X-shooter Science Verification Proposal

Probing AGN accretion through microlensing

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Abstract:

The standard paradigm for understanding the central engine of AGN remains physically unrealistic, and weakly observationally constrained (e.g. Blaes 2007). While the accretion model has met significant successes (e.g. Cataclysmic Variables) it does a bad job describing accretion onto a black hole. AGN accretion disks are impossible to observe directly, having typical angular sizes on the order of micro-to-nanoarcseconds. We have developed a technique to use single-epoch multi-wavelength observations of "anomalous" lensed quasars to place constraints on the size and physics of the accretion disk that would otherwise take decades of observation to obtain. To date we have placed two of the tightest constraints on AGN emission region size and mechanism using only single-epoch broadband optical-NIR imaging (Floyd et al. 2009, Bate et al 2008). We request X-shooter IFU spectroscopy to refine the technique by separating out continuum from emission lines, and to constrain tightly the role of dust in these sources, by examining the Balmer decrement.

Scientific Case:

A range of theoretical models for accretion based on different physical mechanisms (particularly for angular momentum transport) predict different radial emission profiles (see Blaes 2004 for a full review). We can now observationally distinguish between these mechanisms if (as is probable from surface density arguments – Schneider et al. 1992) there is microlensing present, since microlensing produces demagnifications with greater probability for smaller source sizes (e.g. Bate et al. 2007, Schechter & Wambsganss 2002, Witt Mao & Schechter 1995, Wambsganss & Paczynski 1991). Usually such constraints require decades of observations, in order to eliminate the effects of intrinsic variability (seeing the source in different states in each of the lensed images due to their differing light travel times – e.g. Eigenbrod et al. 2008). However, in quasars with two very closely separated images (straddling a critical curve), variability is not a concern since we can constrain the light path differences to within a day or less (e.g. Keeton et al. 2006). Such image pairs straddle a caustic, one forming at a minimum in the light travel-time surface, the other at a saddle point. Microlensing can introduce demagnification in the saddle point image, with respect to the global (macrolens) magnification. There are 10 such quasars known, with 8 of them exhibiting an **anomalously low** X-ray flux in the saddle point image, as expected from microlensing (Pooley et al. 2007). The remaining two are not strongly anomalous. Several observations have shown that the flux anomaly increases with decreasing wavelength (e.g. Floyd et al. 2009, Bate et al. 2008, Lawrence et al. 1995, Wambsganss & Paczynski 1991). The anomaly in these sources is now widely understood to be a product of microlensing by substructure in the lensing galaxy. Of course gravitational lensing is a fundamentally achromatic process and the microlensing interpretation introduces a chromatic effect by virtue of the lensed source size varying with wavelength. Other possible explanations for the observed anomaly are millilensing and preferential absorption by interstellar dust along one path. In SDSSJ0924+0219 (Floyd et al 2009) we have been able to cast significant doubt on both effects. Millilensing cannot explain the chromatic effect seen in this source, and is also inconsistent with multi-epoch observations that show clear variability over 5 years. Dust cannot produce the observed spectral source colours alone – see Fig. 1. Single-epoch multi-wavelength observations of these rare targets offer us nature's most serendipitous window onto the central regions of quasars. Fig. 2 summarises existing measures of quasar emission mechanisms. We need simultaneous multi-wavelength coverage from the optical to the NIR in order to be able to more accurately constrain models of accretion. Spatially resolved spectroscopy will allow us to separate the continuum from the emission line flux and to properly constrain the role of preferential absorption by dust in these sources. We are currently developing detailed AGN models that include a full treatment of the kinematics of the broad line region and its emission using CLOUDY (Ferland et al. 1998). The data obtained from X-shooter will provide valuable input to such models.

Targets and observing mode

Target	RA	DEC	V mag	Mode (slit/IFU)	Remarks
PG1115+080	11:18:16.9	+07:45:58	17.6	IFU	$z_s = 1.72$; $t_int = 450$ s
WFI2026-4536	20:26:10.4	-45:36:28	$i = 17.4$	IFU	$z_s = 2.23$, z_l unknown; $t_int = 450$ s
WFI2033-4723	20:33:41.9	-47:23:43	19.3	IFU	$z_s = 1.66$; $t_int = 1350$ s

Time Justification:

We request spatially resolved spectra of one of the lensed quasars listed in the table, in sufficiently good seeing to resolve the anomalous image pair (≤ 0.6 arcsec), and to sufficient depth to detect the dimmer of the two lensed images. From this we will determine the flux ratio across the spectrum, making separate fits to the continuum and emission lines. We will use the emission lines to further constrain the role of dust (Balmer decrement) and look for any absorption features. In the table above we present the magnitude of the dim (saddle point) image in the anomalous image pair. We need to be able to get to at least this depth in the continuum. An SNR of 5 per spectral resolution element will allow an excellent characterisation of the flux ratio across the spectrum.

