NOAO Observing Proposal *CNTAC proposal* **Panel:** *For office use.*
Date: September 30, 2002 **Category:** High Z Galaxies

The Reddening Effect of High Redshift Galaxies on Background QSOs – A Simultaneous Optical-IR Survey.

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
We propose to perform a simultaneous survey of optical – IR colors on a complete and homogeneous sample of radio-selected QSOs with the principal aim of assessing the effect of dust extinction on the background QSOs by intervening galaxies. This is the first time that such a study has been undertaken using a *complete and unbiased* QSO sample. In addition to the important implications for the identification of intervening damped Lyα systems in magnitude-limited, optically-selected QSO samples, this program will contribute to the on-going debate concerning the origin of red colors of high redshift QSOs. That synchrotron radiation and host galaxy starlight contribute to this is now well-known, the observations here will quantify the effect from intervening dust reddening. These optical-IR colors for a complete radio-selected quasar sample will also enable a comparison with the range of colors found in optical surveys, which may be incomplete for red objects.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-1.3m	ANDI + CCDIR	11.7h	bright	Feb - May	Feb - Jul
2						
3						
4						
5						
6						

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

Our ANDICAM request is for 11.7 hours (including overhead) on 19 objects, which works out to 37 minutes per night *on average.* Observations will be queue scheduled for suitable conditions (i.e. photometric) throughout the period.

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.*

Although quasars are usually regarded as objects characterized by a UV excess, the existence of red QSOs has been known for more than two decades (e.g. Bregman 1981). Red QSOs have attracted much interest in the literature and have been studied with imaging and spectroscopy at all wavelengths ranging from the X-ray to radio regime. One study that has roused particular attention in recent years is that of Webster et al. (1995), who used a sample of radio-loud QSOs (based on a flat-spectrum subset of the Parkes QSOs) to investigate the possibility of dust reddening. From the discovery that a significant fraction of the sample exhibited very red optical–IR colors ($B-K>4$) compared to what was observed in the LBQS, Webster et al. claimed that up to 80% of QSOs may be hidden from optical surveys due to dust extinction. If true, this could have profound implications for models of the background radiation (both UV and X-ray), the QSO luminosity function and their space density. There are certainly individual QSOs where reddening is caused by dust in the host galaxy itself (Hall et al. 2002). There are also other explanations for very red QSO colours, such as synchrotron radiation and the effect of host galaxy starlight (Francis, Whiting & Webster 2000; Benn et al. 1998). However, one factor that could have a significant impact on reddening QSO light remains relatively unexplored; the presence of intervening dust located in foreground galaxies. This scenario is lent credibility by the identification of a handful of lensed QSOs in which dust in the lensing galaxy reddens the background source (e.g., Gregg et al. 2002).

The issue of dusty intervening galaxies is of interest not only in order to assess its effect on QSO reddening but is also of crucial importance for the study of quasar absorption lines. Systems such as the damped Lyman alpha clouds (DLAs) which correspond to the signatures of high redshift galaxies imprinted on the continuum of a background QSO, represent one of our best tools for studying the early galaxy population. Previous studies of DLAs have almost universally relied on using luminous optically selected QSOs to identify DLAs, so there is serious concern that dusty intervening galaxies may obscure the background QSO so that it drops below survey magnitude limits (e.g. Fall & Pei 1993). There are indications both from the study of spectral indices and optical colors that such an effect *does* exist (Pei, Fall and Bechtold 1991; Outram et al. 2001).

These previous studies suffer from the use of biased optically magnitude-limited samples. Now, however, a complete and unbiased QSO sample exists with which to address this question. Ellison et al. (2002) undertook the first complete and unbiased survey (CORALS) for DLAs, in a homogeneous sample of 66 *radio-selected* QSOs taken from the Parkes catalogue, complete down to 0.25 Jy. Extensive optical follow-up observations resulted in identifications for ALL sources. Therefore, CORALS is ideal for determining the extent to which intervening galaxies obscure background QSOs. By determining the number density and neutral gas content of DLAs, Ellison et al. (2002) found that these values may have been previously under-estimated by up to a factor of ~ 2. It was also found that there is some evidence that the number density increases as fainter QSOs were studied (see Fig. 1), evidence that dust may indeed play a role in these systems. CORALS provides the perfect sample to investigate the effects of dust reddening of QSOs by intervening galaxies. By comparing the $B-K$ colors of QSOs with and without DLAs we can quantify the typical dust extinction, assess the bias in DLA surveys using color and magnitude selected QSOs and determine whether intervening galaxies contribute significantly to the reddened QSO population. Comparison of the $B-K$ colors of this complete radio selected quasar sample to the colors of optically selected quasars will also enable a test of the completeness of the latter surveys. To date this has been done using only the incomplete radio sample of Webster (1995) and heterogeneous optical samples (e.g., Barkhouse & Hall 2001). Comparison of our colors to the colors of LBQS quasars (Warren, Hewett & Foltz 2000) will enable a more accurate determination of how many quasars have colors likely to be missed by optical surveys.

