EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME — PERIOD: **71A**

To be submitted only to: proposal@eso.org
Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title — Panel: **A–1**

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

2. Abstract

We propose a simultaneous optical–IR survey of a 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 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. In addition to synchrotron radiation and host galaxy starlight, we will quantify the reddening effect from intervening galaxies. 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. Although allocated time in P69, no data has yet been collected for this project due to adverse weather conditions.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	NTT	SUSI2	9h	any	d	n	PHO	s
B	NTT	SOFI	34h	any	n	n	PHO	s

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:	NTT/1.5D	3n in 69.A-0068, all cloudy
b) still required to complete this project:		

5. Special remarks

Due to the reduction of small telescopes in Chile, we can not continue with our p69 strategy of IR and optical imaging on 4-m and 2-m telescopes *at the same site*. Our selection of SUSI+SOFI represents the conclusion of extensive discussions with La Silla science operations in order to make best use of the facilities available.

6.

Principal Investigator: **S. Ellison** (P. Universidad Catolica, RCH, sellison@astro.puc.cl)

CoI(s): P. Hall (P. Universidad Catolica, RCH)

7. Is this proposal linked to the PhD thesis preparation of one of the applicants?

8. Description of the proposed programme

A) Scientific Rationale: Although quasars are usually regarded as objects characterised by a UV excess, the existence of red QSOs has been known for more than two decades (e.g. Bregman, 1981, Nature, 293, 714). Despite their long history, red QSOs have continued to attract much interest in the literature and have been studied with imaging and spectroscopic observations 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, Nature, 375, 469) who used a sample of radio-loud QSOs to investigate the possibility of dust reddening. From the discovery that a significant fraction of the sample exhibited very red optical–IR colors ($B-K>3$) compared to what was observed in the LBQS, Webster et al. claimed that up to 80% of QSOs may be hidden from the eyes of 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 almost certainly some individual cases where reddening is caused by dust (Rawlings et al. 1995, MNRAS, 274, 428; Gregg et al. 2001, astro-ph/0107441; Brotherton et al. 1998, ApJL, 505, 7), most likely located in the host galaxy itself. However, millimetre observations (Drinkwater, Combes and Wiklind 1996, A&A, 312, 771) of 11 of the reddest Webster et al. (1995) sources failed to detect CO which argues against the presence of host galaxy dust in the majority of cases, although obscuration due to foreground material is still possible.

There are several other explanations to explain very red QSO colours, for example synchrotron radiation and the effect of host galaxy starlight (Francis, Whiting & Webster 2000, PASA, 17, 56; Whiting, Webster & Francis, 2001, MNRAS, 323, 718; Benn et al. 1998, MNRAS, 295, 451). However, there is one factor that could have a significant impact on reddening QSO light that remains relatively unexplored, namely the presence of intervening dust located in foreground galaxies. The identification of a handful of red lensed QSOs lends credibility to this scenario, in which dust in the lensing galaxy reddens the background source (e.g. Gregg et al. 2001 and references therein), although magnification of the host's starlight may also be a factor in some cases.

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. Quasar absorption 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 the large optical databases of QSOs for follow-up spectroscopy in order to identify the intervening galaxy. Since only relatively bright, optically selected QSOs have been used to identify DLAs, there has been serious concern that dusty intervening galaxies may obscure the background QSO so that it drops below survey magnitude limits. Such a selection effect would result in a biased view of high redshift galaxies. The idea of dust in intervening galaxies is far from new and some attempts have been made to quantify it (e.g. Fall & Pei 1993, ApJ, 402, 479). There is also some observational evidence that QSOs with intervening DLAs are redder than those without, either from optical colours or spectral indices (Pei, Fall and Bechtold 1991, ApJ, 378, 6; Outram et al. 2001, MNRAS, 328, 805). However, these previous studies suffer from two drawbacks - they suffer from limited wavelength coverage in the optical regime and were not conducted on unbiased samples (i.e. they were taken from magnitude limited surveys). In fact, until now, there has not been a complete a nd unbiased QSO sample with which to even address the question.

Ellison et al. (2001, A&A, 379, 393) have recently undertaken the first complete and unbiased survey (CORALS) for DLAs in a radio-selected sample of QSOs. The CORALS survey, which has made extensive use of ESO facilities, was based on 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, with no magnitude limit. Therefore, subsequent spectroscopic searches for DLAs are based on a complete sample, 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. (2001) 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. The CORALS sample provides an ideal dataset to assess dust reddening of QSOs since it is not only optically complete, but all of the intervening high redshift DLAs have already been identified. Therefore, we here propose to obtain optical – IR imaging of the CORALS QSOs in order to search for a systematic color difference between sources with and without intervening DLAs in order to quantify the reddening effect by dust in foreground galaxies.

