EUROPEAN SOUTHERN OBSERVATORY

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

VISITING ASTRONOMERS SECTION • Karl-Schwarzschild-Straße 2 • D-85748 Garching bei München • e-mail: visas@eso.org • Tel.: +49-89-32 00 62 23

APPLICATION FOR OBSERVING TIME PERIOD: **70A**

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: **B–6**
Redshifted BAL Quasar Troughs: A Test of BAL Quasar Models

2. Abstract
The Sloan survey has discovered two Low-Ionization Broad Absorption Line Quasars with absorption troughs extending redward of the quasar's host galaxy redshift. These troughs could arise from a rotation-dominated disk wind illuminated by an extended continuum source, or from absorbing clouds randomly orbiting the quasar. These models have very different implications: disk winds mean that BAL quasars are just normal quasars seen at certain orientations, but randomly-orbiting clouds imply that BAL quasars are a distinct population of young quasars surrounded by gas and dust. We propose UVES spectroscopy of these two unique objects to perform one of the few tests which can discriminate between these models. Each model makes different predictions for the trough shapes at high resolution in these objects and for the BAL outflow distance from the central source, which can be obtained by using high-resolution spectra to constrain the physical conditions in the outflow.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	UT2	UVES	9.5h	mar	g	$\leq 1.2''$	THN	s
B	UT2	UVES	9.5h	mar	g	$\leq 1.2''$	THN	s

4. Number of nights/hours Telescope(s) Amount of time
a) already awarded to this project:
b) still required to complete this project:

5. Special remarks

6. Principal Investigator: P. HALL (P. Universidad Catolica, RCH, phall@astro.puc.cl)
Col(s): D. HUTSEMEKERS (ESO, ESO), L. PENTERICCI (MPIA-Heidelberg, D), S. ANDERSON (U. Washington, USA)

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

8. Description of the proposed programme

A) Scientific Rationale: One in every seven quasars is a Broad Absorption Line (BAL) quasar, but how normal and BAL quasars are related is unclear. Most BAL quasars are HiBALs, with outflowing absorption seen only in high ionization lines like C IV, but 1 in 7 is a LoBAL quasar with low-ionization absorption like Mg II as well, and 1 in 50 is a FeLoBAL with excited-state Fe II absorption. At one end of the spectrum of models for BAL quasars, these fractions represent the fraction of sky around every quasar covered by that type of BAL outflow; at the other, the fraction of all quasars surrounded by that type of outflow. Since BAL outflows have mass loss rates comparable to quasar accretion rates and may be present around every quasar for at least part of its lifetime, determining the correct model for BAL quasars will improve our understanding of all quasars and of the influence of outflows on the IGM (Furlanetto & Loeb 2001) and on AGN hosts (Appleton et al. 2002).

The main argument against BAL outflows completely surrounding quasars has been that the absorption and emission EWs for BAL transitions should be the same in that case (Hamann *et al.* 1993), whereas the absorption is often much stronger. But line photons can be preferentially destroyed by dust, and BAL quasars are redder than normal quasars (e.g., Becker *et al.* 2000), probably because of dust. Some LoBAL quasars do show every sign of being 'young', recently (re)fueled quasars seen as they expel a shroud of dust and gas (Voit *et al.* 1993). And yet it is unclear if a random distribution of clouds can explain the observed lack of acceleration in BAL clouds (Wampler *et al.* 1995), whereas the orientation model – in which every quasar is a BAL quasar if seen from the right direction – arises naturally from models of accretion disk winds (e.g. Murray *et al.* 1995), and successfully predicts the very high X-ray column densities of BAL outflows (Green *et al.* 2001). However, Becker *et al.* (2000) have shown that radio-selected BAL quasars have a range of radio spectral indices, indicating a range of orientations. Thus there is a need for tests which can differentiate between these BAL quasar models.

