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LETTER

Letter to the Editor

Multifrequency observations of XTE J0421+560/CI Cam in outburst

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Abstract. We report on two X-ray observations of the transient source XTE J0421+560 performed by BeppoSAX, and on a series of observations performed by the 0.7 m Teramo–Normale Telescope. Outburst peak occurrence time and duration depend on photon energy: the outburst peak is achieved first in the X-ray band, then in the optical and finally in the radio. An exponential decay law fits well the X-ray data except in the TOO2 0.5–1.0 keV band, where erratic time variability is detected. During TOO1 the e-folding time scale decreases with energy up to ∼20 keV, when it achieves a saturation; during TOO2 it decreases up to ∼2 keV and then increases. This change is correlated with a spectral change, characterized by the onset of a soft ($\lesssim$2 keV) component in TOO2 (Orr et al. 1998). This component might originate from the relativistic jets, while the hard component is more likely associated to processes occurring in the circumstellar matter and/or near the compact object. Optical observations show that the object appears intrinsically red even during the outburst. The nature of the compact object is discussed.

Key words: stars: binaries: symbiotic – stars: individual (XTE J0421+560) – stars: novae – X-ray: general – X-rays: stars

1. Introduction

The X-ray source XTE J0421+560 was discovered in the 2–12 keV energy band with the ASM aboard RXTE during a strong outburst, with onset time around 1998 March 31.36, and peak flux of ∼2 Crab on 1998 April 1.04 Smith et al. 1998. Fig. 1, upper panel, shows the light curve of the source on the basis of the ASM data. The decaying curve after the maximum is consistent with an exponential law with e-folding time $\tau_{\rm ASM} = 0.860 \pm 0.007$ d. The outburst was also detected in hard X-rays (up to 70 keV) with the BATSE experiment aboard CGRO at a 20–30 keV peak flux of ∼1.1 Crab between 1998 March 31.91 and April 1.04 Harmon et al. 1998. No hard X-ray emission was observed with BATSE after April 2–3.

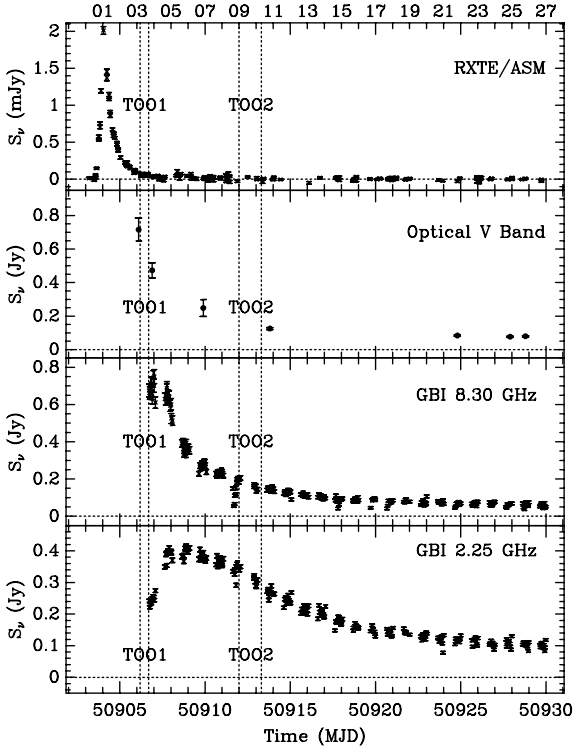

Fig. 1. Light curve of XTE J0421+560 in X-rays (2–12 keV), optical V, and radio (8.3 GHz and 2.25 GHz). Data come from the ASM (*upper panel*) and GBI (*lower panels*) public archives, IAU Circulars and our optical measurements (*second panel*). BeppoSAX observations are marked by dashed lines. The upper scale represents days of April 1998. ASM data after April 12 are upper limits

Prompt observations at different wavelengths were performed with ground based telescopes. Observations performed