B) Immediate Objective: We propose to obtain 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 flat-spectrum sources they are highly variable on short timescales 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, simultaneous optical – IR observations were obtained (Francis, Whiting & Webster 2000). This leaves 54 QSOs requiring 2-band photometry. In period 69, we were awarded

8. Description of the proposed programme (continued)

time on DFOSC, SUSI2 and SOFI to observe 21 of these targets but obtained no data due to adverse weather conditions. Here, we therefore re-apply for observations of 35 QSOs spread over P71, of which $\sim 1/3$ have DLAs. Therefore, with the equivalent of approximately 4 nights, we will obtain a statictically significant sample (47, including the values from the literature) with which to address our scientific questions.

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 *individula* QSOs with and without DLAs. However, with photometry accurate at the 5 % level (see below) we will be able to calculate accurate color differences between the two *populations* in several redshift bins. These color differences can then be averaged for even higher signal-to-noise: although the colors will change with redshift due to emission lines, etc., the color difference between the two populations will change much less. Comparison of the $B-K$ and $V-K$ colors of this complete radio selected quasar sample to the colors of optically selected quasars will 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, AJ, 121, 2843). Comparison of our colors to the LBQS colors of Warren, Hewett & Foltz (2000, MNRAS, 312, 827) will enable a more accurate determination of how many quasars have colors likely to be missed by optical surveys.

C) Telescope Justification: In P69 we requested DFOSC and SOFI time for the optical and IR components of our project respectively (with a short amount of time on SUSI for the faintest objects). However, DFOSC is no longer available due to the decommissioning of the small telescopes on La Silla. Although in P70 the OPC suggested we apply for time on smaller telescopes, such as at CTIO, similar down-sizing is currently underway at other Chilean facilities, including Cerro Tololo, resulting in no observatory with a 1.5 or 2-m telescope offering optical imaging AND a 4-m class telescope with an IR imager (discounting the WFI which is totally unsuitable for this project). For scheduling of the simulataneous B and K band observations, it is highly desirable to keep these runs to the same observatory. Therefore, we must re-consider our strategy, given the available facilities and conclude that the combination of SUSI2 and SOFI offers the best combination for our program. SOFI is the obvious IR choice for this program since we will be targetting QSOs with typical K-band magnitudes between 16 and 19 (see below for S/N calculations). SUSI2 at the NTT offers the most attractive alternative for optical imaging for the following reasons:

1) Both SUSI2 and SOFI are offered in service mode, which is better suited to our constraints than visitor mode (i.e. photometric conditions for both the optical and IR).
2) SUSI2 has a nominally fast readout. Combined with 2x2 binning and windowing, the readout time can be reduced to approximately 15 seconds, minimising the overheads associated with each exposure.
3) SUSI2 is very convenient for quasi-simultaneous scheduling with SOFI since they are available at the same telescope, facilitating the book-keeping of observations. Also, changing between instruments is a regular part of service nights at the NTT (since it takes <5 minutes), so there will be no additional instrument change overheads incurred.

Therefore, despite the relatively short exposure times (typically 10 minutes), the combination of SUSI2 and SOFI offers the best opportunity for this program, particularly given the minimum overheads and the possibility of service observing. Finally, several of out targets are faint ($B>22$) that make the use of a 4-m optical imager essential.

D) Observing Mode Justification (visitor or service): Our previous proposal for this project requested visitor time, since the instrument (DFOSC) we selected for the optical observations was not offered in service mode. However, we have suffered from 3 nights (spread over a week) of cloud in P69 that made this program impossible to carry out. This is, of course, always a risk for visitor runs, but one that was unavoidable in P69 given the instruments most suitable for our program. For P71, we request service time since both instrument choices are available in this mode. We will specify that the IR and optical OBs for a given object should be executed within 5 days of each other, a constraint which should pose no problem for service scheduling. Apart from time constraints, our observations are very straight-forward, a simple imaging program of point sources, that can be easily executed in service mode. Also, in service mode we can cover most of the targets in the sample, allowing us to achieve a statistically significant sample from a single semester's observations.

E) Strategy for Data Reduction and Analysis: Reduction of optical and infrared observations of targets with our expected magnitudes is straightforward. Hall has experience with both optical and IR imaging, and has software for complete reduction of both to final coadded images. Particular attention will be paid to photometric calibration in both the optical and IR, including color terms and nightly extinction coefficients, so as to achieve the highest possible precision. Numerous sets of faint IR standards are now available with the required accuracy.

