RS Ophiuchi (2006) and the Recurrent Nova Phenomenon
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High Energy X-ray Emission from Recurrent Novae in Quiescence: T CrB

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Abstract. We present Suzaku X-ray observations of the recurrent nova T CrB in quiescence. T CrB is the first recurrent nova to be detected in the hard-X-ray band ($E \sim 40.0$ keV) during quiescence. The X-ray spectrum is consistent with cooling-flow emission emanating from an optically thin region in the boundary layer of an accretion disc around the white dwarf. The detection of strong stochastic flux variations in the light curve further supports the interpretation of the hard X-ray emission as emanating from a boundary layer.

1. Introduction

Symbiotic stars are binary systems in which a compact object accretes from a red giant, the wind of which forms a dense nebula around the binary. The nebula is ionized by the hot compact source, which is usually a white dwarf (Kenyon 1986). Among the known symbiotic stars (Belczyński et. al. 2000), four objects have shown recurrent nova (RN) eruptions: T CrB, RS Oph, V3890 Sgr and V745 Sco. These eruptions are triggered by a thermonuclear runaway on the white dwarf (WD) surface after accretion of a critical amount of hydrogen-rich material from the companion.

Orio et al. (2001) suggested that during quiescence, the X-ray emission from RNe could originate in the boundary layer of an accretion disc that was reconstructed around the WD after the outburst. Therefore, X-ray observations should allow one to determine a lower limit for the accretion rate. The low X-ray luminosity measured in 350 novae and recurrent novae in quiescence (Orio et al. 2001) imply a low accretion rate, inconsistent with the observed recurrence times. For example, in the case of RS Oph (Orio 1993), the short recurrence time of ~20 years requires an accretion rate of $\sim 10^{-8}$ $M_\odot$ yr^{-1}, inconsistent with measured X-ray fluxes. This inconsistency is known as the "missing boundary layer problem".

T CrB is a well known recurrent nova with recorded outbursts in 1866 and 1946. Its quiescent-state hard X-ray emission ($E_{max} \sim 100$ keV) was first revealed during a 9 month *Swift* survey (Tueller et al 2005). Two additional

Swift/XRT observations were analyzed by Kennea et al. (in preparation), who report highly absorbed emission that was well fit with a cooling flow model with kT_{max}=23.1 keV. The absorber consisted of components that both fully covered and partially covered the hard X-ray source. Here we describe Suzaku X-ray Imaging Spectrometer (XIS) and Hard X-ray Detector (HXD) observations of the recurrent nova T CrB.

2. Observations and Data Reduction

On 2006 September 6, the Astro-E2/Suzaku X-ray observatory performed a 46 ks (GO) observation of T CrB (ObsId 401043010 start time 22:44:21 UT). We reduced the data according to standard procedures[1] using the software package HEASOFT 6.2[2]. After determining the XIS background count rate from a nearby blank region, we extracted spectra and light curves for the XIS and HXD detectors. We extracted two sets of light curves for each detector – one with a bin size of 360 s (used to search for stochastic bright variations) and the other grouping photons into 8 s bins. We used the light curve with the smaller time bins for power spectrum analysis.

3. Analysis and Results

3.1. Spectral Analysis

Visual inspection of the extracted spectrum showed prominent Fe lines around ~6.5 keV. As these lines are an indication of the presence of thermal emission from a plasma with temperatures $\sim 10^7 - 10^8$ K, we first attempted to fit the spectrum with a single-temperature plasma plus neutral absorption. But no satisfactory fit was obtained. Even using more complex absorbers, such as an absorber that only partially covers the source, or absorption from an ionized plasma, did not produce acceptable fits. We did, however, find acceptable fits (χ^2=1.07) for a multi-temperature, cooling flow plasma model (*mkcflow*). The model required a complex absorber consisting of one absorbing system that fully covered the source [$n_H(\mathrm{full}) = 17.8^{19.2}_{16.6} \times 10^{22}$ cm^{-2}, which includes interstellar absorption of 0.047×10^{22}cm^{-2}] and another that only partially covered the source [$n_H(\mathrm{partial}) = 35.6^{42.2}_{32.3} \times10^{22}$ cm^{-2}, with a partial covering fraction of $0.68^{0.72}_{0.66}$]. The minimum temperature of the cooling-flow model is consistent with the smallest value allowed by the *mkcflow* model (kT=0.0808 keV), and the maximum temperature is kT=$57.4^{68.3}_{48.0}$ keV. We also added a Gaussian emission-line profile to the model to account for the Fe Kα fluorescence line. Figure 1 shows the spectra from the XIS and HXD detectors, with the cooling-flow model overplotted. To estimate the parameters for the Fe lines, we used a simple power-law fit to establish the continuum level, and then fit the Fe Kα, Fe XXV and Fe XXVI emission lines with three Gaussian profiles (see Fig. 1, right panel). The equivalent widths obtained were 185^{187}_{183}, 135^{137}_{134} and 151^{153}_{149} eV respectively.

