NOAO Observing Proposal *CNTAC proposal* **Panel:** *For office use.*
Date: September 30, 2000 **Category:** Active Galaxies

Spectroscopy of a Big Faint Quasar Sample

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
Faint quasar surveys are a necessary complement to bright surveys to enable separation of redshift and luminosity dependencies in quasar properties. Such surveys can also put strong constraints on massive galaxy formation models and on the quasar contribution to the UV and x-ray backgrounds by determining of the faint-end slope of the Quasar Luminosity Function (QLF) and its evolution from z=3.3–5. We have completed a 7 deg^2 BRI imaging survey for faint z=3.3-5 quasars with the CTIO4m + BTC. Our deep imaging enables quasar candidates to be selected to R=23.5, equivalent to $M_B=-23.5$ at z=4-5. We expect to find 115-220 z=3.3-4 and 13-40 z=4-5 quasars in our survey, enough to define the faint end of the z>3.3 QLF as accurately as the bright end is currently known. We propose identification spectroscopy of candidates to R=22.5 in half of our southern fields using the CTIO4m+RCSP. This survey will provide a sample of faint high-z quasars suitable for detailed spectroscopic studies of intrinsic quasar emission and absorption-line properties with 8-meter class telescopes, as well as studies of intervening absorbers, quasar host galaxies, and large-scale structure at z>3.3.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-4m	RCSP + BAS	3	dark	Feb - Jun	Feb - Jul
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Studying the evolution of the quasar luminosity function (QLF) is a simple yet insightful way to study the evolution of the quasar population. The QLF evolution consists of a rapid increase in space density and characteristic luminosity L^*_Q from z=0 to z=2, a peak at z=2–3, and a decline at z>3. Since quasar lifetimes are typically $<10^8$ yr, the QLF evolution reflects the evolution of conditions necessary for quasar activity rather than the evolution of individual quasars. The space densities and inferred black hole masses of quasars are consistent with quasars marking the early phases of massive galaxy formation in dark matter halos.[1] Thus, the QLF can be converted to black hole and halo mass functions which constrain galaxy formation models at high z. A more accurate QLF, especially at low luminosities, is needed to distinguish between current models.[2,3]

A full determination of the QLF at all M_B<-23 and all z<5 would be invaluable for study of the link between quasar and massive galaxy formation and many other topics in quasar research. The sample for such a project must be assembled from both wide, shallow surveys (e.g. 2dF[4] and SDSS[5], which will reach M_B~-24 at z<3 and M_B~-26 at z>3) and narrow, deep quasar surveys. We have conducted a deep 7 deg^2 BRI imaging survey from which we can select z>3.3 quasars to R=23.5 (Figs. 1-2), sufficient to reach M_B=-23.5 at all z<5. We propose spectroscopy of candidate z>3.3, R<22.5 quasars. This sample will **define the faint high-z QLF, complement bright high-z and faint low-z quasar samples, and provide targets for a variety of followup studies.**

- As the largest complete sample of faint z$\gtrsim$3 quasars in existence, this survey will determine the QLF slope at -26.5<M_B<-23.5 and its evolution from z=3–5 with accuracy equal to current data for M_B<-26.5. Recent studies[6,7,19,20] find similar z=4 quasar space densities at $M_B\gtrsim$-25, but differ when extrapolated to M_B=-23. WHO[6] and DPOSS[19] predict ~233 quasars in our survey; SSG[7] and SDSS[20] predict ~155. Our full 7 deg^2 sample will differentiate between these QLFs at the 5-10σ level, at luminosities where lensing amplification is not a concern.[16] The z>3 SDSS[20] QLF has a shallower slope than that of the z<3 2dF[4] QLF; our data on the QLF faint-end slope and z evolution will test this departure from the pure luminosity evolution seen at z<3. We will constrain the x-ray and UV backgrounds and evolution of the latter; low-luminosity quasars are thought to contribute significantly to these backgrounds because of their relatively high space densities.[8] The QLF also constrains massive galaxy formation models through comparison with theoretical studies of the interplay between dark halo collapse and black hole, quasar, and galaxy formation.[15]
- Quasars can provide constraints on the early chemical evolution of galaxies through measurements of N/C & N/He line ratios,[9] which suggest that the cores of luminous quasar host galaxies were already very metal-rich at $z\simeq4$. Our faint quasars may be less metal-rich, if they reside in shallower potentials (less capable of retaining gas against SNe-driven winds) than luminous quasars. Eventual 8m-class spectra will refine the quasar mass-metallicity relation at early cosmic times.[9]
- Despite the strong redshift evolution in L^*_Q, little evidence is seen for redshift evolution of quasar spectral properties. But in any given survey, restricted sampling of the L-z plane leads to a degeneracy between redshift and luminosity dependence. Combining faint and bright surveys avoids this problem by sampling almost all regions of the L-z plane brighter than M_B=–23. This approach works: comparing serendipitous spectroscopically-selected AGN with $\overline{M}_B$=–22.3 from the CNOC2 survey[21] with luminous quasars at similar z suggests that the CIV and Lyα Baldwin effects are weaker at z>2 than at z<1. This approach also enables statistical comparison of absorption in bright and faint quasars to search for signs of intervening dust,[12] absorber lensing,[13] and even heavily reddened lower-z objects.[12,14] Several studies, including that of the faint CNOC2 AGN[21], suggest that associated/intrinsic MgII and CIV absorption is more common in less luminous quasars.
- This sample of faint low-luminosity quasars will provide excellent targets for studies of high-redshift quasar host galaxies, whose correlations with quasar luminosity are little known.[10,11,23]

