OBSERVING REQUEST
University of Arizona Observatories

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

Rest-UV Spectroscopy of Reionization-Era Galaxies

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CoI(s): Juna Kollmeier (Carnegie Observatories), Rob Simcoe (MIT), Ramesh Mainali (SO), Mengtao Tang (SO), Drew Newman (Carnegie Observatories)

Abstract of Scientific Justification

The last year has witnessed a rapid increase in the number of $z > 7$ galaxies which are bright enough to motivate spectroscopic study. With the arrival of efficient IR spectrographs such as FIRE, it might appear likely that we are on the cusp of a golden period of early galaxy spectroscopy. But as a result of the attenuation of Lyα emission by the partially neutral IGM at $z > 7$, it has become clear that the traditional means of redshift confirmation is bound for minimal success. Fortunately, spectroscopic study of reionization-era analogs at z=1.5-3 has revealed that UV lines are much more prominent in lower metallicity galaxies. We have recently provided the first identification of the strongest of these lines (CIVλ1549, OIII]λ1661, and CIII]1909) in four galaxies between $z = 6.0$ and $z = 7.2$, confirming the viability of using UV metal lines as probes of early galaxies. In 2014B, we initiated an ambitious collaborative Magellan/FIRE program (with MIT and Carnegie) with four goals: (a) to utilize the UV metal lines to confirm galaxies at $z \gtrsim 7$ for which large equivalent width Lyα is not present, (b) to obtain insight into the chemistry and stellar population of early star forming galaxies, (c) to study the impact of incomplete reionization on the velocity profiles of Lyα (using the systemic redshift provided by CIII]), and (d) to guide future surveys and GMT instrumentation by characterizing the distribution of UV emission line equivalent widths in reionization-era galaxies. Following a successful start to our campaign in 2014B, we propose to continue this program in 2015A, building the first significant sample of galaxies over the redshift range $6 < z < 8$ with both Lyα and UV metal line constraints.

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	MAG1		FIRE			2	grey	Feb	Jan–May	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: We request grey time. Detailed analysis of the sky background at Las Campanas (Sullivan & Simcoe 2012, PASP, 124,1336) demonstrates that the moon contributes significantly to the inter-line background in the Y and J-bands. Given the need to reach faint flux levels near 1-1.3μm, this program would benefit greatly from scheduling in grey (or dark) time.

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ 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	MACS 1311_z8	13:11:00.9	−03:10:32.00	mag = 25.2, z_p=7.8, Clément et al. 2014
2	RXJ 1347	13:47:36	−11:45:15	mag = 25.7, z_p=6.7 Smit+13
3	UltraVISTA-277912	10:00:43.4	+02:37:52	mag = 24.3, z_p=7.0 Bowler+12
4	UltraVISTA-155880	10:02:06.5	+02:13:24	mag = 24.4, z_p=6.8 Bowler+12
5	UltraVISTA-218467	10:01:52.3	+02:25:42	mag = 25.1, z_p=7.0 Bowler+12
6	UltraVISTA-61432	10:01:40.7	+01:54:53	mag = 24.6, z_p=7.1 Bowler+12
7	RXJ 1347-1046	13:47:36.2	−11:45:15	mag = 25.9, z_p=6.8 Bradley+13
8	borg_0440-5244_682	04:39:50.2	−52:43:52	mag = 25.9, z_p=8 Bradley+12
9	borg_1301+0000_160	13:01:16.3	−00:00:25	mag = 25.4, z_p=8 Bradley+12
10	borg_0909+0002_595	09:09:05.6	−00:01:47	mag = 26.1, z_p=8 Bradley+12
11	BDF-521	22:27:50	−35:08:50	mag = 25.9, z_s=7.008, Vanzella+11
12	NTTDF-6345	12:05:28	−07:41:10	mag = 25.5, z_s=6.701, Pentericci+12
13	MACS 0321	03:29:40	−02:11:52	mag = 23.9, z_p=6.2, Zitrin+12
14	A383-5.2	02:48:03	−03 31 35	mag = 25.2, z_s=6.024 Richard+11, Stark+14b
15	A383-2079	02:48:03	−03 31 35	mag = 25.9, z_p=7.4, Bradley+13
16	MACS 0429	04:29:37	−02:53:49	mag = 24.3, z_p=6.9 Smit+13

