MULTIWAVELENGTH OBSERVATIONS REVEALING THE OUTBURSTS OF THE TWO SOFT X-RAY TRANSIENTS XTE J1859+226 AND XTE J1118+480

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ABSTRACT

We report here on multiwavelength observations of the two new soft X-ray transients (SXTs) XTE J1859+226 and XTE J1118+480, which we observed with *HST*/*RXTE*/UKIRT. For XTE J1118+480 we also used *EUVE* since it is located at a very high galactic latitude and suffers from very low extinction. The two sources exhibited very different behaviour. XTE J1859+226 seems quite normal and therefore a good object for testing the accretion mechanisms in place during the outbursts, XTE J1118+480 is much more unusual because it exhibits i) a low X-ray to optical ratio and ii) a strong non-thermal contribution in the radio to optical domain, which is likely to be due to synchrotron emission. We concentrate here on the near-infrared (NIR) and optical observations of these two systems.

Key words: stars: individual: XTE J1859+226, XTE J1118+480, X-rays: stars, infrared: stars.

1. INTRODUCTION

The SXTs, also called X-ray novae, are a class of low mass X-ray binaries (LMXBs), including GRO J1655–40 and GRO J0422+32. In this class of sources, more than 70% are thought to contain Black Holes (Charles 1998). The compact object accretes matter through an accretion disk from a low-mass star via Roche lobe overflow. The history of these sources is characterized by long periods of quiescence, typically lasting decades, and punctuated by very dramatic outbursts, visible at every wavelength, although these sources are usually discovered in X-rays or the optical, and often accompanied by radio activity. A prototypical outburst is characterized by X-ray emission dominated by thermal emission from the hot inner accretion disk, and optical emission produced by reprocessing of X-rays. Two such sources were discovered during the last year: XTE J1859+226 and XTE J1118+480. Thanks to our override programs with *RXTE*/*HST*/UKIRT we could get early multiwavelength observations of these systems, and follow the evolution of these systems from outburst towards their quiescence, to get more information on the mechanisms underlying their outbursts. We will describe in Section 2 the observations and results on XTE J1859+226 and in Section 3 those on XTE J1118+480.

2. XTE J1859+226

The first source, XTE J1859+226, was discovered by ASM/*RXTE* on 1999 October 9 (Wood et al. 1999), at the galactic coordinates: $(l, b) = (54.05°, +8.61°)$. This source exhibited a fast rise (~ 5 days) and exponential decay (~ 23 days) typical of X-ray novae (see Fig. 1). The optical counterpart reached 15th magnitude at its maximum (Garnavich et al. 1999) exhibiting a period of 9.15 +/- 0.05 hr which could be the orbital period (Garnavich & Quinn 2000). Sanchez-Fernandez et al. (2000) observed the quiescent counterpart of the source at a magnitude of 23 and also confirmed this weak photometric modulation. A strong radio counterpart was detected, but no jet feature was observed (Pooley & Hjellming 1999). The compact object could be a black hole, i) because of the hard X-ray spectrum which showed a high-soft state in October 1999, described by a temperature of T $\sim$ 0.9 keV and a power-law of photon index $\alpha \sim 1.5$, and ii) because of the presence of high-frequency QPOs (≥ 100 Hz), as in GRS 1915+105, GRO J1655–40, and XTE J1550–564 (Cui et al. 2000). The column density was determined as $N_H \sim 3 - 8 \times 10^{21}$ cm^{-2} (Markwardt et al. (1999), dal Fiume et al. (1999)). We undertook a multi-epoch multiwavelength program of observations with *HST*/*RXTE*/UKIRT (see lightcurve in Fig. 1).

2.1. Short timescale modulation

To search for short timescale modulations, we observed with the HiRAC camera on the Nordic Optical Telescope, used in a high speed photometric mode, during the first run of a new camera operating system. This system allows a fast readout in a windowed mode. The operating system was developed by R. Østensen, and converts existing CCD cameras which are equipped with the Copenhagen University Observatory controllers into a fast photometer. On Oct 17 we used an integration time of 5.3 s, readout time of 1.8 s and a cycle time of 7.5 s, with the object and one reference star. The following night we had a sample time of 30 s, and used 3 comparison stars. We detected a faint modulation at 20–24 min (Fig. 2). This QPO may be the result of hydrodynamic oscillations at the L_1 point, where a comparison with V404 Cyg predicts a value of $0.055P_{orb}$ compared to the observed value of $0.042P_{orb}$ (King 1989). This modulation was also seen in several sets of data amounting to 33 hr of optical data with different instruments/telescopes, in the NIR with UKIRT (Hynes et al. 1999), and much later in the outburst by Charles et al. (2000). No periodic modulation was seen in the NIR at shorter timescales.

