OBSERVING REQUEST
University of Arizona Observatories

Year: **Term:** Jul–Dec **Proposal type:** short-term

Confirming the most extreme starbursts

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CoI(s): Mehta⋆ (UMN)

Abstract of Scientific Justification

We propose to use the MMT/Hectospec to build a statistically significant census of extreme emission line galaxies selected through broad band colors in the SXDS field. We have already confirmed our selection function, and our goal is now to categorize these extreme emission line galaxies. It is plausible that they are star-forming LAEs hosting population III stars, or that they are faint QSO with unusually high EW. They could also be local starbursts with very high ionization parameters but also moderate nebular oxygen abundance, deviating from the mass–metallicity relation. Nearby low luminosity AGN are also a possibility.

Our main goal is to find the emission line responsible for the g–band excess. Should this be Lyα we may see the characteristic asymmetric profile caused by resonance scattering in an outflowing ISM (Kunth et al 1998), or the presence of NV1240 or CIV1550Å lines redwards of Lyα. Should they be [OIII]5007Å emitters then we will also be able to identify [OII]3727Å and Hα. For LAEs we may search also for signatures of HeII1640Å emission and for the extreme sturbursts we will observe Hα+[N II]6584Å to measure their metallicity by strong-line methods.

This proposal is a U. Minnesota GTO request.

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/9	Hectospec			2	grey	Sep–Nov	Sep–Dec	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*:

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	SXDS field	02:18:00	-5:00:00	$r = 24$

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 if student is PI on the cover page or if this is a 2nd-year or Thesis program. Send confirmation email to TAC chair in place of signature.)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis
V. Mehta	C. Scarlata		no	yes

Scientific Justification

Much of our knowledge of the high redshift galaxy population is derived from broadband color-selection. Most successfully the Lyman-break method (e.g. Steidel et al 1996) has been widely employed to find galaxies at $z \geq 3$ by virtue of a strong redshifted spectral break, and has recovered tens of thousands of galaxies out to $z \sim 11$ (Bouwens et al 2011; Coe et al 2013; Ellis et al 2013), down to $z \sim 1$ (Oesch et al 2010; Hathi et al 2013), although most are around $z = 3 - 4$ (Reddy et al 2008 and many others).

Complementary to selection by stellar continuum as for LBGs, much ground has also been broken by selecting galaxies by their nebular gas emission; at high–z this mostly means redshifted Lyman alpha (Lyα; Cowie et al 1998; Rhoads et al 2001; Ouchi et al 2003; Gawiser et al 2006; Nilsson et al 2007; Hayes et al 2010). The biases implicit in emission line selection are very different from those of continuum surveys, enabling us to find intrinsically fainter galaxies. Spectroscopic studies of Lyα-emitters (LAEs) and LBGs, their similarities and differences, therefore provide at least two of the observational cornerstones of high-z galaxy studies (e.g. Verhamme et al 2008, Hayes et al 2011; Stark et al 2011).

Most LAEs have been found by narrowband imaging surveys: when the redshifted line falls inside the bandpass, galaxies are easily selected by their narrowband/broadband color. Typically surveys are sensitive to observer frame equivalent widths (EW) higher than the FWHM of the NB filter (few tens of Å in the rest-frame), and lower EW LAEs (20–40Å) are numerous at high-z. Lyα radiation is simply the reprocessed ionizing continuum produced by stars and AGN, and thus its EW provides a measure of the relative luminosities at ionizing and non-ionizing UV wavelengths. This in turn may act as a tracer for exotic systems/extremely low metallicity stellar populations (Schaerer 2003) of which several observational claims have been made (e.g. Malhotra & Rhoads 2002, Kashikawa et al 2012). Very strong line emitters are rare and the small volumes probed by narrowband surveys tend to be insufficient to find them. Thus we do not know much about their nature, and given the use of Lyα surveys in many areas of astrophysics (including reionization, large scale structure, cosmic star-formation) this represents a major shortcoming.

Alternatives do exist. Should the Lyα EW be high enough, it may even contribute significantly to broadband fluxes, and LAEs with EWs in excess of 100Å restframe [$\times(1+z)$ for observed EW] are possible to identify by broadband color selection. In multicolor surveys this essentially opens up the entire redshift range and indeed Prescott et al (2012, 2013) have done precisely this. The more commonplace lower EW LAEs will of course not be found by such a method, but it is likely that the rare galaxies that are identified will be extreme ones – very high EW, extended Lyα-blobs in the case of Prescott et al. After paying careful attention to the evolution of galaxies' spectral colors (Fig 1), we have recently discovered that a large number of these galaxies are hiding amongst the catalogues of the Sloan Digital Sky Survey. SDSS Stripe 82 (Annis et al 2011) is some 2 magnitudes deeper than the standard SDSS observations and it covers an enormous 275 square degrees: this is > 30 times larger than the already impressive 8.5 deg^2 Lyα search of Prescott et al. After focussing on regions of low Galactic extinction and removing transient objects, we have performed a systematic search of the Stripe 82 u, g, and r catalogues and isolated a sample of g–band excess objects. This is sensitive to emission lines that correspond to Lyα at $2.35 < z < 3.2$, and the volume of our (restricted) survey exceeds a billion Mpc^3, exceeding every other LAE survey by orders of magnitude.

