Near-Infrared Spectroscopy of Galaxies During Reionization

One of the most important unknowns in high-z extragalactic astronomy is how reionization occurred; during the epoch of reionization (z≈10–6; EoR), neutral hydrogen (HI) dominates the intergalactic medium (IGM). HI attenuates radiation from early stellar populations, masking galaxies from detection. Understanding how and when reionization occurs can reveal whether or not these young galaxies provided the necessary ionizing radiation to completely reionize the IGM by z≃6, one billion years after the Big Bang. However, due to the high redshift-space this implies, spectroscopic observations are limited as these galaxies are very faint, with their UV spectral features pushed out to near-infrared (NIR) wavelengths.

My background in NIR spectroscopy and observational astronomy has prepared me to assist in addressing this question. **I propose using Lyα and CIII] to investigate the properties and ionization state of young galaxies using ground- and space-based telescopes, the structure and distribution of HI in the IGM and the circumgalactic medium (CGM) of certain galaxies, and implications for the evolution of the neutral fraction of the IGM throughout the EoR.** The individual points proposed will be summarized as follows: (i) small scale testing and building of an analysis technique, (ii) distribution of galaxies and evolution of neutral fraction, and (iii) metallicities of galaxies. By understanding more about the IGM during the reionization era and of the galaxies within it, we can further constrain the properties of current galaxy evolution and reionization models.

Small scale testing & building of analysis technique: In the search for galaxies during the EoR, Lyman-α (λ_0=1216Å; Lyα) traditionally has been the best tracer both in photometric surveys and spectroscopic follow-up. This is in part due to the increasing fraction of UV bright galaxies (with strong Lyα emission) with increasing redshift [1]. By measuring the escape fraction of Lyα many studies have inferred an increasingly neutral fraction of the IGM at z>6.5 [2]. One complication of Lyα is its attenuation due to HI, pushing emission hundreds of km/s redwards of the galaxy's systemic (or true) redshift. A recent method uses a complementary spectroscopic tracer not attenuated by HI, with the UV metal line CIII] (λ_0=1907,1909Å) as the most robust according to mid-z (z≃2–3) analog surveys [1,3,4,5].

In my current work, I measure CIII] H-band emission of galaxies found via Lyα emission using Keck+MOSFIRE [6]. With both measurements, I compare the systemic (CIII]) and attenuated (Lyα) redshifts, shedding light on the structure and ionization of the CGM of these galaxies and surrounding IGM. **From my previous work experience, I have developed a proficiency in coding** which enabled me to gain a close familiarity with the MOSFIRE data reduction pipeline (DRP), having to dive into the sourcecode to fix bugs often encountered when working with incredibly faint emission lines and less common dithering patterns for standard star observations. I wrote code to optimally extract my 1D spectra, adapted from Horne (1986), boosting the S/N of my detection. Using a marriage of IRAF and Python, I developed code that can track the photometric variability of my data from a frame-to-frame basis – important when working with faint emission lines.

Distribution of galaxies and evolution of neutral fraction: Using the foundation built from my previous work, **I will build a statistical sample of galaxies during the last half of the reionization era (z≃8–6.5) in order to track the evolution of the Lyα escape fraction as a function of redshift.** Using my optimized extraction technique to improve measurements, I will use this dataset to constrain the offset between these galaxies' systemic and attenuated redshifts. This work will significantly increase the sample of high-z galaxies with both Lyα and CIII] measurements. In addition, it will provide a more significant comparison with z$\simeq$2–3 LAEs and LBGs, mid-z analogs commonly used in these analyses.

A current complication for this project is the lack of a complete spectroscopic sample of LAEs at z$\geq$6.5 with even fewer galaxies with systemic measurements (via UV metal lines or the [OIII] doublet; $\lambda_0 = 4959{,}5007$Å). This is partly due to these lines being redshifted to NIR and mid-IR wavelengths; the latter is impossible to detect with ground-based telescopes – it is useful to note that during the EoR, both [OIII] and the UV metal lines fall in the range of NIRCam on JWST. As a first approach to resolving this, **I will take the current sample of confirmed LAEs at z$\simeq$6.5–8 and measure their CIII] emission**, using my optimized extraction technique to improve measurements. This has already been attempted for some galaxies [4], providing useful lower limits for determining exposure times and potential telescopes for future observations, including JWST. We are planning proposals for the first JWST cycles for this work. I will then take advantage of the deep multi-wavelength imaging campaigns available to me, including the CANDELS datasets [7]. Moreover, I am part of a proposal to increase the sample of z$\sim$7 galaxies with Keck+MOSFIRE, with early indications that the proposal has so far been successful. Finally, as a scientific collaborator on an ERS JWST proposal, I will prepare for access to that data – understanding what spectra I will be looking for from running binary stellar population models (eg. BPASS), scaled to match expected bandpass magnitudes, through the JWST exposure time calculator.

With a large, statistical sample of LAEs at z$\simeq$6.5–8 with both Lyα and CIII], I will be able to further constrain the amount of hard radiation emitted from these galaxies; as shown with mid-z analogs, this is closely linked to the transmission of Lyα through the CGM [5]. By tracking its evolution through the last half of the EoR, I can inform current reionization models. Lastly, through gathering my sample **I will map out the distribution of these galaxies**, identifying whether galaxies with large escape fractions are tracing over-dense luminous regions, located within large ionized bubbles [3,8].

Metallicities of galaxies: Using my high-z sample of galaxies with deep ground- and space-based spectroscopy, I will study the metallicity of galaxies in the EoR. From a ratio of the fluxes of the CIII] doublet, when measurable, **I can infer an estimate of the electron density of the gas in the CGM**. This is closely linked to the metallicity of the CGM, which directly affects the velocity offset of Lyα emission. Not only do recent studies indicate that a neutral CGM attenuates Lyα photons, diminishing the effect the IGM will have, they also suggest (from mid-z analogs) a strong link between the profile of Lyα emission and the properties of the gas within the CGM [5]. This can be incredibly important as some high-z galaxies have been found to have more symmetric Lyα profiles, contrary to the archetypal asymmetric shape, thought to be indicative of high star formation and galactic winds [6].

Understanding the rate and distribution of reionization, including the factors and processes responsible for it, remains one of the most important unknowns in extragalactic astronomy. My work will aim to shed more light on this question, enabling more precise modeling of this era with the intention of probing ever further back in time towards the youngest of galaxies.

References: [1] Stark et al. 2017 [2] Dijkstra 2014 [3] Stark et al. 2015ab,2016 [4] Matthee et al. 2017 [5] Erb et al. 2014 [6] Finkelstein et al. 2013 [7] Grogin et al. 2011 [8] Furlanetto et al. 2004