References

Barkhouse & Hall 2001, AJ, 121, 2843
Benn et al. 1998, MNRAS, 295, 451
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Drinkwater, Combes and Wiklind 1996, A&A, 312, 771
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Fall & Pei 1993, ApJ, 402, 479
Francis, Whiting & Webster 2000, PASA, 17, 56
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Pei, Fall and Bechtold 1991, ApJ, 378, 6
Warren, Hewett & Foltz 2000, MNRAS, 312, 827
Webster et al, 1995, Nature, 375, 469

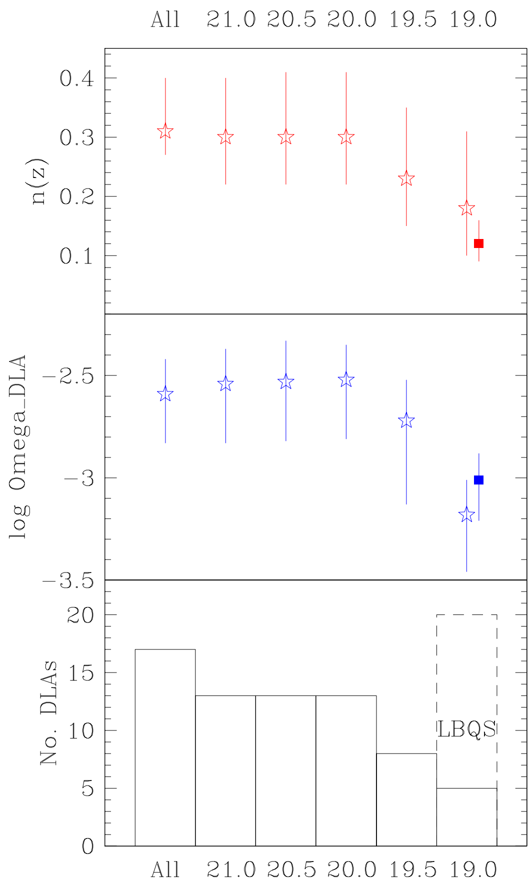

Figure 1: Number of DLAs, their number density (n(z)) and neutral gas content (Ω_{DLA}) as a function of approximate B-band magnitude. The quantities plotted are for the cumulative values in the bins $\leq$ the B-band magnitude on the x-axis. Bottom panel: Cumulative histogram of number of DLAs. The dashed area shows the number of LBQS DLAs used to determine improved statistics towards bright QSOs. Middle and top panels: stars show the values for CORALS DLAs, whilst the solid square shows the same quantity for the LBQS sample ($B < 19$); this point has been offset on the x-axis for clarity).

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. (limit text to one page)*

We propose to use ANDICAM to obtain simultaneous B and K band photometry (V and K for objects at $z > 3$, to avoid the uncertain effect of Lyα forest absorption) of all of the 66 QSOs in the CORALS sample. Although approximate B band magnitudes exist for these QSOs (either from COSMOS, APM or our own observations) these measurements have errors up to 0.5 magnitudes and simultaneous IR observations are not available. Since the CORALS QSOs are all radio-loud flat-spectrum sources they are highly variable and therefore require optical–IR photometry from the same epoch. Of the 66 QSOs, 12 have recently been observed as part of a different survey in which good quality, quasi-simultaneous optical – IR observations were obtained (Francis, Whiting & Webster 2000). In order to capitalize upon the facilities available to us, we will observe the remaining 56 targets with a combination of ESO and NOAO facilities (see next section).

ANDICAM is particularly well-suited for this program since it can provide truly simultaneous optical and IR data. Also, since the K-band exposure times needed for our required high S/N are several times longer than those in the optical bands, we will be able to study very short term optical variations in radio loud QSOs and determine the systematic uncertainty between quasi- and truly simultaneous optical/NIR data. Lastly, since we require photometric conditions, the queue mode of ANDICAM is ideal for this program.

