Abstract

Coordinated observations X-ray+optical observations of two southern X-ray binaries, the black hole candidate XTE J1746-321 and the neutron star accretor Cir X-1 (a ‘microquasar’) are reported. With a photon counting optical photometer on the 1.9m telescope at Sutherland, South Africa and the PCA detector on RXTE, 4h each of simultaneous data were obtained on XTE J1746 and Cir X-1. Cir X-1 showed no X-ray variability at the 2% level, XTE J1746 was variable at 5-7% with a 5Hz QPO. Cross-correlation yielded no correlated signals on either source, to a level of 1%. A problem with a recently published orbital ephemeris of Cir X-1 is pointed out.

1 Introduction

Though X-rays dominate the energetic output from X-ray binaries, the optical emission is a potentially powerful diagnostic of the accretion flow, in particular in combination with the X-ray signal. Reprocessing of X-rays into optical light by the accretion disk provides information on the geometry (thickness as a function of distance) and state of ionization of the disk surface. Reprocessing signals of this kind have been seen in a few neutron star accreters, where the optical ‘echos’ formed by reprocessing of X-rays from type I X-ray bursts on the neutron star surface by the disk have been observed (Matsuoka et al. 1984, Turner et al. 1985, van Paradijs et al. 1990, Kong et al. 2000).

Optical emission of an entirely different kind has been observed in three black hole candidates. In a brief (90s) segment of simultaneous X-ray+optical data of GX 339-4 by Motch et al. (1981,1983) the optical emission was observed to show dips some seconds before X-ray peaks. In simultaneous HST+XTE data on GRO 1655-40, Hynes et al. (1998) found the optical emission to correlate positively with the X-rays, with a delay of some seconds. The most detailed observations of this kind were obtained by Kanbach et al. (2001), on the black hole transient XTE J1118+480 (=KV UMa). These observations showed a strong correlation between X-rays and optical emission, with a cross correlation function showing both a dip preceding X-ray maximum and a following sharp peak.
The shape of the cross correlation function was found to be highly variable, on time scales as short as 25s (Spruit and Kanbach 2003). One of the most curious properties of this variability is a variation of time scale: in different segments of data, the cross correlation function tends to have the same shape, except for expansion/contraction of the time axis. The physical interpretation of these observations is still very uncertain.

The short time scales observed in the optical emission in KV UMa (down to 30ms) and the large optical luminosity are both suggestive of an origin close to the black hole. The only radiation process with sufficient emissivity in the optical is then synchrotron or thermal (cyclo-) synchrotron emission, for which a strong magnetic field would then be required. Such strong magnetic fields, in turn, are the ingredient of choice for current models for the production of the relativistic outflows seen from several black hole transients (Mirabel and Rodríguez 1999). These outflows appear to occur in particular when the sources are in X-ray ‘hard’ states, when the energetic output is dominated by photons around 100keV (Corbel et al. 2000).

In contrast with the ‘soft’ state, understood as evidence of the theoretically predicted of accretion disk structure, the nature of the plasma producing the hard X-ray emission, and the geometry of the accretion flow in which it occurs is still unclear. In the few cases where fast correlated X-ray/optical emission has been found so far, the sources were in such hard states. Correlated X-ray/optical observations thus provide a potentially powerful new diagnostic on the uncertain accretion physics close to the hole.

A difficulty in exploiting this diagnostic is the fact that most black hole candidates are transients whose outbursts are infrequent and of relatively short duration. Other difficulties are the tendency for the sources to lie in optically obscured regions near the galactic center, and the lack of suitably fast photometric instrumentation on most modern telescopes.

The sources selected for the observations reported here are Cir X-1 and the black hole transient XTE J1746-321 (=IGR 17464-3213 =H1743-322), which happened to be in outburst at the time of the observations. Cir X-1 is a micro-quasar (Stewart et al. 1993, Fender et al. 2004) in which the accretor is believed to be a neutron star (the other binary of this type being Sco X-1, Fomalont et al. 2001). Comparison of this object with black hole candidates would answer the question whether fast optical emission is connected with the presence of a black hole, or more generically with the presence of relativistic outflows. Since it is also a persistent X-ray source, it was the primary target of the observations.

The second planned target was GX 339-4, the black hole candidate where correlated X-ray/optical variability was detected for the first time (Motch et al. 1981,1983). Unlike most black hole candidates, GX 339-4 has frequent outbursts of varying strength, often several per year. It was active when our observations were planned, but it turned into an ‘off’ state about 1 month before the observations (as it did in two previous attempts). However, another X-ray transient and possible black hole candidate, XTE J1746-321, happened to be
active during the observations. Though rather obscured, it was still marginally bright enough to attempt optical observations.