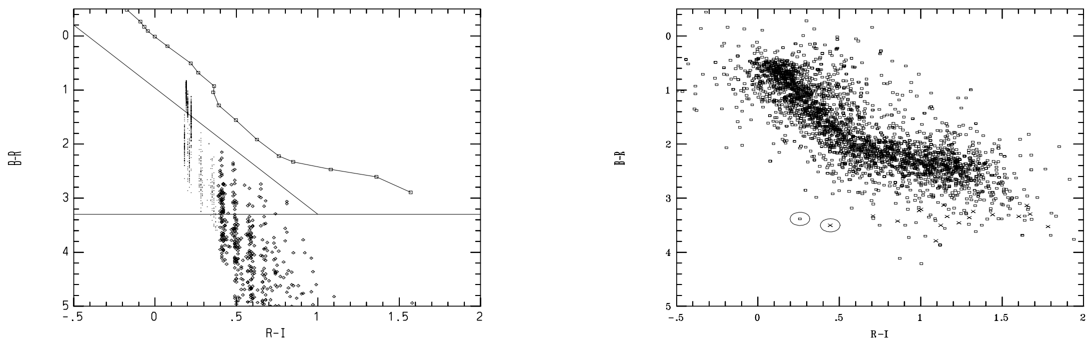

Figure 1: B-R vs. R-I color-color diagrams. **a.** Connected boxes show the main sequence (OV to M5V). Dots are simulated quasars; small dots are at z=3–4 and large dots (actually diamonds) are at z>4. 100 quasars at each redshift from z=3.05 to z=4.95 in steps of Δz=0.1 were constructed using the average LBQS spectrum from Francis *et al.* 1991 [ApJ 373, 465] and intervening absorption from Warren *et al.* 1994 [ApJ 421, 412]. Horizontal and diagonal lines are (respectively) sample selection criteria using just B-R (for z>4 quasars) and B-R & R-I (for z=3.3-4 quasars plus improved selection at z>4). **b.** 0.35□° of CTIO 4m+BTC data (5% of our total area). ~2500 stellar objects are plotted to R=23–23.5. Crosses are objects with only lower limits to B-R. The two circled objects are good z>4 quasar candidates (see Fig. 2). The two objects with B-R~4 and R-I~1 could be quasars or compact red galaxies.

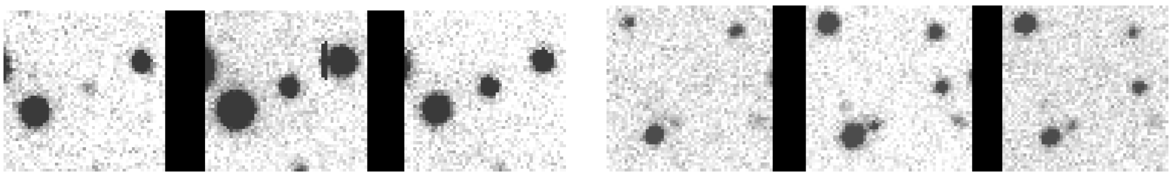

Figure 2: From left to right, B R and I images of the two z>4 quasar candidates circled in Fig. 1b. Both candidates are classified as stars or fuzzy stars in the R and I images by FOCAS. **a.** Bright candidate detected in B (center of images). **b.** Faint candidate undetected in B (at right edge).

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Experimental Design *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. List all telescopes on which you have applied for or been granted time for observations related to this project. For each, indicate the nature of the observations, and describe the importance of the observations proposed here in the context of the entire program. (limit text to one page)*

Candidate Selection: We imaged 7 $\deg^2$ for this project with the BTC. Our typical 3σ limit of B=26.8 enables z>4 quasar selection using B-R>3.3 (Fig. 1) to R=23.5, $>1^m$ above our 5σ limit, where star/galaxy separation is robust (the exact criteria are magnitude-dependent to allow for the spread in the stellar locus due to photometric errors). Using I-band data improves the completeness and efficiency of z>4 quasar selection to ~90% (thus large numbers of spurious candidates are not expected) and selects quasars at 3.3<z<4, where they are distinctly bluer in R-I than stars (Fig. 1a; ref. 22). Multicolor quasar selection remains the most efficient way to survey the dominant radio- & x-ray-quiet quasar population at $z \gtrsim 3$, since ultradeep radio- and x-ray surveys do not cover comparable areas in equivalent exposure times. Our flattened images will be made public along with a data paper nearing completion and submission (in 2000) and catalogs shortly thereafter.