Approval for Instrument Use from PI: ______________________

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

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
Ramesh Mainali	Dan Stark		no	no
Mengtao Tang	Dan Stark		no	no

Scientific Justification

Galaxy Spectroscopy in the Reionization Era: In the last few years, HST imaging has delivered a bounty of over 200 galaxies whose photometric redshifts are likely to be above $z \simeq 7$ (e.g., Schenker et al. 2013). Yet concerted efforts to secure spectroscopic redshifts through detection of Lyα emission have led to minimal progress. At the time of writing there are only 7 spectroscopically-confirmed galaxies beyond $z \simeq 7$ (e.g., Schenker et al. 2012, Finkelstein et al. 2013) and none greater than $z = 7.51$. While this represents a major step forward, the investment (in excess of 300 hours on Keck/VLT) has been costly. These surveys have revealed that the success rate for redshift confirmation via Lyα at $z \simeq 7$ is significantly lower than that at $z \simeq 5 - 6$ where we found large EW (EW > 25 Å) Lyα in 50% of the LBGs observed (Stark et al. 2010, 2011). A possible explanation for the downturn in Lyα transmission is that the IGM is still partially neutral at $z \simeq 7$, causing attenuation of the Lyα line.

The reduced transmission of Lyα at $z \gtrsim 7$ has profound implications for the success of future spectroscopic studies targeting galaxies located in the reionization era. Excitement is now mounting with both the arrival of efficient IR spectrographs and the discovery of a growing number of bright gravitationally-lensed galaxies (e.g., Bradley et al. 2013). But with Lyα increasingly obscured by the IGM at $z > 7$, conventional surveys targeting large equivalent width (EW > 25 Å) Lyα are not likely to yield many redshift confirmations let alone provide physical insight into galaxies at $z > 7 - 8$. This begs the following questions: *If Lyα is no longer detectable in most reionization-era galaxies, are we doomed to rely entirely on photometric redshifts and imaging constraints at $z \gtrsim 7$? If there are no strong features in the rest-UV, will there be any role for GMT in the spectroscopic study of early galaxies?* While JWST will ultimately have access to strong rest-optical emission lines ([OIII], Hα) out to $z \simeq 8$, at the highest redshifts ($z \gtrsim 10 - 15$), spectroscopy will continue to rely on emission lines in the rest-UV. Given the strong attenuation of Lyα, alternative avenues of confirming and characterizing distant galaxies in the rest-frame UV are desperately needed to ensure the optimal exploitation of current and future facilities in studying the earliest-known galaxies.

A New Method of Rest-UV Spectroscopy at $z \gtrsim 7$: Conventional wisdom has long suggested that Lyα is the only strong emission line in the far-UV of star forming galaxies. But this perception is based on spectroscopic studies (e.g., Shapley et al. 2003) of relatively massive, chemically-enriched galaxies undergoing fairly rapid star formation. Galaxies in the reionization era are likely to have far different rest-UV spectra. Through our ongoing survey of low metallicity reionization-era analogs at $z \simeq 2 - 3$, we recently demonstrated that the UV spectra of metal-poor galaxies nearly always have numerous prominent emission lines (Figure 1a; Stark et al. 2014a), reflecting the higher ionization parameters and larger electron temperatures typically seen in low metallicity galaxies with young stellar populations. We argued in Stark et al. (2014a) that absent strong Lyα, the strongest of these emission lines (CIII], CIV, OIII]) are the most likely alternatives to securing redshifts of metal-poor galaxies at $z \gtrsim 7$ and offer, for the first time, the prospect of extracting spectroscopic constraints on the physical nature of early star forming galaxies.

