OBSERVING REQUEST
University of Arizona Observatories

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

Optical spectrometry of emission-line objects in the COSMOS field

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CoI(s): James Rhoads (ASU), Sangeeta Malhotra (ASU)

Abstract of Scientific Justification

Deep surveys using narrow-band filters permit the identification of emission-line objects at various redshifts. The Deep And Wide Narrow-band survey (DAWN) at $10660\AA$ is a uniquely deep, sensitive, and wide-area infrared narrowband survey and has permitted the identification of hundreds of emission-line objects. Here we propose to use the Hectospec spectrograph at the MMT telescope to obtain optical spectra of $\sim$ 500 of these objects. Our work will **(a)** extend the faint end of the $z = 0.6$ Hα and $z = 1.1$ [OIII] luminosity functions; **(b)** extend the equivalent width census of emission line galaxies, and determine whether modest-EW sources significantly affect the overall star formation rate; **(c)** extend the mass-metallicity relation to lower masses for $z = 0.6$ Hα emitters; and **(d)** characterize of a subset of objects with a photometric redshift of $\sim$ 0.3 whose nature is unknown.

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			2	grey	Feb–Apr	Jan–Apr	yes	no

Scheduling constraints and unusable dates *(up to 4 lines)*: During the bright nights of February and March the Moon is too close to our target field, making those nights unusable

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	COSMOS field	10:00:29	+02:14:24	

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 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
Alicia Gonzalez	James Rhoads		no	yes

Scientific Justification

Description of the survey

The Deep And Wide Narrow-band survey (DAWN) a uniquely deep, sensitive, and wide-area near infrarred narrowband survey. It is done using a custom-made narrow-band filter (35 Å wide) centered at 10660 $\AA$. DAWN is an NOAO survey project, using the 4-meter Mayall telescope (Kitt Peak National Observatory, Arizona) and the NEWFIRM instrument. It was awarded 40 nights over the course of two years. As of this writing, 20 nights have been completed and the rest will take place over this fall and next spring.

The purpose of this survey is to detect emission-line galaxies, especially those too faint to be discovered and studied in prior surveys. The nature of the filter employed permits the detection of various emission-lines at specific redshifts, with the most prominent being Hα emitters at z$\sim$0.62 and [OIII] at z$\sim$1.13 and at z$\sim$1.5. The narrow-band available right now is equivalent to an integration time of 65 hours or a 5σ limit detection of 7.7$\times$ 10^{-18} erg/cm^2/s (equivalent to an AB magnitude of $\sim$ 24) on the COSMOS field (RA$\sim$ $150°$, DEC$\sim$ $+2°$).

Selection of NB emitters

The qualitative method for detecting those objects is looking for objects that are much brighter in the narrow-band images than in the broad standard J filter. This criteria permits the identification of objects with a prominent emission-line but a low continuum level. The J-band imaged employed comes from the UltraVISTA Survey Data Release 1. [1]

The detection process starts with calibration of both images, so they have the same zero point. We then use SExtractor to detect all the objects in the narrow-band image and their counterparts in the J-band image. The objects selected as emission-line have fluxes in the narrow-band of at least 1.5 times the flux in J band. They also show a color significance of at least 2.0.

$$\frac{f_{10660A}}{f_{J-band}} \geq 1.5 \qquad\qquad \frac{f_{10660A} - f_{J-band}}{\sqrt{(\Delta f_{10660A})^2 - (\Delta f_{J-band})^2}} \geq 2$$

The redshift of the objects detected has been acquired by comparison with the magnitude limit 25 COSMOS Photometric Redshift Catalog [2]. However, around 200 objects detected in our survey don't appear in this catalog. The spectroscopic analysis of these objects will lead to the determination of their redshift. We expect the majority of these non-matched objects to be to be faint [OIII] emitters at $z \sim 1.13$, Hα emitters at $z \sim 0.62$, and [OII] emitters at $z \sim 1.84$. The Hectospec spectral coverage will include prominent lines for all cases except the [OII] emitters.

Luminosity function

The first result obtainable from the spectroscopy of these objects is the extension of the faint end of the luminosity function for Hα and [OIII] emitters.

Previous surveys have successfully studied the brightest objects of these kinds, but the faintest ones still remain unstudied, as they were too faint to be detected in previous surveys. Our candidates have been selected from the deepest survey available, so this project includes objects too faint to be included in previous works. The optical spectra of this emission-line objects will therefore extend the luminosity function of these kind of objects at the stated redshifts (z $\sim$ 0.62, z$\sim$1.1).

A similar survey designed to detect Hα emitters at a z=8.8 and carried out with the same instrument and a narrow-band filter centered at 11800 $\AA$ (NewHα survey [3]) presented a limiting AB magnitude of 23.63-23.74 at a 3 σ level, equivalent to a 3σ limit detection of 1.9×10^{-17} erg/cm^2/s. This number equates to a 5σ limit detection of 2.85×10^{-17} erg/cm^2/s. If we compare these numbers to the DAWN survey, which has a 5σ limit detection of 7.7×10^{-18} erg/cm^2/s, we can see that the DAWN survey reaches objects up to 4 times fainter.

