Date: March 23, 2005Category: QSO's, Active Galaxies Proposal: C1727

CFHT
OBSERVING TIME REQUEST
Semester: 2005B Agency: Canada

1. Title of the Program *(may be made publicly available for accepted proposals)*:

First High-Resolution Spectropolarimetry of a Broad Absorption Line Quasar

2. Principal Investigator: **Patrick Hall**

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4. Summary of the Program *(may be made publicly available for accepted proposals)*:

About 1 in every 6 luminous AGNs shows broad absorption ($\geq$2000 km/s broad) outflowing at high velocity (up to 0.2c) in ions such as C IV, Si IV and N V. Low-resolution spectropolarimetry has shown that broad absorption line (BAL) quasars are more highly polarized than normal quasars, especially in the troughs, and high-resolution spectroscopy has revealed absorption trough depth variations on velocity scales as small as 12 km/s. These observations suggest that BAL troughs arise in low-latitude, inhomogeneous winds from accretion disks, winds which absorb most direct light but not most scattered light. This model predicts that small-velocity-scale depth variations should be accompanied by small-velocity-scale polarization variations. EsPaDOnS offers the world's only high-resolution spectopolarimetric capability, required to test this model. We propose observations of one of the two BAL quasars bright enough AND known to have troughs polarized enough to yield sufficient signal-to-noise to study BAL trough polarization at velocity resolutions never before probed. Our observations will allow different tests of different BAL quasar models; for example, a lack of small-velocity-scale polarization variations could indicate the 'smearing' signature of scattering by hot (T>20,000 K) electrons.

5. Summary of the Observing Run Requested:

Instrument	Detector	Moon (d)	Filters	Grisms
ESPaDOnS	EEV1	7	standard.	standard.

Time Req.	Service/Queue?	Queue Mode	Image Quality	Opt. LST	Min. LST	Max. LST
3 nights	No	—	—	02:00	00:00	05:00

6a. Is this a joint proposal? NO 6b. If yes, total number of nights or hours requested from all agencies? —

7a. Is this a Thesis Project? NO 7b. If yes, indicate supervisor: —

8. Special instrument or telescope requirements:

Polarimetric mode and xslow CCD readout mode both required.

9. Scheduling constraints:

None.

10. Scientific Justification *(science background and objectives of the proposed observations: 1 page maximum)*:

About 1 in every 6 luminous AGNs shows broad absorption (2000 km/s or more) outflowing at high velocity (up to $0.2c$) in ions such as C IV, Si IV and N V (Reichard et al. 2003). The two extremes among models for these broad absorption troughs are that they are present in all quasars, covering 1/6 of the available lines of sight, or that they represent a phase lasting 1/6 of all quasar lifetimes. Although there is some evidence for the latter picture (e.g. Canalizo & Stockton 2001), the similarity of BAL and non-BAL quasar spectra outside the absorption troughs suggests the former picture is closer to the truth. Furthermore, low-resolution spectropolarimetry has shown that broad absorption line (BAL) quasars are more highly polarized than normal quasars, especially in the troughs (Fig. 1), and high-resolution spectroscopy has revealed substantial absorption trough depth variations on velocity scales as small as 12 km/s (e.g., Hall et al. 2003). These observations suggest that BAL troughs arise in low-latitude, inhomogeneous winds from accretion disks, winds which absorb most direct light but not most scattered light (top view shown in Fig. 2).

BAL quasar polarization observations tell us there are both scattered and direct lines of sight to the emission regions. The standard model invoked to explain BAL trough polarizations is that the scattered line of sight bypasses the BAL region, so that the observed flux in the BAL trough is the sum of the scattered, polarized light plus any residual, unpolarized direct light. In all BAL quasars with troughs amenable to high resolution study, it is found that the troughs have residual flux with structure on small velocity scales because the absorber's covering factor of the continuum source (and to a lesser degree, its optical depth) varies on small velocity scales (e.g., Hall et al. 2003). Therefore, our standard model predicts that the observed polarization should increase when the trough depth increases, regardless of the structure of the absorbers (e.g., winds or clouds) or the velocity scale on which the change in absorption strength occurs. Simply put, the unpolarized direct light is being suppressed by absorption, while the polarized flux is not, and thus the observed degree of polarization increases. This behavior is generally followed in the low-resolution spectropolarimetric samples of Schmidt & Hines (1999; SH99), Ogle et al. (1999; OEA99), and Lamy & Hutsemekers (2004). In the rare cases of BALs with unpolarized or weakly polarized troughs (e.g. Brotherton et al. 1997), it may be that the scattered line of sight is at least partially absorbed as well. (In fact, this is seen at some level in many quasars, including our target (Fig. 1), as evinced by the presence of a weaker but definitely non-zero level of broad absorption even in polarized flux.)

