Probing Star-Forming Regions in the High-Redshift Galaxy SPT0615-JD with JWST

Scientific Category: High-redshift Galaxies and the Distant Universe
Scientific Keywords: Gravitational lensing, High-redshift galaxies
Instruments: NIRSPEC, NIRCAM
Proposal Size: Small
Exclusive Access Period: 0 months (less than default of 12 months)

Allocation Information (in hours):
Science Time: 16.9
Charged Time: 22.6

Abstract

SPT0615-JD (also known as the Cosmic Gems Arc) at z10 is one of the most highly magnified early galaxies ever discovered by gravitational lensing. Recent JWST NIRCam imaging has identified star formation rates in clumps within gravitationally lensed arcs, such as the MACS0308-zD1, providing an unprecedented opportunity to study the formation and assembly of stellar populations in the very early universe.

We propose targeted JWST observations combining deep NIRCam imaging with NIRSpec MSA spectroscopy to fully characterize these star-forming regions and their role in early galaxy formation. NIRCam's high-resolution, multi-filter coverage from rest-UV to rest-optical wavelengths will measure each region's luminosity, size, stellar mass, dust attenuation, and stellar population age, providing essential data to determine their star formation properties. NIRSpec's low-resolution prism mode will capture key emission lines to confirm the galaxy's redshift, reveal metallicities, ionizing photon production rates. Together, these data will refine our understanding of star formation in early galaxies and their assembly processes.

We waive exclusive access to all data obtained from this program to benefit the community.

Target Summary:

Target	RA	Dec
SPT0615-JD-NIRCam	06 15 55.0450	-57 46 19.90
SPT0615-JD-MSA	06 15 55.0450	-57 46 19.90

Observing Summary:

Target	Observing Template	Flags	Allocation *
SPT0615-JD-NIRCam	NIRCam Imaging *F444W, F090W, F410M, F115W, F356W, F150W, F277W, F200W*		42,096 / 55,216
SPT0615-JD-MSA	NIRSpec MultiObject Spectroscopy *CLEAR*	*NOPAR*	18,555 / 25,993

* Science duration / charged duration (sec)

Total Prime Science Time in Hours:	16.9
Total Charged Time in Hours:	22.6

Observing Description

We will employ a combined imaging and spectroscopic approach using JWST's NIRCam and NIRSpec MSA on SPT0615-JD to link small-scale star formation in individual clusters to the larger process of galaxy assembly at z10. Our plan includes:

NIRCam Imaging:

1) Filters and Exposure: Acquire deep multi-filter imaging (11.7 science time hours total) using NIRCam bands of short filters (i.e., F090W, F115W, F150W, and F200W) and long filters (i.e., F277W, F356W, F410W, and F440W).

2) Objectives: These filters will bracket the Lyman break and provide coverage from rest-UV through rest-optical wavelengths, allowing us to map the continuum and identify sub-parsec-scale star clusters.

3) Techniques: Implement multiple dithered exposures to enhance image quality, improve spatial resolution, and mitigate detector artifacts. This will enable precise measurements of each cluster's luminosity, size, color, stellar mass, dust attenuation, and stellar population age.

NIRSpec MSA Spectroscopy:

1) Configuration: Design NIRSpec MSA slitlets based on the pre-imaging catalogs from NIRCam to target multiple star-forming clumps and candidate star clusters along the gravitationally lensed arc.

2) Mode and Exposure: Utilize the low-resolution PRISM mode for comprehensive wavelength coverage, capturing key emission lines from Ly and other UV metal lines to rest-optical transitions. Allocate 5.15 science time hours of spectroscopy, divided into several dithered pointings to maximize spatial coverage and reduce systematic errors.

By integrating high-resolution NIRCam imaging with targeted NIRSpec spectroscopy, these observations will provide a detailed characterization of star-forming clumps within SPT0615-JD. This will illuminate how these small-scale star-forming units contribute to the overall mass assembly and star formation history of the galaxy, offering critical insights into the processes driving early galaxy formation at z10.

Investigators:

Investigators and Team Expertise are included in this preview for your team to review. These will not appear in the version of the proposal given to the TAC, to allow for a dual anonymous review.

