Summary of Previous and Current Research

Why Does Reionization Matter?: The epoch of reionization (EoR) marks the last major phase transition of the universe when neutral hydrogen (H I) in the intergalactic medium (IGM) was ionized by the ionizing photons dominantly emitted from the first stars and galaxies. Thus, scrutinizing the detailed history of reionization is a key frontier in observational cosmology. Furthermore, as reionization is inherently coupled with galaxies—the dominant sources of ionizing photons—understanding galaxy evolution in the early universe relies on understanding the process of reionization (e.g., Robertson et al., 2015; McQuinn, 2016; Finkelstein et al., 2019). *In short, understanding the temporal and spatial evolution of reionization by tracing the IGM* H I *fraction provides a key constraint on the ionizing emissivity required from galaxies as a function of redshift.*

Lyα Spectroscopy as a Probe of Reionization: Since Lyα photons are resonantly scattered by H I in the IGM, an analysis of Lyα emission from galaxies has been used as a currently accessible method to trace the existence of H I gas in the IGM at different points in the history of the universe (Miralda-Escudé & Rees, 1998; Rhoads & Malhotra, 2001; Dijkstra, 2014). This technique uses follow-up spectroscopic observations, targeting high-z candidate galaxies, to measure the strength of Lyα emission from galaxies in the reionization era. Initial studies using Lyα spectroscopy have found an apparent deficit of Lyα emission at $z > 6.5$ from the measurements of the Lyα fraction (e.g., Stark et al., 2010; Fontana et al., 2010; Pentericci et al., 2011) as well as the Lyα luminosity function (e.g., Hu et al., 2010; Ouchi et al., 2010), implying an increasing H I fraction in the IGM from $z \sim 6 \to 7$.

Ground-based Spectroscopic Data for Lyα Emission during the EoR: In my past research, I have focused on completing a spectroscopic survey of galaxies in the early universe, the Texas Spectroscopic Search for Lyα Emission at the End of Reionization Survey ("the Texas Lyα Survey", hereafter), to measure the Lyα equivalent-width (EW) distribution and investigate the evolution of the IGM into the EoR (Jung et al., 2018, 2019, 2020). To search for Lyα emission from galaxies in the reionization era, I have performed deep spectroscopic observations of $z \sim 6-8$ candidate galaxies, selected from the photometrically-selected high-redshift galaxy catalog of Finkelstein et al. (2015, 2021), which is based on the Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey (CANDELS: PIs Faber & Ferguson). The entire observing program of this study is a total of 18 nights of spectroscopic integration for ~200 $z > 6$ galaxies with Keck/DEIMOS and MOSFIRE observations.

Unbiased Measure of the Lyα EW Distribution as a Probe of Reionization: The Lyα EW distribution function has been well studied at $0.3 < z < 6$, and has been found to have the form of an exponential distribution, dN/dEW $\propto$ exp(-EW/W_0), with a characteristic EW e-folding scale (W_0) of $\sim$ 60Å over the epoch $0.3 < z < 3$ (e.g., Gronwall et al., 2007; Guaita et al., 2010; Ciardullo et al., 2012; Wold et al., 2017); and possibly higher at higher redshift (e.g., Ouchi et al., 2008; Hu et al., 2010; Zheng et al., 2014; Hashimoto et al., 2017). Particularly, in the EoR, the H I atoms in the IGM are expected to diminish these EWs, lowering the e-folding scale (W_0) of the observed Lyα EW distribution (e.g., Bolton & Haehnelt, 2013; Mason et al., 2018a).

Motivated by earlier studies (e.g., Treu et al., 2012, 2013), I implemented a more detailed analysis of my dataset, where I placed constraints on the evolution of the Lyα EW distribution, using detailed simulations to include the effects of incompleteness. I introduced my