EsPaDOnS offers the world's only high-resolution spectopolarimetric capability, required to test the predictions of our standard BAL trough model. We have never before explored polarization in broad absorption line (BAL) quasars at the very small velocity scales made possible by EsPaDOnS. While it is therefore rather difficult to predict with certainty what will be found by such observations, the standard model of BAL trough polarization predicts that there will be polarization structure at all velocity scales where there is also structure in the depth of the absorption trough. We therefore propose observations of one of the two BAL quasars bright enough *and* known to have troughs sufficiently polarized to yield the signal-to-noise needed to study BAL trough polarization structure at unprecendented velocity resolution.

Our results will have different implications for different BAL quasar models. If the weak troughs seen in polarized light come from photons which are absorbed and then scattered (e.g. the diagonal line in Fig. 2), the trough could contain a kinematic signature of the scatterers (Goodrich & Miller 1995; GM95). For instance, hot electrons would smear out sharp absorption troughs. GM95 set a limit of $T < 10^5$ K for such electrons from resolution $R \simeq 1000$ data; we will push this limit down to $T \simeq 2 \times 10^4$ K. We will also search for small-velocity-scale structure in the polarization position angle θ, and attempt to verify the large-velocity-scale variations in θ for this object discussed by Ogle (1997). A smooth change in θ requires more than one polarized light component to be present.

Lastly, the absorption spectrum of our target (the $z = 2.256$ quasar [WFM91] 0226-1024) is quite rich below C IV λ1550, with at least four systems between outflow velocities of 2000 km/s and 30,000 km/s (Fig. 1), and polarization reaching 7% (OEA99) to 10% (SH99) in the deepest BAL trough. We will have a very high-resolution, high-S/N spectrum of the quasar with which to model the absorption troughs wherever we can separate the two components of doublet absorption lines and use their residual intensities to solve for the two unknowns — the absorber covering factor and optical depth (e.g., Hall et al. 2003).

11. References *(1 page maximum)*:

Brotherton, M. S.; Tran, Hien D.; van Breugel, Wil; Dey, Arjun; Antonucci, Robert; 1997ApJ...487L.113B, Spectropolarimetry of FIRST Broad Absorption Line Quasars

Canalizo, Gabriela; Stockton, Alan; 2001ApJ...555..719C, Quasi-Stellar Objects, Ultraluminous Infrared Galaxies, and Mergers

Goodrich, Robert W.; Miller, Joseph S.; 1995ApJ...448L..73G, Polarization Clues to the Structure of Broad Absorption Line Quasi-stellar Objects

Hall, Patrick B.; Hutsemkers, Damien; Anderson, Scott F.; Brinkmann, J.; Fan, Xiaohui; Schneider, Donald P.; York, Donald G.; 2003ApJ...593..189H, VLT+UVES Spectroscopy of the Ca II Low-Ionization Broad Absorption Line Quasar SDSS J030000.56+004828.0

Hines, Dean C.; Schmidt, Gary D.; Smith, Paul S.; 1999ApJ...514L..91H, The Polarized Spectrum of APM 08279+5255

Lamy, H.; Hutsemékers, D.; 2004A&A...427..107L, Polarization properties of broad absorption line QSOs: New statistical clues

Ogle, P. M.; 1997ASPC..128...78O, Keck Spectropolarimetry of BAL QSOs, in Mass Ejection from Active Galactic Nuclei; ASP Conference Series; Vol. 128; 1997; ed. N. Arav, I. Shlosman, and R. J. Weymann, p.78

Ogle, P. M.; Cohen, M. H.; Miller, J. S.; Tran, H. D.; Goodrich, R. W.; Martel, A. R.; 1999ApJS..125....1O, Polarization of Broad Absorption Line QSOS. I. A Spectropolarimetric Atlas (OEA99)

Reichard, Timothy A.; Richards, Gordon T.; Hall, Patrick B.; Schneider, Donald P.; Vanden Berk, Daniel E.; Fan, Xiaohui; York, Donald G.; Knapp, G. R.; Brinkmann, J.; 2003AJ....126.2594R, Continuum and Emission-Line Properties of Broad Absorption Line Quasars