B) Immediate Objective: The SDSS (York *et al.* 2000) has discovered two unique FeLoBAL quasars which can discriminate between these models (Hall *et al.* 2002). Each of these two quasars has absorption troughs that extend *redward of the host galaxy redshift* (Figs. 1-2). The two leading models for BAL quasars make very different predictions for the absorption trough shapes at high resolution in these objects. We propose to test these predictions with UVES spectroscopy. Modeling UVES spectra of the many absorbing transitions seen in these objects also will enable us to constrain the distance of the outflow from the central source in each object (e.g. Wampler *et al.* 1995). For these objects the two leading BAL quasar models predict distances which differ by a factor of ten; thus, UVES spectroscopy of them provides two independent tests of which model is correct.

Our two targets, 1125+0029 and 1128+0113, have very similar spectra with narrow absorption troughs from many transitions (mostly Fe II; Figs. 1-2). Their most interesting feature is their Mg II doublet absorption, which extends redward of the systemic redshift (dashed vertical lines) by $\sim$1200 km s^{-1} in 1125+0029 and $\sim$1800 km s^{-1} in 1128+0113. These redshifts are secure. The systemic redshift of 1125+0029 is $z = 0.8654 \pm 0.0001$, measured from Ca II K. Its narrow [O II] emission is blueshifted by 310$\pm$130 km s^{-1}. 1128+0113 has a systemic $z = 0.8931 \pm 0.0001$ from narrow [O II] emission. This probably slightly underestimates its true systemic redshift, but the 1500 km s^{-1} blueshift needed to remove the redshifted absorption would be unprecedented (McIntosh *et al.* 1999). Note that there are no lines of Fe II (or other ions) immediately redward of 2800 Å which are strong enough to explain the smooth extension of the Mg II trough redward of the systemic redshift.

Our proposed UVES spectroscopy will test several possible explanations for redward-of-systemic BAL troughs:
• If they are due to infalling discrete gas clouds crossing our line of sight, the apparently smooth troughs in the SDSS spectra will break up into many narrow ($\lesssim$15 km s^{-1}) lines in high-resolution UVES spectra.
• The absorption could be from an outflow of discrete clouds distributed with a substantial virial velocity dispersion. If the velocity dispersion is isotropic, as seems likely, the clouds will completely surround the quasar. As discussed above, this has been predicted for some LoBALs from other considerations (e.g. Canalizo & Stockton 2001), and it would mean that BAL quasars are a distinct, young class of quasars. **In this model the extent of the absorption redward of the systemic redshift would be the same for all troughs.**
• The competing model, in which all quasars can be BAL quasars if seen along certain lines of sight, is one in which BALs are produced in a wind from a rotating accretion disk. The wind will start out helical, with its velocity dominated by the disk's rotation velocity. If our line of sight passes through this section of the wind, and if the continuum source is no more than an order of magnitude smaller than the inner radius of the wind, the wind can have both approaching *and receding* velocities along our line of sight (Hall *et al.* 2002; independently recognized by Proga *et al.* (2002) for cataclysmic variable winds). Redshifted absorption is demonstrated in Fig. 3, which shows a top view of a rotating disk with a wind which begins at radius R. The continuum at some wavelength of interest is assumed to arise at $r<r_{max}$, the disk beyond r_{max} being too cool to emit significantly at that wavelength. A wind element at (R, ϕ) will absorb at velocity $v_{\rm LOS}$, which can be redshifted if the rotational velocity component dominates at R and if $r_{max}/R \gtrsim 0.1$. **In this model the extent of the absorption redward of the systemic redshift would be smaller for troughs at bluer wavelengths.** This is because bluer continuum wavelengths are emitted at smaller r_{max}, which decreases the maximum observable redshifted velocity. The SDSS spectra have limited blue wavelength coverage and insufficient resolution to deblend the many troughs and detect variation in the trough extents, but the proposed UVES data will be able

8. Description of the proposed programme (continued)

to do so. The maximum possible redshifted velocity at a given λ scales with $\sin(\theta)=r_{max}(\lambda)/R$, where $r_{max}(\lambda)$ is the outermost radius of significant emission for that λ. Our proposed UVES spectroscopy should reach 1670 Å rest frame in both objects, and in a standard $T(r) \propto r^{-0.75}$ accretion disk model, $r_{max}(1670\,\text{Å}) \simeq 0.5 r_{max}(2800\,\text{Å})$. Thus the Al II λ1670 trough should have a maximum redshifted velocity of $\sim$750 km s^{-1}– only half that of Mg II. (Because of the similar ionization potentials of Al II and Mg II, there is only a negligible correction for the different inner radii R of the winds in each ion, and the different disk rotation velocities v_{rot} at those R.)

