# Roman CCS White Paper

# Studying the Cosmic Dawn at z>10 with Roman

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

**Scientific Categories:** *galaxies;*

**Additional scientific keywords:** *Galaxy evolution; Galaxy formation; High-redshift galaxies*

**Submitting Author:**
Name: Yuichi Harikane
Affiliation: The University of Tokyo, Institute for Cosmic Ray Research
Email: hari@icrr.u-tokyo.ac.jp

**List of contributing authors**:
Masami Ouchi (NAOJ / U. Tokyo, ouchims@icrr.u-tokyo.ac.jp)
Yoshiki Matsuoka (Ehime University, yk.matsuoka@cosmos.ehime-u.ac.jp)
Takashi Moriya (NAOJ, takashi.moriya@nao.ac.jp)
L. Y. Aaron Yung (NASA Goddard, aaron.yung@nasa.gov)

---

## Abstract

Recent JWST observations have found many galaxies at z>10 whose number density is surprisingly higher than theoretical model predictions, suggesting a possibility that the physics in the early galaxy/star formation is fundamentally different from that in the lower redshift universe. However, due to the small field-of-view of JWST/NIRCam, the number of such high redshift galaxies is limited, especially for bright sources, which prevents us to conduct statistical studies. Here, **we propose to include F129, F158, F184, and F213 deep imaging observations in the Roman surveys**. Implementing the longer wavelength imaging will provide a large sample of bright galaxies at z=12-16, allowing us to investigate formations of massive galaxies, first AGNs, and Pop-III stars in the early universe with unprecedentedly large survey volumes that JWST/NIRCam cannot reach. Thanks to their brightness, we can not only conduct statistical studies (e.g., UV luminosity function, cosmic SFR density), but also investigate detailed properties (e.g., chemical properties, dynamics, stellar populations) by spectroscopically following up these galaxies using JWST/NIRSpec, MIRI, and ALMA. By including these observations, we can efficiently add valuable science cases for early galaxy formation in the Roman surveys.

---

# Studying the Cosmic Dawn at z>10 with Roman

(Harikane et al.)

## 1. Introduction:

Understanding the galaxy formation in the early universe is one of the frontiers of modern astronomy. Recent James Webb Space Telescope (JWST) observations have found many galaxies at the redshifts of z>10 thanks to their excellent sensitivity in the infrared wavelength (e.g., Naidu et al. 2022, Castellano et al. 2022, Finkelstein et al. 2022, Donnan et al. 2023, Harikane et al. 2023a, Robertson et al. 2023), including some spectroscopically-confirmed sources up to z=13.20 (**Figure 1**, e.g., Curtis-Lake et al. 2023, Arrabal Haro et al. 2023ab, Harikane et al. 2023b). These studies report that the number densities of such z>10 galaxies, especially bright ones, are surprisingly higher than theoretical model predictions, suggesting a tension between JWST observations and model predictions (**Figure 2**).

Among the galaxies spectroscopically confirmed with JWST, a luminous galaxy at z=10.60, GN-z11, is remarkable in many aspects. GN-z11 was originally identified in the Hubble Space Telescope (HST) observations and spectroscopically confirmed with HST grism and JWST NIRSpec spectroscopy (**Figure 3**; Oesch et al. 2016, Bunker et al. 2023). Interestingly, the NIRSpec spectrum of GN-z11 shows unusually strong nitrogen emission lines, suggesting a super-solar N/O abundance ratio that cannot be explained by normal models (e.g., Cameron et al. 2023), AGN features with a low-mass black hole of 10^6 Msun (Maiolino et al. 2023a), and possible Population III signatures in its halo (Maiolino et al. 2023b). However, as the sole luminous example beyond z>10, GN-z11 may be atypical.

These recent observations suggest that the physics of bright galaxy formation at z>10 may be fundamentally different from that at z<10. However, due to the small field-of-view (FoV) of HST and JWST, the number of such bright z>10 galaxies is limited, which prevents us to conduct statistical studies. We clearly need wider-area deep imaging observations in the near-infrared, like with Roman.

## 2. Examples of Proposed Observations and Possible Outcomes:

To construct a large sample of bright galaxies at z>10, **we propose to include F129, F158, F184, and F213 deep imaging observations** in the Roman High Latitude Time Domain and High Latitude Wide Area Surveys. By implementing these longer wavelength observations, we can select a large number of bright galaxies at z>10, including N>100 GN-z11-like galaxies, which cannot be obtained with JWST whose FoV is small (see **Figure 4**). The galaxies will be selected with the F129-dropout (z~11), F158-dropout (z~13), and F184-dropout (z~15) selections. Table 1 summarizes examples of proposed observations and the expected numbers of z>10 galaxies. By including these observations whose total observing time is less than 10% of the entire survey, we can efficiently add valuable science cases for early galaxy formation, as discussed in the next section.

