論文の内容の要旨

Spectroscopic Study and TMT/IRIS Instrumentation for Uncovering Galaxy Formation in Gaseous Large-Scale Structures
(ガスの宇宙大規模構造における銀河形成を探るための分光学的研究とTMT/IRISの装置開発)

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We aim to address galaxy formation in gaseous large-scale structures (LSSs) by a spectroscopic study and TMT/IRIS instrumentation.

In the spectroscopic study, we investigate distributions of intergalactic medium (IGM) neutral hydrogen (HI) gas around $z \sim 2$ galaxies in the following three galaxy environments: a blank region (COSMOS), an extreme galaxy overdensity region (BOSS1441), and an extreme quasar overdensity region (EGS). We use large datasets of galaxies and quasars at $z \sim 2$ that are mainly constructed based on the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) and the extended Baryon Oscillation Spectroscopic Survey of the Sloan Digital Sky Survey IV (SDSS-IV/eBOSS), respectively. We probe IGM HI gas distributions at $z \sim 2$ with HI Lyα forest absorptions (HI absorptions) found in spectra of background quasars and galaxies at $z > 2$. These background quasar and galaxy spectra are taken from archival data and our Keck/LRIS spectroscopy. We perform HI tomography that is a powerful technique to reconstruct three-dimensional (3D) HI LSSs based on HI absorptions, and reveal the IGM HI gas distributions at $z \sim 2$ in the (BOSS1441, EGS) with the spectra of background (1 quasar+ 16 galaxies, 43 quasars). In the COSMOS region, we use the HI tomography map of **?**. These (COSMOS, BOSS1441, EGS) HI tomography maps have cosmic volumes of ($30 \times 24 \times 444$, $16 \times 19 \times 131$, $124 \times 136 \times 444$) h^{-3}comoving Mpc^3 (cMpc^3) with spatial resolutions of (2.5, 2.6, 20.0) h^{-1} cMpc at $z = 2.3$.

To study IGM HI-gas distributions around $z \sim 2$ galaxies, we carry out the following two measurements with the three HI tomography maps: spherically averaged HI radial profiles of the galaxies and spatial correlations between the galaxy overdensity and HI absorption excess (HI overdensity). In the COSMOS region, we find that galaxies (galaxy overdensities) reside in volumes with enhanced HI absorptions where none of the eBOSS quasars are found in the cosmic volume of the HI tomography map. This suggests the spatial correlations between HI gas and galaxies. In the BOSS1441 region, contrary to the results in the

COSMOS region, we find that galaxies (galaxy overdensities) are in volumes with HI absorptions reduced to the cosmic mean level. On the other hand, we find possible suppression of HI absorptions around three eBOSS quasars found in the HI tomography map. This suggests that these quasars might have proximity zones where quasar illuminates and photo-ionizes the surrounding HI gas. A similar HI radial profile is obtained for an enormous Lyα nebula (ELAN), MAMMOTH-1 nebula, hosted by an obscured quasar, which implies that the MAMMOTH-1 nebula is probably a photo-ionized hydrogen gas cloud embedded in the cosmic web. In the EGS region, we discover an extreme quasar overdensity, dubbed EGS-QO1. Our HI tomography map reveals that EGS-QO1 is surrounded by an HI underdensity region with weak HI absorptions, and that EGS-QO1 would reside in the part of the HI underdensity. The possible correspondence between EGS-QO1 and the HI underdensity may imply that group of quasars would form a large ionizing bubble and widely photo-ionize the surrounding HI gas. The results of the COSMOS, BOSS1441, and EGS regions might suggest an evolutionary picture that HI gaseous LSSs around galaxies could be photo-ionized by quasars as overdensities of galaxies and quasars evolve and quasars photo-ionize most of the surrounding hydrogen gas.

To verify the IGM ionized hydrogen gas around $z \sim 2$ quasars, we plan near-infrared (NIR) observations of Hα emission from an ELAN at $z \sim 2$, the Slug nebula. We perform pilot observations with Subaru/MOIRCS, and present infeasibility of detecting and resolving the Hα emission from the Slug nebula with 8m-class telescopes. We then estimate the observing plans with NIR instruments for 30m-class telescopes such as InfraRed Imaging Spectrograph (IRIS) on Thirty Meter Telescope (TMT), and find feasibility to study the Hα emission from the intergalactic hydrogen gas clouds of the Slug nebula. We thus prepare the TMT/IRIS observations by contributing to the successive TMT/IRIS instrumentation.

In the TMT/IRIS instrumentation, we present results of our simulations to correct optical distortion of TMT/IRIS. We implement a self-calibration method which extracts the optical distortion by measuring the difference of pinhole positions between dithered images. We investigate the calibration performance with various parameters of pinhole mask, i.e., number of pinholes, dither length, and dither pattern, to characterize our implementation of the self-calibration algorithm. We demonstrate that the algorithm achieves an unprecedented distortion correction accuracy of as low as 3 μarcsec when the dither length is longer than the smallest distortion scale of interest and the pinhole distribution is uniform after dithering is applied. The suggested set of parameters is consistent with the current IRIS design. Our calibration contributes to realizing scientific performance for planned instrument suites on 30m-class telescopes, which will provide a signpost toward our planned TMT/IRIS observations for testing photoionization of HI gaseous LSS.