OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

Lyα emission of high redshift strong Hα emitters

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Abstract of Scientific Justification

Lyα emission line is an important tool to get a measure of high redshift galaxies and reionization of universe, but the power of Lyα emission line is restricted by the resonant scattering of the Lyα line and a complex escape process. The production and escape of Lyα photons is potentially influenced by many properties of the Lyman break galaxies (LBG) and Lyman alpha emitters (LAE) galaxies. However, LBG and LAE samples may be heterogenous, making the Lyα escape hard to understand. A useful technique is to isolate galaxies with high specific star formation rate and young starbursts (age$<$ 20Myrs). Those galaxies have high Hα equivalent width (EW) and guaranteed large intrinsic Lyα emission, thus serve an ideal sample to investigate Lyα escape. Low redshift studies with high EW(Hα) galaxies have high detection rate of Lyα emission. At high redshift, however, Lyα escape properties of high EW Hα emitters have not been addressed. We select a sample of high redshift (3.8$<$ z$<$5.0) high EW Hα emitters (rest frame EW(Hα) $>$ 500Å) to investigate Lyα escape in those galaxies. With the proposed spectroscopy, we can determine how many high redshift strong Hα emitters show Lyα emission lines, estimate Lyα escape properties of high redshift strong Hα emitters, and compare with strong Hα emitters at low redshift and LBG and LAE at similar redshift. Using one Hectospec mask we can target 100 high EW(Hα) galaxies and a control sample of 150 other LBGs at (3.8$<$ z$<$5.0).

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/5	Hectospec			1	grey	Feb-Apr	Jan-Apr	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: Hectospec is not available for December 20 through January 20 due to cold temperatures (ambient air temp must be above 20F). During the bright nights in Feb and Mar 2015, the moon is very near our targets (less than 30 deg), so those nights are not good.

no text past this line

A $\star$ appended to the proposal type indicates a continuation proposal; a $\star$ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a $*$ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	COSMOS	10:00:30.20	+2:15:15.06	z=3.8-5.0, about 300 galaxies in COSMOS field

Approval for Instrument Use from PI: N/A

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
Huan Yang	S. Malhotra		no	yes

Scientific Justification

Background: The UV emission of young stars in star-forming galaxies generate a lot of Lyα photons. Those Lyα photons will interact with the interstellar medium, being resonantly scattered by HI and absorbed by dust, and finally a fraction of photons can escape from galaxy as the Lyα emission lines. Lyα emission line is an important tool to measure properties of high redshift galaxies and reionization of universe (e.g. Malhotra et al. 2004; Stark et al. 2010; Steidel et al. 2010). However, the full power of Lyα emission line is restricted by the complex Lyα escape process. The escape of Lyα photon is determined by the interplay of many properties of galaxies, including dust extinction, HI gas covering fraction, gas kinematics, and dust geometry. To understand the role of each property, a lot of works have been done on Lyman break galaxies (LBG), Lyman alpha emitters (LAE), and local star forming galaxies (e.g. Shapley et al. 2003; Blanc et al. 2011; Hayes et al. 2014). The LBG and LAE samples have a variety of physical properties and may be heterogenous in important properties such as the stellar population age. It will be helpful to compare the Lyα escape of different galaxies subsamples with carefully selected properties such as stellar age.

We propose to study a sample of galaxies that have very young (age$<$ 20Myrs) starburst and high specific star formation rate. The massive young stars in those galaxies emit a lot of ionizing photons, then generate a lot of Lyα and Hα photons. Due to the young ages, those galaxies have large Hα emission line equivalent width (EW) (Fig.1, Levesque & Leitherer 2013). In a local star forming galaxies sample studied with HST (LARS sample, Hayes et al. 2014) with EW(Hα) $>$ 100Å, nearly all of those galaxies show Lyα emission lines (Ostlin private communication). Thus high EW(Hα) seems to be a good predictor of Lyα emission lines. **Because their strong intrinsic Lyα emissions and high rate of Lyα emission lines, those high EW Hα emission line galaxies (HAE) are great labs to investigate Lyα escape.**