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on April 2.63 in the radio band at 1.4 GHz with the VLA Hjellming & Mioduszewski 1998 showed the presence of a variable source within the RXTE/PCA error box, whose position was coincident with that of the symbiotic star CI Cam (MWC 84). The light curve of the source obtained at two different frequencies with the NRAO/NASA GBI telescope Ghigo 1998 is shown in Fig. 1, lower panels. The decaying curve after the maximum is consistent with e-folding times $\tau_{8.30} = 3.19 \pm 0.08$ d and $\tau_{2.25} = 12.55 \pm 0.08$ d at 8.30 and 2.25 GHz, respectively. The radio source appeared point-like ($<0.1''$ at 22.5 GHz) on 1998 April 3.83 and became extended on April 5.08. Since April 6.94 it exhibited an almost symmetrical S-shaped twin-jet Hjellming & Mioduszewski 1998, strikingly similar to the radio jets of SS 433. The jet motion was estimated to be about 26 mas/day, corresponding to a $0.15\ c$ velocity assuming a source distance of one kpc. This distance was estimated on the basis of absorption considerations and spectral properties by Chkhikvadze (1970) and Bergner (1995), and now confirmed with 20% uncertainty by Hjellming et al. (1998). We assume this value for luminosity estimates.

Triggered by the ASM detection of the source, BeppoSAX observed XTE J0421+560 twice (Orlandini et al. 1998). In this *Letter* we concentrate on light curve properties, and on their correlation with the spectral behavior. In another *Letter* Orr et al. (1998) attempt to model the source spectrum and its behavior with time. We also report on optical results obtained in the V and R bands.

2. X-ray observations and data analysis

XTE J0421+560 was observed as a Target of Opportunity on 1998 April 3 from 05:03 UT to 17:44 (TOO1), and from 1998 April 9 00:48 to April 10 06:49 UT (TOO2). These time intervals are indicated in Fig. 1 with dashed lines.

The BeppoSAX observations were performed with the Narrow Field Instruments (NFI). They include a Low Energy Concentrator Spectrometer (LECS, 0.1–10 keV; Parmar et al. 1997), the Medium Energy Concentrators Spectrometers (MECS, 1.5–10 keV; Boella et al. 1997), a High Pressure Gas Scintillator Proportional Counter (HPGSPC, 5–120 keV; Manzo et al. 1997), and a Phoswich Detection System (PDS, 15–300 keV; Frontera et al. 1997). Both LECS and MECS have imaging capabilities, while HPGSPC and PDS are mechanically collimated direct viewing instruments that use rocking collimators for background monitoring.

We used the default criteria to select good data. Library background blank field measurements were used for the imaging instruments, while the background for the collimated instruments was evaluated from offset fields. Data were analysed using SAXDAS 1.3.0 and XAS 2.1 software packages. From the source image obtained with LECS and MECS we derived the best source location (epoch 2000): α=$04^{\rm h}19^{\rm m}46^{\rm s}.0$ and δ=$+55^\circ59'24''$, with an error radius of $50''$ (all the uncertainties reported are given at the 90% confidence level). This position is consistent with the RXTE Marshall et al. 1998 and the radio Hjellming & Mioduszewski 1998 position.

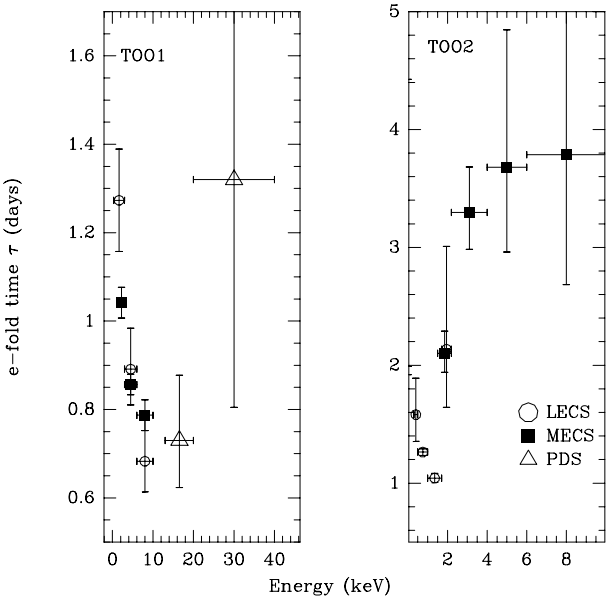

Fig. 2. Dependence of the e-folding time τ on energy for the two BeppoSAX XTE J0421+560 observations