The NewHα survey covers a comoving volume of $9.12 \times 10^4\ h_{70}^{-3}\ Mpc^3$ at z=0.8 while the DAWN survey covers $\sim 2.83 \times 10^4\ h_{70}^{-3}\ Mpc^3$. That means the NewH$\alpha$ survey covered a volume approximately 3 times bigger than the DAWN survey.

Despite surveying a greater volume, the fact that the NewHα survey can't detect the faintest objects translates into a big uncertainty in the calculations of the Schechter parameters at the faint end.

A combination of the bright objects already studied with the fainter ones that we now propose to study would lead to a better understanding of the whole brightness range of emission line objects at various redshifts. This would be a big contrast to the current knowledge, which has substantial uncertainties in the faint end slope particularly, since prior samples are missing the faintest objects.

Bump at $z \sim 0.3$

The second result we can obtain from the optical spectra of some of the candidates is the characterization of those objects with a photometric redshift of around 0.3.

This redshift corresponds to a rest wavelength of 8200 $\AA$. Given the nature of the candidate selection, all the objects we are proposing to study are emission-line objects. However, there are no prominent emission lines at the wavelength stated. The spectroscopic characterization of the objects will lead to a clarification on their nature.

Completing the Equivalent Width Census In addition to exploring fainter flux levels than competing narrowband surveys, the DAWN survey also explores a more complete range of emission line equivalent widths. Selecting emission line sources by narrowband excess involves a threshold in f_ν(NB) / f_ν(BB), which we set at a factor of 1.5 (i.e., an 0.45 magnitude narrowband excess). Significantly smaller factors are generally impractical, as continuum slope variations can introduce $\sim 10\%$ variations in f_ν(NB) / f_ν(BB) even in the absence of line emission. For our 35$\AA$ filter, a factor of 1.5 in flux density corresponds to an observer-frame equivalent width of 17.5$\AA$. For the more conventional 1% narrow bandpass filters, the corresponding limit is $\sim 3\times$ greater.

Thus, DAWN survey followup will allow us to determine how much star formation is ongoing in objects of comparatively modest equivalent width, and so quantify a potentially significant gap in our understanding of the z$\sim$ 0.6 star formation rate.

The Mass-Metallicity Relation

Metallicity (z_{gas}) of galaxies increases with M_{star} ([4]) for z=0 galaxies of moderate mass. At higher redshifts, the M_Z relation shifts toward lower Z (e.g., [5]).
It has been suggested that a second parameter, the specific SFR (SFR/M_{star}); hereafter, sSFR), is anti-correlated (at a given M_{star}) with metallicity ([6]. Accounting for the higher sSFRs seen in typical high-z galaxies, it is even possible that galaxies at $z \lesssim 3$ might obey an unchanging "Fundamental Mass Relation" (FMR; [7]). One explanation for the strong sSFR dependence is the possible influence that stellar feedback has on the interstellar medium (ISM). In fact, observed blue-shifted absorption lines reveal the presence of out-flowing gas in star-forming galaxies (e.g., [8]). However, others have disagreed, proposing different $M_Z S$ relations (e.g., [9]).

So far, metallicity measurements have been done for continuum selected galaxies (e.g. Tremonti et al. 2004, Zahid et al. 2011 at z=1, Erb et al. 2006 at z 2). At the other extreme, galaxies with high equivalent width emisison lines have a mass-metallicity relation that is displaced to lower metallicities by about 0.6 dex; perhaps due to high specfic star-formation rates (e.g. Xia et al. 2012, 2014; Ly et al. 2014, Finkelstein et al. 2011). The current sample of emission line galaxies spans the parameter space between continuum selected galaxies (which are relatively high stellar mass) and high equivalent width emission line galaxies which have extreme specific star-formation rate. In this sample we have galaxies with modest equivalent widths and yet probe low stellar masses. Thus we have the potential to see if the mass-metallicity relation is continuously dependent on the star-formation rate (i.e. does it fall on the Fundamental Metallicity Relation –FMR).

References

[1] McCracken et al. 2012

[2] Ilbert, Capak, Salvato et al. 2008, ApJ 690:1236
[3] C. Ly, J.C. Lee, D.A. Dale et al. 2011, ApJ 726:109
[4] Zaritsky 1994, Tremonti et al. 2004
[5] Erb et al. 2006
[6] Ellison et al. 2008
[7] Mannucci et al. 2010
[8] Weiner et al. 2009
[9] Yates et al. 2012, Lara-Lopez et al. 2013