**Table 1**: Examples of the proposed observations (area and depth) and expected numbers of galaxies detected in each survey.

| Survey | Area (deg2) | F129 (mag) | F158 (mag) | F184 (mag) | F213 (mag) | N(z~11) | N(z~13) | N(z~15) |
|---|---|---|---|---|---|---|---|---|
| Time Domain | 19.0 | 28.0 | 28.0 | 27.5 | 27.2 | 900-2000 | 60-700 | 1-200 |
| Wide Area | 1700 | 26.7 | 26.0 | 25.8 | 25.5 | 400-14000 | 1-6000 | 0-3000 |

The depths are 5sigma limiting magnitudes for a point source. The survey parameters for the Time Domain Survey are based on the 25% spectroscopic plan in a white paper by the Roman Supernova Science Investigation Teams (Rose et al. 2021).

## 3. Possible Scientific Outcomes:

The large sample of z>10 bright galaxies identified with Roman will allow us to conduct many studies that will answer pressing questions in early galaxy formation.

**Bright End of the Luminosity Function:** We will find many more GN-z11-like bright galaxies at z>10, and can precisely measure the number density of such bright galaxies with unprecedentedly large survey volumes that JWST/NIRCam cannot reach. This allows us to statistically discuss whether the bright end of the UV luminosity function is in tension with the theoretical model predictions, important to understand efficiencies of star formation and feedback in bright galaxies at z>10.

**Physical Properties of Bright z>10 Galaxies:** Thanks to their brightness, we can easily conduct spectroscopic follow-ups. Spectroscopy with JWST/NIRSpec, MIRI, and ALMA will allow us to detect emission lines and to investigate detailed physical properties (e.g., chemical properties including the N/O ratio, dynamics, AGN, activity, stellar populations including Pop-III) of these bright galaxies at z>10. These observations can answer the question that whether GN-z11 is atypical or not.

**Massive Galaxies:** The bright galaxies found in Roman observations are expected to be one of the most massive galaxies at z>10. Recent JWST observations have posed a possibility that such most massive galaxies in the early universe may be in tension with the framework of LCDM cosmology (Labbe et al. 2023). The large sample of bright z>10  galaxies identified with Roman allows us to test whether such massive galaxies violate the LCDM cosmology or not.