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[1] http://www.astro.isas.jaxa.jp/suzaku/analysis/

[2] http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/

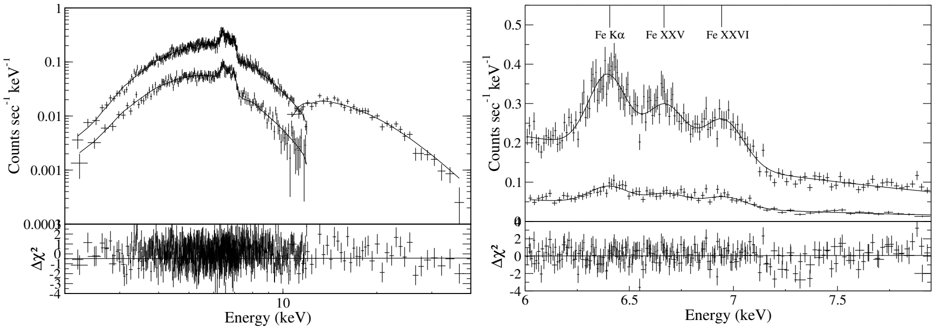

Figure 1. Left panel: Suzaku background-subtracted spectra of T CrB between 0.3 and 40.0 keV. The top spectrum on the low-energy side is the sum of spectra from the front-side illuminated XIS detectors (0, 2, and 3). The bottom spectrum on the low-energy side is from the back-side illuminated XIS detector (1). The high-energy spectrum is from the HXD. The best-fit absorbed cooling flow model is overplotted. Right panel: Fe line region ($\sim$ 6.5 keV), with best-fit power-law continuum plus three Gaussian profiles overplotted. The bottom panels show the residuals with respect to the models.

3.2. Timing Analysis

We examined the XIS time series binned at 360 s (Figure 2) and found significant stochastic variability above the level expected from Poisson noise. The fractional amplitude of the stochastic variations, represented as the ratio between the measured rms variation, s, and that expected from Poisson fluctuations alone, s_{exp}, is 3.75. In the case of the HXD light curve, no stochastic variations were found above the Poisson level. Although by eye there appears to be a periodic (or quasi-periodic) variation in the light curve at a period of around 100 minutes, we did not detect a statistically significant oscillation at this period in our preliminary Lomb-Scargle analysis (taking into account the underlying broadband continuum power) of the XIS and HXD light curves.

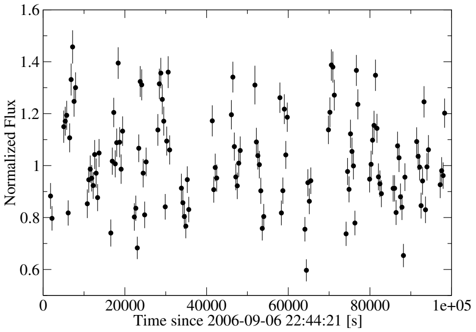

Figure 2. The mean normalized XIS light curve (all four detectors combined) with a 360 s bin size. The plot shows the flux as a function of time in the energy range 0.3-12.0 keV. The X-ray emission is clearly variable on a time scale of minutes.

4. Discussion

Hard X-ray emission with energy up to 100 keV is observed from the dwarf nova SS Cyg in quiescence (Barlow et al. 2006). Dwarf novae observed with XMM-*Newton* in quiescence also display spectra with energies up to ∼12 keV (Pandel et al. 2005). For low accretion rates ($< 3\times10^{-9}$ $M_\odot$/yr), Narayan & Popham (1993) showed that the innermost part of an accretion disc around a 1 $M_\odot$ WD, the boundary layer, radiates as an optically thin plasma at ∼ 10 keV. The hardness of the X-ray emission detected from T CrB strongly suggests that it comes from the accretion region closest to the WD. From the spectral model fitted, the accretion rate is $\dot{M} \sim 4.2\times10^{-9}$ $M_\odot$ yr^{-1} $(d/1 \text{ kpc})^2$. The detection of rapid flickering, which typically emanates from regions close to the WD, supports an accretion origin for the detected emission. Moreover, the cooling-flow spectral model, as with boundary layer emission from non-magnetic cataclysmic variables (Mukai et al. 2003) and other accreting high-mass white dwarfs (Luna & Sokoloski 2007; Smith et al. 2008), provides a natural context for the flickering.