Naturally the objects are very bright and high EW, but their extreme nature is precisely the goal. Using the LBT and Palomar 5.1 meter Hale telescope, we have taken spectra of four of these candidates, and showed that they are all strong emission line objects: one is clearly an AGN (showing Lyα, NV and CIV at $z = 2.35$; two a narrow line LAEs at $z = 3.1$; and one is a local starburst galaxy with extremely strong [OIII] emission. This confirms the validity of our selection method for high-z galaxies, which includes, as always, a fraction of interlopers. However these interloper galaxies are not less interesting: they are $10\times$ fainter equivalents of the "green pea" galaxies (very high EW [OIII] emitters), also found SDSS by Galaxy Zoo volunteers, which have attracted much attention in recent years (Cardamone et al 2009; Amorin et al 2010).

Here we propose to extend the search for extreme LAEs and starburst galaxies to even fainter continuum. In particular, we have applied our successful criteria to the deep data available in the SPLASH SXDS field, and identified ~ 400 galaxies a magnitude fainter in the continuum than those discovered in the SDSS–Stripe82 area, i.e., down to $r = 24$AB. Our goal is to categorize these extreme emission line galaxies. It is plausible

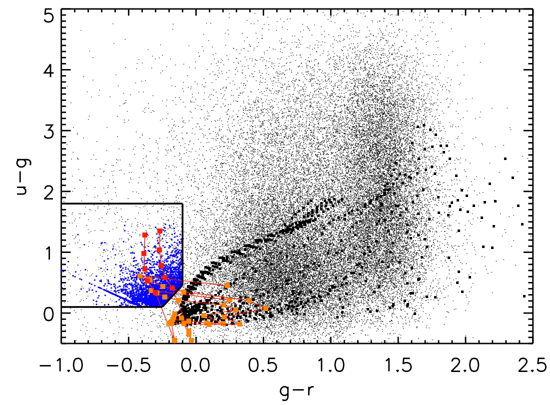

Figure 1: Color-color selection of $z \sim 2.5$ LAEs and low-z high EW galaxies. Blue points inside the selection region show the candidates high–EW galaxies. Dots show the colors the general galaxy population. Black small squares show synthetic colors computed for a variety of models with different ages, and no emission lines. Orange squares show synthetic models for emission line galaxies going from $z = 0$ to $z = 2$. Red squares show colors of LAEs at $z > 2.2$.

that they are star-forming LAEs hosting population III stars, or that they are faint QSO with unusually high EW. They could also be local starbursts with very high ionization parameters but also moderate nebular oxygen abundance, occupying a corner far from the mass–metallicity relation. Nearby low luminosity AGN are also a possibility.

Our first goal is to find the emission line that causes the g–band excess. Should this be Lyα we may see the characteristic asymmetric profile caused by resonance scattering in an outflowing ISM (Kunth et al 1998), or by the presence of NV1240 or CIV1550Å lines redwards of Lyα. Should they be [OIII]5007Å emitters then we will also identify [OII]3727Å and Hα. For LAEs we may search also for signatures of HeII1640Å emission and for peas we will observe Hα+[N II]6584Å to measure their metallicity by strong-line methods. Subsequent analyses will include many "standard" methods: NIR spectroscopy, optical SED fitting and so on, but the logical next step is to build a statistically meaningful spectroscopic sample.

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)***

The goal of this program is to characterize the nature of extreme emission line galaxies identified via an excess of flux in the g band, with respect to the adjacent u and r band filters. Therefore, we are after strong emission lines in the $4000 - 4500$Å wavelength range. The field of Hectospec makes it an ideal instrument for this study. We propose to use Hectospec with the 270 gpm grating to observe the region that includes the expected emission lines. This grating provides a resolution of 5Å and so corresponding velocity resolution of about 300 km sec^{-1}. Although this is not ideal to accurately measure the asymmetry of the Lyα profile, the extended wavelength range will provide us with additional lines for redshift identification.

The galaxies will span a range of magnitudes with $r < 24$ (SDSS r) within the fiber aperture. The goal of the spectroscopic observations is to reach a $S/N \geq 3$ in the continuum, in order to confirm the detection of the emission lines with high significance. In order to estimate the exposure times, we used the SAO ETC (V0.5). We find that we can reach the required S/N in the g band in 10 hours, assuming gray conditions, a seeing of $1''.0$, and a typical size of these galaxies of $0''.6$ (i.e., unresolved in typical seeing conditions). Our objects are located within a field of $\sim$0.8 deg^2 centered around (34.55,-4.84). The source density (~ 400 in the full field) ideally matches the number of available fibers. With overheads and allowing for either some moon or poorer than ideal seeing, which will increase our exposure times, we request the equivalent of two nights for this program.

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**)*

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 – 2 Nights 2017A – ”Outflows in Emission and Absorption: Is resonant Mg II a good measure of galaxy winds?” Data have been obtained on March 28/29.

Other Information *Provide any additional program-related information including, for example, relation of current program to externally funded research, to the development of expanded capabilities for UA telescopes, or to individual timescales (e.g. PI is finishing postdoc appointment and this request would complete program). (**up to one page**)*

LaTeX 2_ε UAO Observing Proposal class, ’soprop.cls’ v1.3 (2007 Aug 01 [RAJ]).