OBSERVING REQUEST
University of Arizona Observatories

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

A Pilot survey of bright quasars at $3 < z < 6$

P.I.: Jan-Torge Schindler* (SO; *jtschindler@email.arizona.edu*;)

CoI(s): Xiaohui Fan (SO), Jinyi Yang (SO), Feige Wang (SO)

Abstract of Scientific Justification

We are proposing to carry out spectroscopic follow-up observations of 30 bright quasars candidates selected from the SDSS-ALLWISE dataset. We apply a new selection technique including near-infrared photometry from WISE that have been missed before due to their red colors. This pilot survey is a test of this selection technique and the first step of a long-term project to identify quasars across the entire sky using surveys like Pan-STARRS, 2MASS and WISE to build a large sample of bright quasars in the redshift range $3 < z < 6$ that cover more than twice the area of the current SDSS sample.

With this sample we will study the physics of black hole mass growth by accretion and mergers and the co-evolution of super massive black holes with their host galaxies. Also bright high redshift quasars are important tools to study the IGM in the era of reionization. Furthermore bright quasars in this redshift regime are also needed to populate the black hole mass function and the quasar luminosity function, two important statistics to study quasar and black hole evolution as a whole.

We request 5 dark/grey nights on the BOK/BCSpec or the VATT/VATTSpec to carry out our 30 pilot observations which are an important test for the long-term project.

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	Bok		BCSpec			5	dark/grey	Feb–Apr	Feb–May	no	no

or:

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1a	VATT		VATTSpec			5	dark/grey	Feb–Apr	Feb–May	no	no

Scheduling constraints and unusable dates *(up to 4 lines)*: Since I will take the written prelim at the beginning of February 2015 I ask to not be scheduled around that 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	Quasar candidates	8h-16h	-10 to +50	$z_{\mathrm{AB}} < 19$

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
Jan-Torge Schindler	Xiaohui Fan		no	no

Scientific Justification

Quasars at higher redshifts are important tools to learn about the co-evolution of galaxies and black hole growth. A recent publication by Trakhtenbrot et al. (2011) suggests that $z \sim 5$ quasars have higher accretion rates than those observed at lower redshifts. According to the authors these quasars are the progenitors for the most massive black holes observed at intermediate redshifts ($z \simeq 2.4$, $z \simeq 3.3$). To investigate these findings and further study the mass growth of the most massive objects a larger sample of bright quasars at redshifts of $3 < z < 6$ is necessary.

The quasar luminosity function is an important statistic in the study of quasar evolution and there have been numerous calculations of it at various redshifts (at z < 2.2 (Fan et al. 2001;Croom et al. 2009) ,at 2.2 < z < 3.5 (Ross et al. 2012; Palanque-Delabrouille et al. 2013), at $z \leq 4$ (La Franca et al. 2005), at 4.7 < z < 5.1 (McGreer et al. 2013),at z ∼ 6 (Jiang et al. 2009; Willott et al. 2010)). However the redshift range between $5.2 < z < 5.7$ of the QLF has high uncertainties due to the limited sample size of ~ 20 known quasars. This gap in the known redshift distribution of quasars stems from a degeneracy with late-type stars (M, L, T dwarfs) in the optical color selection. Especially the bright objects in this redshift range are missing. The most recent high redshift work of the QLF at $z \sim 5$ by McGreer et al (2013) only encompasses nine quasars in their sample that are brighter than i=20. This lack of luminous quasars in the QLF causes some uncertainties in its bright end slope.

Another important tool for understanding black hole mass accretion and growth or the co-evolution between supermassive black holes (SMBH) and their hosts is the black hole mass function (BHMF). Willott et al (2010) suggested that the evolution in the black hole mass function from $z = 6$ to $z = 0$ is of a factor of $\sim 10^4$. This is much larger than the $\sim 10^2$ increase in the stellar mass function over the same redshift interval. In combination with the local black hole to stellar mass relation (e.g. Haering et al. 2004) this evidence suggests that black holes grow very rapidly from $z = 6$ to $z = 0$. The previously mentioned publication of Trakhtenbrot et al. (2011, see Figure 1) argues that the first of such rapid growth phases happens around a redshift of $z \simeq 4.8$. To answer questions on when this growth phase begins and how black holes evolve a larger sample of quasars at this redshift range is needed.

