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LETTER

Letter to the Editor

Unusual quiescent X-ray activity from XTE J0421+560 (CI Cam)

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Abstract. We report on BeppoSAX observations of the X-ray transient XTE J0421+560 in quiescence 156, 541, and ~690 days after the maximum of the 1998 April outburst. In the first observation the source was soft with a power-law photon index, α, of $4.0\pm^{1.9}_{0.9}$ and absorption, $\mathrm{N_H}$, of $(1.1\pm^{4.9}_{1.1}) \times 10^{21}$ atom cm^{-2}. In the second observation, the source brightened by a factor ~15 in the 1–10 keV energy range, became significantly harder with $\alpha = 1.86\pm^{0.27}_{0.32}$ and was strongly absorbed with $\mathrm{N_H} = (4.0 \pm 0.8) \times 10^{23}$ atom cm^{-2}. There is evidence for a narrow emission line in both spectra at ~7 keV. In the third observation, the source had faded by a factor $\gtrsim$8 from the previous observation to below the BeppoSAX detection level. It is possible that these variations result from orbital motion of a compact object around the B[e] star companion with the intense, absorbed, spectrum arising during passage through dense circumstellar material. If this is the case, the system may be continuing to exhibit periodic activity.

Key words: stars: binaries: symbiotic – stars: individual: – stars: novae, cataclysmic variables – X-rays: stars

1. Introduction

On 1998 March 31 a soft X-ray transient (XTE J0421+560) was detected by the All-Sky Monitor onboard R-XTE (Smith et al. 1998). The source brightened rapidly, reaching ~2 Crab after a few hours and then quickly decayed with an initial e-folding time of only 0.5 day. The outburst was observed by CGRO (Paciesas & Fishman 1998), R-XTE (Belloni et al. 1999), ASCA (Ueda et al. 1998) and BeppoSAX (Frontera et al. 1998; Orr et al. 1998). This was the fastest rise and decay of any outburst from a soft X-ray transient (see e.g., Chen et al. 1997). The outburst X-ray spectra are complex and cannot be fit by any of the models usually applied to soft X-ray transients. A two-temperature bremsstrahlung model was used to describe the spectra of the ASCA and two BeppoSAX outburst observations. Both BeppoSAX spectra included line features identified with O, Ne/Fe-L, Si, S, Ca and Fe-K. During the second observation the O and Ne/Fe-L line energies decreased smoothly by ~9%, while the other line energies remained unchanged (Orr et al. 1998). No bursts, pulsations, or quasi-periodic pulsations have been detected, and so the origin and nature of the X-ray emission remains uncertain.

Radio and optical observations identified XTE J0421+560 with a B[e] star CI Cam (MWC 84). Radio observations of XTE J0421+560 revealed a slow (~1000 m s^{-1}), shell-like motion (Hjellming et al. 1998) as well as the presence of SS 443-like jets (Hjellming & Mioduszewski 1998a, 1998b) with a velocity of $0.15\ c$. Spectroscopic observations by Wagner & Starrfield (1998) revealed a rich emission line spectrum with He II in emission. These features were absent in previous spectra (Downes 1984). The class of B[e] stars include many objects of different types and evolutionary status (e.g., Lamers et al. 1999). They differ from classical Be stars in showing a pronounced IR excess due to emission from warm dust, rather than the free-free and free-bound emission from the gaseous envelopes of classical Be stars. Near IR spectroscopy of CI Cam by Clark et al. (2000) reveals a complex circumstellar environment with a highly ionized region (presumably near the compact object) responsible for the He II emission embedded in a dense stellar wind. The circumstellar envelope includes cold dense regions which may by located in a disk, or the result of discrete mass ejections.

The distance to CI Cam is quite uncertain. Hjellming (private communication) infers a distance of 1.0 ± 0.2 kpc from an observation of the 21 cm H I absorption profile. Based on the optical properties of the source Zorec (1998) and Clark et al. (2000) estimate distances of 1.75 kpc and ~0.6–2.0 kpc, respectively. This uncertainty in distance is important, since at 2 kpc the peak outburst luminosity of several 10^{37} erg s^{-1} is high enough to exclude accretion onto a white dwarf as the origin of the (assumed isotropic) X-ray emission. If the source is at 1 kpc, then it is not.

