Roman CCS White Paper

Obscured star formation and supermassive black hole growth histories studying with the Roman and infrared all-sky surveys

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

Scientific Categories: *galaxies; Large Scale Structure of the Universe*

Additional scientific keywords: *galaxies; Galaxy evolution, Large Scale Structure of the Universe: Galaxy clusters*

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Abstract: Many galaxy clusters/protoclusters at $1 < z < 3$ will be discovered by the deep, wide, and uniform survey of galaxies by the Roman Space Telescope. According to the deep sub-mm observations of protoclusters, there are likely enormous dusty starbursts and active galactic nuclei in protoclusters. We present a science case for studying the dusty star formation and supermassive black hole growth of galaxy clusters/ protoclusters selected with the Roman High Latitude Wide Area Survey using the mid to far-infrared all-sky surveys in archives.

1. Introduction

Overdense regions of galaxies at high redshift or protoclusters are plausible progenitors of clusters of galaxies and inform us how the environmental dependence of galaxies today has been formed. Protoclusters are generally found as the overdense regions of galaxies selected in the optical or near-infrared (NIR). On the other hand, significant overdensities of dusty star-forming galaxies in protoclusters have been reported through the observations at sub-mm (e.g., Tamura et al. 2009; Dannebauer et al. 2014). Therefore, to understand the star formation histories of clusters of galaxies, we need to constrain the dusty star formation in protoclusters. Furthermore, supermassive black holes (SMBHs) are thought to grow in dusty starburst galaxies. To characterize such heavily obscured populations in protoclusters, we need to constrain the luminosities and spectral energy distributions (SED) of them at mid to far-infrared that cannot be accessed from the ground. A statistical study of protoclusters (number >>10) is also needed to constrain their average evolution. However, deep and wide surveys are needed where the expected surface densities of progenitors of Coma-like clusters is Npcl ~ 1 /deg2 / Δz=1 at z=2-4 (Chiang et al. 2013). Protoclusters are thought to be non-vilialized, filamentary structures. The geometry of protoclusters and where starbursts and SMBH growths preferentially occur are also important to understand how the environmental dependence of galaxies has been developed.

2. Proposed study

The Wide Field Instrument (WFI) of the Roman Space Telescope has the capability to survey and confirm galaxy clusters/protoclusters at cosmic noon ($1<z<3$) quite effectively. Our scientific goal is to constrain the average star formation and SMBH growth histories in various environments by using these protoclusters selected with the Roman and the infrared all-sky surveys in archives.
The Planck has a point source sensitivity corresponding to star formation rate (SFR) ~ 10000 Msun/yr at z ~ 4 and a beam size ~ 5 arcmin at 350 - 850 um. The spatial size of the core of the protoclusters is a few arcmin. Thus, they are regarded as point or marginally-resolved sources on the Planck images. In Kubo et al. (2019), we performed an image stacking analysis of the WISE, IRAS, AKARI, Herschel, and Planck images of ~ 200 candidate protoclusters at z ~ 4 found with the Hyper Suprime-Cam on Subaru Telescope. We successfully constrained their average of the total infrared SED and found that two third of the whole star formation can come from dusty starburst galaxies. We will perform a similar stacking analysis for (candidate) protoclusters selected with the Roman High Latitude Wide Area Survey. Such a combination of the large catalog of clusters/protoclusters and infrared all-sky surveys in the archives is the only channel to explore the environmental dependence of obscured star formation and SMBH growth statistically in the era of the Roman.

3. Requirements

To achieve our science goal, a large catalog of clusters/protoclusters at $1 < z < 3$, with robust measurements of the redshifts and halo masses ideally, is required. We will also perform a stacking analysis for protoclusters aligning the major axis of the structure to test whether star formation and SMBH growth preferentially occur along the filamentary structures.

According to the cosmological numerical simulations, the peak of the total SFR of Coma progenitors is a few 1000 Msun/yr at z = 2 – 4 (Chiang et al. 2017; Yajima et al. 2022). Thus once

~ 100 protocluster candidates are discovered, the infrared emission will be easily detected by a stacking analysis of the Planck images. From the test stacking analysis for luminous radio galaxies at 1 < z < 3 where N ~ 200 / Δz = 0.5 (Kubo et al. in prep; Figure 1), which are thought to be hosted by the most massive halos at those redshifts, significant emission at ~ 12 um of WISE likely due to the excess Active galactic nuclei (AGN) emission around radio galaxies were observed.