In addition, observations of the Gunn-Peterson effect using absorption spectra of quasars at $z \gtrsim 5.7$ have established a redshift of $z \sim 6$ as the end of cosmic reionization, when the IGM is rapidly transforming from largely neutral to completely ionized (e.g. Fan et al. 2006). However, the detailed reionization history remains largely undetermined by current observation. The physical conditions of the IGM post reionization, at $z \sim 5 - 6$, provides the basic boundary conditions of models of reionization, such as the evolution of the IGM temperature, it's metallicity, the photon mean free path and the impact of helium reionization (e.g. Bolton et al 2012). All these measurable parameters place strong constraints on models of reionization topology as well as on the sources of reionization and chemical feedback by early galaxy population. However, the lack of known luminous quasars at $z \sim 5 - 5.7$ is a significant limiting factor to understanding this key era of reionization history.

We are targeting quasars in the SDSS footprint in this pilot survey to test a new selection algorithm for quasars based on near-infrared photometry from WISE. As shown in Figure 1 the average selection probability of quasars in SDSS is dependent on the continuum slope and the emission line strength. For quasars with $M_{1450} = -26.5$ the average probability drops to 40% for $\alpha > -0.9$ and 20% for $\alpha > -2.0$. As a consequence the current SDSS survey is less complete for redder quasars. Using optical and infrared colors we have developed a method to discover quasars at intermediate redshifts up to $z \approx 5$ (Wu $\&$ Jia 2010; Wu et al. 2011,2012,2013). If the near-infrared photometry from WISE is included in the SDSS quasar color selection quasars at redshifts $\gtrsim$2.2 are much more easlily distinguished from stars (see Figure 2). This quasars selection can be further improved by adding the W1-W2 color of WISE to select quasars at redshifts $z > 4.7$. This observation will definitely identify new quasars in the SDSS footprint and serves as a preparation to follow these quasars up with larger telescopes such as the MMT.

The long term goal is to use our advanced color selection criteria to build a catalog of bright quasars at $3 < z < 6$ over the entire sky. For this we will use the datasets from surveys like Pan-STARRS, 2MASS and WISE. We want to track the population of the most active AGN and most massive black holes to study the merger and accretion history of these objects in great detail. Furthermore bright high-redshift quasars are the most important probes to study the IGM in the era of cosmic reionization. And our sample will populate the bright end of the quasar luminosity function and help to constrain the bright end slope from $3 < z < 6$.

References

Bolton J.S. et al 2012, MNRAS, 419, 2880
Croom,S.M. et al., 2009, MNRAS, 399, 1755
Fan, X. et al., 2001, AJ 121, 31
Fan, X. et al., 2001, AJ, 121, 54
Fan, X., Carilli, C.L., Keating, B. 2006, ARA&A, 44, 415
Jiang, L. et al., 2009, AJ, 138, 305
La Franca, F. et al., 2005 ApJ, 635, 864
McGreer, I. et al., 2013, ApJ, 768, 105
Palanque-Delabrouille, N. et al. 2013, A&A, 551, A29
Richards, G.T. et al., 2006, AJ, 131, 2766
Ross, N.P. et al., 2012, ApJS, 199, 3
Trakhtenbrot, B. et al., 2011, ApJ, 730, 7
Willott, C.J. et al., 2010, AJ, 140, 546
Wu, X.-B., & Jia, Z., 2010, MNRAS, 406, 1583
Wu, X.-B. et al., 2011, AJ, 142, 78
Wu, X.-B. et al., 2012, RAA, 12, 1185
Wu, X.-B. et al., 2013, AJ, 146, 100