Detection of UV Metal Lines at $z \simeq 6 - 7$. In early 2014, we provided the first identification of CIV, OIII], and CIII] in three star forming galaxies between $z = 6.02$ and $z = 7.21$ (Figure 1, Stark et al. 2014b; 2014c in prep). Each of the galaxies we targeted had a known redshift from Lyα, allowing us to predict the exact wavelengths of the UV metal lines. These early results confirmed the feasibility of observing metal lines in the UV spectra of reionization-era galaxies, and provided new insight into the physics of early galaxies. In particular, detection of powerful CIV emission (with equivalent widths comparable to AGN) requires an energetic ionizing source whose nature is unknown. But given the small sample and Lyα pre-selection, it is impossible to know whether these sources are representative of the $z \gtrsim 6$ population.

Initial Results from 2014B Magellan/FIRE Program. Motivated by the first detections of UV metal lines, we initiated an ambitious Magellan/FIRE program in 2014B with the goal of building the first significant sample of galaxies with UV metal line detections at $z \gtrsim 6 - 8$. While analysis is still underway (second run was Sep 27-30), the first two observing blocks have yielded detections of UV metal lines (CIV, CIII], OIII]) in two $z = 6$ galaxies with known Lyα redshifts (Figure 2), demonstrating that early galaxies might have a much harder ionizing spectrum than was previously thought to be the case. While detection of UV metal lines in systems without Lyα redshifts is certainly more challenging, our first run has potentially delivered the first detection of CIII]+CIV at $z = 6.9$ in a galaxy without a previously known redshift.

This Proposal. We now seek to build on the progress from our 2014B campaign. Our ultimate goal is to build a large enough sample at $6 < z < 8$ with deep rest-UV spectra to provide the first meaningful constraints on the UV metal line equivalent width distribution (offering guidance for future surveys and insight into the nature of early galaxies), the flux ratios of UV metal lines (illuminating the origin of high ionisation emission features), and the redshift evolution of quantities sensitive to reionization (i.e., Lyα velocity profiles). We describe each of our objectives in more detail below:

1. **Equivalent Width Distribution of UV Emission Lines.** If the UV lines are to both serve as useful spectroscopic probes of reionization-era galaxies and guide future surveys with GMT and JWST, we will need constraints on the equivalent width distribution. The current sample (containing only 4 galaxies) is still too small for these purposes and may be biased given our initial strategy of targeting the few bright $z > 6$ galaxies with strong Lyα. By building a larger sample of galaxies (including systems without known Lyα emission), we seek to derive the first measure of the equivalent width distribution of CIII], CIV, He II, and OIII] at $z > 6$. The information obtained via this campaign will directly impact JWST GTO programs (now being planned at Steward) and will help define the case for adding an IR arm to GMACS, one of two instruments planned for 'first light' of the GMT.

2. **Stellar populations and chemistry at $z > 6$.** We seek to build a $z \gtrsim 6$ spectroscopic sample with constraints on the relative strength of CIV, NIV], [NIII], He II, OIII], and CIII]. Measurement of the CIV/CIII] ratio (often reaching up to 0.5-0.8 in our reionization-era analog sample, see Figure 1a) will provide our first constraints on the hardness of the radiation field in normal star forming galaxies at $z > 6$, while the CIII]/OIII] and [NIII]/CIII] ratios will yield a measure of the relative abundance of carbon, nitrogen, and oxygen in reionization-era galaxies, delivering direct constraints on the early metal build-up of typical galaxies. Through comparison to photoionization models with the latest stellar evolutionary synthesis models, we will consider implications for the nature of early stellar populations and the contribution of galaxies to reionization.

3. **Insight into Reionization.** In a partially neutral IGM, red damping wing absorption from neutral hydrogen in the IGM will begin to attenuate Lyα radiation at wavelengths greater than 1216 Å, transforming the line profile of Lyα. Because of the wavelength-dependent attenuation, a partially neutral IGM can broaden the FWHM of a Lyα emission line (Dijkstra et al. 2007). Evolution of the Lyα profile thus offers an independent probe of the IGM ionization state. If the reduced transmission of Lyα indeed reflects a partially neutral IGM, we should see evolution in the line widths over $6 < z < 7$.