At high redshift, observations of Hα lines are difficult as Hα lines shift to infrared. However, a population of high EW(Hα) galaxies at z=3.8-5.0 have been found with the help of Spitzer photometry. Shim et al. 2011 and Stark et al. 2013 compiled LBG samples with spectra redshift in z=3.8-5.0 and Spitzer IRAC 3.6μm and 4.5μm band detection, and found that about 40% of galaxies in their sample have a very blue Spitzer color (mag(3.6μm)-mag(4.5μm)$<$-0.3). At redshift z=3.8-5.0, the Hα emission line shift to the Spitzer 3.6μm band (3.179 - 3.955 μm) and no other emission line is in Spitzer 4.5μm band, so the blue 3.6μm and 4.5μm band color of those galaxies are due to the contribution of Hα emission line in 3.5μm band. From the spectral energy distribution (SED) fitting method, those galaxies have rest frame Ha EW $>$500 Å, due to their very young stellar population ($<$ 20Myrs, Fig.1) and high specific star formation rate. **Thus we can reverse the method in these previous works (Shim et al. 2011; Stark et al. 2013), and use the Spitzer 3.5μm and 4.5μm band color to select high EW(Hα) young starburst galaxies at redshift 3.8-5.0 to investigate Lyα escape in those great labs.**

Objectives: The Lyα escape properties of those high redshift strong Hα emitters have not been addressed. What fraction of high redshift strong Hα emitters show Lyα emission lines? Do those high redshift strong Hα emitters have different Lyα escape properties from the strong Hα emitters sample at low redshift and the general LBG and LAE sample at similar redshift?

To answer those questions, we select a sample of young starburst galaxies with high EW(Hα) emission lines. We propose to take spectroscopy observation of the Lyα emission lines of these strong Hα emitters and achieve a few science goals:

1. These strong Hα emitters are expected to show Lyα lines. We can measure the fraction of high EW HAE that show Lyα emission lines and compare this fraction with strong Hα emitters at low redshift (the LARS sample) and LBG and LAE at similar redshift.

2. We can estimate the intrinsic Lyα emission line strength from Hα emissions, then get the fraction of Lyα photons escape from galaxy, i.e. the Lyα escape fraction (f$_{esc}(Ly\alpha)$, defined as the ratio of observed to intrinsic Lyα emission).

3. In a clumpy dust geometry case, the Lyα emission can be boosted by scattering and appear larger than intrinsic Lyα emission (Finkelstein et al. 2008). By measure the Lyα escape fraction, we can test if the dust clumpy geometry model is effective in some of those galaxies .

4. Luminous LBG samples generally show weak Lyα lines (Ando effect (Ando et al. 2006)). Those Spitzer selected high EW HAE have relatively bright continuum magnitudes, so it is interesting to test if they have strong Lyα lines.

Sample: To select a sample of high redshift strong Hα emitters, we use Spitzer data from the Spitzer Extended Deep Survey program (Ashby et al. s2013). The Spitzer data reach a depth of 26 AB mag (3σ) in both 3.6μm and 4.5μm band in about 600 $arcmin^2$ sky area of the COSMOS field. The total Spitzer imaging area is also covered by CFHT and Subaru broad and medium band optical deep imaging. Part of the Spitzer imaging area is covered by HST imaging. Those HST and ground telescopes photometries enable accurate photometric redshift measurement.

We select strong Hα emitter candidates that have photometric redshift in 3.8-5.0 and blue 3.6μm and 4.5μm band color. First in the 184 $arcmin^2$ sky area covered by HST, we use the photometric redshift (photo-z) catalog (Skelton et al. 2014) to select sources with reliable photo-z in 3.8-5.0 and (S/N(U band)<2.0), resulting in 674 sources. At z=3.8-5.0, the 912Å break shifts to red ward of U band, so we include no detection in deep U band imaging (5σ depth 26.7 AB mag) to the selection criteria. Then we apply Spitzer color selection criteria – (S/N(3.6um)>5) & (S/N(4.5μm)>3) & (mag(3.6μm)-mag(4.5μm)<-0.3) to select rest frame EW(Hα) > 400-500 Å candidates. We get 49 high EW HAE candidates from this HST detected catalog. Then for the Spitzer imaging sky area not covered by HST, we match the Spitzer photometry catalog (Ashby et al. 2013) with Subaru optical photometry catalog (Capak et al. 2007) and ULTRA-VISTA near infrared photometry catalog (Muzzin et al. 2013). We use Eazy code and the LBG selection criteria (Ouchi et al. 2004) to select z$\sim$4-5 galaxies and apply the same Spitzer color selection criteria. We get another 50 high EW HAE candidates from this matched catalog. In total we have about 100 high EW HAE candidates in COSMOS field. Figure 2 shows two SED plots of high EW HAE candidates.

In summary, we select high EW Hα emission line galaxies with very young (age< 20Myrs) starburst and high specific star formation rate. To address the Lyα properties of those high redshift strong Hα emitters, we propose to take spectroscopy observation of Lyα emission line of those galaxies. With the proposed observation, we can answer how many of those high redshift strong Hα emitters show Lyα emission lines, estimate $f_{esc}(Ly\alpha)$ of high redshift strong Hα emitters, and compare those strong Hα emitters with strong Hα emitters at low redshift and LBG and LAE at similar redshift.