2.2. Evolution of the Spectral Energy Distribution

The early spectral energy distribution (SED) observed by *HST* & UKIRT (see Fig. 3) is well fitted by a typical X-ray irradiated disk model ($T \propto R^{-3/7}$). The model used was actually generated to fit the SED of GRO J0422+32 in outburst, which has an orbital period of 5.1 hr, and then scaled to fit the new data with no other adjustment. This suggests that XTE J1859+226 is also a relatively short period system (less than one day). If the disk were heated by viscous processes instead of irradiation we would expect intead to see $f_\nu \propto \nu^{1/3}$ (corresponding to $T \propto R^{-3/4}$). Gratifyingly, this is seen in our last visit where the SED is better fitted by a viscously heated accretion disk model with an edge temperature of ~ 8000 K, suggesting evolution from an irradiation dominated to viscosity dominated regime.

3. XTE J1118+480

The second source, XTE J1118+480, is a very unusual object, and therefore certainly very interesting. Its galactic coordinates are $(l, b) = (157.62°, +62.32°)$. The X-ray object was discovered by *RXTE* on 2000 March 29 (Remillard et al. 2000) as a weak, slowly rising source, the post-analysis revealing an outburst in January 2000, with a similar brightness (see Fig. 4). The optical counterpart is a 13th magnitude star, coincident with a 18.8 mag object in the DSS (Uemura et al. 2000). Its optical spectrum was typical of X-ray novae in outburst (Garcia et al. 2000). This system was characterized by a very low X-ray to optical flux ratio of 5 (see Remillard et al. (2000) & Uemura et al. (2000)), when the typical value is 500 (see e.g. Tanaka & Shibazaki (1996)). A weak photometric modulation on 4.1 hr (0.17082 d) period was rapidly discovered (Cook et al. 2000), which was associated with the orbital period, the shortest among the black hole candidates. Flickering with an amplitude of ~ 0.4 mag, and also a quasi-periodic oscillation (QPO) at 10 s, was observed in the optical, in the UV (Haswell et al. 2000b) and also in the X-rays, with an evolving frequency (Wood et al. 2000). A faint radio counterpart was detected at 6.2 mJy, but no jet feature could be spatially resolved. The large value of the mass function, f(M) = 5.9 +/- 0.4 solar masses, suggests that the compact object is a black hole (Wagner et al. (2000) & McClintock et al. (2000a)).

Its location at an unusually high galactic latitude ($b = +62°$) at an estimated distance of 0.8 kpc (McClintock et al. 2000b) implied that there is a very low absorption along the line of sight of the source, with a column density estimated to $N_H \sim 0.75 - 1.3 \times 10^{20}$ cm^{-2} (Hynes et al. (2000), McClintock et al. (2000b)). Triggering our multi-epoch multiwavelength program with *HST*/*RXTE*/UKIRT and requesting Director's Discretionary *EUVE* observations, we got unprecedented broadband coverage (see lightcurve in Fig. 4 & SED in Fig. 6, more details in Hynes et al. (2000)). The SED suggests that the system was exhibiting a low-state mini-outburst, with the inner radius of the accretion disk at $\sim 2000R_s$ (R_s: Schwarzschild radius). One of the most striking features was the strong non-thermal (likely synchrotron) contribution in the optical and NIR wavelengths. Indeed, the SED shows a very flat spectrum from the NIR to the UV ($\sim 1000 - 50\,000 Å$), suggesting that there is another source of NIR flux apart from thermal disk emission, likely related to radio emission, and therefore possibly synchrotron.

3.1. Non-thermal contribution

The ~ 10 s QPO was also seen in the UV, implying a common nature for this QPO from the optical to the X-rays. We looked for a rapid periodicity in the NIR wavelengths, and we therefore observed with the 3.8-m U.K. Infrared Telescope and IRCAM3 instrument on June 24.23 UT when the source was at K = 11.512 +/− 0.004 and on July 15.25 UT, when the source was at K = 11.948 +/− 0.006. The 0.02 mag/day mean decline between these two dates was therefore much stronger than from April to June (Hynes et al.