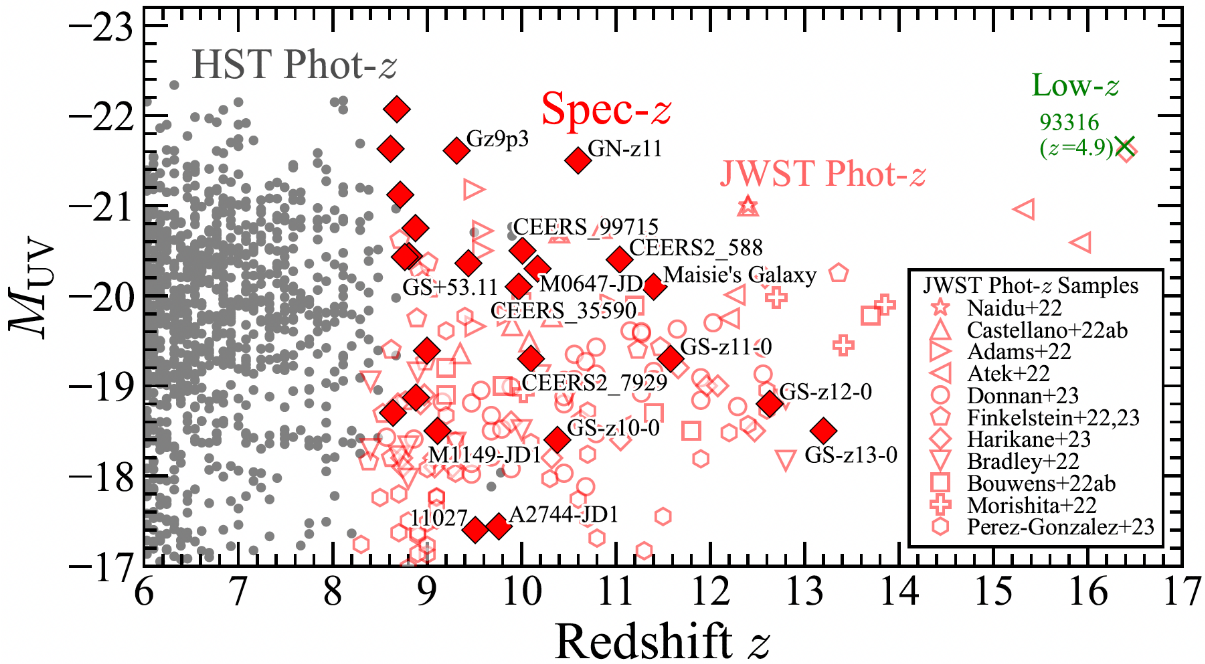


**Figure 1:** UV magnitude as a function of the redshift for galaxies at 6<z<17 taken from Harikane et al. (2023b). JWST has identified many galaxies at z>10 and some of them are spectroscopically confirmed. However, the number of bright galaxies (e.g., $M_{UV}$<-21 mag) is limited due to the small FoV of JWST/NIRCam.

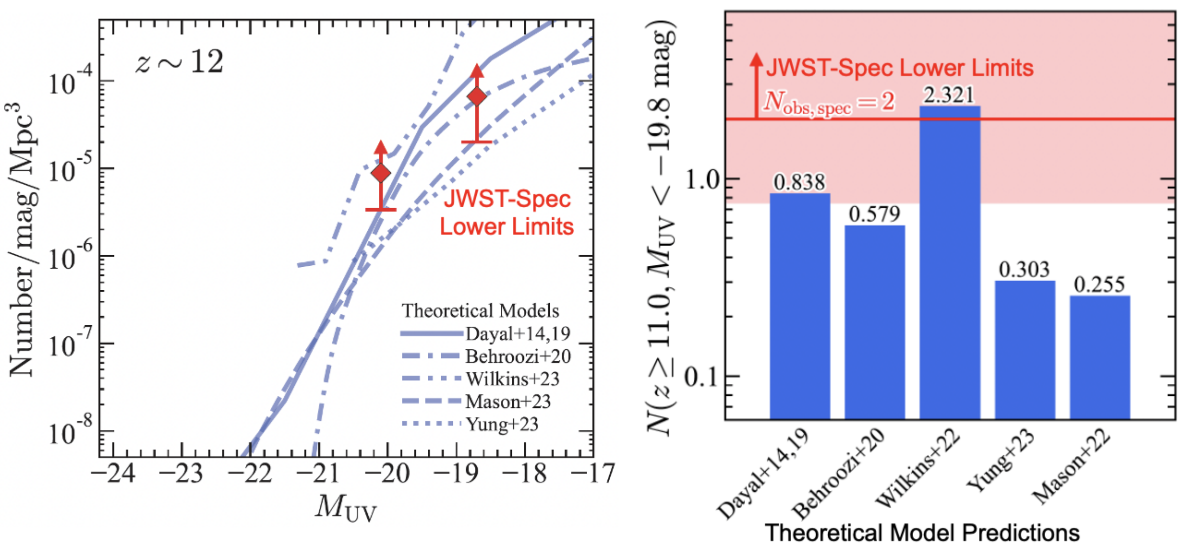


**Figure 2**: Left:) Constraints on the lower limits of the number density of galaxies at z~12 based on spectroscopic datasets (the red diamonds), taken from Harikane et al. (2023b). The lower limit at the brighter bin is higher than some model predictions (the blue curves). Right:) Number of bright galaxies at z>11.0 with Muv<-19.8 mag, taken from Harikane et al. (2023b). The red line (N=2) is the JWST spectroscopic constraint on the lower limit. The blue histograms are model predictions.

