A SPectroscopic survey of biased halos In the Reionization Era (ASPIRE): A JWST Quasar Legacy Survey

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Proposal Size:	MEDIUM
Exclusive Access Period:	12 months
Allocation Information (in hours):	
Science Time:	29.6
Coordinated Parallel Time:	29.6
Charged Time:	61.5

Abstract

After two decades of search, the first large sample of quasars has been identified in the reionization era. We propose to obtain NIRCam observations of a flux-limited sample of 25 quasars at 6.5<z<=6.8 with extant high resolution ALMA sub-mm observations and deep optical-to-infrared spectra. This program will enable a powerful spectroscopic (WFSS mode) and imaging survey along the entire quasar light cones, resulting in the detection of Hbeta+[OIII] lines of ~350 galaxies at 5.3<z<7 over 240 arcmin^2 sky area, including 45 galaxies physically associated to the central quasars. It will finally resolve the long-standing question of whether the earliest supermassive black holes (SMBHs) reside in the most massive dark matter halos and inhabit large scale galaxy overdensities. We will simultaneously image the host galaxies and close companions of quasars, measure the masses of the central SMBHs and characterize quasar feedback with Hbeta+[OIII] emissions, providing unprecedented constraints on the connection between SMBHs and their hosts as well as their primordial environment. This program will also provide unparalleled constraints on cosmic reionization and galaxy formation by measuring ionizing photon escape fractions of faint galaxies and probing the circumgalactic media of galaxies at z~5-7. In addition, this survey will give the most accurate bright-end galaxy luminosity function and Hbeta+[OIII] equivalent width measurements at z~5-7, complementary to the GTO JADES deep spectroscopic survey. Finally, the coordinated NIRISS parallel imaging will allow us to identify additional galaxies at z~6.5-6.8 to probe quasar-galaxy clustering at larger scales.

■ Scientific Justification

Since the discovery of the first $z > 6$ quasar (Fan et al., 2001), over two decades of painstaking searches have delivered a sample of ∼50 of these extremely rare objects at $z > 6.5$ up to the current redshift record at $z = 7.5$ (Bañados et al., 2018). The existence of these quasars powered by $\sim 10^9\ M_\odot$ black holes (e.g. Mortlock et al., 2011; Yang et al., 2020a) in the Epoch of Reionization (EoR) challenges our understanding of supermassive black hole (SMBH) formation. An assortment of cosmological simulation models are able to produce such massive SMBHs (e.g. Di Matteo et al., 2005; Khandai et al., 2015) powering quasars with roughly the observed abundance 0.4 Gpc^{-3} (Wang et al., 2019) starting with massive $\gtrsim 10^4\ M_\odot$ seed BHs. These models generically predict that these SMBHs are hosted by massive $M_\star \gtrsim 10^{11} M_\odot$ galaxies with star formation rate SFR $\gtrsim 100 M_\odot\ \mathrm{yr}^{-1}$, and reside in the rarest $M_{\mathrm{DM}} \gtrsim 10^{12.5} M_\odot$ halos situated in the most overdense regions (Costa et al., 2014). While these numerical studies have established the plausibility of the existence of $z \sim 7$ quasars in a cosmological context, to date, testing these theories has proven impossible given the current sensitivity of observations. As we argue in this proposal, JWST will deliver the sensitivity to finally test these predictions in detail, answering long-standing questions about the primordial environment and the fueling mechanisms of the earliest SMBHs.

We propose to conduct a spectroscopic and imaging survey of **25** quasars in the EoR with NIRCam. This survey will enable a powerful *redshift survey* along the entire quasar light cones, resulting in the detection of Hβ+[O III] lines of ∼**350** galaxies at $5.3 < z < 7$ over ∼**240** arcmin^2 of the sky. It will also image the host galaxies and close companions of quasars spanning the rest-frame UV to optical. This program will allow us to:

- Measure the distribution of star-forming galaxies around these quasars to finally resolve whether the earliest SMBHs reside in the most massive dark matter halos.
- Detect or tightly constrain the UV-optical continuum emitted by stars in quasar hosts, providing unprecedented constraints on the galaxies hosting these SMBHs.
- Precisely measure the mass of the SMBHs with the Hβ line width and characterize whether quasar feedback regulates the formation of the earliest SMBH-galaxy systems.
- Assemble a large statistical sample of foreground galaxies along quasar light cones probed by co-spatial absorption spectroscopy allowing us to 1) constrain ionizing photon escape and the galaxy contribution to cosmic reionization and 2) probe the metal enrichment and ionization state of circumgalactic medium of galaxies at $z \sim 5 - 7$.

The Environments of the Earliest SMBHs. A fundamental result of the ΛCDM structure formation paradigm is that the clustering of a population can be directly related to their host dark halo masses (Mo & White, 2002). The auto-correlation length r_0 of quasars is observed to steadily rise with lookback time over the range $0 \lesssim z \lesssim 4$ (e.g. Eftekharzadeh et al., 2015). Shen et al. (2007) found that $z \sim 4$ quasars have $r_0 = 24 \pm 2.4$ cMpc/h, making them the most clustered population known at high-z. Such strong clustering implies quasars must be hosted by massive halos $M_{\mathrm{halo}} > 10^{12.5}\,\mathrm{M}_\odot$ (Costa et al., 2014), and is consistent with independent constraints on small-scale < 1 cMpc/h clustering at $z \sim 4 - 5$ from binary