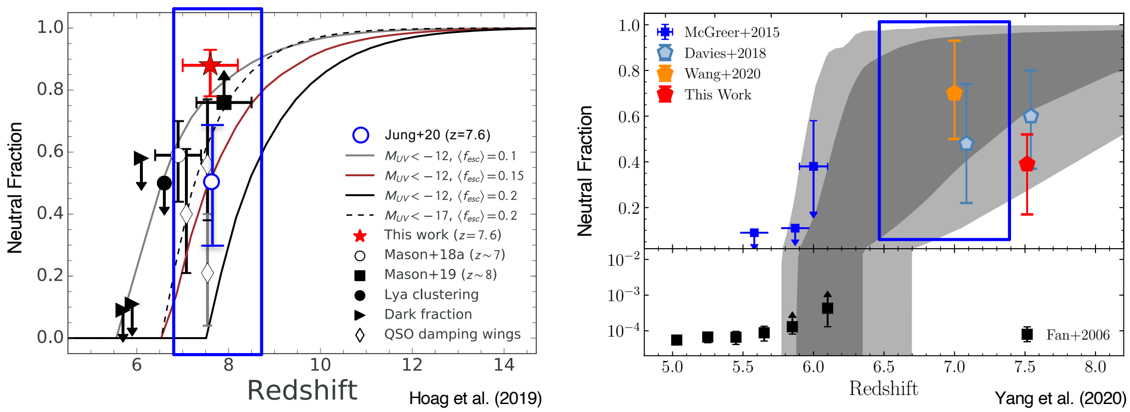


Figure 1: Recent Lyα studies suggest a very complicated picture of reionization. The left panel shows the recent IGM neutral fraction measurements from various Lyα studies (Figure 12 in Hoag et al. (2019); the measurement from Jung et al. (2020) overplotted). These Lyα studies show disagreement between their measurements at $z \sim 7-8$. Furthermore, quasar's Lyα damping wing analyses provided a large scatter of the IGM neutral fraction at $z > 7$ from their quasar observations (right panel; Figure 4 in Yang et al., 2020).

new scheme to constrain the Lyα EW distribution in Jung et al. (2018) by considering the sources of incompleteness of my dataset, the photometric redshift probability and observational conditions. I simulated the expected number of detections with the various shapes of Lyα EW distributions, and fit the constructed probability distribution of the expected number of detections to the actually observed detections to derive the probability distribution of e-folding scale (W_0) of the Lyα EW distribution. My first measurement of the Lyα EW distribution from the DEIMOS observations has been published in Jung et al. (2018), where I provided a decreased value of e-folding scale (W_0) of the Lyα EW distribution at $z \sim 6.5$, suggesting an increasing neutral fraction in the IGM at that epoch.

Inhomogeneity of Reionization: Recent Lyα studies suggest a complicated picture of reionization. For instance, recent Lyα fraction measurements at $z \sim 6$ and $z \sim 7$ from the VLT survey (Pentericci et al., 2018) show a possible flattening or a steady increase in the Lyα fraction from $z \sim 5 \rightarrow 6$ and a relatively smoother evolution from $z \sim 6 \rightarrow 7$, compared to previous studies (e.g., Stark et al., 2011; Tilvi et al., 2014). Furthermore, while existence of ionized bubbles around bright galaxies at $z \gtrsim 7$ indicates a moderately-ionized universe (Zheng et al., 2017; Castellano et al., 2018; Tilvi et al., 2020), non/rare detections of Lyα from faint galaxies at $z \sim 7.5$ (Hoag et al., 2019; Mason et al., 2019) suggest a significantly higher H I fraction in the IGM at this redshift (left in Figure 1). Particularly, I analyzed the deepest NIR observations, a part of the Texas Lyα survey, obtained from Keck/MOSFIRE observations in GOODS-N, where I spectroscopically confirmed Lyα emission lines from 10 galaxies at $z > 7$ (Jung et al., 2019, 2020). This is a record high in detecting Lyα emission lines at this redshift. The study suggests a highly-ionized universe with the inferred IGM neutral fraction of $49^{+19}_{-19}\%$ at $z \sim 7.6$ (shown as a blue circle in the left panel of Figure 1), which is lower than other Lyα studies at the same redshifts. Additionally, recent Lyα damping wing optical depth studies based on quasar observations show a diverse range of neutral fraction measurements at $z \simeq 7.0$–7.5 (right in Figure 1; Yang et al., 2020).

