1. Science aim/goal: Galaxies at Reionization: Aggregate Measures of Star Formation and Context in Galaxy Evolution

2. Overview:

Scientific Importance: To understand the sources and process of Reionization, it is essential to probe the population of low-metallicity ($Z < Z_{\odot}$), low-luminosity ($L < 10^{10}$ $L_{\odot}$), and low stellar mass ($M_{star} < 10^{9.5}$ $M_{\odot}$) galaxies at $z > 6$, which are expected to be dominant in terms of the number densities inferred from UV luminosity functions [Finkelstein et al. 2015, Bouwens et al. 2014] as well as their contribution of photons to ionize the intergalactic medium (IGM) during the Epoch of Reionization (EoR) [Wise et al. 2014]. Observations of z~0 low-metallicity dwarf galaxies provide important clues to the properties of their high-redshift analogs, and reveal important differences from their more massive and more chemically enriched counterparts, such as harder radiation fields and the prevalence of high-excitation, ionized gas in a porous interstellar medium populated by sparse clumps of neutral gas (ISM) [Madden et al. 2013, Cormier et al. 2015, Chevance et al. 2016]. The brightness of the [OIII]88 line emission relative to other important ISM coolants like [CII]158 is also an unusual feature common to the local low-metallicity dwarfs, due to the large fraction of moderate density ionized gas in these systems. Recent observations at z ~ 7 suggest this property may also be characteristic of dwarf systems during EoR [Inoue 2016]. The tight correlation between [OIII]88 luminosity and star formation rate (SFR) [De Looze et al. 2014] coupled with its exceptional brightness suggests that this line will become a workhorse for reliable SFR measurements in the high-z Universe, even in the presence of dust [Watson et al. 2015].

Measurements: Tomographic line intensity mapping offers a powerful means of observing the dwarf galaxy population during EoR, as the power spectrum analysis of intensity fluctuations in spectral line emission is sensitive on large-scales to *the aggregate intensity of all galaxies in a given volume—including intrinsically faint sources that may otherwise remain below sensitivity thresholds for individual detection*. Wide-area spectroscopic surveys with a large instantaneous bandwidth will enable high-fidelity power spectrum measurements of important rest-frame IR FS lines (Figure 1, lefthand panel) such as [OIII]52, which is expected to be a robust SFR indicator based on observations of [OIII]88 in low metallicity dwarfs (assuming [OIII]88/[OIII]52 ~ 1, as is appropriate for typical HII densities $n_{H^+} \sim 100$ cm^{-3} in these galaxies). Surveying 1 deg^2 in the 400 μm channel, FIRS can achieve SNRs up to ~ 1,000 on the total [OIII]52 power spectrum (including shot noise) and up to SNR ~ 100 on the linear clustering power at k's ~0.1 h/Mpc, which is used in extracting the mean line intensity (Figure 1, righthand panel). Contamination from brighter interloper line emission (Figure 1, lefthand panel) such as [CII]158 at emitted redshift $z_{em} = 1.5$ can be removed effectively by masking individual >5-sigma detected sources. Note that the masking depths for each considered survey area are above the spectral confusion limit, 10^{-22} W m^{-2}. In the case where masking is not sufficient to remove interloper emission on a source-by-source basis, there are additional methods to identify contaminating foregrounds [Lidz et al. 2016, Cheng et al. 2016].

Uniqueness to 10 μm to few mm facility: 3-D intensity mapping in the optical / near-IR has been proposed, but has two key limitations: 1) the potential for dust extinction, and 2) the complicated radiative transfer effects with Ly-α mean that it is unobservable and/or unreliable for some portion of EoR [Treu et al. 2013], being biased towards highly ionized regions. At longer wavelengths, proposed [CII] intensity mapping experiments in the millimeter can access the redshifted signal from the ground, but recent results suggest that [OIII] may be a better SFR tracer in the low-metallicity systems. In any case, the far-IR lines complement the [CII] measurements, and large spectral coverage uniquely allows one to carry out cross-correlation analyses between many spectral lines across different redshifts, providing line ratios and a means of overcoming systematics in the measurement.

Longevity/Durability: 2020-2030s: JWST will observe the EoR galaxies in deep, small area integrations and perform targeted follow-ups of individual sources, but will not directly observe the faintest galaxies. WFIRST will provide complementary large-area datasets for cross-correlation with sources traced by rest-frame IR lines. High significance measurements of 21 cm power spectrum from Reionization (e.g., using next-generation 21 cm ground-based experiment HERA) will provide a dataset for cross-correlation, but will not probe the galaxies themselves.