2.1. TOO1

TOO1 was carried out during the rising part of the radio flare from CI Cam (see Fig. 1) when the source was in a clear optically thick radio state. It is the first time that a deep X-ray observation is carried out during this state. The source was detected with all NFI, including PDS. The source spectrum is very complex, showing a turn-over at $\sim$1.5 keV and a strong Iron line emission at 6.7 keV Orr et al. 1998. In the 1.5–10 keV the flux level at the beginning of the observation was $\sim$65 mCrab. To model the decay of the source we tried simple decaying functions (linear, exponential, power law): only the exponential law fits well the data. The e-folding time τ is 1.27 ± 0.11 d, 0.92 ± 0.02 d, and 0.7 ± 0.3 d in the 0.3–3 keV (LECS), 1.5–10 keV (MECS), and 15–100 keV (PDS) energy bands, respectively. The decay constant obtained with MECS is consistent with $\tau_{\rm ASM}$. A decrease in the decay constant is also evident moving from lower to higher X-ray energies. The behavior of the e-folding time $\tau(E)$ with energy is shown in Fig. 2. The erratic time variability of the source on 100 s time scales is extremely low, once the general trend due to the exponential decay has been subtracted. The observed variance of 0.077 ± 0.008 s^{-2} is consistent with that expected assuming a Poissonian noise (0.071 ± 0.007 s^{-2}). We have also searched for periodic or quasi-periodic oscillations from the source: there is no evidence for such oscillations in the frequency band from 10^{-4} to 50 Hz.

2.2. TOO2

TOO2 was carried out during the decay part of the radio flare, during the optically thin phase of radio emission. The source was detected with the LECS and the MECS, but not with the PDS. In the 1.5–10 keV, the flux level at the beginning of the observation was $\sim$8 mCrab, while the 2σ upper limit to the

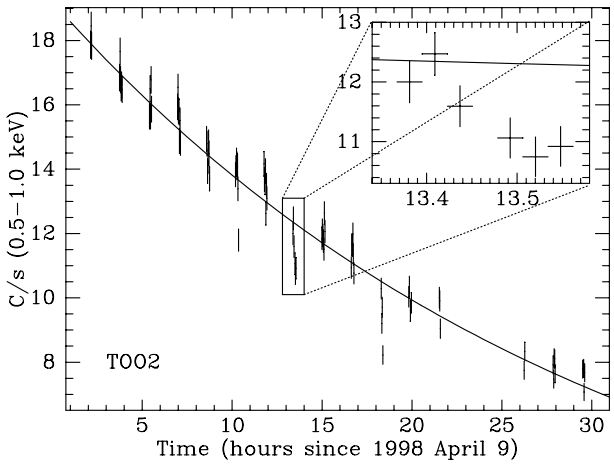

Fig. 3. 0.5–1.0 keV LECS light curve for TOO2 rebinned at 100 s, together with the exponential fit to the data ($\chi^2_\nu = 3.71$ for 80 degrees of freedom). The inset shows an enlargement of the boxed data

flux in the 15–40 keV band was 0.5 mCrab. An exponential decay law fits well the data but in the 0.5–1.0 keV band (see Fig. 3), where the source spectrum shows the emergence of a soft ($\lesssim$2 keV) component Orr et al. 1998. The e-folding time is 1.2 ± 0.2 d and 2.3 ± 0.3 d in the 0.3–3 keV (LECS) and 1.5–10 keV (MECS) energy bands, respectively. The latter value is about 3 times larger than $\tau_{\rm ASM}$, indicating that the source decay slows down. A possible explanation could be the presence of a steady component. The decay constant has a different behavior as a function of energy with respect to TOO1, as is shown in Fig. 2: the e-folding time decreases up to about 1 keV and then increases with energy. The variance of the 1.5–10 keV data, once the decaying law has been subtracted, is completely consistent with a Poissonian statistics, while the 0.5–1.0 keV light curve shows significant variability on a 100 s time scales (see Fig. 3).