Boosted Lyα Transmission in the IGM: Taken together, it has been suggested that Lyα visibility during the EoR may evolve differently in UV-bright and -faint galaxies (e.g., Mason et al., 2018b; Hu et al., 2021; Endsley et al., 2021a), consistent with theoretical predictions from reionization simulations where reionization begins in over dense regions and progresses into low-density regions (e.g., Finlator et al., 2009; Katz et al., 2019). In Jung et al. (2021, submitted), I investigated the Lyα transmission in the IGM during the EoR and its dependence on UV absolute magnitude (M_{UV}), using IR slitless spectroscopy from the Hubble Space Telescope (HST) Wide-Field Camera 3 (WFC3) of 148 galaxies selected via photometric redshifts at $6.0 < z < 8.2$. The galaxy spectra were extracted from the CANDELS Lyα Emission at Reionization (CLEAR) survey, which includes 12-orbit depth HST/WFC3 G102 grism observations over 12 WFC3 fields within the CANDELS GOODS survey (PI: C. Papovich). In the study, we found that the UV-bright ($M_{\mathrm{UV}} < -21$) galaxies show weaker evolution while UV-faint ($M_{\mathrm{UV}} > -21$) galaxies exhibit a significant drop in W_0 from $z < 6$ to $z > 6$, which adds to the accumulating evidence that UV-bright galaxies exhibit boosted Lyα transmission in the IGM, suggesting that reionization completes sooner in regions proximate to galaxies of higher UV luminosity.

Theoretical Perspectives: I also participated in a theoretical analysis with Dr. Hyunbae Park and Dr. Hyunmi Song (Park et al., 2021, accepted for publication in ApJ), studying the Lyα transmission of the IGM from the Cosmic Dawn II (CoDa II) simulation of Ocvirk et al. (2020). In the theoretical study, we suggest that UV-bright galaxies tend to reside in "bubbles" as they ionize large volumes and are located in overdense regions where nearby fainter galaxies also can contribute to the ionizing emissivity, which also supports the boosted IGM transmission nearby UV-luminous galaxies in observations. I will continue to collaborate on theoretical studies to understand Lyα radiative processes in the interstellar medium (Song et al. in preparation) and the circumgalactic medium (Part et al. in preparation).

Spatially-Resolved Stellar Population Study for $z \sim 4$ Galaxies: Before I started to work on Lyα emission as a probe of reionization, I performed spatially-resolved stellar population study from $z \sim 4$ galaxies using *HST* images, which was published in Jung et al. (2017). A key discovery of the study is that the galaxies with the highest central mass densities have reduced star formation in their centers, possibly observing the earliest phases of bulge formation. As a co-investigator in multiple JWST programs in cycle 1 (1 ERS and 4 GO programs) my research will be extended to galaxies at even earlier epoch ($z > 4$) with NIRCam observations which provide high-resolution rest-optical imaging. I will also contribute to generating PSF-matched photometric data of NIRCam imaging and galaxy catalogs derived from spectral energy distribution (SED) fitting with my expertise.

Qualifications: In my past and current research, I have trained myself to be equipped with necessary skills for executing the proposed program. I performed spectroscopic analyses on datasets obtained from various multi-object spectrograph observations (e.g., HST/WFC3 grism and Keck/DEIMOS+MOSFIRE) with efficient targeting and searching for faint emission lines of high-redshift galaxies, which brought the comprehensive spectroscopic dataset of Lyα during the EoR (Jung et al., 2018, 2019, 2020). I developed an improved methodology of constraining Lyα EWs during the EoR, which successfully reconstructed the evolution of Lyα EW distribution into the EoR (Jung et al., 2018, 2020). Also, my latest studies on the UV dependency of the Lyα IGM transmission reveals an inhomogeneous nature of reionization both observationally (Jung et al. 2021, submitted) and theoretically (Park et al., 2021). Additionally, I performed spatially-resolved stellar population study for high-redshift galaxies in Jung et al. (2017), developing my own SED fitting procedure based on a Markov Chain Monte Carlo algorithm. With my diverse expertise, I am confident that I can perform the proposed research during the fellowship years.

Predicting Lyman-alpha Emission from Reionization-Era Galaxies with a Supervised Machine-Learning Approach

1. Motivation: Limited Knowledge on Lyα Systematics

Recent Lyα observations potentially demonstrate the inhomogeneous nature of reionization. However, interpreting these results remains yet challenging. The measurements of the IGM H I fraction via Lyα observations are unavoidably sensitive to the assumptions on the intrinsic properties of Lyα; for instance, the Lyα equivalent-width (EW) distribution. While estimating the observed EWs from Lyα observations ($\mathrm{EW_{obs}}$) is rather straightforward (although observational conditions and the selection function must be properly considered), the intrinsic shape of the Lyα EW distribution before the IGM effect ($\mathrm{EW_{int}}$) is largely unknown.

