Roman CCS White Paper

Subaru-Roman Synergetic Galaxy Survey-II: Galaxy clusters and large-scale structures

Roman Core Community Survey:
High Latitude Wide Area Survey

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Subaru-Roman Synergetic Galaxy Survey-I: Galaxy clusters and large-scale structures

Abstract

We propose to expand the on-going survey of LSSs including galaxy proto-clusters with wide-field optical camera HSC and wide-field NIR cameras such as WFCAM and VISTA, to higher redshifts (z>2), to small masse systems (groups and filaments), and to small mass galaxies therein. We will use the deep and wide Roman High Latitude Wide Area Survey. The large survey area of 1,700 deg^2 in 4 NIR bands (F106, F129, F158, F184) and a significant fraction of it in F213, will enable us to trace the LSSs and will provide the 1,000s of galaxy clusters/groups per each redshift interval (Δz=1) out to z~4, by capturing the 4,000A/Balmer break feature. The planned slitless (grism) spectroscopy is also essential to trace star forming emission line galaxies, such as H-alpha, [OIII] and [OII] emitters out to z~3 along the structures. We will be thus able to quantify the history of galaxy formation, evolution, and eventually quenching as a function of time and environment in much greater detail.

1. Introduction:

Growth of large-scale structures (LSSs) and the formation and evolution of galaxies therein, and the interplay of the two are among the key subjects in modern extragalactic astronomy. Subaru Telescope and its unique suit of wide field instruments (eg. Hyper Suprime-Cam; HSC) have been playing key roles in mapping the LSS in the distant Universe and the characterization of global/statistical galaxy formation and evolution as a function of time and environment. The wide-field survey of HSC is conducted at optical wavelength, and thus limiting the redshift range that can be probed with rest-frame optical light to z<1.2. To extend the survey to more distant Universe at higher redshifts (z>1.2), we are currently combining the HSC data with the wide-field near-infrared (NIR) data taken with ground-based 4-m class telescopes such as VISTA and UKIRT, although the depth is limited. Roman will offer a unique, unprecedentedly wide and deep NIR imaging at up to 2.3 μm, providing a stellar-mass selected sample of galaxies and clusters/groups of galaxies out to z~4.

2. Stellar mass selected sample of clusters/groups, and LSSs back to z=4:

Taking the Roman's great advantages of wide field-of-view (0.28 deg^2) and low background at NIR in the space, we aim to map out the cosmic LSSs including clusters/groups back to z=4 using the High Latitude Wide Area Survey. We request to include the Subaru HSC-Deep Survey areas (27 deg^2 in total, consisting of COSMOS, UDS, ELAIS-N1, and DEEP2-3), where deep optical imaging data-set is already available. The combination of Roman and Subaru with a large survey area of *at least* 10-100 deg^2 in 4 NIR bands (F106, F129, F158, F184) and a significant fraction of it in F213, will enable us to trace the LSSs and will provide the 10-100s of galaxy clusters/groups per each redshift interval (Δz=1) out to z~4, by capturing the 4000A/Balmer break feature. The planned slitless (grism) spectroscopy is also essential to trace star-forming emission line galaxies, such as H-alpha, [OIII], and [OII] emitters out to z~3 along the structures. In fact, HSC cluster survey program called HSC^2 has been mapping LSSs and clusters/groups out to z=1.2-1.5 by combining both broad-band filters (tracing red sequence galaxies) and a unique set of narrow-band filters (tracing emission line galaxies or star-forming galaxies). This strategy has been successful in tracing more representative LSSs and clusters/groups with mitigated selection bias (see Figure 1) (e.g., Koyama et al. 2010; Hayashi et al. 2011; Tadaki et al. 2012). We will continue to take this approach and will also utilize Roman's grism spectroscopic survey data, which can capture star-forming galaxies (emission line galaxies) associated to the LSSs on top of the red sequence galaxies.

The 10-100 deg^2 area on the sky, which correspond to 40-400 Roman pointings, will cover a comoving volume of 10^8 Mpc^3 / (Δz=1) and can host ~10 progenitors of rich galaxy clusters like