3. Optical observations and data analysis

Optical photometry in V and R bands has been performed on 1998 April 6.9, 10.8, 21.8, 24.9 and 25.9 with the 0.70 m TNT (Teramo–Normale Telescope) of the Teramo Observatory, equipped with a Tektronics TK512CB1-1 CCD camera (pixel size of 0.46 arcsec/pixel). A total of 37 frames were collected, with exposure times ranging from 60 to 600 sec for the V band and from 40 to 200 sec for the R band, depending on the seeing conditions. The frames were debiased and flat-fielded in the usual way, reduced with simple aperture photometry inside MIDAS, and calibrated using field stars Granslo 1998. The uncertainty on our data is mainly due to calibration errors.

By combining our photometrical data with those published by Garcia et al. (1998) and Hynes et al. (1998) we find that the V magnitude of the star faded from 9.25 ± 0.1 mag on April 3.13 to 9.7 ± 0.1 on April 3.87, to 11.2 ± 0.05 on April 10.80. The light curve of the source in the V band is shown in Fig. 1, second panel. No remarkable changes in the V–R color are noticed during the outburst: it remains $\sim$1.1. As also noted by Hynes et al. (1998), this is the same value measured by Bergner et al. (1995) during quiescence. Then, from April 21 the magnitude varies around $V \sim$11.8: this is $\sim$0.2 mag fainter than the mean value reported by Bergner et al. (1995). Appreciable flickering with amplitude $\sim$0.3 mag on a timescale of about 1 hr is seen on April 6, while no variations are detected in the later observations. Assuming an exponential decay also for the optical light curve, and once the contribution of the quiescent optical counterpart has been subtracted, we find that V and R e-folding times are $\tau_V = 1.6 \pm 0.7$ d and $\tau_R = 1.19 \pm 0.14$ d for TOO1; $\tau_V = 3.54 \pm 0.37$ d and $\tau_R = 3.16 \pm 0.35$ d for TOO2. These values are compatible with those obtained from the BeppoSAX observations.

4. Discussion

The observed outburst shows several peculiarities, some of which could give hints on the nature of the source. The X-ray outburst is followed by a radio outburst and by a change in the brightness of the optical counterpart (CI Cam) associated with XTE J0421+560.

Outburst peak occurrence time and outburst duration depend on photon energy. It is evident from Fig. 1 that the outburst peak is achieved first in the X-ray band (April 1.04), and eventually at 2.25 GHz ($\sim$April 6), with the X-ray outburst duration much shorter than the radio one. This can be an indication of a transition from an optically thick to an optically thin medium. It is worth noting that this transition coincides with the onset of the radio jets.

The X-ray e-folding time depends on photon energy. During TOO1 it appears to decrease with energy up to about 20 keV where it achieves a saturation; during TOO2 it decreases up to about 1 keV and then increases. One of the major changes occurred in the energy spectrum from TOO1 to TOO2 is the emergence during TOO2 of the soft component below 2 keV, modeled with two narrow emission lines with energies at $\sim$0.7 and $\sim$1.1 keV that smoothly decrease during the observation Orr et al. 1998. From Fig. 2 we can see that this soft component is characterized by a different temporal behavior: it evolves more rapidly than the corresponding hard ($\gtrsim$2 keV) component. A possible explanation for this behavior is the association of this component to the radio jets (or to the process that created them). This is supported by the presence, *only* in the soft component, of 100 s time scale temporal variability (see Fig. 3), implying an upper limit for the emitting region of 3×10^{12} cm. The hard component, also because of the presence of various emission lines Orr et al. 1998, could be associated to the circumstellar matter around the XTE J0421+560/CI Cam system.

