Escape Fractions in the Lyman Continuum: Using Ly-alpha emitters to Understand the Epoch of Reionization

Scientific Category: High-redshift Galaxies and the Distant Universe
Scientific Keywords: Cosmology, High-redshift galaxies, Reionization
Instruments: NIRSPEC
Proposal Size: Small
Exclusive Access Period: 12 months
Allocation Information (in hours):
Science Time: 18.4
Charged Time: 25.0

Abstract

We propose to use JWST NIRSpec MOS to observe a sample of high-redshift galaxies ($z = 6.5 – 10.6$) identified as Lyman-alpha emitters (LAEs) in fields such as GOODS-S, GOODS-N, and COSMOS These observations aim to investigate the physical properties of early galaxies and the ionization state of the intergalactic medium (IGM) during the epoch of reionization. By targeting Lyman-alpha lines, we will constrain star formation rates, metallicities, ionizing photon production, and the role of faint galaxies in reionization.

Additionally, we will map ionized bubbles around clustered LAEs to probe the spatial distribution of reionization. The program leverages NIRSpec MOS's multiplexing and sensitivity to capture spectra of both bright and faint LAEs, including gravitationally lensed sources. These observations will provide critical insights into early galaxy evolution and the timeline of cosmic reionization, building on photometric datasets from JADES, COSMOS, and HST surveys.

Target Summary:

Target	RA	Dec
JADES-Gnz11	12 36 25.4000	+62 14 32.00
COSMOS-CR7	10 00 58.0050	+01 48 15.25
JADES-GSz7	03 32 40.1904	-27 46 19.24
COSMOS-LA1	10 00 27.4800	+02 12 24.41

Observing Summary:

Target	Observing Template	Flags	Allocation *
JADES-Gnz11	NIRSpec MultiObject Spectroscopy *F170LP*	*NOPAR*	8,053 / 13,215
COSMOS-CR7	NIRSpec MultiObject Spectroscopy *F170LP*		19,329 / 24,417
JADES-GSz7	NIRSpec MultiObject Spectroscopy *F100LP*		19,329 / 26,089
COSMOS-LA1	NIRSpec MultiObject Spectroscopy *F100LP*		19,329 / 26,089

* Science duration / charged duration (sec)

Total Prime Science Time in Hours:	18.4
Total Charged Time in Hours:	25.0

Observing Description

Overview

This program aims to observe a sample of high-redshift Lyman- emitting (LAE) galaxies at redshifts in the range z~6 to z~11 to understand the epoch of reionization. Using the JWST NIRspec instrument in its Multi-Object Spectroscopy (MOS) mode, we will capture Lyman-alpha emission lines and continuum features to perform later analysis.

Selected targets in this program include galaxies surveyed in the JADES GOODS-N and GOODS-S fields, and the COSMOS field. This program takes advantage of the MOS mode to observe multiple LAE galaxies as once, reducing the observing time and increasing efficiency.

Target Selection

The selected targets and fields are based on existing surveys and photometric redshift calculations. The JADES and COSMOS surveys offer the best known candidates for LAEs and lensed systems to improve faint emission capture.

Instrument Setup

Instrument: NIRSpec Multi-Object Spectroscopy (MOS)

Filters & Dispersers:
- F100LP/G140H for Lyman-alpha at z 6.5 – 8.
- F170LP/G235H for z > 8 and rest-frame optical lines.

Spectral Resolution: High-resolution mode (R ~ 2700) to resolve Lyman-alpha line profiles and measure velocity offsets between Lyman-alpha and systemic redshifts.

Wavelength Coverage: 0.6–5.3 m to encompass Lyman-alpha and other diagnostic lines.

Science Goals

Lyman-alpha Studies:
- Measure Lyman-alpha line profiles tounderstand ionization states of the intergalactic medium (IGM).

Galaxy Properties:
- Derive star formation rates (SFRs), metallicities, and ionization parameters from rest-frame UV and optical emission lines.

Reionization Mapping:
- Identify regions with clustered LAEs to map ionized bubbles in the neutral IGM.

Justification for NIRSpec MOS

NIRSpec MOS is the optimal mode for this program due to its ability to observe multiple faint galaxies at once, its high sensitivity to emission lines, and its excellent spectral resolution. Unlike slitless spectroscopy, MOS minimizes contamination from nearby sources, crucial for faint, high-redshift targets in crowded fields. This configuration is specifically called to address the faintness of LAEs at $z > 6$.

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
CoI	Prof. Gautham Narayan	University of Illinois at Urbana - Champaign	USA/IL
PI &	Mr. Varun Satish	University of Illinois Urbana-Champaign	USA/IL

Number of investigators: 2
& Contacts: 1

Team Expertise:

Varun Satish (PI) is an undergraduate student at the University of Illinois Urbana Champaign working with Prof. Kirk Barrow on extragalactic astronomy. The project involves mapping escape fractions of high-redshift galaxies in the Lyman-continuum using ray-tracing computational techniques.

Prof. Gautham Narayan (Co-I) is an Associate Professor of Astronomy at the University of Illinois Urbana Champaign. His expertise in Observational Astronomy has been key in this proposal.

■ Scientific Justification (required for all)

The epoch of reionization (EoR) (Witten et al., 2024) is a pivotal period in cosmic history, marking the transition from a neutral intergalactic medium (IGM) to the ionized universe we observe today. This era, occurring between redshifts $z \sim 6$–10, was driven by the emergence of the first galaxies and their ionizing photon output. However, key questions about the nature of these galaxies, the timeline of reionization, and the interaction between galaxies and the IGM remain unresolved.