There is also a speculative but exciting way which the disk wind model might explain the fact that the deepest absorption is near the high-velocity ends of the troughs in these objects, Relativistic beaming will brighten the approaching half of the disk and dim the receding half (Krolik & Voit 1998). *BAL gas with a redshifted line of sight velocity can only absorb emission from the receding half of the disk.* Since that half is fainter, in each transition a smaller fraction of the disk's continuum emission will be absorbed at velocities redward of systemic than at velocities blueward. With the reasonable assumption of constant partial covering with velocity, the result is asymmetric absorption profiles deeper at bluer wavelengths, exactly as observed in these objects. If modelling of the line profiles at UVES resolution shows that the BALs in these objects probe different regions of the accretion disk as a function of velocity, they would provide powerful constraints on accretion disk models.

Finally, high-resolution spectra will allow us to constrain the physical conditions in these objects' BAL outflows; namely, the electron density n_e, numerous ion densities N_{ion}, and the excitation temperature T_{exc}. Because most BAL troughs are saturated even though they only partially cover the continuum source (Arav et al. 1999a), such constraints can only be derived for rare objects (like these) with relatively narrow absorption from many different transitions, elements and ions. Most of the absorption lines in these objects are excited-state Fe II transitions from levels up to $\sim$2–3 eV above ground, but UVES will also cover Fe III at $\sim$1910 Å, Al III $\lambda\lambda$1854,1862 and Al II λ1670. In addition, at least one of our targets – 1125+0029 – shows absorption from Mn II, Ti II, excited-state Cr II, and the metastable 2^3S level of He I (populated mainly by recombination of He II, this level sets a lower limit on the column density in He II and therefore H II).

Using the velocity profile of absorption from unblended lines, a model of the entire spectrum can be constructed and fit to the observations, yielding best-fit N_{ion}, T_{exc}, and n_e values in the BAL region (e.g., de Kool *et al.* 2002). Assuming the BAL gas is in photoionization equilibrium with the quasar, the n_e and N_{ion} constraints can be combined with photoionization models to determine the ionization parameter U of the BAL gas and its distance from the central continuum source. **This distance can be compared with the expected distance for the model that best fits the redward-of-systemic absorption troughs, for an independent check on the validity of that best-fit model.** For a disk wind, we expect a distance $\gtrsim 3\times10^{16}$ cm; for a virialized population of clouds, $\gtrsim 5\times10^{17}$ cm (Hall et al. 2002). Either way, such distance measurements are also valuable because they have been made for only 3 other BAL quasars (Hamann *et al.* 2001, de Kool *et al.* 2001, 2002; Everett *et al.* 2002). In two cases the distances are 1–4 parsecs, but the Hamann result on the 'mini-BAL' in 3C 191 is a remarkable 28 kpc! Even if it is just left over from an earlier BAL phase, it is difficult to understand how the gas could remain confined or collimated at such large distances. More BAL outflow distances from the continuum sources need to be measured to address the issue.

C) Telescope Justification: Our targets are faint enough to be simply beyond the reach of NTT + EMMI. Our scientific goals require SNR$\geq$15 per 2-pixel resolution element at $R\geq$20000 (Arav et al. 1999a, Fig. 1) in the wavelength range 3500$-$6500 Å (observed). This requires 4 hours each in DIC1 and DIC2 for each object.

D) Observing Mode Justification (visitor or service): Our observations are routine and can easily be done in service mode. Given the amount of time needed for these two objects and their proximity in the sky, service mode is also more efficient since it allows for the possibility of distributing the OBs over several different nights.

E) Strategy for Data Reduction and Analysis: Hutsemekers has extensive experience with high-resolution spectra. Between them the investigators have experience with BAL quasar spectra, modelling of high-resolution spectra, and use of photoionization codes, skills required to meet the immediate objectives outlined above.