   Thanks to the extended wavelength coverage of FIRE in echelle mode, the proposed ultra-deep spectra will *simultaneously* deliver significant improvements in Lyα S/N with respect to the discovery spectra, allowing the line profile of Lyα emission to be characterized. Moreover, since the CIII] and OIII] nebular lines tend to trace the systemic redshift of the galaxy, their detection enables us to shift the Lyα line profile into the rest-frame (Fig. 2b), providing a more accurate picture of Lyα radiative transfer through the galaxy and IGM at $z \simeq 7$. To ensure progress in this goal, a subset of our targets will include known Lyα emitters at $6 < z < 8$. Deep FIRE spectra will allow us to determine the average Lyα line width and velocity profile at $z \simeq 7$. Through comparison of the velocity profiles to Lyα radiative transfer models (Kollmeier et al. 2010) and our large sample of galaxies at $z \simeq 6$ (Stark et al. 2011), we will obtain improved constraints on the IGM ionization state at $z \simeq 7$.

References: Bradley et al. 2013, arxiv:1308.1692 • Dijkstra et al. 2007, MNRAS, 377, 1175 • Finkelstein et al. 2013, Nature, 502, 524 • Kollmeier et al. 2010, ApJ, 708, 1048 • Schenker et al. 2012, ApJ, 744, 179 • Schenker et al. 2013, ApJ, 768, 196 • Shapley et al. 2003, ApJ, 588, 65 • Stark et al. 2010, MNRAS, 408, 1628 • Stark et al. 2011, ApJ, 728, 2 • Stark et al. 2014a, MNRAS accepted, arxiv:1408:1420 • Stark et al. 2014b, MNRAS submitted, arxiv:1408.3649

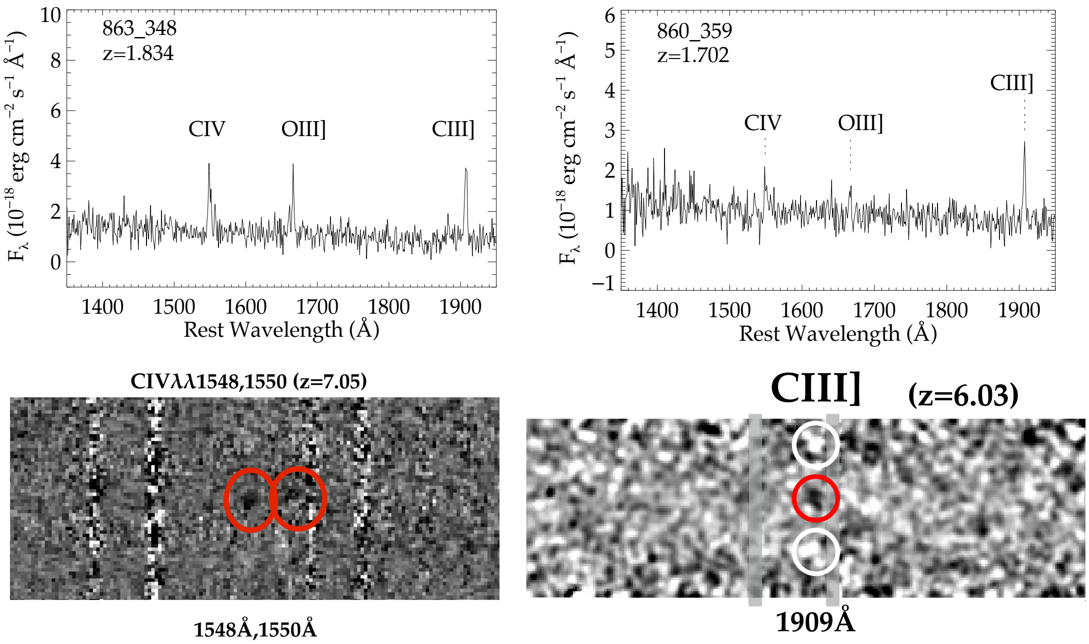

Figure 1: *(Top:)* Example UV spectrum of reionization-era analogs at $z \simeq 2-3$ from Stark et al. (2014a). Given the attenuation of Lyα, the prominent nebular lines in these galaxies (CIV, OIII], and CIII]) offer the most likely route toward confirming redshifts of similarly metal-poor $z > 7$ galaxies. *(Bottom:)* Detection of UV metal lines (CIVλ1549 and CIII]λ1909) in star forming galaxies with known spectroscopic redshifts (from Lyα) at $z = 6.02$ and $z = 7.05$ (Stark et al. 2014b).