References

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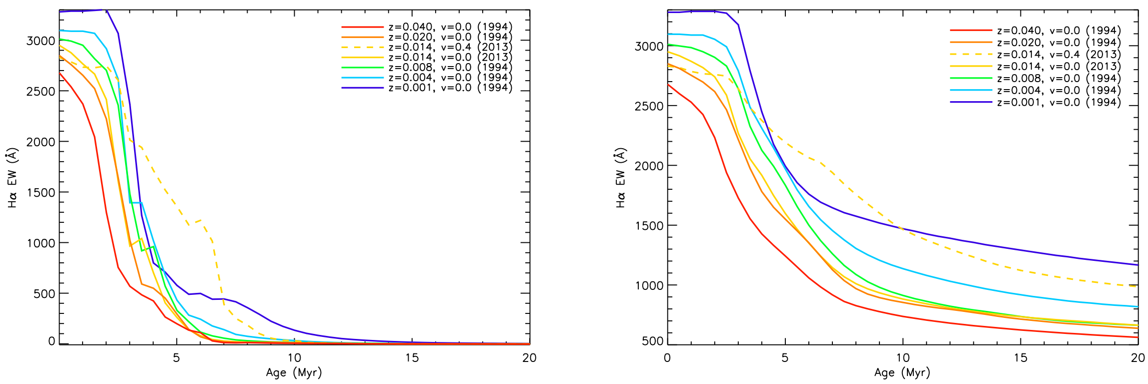

Figure 1: This figure from Levesque & Leitherer 2013 shows the evolution of EW(Hα) with age. Models in the left panel adopt an instantaneous burst star formation history. Models in the right panel adopt a continuous star formation history. Those High EW HAEs with rest frame EW(Hα) $>$ 500Å are very young galaxies with age $<$ 20Myrs.

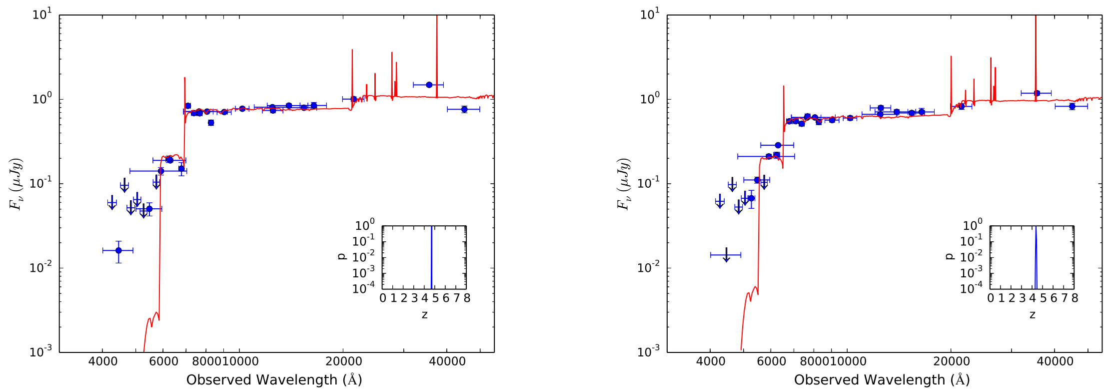

Figure 2: This figure shows SED of two sources in the sample. Non-detections are plotted as 3σ upper limits. We also plot the Eazy best fit template with red line and the probability distribution of photometric redshift in the inset figure. Those sources have a high probability in z=3.8-5.0 and show Spitzer 3.6μm excess due to Hα emission lines.

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (**up to one page**)*

Our observation goal is to get Lyα emission line spectra of a sample of high EW HAE candidates and a comparison galaxies sample in COSMOS field. As discussed below, MMT Hectospec is necessary to take the deep spectra for a large sample of galaxies.