REFERENCES

Appleton *et al.* 2002, ApJ, 566, 682
Arav *et al.* 1999a, ApJ 516, 27
Becker *et al.* 2000, ApJ 538, 72
Canalizo & Stockton 2001, ApJ 555, 719
de Kool & Begelman 1995, ApJ 455, 448
de Kool *et al.* 2001, ApJ 548, 609
de Kool *et al.* 2002, ApJ 678, 58
Elvis, M. 2000, ApJ, 545, 63
Everett, J. *et al.* 2002, ApJ in press (astro-ph/0201268)
Furlanetto & Loeb 2001, ApJ 556, 619
Green, P., *et al.* 2001, ApJ 558, 109
Hamann, F., *et al.* 1993, ApJ 415, 541
Hamann, F., *et al.* 2001, ApJ 550, 142
Hall, P., *et al.* 2002, ApJS in press (astro-ph/0203252)
McIntosh, D., *et al.* 1999, ApJ, 514, 40
Murray, N., *et al.* 1995, ApJ, 451, 498
Proga, D. *et al.* 2002, ApJ, in press (astro-ph/0202384)
Voit, Weymann & Korista 1993, ApJ 413, 95
Wampler, Chugai & Petitjean 1995, ApJ 443, 586
York, D. *et al.* 2000, AJ, 120, 1579