Schmidt, Gary D.; Hines, Dean C.; 1999ApJ...512..125S, The Polarization of Broad Absorption Line QSOs (SH99)

12. Figures *(all figures must appear on a single page)*:

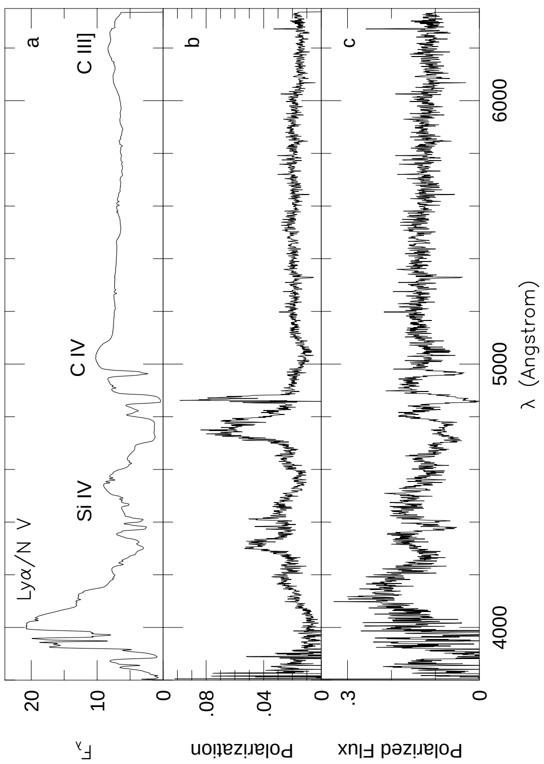

Figure 1: low-resolution spectropolarimetry of our target, 0226-1024 (Ogle 1997). a) Total flux. b) Fractional polarization. c) Polarized flux (product of a and b).

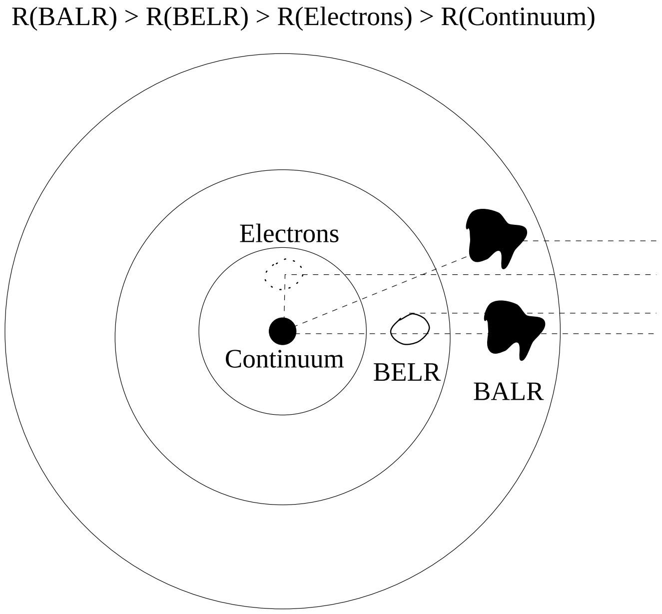

Figure 2: Relative sizes of the nuclear continuum emission, broad emission, electron scattering, and broad absorption regions in BAL quasars. Direct and scattered rays toward our line of sight are also shown. From Ogle (1997).

13. Technical Justification

(provide technical details of the proposed observations; justify the use of the CFHT, the requested instrument configuration, and the amount of telescope time requested: 1 page maximum):

EsPaDOnS is the only high-resolution spectropolarimeter on a 4-m telescope or larger. Our target is one of the two BAL quasars bright enough ($V < 17$) and with troughs *known* to be polarized enough to make a study of their small-velocity-scale trough polarization characteristics feasible.

The most important wavelength range for our study is that of the redshifted C IV trough, from 4600-5000 Ang (Fig. 1). Based on the EsPaDOnS exposure time calculator, we estimate we can achieve S/N=18 per 2.6 km/s velocity bin at those wavelengths for a V=16.6 source in a 4x20-minute spectropolarimetric exposure sequence (one 20-minute exposure for each orientation of the Wollaston prism) in 0.8" seeing at an average airmass of 1.375, with the CCD in xslow readout mode, and with a 7 day old moon or less. (Since we are working at 5000 Ang and bluer, moonlight is not a strong contributor to the total S/N, but we would prefer the youngest moon possible in order to minimize any possible systematics from scattered, polarized moonlight, and because direct sky subtraction is not possible in EsPaDOnS's spectropolarimetry mode.)