8. Attachments (Figures)

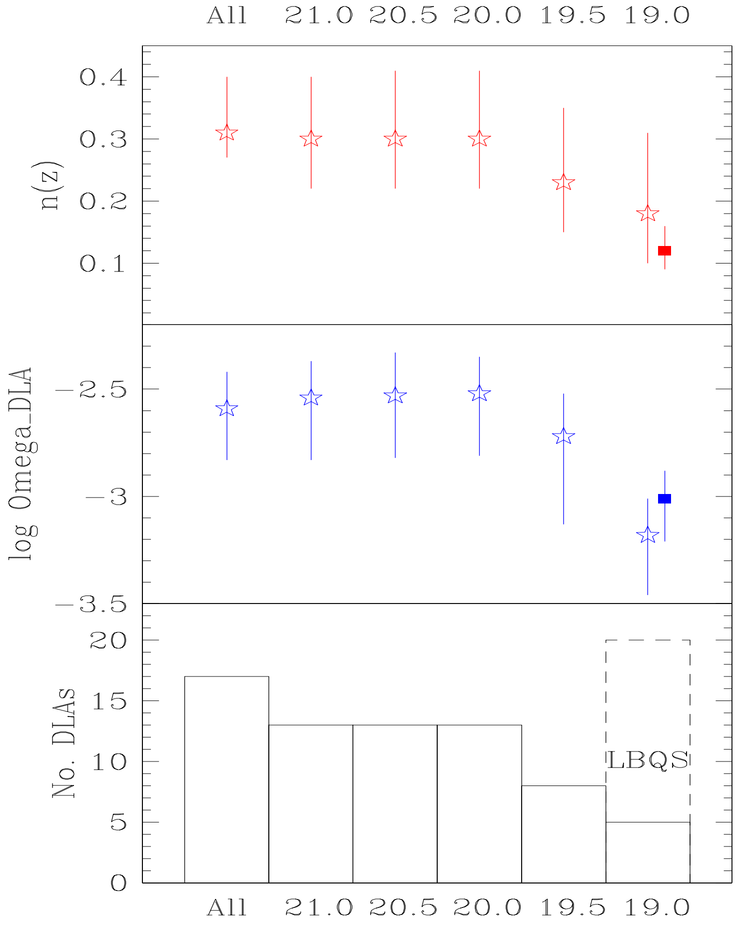

Fig. 1 - Cumulative DLA statistics vs. B mag.

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).

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: Most of our targets have $B < 21$ and can be observed in the B band with grey moon. However, since we have some targets as faint as B=24, we request dark time (which would be relaxed at phase II for many of our targets), so that we can schedule the faintest targets when there is no moon. Therefore, in practice, approximately half of the requested 9 hours on SUSI will need dark time. There is no lunar restriction for out K-band observations, although in practice they need to be taken within 5 days of the B-band observations due to the strong variability of flat spectrum QSOs that will intriduce errors into the $B - K$ colors if not taken together.

Time Justification: In order to achieve $B - K$ or $V - K$ colors accurate to 0.05 mags, we aim for a S/N > 100 in the optical and 50–100 in the IR. For all S/N calculations we used the latest version of the instrument on-line exposure time calculators, using published APM B magnitudes (which range from 17 to 24, but are mostly fainter than ∼20) and assuming a $B - K$=2. Example exposure times are 400,1800 seconds for B=20.5,21.5 in the B band and 300,1800 seconds for K=17,18. We calculate a total on-target time of 31.1 hours for SOFI and 6.3 hours for SUSI2. We allow 4 minutes overhead for each OB (i.e. 1 target or one hour block for faint targets), resulting in overheads of 2.3 hours for SUSI and 2.8 hours for SOFI. The total request is therefore 34 hours of SOFI time (approximately 3 nights) and 9 hours of SUSI time. Therefore, with the equivalent of only 4 nights, we will be able to compile a statistically significant sample for this program.

Calibration Request: Standard Calibration

10. Report on the last use of ESO facilities

69.-A-0068 / P. Hall / The Reddening Effect of High Redshift Galaxies on Background QSOs

Telescope	Instrument	Obs. Dates	Completion (%)	Time lost (%)	Reason
1.5D	DFOSC	4 Sept 2002	0%	100%	weather
NTT	SUSI	8-9 Sept 2002	0%	100%	weather
NTT	SOFI	8-9 Sept 2002	0%	100%	weather

Current status of obtained data:

Remarks: The last use of ESO facilities was our first attempt at observations for this program. We lost all 3 nights due to weather (1 night completely cloudy, 2 more nights with thick variable cirrus, impossible for photometry).