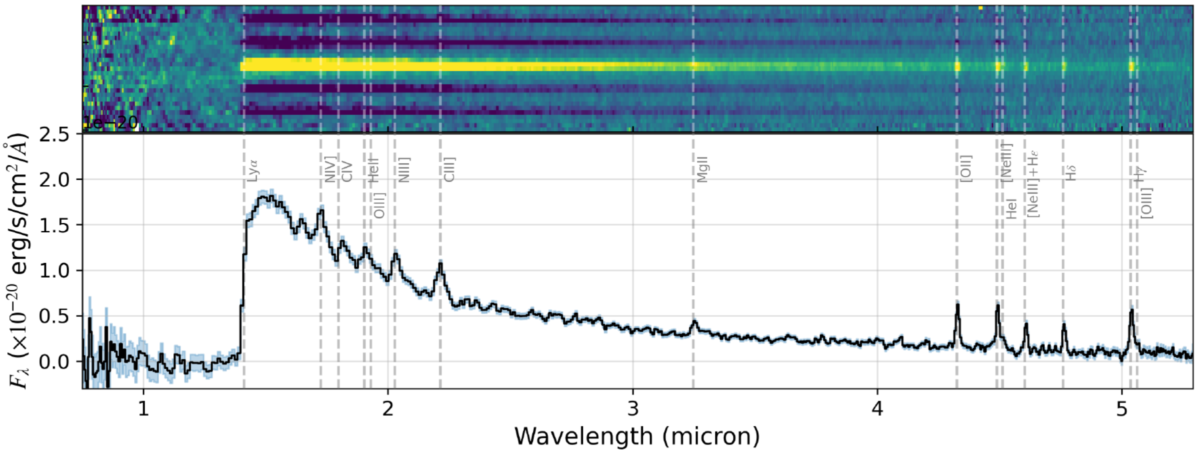


**Figure 3**: JWST/NIRSpec spectrum of GN-z11 at z=10.60 taken from Bunker et al. (2023). Nebular emission lines including NIV] and NIII] are clearly detected, indicating an unusually high N/O abundance ratio and AGN activity.

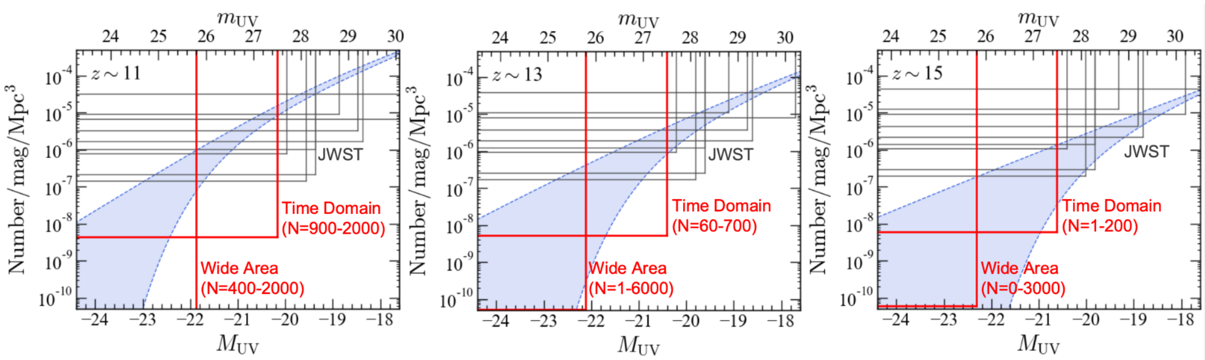


**Figure 4**: UV luminosity functions for F129-dropouts (z~11), F158-dropouts (z~13), and F184-dropouts (z~15). The blue-shaded region is the observational constraint of the UV luminosity function at each redshift, and its upper and lower limits are the double power-law and Schechter functions, respectively, interpolated and extrapolated using the results at z~9-12 in Harikane et al. (2023a). The gray lines show the survey parameters of JWST cycle 1 programs, and the red lines are those of the Roman observations proposed here. Thanks to its wide FoV, Roman can search bright galaxies in an unprecedently large cosmic volume, which is complementary to JWST surveys that are deep but in small volumes. See also Harikane et al. (2022).

**References:**


Arrabal Haro et al. 2023a, arXiv:2303.15431
Arrabal Haro et al. 2023b, arXiv:2304.05378
Bunker et al. 2023, arXiv:2302.07256
Castellano et al. 2022, ApJL, 938, L15
Cameron et al. 2023, arXiv:2302.10142
Curtis-Lake et al. 2023, Nature Astronomy, 7, 622
Donnan et al. 2022, MNRAS, 518, 6011
Finkelstein et al. 2022, ApJL, 940, L55
Harikane et al. 2022, ApJ, 929, 1
Harikane et al. 2023a, ApJS, 265, 5
Harikane et al. 2023b, arXiv:2304.06658
Labbe et al. 2023, Nature, 616, 266
Maiolino et al. 2023a, arXiv:2305.12492

Maiolino et al. 2023b, arXiv:2306.00953
Naidu et al. 2022, ApJL, 940, L14
Oesch et al. 2016, ApJ, 819, 129
Robertson et al. 2023, Nature Astronomy, 7, 611
Rose et al. 2021, arXiv:2111.03081