3. Figure

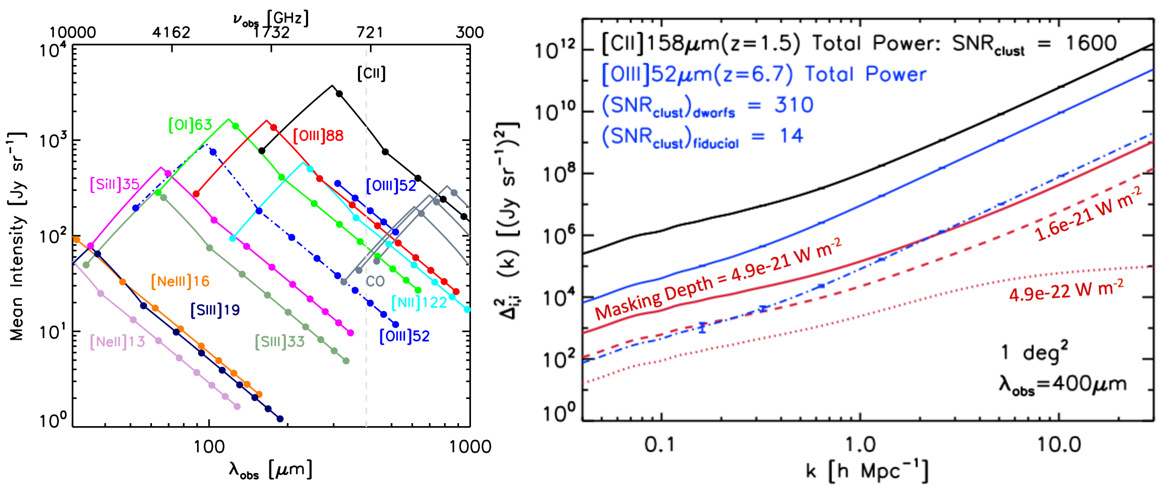

Figure 1: (Left) Mean line intensity as a function of observed wavelength for a suite of diagnostic FS and molecular lines from the empirical model of [Uzgil et al. 2014]. Curves are punctuated with filled circles to indicate emitted redshifts, z_{em} = 0 to z_{em} = 9, in steps of dz_{em} = 1. Mean [OIII]52 intensity is shown using the fiducial model (*dot-dashed blue*) and a modified model (*solid blue*), which uses the [OIII]88-to-IR continuum luminosity ratio determined from observations of local low-metallicity dwarf galaxies presented in Cormier et al. 2015. This modified model reflects the enhanced [OIII] emission expected for low-metallicity systems at z > 6; note mean intensity is plotted only for z_{em} = 5 to z_{em} = 9 here. (Right) Total expected power spectra for [CII] at z = 1.5 (*black*) and [OIII]52 at z = 6.7 (*blue*) in a 1 deg^2 survey with 3,000 hours of integration time at 400 μm. Note that the power spectrum is expressed as $\Delta^2(k) = k^3P(k)/(2\pi^2)$. Predictions and error bars are plotted for [CII], and for the [OIII]52 signal using the fiducial (*dot-dashed blue*) and modified (*solid blue*) models. Red curves represent the residual power in [CII] once all ≥5-sigma detected sources have been removed from the dataset at depths achieved for survey areas 10 deg^2 (*solid*), 1 deg^2 (*dashed*), and 0.1 deg^2 (*dotted*).

4. Performance requirements

Parameter	**Unit**	**Required**	**Desired**	**Comments**
Wavelength/band	um	30 - 500	30-500	[OIII]52 at z > 6; cross-correlation analysis with FS lines across a wide range of redshifts to mitigate

				interloper contamination
Survey area	deg.^{2}	1	1	Optimized for SNR on large-scale clustering power and effective removal of lower-z contaminating foregrounds with bright-source masking
Angular resolution	arcsec	9.4	9.4	measure shot noise power on small-scales (beam width = 0.28 Mpc/h)
Spectral resolution	$\lambda/\delta\lambda$	500	500	Shot noise power (channel width = 4.2 Mpc/h)
Bandwidth	GHz	300	1000	Probe LSS in line-of-sight; should be large enough (~1,000 Mpc/h) to compare with 21 cm maps
Spectral line sensitivity (5-sigma, 1hr)	W m^{-2}	1.5E-21	5E-22	Required for effective masking of [CII] at z = 1.5 in a 1 deg^2 field. For intensity mapping experiments, these line sensitivities translate to a surface brightness sensitivity (1-sigma) of 0.01 – 0.003 MJy sr $^{-1}$.

5. Key references: [1] Wise et al. 2014 [4] Cormier et al. 2015 [3] Uzgil et al. 2014