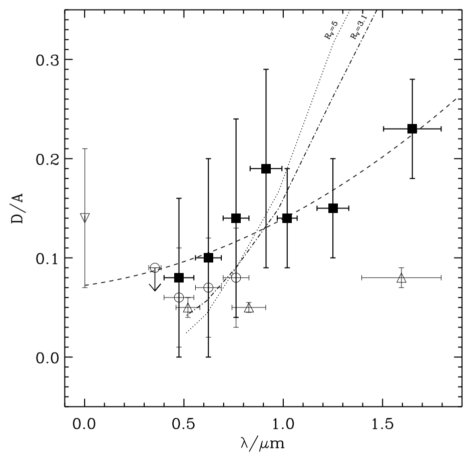
We will position the small IFU field-of-view in order to cover the anomalous image pair, and to include the lensing galaxy. The lensing galaxy is only essential for WFI2026-4536 for which there is no published lens redshift. For this source it is possible to fit the entire 4-image system into the field of view of the IFU due to its compactness.

For our first two sources, PG1115+080 and WFI2026-4536, 450 s of integration is sufficient to provide SNR>5 per spectral resolution element except at the very extremes of the covered spectral range ($> 2\mu$m and ~ 300 nm). Calculations assume 0.6 arcsecond seeing, and grey time (7 days after new moon), for a quasar SED model at the redshift of each source. We have adopted the slow read mode, high gain and no binning. We will also require off-target dithers in order to perform accurate sky-subtraction. Thus the total time requested 15 minutes for PG1115+080 and WFI2026-4536, and 45 minutes for WFI2033-4723.

Research Plan:

D. Floyd will take charge of reducing the spectra using the X-shooter pipeline. We have a powerful statistical microlensing package in place at Melbourne for modelling the resulting continuum flux ratios (Bate et al. 2007). We anticipate a quick turnaround on this dataset, to publish a follow up to Floyd et al. (2009) and Bate et al. (2008) by the end of the year. Examining the emission lines will require some new work, but we are developing detailed AGN models which include a full treatment of the kinematics of the broad line region, and its emission using CLOUDY (Ferland et al. 1998). Finally, the publicly available data will form a valuable dataset to other groups studying these objects, and requiring multiple epoch observations

We feel this is an ideal science verification case for X-shooter. We require simultaneous coverage of the spatially-resolved optical-NIR spectrum of two nearby ($\lesssim 1$ arcsec) lensed quasar images. This is currently only possible using X-shooter on the VLT. The work it requires a minimum investment of observing time (albeit with excellent seeing), and can provide a rapid scientific result on an exciting topic in modern astrophysics.



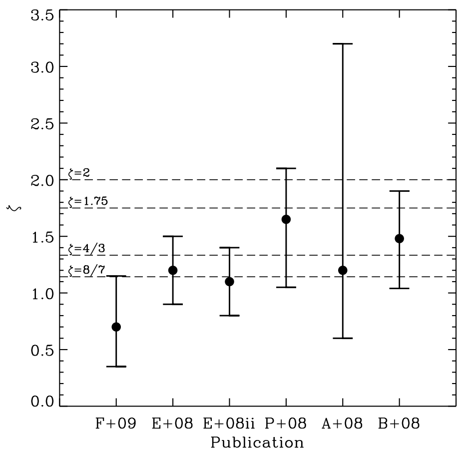


Figure 1: Anomalous flux ratio (macrolensing predicts a ratio close to unity) with wavelength for SDSS0924+0219 by Floyd et al. 2009 (filled squares) and for earlier data: Circles (Inada et al 2003); Triangles (Keeton et al 2006); Down-pointing triangle (Pooley et al 2007). The dashed line shows the best quadratic fit to our new data only. For reference, we model the ratios if we assume that D is simply extinguished by dust, with no microlensing. Two dust models are shown (Mathis 1990) with $R_V = 3.1$ (dot-dashed line – typical diffuse ISM) and $R_V = 5$ (dotted line – dense dust clouds). Partial extinction would result in the lines moving to the right, with the same slopes.

Figure 2: Constraints on quasar accretion mechanism in the literature (peak probability value $\pm 1\sigma$). Examples shown are: F+09 (Floyd et al. 2009) – SDSS0924+0219 multi-band single-epoch imaging; E+08 (Eigenbrod et al. 08) – QSO 2237+0305 spectroscopic monitoring; E+08ii (Eigenbrod et al. 08) – as E+08, but with no velocity prior; P+08 (Poindexter et al. 08) – HE 1104-1805 multi-band monitoring; A+08 (Anguita et al. 08) – QSO 2237+0305 multi-band monitoring; B+08 (Bate et al. 08) – MG 0414+0534 multi-band single-epoch imaging.

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