Role	Investigator	Institution	Country
PI &	Ferdinand Ferdinand	University of Illinois Urbana-Champaign	USA/IL

Number of investigators: 1
& Contacts: 1

Team Expertise:

Ferdinand is an undergraduate student at the University of Illinois Urbana-Champaign whose ambitions is to uncover the properties of high-redshift galaxies.

Scientific Justification

1. Extending the Cosmic Star-Formation History to $z \sim 10$

Understanding the emergence of the first stars and galaxies during the epoch of reionization is fundamental to cosmology. Current observations suggest the history of cosmic star formation is only consistent up to $z = 8$. However, a robust census above it has yet to be identified [1]. Investigating star formation at redshifts $z > 8$ is crucial for comprehending the early universe's evolution, as stars are the building blocks of galaxies.

SPT0615-JD, a gravitationally lensed galaxy at $z \sim 10$, offers a unique opportunity to study star formation during this early epoch. This galaxy enables us to examine whether star formation and the formation of star-forming regions were already underway at $z \sim 10$, thereby extending the observational frontier of cosmic star-formation history.

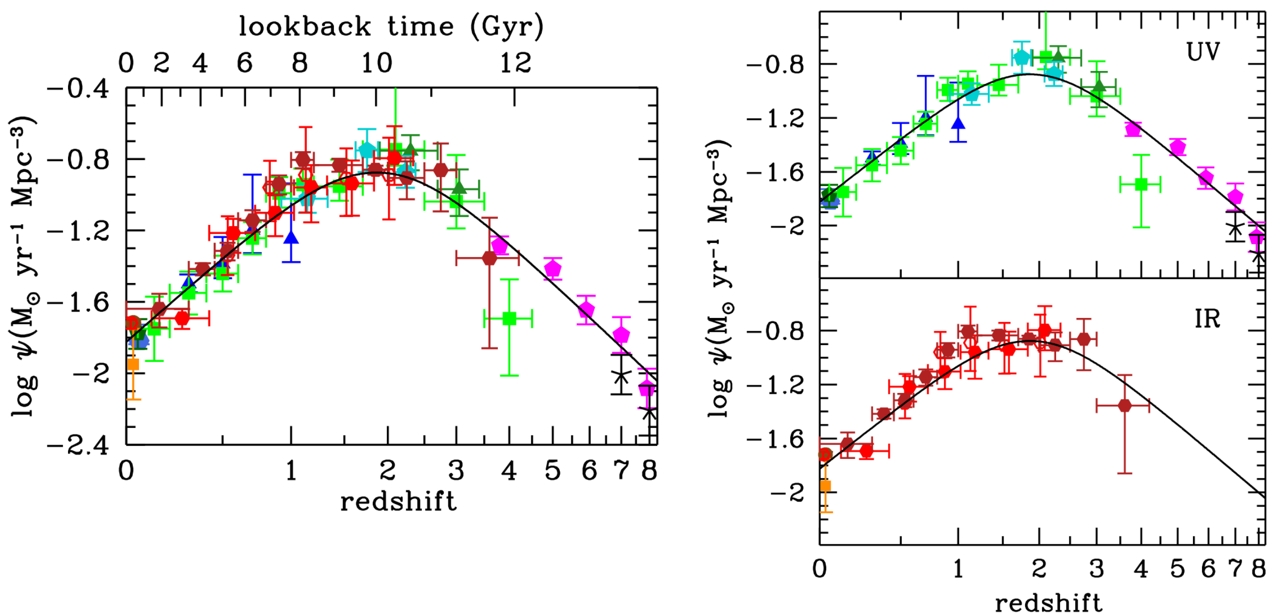

Figure 1: The history of cosmic star formation from (top right panel) FUV, (bottom right panel) IR, and (left panel) FUV+IR rest-frame measurements. [1]

2. Star-Forming Regions

Recent studies have demonstrated that gravitational lensing allows for the observation of small-scale star formation in high-redshift galaxies. For instance, Vanzella et. al. (2023) identified star-forming clumps with delensed radii as small as one parsec in a galaxy at $z > 6$. By resolving these regions, we can determine their star formation rates, and understand their star formation evolution and role in galaxy formations in the early universe.