8. Attachments (Figures)

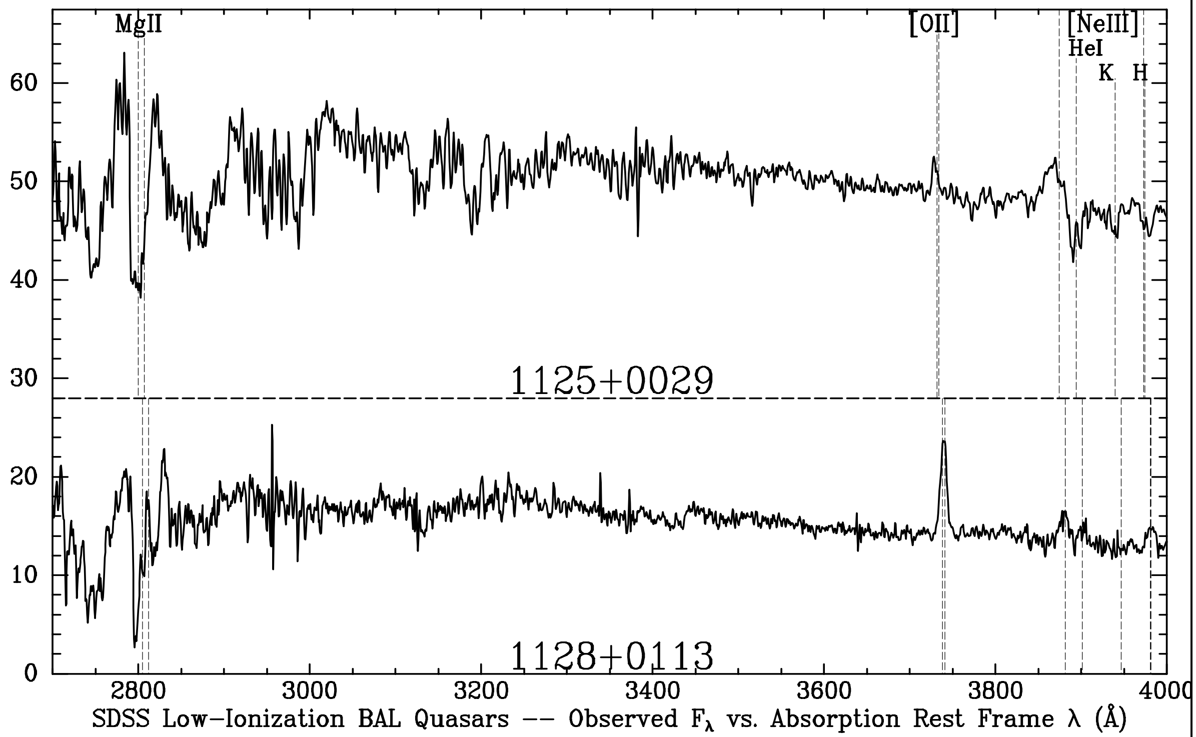

Fig. 1 - Spectra of our targets from rest-frame 2700-4000 Å at the redshift of peak absorption. Dashed vertical lines show the wavelengths of Mg II, [O II], He I λ3889, Ca II H&K, [Ne III] $\lambda\lambda$3869,3969 in the adopted *systemic* rest frame of each object (note the slight [O II] & [Ne III] λ3869 blueshift in 1125+0029). The Mg II absorption redward of the dashed lines shows that the Mg II BAL troughs extend redward of the robust systemic redshifts by ~1500 km s^{-1}, many times the ~150 km s^{-1} resolution. Despite the many Fe II absorption features in the spectrum, there are no Fe II transitions which can produce such strong absorption immediately redward of Mg II.

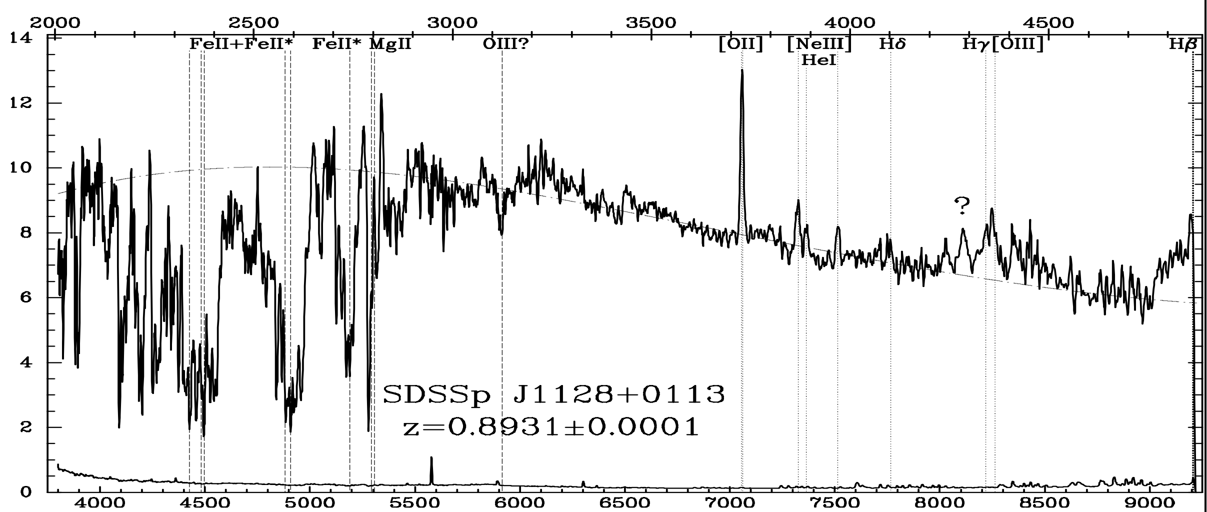

Fig.2 - SDSS J1128+0113

Fig. 2 - Full SDSS spectrum (F_λ vs. λ) of one target, showing the large number of absorption troughs present, most of which are from Fe II. Observed λ (in Å) is displayed along the bottom axis, and rest λ along the top).