Using the extinction curves compiled by Pei (1992, ApJ, 395, 130) we estimate the typical extinction we may expect in the $B-K$ (or $V-K$) colors. Taking the example of a DLA at $z = 2$, the observed frame B and K bands correspond to rest frame wavelengths of 1500 and 7200 Å. Assuming a typical column density of log N(H I) = 20.7 and adopting an SMC-type extinction law and dust-to-gas ratio (Bouchet et al. 1985, A&A, 149, 330) would give an $E(B-K)$=0.12 mags. For the highest column density systems in our sample, the extinction could be as much as 10 times this value. In practice, since there will be an intrinsic spread of QSO colors, it is unlikely that we will be able to detect an obvious color distinction between *individual* QSOs with and without DLAs. However, with $B-K$ colors accurate to $\sigma(B-K)$=0.04, we will certainly be able to calculate accurate color differences between the two *populations* in several redshift bins.

Use of Other Facilities *Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program.*

In order to obtain $B-K$ colors for our complete QSO sample, we will combine the CTIO observations proposed here with ESO observations of the fainter targets. The facilities at ESO are an excellent complement to those at Cerro Tololo and capitalizing on access to both sites renders this an efficient observing strategy. With ANDICAM on the 1.3-m we will obtain $B-K$ colors for the brighter CORALS QSOs, whilst completing the fainter targets with ESO facilities. SUSI2 at the NTT offers extremely efficient optical imaging observations and will be supplemented with deep SOFI near-IR observations, also at the NTT.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI 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. Please include original proposal semesters and ID numbers when available.*

This will be my first use of NOAO facilities.

Observing Run Details for Run 1: CT-1.3m/ANDI + CCDIR

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).*

Our scientific goals ideally require $\sigma(B - K_s) \leq 0.04$, which translates to S/N goals of 50 in both B and K (assuming 2% systematic uncertainty in both the optical and IR photometric calibrations).

In estimating exposure times, we assumed $B - K_s$=3 for all objects, which is the average for PG quasars. For the bluest quasars, with $B - K_s$=2, we will achieve only S/N=20, but such quasars are not likely to be reddened and so the larger errors can be tolerated. (Of course, we will also achieve S/N$\gg$50 for redder quasars, and for our ESO subsample we will obtain S/N=50 for even the bluest quasars.) The estimated exposure times for the targets listed below are driven by the expected K_s-band magnitudes and are typically $\sim$10 times longer than needed for the B-band; thus, bright time is acceptable. (We will take care in Phase II to calculate individual B-band exposure times which avoid saturation even at full moon.)

Since ANDICAM's performance on the 1.3m is not yet known, we estimated K_s-band exposure times using the exposure time calculator for the CTIO 1.5m and OSIRIS. We assumed a large ($1''.4$ radius) and thus noiser aperture to compensate for the different mirror sizes and different IR pixel scales of the 1.5m+OSIRIS ($0''.461$ at f/7) and the 1.3m+ANDICAM ($0''.115$?).

The total required exposure time for our sample is 10 hours and 20 minutes. Allowing for overheads per object of 3 minutes for acquisition and 80 seconds for the final CCD image readout, we arrive at a total requested time of 11 hours and 43 minutes (11.7 hours). Assuming one object per night, this is 37 minutes per night *on average*; exposure times per target range from 80 seconds to 2 hours.

ANDICAM CORALS TARGETS

Target	DLA?	Redshift	B	Exposure (sec)
B0528-250	Y	2.765	18.1	240
B0537-286	Y	3.110	19.8	4800
B0601-172	N	2.711	20.0	7200
B0610-436	N	3.461	18.5	480
B0819-032	N	2.352	18.2	280
B0834-201	N	2.752	19.0	1200
B0919-260	N	2.300	19.0	1200
B0933-333	Y	2.906	20.0	7200
B1010-427	N	2.954	17.5	80
B1055-301	Y	2.523	19.3	2000
B1136-156	N	2.625	19.1	1380
B1147-192	N	2.489	19.4	2400
B1149-084	N	2.370	18.5	480
B1230-101	Y	2.394	19.6	3600
B1228-310	N	2.276	19.0	1200
B1256-243	N	2.263	19.4	2400
B1354-107	Y	3.006	18.4	400
B1402-012	N	2.518	18.0	200
B1418-064	Y	3.689	18.5	480

Instrument Configuration

Filters: B, V, K_s
Grating/grism: N/A
Order: N/A
Cross disperser: N/A

Slit: N/A
Multislit: no
$\lambda_{\rm start}$: N/A
$\lambda_{\rm end}$: N/A

Fiber cable:
Corrector: N/A
Collimator:
Atmos. disp. corr.: no

R.A. range of principal targets (hours): 05 to 15

Dec. range of principal targets (degrees): -44 to +00

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

NOAO observing proposal LaTeX macros v2.7.