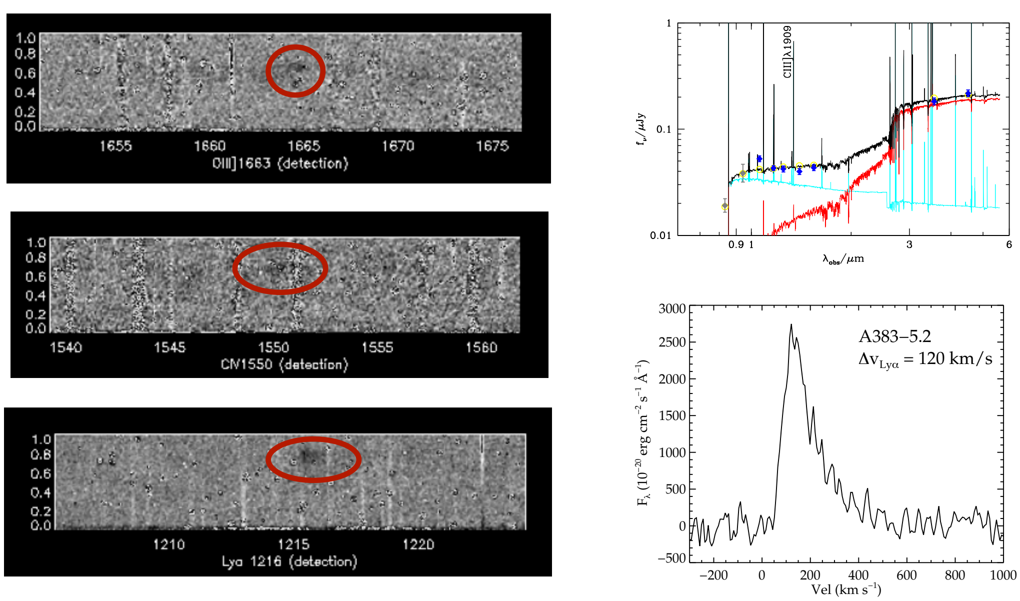

Figure 2: *(Left:)* First results from 2014B program, illustrating detection of OIII]λ1666, CIVλ1549, and Lyα in a galaxy at $z = 6.2$. *(Right :)* The simultaneous fit to continuum SED and CIII] EW in a $z = 6.024$ galaxy requires a bursty star formation history (top panel; Stark et al. 2014b). Velocity profile of Lyα in $z = 6.024$ galaxy (bottom panel; Stark et al. 2014b), yielding unique insight into transmission of Lyα.

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)***

Requirements: We propose to use FIRE in echelle mode to obtain deep infrared spectra of galaxies in the redshift range $6 < z < 9$. This program is driven by three key requirements. First, we seek to integrate long enough to secure detection (or robust upper limits) on the UV metal (i.e., CIII], OIII], and CIV) emission lines. As detailed below, this requirement forces us to limit our search to the brightest galaxies known over $6 < z < 8$. Second, in order to conduct the Lyα velocity profile science, we not only require that Lyα be present in a subset of our sample, but the infrared spectrum must be of sufficient resolution and S/N to enable characterization of the Lyα line profile. Third, we require that the metal emission lines are situated in regions where the atmospheric transmission is near unity. This forces us to select galaxies with redshifts which place the relevant emission lines in the Y, J, or H-bands.

Sample Selection: We have assembled the brightest galaxies visible from Magellan in 2015A. In addition to including bright galaxies with spectroscopic redshifts (those with z_s in the target list), we also consider galaxies with robust photometric redshifts (those with z_p in the target list). Following the third requirement described above, we ensure that the photometric candidates have tight photometric redshift distributions which place UV lines in clean regions of the near-infrared sky spectrum. The targets are chosen to be bright with continuum magnitudes of AB = 23.9-25.9. Many of the galaxies are gravitationally lensed systems located via HST imaging of massive cluster fields. Other systems are bright examples found via wide area imaging campaigns with HST and ground-based facilities.