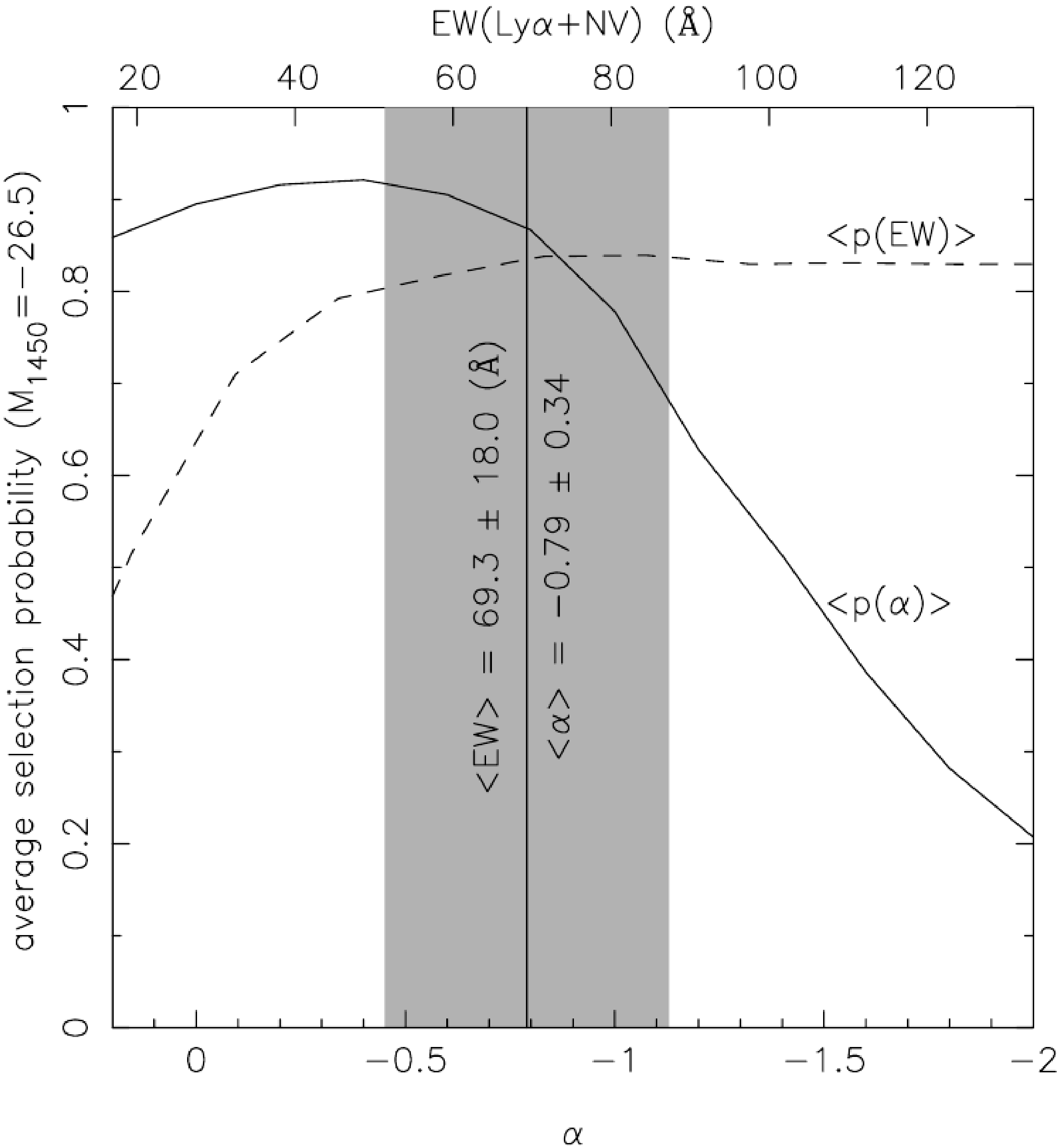

Figure 1: In this figure from Fan et al. (2001) the average selection probability of QSOs for $M_{1450} = -26.5$ over a redshift range of $3.6 < z < 5.0$ is shown. The solid line is the average probability as a function of the continuum slope, and the dashed line is the average probability as a function of emission-line strength for a pure optical color selection such as those used in the SDSS main survey. The shaded area shows the $1\,\sigma$ scatter of the distributions of continuum slope and emission-line strength measured from the SDSS sample. Our new selection will have high completeness for red quasars ($\alpha < -0.8$) because of the inclusion of IR photometry