To account for the inability to accurately measure $\mathrm{EW_{int}}$ at high redshift due to the intervening H I gas, estimates of $\mathrm{EW_{int}}$ are often taken from measurements at low-z after reionization completed (De Barros et al., 2017; Santos et al., 2020), considering an empirical relation between Lyα and UV luminosity (Mason et al., 2018a; Weinberger et al., 2019). However, while previous studies exploring empirical proxies for Lyα photon production and the Lyα escape fraction have been successful in the low-z universe at $z \lesssim 2$ (e.g., Hayes et al., 2014; Yang et al., 2017; Trainor et al., 2019; Tang et al., 2019; Du et al., 2020), these methods are limited in terms of predicting Lyα emission from galaxies during EoR, and such an empirical relation does not tell explicitly what the intrinsic Lyα EWs would be from reionization-era galaxies. Additionally, this approach largely does not account for the potential redshift evolution of galaxy physical properties without the IGM effect (e.g., Hassan & Gronke, 2021)

A machine-learning (ML) approach could be a powerful tool here, which is the most widely used scheme in data science and has been increasingly applied in the field of astronomy as well. For instance, machine-learning has been utilized for estimating photometric redshifts (Samui & Samui Pal, 2017) as well as predicting the escape of ionizing photons from $z = 7$ galaxies (Jensen et al., 2016) and the 21cm signal from EoR (Shimabukuro & Semelin, 2017).

I will implement machine-learning for investigating the Lyα systematics and appropriately predicting Lyα from reionization-era galaxies, ultimately aiming to deliver an enhanced knowledge on Lyα emitter properties in this era and improved reionization constraints on the Lyα transmission in the IGM.

2. Data: Lyα Spectroscopy before/after Reionization

2.1 Lyα Data at $3 < z < 6$ in the *HST*/CANDELS field: Now a more robust investigation of Lyα systematics has become possible in the highest redshift universe thanks to recent Lyα surveys available at $3 < z < 6$ from the MUSE/Wide (Urrutia et al., 2019) and VANDELS (Garilli et al., 2021) surveys. VANDELS is a deep VIMOS survey in the CANDELS CDFS and UDS fields, including an optical spectroscopic dataset of >2000 galaxies (>300 Lyα emitters at $3 < z < 5.5$), and the MUSE/Wide spectra are also publicly available for >400 Lyα emitters in the GOODS-S field in this range range. Additionally, these surveys are based on different selection schemes: emission-line-selected (MUSE) *vs.* continuum-selected (VANDELS), thus any possible selection bias between the selection schemes will be thoroughly taken into account (Jung et al. in preparation). *These datasets will allow us to provide a reference measure of Lyα properties related to the host galaxies shortly after the reionization completed when the IGM became transparent.*

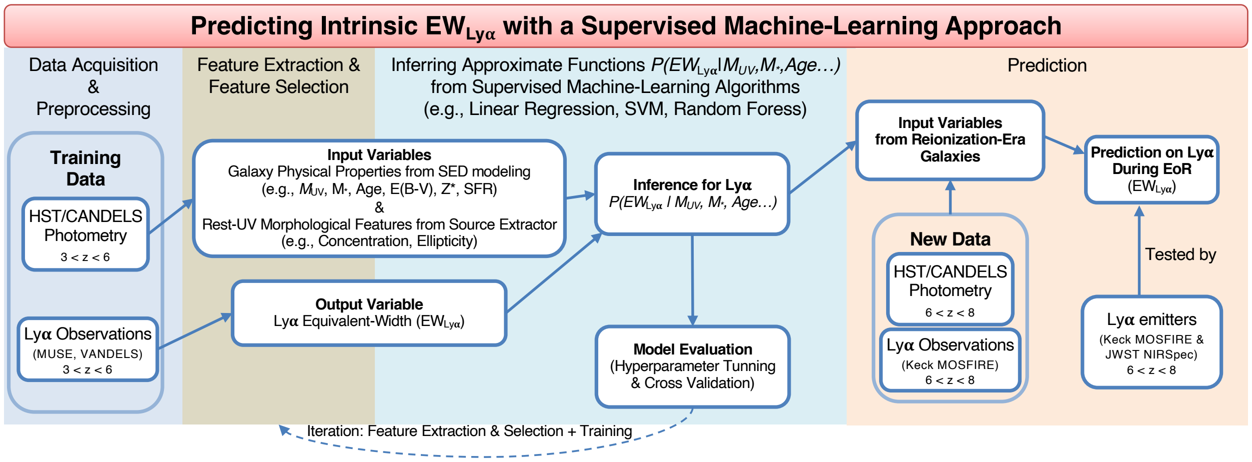


Figure 2: Graphical representation of the ML approach for predicting Lyα from reionization-era galaxies.