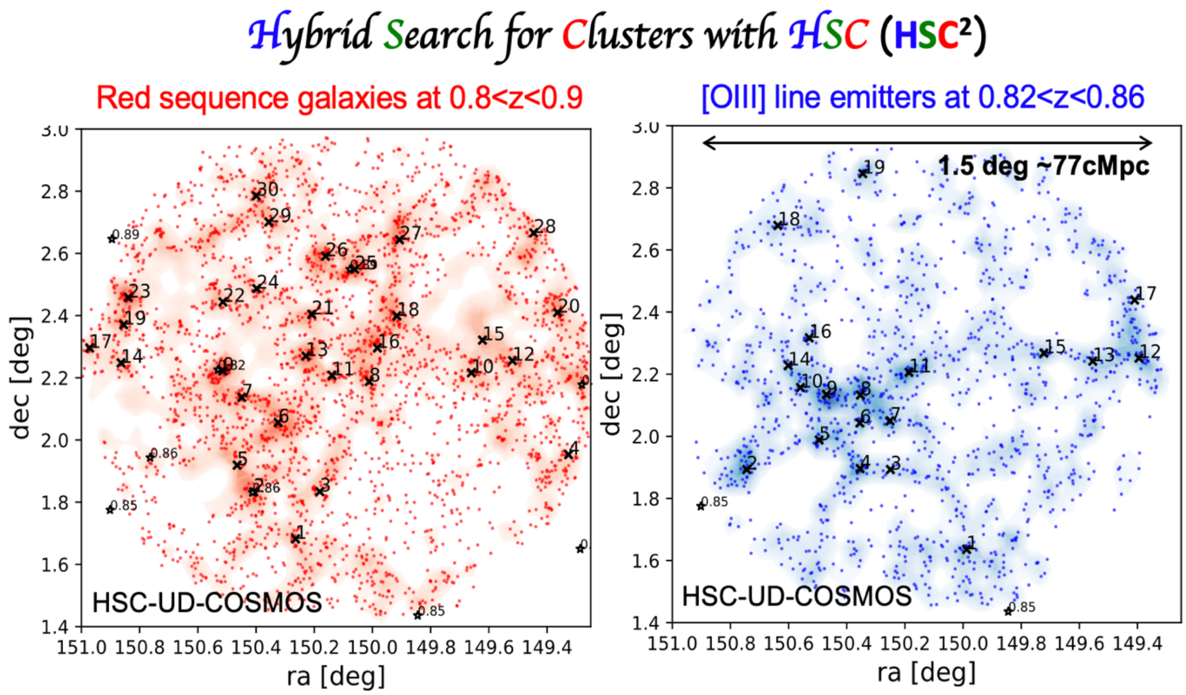

Figure 1: Large-scale structures at z=0.84 over a 1.5 deg^2 field in COSMOS traced by HSC broad-band (left) and narrow-band (right) surveys (HSC^2 program; Yamamoto+, Ishida+ 2023). The former maps red sequence galaxies (quiescent galaxies), while the latter maps [OIII] line emitters (star-forming galaxies). The combination of the two methods can trace the more representative cosmic large-scale structures including galaxy cluster/group candidates as shown by cross marks and numbers by mitigating the sampling bias by stellar populations. We note that some clumps of star-forming galaxies do not have any counterparts in red sequence concentrations, suggesting the existence of star-forming dominated structures, e.g. young cluster/group candidates. This concept can be used for the proposed Roman survey for more distant galaxy clusters and large-scale structures at higher redshifts up to z~4.

Coma (>$10^{14.5}M_{\odot}$) at every redshift interval up to z=3-4. One hour net exposure with F184, for example, can reach 26.9 mag (5σ) which corresponds to 1 (or 5) x 10^9 $M_{\odot}$ in stellar mass at z=4 for const SF (or SSP) models. This is deep enough not just to find galaxy clusters/groups, but to characterize stellar populations in the structures to low mass galaxies. High spatial resolution of 0.14" at F184 can also resolve individual galaxies with ~1 kpc resolution. Grism spectroscopy's line sensitivity of 6 x 10^{-17} ergs/s/cm^2 (1 hour, 5σ) can capture emission line galaxies down to the star formation rates (SFR) of 14 $M_{\odot}$/yr (Hα) at z~2 and 34 $M_{\odot}$/yr ([OIII]) at z~3, respectively, without dust extinction corrections.

Immediate science goals will include the following:

1. Finding galaxy clusters and the surrounding structures back to z~4. We will mitigate the sample selection bias by tracing both red sequence galaxies and star forming galaxies.
2. Mapping star formation activities in and around clusters and within galaxies. We will investigate the spatial propagation of star formation along the LSSs and within individual galaxies.
3. Quantifying starburst, normal star-forming, and quenched fractions. We will quantify the redshift, environment (overdensity, cluster/group mass), and galaxy stellar mass dependences to characterize star formation boosting and quenching histories of galaxies.
4. Quantifying intrinsic scatter in the properties of cluster galaxies even at the same cosmic epoch. We will measure the intrinsic scatter in the evolutionary stages of galaxy clusters/groups, such as red galaxy fraction and morphological mix as a function of cluster mass , and its physical origins.

Once the LSSs and clusters/goups are mapped photometrically, these will provide excellent targets for intensive spectroscopic follow-up observations with PFS on Subaru and for medium-band/narrow-band imaging observations with ULTIMATE on Subaru (see Koyama et al's white paper).

References:

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