Roman CCS White Paper

Subaru-Roman Synergetic Galaxy Survey-III: Cosmology with Large-scale Structure Measurements at z>4 using Lyman-break Galaxies and CMB Lensing

Roman Core Community Survey: *High Latitude Wide Area Survey*

Scientific Categories: *large scale structure of the universe*

Additional scientific keywords: *Cosmology, Cosmological parameters, Dark energy, Gravitational lensing, Large-scale structure of the universe*

Submitting Author:
Name: Hironao Miyatake
Affiliation: Nagoya University
Email: miyatake@kmi.nagoya-u.ac.jp

List of contributing authors (including affiliation and email):
Yuichi Harikane (The University of Tokyo, Institute for Cosmic Ray Research, hari@icrr.u-tokyo.ac.jp),
Atsushi J. Nishizawa (Gifu Shotoku Gakuen University; atsushi.nishizawa@iar.nagoya-u.ac.jp),
Masami Ouchi (NAOJ / University of Tokyo; ouchims@icrr.u-tokyo.ac.jp),
Tomomi Sunayama (Univ. of Arizona; tsunayama@arizona.edu),
Tsutomu T. Takeuchi (Nagoya University; tsutomu.takeuchi.ttt@gmail.com),
Takayuki Tamura (JAXA / ISAS; tamura.takayuki@jaxa.jp)

Abstract:

Measurements of high-redshift ($z>4$) large-scale structure with Lyman break galaxies (LBGs) and CMB lensing open a new window to explore the S_8 tension. The major challenge in this measurement is to quantify the fraction of interlopers from low redshift galaxies. We propose several options to quantify the contamination fraction using Subaru HSC/PFS and Roman data, i.e., combining the HSC survey data with Roman F184 and F213, using Subaru HSC medium-band filters and PFS to obtain the robust redshift of the LBG sample.

Introduction

The ΛCDM cosmological model can phenomenologically explain the accelerating expansion of the Universe. However, to explain the observed cosmic acceleration, it needs to be assumed that 68% of the energy density of the Universe is the cosmological constant Λ, or in general dark energy, which cannot be described by the fundamental theory of physics, i.e., particle physics or general relativity.

In the late 2010s, a smoking gun of the breakdown of the ΛCDM model, the so-called S_8 tension, emerged; the clumpiness of the Universe at present S_8 measured through the large-scale structure (LSS) of the Universe at $z<1$ appears to be lower than S_8 inferred from measurements of the fluctuations in cosmic microwave background (CMB) under the assumption of ΛCDM model (Abdalla et al., 2022).

There are two approaches to tackling the S_8 tension. One is to measure LSS at low redshift with better precision, which can be achieved by established methods such as cosmic shear, galaxy-galaxy lensing, and galaxy-galaxy clustering, and the other is to investigate the time evolution of S_8 with the high-redshift LSS measurements, which can be achieved by combining the clustering and CMB lensing of Lyman-break galaxies (LBGs) selected by the dropout technique (Willson & White, 2019). Miyatake et al. (2022) demonstrated the first measurement of CMB lensing signal around LBGs at z~4 and cosmological constraints combined with the LBG clustering signal (Harikane et al., 2022), using the Subaru Hyper Suprime-Cam (HSC) survey wide-layer data and the Planck lens map. In this paper, we explore possible extensions to obtain precise S_8 constraints at high redshift through the synergies between Roman and Subaru.

Motivation: Reducing and Quantifying Contamination Fraction

The challenge in the LBG selection with the dropout-technique lies in removing and quantifying the contamination by interlopers. A majority of interlopers is due to the misidentification of 4000Å/Balmer break as Lyman break. For example, g-dropouts, which provide LBGs at z~4, have contaminations from galaxies at z~0.5. Ono et al. (2018) showed that the contamination fraction of the g-dropouts selected from the HSC Wide Layer is about 20%, whereas that of the Deep Layer is less than 10%. Regardless of depth, reducing and quantifying the contamination fraction is essential to making the high-redshift LSS measurements precision cosmology.

There are several approaches to reducing and quantifying the contamination fraction; using near-infrared bands to capture the Balmar break to make sure we detect both the Lyman and Balmer break for a given object, using medium-band filters to distinguish the Lyman break and Balmar break (Nishizawa et al., 2023), carrying out spectroscopic follow-up. In the following section, we will describe possible cases of Subaru-Roman synergetic observations to enable these studies.

Subaru-Roman Synergetic Observations

Subaru g-band + Roman F184 dropouts to obtain a z~4 galaxy sample

The Lymam break of z~4 galaxies falls between the g-band and r-band of Subaru HSC, whereas the Balmer break between F184 and F213. Thus, by combining HSC and Roman data, we can obtain a sample without interlopers. The wide layer of Subaru HSC survey covers about 1,100 deg^2 of the sky with the limiting magnitude of 26.5 for g- and r-band (5σ, point source). To capture the Balmer break with Roman, we need a similar depth, about 10 minutes (1 hour) integration for F184 (F213). Assuming 100 deg^2 observations to derive the contamination fraction, we need about 430 hours (18 days) of observations.

Quantifying contamination fraction with Subaru HSC medium-band filters and Subaru PFS

We plan to fabricate medium-band filters ($\Delta\lambda$~400 Å) for Subaru HSC (Nishizawa et al., 2023). According to simulation studies by Nishizawa et al. (2023), medium-band filters have the potential to distinguish the Lyman break and the Balmer break. For faint LBGs, we can quantify the contamination fraction by a deep HSC medium-band survey. The primary target of the HSC medium-band survey would be HSC Deep Fields, i.e., approximately 6 deg^2 fields, each of which is centered at COSMOS (150.2, +2.5), XMM-LSS (35.5, -4.7), DEEP2/3 (352, -0.2), and ELAIS-N1 (243, +55).

We plan to conduct PFS follow-up observations for a subsample of LBGs within the HSC Deep Fields, enabling us to obtain the most robust contamination fraction. However, even with PFS, we can obtain a continuum to the bright end, e.g., g~24. Combining with medium-band filters will maximize the number of galaxies used for cosmology analysis.

Using the HSC medium-band and PFS data, we should be able to estimate the robust contamination fraction for LBGs selected by Roman and/or Subaru HSC Wide Layer data.

Summary

Measurement of high-z LSS with LBGs and CMB lensing is one of the directions to investigate the S_8 tension. To achieve precision cosmology, it is important to quantify the contamination fraction in an LBG sample. In this paper, we have discussed several options to quantify the contamination fraction using Subaru data; combining F184 and F213 with the Subaru HSC Wide Layer data and using the HSC medium-band filters (PFS) to estimate the contamination fraction for faint (bright) LBGs. Subaru-Roman synergetic observations to estimate the contamination fraction are not limited to the options outlined in this paper. We will explore other options and are open to any other ideas.

References

Abdalla et al., 2022, JHEAp, 34, 49
Buchs et al., 2019, MNRAS, 489, 820-841
Harikane et al., 2022, ApJS, 259, 20
Miyatake et al., 2022, PRL, 129, 061301
Nishizawa et al., 2023, Roman CCS white paper
Ono et al., 2018, PASJ, 70, S10
Wilson M. J., White M., 2019, JCAP, 2019, 015