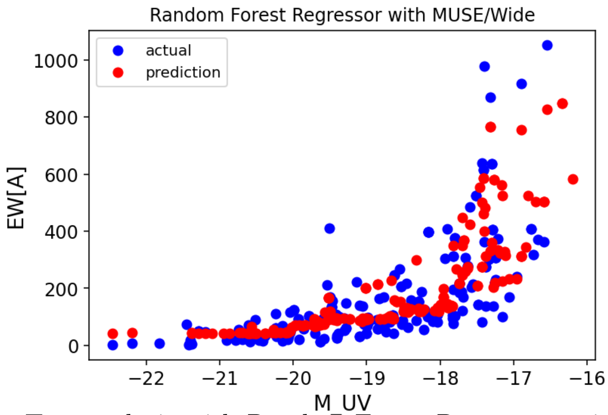
2.2 Lyα Data during the EoR at $6 < z < 8.2$: The Texas Lyα Survey (Jung et al., 2018, 2019, 2020) provides deep spectroscopic data of over 120 $z > 6$ galaxies in the GOODS-N fields (65 galaxies from DEIMOS and 62 galaxies from MOSFIRE observations). These data include the largest sample of confirmed Lyα emitters at $z > 7$ with which to constrain the IGM H I fraction at $z \sim 7.6$ (Jung et al., 2020). Additionally, another Keck observations are available in the CANDELS EGS field: two nights of MOSFIRE observations obtained in the NASA/Keck 2021A time (PI: I. Jung). The 2021A dataset are being analyzed, which will add more Lyα emitters confirmed at $z > 7$ in the area at a widely separated slight line from the previous observations. Moreover, the HST/WFC3 G102 grism observations from CLEAR are available for additional ∼150 $6 < z < 8.2$ galaxies (Jung et al. 2021, submitted).

2.3 Upcoming JWST Spectroscopic Data: The use of Lyα observations during EoR is yet limited due to the lack of information on the Lyα velocity offset and the size of ionized bubbles around the reionization-era galaxies as these key quantities dominate the resulting Lyα transmission, depending on the IGM neutral fraction. However, the JWST observations will make the measurements of these quantities possible, which will improve the use of Lyα as a probe of reionization, testing the redshift evolution of Lyα. I am a member of the CEERS JWST ERS program (PI: S. Finkelstein) which will execute the NIRSpec and NIRCam observations for detecting rest-UV and optical emission for ∼40 $6 < z < 9$ galaxies.

The combination of the Keck data and the CLEAR data in addition to the upcoming JWST observations will provide an access on the unique and most comprehensive spectroscopic dataset of the reionization-era galaxies, which will allow us to examine the Lyα transmission and the neutral fraction in the IGM during the EoR. The existing Lyα surveys, such as MUSE/Wide and VANDELS, will provide a solid basement with an aid of ML techniques.

3. Machine-Learning Approach

3.1 Predicting Lyα from Galaxies in EoR: I will implement a supervised ML approach to make predictions on Lyα from reionization-era galaxies by analyzing $3 < z < 6$ Lyα observations as a training set. Specifically, we can infer approximate functions to produce desired predictions from labeled training data from supervised ML algorithms (e.g., linear and logistic regression, support-vector machines, and random forest and boosting). Over the course of applying ML algorithms, I will also assess the feature importances via the explanatory artificial intelligence approach (Lundberg & Lee, 2017, e.g., SHAP), which informs us how much individual input features (or galaxy physical properties in our program) are



Feature Importance Scores

Input variables	Scores
$M_{\rm UV}$	**0.60**
Stellar Mass	0.06
Age	0.05
Dust Content	0.02
Metallicity	0.11
SFR	0.07
Ellipticity (Rest-UV morphology)	**0.28**

Figure 3: Test analysis with Random Forest Regressor training, applied to the MUSE/Wide dataset. A comparison between actual data (blue) and prediction (red) on Lyα EWs is shown in the left. X-axis is the UV magnitude as one of the input variables, and the output variable (Lyα EW) is in Y-axis. This figure demonstrate the prediction matches the actual data in general although the prediction suggests a bit tighter distribution than the actual data. In the right table, a feature importance analysis informs us what input features are dominating in model prediction. Our preliminary result indicates the absolute UV magnitude as the most apparent indicator of Lyα EWs, and ellipticity comes next.

useful/dominant for making predictions on the outcome (or Lyα). The detailed step-by-step analysis plan is described in the following and outlined in Figure 2.