In quiescence the X-ray luminosity of soft X-ray transients appears to depend on the nature of the compact object. From a systematic study of 13 soft X-ray transients, Asai et al. (1998) find that the quiescent luminosity of systems containing neutron stars is $\sim 10^{32-33}$ erg s^{-1}, whereas those of systems con-

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Table 1. BeppoSAX observing log of XTE J0421+560 in quiescence. (There were also 2 BeppoSAX observations in 1998 April during the outburst.) The third quiescent observation consists of two pointings separated by 5 days which are analyzed together. Uncertainties and upper limits are given at 3σ confidence. The flux estimates are discussed in Sect. 3

Obs	Observation		Exposure		Count rate		Flux
	Start	End	LECS	MECS	LECS	MECS	(1–10 keV)
	(yr mn dy hr:mn)	(mn dy hr:mn)	(ks)	(ks)	(0.1–8 keV; s^{-1})	(2–10 keV; s^{-1})	(erg cm^{-2} s^{-1})
1	1998 Sep 03 14:19	Sep 04 14:19	19.1	44.8	0.0033 ± 0.0006	0.0015 ± 0.0003	4.5×10^{-13}
2	1999 Sep 23 11:17	Sep 25 15:07	30.8	60.7	0.0024 ± 0.0010	0.0078 ± 0.0004	7.6×10^{-12}
3	2000 Feb 20 10:05	Feb 21 20:41	13.0	66.5	$<$0.0020	$<$0.00092	$<9 \times 10^{-13}$
	2000 Feb 25 11:03	Feb 26 05:42					

taining blackholes are systematically lower with most of them having upper limits in the range $\lesssim 10^{32}$ erg s^{-1}. In order to investigate the nature of any quiescent emission, XTE J0421+560 was observed by BeppoSAX in 1998 September, 156 days after the outburst maximum. A faint source at a position consistent with XTE J0421+560 was detected (Orlandini et al. 2000). The spectrum can be fit with the same two temperature (kT_1, kT_2) model as during the outburst with the same value of kT_1 as during the second outburst observation and a lower value of kT_2. We report here also on two further BeppoSAX observations of XTE J0421+560 in quiescence, made 541 and $\sim$690 days after outburst maximum. During the first observation, in 1999 September, an absorbed, hard source was detected, while during the second, in 2000 February, the source intensity was below the detection threshold.

2. Observations and results

Results from the imaging Low-Energy Concentrator Spectrometer (LECS; 0.1–10 keV; Parmar et al. 1997) and Medium-Energy Concentrator Spectrometer (MECS; 1.8–10 keV; Boella et al. 1997) on-board BeppoSAX are presented. Due to the faintness of the source XTE J0421+560 was not detected by the non-imaging high-energy instruments. The region of sky containing XTE J0421+560 was observed three times by BeppoSAX following the end of the 1998 April outburst (see Table 1). The results of the first of these observations are reported in Orlandini et al. (2000) and we include these data here for completeness. As usual, good data were selected from intervals when the elevation angle above the Earth's limb was $>4^\circ$ and when the instrument configurations were nominal, using the SAXDAS 2.0.0 data analysis package. LECS and MECS data were extracted centered on the position of XTE J0421+560 using radii of $4'$ and $2'$, respectively.

A source with a MECS 2–10 keV count rate of 0.0078 s^{-1} was detected at a position consistent with XTE J0421+560 during the 1999 observation. This value can be compared to the MECS 2–10 keV count rate during the 1998 September observation of 0.0015 s^{-1}, indicating that the source had brightened substantially. There is no evidence for any variability during the 1999 observation with a 3σ limit to rms fractional variability of 7.1%. During the 2000 February observation, the source was not detected with a 3σ upper limit to the 2–10 keV MECS count rate of 0.00092 s^{-1}. We note that a preliminary comparison of optical (4000–8000 Å) spectra acquired simultaneously with the 1999 and 2000 BeppoSAX observations (Bartolini et al., in preparation), as well as with the optical spectra reported by Orlandini et al. (2000), shows no obvious differences in the relative strengths of the Balmer and He I emission lines.

The usual method of background subtraction for the LECS and the MECS is to use deep exposures of "standard" high galactic latitude fields. Since the X-ray sky background is spatially structured, especially at low energies (see e.g., Snowden et al. 1995), this may not be appropriate for XTE J0421+560 (l, b = $149^\circ, +4.1^\circ$). To investigate this effect, LECS background spectra were produced using the annulus method described in Parmar et al. (1999), using the central $8'$ of the LECS and MECS fields of view during the 2000 observation (when the source was not detected), and using standard files. The spectral fit results for the 1998 September and 1999 observations do not depend significantly on which method was used, and all quoted results used the annulus method.

3. Spectral fits

In order to further investigate the nature of this brightening, LECS and MECS spectra for the 1998 September and 1999 observations were extracted. They were rebinned to oversample the full width half maximum of the energy resolution by a factor 3 and to have additionally a minimum of 20 counts per bin to allow use of the χ^2 statistic. The photoelectric absorption cross sections of Morisson & McCammon (1983) were used throughout. A factor, constrained to be within its usual 0.8–1.0 range, was included in the spectral fit models to allow for the normalization uncertainty between the LECS and MECS. The results of simple model fits, including absorbed power-law, thermal bremsstrahlung and collisionally ionized thermal equilibrium plasma (MEKAL in XSPEC) models, are given in Table 2. In the MEKAL fits, the abundance of the emitting material was fixed at the solar value. Orlandini et al. (2000) report the detection of an emission feature with an energy of $\sim$7 keV in the 1998 September spectrum. We therefore included a power-law model together with a narrow Gaussian emission feature in the fits. The acceptable values of χ^2 indicate that more complex models are not required.

