development of millimeter/submillimeter wave receiver FINER

In order to precisely measure faint and narrow emission lines over a wide frequency range, FINER employs a novel superconducting device and ultra-wideband spectrometers. This offers an instantaneous bandwidth 5x wider than ALMA, while achieving the same sensitivity as ALMA. LMT-FINER will provide 40% of ALMA’s light-collecting area, a similar atmospheric transmittance to ALMA, and a 5x wider bandwidth than ALMA. This offers the most sensitive spectral-scanning capability among mm/submm telescopes in the northern hemisphere, allowing us to have the following scientific results.

●Revealing the fundamental processes of galaxy formation

By exploiting the unique capability of LMT-FINER and ALMA, we investigate how common massive galaxies are and how their number density changes over time from 400 to 600 million years after the Big Bang. On top of that we explore galaxies in the untrodden epoch from 250 to 400 million years. This improves the sample size by a factor of 10 of the current sample and thereby provides new insights into the fundamental processes of galaxy formation.

In addition, we reveal the physical properties of their gas and stars using the far-infrared spectral lines and the ultraviolet to optical broadband spectra. They offer the key information on the physical properties of galaxies, such as the age of the galaxies, the conversion rate from gas to stars (star formation rate), the total mass of stars, and the abundance of heavy elements they have. Furthermore, the detailed modeling the physical and chemical processes of the gas constrained by the far-infrared lines will give us the insights into the physical state of the interstellar gas of galaxies. Combined with high-resolution imaging by ALMA and infrared space telescopes, which will be carried out in parallel, it is expected to establish a universal picture of massive galaxies in the pre-cosmic reionization period.

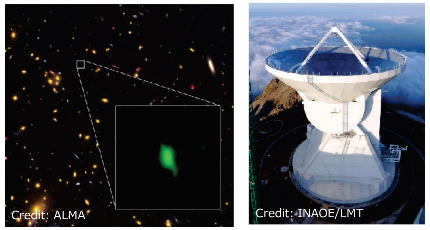

Figure 2. The earliest galaxy identified with ALMA (left) and the Large Millimeter Telescope (LMT) in Mexico (right).

Homepage Address, etc.	PI’s website: https://www.a.phys.nagoya-u.ac.jp FINER project website: https://sites.google.com/view/lmt-finer/