Exposure Depth: We can estimate the expected Lyα flux of our sample from the Spitzer photometry. Assuming a flat SED shape ($f_v(3.6um) = f_v(4.5um)$, accurate SED of the galaxy can be estimated from SED fitting), we convert the Spitzer 3.6 μm color excess to Hα flux, then convert to Lyα flux assuming the intrinsic Lyα to Hα ratio of 8.7 from Case B recombination theory. The intrinsic Lyα flux of our sample is about $10 - 100 \times 10^{16}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. For normal star forming galaxies, a fraction $\sim$ 0.01-0.1 of those intrinsic Lyα photons are expected to escape from galaxies. To achieve our scientific goals, we need to detect the Lyα emission lines of galaxies with f$_{esc}(Ly\alpha)$ >0.01, which requires to reach a 5σ Lyα flux limit about $1 \times 10^{17}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. Based on our personal experience, 1 hour Hectospec exposure with 270gpm grating and seeing 0.5-0.8" can reach a 5σ flux limit of $3 \times 10^{17}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$ at about 6600Å. So we need 1 night (8 hours) exposure to reach a 5σ flux limit of $1.1 \times 10^{17}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$.

Sample Size: To achieve our science goal, we need to get about 30 secure Lyα emission lines spectra of high EW HAE to estimate an accurate fraction and address those questions about Lyα escape. As our candidates are selected using photometric method, a fraction about 20% of them are expected to be low redshift interlopers. About 10-20% candidates are expected to fall in spectra region (6900-7400Å) with strong telluric absorption lines. Due to the uncertainties in the rough estimation of Lyα flux from the Spitzer photometry and assumed f$_{esc}(Ly\alpha)$, a fraction of candidates would have Lyα flux smaller than our detection limits. To be conservative, we need a sample of about 80-100 high EW HAE candidates. As those sources in the sample are distributed in a $60 \times 15\ arcmin^2$ sky area, so with 300 fibers and 1 degree field of view, Hectospec can cover all of them in one pointing.

Comparison Sample: In our sample selection, we also selected a few hundreds z=3.8-5.0 galaxies candidates without strong Hα emission lines. Those galaxies are selected with the same photometry method except that they don't have the blue 3.6μm and 4.5μm band color. By taking spectra of galaxies in this comparison sample, we can get a Lyα fraction of those galaxies without high EW(Hα) in this redshift range and compare with the strong Hα emitters. We will put all our selected high EW HAE candidates in fibers, and randomly choose sources in the comparison sample to fill the other fibers.

Lunar Justification: As Lyα emission lines of the sample are expected at 5500-7500 Å, the spectroscopy observation is not very sensitive to the sky brightness. Grey sky is acceptable to reach the required sensitivity. We also note that during the bright nights in February and March 2015, the moon is very near our targets (less than 30 degree), so those nights are not usable.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

This is our first request of telescope time for this project. We have used the archive photometric data from HST, Spitzer and many ground telescopes to select a sample of galaxies with high EW(Hα). To achieve the science goals, we request 1 night of MMT time to take spectroscopy observation of the Lyα emission lines of those galaxies. The archive photometric data and the proposed spectra data are enough to complete this project and publish science results. We do not anticipate requesting more time for this project. This project is part of the PhD thesis of PI Huan Yang.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

This is PI's first UAO proposal. The PI had no previous time allocation through UAO. Based on Magellan time allocated through China Telescope Access Program, PI has published one paper Yang et al. 2014, ApJ 784, 35 "A z $\sim$ 5.7 Lyα Emission Line with an Ultrabroad Red Wing".

Co-investigators Malhotra and Rhoads have supervised, in total, four PhD theses heavily based on UAO data (L. Xia, Z. Zheng, E. McLinden, and S. Finkelstein).

Recent allocations involving co-investigators on this proposal include:

Magellan + FourStar, PI=Rhoads, March 6-7 2013: Narrowband search for $z = 8.8$ Lyα galaxies. One night completely lost (dome closed); other fairly useless due to heavy cirrus clouds.

Magellan + FourStar, PI=Rhoads, November 24–25 2013: Narrowband search for $z = 8.8$ Lyα galaxies. Total of 1 night of useful data; NB observations of Abell 370. Data to be published together with results of upcoming runs on this project.

Magellan + FourStar, PI=Rhoads, February 6 2014: One reasonably good night on COSMOS. Combined with 35 hours of data from OCIW collaborators, this yielded narrowband images with a limiting sensitivity of $\sim 4 \times 10^{-18}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$. Spectroscopic followup time for this program has been awarded on Keck+MOSFIRE through the NASA TAC process.

MMT + Hectospec, PI=Malhotra, spring 2014: Gas metallicity of low-mass starburst galaxies, $0.2 < z < 0.6$. The data are promising, and papers are in preparation.

LBT+LUCIFER spectroscopy, 1 night allocated during 2012 April 14–18 queue block. PI = McLinden, with both Rhoads & Malhotra as co-Is. Three $z \approx 3.1$ Lyα galaxies observed in NIR. Published in McLinden et al. 2014, MNRAS 439, 446.