Instrument Justification: This program requires sensitive spectroscopic constraints at a series of specific wavelengths within the Y-band (Lyα), J-band (He II, OIII], CIV), and H-band to 1.5μm (CIII]). Given the small number of bright galaxies at $z > 7$, there is little multiplex advantage to be gained from multi-object spectrographs. Given the wavelength coverage required (and need for accurate line ratios), this campaign is most efficiently completed using a single-object infrared spectrograph providing simultaneous near-IR coverage. These reasons motivate our proposed use of FIRE to complete this program.

Detection of Emission Lines: Based on our survey of low mass lensed galaxies at $z \simeq 2-3$ (Stark et al. 2014a) and the first constraints at $z \simeq 6-7$ (Stark et al. 2014b), we can predict the likely observed EWs of UV nebular emission lines at $z = 6-8$. We find that the observed CIII] and CIV EWs should reach $\simeq 50-70$ Å while He II can reach as high as $\simeq 24$ Å. In the spectroscopically-confirmed galaxies, the CIII] and/or CIV emission translates into a line fluxes ranging between 0.2 and 1×10^{-17} erg cm^{-2} s^{-1}. From our 2014B campaign with FIRE, we estimate that it will require typical integration times of 9 hrs (including overheads) to reach the necessary flux limits for multiple UV lines at 5σ.

Lyα Line Width: One of the key goals is to improve the S/N of the Lyα detection, enabling more accurate measurement of the line width and asymmetry. Based on personal experience, reliable measurement of these quantities requires at least a 10σ detection and $\simeq 3$ Å spectral resolution (e.g., Stark et al. 2010; see also Fig. 2). Use of echelle mode together with a 0.7 arcsec slit width will deliver a resolving power of 5100. This configuration will provide the necessary resolution, while still maintaining enough signal from the source under good seeing conditions. At $z \simeq 7$, Lyα falls at $\simeq 1.0$ μm. Based on sensitivity estimates from previous experience with Magellan, we find that we will be able to achieve a 10-20σ detection of Lyα in the time required to detect CIII] or CIV, providing the necessary 2-4x increase in Lyα S/N.

Required Sample Size: Given the inevitable galaxy-to-galaxy variation in the metal line EWs and flux ratios (i.e., CIV/CIII]) we must increase the sample size considerably if we are to reliably establish the average UV spectroscopic properties at $z > 6$. Based on our $z \simeq 2$ survey (Figure 1a), we estimate that a sample of 15 galaxies should yield a reasonable estimate of the mean EW and flux ratios. Following our 2014B campaign (assuming good conditions for our final November block), we estimate will require spectra for an additional 7 galaxies, amounting to a total of $\simeq 63$ hours of on source integration. Accounting for standard FIRE overheads for acquisition and tellurics, this program will require 6 additional nights, which we divide among the co-I's. Here **we request 2 nights** from the Steward TAC.

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 the second request for this phase of our program with UAO facilities. We were allocated two nights in 2014B scheduled for late November. We completed three Carnegie nights in July and at the time of writing this proposal (Sep 27-30) are in the middle of another three night Carnegie block.

Based on the requirements described on the previous page, we are asking for two nights with Magellan through the Arizona TAC and four nights through the Carnegie TAC. If weather cooperates, we should have a sufficient sample to achieve our goals in 2015A, requiring no further allocations.

Substantial amounts of observing are not coming for other observatories. We have not applied for VLT time for this program this semester. We were awarded two nights from the Keck/NASA TAC to search for CIII] emission in a $z \simeq 11$ galaxy that is only visible from the northern hemisphere. While major allocations have been allotted to other teams in the coming semester for IR observations with Keck and VLT, these efforts are still primarily geared toward targeting Lyα. As the strength of UV nebular emission lines in $z \simeq 2-3$ low metallicity galaxies becomes more widely-known in the coming year (upon publication of our results in Stark et al. 2014a, b), efforts will likely turn toward confirmation of CIII]λ1909. Hence this is an important window for Magellan to make a significant contribution.