The similarity between the hard X-ray and optical e-folding time scales should suggest a common nature for these emissions, such as reprocessing of X-rays from the central object into optical light. However, other optical properties are not in agreement with this interpretation. In the optical band, where most of the outburst flux is emitted in the red part of the spectrum, the V–R color does not change appreciably during the decay to quiescence. This is surprising because the outburst would imply a heating of emission zones such as a disk or the side of the mass-

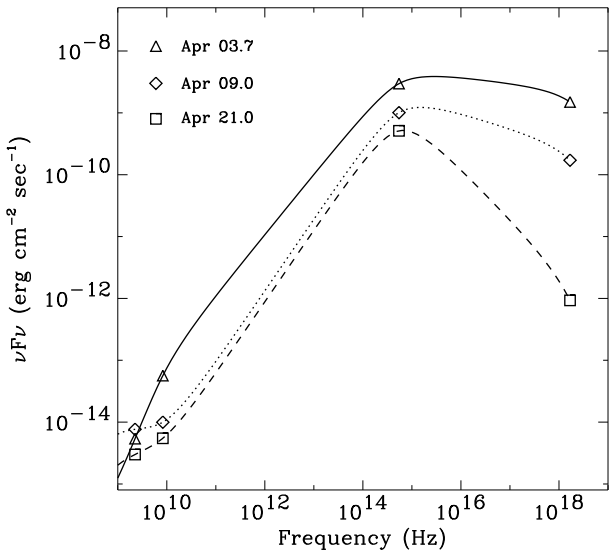

Fig. 4. $\nu F\nu$ plot of XTE J0421+560 at different times during outburst. The lines are the interpolation with splines of the data points. The optical point is the average of B, V, R measurements. The Apr 21 X-ray point is estimated from the TOO2 decay law

losing star facing the compact object. For instance, cataclysmic binaries and X-ray novae (XN) become appreciably bluer during the outburst and most of their luminosity is emitted at low wavelengths in the optical (see, e.g., van Paradijs & McClintock 1995).

The presence of an optical and a radio outburst associated with the X-ray one is typical of XN outbursts in which the compact object is a neutron star (NS) or a black hole (BH) (see review by Tanaka & Shibazaki 1996). Also the presence of relativistic jets of matter has been considered typical of NS/BH system. In spite of this, the features shown by XTE J0421+560 rise several doubts on a similar nature of the compact object.

The 2–12 keV X-ray luminosity at the maximum of the outburst, assuming an isotropic emission of the radiation, results to be 5.1×10^{36} erg s^{-1}. For comparison, known NS or BH XN exhibit higher peak luminosities Tanaka & Shibazaki 1996, Tanaka & Lewin 1995. The X-ray energy emitted in the outburst by XTE J0421+560 is estimated to be 3.7×10^{41} erg in the X-ray band, 1.6×10^{41} erg in the optical band (R filter), 4.6×10^{36} erg at 8.3 GHz and 1.8×10^{36} erg at 2.25 GHz. For comparison that emitted by NS and BH XN in the X-ray band is much higher (10^{43}–10^{45} erg; Tanaka & Shibazaki 1996). We also evaluated the bolometric energy emitted in the outburst, by making use of the X-ray, optical and the radio data. The derived broad band logarithmic power per photon energy decade (the $\nu F\nu$ spectrum) is shown in Fig. 4 at different times during outburst. The upper limit to the total energy emitted during the entire outburst is 1.5×10^{44} erg, similar to that estimated for classical novae (CN) systems, although X-ray and γ-ray emission is generally not detected in them Warner 1995.

This object seems to have experienced an impulsive eruption, with a characteristic time scale more similar to that of a dwarf nova outburst ($\sim$1 week) than to those of CN or XN ($\sim$months), which also show more complex light curve features Tanaka & Shibazaki 1996. Furthermore, the X-ray emission from XTE J0421+560 does not show the erratic flux variability of NS or BH XN systems, that is likely associated to the accretion process that takes place in these systems.

In conclusion, X-ray observations clearly indicate the presence of a compact object in XTE J0421+560, but the available data do not allow its nature to be pinpointed. The presence of X-ray, optical and radio outburst, together with relativistic jets, is typical of neutron star and black hole systems. On the other hand, the temporal behavior and the energetics are compatible also with a white dwarf system. Our data suggest that the soft X-ray emission might originate from the relativistic jets, while the hard component is more likely to be associated to processes occurring in the circumstellar matter and/or near the compact object.

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