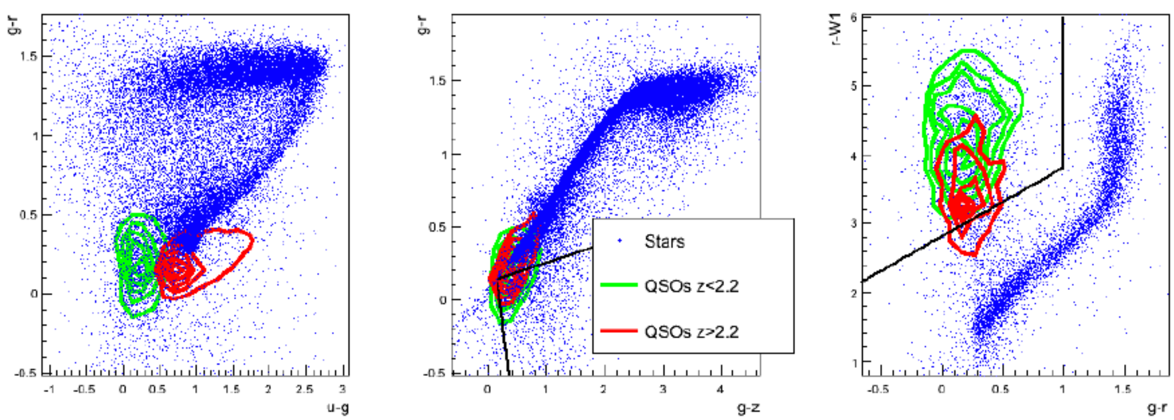

Figure 2: This figure, taken from the DESI Critical Design Review, shows the ugrz and near-infrared (WISE W1 band) colors of objects photometrically classified as stellar point objects (blue points) and those spectroscopically indentified as QSOs (green contours, $0.9 < z < 2.3$) and Ly-α QSOs (red contours, $z > 2.15$). Note the large discrimination between QSOs and stars in the right-hand panel where the r-W1 band color is shown. The black lines show the boundaries for color selection of QSOs.

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)***

Target selection: We are selecting our quasar candidates from the SDSS-ALLWISE sample, using catalogs of high-redshift quasar candidates selected from SDSS based on two different methods (extreme deconvolution & k-nearest neighbor). We ensure that only point sources with clean SDSS photometry are selected. In the next step we cross-match them with the ALLWISE dataset and carry out our color selection, limiting our sample to SDSS $r - i > 1.5$ and ALLWISE $W1 - W2 > 0.6$. We delete targets with SED shapes that show substantial differences to our quasar composite SED. Known quasars are then excluded from the sample and we consider objects for our pilot survey with RA between 8h-16h.

Configuration and exposure time: We propose to use either the Bok/BCSpec or the VATT/VATTSpec to do spectroscopic identifications of ~ 30 high redshifts quasar candidates ($3 < z < 6$). The Lyman-α line ($1215.67\AA$ rest frame) will therefore move from $4862.68\AA$ at $z = 3$ to $8509.69\AA$ at $z = 6$. Using the BCSpec the $400\,\mathrm{g/mm}$ grating in first order blazed at $7506\AA$ and a spectral coverage of $3411\AA$ allows us to identify quasars easily in the redshift range we proposed.

Alternatively we would use the $600\,\mathrm{g/mm}$ grating in first order blazed at $7500\AA$ and with a spectral coverage of $2000\AA$ on the VATTSpec.

In order to address whether these candidates are real quasars, we need the signal-to-noise ~ 5 per resolution element. Our 30 targets have z-band magnitudes of $z_{\mathrm{AB}} < 19$ and we thus require an exposure time of $\sim\ 30 - 60$ minutes for each target at the typical seeing of 1.2". Considering about 10-15 minutes overhead for each target and taking the spectra of flat-fields, lamps and several standard stars each night, we estimate the total exposure time we need is about 37 hours. Therefore, we request 5 dark/grey nights for the observations of 30 high redshift quasar candidates.

Lunar phases: As possible $z = 3 - 6$ quasars, our targets are faint in the whole optical window and much fainter in the wavelength shorter that $7000\AA$. The moon light will affect our spectroscopy significantly. We have to carry out our observations in dark and grey nights to ensure the quality of the spectra.

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**)*

We request 5 dark/grey nights on either the Bok/BCSpec or the VATT/VATTSpec to observe ~ 30 quasars. There is no non-UAO telescope associate to this program. This project is a pilot project for a survey of bright quasars $3 < z < 6$. In future time we plan to follow up observations on larger telescopes to expand our sample. If our pilot observations are successful, this project will likely grow into a key component of Jan-Torge Schindler's Ph.D. thesis.

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**)*

Jan-Torge Schindler is proposing for the first time as PI.