3.2 Data Preprocessing and Feature Extraction: The archival *HST*/CANDELS photometry and the combined $3 < z < 6$ Lyα dataset of MUSE/Wide and VANDELS will be fed to supervised ML algorithms as training data. Specifically, I aim to draw approximated inference functions on Lyα EWs correlated with galaxy physical properties (e.g., $M_{\rm UV}$, M_*, Age, Dust content, metallicity, SFR, rest-UV morphologies) from supervised ML analyses.

3.3 Inferring Approximate Functions and Model Evaluation: The inference models need to be validated through the iterative process of model evaluation. As our Lyα spectroscopic data consists of survey datasets based on different observing strategies (continuum-selected in VANDELS *vs.* emission-selected in MUSE) as well as different observing conditions (varying EW limits), it is critically important to validate models by cleaning data and considering heterogeneous sample biases. I will test several popular supervised ML algorithms and choose the most appropriate approach to predict Lyα EWs by performing cross validation, which tests the model performance; and by optimizing hyperparameters in each algorithm to enhance the inference models. Our proof-of-concept analysis from the test with Random Forest Regressor, one of the most popular supervised ML algorithms, is shown in Figure 3, demonstrating its capability of predicting performance on Lyα EWs.

4. Project Timeline & Key Outcomes

I plan to complete the proposed research over my fellowship years, resulting in at least *three* journal papers. This includes: (i) the analysis of Lyα systematics at $3 < z < 6$ based on existing Lyα surveys from VLT, (ii) the analysis of Lyα emitters during the EoR with JWST and Keck observations, and (iii) the prediction on Lyα for the reionization-era galaxies based on ML, which eventually provides the improved measurement of the IGM H I fraction.

(1) **Prior to the Fellowship** – Data Collection and Preprocessing: I will finish data collection and the measurements of galaxy physical properties and Lyα emission properties of $3 < z < 6$ galaxies, utilizing the *HST* CANDELS photometry and the MUSE/Wide and VANDELS surveys. I will also finish the data analysis of the Keck/MOSFIRE observations in the EGS field, obtained via the NASA/Keck 2021A time (PI: I. Jung).

(2) **Year 1** – Developing Inference Models from the $3 < z < 6$ Dataset: I will feed the $3 < z < 6$ dataset of *HST* imaging and Lyα spectroscopy to ML algorithms to develop the most appropriate inference model on predicting Lyα from galaxy physical properties.

(3) **Year 2** – Analyzing JWST and Keck observations: The reduced dataset of the CEERS JWST ERS observations will be available shortly after observations. I will collect the NIRSpec 2D and 1D spectra for $6 < z < 9$ galaxies in EGS, searching for detected emission lines. Combined with the Keck observations of $z > 6$ Lyα emitters in the EGS field, I will provide the direct measurement of Lyα velocity offsets (from other rest-UV emission lines) and the accurate estimate of ionized bubble sizes with HST and JWST combined photometry for the reionization-era galaxies.

(4) **Year 3** – Predicting Lyα EWs for Reionization-era Galaxies: I will make Lyα predictions for galaxies at $z > 7$ and eventually provide an improved measurements of the Lyα IGM transmission and the H I fraction by comparing the predicted Lyα EWs to the observed.

My proposed study aligns with the science implementation of **NASA's Cosmic Origins Program** (see *"This program seeks to understand how the universe has evolved ..."*) as well as **NASA's strategic objective of the Astrophysics Division** (see *"Explore the origin and evolution of the galaxies ..."*) in Chapter 4.4 of the NASA SMD 2014 Science Plan. Critically, the proposed research is very timely, as the first JWST data is coming out in the first year of the fellowship program.

5. Leadership Potential

5.1 Teaching and Mentoring Activities: I worked as a teaching assistant for seven astronomy courses during my graduate programs from introductory courses for both non- and astronomy major students to upper-division courses. I also completed a teaching & mentoring training, *Concentration in Teaching and Mentoring*, comprised of three courses. The program is designed to train PhD students or postdoctoral fellows to be well-prepared, engaging, and effective teachers and mentors. Completing the program above, I was able to (1) build my own courses at different levels, (2) provide my own lecture on *the cosmic star formation history in Galaxies and the Universe* in the upper-division class, and (3) learn mentoring strategies on students' research and design my own research projects for students.

