OBSERVING REQUEST
University of Arizona Observatories

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

Finding missing quasars and massive early-type galaxy lenses in the COSMOS/UltraVISTA field

P.I.: Jinyi Yang⋆ (SO; *jinyiyang@email.arizona.edu*; 520-834-9191)
CoI(s): Xue-Bing Wu (Peking University), Xiaohui Fan (SO), Dezi Liu⋆ (Peking University), Feige Wang⋆ (SO)

Abstract of Scientific Justification

We have selected 265 quasar candidates and 112 massive early-type galaxy lens candidates in the 1.5 deg^2 COSMOS/UltraVISTA field. In 2015A, we propose to obtain deep MMT/Hectospec spectroscopy in a single 1 deg^2 field that includes 247 quasar and galaxy lens candidates. The COSMOS/UltraVISTA field has the deep Subaru and CFHT optical photometric data, as well as HST/ACS images which are crucial to separate point sources from galaxies. With the additional UltraVISTA deep near-infrared photometry and two newly proposed quasar selection criteria, we will construct the most complete sample of quasars in the COSMOS/UltraVISTA field, especially by efficiently finding quasars at redshift range of 2 $\sim$ 3 that were missing from previous optical-based selections. We have found 265 quasar candidates with i<23.5 based on the Y-K/g-z and J-K/i-Y quasar selection criteria, including 46 normal quasar candidates with photometric redshift at $2 < z < 3$ and 69 dust-reddened quasar candidates. The new, complete sample of spectroscopically confirmed quasars will allow us to study the quasar luminosity function at intermediate redshift range, and set a further constraint on the poorly determined fraction of dust redden quasars. In addition, we have also selected 112 massive early-type galaxy lens candidates in order to study the mass distribution model of dark matter as well as the evolution of initial mass function in these systems. We select a 1 deg^2 area within the COSMOS/UltraVISTA field for a single MMT/Hectospec pointing and request 0.6 night for spectroscopic observations reaching $i \sim 23.5$.

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	*		0.6	dark/grey	Mar-Apr	Feb-May	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	Plate 1	10:00:24	02:12:00	Center of one degree field; $18 < i < 23.5$

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
Jinyi Yang	Xiaohui Fan		no	yes
Dezi Liu	Zuhui Fan		no	no
Feige wang	Xiaohui Fan		no	no

Scientific Justification

Researches based on various quasar samples have given us much information about the large scale structure, galaxy formation and evolution, and accretion history of SMBHs. However, quasar samples, especially those based on optical selection technique, still suffer from significant selection incompleteness (e.g., Richards et al. 2002). A complete survey at redshift $2 < z < 3.3$ remains a main challenge. For most surveys, the distribution of quasar redshift exhibit a glaring a gap at redshift range of $2 < z < 3.3$, while a predicted density peak of quasars at z $\sim$ 2-3 has been proposed by many previous studies. This significant incompleteness at $2 < z < 3.3$ is a consequence of the contaminations contributed by stars with similar optical colors as quasars (Fan 1999), which is a serious limitation for building quasar luminosity function (QLF) from lower to higher redshift over this peak and understanding the evolution of nuclear activity with cosmic time (Assef et al. 2011). Therefore, finding missing quasars at $2 < z < 3.3$ is a key task for studying quasar evolution at this redshift range.

Recently Wu & Jia (2010) proposed two new selection criteria(Y-K/g-z, J-K/i-Y), by combining optical and near-IR colors, for selecting quasars with $z < 4$ and $z < 5$ respectively. Recent spectroscopic observations carried out by Wu et al. (2010a,b, 2011) have demonstrated the effectiveness of near-IR selection in discovering the SDSS missing quasars with $2 < z < 3.5$. We propose to find missing quasars in the COSMOS/UltraVISTA field using this method. COSMOS field has multiwavelength imaging from X-ray to radio wavelengths covering a 2 deg^2 area, including HST imaging covering $\sim$1.5 deg^2. Based on these multiwavelength data, more than 300 quasars have been identified in this field so far by various groups. But the expected number in the COSMOS field is about 600 (Scoville et al. 2007; Croom et al. 2001), which means that some quasars are still missed. In addition, from the quasar redshift distribution, we still note an obvious gap at the redshift range $2 < z < 3.3$ (See (Fig.2)). A more complete sample of quasars at redshift range $2 < z < 3$ is necessary for COSMOS. With the new ultra-deep near-infrared survey (UltraVISTA, McCracken et al. 2012) in COSMOS field, the two optical/near-IR color selection criteria can be useful in finding missing quasars. We have selected quasar candidates based on the COSMOS/UltraVISTA Ks selected catalog (Muzzin et al. 2013). The available HST/ACS data is further utilized for the separation of point sources and extend sources. Figure 1 illustrated our selection technique when applied to COSMOS data. Figure 2(top panel) shows the comparison between the redshift distribution of known quasars and the photometric redshifts of our new quasar candidates. Our project will add tens of quasars at $2 < z < 3.3$. Spectroscopically identification will help us to check the robustness of our selection and construct the most accurate QLF in the COSMOS field. In addition, our quasar selection criteria are also very effective for selecting dust redden quasars (Wu et al. 2013). Among our candidates there are 69 dust-reddened quasar candidates which also meet the highly complete optical/near-infrared red QSO selection criteria posed by Fynbo et al.(2013). It supports that they are efficient at selecting both unobscured and obscured quasars. With spectroscopic identification, we will put strong constraints on the fraction of redden quasars by our unbiased selection criteria. We will also construct a redden quasar template to be used for calculating photometric redshift and extinction properties of dust redden quasars.