8. Attachments (Figures)

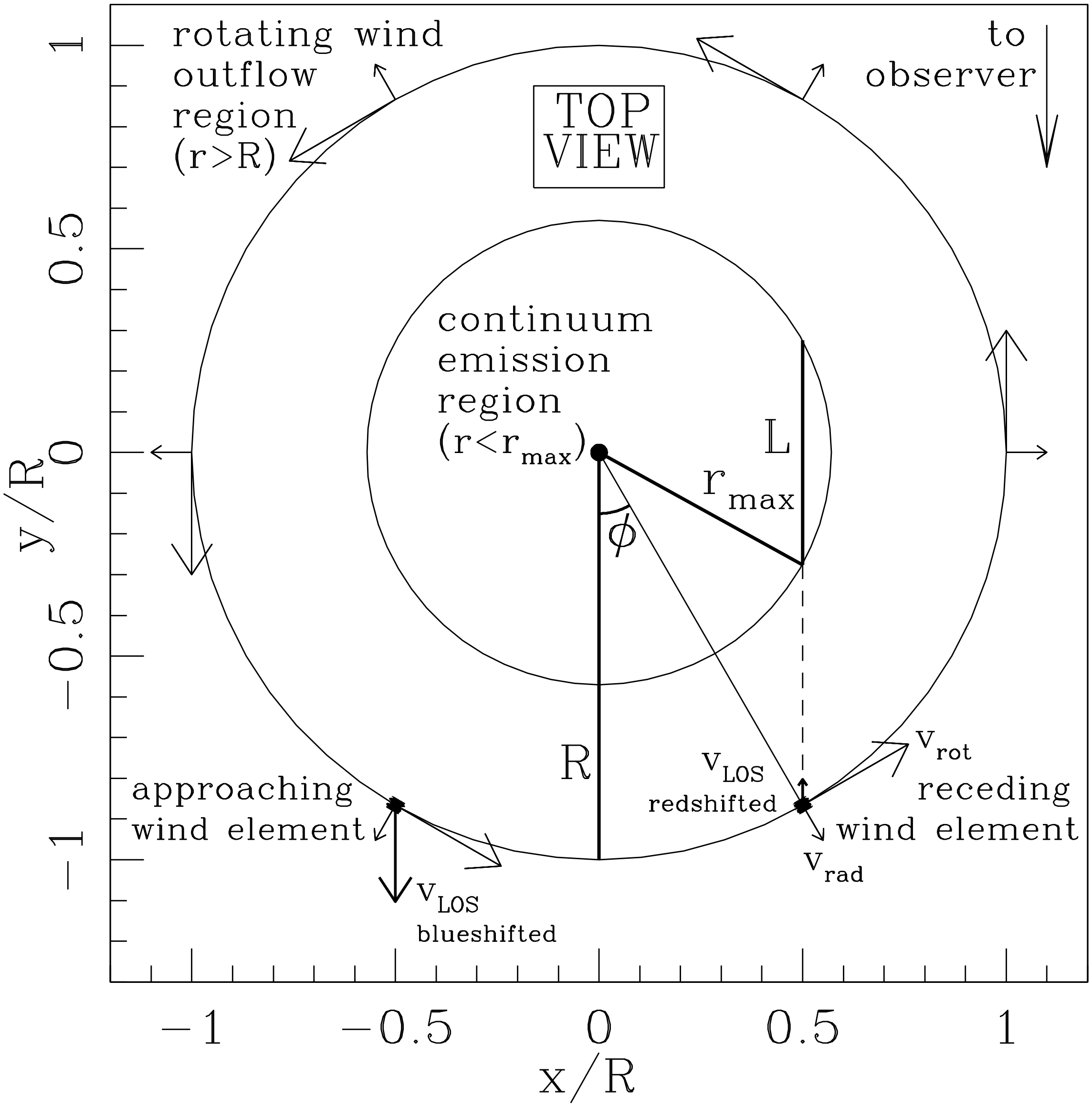

Fig. 3 - How a rotating disk wind plus an extended continuum source can give rise to redshifted BAL troughs. In this top view of an accretion disk, the black hole is the black circle at (0,0), the y axis is the line of sight to the observer, and the x and z axes are in the plane of the sky. The continuum emission at a given wavelength arises at $r < r_{max}$, and the wind begins at radius R. A wind element at (R, ϕ) will absorb at a line of sight velocity $v_{\rm LOS}$, which will be redshifted if the tangential velocity dominates the radial velocity. (If the disk is not exactly edge-on, along the line of sight the tangential velocity component must dominate both the radial and vertical velocity components.) In Hall et al. (2002) we show that both the Elvis (2000) and Murray et al. (1995) disk wind models can produce redward-of-systemic troughs, but not the de Kool & Begelman (1995) model, which posits a wind arising too far from the continuum source for the latter to appear appreciably extended.

9. Justification of requested observing time and lunar phase

Lunar Phase Justification: All calculations of exposure times were made with the UVES ETC version 2.8.0 using the depolarizer and assuming 7 days of moonlight since this is high-resolution work. This reduces the SNR no more than 10% from that at new moon, but beyond 7 days the SNR losses become unacceptable.