As a postdoctoral fellow, I continued to make every effort on the engagement of teaching and mentoring activities. For example, I attended the CRESST II[1] Undergraduate Interaction Day at the NASA Goddard Space Center (GSFC) and presented my research to the attending undergrad students from local universities. Additionally, I am already mentoring a graduate student, Seonwoo Kim at Yonsei University in Korea on her research of analyzing Keck MOSFIRE spectra. The student has been successfully making research progress on developing her own data reduction pipeline for detecting faint emission from spectra.

Based on my diverse experience in educational training, I will develop course materials specifically focusing on the formation and evolution of galaxies in the early universe, that can be used for teaching undergrad seniors or graduate students. Also, I will mentor undergrad/graduate students in the University of Arizona on their research activities.

5.2 Outreach Activities & Community Services: As a scientist working at NASA's Goddard Space Flight Center I was involved in several public outreach activities to promote the science interest of the public and help people learn the latest updates on NASA's space

[1] Collaboration between NASA Goddard Space Flight Center (GSFC) and regional universities.

missions. For instance, I participated in NASA's social media Q&A event on May 13-14, 2021 where I provided answers to questions from the public on NASA's James Webb Space Telescope through the NASA's Webb Instagram account. Also, I am a speaker for JWST pubic talks as part of the Webb Space Telescope Community Events[2] led by the Space Telescope Science Institute, which included giving a public presentation introducing JWST at the Cape Fear Museum of History and Science in Wilmington, North Carolina.

For community services, I am a journal reviewer for ApJ, A&A, and MNRAS. Also, I have served as an external panel in HST (Cycle 28 & 29) and ALMA (Cycle 8) proposal reviews as well as in the Future Investigators in NASA Earth and Space Science and Technology (FINESST) review. Furthermore, I was involved in the US/ELT Key Science Program team, which proposed a future Lyα science with the extremely large telescopes (e.g. Giant Magellan Telescope and Thirty Meter Telescope) to the Astro2020 Decadal Survey.

Based on my past and current roles in community, I will continue to participate in and lead in community services and outreach activities as a local scientist in Tucson, Arizona. My faculty contact, Dr. Daniel Stark and Stark's group in the University of Arizona, are working with the Mount Lemmon Sky Center to help develop the "University of Arizona Sky Ambassador" program. The program aims to connect regional science teachers and their students with front-line research and resources in astronomy at the University of Arizona. I will work on developing the program as an active local astronomer, reaching out students from diverse backgrounds to inspire an interest in astronomy or other STEM fields.

6. Justification of the Host Institution

I will work with Dr. Daniel Stark on the proposed program and other faculties and research staffs at the University of Arizona, who specialize in extragalactic astrophysics and observational cosmology. Dr. Daniel Stark is an expert in extragalactic astrophysics, specifically pioneering this field of study regarding Lyα emission as a probe of reionization (e.g., Stark et al., 2010, 2011). He and his research group continue to lead the research area of galaxies in the early universe and reionization (e.g., Stark et al., 2017; Tang et al., 2021; Endsley et al., 2021b). Also, the University of Arizona has an access to world-class facilities, including LBT, MMT, and the Magellan Telescopes, which can be used for observing rest-UV emission (e.g. C III]) as well as searching for Lyα during the EoR. Thus, I will have Dr. Daniel Stark at the University of Arizona as a faculty contact for my proposed program.

7. Concluding Remarks

In the long run, there will be the extremely large telescopes, such as the Giant Magellan Telescope and the Thirty Meter Telescope, exploring the reionization topology with extensive dataset. Along with Lyα spectroscopic study as a probe of reionization, the future radio observations (e.g, Square Kilometer Array) will directly map the distribution of H I during the EoR in the coming years. The research on Lyα emission in this program and these 21cm radio observation studies will complement each other toward understanding the detailed evolution of the IGM and galaxy properties during the EoR. Additionally, Lyα forest studies of quasar observations will reveal residual components of neutral patches around the end of reionization. Together with the other means of probing reionization such as Lyα forest from quasar observations and H I mapping from 21cm radio observations, the proposed program will bring an unprecedented understanding of the reionization history.

[2] https://outerspace.stsci.edu/display/WSTCE/Webb+Space+Telescope+Community+Events

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