2000), and comparable to the 0.015 mag/day mean decline seen in the optical (VSNET observations). During both observations we took rapid photometric observations for nearly 1 hour, with 2 s integration time on the source and nearly 7 s sampling time. The source showed rapid fluctuations through nearly 0.5 mag, with a 0.05 mag error bar for each individual frame. A periodicity search analysis in both runs did not show any secure quasi-periodic oscillation, although there could be some modulations around 35 s. Unfortunately our sampling time could not address the presence or absence of the periodicity of 10 s seen in the optical and in the X-rays.

However, we could detect flickering at NIR wavelengths, of bigger amplitude (~ 0.8 mag) than in the optical (~ 0.4 mag). This flickering in the K band is reported in Figure 5. We also took a NIR K-band spectrum of this source using the CGS 4 instrument and a $0.6''$ slit on June, 27.2 UT, which was featureless, also consistent with the fact that the disk is not the only source of emission in this part of the spectrum. These two facts suggest a strong non-thermal (likely synchrotron) emission in the NIR wavelengths. This is consistent with the flat slope of the SED, shown in Figure 6 from the radio to the IR, and will be developed in Chaty et al. (in prep.).

3.2. The nature of the system

In our *HST* UV spectra we observed a complete absence of carbon and oxygen lines, suggesting that the material accreted from the companion star has undergone significant CNO-cycle processing resulting in C and O depletion (Haswell et al. 2000a). Since a 4 hr binary would normally be thought to contain an M dwarf companion, no CNO processing would be expected. Therefore it is likely that the companion star is the core of a larger star that has lost its envelope: a stripped giant. To test this hypothesis and try to reveal the nature of the companion star of the system, we will need to observe this source in quiescence with spectroscopic observations, at both optical and NIR wavelengths.

4. CONCLUSIONS

XTE J1859+226 allows us to study the accretion mechanisms during the outburst and the changes in temperature distribution due to irradiation. XTE J1118+480 allowed us to get broadband coverage from the radio to the X-rays, showing that it was exhibiting a very low-state mini-outburst, with a strong non-thermal (likely synchrotron) contribution.

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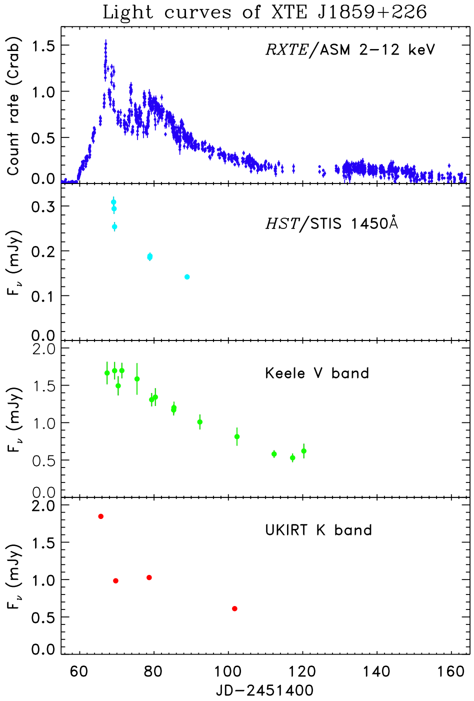

Figure 1 – The Outburst History: *Respectively from top to bottom are shown: RXTE/ASM 2-12 keV counts, HST/STIS 1450 Angströms, Keele V, and UKIRT K bands.*

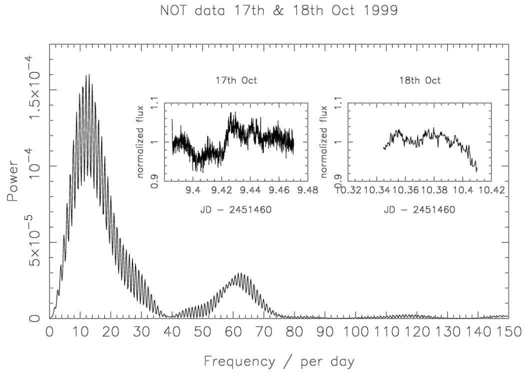

Figure 2 – Periodicities: *A* ~ 23 *min periodicity (frequency* ~ 62 *per day) was seen in the Nordic Optical Telescope data acquired on 1999 October 17–18th, perhaps related to a Lagrange point oscillation.*