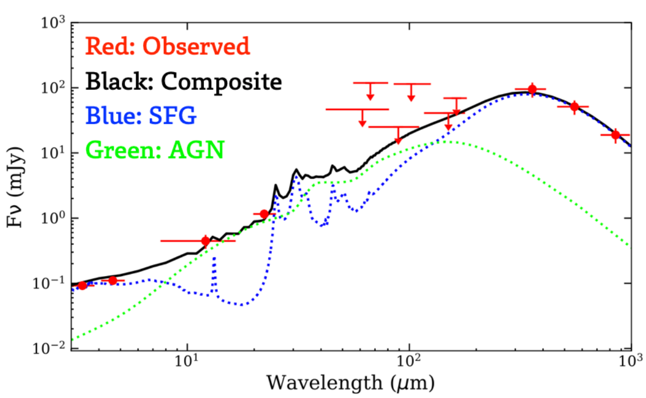
To show the distribution of dusty starbursts and AGNs along the large-scale structures, by performing stacking analysis for protoclusters aligned with the major axis, we need to detect the infrared emission from the outskirt of the structure. Several SMGs with SFR of 500 - 1000 Msun/yr for each are possibly in a filamentary structure extended to 5 - 10 arcmin from the core of protoclusters (Tamura et al. 2009; Dannebauer et al. 2014). The structures with ~ 300 Msun/yr at z < 3 will be detected by a stacking analysis of the 1000 Planck images.

Field of view and regard: >1000 deg^2 survey to obtain ~ 1000 Coma progenitors at z = 2 - 3 (Chiang et al. 2013). Follow-up observations of several protoclusters selected with the Roman are also important to understand the origins of the dust emission. Especially the access to Subaru, which (will) has the wide field spectrographs/imagers with unique narrow and medium band filters like PFS, HSC, and ULTIMATE, is beneficial.

Filter or spectral coverage: F106 to F184 and full spectral coverage of the Roman are critical. If F213 is added, Balmer break galaxies at z ~ 4 can be surveyed.

Depth of observations: The sensitivity of Roman at 1 hr (F184 = 25.2 mag, line sensitivity ~ 1E-16 erg/s/cm^2 at 5 σ) is enough to survey and confirm protoclusters effectively. But only a small fraction of the galaxies in a protocluster will be confirmed at z ~ 2.7 by detecting [O III] at this depth (Kubo et al. 2015). To characterize the star formation and AGN activities in a protocluster, our technique or deeper (not realistic) Roman survey or follow-up observations are required.

We request to include a 100 deg^2 survey with F213 (1 hr ~ 25.2 mag at 5σ, 0.5 hr per pointing is accepted, but ≧100 deg^2 survey area is critical) in the HSC-SSP or LSST survey fields to select ~ 100 protoclusters, enough to constrain the mid to far infrared emission by a stacking analysis, robustly by detecting both Balmer and Lyman breaks shifted at z ~ 4.



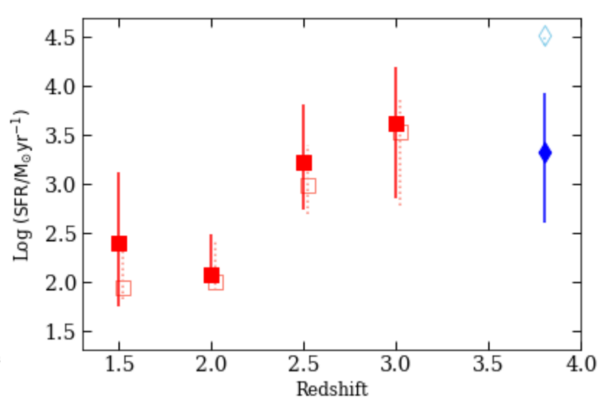


Figure 1 (left) The average of the total mid to far infrared emission of a luminous radio galaxy at spectroscopic redshift z ~ 3 obtained by stacking analyses of the infrared archival data. (Right) The total SFR for a luminous radio galaxy at z = 1.5 – 3 (red) and z ~ 4 candidate protoclusters (blue) (filled: AGN is subtracted, open: AGN is not subtracted) (Kubo et al. 2019 & in prep).

References:

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