The work will be coordinated by D. Stark at Arizona in close collaboration with J. Kollmeier at Carnegie and R. Simcoe at MIT. The group is a small team made up of experts in high-redshift galaxies and Lyα radiative transfer. Co-I Kollmeier will lead the modelling of Lyα velocity profiles. Co-I Simcoe is in charge of reducing the data. In 2014B, he developed a new version of the pipeline to handle the long integrations of faint targets that are typical for this program. And Co-I's Mainali and Teng (Ph.D students of Stark) will help assist in observations and analysis. Co-I Mainali will work on the EW distribution of UV metal lines, while Co-I Teng will focus on comparing Lyα detections at $z \simeq 4-6$ to the constraints emerging at $z \gtrsim 6$.

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)***

MMT: Eight MMT nights have been obtained with the Blue and Red Channel Spectrograph between 2011C and 2012C with the goal of obtaining a large spectroscopic sample of gravitationally lensed galaxies in SDSS. Through this program, 26 new gravitationally-lensed galaxies have been confirmed. The catalog paper describing the spectroscopic survey and some of the first science results is now accepted in MNRAS (Stark et al. 2013b). The discovery of this population is motivating detailed investigations with other facilities. Time has been awarded to follow-up these sources with Keck AO-assisted near-IR IFU spectroscopy and moderate resolution optical echelle spectroscopy.

Three MMT nights awarded in 2014A for exploration of a new population of nearby metal poor galaxies. Two nights were cloudy. One night of useful data taken. Observations have resulted in discovery of one of the most metal poor galaxies known (see MMT proposal). First paper describing the new sample has recently been submitted (James, Koposov, Stark et al. 2014).

Summary: 11 nights awarded, catalog paper describing survey published in MNRAS (Stark et al. 2013). Detailed follow-up underway. First data taken for new program targeting blue diffuse dwarf galaxies in Jan 2014. One paper submitted.

Magellan: Two nights were awarded with Magellan/FIRE in 2012B to follow up lensed galaxies. Conditions were cloudy and no data were acquired.

⋆ Two nights were awarded with Magellan/FIRE in 2013A to obtain the first detection of CIII] at $z \gtrsim 6$. Clouds and poor seeing prevented acquisition of any useful data on the primary program. In short gaps in the clouds, we were able to obtain constraints on rest-optical emission lines in one of our reionization-era analogs. Results are included in Stark et al. (2014a).

One night awarded for June to target metal poor reionization-era analogs with FIRE. Data taken and are part of a paper in preparation by Steward graduate student Ramesh Mainali.

⋆ Two nights awarded from Steward in November 2014 to target $z \simeq 6-8$ galaxies with FIRE. Results from time allocated to Carnegie have been discussed above and shown in Figure 2. Several papers in preparation.

Summary: 5 nights allocated for various programs. No useful data taken for primary program owing to poor weather conditions. One clear night in June. Two scheduled for November. One paper published, and several more are in preparation.

LBT:

Two nights are allocated with LUCI in 2013B to observe bright lensed galaxies at $z \simeq 2-3$. Program could not be completed because LUCI was broken. Instead we acquired $\simeq$ 3 hrs of imaging of gravitationally-lensed galaxies from Stark et al. (2013) using MODS in cloud and poor seeing (1.5-2$''$). Data will be written up in a paper by Ramesh Mainali.

⋆ Two nights allocated in 2014A with LUCI to target CIII] in a $z \simeq 7$ galaxy with confirmed redshift. No data taken owing to instrument problems.

Summary: Four nights allocated with LUCI, but no data on primary science programs yet acquired.

Bibliography (papers from proposals led by PI on Steward facilities in last two years):

Stark et al. 2013, MNRAS, 436, 1040
Stark et al. 2014a, MNRAS in press, arXiv:1408.1420
Bian, Stark, et al. 2014, submitted to ApJ
James, Koposov, Stark et al. 2014, submitted to MNRAS