論文の内容の要旨

Exploring the Frontiers of Low-Mass Galaxy Formation over the Cosmic History Using Large Observational Data

(大規模観測データで探る宇宙史を通した低質量銀河の形成)

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In hierarchical structure formation, low-mass galaxies play a key role as the building blocks of the galaxy assembly. It is therefore important to reveal the physical processes that regulate low-mass galaxy formation. To this end, we investigate stellar mass functions (SMFs), rest-frame far ultra-violet (UV) luminosity functions (LFs), and Lyman-α (Lyα) emission radial profiles and their redshift evolution at $z \sim 0-9$, exploiting large observational data sets over the UV to mid-infrared (MIR) wavelength range. Estimating these three quantities help to understand the galaxy formation processes in a comprehensive way, because the stellar mass $M_\star$, UV magnitude $M_{\rm UV}$, and Lyα emission reflect the completed, ongoing, and future star formation activities, respectively.

First, we estimate SMFs at $z \sim 6-9$ and $z \sim 0$ using optical to MIR data of the *Hubble*+*Spitzer* Space Telescopes and the Sloan Digital Sky Survey (SDSS), respectively. To derive SMFs at $z \sim 6-9$, we use the very deep optical to MIR images of the *Hubble* Frontier Fields (HFF; $\sim 28-29$ and $\sim 25-26$ mag at 5σ in the optical and MIR bands, respectively) and 453 dropout galaxies that are strongly magnified by the foreground galaxy clusters. We investigate the stellar populations of the dropouts to estimate their $M_\star$ by fitting a stellar population synthesis and

photoionization model to the observed photometries. For $z \sim 0$, we use the latest SDSS spectroscopic survey data over the very wide fields (~ 9400 deg^2). We apply the $1/V_{\rm max}$ method to 651202 galaxies at $z = 0.003 - 0.2$ to derive the SMF. We find that the SMFs reach down to $M_\star \sim 10^6 - 10^7\ M_\odot$ both at $z \sim 6-9$ and 0, with the flatter low-mass-end slopes $\alpha_\star$ toward low redshifts (from ~ -1.8 to -1.5). A turnover is identified in the very low-mass end of our $z \sim 0$ SMF ($M_\star^{\rm T} = 6.71^{+0.60}_{-0.42} \times 10^6\ M_\odot$), while no clear turnovers are found at $z \sim 6-9$.

Second, we discuss UV LFs at $z \sim 0-9$. We estimate a UV LF at $z \sim 0$ with the *Galaxy Evolution Explorer* (GALEX) survey data. We choose 67277 galaxies at $z = 0.003 - 0.2$ over the very large area of $> 10^4$ deg^2 from the latest GALEX catalog cross-matched with the SDSS spectroscopic catalog. We derive the UV LF down to $M_{\rm UV} \sim -10$ mag with the $1/V_{\rm max}$ method, finding that the faint-end slope is very flat ($\alpha_{\rm UV} = -1.30 \pm 0.01$). Comparing our UV LF with those at high redshifts taken from the literature, we identify an increasing trend of $\alpha_{\rm UV}$ toward low redshifts. We also find a tentative turnover at $M_{\rm UV}^{\rm T} \sim -11$ mag in our ~ 0 UV LF, while turnovers at $z > 6$ are controversial due to the observational limits and lens model uncertainties.

Third, we probe extended diffuse Lyα emission around Lyα emitters (LAEs) at $z \sim 2-7$. We use the deep (~ 26 mag at 5σ) and large-area (~ 4.5 deg^2) data of the Subaru Telescope/Hyper Suprime-Cam (HSC) Strategic Program (SSP) and the Cosmic HydrOgen Reionization Unveiled with Subaru (CHORUS) project. We apply the intensity mapping technique to the narrow-band (NB) images and 1781 LAEs at $z = 2.2$, 3.3, 5.7, and 6.6, deriving the average Lyα surface brightness (SB$_{{\rm Ly}\alpha}$) radial profiles around the LAEs. By carefully estimating systematics, we detect diffuse Lyα emission ($\sim 10^{-20} - 10^{-19}$ erg s^{-1} cm^{-2} arcsec^{-2}) at $\sim 100 - 1000$ comoving kpc around $z = 3.3$ LAEs at the 4.1σ level and tentatively ($\sim 2\sigma$) at the other redshifts, beyond the virial radius $R_{\rm vir}$ of a dark-matter halo with a mass of $10^{11}\ M_\odot$. We tentatively identify a decreasing trend SB$_{{\rm Ly}\alpha}$ toward low redshifts when we correct SB$_{{\rm Ly}\alpha}$ for the cosmological dimming effect. This result may be due to the decreasing cosmic hydrogen gas density according to the cosmic expansion. Comparisons with theoretical models suggest that extended Lyα emission outside $R_{\rm vir}$ is produced by Lyα photons that are resonantly scattered in the circum- and inter-galactic medium (CGM and IGM, respectively), and/or that are emitted from surrounding dwarf galaxies outside $R_{\rm vir}$.

Based on these results, we discuss the galaxy formation processes. We find that both low-mass ends of the SMFs and faint ends of the UV LFs are steep at high redshifts, which implies that low-mass galaxies are abundant in the early universe. The low-mass- and faint-end slopes become flatter toward low redshifts as galaxies become massive through merging processes. At the lowest mass limits, star formation is strongly suppressed, which appears as turnovers in SMFs and UV LFs. We compare our estimation of $M_\star^{\rm T}$ and $M_{\rm UV}^{\rm T}$ with theoretical predictions, finding that the turnovers can be explained by the atomic gas cooling limit, supernova feedback, and/or photoionization due to the UV background (UVB) radiation. We also find that our $z \sim 0$ SMF is similar to that of the local satellite galaxies. This may suggest that the local satellite galaxies form in the physical process same as the central galaxies.