Spectroscopy Requirements: Quasars at 3.3<z<5 are easily identified via Lyα and the absorption blueward of Lyα from the Lyman forest (~40% of the continuum at z=3.5 and ~60% at z=4.5). This feature is very distinctive and will allow for the unambiguous identification of quasars at high redshift. To detect Lyα at these redshifts we desire wavelength coverage from ~4500Å to as red as possible, at least to ~9000Å for CIV λ1549 to z=5. We need only S/N=2 per resolution element, enough to identify broad emission lines or the Lyα forest or rule out their presence and reject interloping stars and compact galaxies which lack such features. Longer exposures will be taken of ambiguous objects as needed, but most quasars should be easily identifiable.

Fiber or Slit Spectroscopy? Our goal is to obtain low-dispersion identification spectroscopy of a complete sample of R<23 quasars for luminosity function and quasar clustering studies, and as a prelude to detailed followup. Fiber spectroscopy using HYDRA-WIYN or -CTIO may offer a multiplexing advantage if R=23 spectra of the required S/N can be obtained in reasonable times. We have data from 1 night of shared-risk HYDRA-CTIO time in March 1999 with which to evaluate its sensitivity. Data were obtained for one target field and one backup field from the Deep Multicolor Survey (DMS).[18] These data were taken with an unoptimized camera and CCD, large $2\farcs0$ diameter fibers. no atmospheric dispersion compensation, and a high ratio of sky to object fibers among the ~60 available. A software mismatch between the HYDRA simulator and the instrument meant that some targeted objects were not observed (unfortunately including the two good quasar candidates in Fig. 1b & Fig. 2) and the handful of other candidates observed were either M stars or too faint for this setup. For a previously known z=3.4 DMS quasar with R=19.72, we reached S/N=18 per 4.5 Å resolution element at 6500 Å in 4 hrs. This corresponds to S/N=2.2 per resolution element in 4 hrs at R=22. The new HYDRA-CTIO bench spectrograph may improve these numbers somewhat, but our earlier hope of reaching R=23 with HYDRA-CTIO is clearly impractical. HYDRA-WIYN has similar sensitivities: S/N=1.9 per 5.72 Å resolution element in 4 hrs at R=22.0. We expect 2–3 quasars per HYDRA-CTIO field, 2.5–4 per WIYN field for adjacent BTC pointings or 5.5-9 per WIYN field for mosaiced fields where dithers were made to fill in the BTC gaps. Only HYDRA-WIYN observations of mosaiced fields offer a significant advantage over slit spectroscopy.

Telescope Request: For 60% of our survey, followup with HYDRA-WIYN is impossible or disadvantageous. We propose to obtain spectra down to R=22.5 in half of these fields with the CTIO4m+RCSP (3 nights). We should reach S/N=2 per 4.87 Å resolution element in 25 minutes at R=22 and in 54 minutes at R=22.5. We expect to propose for 3 more CTIO nights over the following two semesters to complete the survey, as well as for HYDRA-WIYN time next spring.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the Principal Investigator during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal.*

