X-shooter Science Verification Proposal

Disentangling spectral curvature in black hole X-ray binaries

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Abstract:

The accretion environments of X-ray binaries possess a wealth of structure. Discrete but inter-connected components, including an accretion disc, a compact jet, and a hot corona, all contribute in varying degrees, depending on the source state and wavelength of observation. X-SHOOTER provides a first, excellent opportunity for accurate broad-band spectral decomposition of their complex emission. We propose a short (1 h) X-SHOOTER observation of the black hole binary GX 339–4, close to time to an approved multi-wavelength campaign that we are carrying out on June 29/30 2009, in particular RXTE/X-ray observations. We aim to clearly detect a continuum break marking the transition from optically-thick to thin jet emission; based on previous broad-band photometry, this break is most likely to lie in the near-infrared. Furthermore, we will also obtain accurate normalization of the accretion disc to jet power-law contributions. GX 339–4 is the best source for this work because of the faintness of its binary companion. This observation will serve as an excellent pilot study for an enlarged sample.

Scientific Case:

Accreting black hole binaries: A fundamental goal of studies of accreting cosmic sources is to understand the physical nature of their broad-band radiated powers. Multi-wavelength observations of several black hole X-ray binaries in our Galaxy have revealed evidence of a rich structure to the environments of the primary compact objects, including an optically-thick accretion disc, a diffuse hot coronal plasma, as well as a bipolar jet (e.g. Done et al. 2007 A&A Rev. 15 1). The dominance of these various physical components changes with wavelength, and also varies dramatically with time, driven by large-scale, stochastic accretion rate variations (e.g. Patterson 1984 ApJS 54 443).

The so-called 'low/hard' state of X-ray binaries (with a low X-ray flux, and spectrum extending to high [hard] energies) shows particularly complex spectral and temporal morphology, with no single component dominating the optical regime. The appearance of relativistic jets in this state has been widely recognized over the past few years (e.g. Fender et al. 2004 MNRAS 355 1105). Corbel & Fender (2002 ApJL 573 L35) have shown that self-absorbed synchrotron emission from the compact jet of GX 339–4 likely extends from the radio to near-infrared (near-IR) regimes. At a wavelength of a few microns, the spectrum is inferred to break to a steeply-declining power-law, characteristic of optically-thin non-thermal radiation (see Fig. 1). Accurate measurement of this break is essential to determine the physical conditions, composition and energetics of the jet particles. At blue optical wavelengths, the accretion disc begins to dominate over this non-thermal component. Thus, the optical–to–near-IR regime is expected to be a mixture of several significant features.

Proposed X-SHOOTER observation of GX 339–4: Yet, the inference of spectral curvature is so far based only on coarse photometric measurements, as clearly seen in Fig. 1. X-SHOOTER now provides an excellent opportunity to obtain broad-band spectra contiguously over the near-IR to blue optical regimes. We thus propose a UV-to-NIR X-SHOOTER observation of GX 339–4 in 2009 June. Our goal is to search for slope change (break) in the near-IR, and accurate spectral deconvolution of the jet and accretion disc. Note that the exact wavelength of the jet break is likely to be variable in time from blue (optical) wavelengths to several microns, with a probable location in the near-IR (Nowak et al. 2005 ApJ 626 1006; also see Fig. 1). In any case, its observational signature will be a curving continuum slope over a range of ∼ 1 micron which is likely to be detectable with the broad-band sensitivity of X-SHOOTER. Several optical and near-IR recombination/forbidden emission lines from the accretion disc will also be used to accurate normalize the disc:jet contribution, in combination with continuum modeling.

GX 339–4 is, perhaps, the best target for such a study, as a result of its bright primary optical counterpart and negligible contribution from the secondary star of the binary (e.g. Shahbaz et al. 2001 A&A 376 L17). It is typically found in a low/hard state with an apparent magnitude $V\sim17$. The source has maintained this low-level, active state in the past few months. We have an approved optical (NTT/Ultraspec) and X-ray (RXTE) campaign to observe GX 339–4 on 2009 June 29/30, exactly matching the current scheduling of X-SHOOTER SV. We request observations of the source on one of these two nights, if possible. The X-ray source flux will be used to estimate the radio flux using well-known radio–X-ray correlations (e.g. Corbel et al. 2003 A&A 400 1007), effectively giving us truly broad-band coverage.

