Towards 4U 1630−47: a black-hole soft X-ray transient odyssey

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Abstract

4U 1630−47 is a black-hole X-ray transient with one of the shortest recurrence times. Despite its regular outburst behaviour little is known about this source. Only recently has attention to this system increased. I discuss there the basic known (X-ray) properties of 4U 1630−47 and report on X-ray and radio observations obtained during its recent outburst, starting in 1998 February. These observations strengthen some of the similarities seen between 4U 1630−47 and the Galactic superluminal sources GRO J1655−40 and GRS 1915+105, and provide the first detection of 4U 1630−47 in the radio. Using an updated outburst ephemeris I predict the next outburst to occur about a week before Christmas 1999.

1. Introduction

4U 1630−47 is a member of the transient class of low-mass X-ray binaries. The nature of the compact star in the system is, however, unknown. Its X-ray spectral (Parmar, Stella & White 1986; Barret, McClintock & Grindlay 1996) and X-ray timing (Kuulkers, van der Klis & Parmar 1997a) properties during outburst suggest it is a black-hole. Until 1998 no optical/infra-red or radio counterpart has been reported.

Soon after its discovery in 1972, 4U 1630−47 was shown to exhibit outbursts every ∼600 days (Jones et al. 1976; Priedhorsky 1986), i.e. one of the shortest recurrence times among the black-hole soft X-ray transients. It became clear that 4U 1630−47 continued to undergo regular outbursts at approximately the 600 day period (Parmar, Angelini & White 1995; Parmar et al. 1997). However, by including the outbursts as seen with the Ginga ASM and the RXTE ASM it was found that the outburst recurrence interval changed from ∼600 days to ∼690 days, somewhere between 1984 and 1987 (Kuulkers et al. 1997b). Such a large change in recurrence time suggests that the 600/690 day period is not associated with the binary period of the system. It was predicted that if the recurrence interval of ∼690 days continued, the next outburst of 4U 1630−47 would occur near 1998 Jan 31 (JD 245 0845).

The outburst behaviour of 4U 1630−47 is more complex than was previously realized. In the standard X-ray band (∼2–10 keV), the source shows outbursts with durations on the order of a few months (e.g. Fig. 1) and sometimes intervals of long-term X-ray activity of up to ∼2.4 years (Kuulkers et al. 1997b). X-ray activity in the hard X-ray band (∼20–100 keV) associated with these outbursts has also been seen by CGRO BATSE (Bloser et al. 1996, 1998), but lasted for only ∼weeks. The detection of X-ray absorption dips during outburst with the RXTE PCA (Tomsick et al. 1998; Kuulkers et al. 1998a) suggests that we see the system at an inclination angle of ∼60–75°.

Recently, Kuulkers et al. (1997a,b; 1998a) pointed out similarities in the X-ray behaviour between 4U 1630−47 and the two Galactic superluminal X-ray transient sources GRO J1655−40 and GRS 1915+105. It was, therefore, postulated that the physics involved are similar in these systems, and that 4U 1630−47
Fig. 1. RXTE ASM outburst light curve of 4U 1630−47 in 1996 (a) and 1998 (b) on the same scale. Plotted are the daily averages as obtained from the MIT RXTE ASM web pages. ∼75 cts s$^{-1}$ SCC$^{-1}$ corresponds to 1 Crab. Note the clear differences in outburst shape. Indicated at the top are the times of the pointings with the RXTE PCA/HEXTE instruments.

might also show radio activity during its outburst, possibly in the form of (relativistic) jets.

2. 1998 Outburst

2.1. X-ray observations: showing the strongest QPO ever seen

Both the RXTE ASM and CGRO BATSE picked up renewed X-ray activity from 4U 1630−47 near 1998 Feb 2 (JD 245 0847), i.e. very close to that predicted (see Sect. 1; Kuulkers et al. 1998b; Hjellming et al. 1998). The source did not rise to maximum immediately, but exhibited a standstill in the 2–12 keV band for about a week. During this time CGRO BATSE showed a considerable contribution from 4U 1630−47, indicating that during this initial part of the outburst the source spectrum was hard.

The 1998 outburst as seen with the RXTE ASM is shown in Fig. 1b. The shape of the outburst differs considerably from the previous outburst in 1996, which was covered as well by the RXTE ASM (Fig. 1a).

As soon as 4U 1630−47 started to rise rapidly as seen with the RXTE ASM, TOO programs were triggered with the RXTE PCA/HEXTE. Since Feb 9 (JD 245 0854) almost daily pointings were obtained (see top of Fig. 1b), in order to investigate the spectral and timing behaviour of the source as it evolved through possible different black-hole transient states. Clearly, this outburst has been well covered, compared to e.g. the 1996 outburst (Fig. 1a). Several other X-ray satellites also performed TOO observations, including ROSAT HRI/PSPC between Feb 17 and 28 (JD 245 0862–873), BeppoSAX (Oosterbroek et al. 1998) on Feb 20, 24, Mar 7/8, 19/20 and 26/27 (JD 245 0865, 871, 880/881, 892/892, 899/900) and ASCA on Feb 25/26 (JD 245 0871/872).