The equivalent width (EW) of the neutral Fe Kα line suggests that the X-ray source is surrounded by large amounts of neutral material (Inoue 1985). Reflection of radiation off the WD surface can also contribute to the formation of this line. From George & Fabian (1991), the EW of the Fe Kα line when a 2π source reflects bremsstrahlung photons with ∼10 keV is 100-200 eV. Therefore the intense Fe Kα line is consistent either with large amounts of neutral material, as with RT Cru and CD -57 3057 (Luna & Sokoloski 2007; Smith et al. 2008, Kennea et al. in preparation), or with reflection from the surface of the WD.

5. Conclusions

Using the Suzaku X-ray satellite, we observed hard-X-ray emission from the recurrent nova T CrB in quiescence. Assuming that a more detailed timing analysis confirms the lack of periodic variations, the presence of flickering on a timescale of minutes and the cooling-flow type spectrum suggest that the accretion onto the WD proceeds through a disc with an optically thin boundary layer. T CrB is the first recurrent nova to show hard-X-ray emission from a boundary layer during quiescence.

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References

Barlow, E. J. et al. 2006, MNRAS, 372, 224
Belczyńsky, K. et al. 2000, A&AS,**146**,407
George, I., & Fabian, A. 1991, MNRAS, 249, 352
Inoue, H. 1985, Sp. Sci. Rev., 40, 317
Kenyon, S. J. 1986, The Symbiotic Stars (Cambridge: Cambridge University Press)
Luna, G. J. M.,& Sokoloski J. L. 2007, ApJ, 671, 741
Mukai, K. et al. 2003, ApJ, 586, 77
Narayan, R. & Popham, R. 1993, Nature, 362, 820

Orio, M. 1993, A&A, 274, L41
Orio, M., Covington, J., & Ögelman, H. 2001, A&A, 373, 542
Pandel, D., Córdova, F. A., Mason, K. O., & Priedhorsky, W. C. 2005, ApJ, 626, 396
Smith, R. et al. 2008, PASJ, 60, S43
Tueller, J. et al. 2005, Astronomer's Telegram 669

Discussion

Rupen: Where physically do the soft and the hard X-rays arise? If in the same place, why are the two $N_{\rm H}$ values so different?

Luna: They likely arise from a boundary layer in the accretion disc. The difference in $N_{\rm H}$ is probably an artefact of the fit. A more 'realistic' model would include a distribution of absorbers along with a multi-temperature thin thermal emission component.

Mikołajewska: What will happen if the white dwarf mass is only $1.2\,{\rm M}_\odot$? Will it still be consistent with your data?

Luna: Yes, it's still consistent. The accretion rate is still a lower limit on the one needed for a recurrence time of ∼80 years. However, I don't know if a $1.2\,{\rm M}_\odot$ white dwarf would reproduce the post-outburst optical light curve using, for example, models from Hachisu & Kato.

Osborne: What is it about this system that makes it look so different to a typical quiescent non-magnetic cataclysmic variable? For example, the temperatures and luminosity are much higher.

Luna: The white dwarf mass is probably the important factor. From Hernanz et al (in preparation), a basic scaling between SS Cyg in quiescence and T CrB could be invoked (besides an unknown scaling factor) and in order to have the observed temperature there has to exist a massive white dwarf. However this is a preliminary speculation and certainly more work is needed.

Mukai: Yes, it is much more luminous. The interpretation in Kennea et al (in preparation) is that T CrB has a very massive white dwarf. The difference between the $\sim 1\,{\rm M}_\odot$ white dwarf in SS Cyg and the $\sim 1.4\,{\rm M}_\odot$ white dwarf in T CrB may explain the hardness of emission in T CrB.

Ness: How precise is the determination of $N_{\rm H}$? Leaving $N_{\rm H}$ as a free parameter allows a lot of flexibility, and a 'hard' spectrum may still be a low-temperature plasma below a large column of absorbing material.

Luna: The $N_{\rm H}$ determination from Suzaku data includes the galactic absorption expected in the direction of T CrB. This is the lower limit that we could fix. However there's not much data that we could use to determine $N_{\rm H}$ and estimate the temperature of the gas. Even estimations of how much absorption could come from a red giant atmosphere (van den Berg et al 2006, ApJ, 647, 135) don't allow a good fit to the X-ray spectrum.