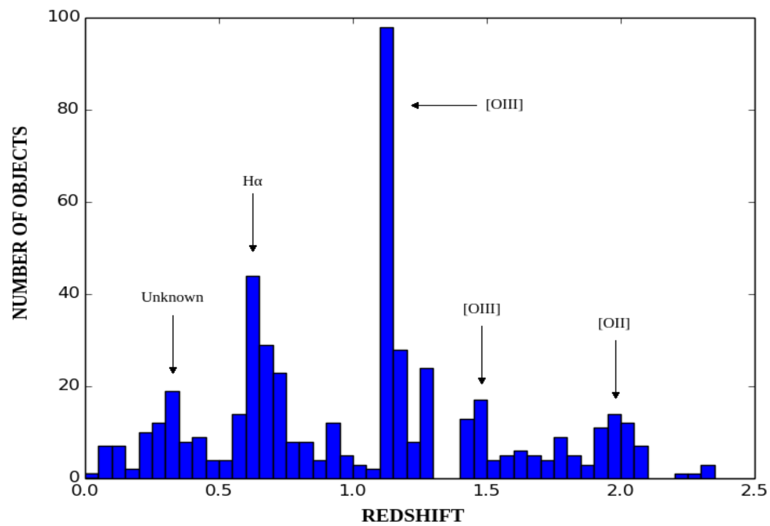

Fig. 1 Histogram of the objects from DAWN survey with available photometric redshifts.

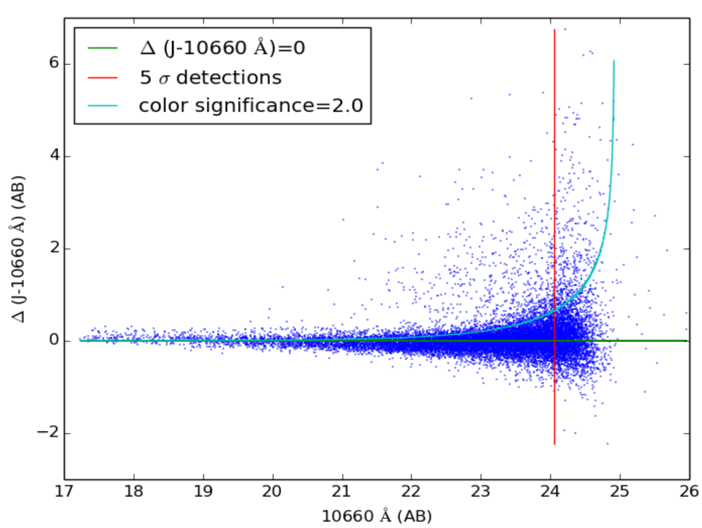

Fig. 2 Color-magnitude plot ilustrating the selection of emission-line objects.

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 observational goal of this project is to obtain optical spectra for a sample of objects detected during a narrow-band survey at a wavelength of 10660 $\AA$. The objects to study lie in one out of five categories: H emitters at z$\sim$ 0.62, [OIII] emitters at z$\sim$1.1, [OIII] emitters at z$\sim$1.5, unknown sources at z$\sim$0.3 or sources with no available photometric redshift.

Exposure depth

The narrow-band flux of our targets lies between 5x10^{-18} and 5x10^{-16} erg cm^{-2} s^{-1}. Our previous experience using this instrument tells us that a 5 sigma flux limit of 3 x 10^{-17} erg cm^{-2} s^{-1} can be achieved in 1 hour of Hectospec observation considering a seeing of 0.5-0.8". This implies that we would need 2 nights (around 16 hours) in order to achieve a 5 sigma flux limit of 7.5x10^{-18} or a 3 sigma flux of 4.5 x 10^{-18} erg cm^{-2} s^{-1}.

Sample size

For the whole set of science objectives we have about 500 emission-line selected objects distributed in 28x28 $arcmin^2$, which corresponds to a field of view of 0.22 degrees. Just under 300 of these have published photometric redshifts. The nature of Hectospec, with a field of view of 1 degree, permits the coverage of our full survey field in just one pointing. We will use $\sim$ three fiber setups in total, with the faintest sources placed on all setups, and brighter sources in just one setup. That way we can cover all our objects in the requested time. All the objects identified with a corresponding photometric redshift available will show interesting features in the Hectospec range of operation (3650 - 9200 $\AA$), which makes it an ideal instrument for studying them. In the case of those objects with photometric redshifts of z$\sim$0.3, this kind of spectra will lead to the identification of their nature. Regarding the objects not included in the photometric redshift catalog, optical spectra will permit the calculation of their redshift. Furthermore, as most of them are expected to be either Hα or [OIII] emitters, further analysis of their characteristics will be posible.

Lunar justification

The nature of this project permits carrying out the observations during grey nights. During the bright nights in February and March 2015 the Moon will close enough to our field to interefere with the observations, making those nights 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 the first request from UAO for this project, and should be sufficient to confirm spectroscopically the emission line sample in the COSMOS field.

The DAWN survey is based on a 40-night Kitt Peak survey program using the Mayall telescope and NEWFIRM.

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)***

The PI has had no previous time allocation through UAO.

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 $\sim$ 4x 10^{-18} 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.