The first two RXTE PCA observations on Feb 9 showed two strong quasi-periodic oscillations (QPO) peaks and strong band-limited noise in the power spectrum of the 2–14 keV X-ray intensity (Dieters et al. 1998). During the first observation the lowest-frequency QPO peak was asymmetric and had a centroid frequency of ∼2.7 Hz, FWHM of ∼0.2 Hz and a fractional rms amplitude of ∼16% (∼23% including the asymmetric wing), whereas for the highest-frequency QPO the values were ∼5.6 Hz, 1.2 Hz and ∼5.5%, respectively. The higher-frequency QPO is most likely the harmonic of the lower-frequency QPO. The
Fig. 2. The time residual in days of all outburst times after a linear fit to the first eight outburst times to cycle number. The error bars reflect the uncertainties in deriving the outburst start times (see text; Parmar et al. 1997; Kuulkers et al. 1997b). The dashed line shows the linear fit to the last six residual outburst times to cycle number. As shown by Kuulkers et al. (1997b), the recurrence interval changed its period and phase between the 1984 (cycle 9) and 1987 outbursts (cycle 11).

QPO near 3 Hz is the strongest ever seen (see e.g. van der Klis 1995).

In subsequent RXTE PCA observations (Dieters et al., in preparation), during which the X-ray intensity increased further, the QPO centroid frequency increased as well; it became also broader, and its strength decreased. When the RXTE ASM flattened off (near Feb 14; JD 245 0859), the 3–10 Hz QPO had vanished. The fast increase near Feb 18 (JD 245 0863) marked the beginning of the so-called high state (HS), generally seen in black-hole binaries.

Dieters et al. (1998) noted that the power spectral shape showed similarities to those seen in power spectra in the so-called very-high state (VHS) of black-hole binaries (see e.g. van der Klis 1995). However, in the VHS the ∼1–10 keV X-ray intensity is generally high (even higher than in the HS). Instead, the 3–10 Hz QPO during the low soft and high hard X-ray intensity state of 4U 1630−47, resembles the QPO seen in GRS 1915+105 in a similar frequency range and also during one of its similar low soft and high hard X-ray intensity state (so-called “low-hard” state; Morgan, Remillard & Greiner 1997).

2.2. Radio observations: tune in to 4U 1630−47

Radio measurements when the 1996 outburst was well underway failed to detect emission from 4U 1630−47, with 3σ upper limits of 5 mJy and 2 mJy at 1.4 GHz and 2.4 GHz, respectively (Kuulkers et al. 1997b). The first radio observations of the 1998 outburst on Feb 9 also did not show any emission (<0.7 mJy at 8.6 GHz; Kuulkers et al. 1998b). However, a few days later (Feb 12; JD 245 0857) a radio source was discovered with the VLA within the X-ray position error region (Hjellming & Kuulkers 1998). Subsequently, the source was confirmed by ATCA (Buxton et al. 1998). The radio observations allowed Hjellming et al. (1998) to identify an accurate position of 4U 1630−47 (equinox 2000.0): $16^h34^m1.60^s\pm0.05^s$, $-47^\circ23'33''\pm2''$ (VLA) or $16^h34^m1.60^s\pm0.02^s$, $-47^\circ23'34.8''\pm0.3''$ (ATCA).

The radio outburst most probably started between Jan 30 and Feb 5 (JD 245 0844–850), i.e. during which the source was in a hard state (Hjellming et al. 1998). The radio outbursts seen in GRO J1655−40 and GRS 1915+105, and possibly in other soft X-ray transients, have been seen to originate during similar hard X-ray states (see Hjellming et al. 1998, and references therein). The peak of the radio
outburst occurred near Feb 18 (JD 2450862) with a flux density of $\sim$2.6 mJy at 4.8 GHz (Buxton et al. 1998; Hjellming et al. 1998). During these peak measurements the ATCA detected very strong linear polarisation, i.e. $\sim$28% at 4.8 GHz. This is much larger than is generally found in radio sources ($\lesssim$10%); large linear polarization ($\gtrsim$16%) has up to now only been seen from jet sources like SS433, GRO J1655−40 and GR51915+105 (Hjellming et al. 1998). As suggested by Hjellming et al. the radio (and correlated X-ray) properties might imply that 4U1630−47 ejected radio jets during its 1998 outburst.

3. Outburst ephemeris

The 1998 outburst of 4U 1630−47 enables me to update the outburst ephemeris. For the time of occurrence of the 1998 outburst I take the time of peak intensity from the RXTE ASM data, i.e. near Feb 22 (JD 245 0867). The peak is well determined; I use, however, a typical uncertainty of 15 days, similar to e.g. Parmar et al. (1997).

For the fit to the outburst recurrence times I follow Kuulkers et al. (1997b), where they allowed the recurrence period and phase to change between the 1984 and 1987 outbursts. The resulting period before the period/phase change is still 601±2 days; after the change it is now 682±4 days. The deviation of the outburst times from the expected times of a $\sim$601 day period is shown in Fig. 2, together with the results of the fits. Assuming that the next outburst occurs $\sim$682 days after the start of the 1998 outburst, I predict it will occur about a week before Christmas 1999, i.e. near 1999 December 16 (JD 245 1529).

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