This short, simple observation of a relatively-bright target will serve as a pilot study for future proposals of other potentially-interesting targets, and makes for a good science verification project.

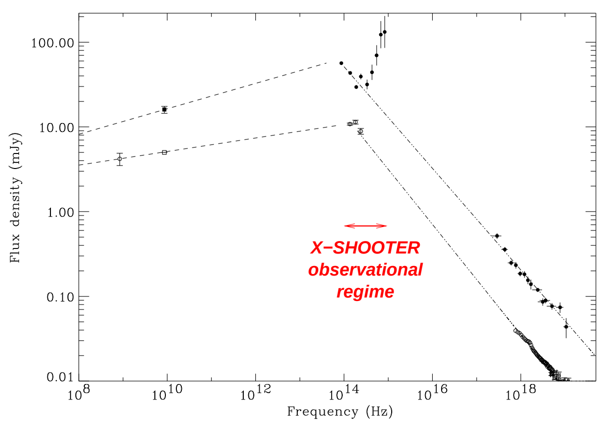

Figure 1: Broad-band (de-reddened) flux density of GX 339–4 (Corbel & Fender 2002 ApJL 573 L35). Simultaneous radio to X-ray fluxes from two epochs – 1981 (upper set) and 1992 (lower set) are shown. The most probably location of the jet break between self-absorbed (dashed) and optically-thin (dotted) power-law spectra is in the near-IR, at $\lambda\sim$few$\times10^{14}$Hz. In the upper set of data points, the large optical excess above the optically-thin spectrum is due to accretion disc radiation. X-SHOOTER will be able to probe either part, or all, of the jet break (depending on exact source state), as well as optical continuum including the accretion disc.

Calibration strategy:

We wish to obtain good cross-calibration between the arms and to calibrate the spectral shape (continuum slope) in each arm. Absolute flux calibration to within about 10 per cent will be sufficient for broad-band modeling. This can be achieved with standard spectro-photometric stars, according to the latest X-SHOOTER manual.

Targets and number of visibility measurements

Target	RA	DEC	V mag	Mode (slit/IFU)	Remarks
GX 339-4	17 02 49.5	-48 47 23	16-18	slit	Variable stellar-mass black hole

Time Justification:

The intrisic spectrum of GX 339–4 in the optical is that of an accretion disc (i.e. QSO-like), but this is actually reddened by significant interstellar absorption of $A_V\approx3$ mags. It turns out that a power-law $F_\lambda \propto \lambda^{1.4}$ is a reasonable approximation to the *observed* spectrum over the 4000 Å – 2.5 μm regime, because the red jet power-law emission begins to contribute in the near-IR, where the accretion disc flux falls off. Using ETC v3.2.8, for a point-source with an optical counterpart of V=18 (at the faint end of the distribution of expected magnitudes), observed through a 1″ (or 0.″9, depending on arm) slit, 3 days from New Moon, at an airmass of 1.2, and under a seeing of 0″.8, we find that we can obtain signal:noise (S/N) of >100 in **40 mins of integration** over our main region of interest in the NIR arm. This giving us excellent sensitivity to any change in slope due to a jet break, even if the break itself lies at wavelengths just beyond the K-band. Note that predicted sensitivities are actually >200 beyond 1.2 μm, but the NIR arm is not yet fully calibrated so we have been conservative by a factor of 2× in S/N for this computation. Over the UV/VIS arms, S/N>15 is expected at all wavelengths beyond ≈4000 Å, which will be sufficient to probe the strong accretion disc emission. Of course, for more typical expected source magnitudes of $V\approx17$, the S/N will be much higher. Including overheads, we request a total time of 1 h.