Table 2 shows the very different spectral shapes during the two observations. In 1998 September the source could be modeled by a power-law with a photon index, α, of $4.0\pm^{1.9}_{0.9}$ and

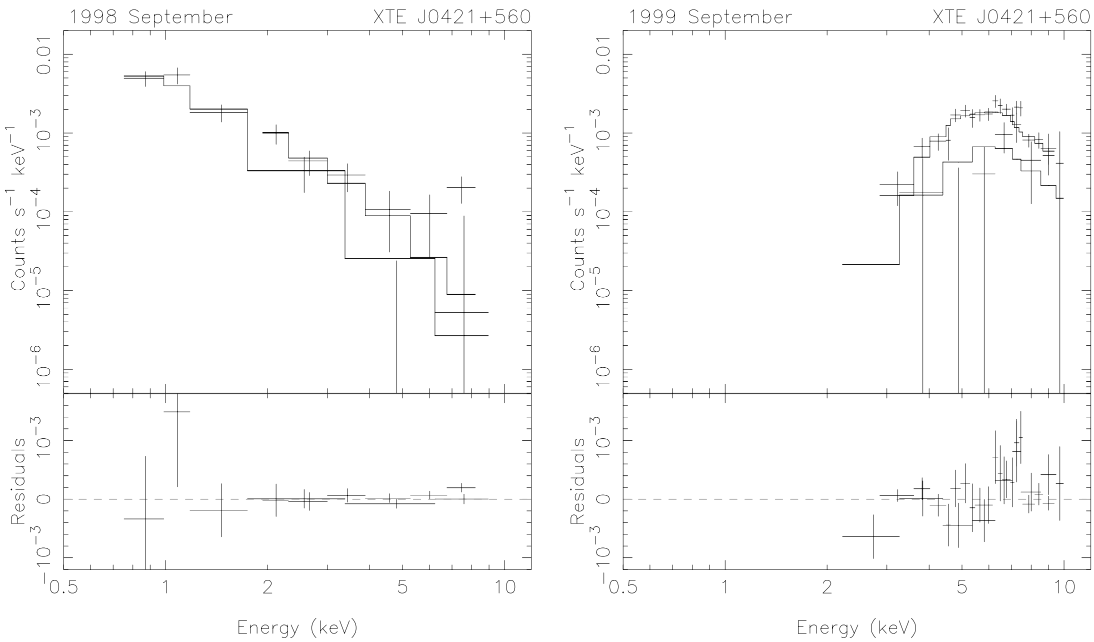

Fig. 1. The observed LECS and MECS spectra of XTE J0421+560 together with the best-fit power-law and Gaussian line models for the 1998 September (left panels) and 1999 (right panels) observations. In the lower panels the line normalization has been set to zero

Table 2. XTE J0421+560 fit results. N_H is in units of 10^{22} atom cm^{-2}. 90% confidence limits are given. For the MEKAL fits the abundance was fixed at the solar value. PL = Power-law

Model	N_H	kT (keV)	α	χ^2/dof
Observation 1				
Power-law	$0.0\pm^{0.44}_{0.0}$	…	$3.5\pm^{1.7}_{0.6}$	10.3/8
Brems.	$0.0\pm^{0.17}_{0.0}$	$0.76\pm^{0.42}_{0.28}$	…	15.0/8
MEKAL	$0.0\pm^{0.54}_{0.0}$	$1.24\pm^{0.24}_{0.47}$	…	10.1/8
PL + Line	$0.11\pm^{0.49}_{0.11}$	…	$4.0\pm^{1.9}_{0.9}$	3.3/6
Observation 2				
Power-law	$41\pm^{15}_{4}$	…	$1.72\pm^{0.80}_{0.38}$	37.3/30
Brems.	$41\pm^{13}_{11}$	>6.4	…	37.0/30
MEKAL	35 ± 6	>14	…	34.2/30
PL + Line	40 ± 8	…	$1.86\pm^{0.27}_{0.32}$	28.0/28