Time Justification: Our scientific goals require SNR$\geq$15 per 2-pixel spectral resolution element (cf. Arav et al. 1999a, Fig. 1) in the wavelength regions of main interest (3500 – 6500 Å, observed frame). Using the known SDSS $u'g'r'i'z'$ magnitudes for each object and version 2.8.0 of the UVES exposure time calculator, we compute the following exposure times needed to achieve that goal, assuming airmass 1.3 and 7 days of moonlight.

- 1125+0029: 4 x 1 hrs DIC1 + 4 x 1 hrs DIC2.
- 1128+0113: 4 x 1 hrs DIC1 + 4 x 1 hrs DIC2.

Since our objects have very similar magnitudes, their exposure times are identical. For these faint objects, we have assumed a 1″ slit, 1″ seeing, and binning by 2 pixels in the dispersion direction. This still provides the required $R \geq 20000$ ($\leq$15 km s^{-1}).

For each run we also need one telluric standard star, such that, taking into account 10 min overhead per OB, the total observing time amounts to 9.5 hrs for each run (1 object per run).

Note that since these objects may be highly polarized, especially in the absorption troughs, we plan to use the depolarizer to ensure that the effective throughput does not vary in an unknown fashion with wavelength (due to the possible polarization dependent efficiency of some UVES optics).

Calibration Request: Standard Calibration

10. Report on the last use of ESO facilities

67.A-0544 / P. Hall / Spectroscopy of Candidate Reddened Quasars from SDSS+2MASS

Telescope	Instrument	Obs. Dates	Completion (%)	Time lost (%)	Reason
NTT	EMMI	17-20 Apr 2001	100%	5%	technical

Current status of obtained data: paper-submitted

Remarks: No reddened quasars found, indicating that SDSS is very complete even for very reddened quasars (paper in preparation). Several candidates were carbon stars, to appear in Margon et al. (submitted). One highly reddened FIRST/2MASS quasar was found as well (Hall et al. in preparation). Observations of SDSS gravitational lens candidates also made to take advantage of excellent seeing; no lenses found, but one quasar binary and one quasar companion galaxy found (paper in preparation). Observations also made of the strange [OII]-without-[OIII] galaxy RCS 1443+0805 (paper in preparation).

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

- Hall, P., *et al.* 2000, AJ, 120, 2220: Active Galactic Nuclei in the CNOC2 Field Galaxy Redshift Survey
- Hall, P., *et al.* 2001, to appear in Mass Outflow from AGN: New Perspectives, eds. Crenshaw, Kraemer & George (astro-ph/0107182): Extreme Broad Absorption Line Quasars from the Sloan Digital Sky Survey
- Hall, P., *et al.* 2002, ApJS in press (astro-ph/0203252): Unusual Broad Absorption Line Quasars from the Sloan Digital Sky Survey
- Hall & Hutsemekers *et al.* 2002, to be submitted: VLT+UVES Spectroscopy of the Unusual BAL Quasars SDSS 0300+0048 and SDSS 1453+0029
- Lamy & Hutsemekers 2000, A&A, 356, L9: Spectropolarimetry of the iron low ionization broad absorption line quasar Q 0059-2735
- Menou, K., *et al.* [including Hall] 2001, ApJ, 561, 645: Broad Absorption Line Quasars in the Sloan Digital Sky Survey with VLA-FIRST Radio Detections

12. List of targets proposed in this programme

Run	Target/Field	α	δ	Eq.	Mag.	Diam.	Additional info	Reference star
A	SDSS J1125+0029	11 25 26	+00 29 01	J2000	g=19.29			
B	SDSS J1128+0113	11 28 28	+01 13 37	J2000	g=19.60			

Target Notes: The magnitudes given are for the band closest in wavelength to 2500 Å rest frame, where most of the absorption we propose to study occurs.

13. Scheduling requirements

14. Instrument configuration

Telescope	Instrument	Parameter	Value or list
UT2	UVES	DIC-1	Standard setting: 346+580
UT2	UVES	DIC-2	Standard setting: 437+860