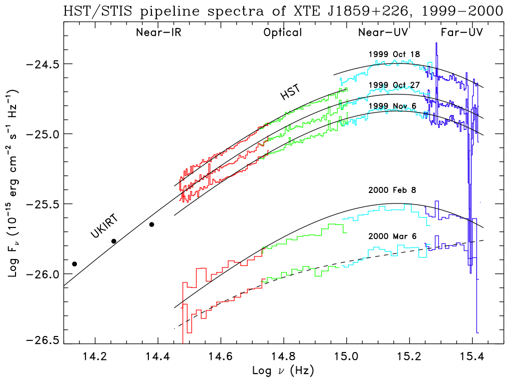

Figure 3 – The irradiation view: *Note the change from an irradiated spectrum during the outburst (top curves) to a viscously heated disk after the outburst (bottom curve).*

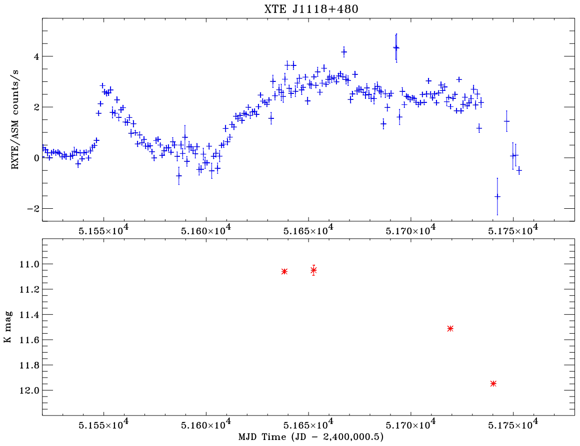

Figure 4 – The Outburst History: *RXTE/ASM 2-12 keV counts (top) & UKIRT K bands (bottom).*

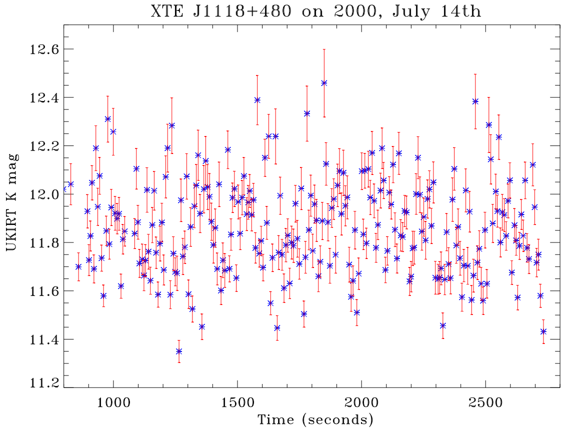

Figure 5 – IR Flickering: *Significant Flickering as seen in K band with UKIRT, on a 0.8 mag amplitude with error bars of only 0.1 mag.*

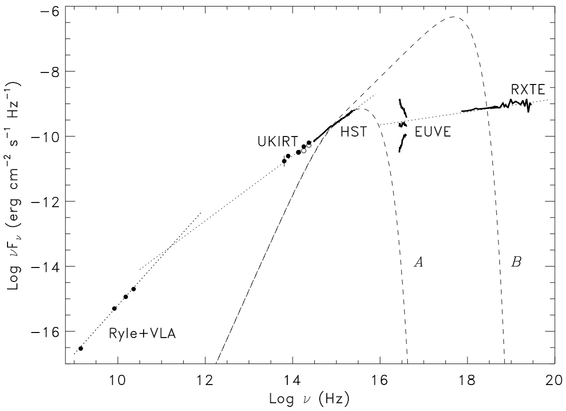

Figure 6 – Spectral Energy Distribution: *The EUVE fluxes are corrected with* $N_H = 0.35, 0.75, \& 1.15 \times 10^{20}$ *cm*$^{-2}$. *Dashed lines: two steady-state disk models with an outer disk layer at 8000K and internal disk layer at 2000 Rs (model A) and 3 Rs (model B). Dotted lines: different power laws, with spectral indices of 0.5, 0.0 and -0.8 (Hynes et al. 2000).*