With 21 hours of observation over 3 nights (our target is above airmass 2 for about seven hours per night), we should achieve a S/N=71 (1σ flux uncertainty of $\pm 1.4\%$) per *full resolution* velocity bin. Such a high S/N is required since the *continuum* polarization in our target is only 3% below 5000 Ang. Fortunately, the *trough* polarization reaches 7-10% in the deepest C IV trough and where necessary we can bin by a factor of two or more in velocity (yielding a $\geq 4\sigma$ *continuum polarization* detection per rebinned resolution element) and still explore polarization at unprecedented velocity resolution for quasars.

Although our target will be about ten times fainter than any observed to date with EsPaDOnS, we do not anticipate any problems because of this. **Our S/N and resolution requirements are lower than typically required for modern stellar spectroscopy, which is why we can usefully observe a relatively faint target.** There are several objects in the (Cassegrain) field as bright or brighter than the target, useful for guiding if needed. We are working well into the blue, so the sky level will be at most 5% of the object flux level. Interstellar polarization in this direction is negligible ($\leq 0.02\%$; OEA99).

14. Targets:

Object/Field	α	δ	Epoch	Mag/Flux	Comment
[WFM91] 0226-1024	02:28:39.2	-10:11:10.0	2000	16.6	V=16.3 (POSS); V=16.9 (Ogle 1999)

15. General Target Information:

16. Is this program conducted in relation with other observations (optical, radio, space)?
NO

17. How many additional nights or hours at CFHT would be required to complete this project? 0 nights

18a. Is an extension of the one-year proprietary period required? NO 18b. Proposed proprietary period? 12 months
18c. If yes, justify the request for an extension:

19. Recent Allocations on CFHT and Other Telescopes:

- JCMT 04-B w/SCUBA: A submm survey of LBQS and SDSS BAL quasars (22.5 hours). No data obtained.
- ESO-3.6m 03-A w/EFOSC: Polarization Properties of a Large, Uniformly Selected Sample of BAL and non-BAL Quasars (5 nights). Run successful, paper in preparation.
- NOAO-Keck 03-A w/HIRES: Redshifted Troughs in Broad Absorption Line Quasars: Testing the Rotating Disk Wind Model (1 night). Poor weather led to very little data being obtained.
- CFHT 03-A w/CFHT-IR: Infrared Confirmation of $z > 5.5$ Quasar Candidates (2 nights). Run successful, paper in preparation.

20. Publications Resulting from CFHT Observations *(only the 12 most recent contained in the database are displayed)*:

Hall et al. 2004, AJ, 127, 3146
Gladders, Hoekstra, Yee, Hall & Barrientos 2003, ApJ, 593, 48
Patton, Pritchet, Carlberg, Marzke, Yee, Ellingson, Hall, Lin, Morris, Sawicki, Schade, Shepherd & Wirth 2002, ApJ, 565, 208
Hall et al. 2002, ApJS, 141, 267
Hoekstra, Yee, Gladders, Barrientos, Hall & Infante 2002, ApJ, 572, 55
Hall, Sawicki, Martini, Finn, Pritchet, Osmer, McCarthy, Evans, Lin & Hartwick 2001, AJ, 121, 1840
Carlberg, Yee, Morris, Lin, Hall, Patton, Sawicki & Shepherd 2001, ApJ, 563, 736
Carlberg, Yee, Morris, Lin, Hall, Patton, Sawicki & Shepherd 2001, ApJ, 552, 427
Carlberg, Yee, Morris, Lin, Hall, Patton, Sawicki & Shepherd 2000, ApJ, 542, 57
Yee, Morris, Lin, Carlberg, Hall, Patton, Sawicki, Wirth, Ellingson & Shepherd 2000, ApJS, 129, 475
Rusin, D., Hall, P., Nichol, R., Marlow, D., Richards, A. & Myers, S. 2000, ApJ, 533, L89
Hall, Yee, Lin, Morris, Carlberg, Patton, Sawicki, Shepherd & Wirth 2000, AJ, 120, 1660