Additionally, we select 112 massive early-type galaxies lens candidates for the study of lensing effect. Faure et al (2008) found 67 strong elliptical galaxy lens candidates (F814w <25mag) in the COSMOS field for the first time only with optical photometry (Fig. 3). The photometric redshifts of these candidates range from 0.22 to 1.05. Deep optical/near-IR colours will help us to select more elliptical galaxy lens candidates. We first use UVJ color method to select early-type galaxies (i<22), and then visually inspect them to generate the sample of potential strong lensing systems. With spectroscopic observations, it is promising to perform more valid estimate of the mass distribution and associated dark matter halo, which is great important for the study of cosmology and the formation and evolution of such galaxies. For such systems, singular isothermal sphere (SIS) profile is a reasonable proxy of the mass distribution of early-type galaxies. Therefore, we simply utilize SIS profile to model the surface mass density of lenses. Additionally, the Sersic profile is used to model the light distributions to provide further constraints on the lensing systems. With the spectroscopy information, we can utilize the typical metal absorption lines to infer the stellar mass and mass-to-light ratio which are necessary for IMF study. In addition, one remarkable importance of early-type galaxy lens is that we can obtain more accurate dynamical mass estimate. However, all of these require us to perform spectroscopic observations to obtain accurate redshifts.

References

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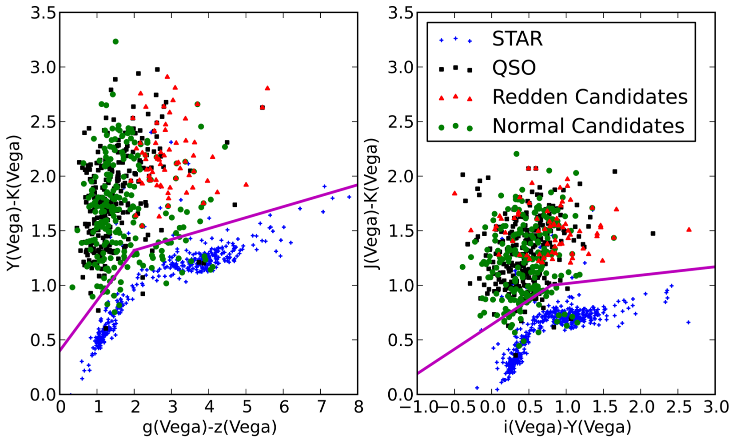

Figure 1: The Y-K/g-z and J-k/i-Y color-color diagrams of the spectroscopically identified quasars (black), stars (blue), normal quasar candidates (green) and dust-reddened quasar candidates (red).

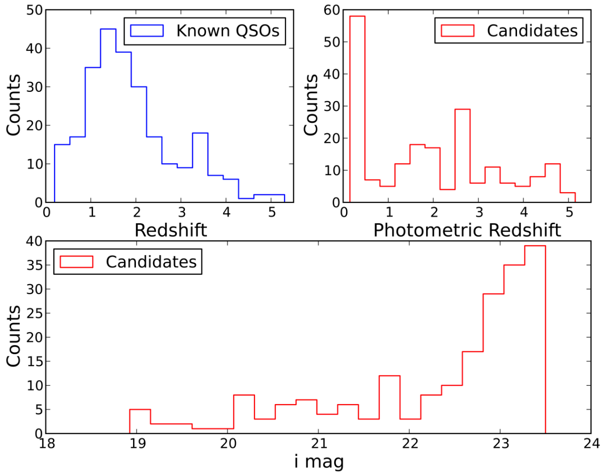

Figure 2: $UpperLeft$: The redshift distribution of previously identified quasars in the COSMOS field. There is an obvious gap at the redshift range $2 < z < 3.3$. $UpperRight$:The photometric redshift distribution of our quasar candidates. The photometric redshifts show that our selection can be expected to effectively find missing quasars, especially for $z \sim$ 2-3. $Bottom$:The i band magnitude(AB) distribution of our quasar candidates.