N_H of $(1.1\pm^{4.9}_{1.1}) \times 10^{21}$ atom cm^{-2}, together with a narrow Gaussian line feature at $7.0\pm^{1.6}_{0.2}$ keV for a χ^2 of 3.3 for 6 degrees of freedom (dof). The same model also gives the best-fit to the 1999 spectrum, but now α is $1.86\pm^{0.27}_{0.32}$ and N_H is $(4.0\pm0.8)\times10^{23}$ atom cm^{-2} for a χ^2 of 28.0 for 28 dof. The line energy is 7.3 ± 0.2 keV and the equivalent width 620 ± 350 eV. Fig. 1 shows the observed LECS and MECS spectra for the 2 observations together with the best-fit (power-law and Gaussian line) model. The contrast in spectral shape is striking. During the 1999 observation the source was not detected by the LECS below 2 keV, whereas the majority of the emission was below this energy in the 1998 September observation. The unabsorbed 1–10 keV fluxes given in Table 1 are derived using the best-fit parameters and by setting $N_H = 0$. In the case of the 2000 observation, the upper limit to the flux is derived assuming the absorption corrected spectral shape of the 1999 observation (when the source was strongly absorbed). If the absorption corrected spectral shape from the 1998 September observation is used, the 3σ upper-limit to any 1–10 keV flux is 2.8×10^{-13} erg cm^{-2} s^{-1}. This implies that the source had faded by a factor $\gtrsim$8 in the 1–10 keV energy range from the 1999 observation.

From an analysis of diffuse interstellar bands in the optical spectrum of CI Cam, Clark et al. (2000) estimate that the interstellar E(B–V) is 0.65 ± 0.20. This implies $A_v = 2.0 \pm 0.6$. Using the relation $N_H[cm^{-2}/A_v] = 1.79 \times 10^{21}$ from Predehl & Schmitt (1995) implies that observed X-ray absorption should be not less than $(3.6 \pm 1.1) \times 10^{21}$ atom cm^{-2}. The best fit to the 1998 September spectrum gives an N_H of $(1.1\pm^{4.9}_{1.1}) \times 10^{21}$ atom cm^{-2}, consistent with the predicted interstellar value. For a distance d in kpc, the fluxes listed in Table 1 correspond to 1–10 keV luminosities of 5.4×10^{31}, 9.1×10^{32}, and $<1 \times 10^{32}$ d^2_{kpc} erg s^{-1} for the 1998 September, 1999, and 2000 observations, respectively. We note that the distance to CI Cam is probably in the range 0.6 to 2.0 kpc (see Sect. 1).

4. Discussion

XTE J0421+560 is a highly unusual X-ray transient due to (1) the high-mass nature of its companion, (2) the extremely short outburst duration, (3) the complex, time varying, line-rich outburst X-ray spectra to which must now be added (4) the long duration, and highly variable quiescent emission. In the 1998 September observation the source was soft with low absorption (1.1×10^{21} atom cm^{-2}) while during the 1999 observation it had hardened and brightened by a 1–10 keV factor of $\sim$15 and N_H had increased to 4.0×10^{23} atom cm^{-2}. In the 2000 observation XTE J0421+560 was not detected indicating that the source was a factor $\gtrsim$8 times fainter than during the second observation. Despite these variations in X-ray emission, the main features of the optical spectrum of CI Cam did not change appreciably.

The quiescent variability of soft X-ray transients has been poorly studied. This is primarily because these objects are faint in quiscence, with intensities often close to the detection limit of current instruments, and therefore difficult to observe (e.g., Verbunt et al. 1994; Asai et al. 1998; Campana & Stella 2000). It is possible that the decreasing emission observed here represents a long lived component of the original (∼10 day duration) outburst. In this case the brightening seen in 1999 may result from some sort of re-flare. It is then unclear why the 1999 absorption was so high, since near the peak of the 1998 April outburst the absorption was only $\sim 5 \times 10^{22}$ atom cm^{-2} which then decreased as the outburst decayed (Belloni et al. 1999). There is no evidence for similar long lived activity from other soft X-ray transients (e.g., Chen et al. 1997), although it is quite possible that similar low-level emission may have been missed due to a lack of suitable observations.

Even at the maximum likely distance of 2 kpc the upper-limit to the luminosity during the 2000 observation of $<4 \times 10^{32}$ erg s^{-1} is more similar to those of quiescent soft X-ray transients containing black holes than those containing neutron stars. However, the comparison with other soft X-ray transients may be misleading since it is unclear whether the accretion mechanism is the same in all cases. The hard spectrum observed in 1999 means that at times there may be sufficient hard X-ray photons to trigger the mass loss instability of Hameury et al. (1986) discussed in the context of the 1998 September observation by Orlandini et al. (2000).

It is possible that the observed quiescent X-ray properties result from orbital motion. As the compact object passes through the material located around the B[e] star the spectrum hardens, becomes more intense, and the absorption increases. At some distance from the B[e] star both the absorption and accretion rate decrease resulting in a spectrum similar to that observed in 1998 September. The non-detection in the 2000 observation may then result from an extremely low accretion rate far from the companion star. If this is the case, then the system may continue to be active for some time and continued multi-waveband monitoring could be important in helping elucidate the nature of the system.

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