11. Applicant's publications related to the subject of this application during the past two years

Ellison, S., Mallen-Ornelas, G., Sawicki, M., 2002, submitted: The absorption and emission properties in the z=0.745 absorber towards Q1331+17

Lopez, S., & Ellison, S., 2002, A&A, submitted: Distinct Abundance Patterns in Multiple DLA Galaxies: Evidence for Truncated Star Formation

Ellison, S., Yan, L., Hook, I., Pettini, M., Shaver, P., Wall, J., 2001, A&A, 379, 393: The CORALS Survey I: New Estimates of the Number Density of DLAs from Dust Bias

Ellison, S., Yan, L., Hook, I., Pettini, M., Shaver, P., Wall, J., 2002, A&A, 383, 91: The CORALS Survey II: Clues to Galaxy Clustering Around QSOs from $z_{abs} \sim z_{em}$ DLAs.

Ellison S., Pettini M., Steidel C., Shapley A., 2001, ApJ, 549, 770: An Imaging and Spectroscopic Study of the z=3.38639 Damped Lyman Alpha System in Q0201+1120: Clues to Star Formation at High Redshift

Hall, P. et al, 2001, ApJ, 121, 1840 : Galaxies in the Fields of Z 1.5 Radio-Loud Quasars Hall, P., et al, 2000,

ApJ, 120, 2220: Active Galactic Nuclei in the CNOC2 Field Galaxy Redshift Survey Barkhouse, W. A. and

Hall, P. B., 2001, AJ, 121, 2843 Quasars in the 2MASS Incremental Data Release

Hall, P. B., Anderson, S. F., Strauss, M. A., York, D. G., et al, 2002, ApJS, 141, 267: Unusual Broad Absorption Line Quasars in the Sloan Digital Sky Survey

12. List of targets proposed in this programme

Run	Target/Field	α	δ	Eq.	Mag.	Diam.	Additional info	Reference star
AB	B0017-307	00 17 13.0	-30 47 56	B1950	20.0			
AB	B0039-407	00 39 37.6	-40 47 06	B1950	19.7			
AB	B0104-275	01 04 02.1	-27 34 14	B1950	19.3			
AB	B0113-283	01 13 01.6	-28 20 45	B1950	19.9			
AB	B0122-005	01 22 43.6	-00 34 04	B1950	18.5			
AB	B0244-128	02 44 34.7	-12 49 02	B1950	18.5			
AB	B0256-393	02 56 18.9	-39 21 44	B1950	20.6			
AB	B0325-222	03 25 47.5	-22 12 26	B1950	19.0			
AB	B0329-255	03 29 00.5	-25 34 53	B1950	17.6			
AB	B0335-122	03 35 33.5	-12 13 59	B1950	21.5			
AB	B0347-211	03 47 45.7	-21 11 47	B1950	21.1			
AB	B0405-331	04 05 38.5	-33 11 42	B1950	19.1			
AB	B0420+022	04 20 16.1	+02 12 29	B1950	19.7			
AB	B0422-389	04 22 49.1	-38 55 30	B1950	18.4			
AB	B0432-440	04 32 30.2	-44 02 03	B1950	19.6			
AB	B0434-188	04 34 49.0	-18 50 48	B1950	20.0			
AB	B0438-436	04 38 43.2	-43 38 53	B1950	19.5			
AB	B0451-282	04 51 15.1	-28 12 29	B1950	19.0			
AB	B0458-020	04 58 41.3	-02 03 34	B1950	20.0			
AB	B1228-113	12 28 05.7	-31 04 39	B1950	22.0			
AB	B1230-101	12 30 37.7	-10 08 46	B1950	19.8			
AB	B1251-407	12 51 12.6	-40 43 15	B1950	23.7			
AB	B1318-263	13 18 28.2	-26 20 29	B1950	21.3			
AB	B1351-018	13 51 32.0	-01 51 20	B1950	21.5			
AB	B1406-267	14 06 58.4	-26 43 28	B1950	21.8			
AB	B1535+004	15 35 42.6	+00 28 51	B1950	24.1			
AB	B1701+016	17 01 35.1	+01 38 12	B1950	21.7			
AB	B1937-101	19 37 12.7	-10 09 40	B1950	19.0			
AB	B2224+006	22 24 13.1	+00 36 52	B1950	22.0			
AB	B2245-059	22 45 24.2	-05 57 11	B1950	19.7			
AB	B2256+017	22 56 24.6	+01 47 34	B1950	19.2			
AB	B2311-373	23 11 15.5	-37 21 07	B1950	18.5			
AB	B2314-340	23 14 00.9	-34 05 35	B1950	19.0			
AB	B2315-172	23 15 33.7	-17 15 53	B1950	21.0			
AB	B2325-150	23 25 11.6	-15 04 27	B1950	19.5			

Target Notes: All magnitudes are B-band taken from the APM catalogue (UKST or POSS).

13. Scheduling requirements

14. Instrument configuration

Telescope	Instrument	Run ID	Parameter	Value or list
NTT	SUSI2	A	Imaging-filters	#811,#812
NTT	SOFI	B	Imaging	yes