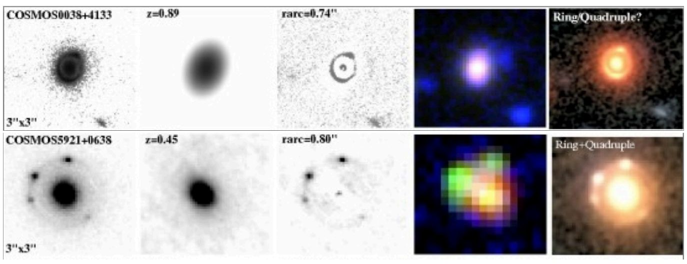

Figure 3: Two brightest elliptical galaxy lens candidates found by Faure et al.(2008), with F814W magnitudes are 20.5 and 20.6, respectively.

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)***

Targets selection: Our selection of quasar candidates involves the following steps: (1)To separate point sources from galaxies. The HST/ACS data is further utilized for the separation. We use HST/ACS data to remove most galaxy contaminants effectively. (2) We use the Y-K/g-z and J-K/i-Y coloc-color selection to select quasar candidates (See Fig.2). 250 of 253 known quasars in the COSMOS/UltraVISTA field can be selected as quasars by these two color selection criteria; (3) Using photometric redshift estimation to remove most star contaminants. We limit the $\chi^2 < 15$. (4) We limit the i band magnitude with i < 23.5. After applying these selection criteria and removing all known objects, there are 265 new quasar candidates. Figure 2 shows the distribution of photometric redshift and i band magnitude of these candidates. Among our 265 candidates there are 69 dust-reddened quasar candidates which can meet the highly complete optical/near-infrared red quasar selection criteria posed by Fynbo et al.(2013). It supports that they are efficient at selecting both unobscured and obscured quasars. For galaxy lensing candidates, we first use UVJ color method to select a set of bright early-type galaxies (i<22), and then visually inspect them to generate the sample of potential strong lensing systems. We require all the systems have significant arcs within 5 arcsec radius and their photometric redshifts are in the range $0.2 < z < 1.0$. Under these criteria, we select in total 112 lensing candidates. Among these candidates, 53 are also detected by Faure (2008) with their photometric redshift. There are total 377 candidates within the whole 1.5 deg^2 field. For the observation on Hectospec, we will target 247 of 377 candidates within a 1 deg^2 circle field.

Configuration: Because Hectospec has 1 deg^2 field of view and 300 fibers, we will target quasar and galaxy candidates with $i < 23.5$ within the central 1 degree circle field. There are 247candidates within the 1 deg^2 circle field. Since Hectospec will not achieve 100% targeting efficiency due to fiber collision, we expect to be able to allocate $\sim$ 230 science fibers, and use the rest for standard stars and sky calibration. Since we propose to identify quasar candidates at 0.2 < photo-z < 5.1, we require a wide wavelength range $\sim$ 3000$\AA$ - 9000$\AA$ and a blaze wavelength $\sim$ 5000$\AA$. We do not need a high resolution for quasar identification using broad emission lines. Considering these, the grating of 270 lines/mm with wavelength range $\sim$ 3650$\AA$ - 9200$\AA$, blaze wavelength $\sim$ 5200$\AA$ and dispersion $\sim 1.21\AA$/pix is suitable for our quasar identification.

Exposure time: We base our estimate of required exposure time from the result of our Hectospec observations in 2013. During our 2013 run, using the same 270 line/mm grating, we found that we could reach a S/N of ~ 5 on the continuum for quasar candidates at $i = 22.4$ after 90 min exposure under good seeing. For our 2015A observations, we are requesting a total exposure time of 300 min, which will reach S/N ~ 4 on the continuum for quasars at i < 23.5; this is the minimum requirement to identify quasars with broad and strong emission lines (average observed equivalent width of Lyα is $\sim$ 200Å at $z \sim 2.5$). Similarly, this exposure time will yield a S/N of > 10 for our faint early type galaxy candidates at $i \sim 22$, sufficient for absorption line redshift determination. We will decide the observation into ten exposure of 30 min each for cosmic ray removal. Including overheads, our total request is 0.6 night.

Lunar Phase: Because we will do optical spectroscopy on fainter quasars and galaxies, we have to request dark or grey nights for our observations.

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**)*

MMT/Hectospec is the most effective optical multifiber spectrograph which is very suitable for targeting a complete faint quasar sample in a small area. We have used Hectospec to observed a sample of quasar candidates which also selected by our two color-color selection criteria in VVDS F22 field in Oct. 2013. Together with those quasars, we can make a complete study on the quasar luminosity function both in redshift desert and faint magnitude end, which is the mainly part of the PhD thesis of Jinyi Yang. Our proposed observations with MMT/Hectospec will form a unique, large and the most complete quasar sample in the COSMOS field. We will complete this project with the 0.6 night requested in the proposal.

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 the first proposal by the PI through UAO.

⋆ We have a related project on MMT through TAP program. We have selected a sample of faint quasars with $i < 22.5$ in a 1 deg^2 field within VVDS F22 field also based on our two color-color selection criteria and used Hectospec to observed those candidates in Oct. 2013. Together with those quasars, we can make a complete study on the quasar luminosity function both in redshift desert and faint magnitude end, which is the mainly part of the PhD thesis of Jinyi Yang.