3. Measuring Star Formation Rate and Ionizing Radiation

The star formation rate (SFR) is a key indicator of galaxy evolution. Certain emission lines, such as Hα and Lyα, directly reflect how many ionizing photons are produced by hot, young stars. By using JWST's NIRSpec spectroscopy on SPT0615-JD, we'll be able to pinpoint the SFR within its star-forming regions with remarkable clarity.

With this information, we can see if the actual star formation rates match what our theoretical models predict at these early cosmic times. If we find SFRs that are unexpectedly high, it may mean that star formation was more efficient in the early universe than we've assumed so far.

4. Probing the Interstellar Medium

NIRSpec spectroscopy will also provide insights into the interstellar medium (ISM) properties of SPT0615-JD, including metallicities, ionization parameters, and kinematics. Metallicity measurements are linked to the chemical enrichment from early stellar populations, offering clues about the galaxy's evolutionary stage.

Kinematic data will help distinguish between ordered rotational motions and turbulent dynamics within the galaxy, shedding light on the mechanisms driving early star formation and galaxy assembly.

Technical Justification

We aim to uncover the star formation activities in the high-redshift galaxy SPT0615-JD at $z \sim 10$. By combining the powerful imaging capabilities of JWST's NIRCam with the spectroscopic reach of NIRSpec in Multi-Object Spectroscopy (MOS) mode, we'll obtain both detailed images and spectral signatures of the galaxy's star-forming regions. This approach will let us measure the star formation rates of these clumps and understand their physical properties like age, size, and metalicities.

Instrument Choices & Methods

- NIRCam Imaging:

  Rationale: We'll use NIRCam's high-resolution infrared imaging to see individual star-forming clumps and measure their brightness and size.

  Filters: We plan to use multiple bands of short filters (i.e., F090W, F115W, F150W, and F200W) and long filters (i.e., F277W, F356W, F410W, and F440W) to cover a wide range of wavelengths from the rest-UV through the rest-optical. This will help us figure out how massive and old these clumps are, as well as how much dust they contain.

  Exposure Time: With science time of 11.7 hours total, spread out over these filters. With this depth, we can confidently detect star clusters as faint as AB mag 28, giving us strong signals (SNR $>$ 5) for reliable measurements.

- NIRSpec MSA Spectroscopy:

  Rationale: alone can't tell us everything. We need spectra to confirm the galaxy's distance (redshift) and to measure emission lines that reveal star formation rates, chemical enrichment, and the energy output of these young clusters.

  Mode & Wavelengths: Using the PRISM mode at low resolution ($R \sim 100$) gives us continuous coverage from about 0.6˘5.3μm in a single shot. This means we can detect key lines like Hα, Hβ, [O III], and [N II], all of which help us understand the physics inside these star-forming clumps.

  Exposure Time: With science time of 5.15 hours total. With this, we'll achieve SNR > 5 on faint emission lines, so we can confidently measure line fluxes and determine star formation rates down to about 0.1 solar masses per year, assuming lensing boosts the brightness by a factor of about 10.

Expected Outcomes

The proposed observations will achieve the following outcomes:

1. Measure the star formation rate (SFR) in the clumps within SPT0615-JD using rest-frame UV and Hα emission.
2. Determine the star-forming regions ages to map the star formation evolution along the arc
3. Probe the interstellar medium (ISM) of the galaxy, including metallicities, dust attenuation, and kinematics.
4. Extend the cosmic star-formation history to $z \sim 10$, pushing our understanding of early galaxy formation and evolution.

References

[1] Madau, P., & Dickinson, M. (2014). Cosmic Star-Formation History. *Annual Review of Astronomy and Astrophysics*, 52(1), 415–486. `http://dx.doi.org/10.1146/annurev-astro-081811-125615`

[2] Welch, B., Coe, D., Zitrin, A., Diego, J. M., Windhorst, R., Mandelker, N., Vanzella, E., Ravindranath, S., Zackrisson, E., Florian, M., Bradley, L., Sharon, K., Bradač, M., Rigby, J., Frye, B., & Fujimoto, S. (2023). RELICS: Small-scale Star Formation in Lensed Galaxies at z = 6–10. *The Astrophysical Journal*, 943(1), 2. `http://dx.doi.org/10.3847/1538-4357/aca8a8`

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