$\boxed{\star}$ **Hall**, Green, Kennefick, Osmer, Smith: 1 night Mar. 1999 w/HYDRA+CTIO4m for this project; 1 project & 1 backup field observed; data reduced (see Experimental Design)
• **Hall**, Ellingson, Carlberg, Yee, Lin & Marzke; 3 nights Feb. 1999 (2.5 usable) and 1 night June 1999 with ONIS on KPNO 2.1m for near-IR survey of CNOC1 cluster fields as a quasi-independent Ω_M measurement; data being analyzed, paper in preparation
$\boxed{\star}$ **Hall**, Green, Kennefick, Osmer, Smith: 8 nights (5 usable) Spring 1997 & 1998 w/BTC+CTIO4m for this project; processing pipelines up and running; data paper to be submitted in 2000
• Kennefick, Falco, Green, **Hall**, Osmer, Smith, Monier, Conti; 8 nights Fall 1999 - Fall 2000 for longslit spectra of candidate z>5 quasars & gravitational lenses from a 40 deg^2 BVIZ survey; two z$\sim$4.75 quasars found in 3 good + 3 poor seeing nights to date; 2 nights upcoming Oct. 2000; paper in preparation
• Yee, Barrientos, Gladders, Ellingson, **Hall**, Infante, Kodama; 10 nights Fall 1999 - Fall 2000 w/CTIO4m+MOSAIC for RZ imaging survey for 0.5<z<1.4 clusters; 4.5/7 useful nights to date; 3 upcoming in Jan. 2001; 18 deg^2 imaged, 8 deg^2 data reduced to calibrated catalogs
• Impey, Conti, Falco, **Hall**, Kennefick, Kochanek, Smith, Osmer; 32 deg^2 U-band extension of BTC40 survey to assemble a sample of 6000 faint quasars, plus luminous U-dropout galaxies; 9 nights Fall 1998-1999 on KPNO 4m: 4.5 nights 'usable', but 2$''$ seeing and mostly nonphotometric
• Kennefick, Falco, Green, **Hall**, Osmer, Smith; 6 nights (5.5 usable) total 1998 & 1999 for Z-band BTC40 imaging to reduce contamination of z>5 quasar candidates by very late M stars; data reduced, cataloguing and candidate selection complete, paper in preparation
• Kennefick, Falco, Green, **Hall**, Osmer, Smith; 3 nights Spring 1998 for longslit spectra of candidate BTC40 z>5 quasar & gravitational lenses; <1 night usable; no quasars or lenses found
• Falco, Kochanek, Schechter; Green, **Hall**, Kennefick, Osmer, Smith; Postman: 8 nights total Spring & Fall 1997 with BTC on CTIO 4m for BTC40 survey, a "shallow" z>5 quasar / z$\sim$1 cluster / gravitational lens survey; 40 deg^2 covered; reduction and cataloguing complete; paper in preparation
• Green, He, & **Hall**: 6 nights on 2.1m+Goldcam in Feb. 1997 & 1998, for spectroscopic confirmation of X-ray/optical selected AGN, data reduced, paper nearing submission, project continuing.

Why CTIO? *(For CTIO proposals only.) Explain why access to the southern hemisphere is needed to achieve your scientific goals.*

The imaging observations for this survey were made at CTIO. Many of the fields are equatorial, and for such fields with dithered observations we will request HYDRA-WIYN observations. For the remaining fields CTIO time is requested since it is most efficient.

Observing Run Details for Run 1: CT-4m/RCSP + BAS

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

With the CTIO 4m + RCSP within 6 days of new moon, we should reach S/N=2 per 4.87 Å resolution element in 25 minutes at R=22 and in 138 minutes at R=22.5. In the 4.25 deg^2 where slit spectroscopy is more efficient than HYDRA-WIYN spectroscopy or which are too far south for HYDRA-WIYN (all these fields are listed in the Target Table), we expect to find 35–58 z>3 quasars with R<22 and 15–24 with 22<R<22.5. In three nights we should be able to obtain identification quality spectra for about half these candidates. We expect to request three further nights over the next two semesters for the remaining candidates.

Instrument Configuration

Filters: GG455
Grating/grism: G181
Order: 1
Cross disperser:

Slit: Y
Multislit: no
$\lambda_{\rm start}$: 4500
$\lambda_{\rm end}$: >10000

Fiber cable:
Corrector:
Collimator:
Atmos. disp. corr.: no

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for Run 1: CT-4m/RCSP + BAS

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
001	BTC203	08:21:04.1	+03:33:38	2000.0		BRIz'			6	spec	1.0	Diagonal to BTC005
002	BTC005	08:22:40.0	+04:12:44	2000.0		BRI			6	spec	1.0	Diagonal to BTC203
003	GRB980326	08:36:34.3	–18:51:23.9	2000.0		BRz'			6	spec	1.0	
005	BTC011	10:48:25.9	+00:15:49	2000.0		BRI			6	spec	1.0	
006	BTC124-125-126	10:58:05.0	–03:19:45	2000.0		BRI			6	spec	1.0	Adjacent to BTC127-128-129
007	BTC127-128-129	10:58:48.5	–04:03:52	2000.0		BRI			6	spec	1.0	Adjacent to BTC124-125-126
008	BTC028-029	12:45:25.8	–00:35:12	2000.0		BR,some I			6	spec	1.0	E-W pair
009	BTC039-040	13:46:40.9	+02:12:17	2000.0		BR_TI			6	spec	1.0	Adjacent to BTC131-132
010	BTC131-132	13:48:57.6	+02:48:55	2000.0		BRI			6	spec	1.0	Adjacent to BTC039-040
011	BTC139	13:43:32.0	+01:43:27	2000.0		BRI			6	spec	1.0	Near BTC039-040,131-132
013	BTC041	15:30:41.3	+05:49:54	2000.0		BR_TI			6	spec	1.0	
014	GB2025-42	20:25:59.0	–41:16:35	1950.0		BR_T			6	spec	1.0	Mosaiced; no *I*