1 The Role of Galaxies in Reionization

Observations suggest that faint galaxies (da Cunha et al., 2020) are the primary sources of reionizing photons, but direct measurements of their properties are limited due to their extreme faintness. Our proposed NIRSpec MOS observations will target high-redshift Lyman-alpha emitters (LAEs), which provide critical diagnostics for understanding the role of galaxies in reionization. The detection and analysis of Lyman-alpha ($\lambda = 1216$ Å) emission will allow us to:

1. Quantify ionizing photon production: The efficiency of ionizing photon production in these galaxies can be constrained using emission line strengths and UV continuum slopes.

2. Determine star formation rates (SFRs): Lyman-alpha and Hβ fluxes directly trace SFRs, providing insight into the growth of galaxies during this period.

3. Explore escape fractions (f_{esc}) in the Lyman Continuum (LyC): to constrain the all-important escape fraction of ionizing photons from reionization era galaxies, it is of the utmost importance to find reliable indirect indicators of f_{esc}(LyC) (Saxena et al., 2024).

2 Lyman-alpha Emission and the IGM

Lyman-alpha emission is a powerful probe of the IGM's ionization state. At $z > 6$, Lyman-alpha photons are increasingly scattered or absorbed by neutral hydrogen in the IGM, leading to a decline in observable LAEs. By studying the Lyman-alpha line profiles of galaxies across $z = 6.5$–10.6 (Maiolino et al. (2024), Tang et al. (2024)), this program will:

- Trace the reionization timeline: The visibility of Lyman-alpha at different redshifts provides direct constraints on the neutral fraction of hydrogen in the IGM.

- Measure velocity offsets: The velocity shift between Lyman-alpha and systemic lines reveals information about the galaxy-IGM interaction and feedback processes.

3 Reionization Topology

The spatial distribution of ionized regions during reionization is expected to be highly non-uniform, with ionized "bubbles" forming around groups of galaxies. Observing LAEs in clustered environments provides a way to map these bubbles and study the large-scale structure of reionization. This program will specifically target known overdensities of LAEs in fields like GOODS-S, GOODS-N, and COSMOS (Retzlaff et al. (2010), Jones et al. (2024)), leveraging JWST's sensitivity to study these environments in detail.

4 Impact on Reionization Models

The results of this program will directly inform models of galaxy formation and cosmic reionization. Observations of faint galaxies in cluster fields, amplified by gravitational lensing, will extend our understanding of the faint-end of the luminosity function, critical for estimating the total ionizing photon budget. By combining spectroscopic data with theoretical models, we will refine estimates of the star formation efficiency, ionizing photon escape fraction, and the timeline of reionization.

Technical Justification (required for GO, DD and Survey only)

The proposed observations of high-redshift Lyman-alpha emitters (LAEs) require the sensitivity, spectral resolution, and multiplexing capabilities of JWST NIRSpec in Multi-Object Spectroscopy (MOS) mode. These capabilities are uniquely suited to achieving the program's science goals of studying galaxy properties and the intergalactic medium (IGM) during the epoch of reionization (EoR).

1 Instrument and Mode Selection

We selected the JWST NIRSpec instrument in the Multi-Object Spectroscopy (MOS) mode due to the following:

- It enables simultaneous spectroscopy of multiple galaxies, optimizing observing efficiency for fields with high target densities.
- It avoids contamination and spectral confusion often seen in slitless spectroscopy (JWST NIRISS).
- Its high sensitivity and spectral resolution (R $\sim$ 2700 with gratings G140H and G235H) are critical for resolving Lyman-alpha line profiles.

2 Filters and Dispersers

To cover the relevant spectral features, we will use:

1. F100LP/G140H for detecting Lyman-alpha and UV metal lines ($z \sim 6.5$–8.5).
2. F170LP/G235H for redshifted UV-optical lines at $z > 8$.

The chosen gratings provide high spectral resolution required to resolve Lyman-alpha emission, identify velocity offsets, and minimize contamination by sky background.

3 Sensitivity Requirements

Many of the selected targets are faint ($m_{\text{AB}} \sim 27 - 29$) based on photometric catalogs from JADES (Eisenstein et al., 2023) and COSMOS. Simulations using the NIRSpec exposure time calculator (ETC) indicate that to achieve a signal-to-noise ratio (SNR) > 5 for Lyman-alpha emission or UV/optical lines, the following integration times are required:

- 8,000 – 12,000 seconds for moderately bright LAEs ($m_{\text{AB}} \sim 27$).
- 15,000 seconds for fainter targets ($m_{\text{AB}} \sim 28$–29), particularly in lensing cluster fields.

4 Field Selection

The selected fields (GOODS-N, GOODS-S, and COSMOS) are well-studied regions with extensive photometric imaging data, providing complete target catalogs and accurate photometric redshifts. Gravitational lensing fields in these cluster fields improves sensitivity to ultra-faint lyman-alpha galaxies by magnifying their fluxes by factors of up to 10.

5 Why JWST NIRSpec MOS?

JWST is the only facility capable of achieving these observations. Ground-based telescopes are limited by atmospheric absorption and sky brightness in the infrared, restricting their sensitivity to faint emission lines like Lyman-alpha. While HST can detect Lyman-alpha, it lacks the spectral resolution and multiplexing capabilities needed to resolve line profiles and study faint galaxies efficiently. NIRSpec MOS, with its combination of multiplexing, high sensitivity, and spectral coverage from 0.6 to 5.3 μm, is essential for this study.

6 Expected Outcomes

This configuration will provide the required SNR to measure Lyman-alpha line profiles. It will enable detailed studies of galaxy properties, constrain reionization timescales, and map the spatial distribution of ionized regions. The data will be essential for understanding galaxy formation at these redshifts, and understand the role of LAEs during the period of reionization.

References

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