2 Observations

The optical observations were obtained in the nights of 27 through 31 May 2003 with the 1.9m Radcliffe telescope of the South African Astronomical Observatory at Sutherland. Fast photometry was obtained with the OPTIMA photometer, a photon-counter based on avalanche photo diodes developed at the Max Planck Institute for Extraterrestrial Physics (Straubmeier et al. 2001). Arrival times of the photons are recorded with a GPS-based clock. Light was fed to the diode by a fiber with microlenses at both ends, optimized for the f/18 focus of the telescope. The effective aperture of the fiber in the focal plane was 4′.

On several of the nights the observations were affected by cirrus. Since the transparency variations occurred on time scales longer than those of interest, the effect on the results is probably unimportant.

Cir X-1 is a relatively obscured source ($A_V \sim 4$, Glass 1994), but still sufficiently bright ($I \sim 17.5$) for good photon statistics with the red-sensitive detector used (to $\sim 950$ nm). Cir X-1 produces X-ray flares associated with infrared and radio emission around the times of pericenter in its 16.5d eccentric orbit\(^1\). These flares last only a few days, but X-rays continue at a quiescent level throughout the orbit. Our observations did not cover the pericenter passage.

The optical brightness of XTE J1746-321 (identification and astrometry by Steeghs et al 2003) is around $I=19$. The expected optical count rate (around $400 \text{s}^{-1}$) is below the sky background in the aperture in this case, but still high enough to extract a signal through cross-correlation with the X-rays, if the source is sufficiently variable.

Simultaneous X-ray observations were made by the RXTE satellite on each of these nights for both sources. Total effective simultaneous exposure time was about 4 hrs each for XTE J1746-321 and Cir X-1.

3 Results

Both the optical and X-ray light curves are dominated by noise. In the case of the X-rays the noise is just photon statistics, while the noise in the optical signal was dominated by seeing-related aperture losses. With the long integration times available, low level intrinsic variability can still be extracted out of the noise\(^1\)The new orbital ephemeris given by Parkinson et al. (2003) appears to be in error. The predicted phases of X-ray flares do not agree with the ASM light curve. The ephemeris given by Glass (1994) and attributed to Nicholson, on the other hand, still appears to hold. See also Clarkson et al. (2004)
Figure 1: X-ray power spectra ($\nu P_\nu$) of XTE J1746-321 during the first half of the observations (left panel, bin width 3ms) and the second half (right, bin width 30 ms)

by cross-correlation of the X-rays with the optical signal, provided correlated variability is present.

The X-ray variability of Cir X-1 happened to be so low as to be barely measurable in the 4hr integration time; a conservative upper limit is 1.5% rms (0.01-100 Hz). In view of this it is not surprising that no significant correlation with the optical light was detected. The PCA count rate was about 1000 s$^{-1}$ (2 PCUs).

XTE J1746-321 has been mostly in a soft quiet state during its 2003 outburst (e.g. Homan et al. 2003, but transitions to a hard X-ray state with large variability have been observed, in particular in September (Grebenev et al. 2003) and October (Tomsick and Kalenc 2003). Our observations took place during a fairly quiet phase, with modest variability to correlate the optical signal with (5-8% rms, 0.1-100Hz). Figure 1 shows X-ray power spectra (in $\nu P_\nu$). A quasiperiodic oscillation was present at 5 Hz; its amplitude, as well as the overall level of variability was higher during the first half of the observations (left panel). PCA count rate was about 3000 s$^{-1}$ (2 PCUs). No significant variability was detected in the optical (< 2% rms, 0.1-100 Hz).

No significant cross correlations between X-rays and optical were detected at the 1% level. This is probably due to the relatively low level of the X-ray variability, combined with the faintness of XTE J1746-321 in the optical (near the sky background).

4 Discussion

No significant correlation between the X-rays and optical signals was detected in either Cir X-1 or XTE J1746-321. In the case of Cir X-1 this is probably due to its very low level of X-ray variation at the time of the observations. In the
case of XTE J1746, a combination of its relatively low X-ray variability and its faintness in the optical. Upper limits on correlated X-ray/optical variations are of the order 1% in both Cir X-1 and XTE J1746-321.

These results demonstrate the difficulties of multi-wavelength observing campaigns at high time resolution. Few observatories are equipped for high time resolution photometry, also on the southern hemisphere where most of the black hole transients appear. The use of visitor instruments, as in the observations described here, has limitations due to the transient nature of the most promising (sufficiently variable) sources.

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