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XMM Observations of A0538-66 in quiescence

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Abstract

We have observed the recurrent Be/X-ray transient A0538-66, situated in the Large Magellanic Cloud, in the quiescent state with XMM/Newton. Despite a very low luminosity state, the source is clearly detected and spectra can be extracted. The spectral analysis confirms previous findings that the off-state spectrum is hard without requiring any soft component, contrary to the majority of neutron stars observed in quiescence up to now.

1 Introduction

The recurrent Be/X-ray transient A 0535–66 (X 0535−668) was discovered in 1977 when two outbursts were observed with the *Ariel 5* satellite (White & Carpenter 1978). In the following years several other outbursts were observed with *HEAO 1* and *Einstein (HEAO 2)* (e.g. Johnston et al. 1980; Skinner et al. 1980) with coincident X-ray and optical flares showing a recurrence of 16.65 days (Skinner 1980) interpreted as the period of an eccentric binary orbit. This period has been confirmed as a by-product of the *MACHO* project by Alcock et al. (2001), who also found a longer optical modulation of 421 days. The optical counterpart, identified by Johnston et al. (1980), was found to be a member of the Large Magellanic Cloud by Pakull & Parmar (1981). Optical and UV spectroscopy (Charles et al. 1983) classify the counterpart as B2 IIIe star.

Based on the distance to the LMC, the luminosity of the outbursts observed in the first years after detection can be estimated as around 10^{39} ergs/s making this a super-Eddington source and one of the most powerful X-ray binaries known. An observation with *Einstein (HEAO 2)* 1980/81 during a strong outburst found 69 ms pulsations (Skinner et al. 1982; Ponman et al. 1984); up to this day this remains the only measure of the pulse period of this accreting pulsar. From the rapid spin period and the luminosity Skinner et al. (1982) inferred an upper limit to the magnetic field of $B \sim 10^{11}$ G assuming that matter accreted onto the polar caps uninhibited by a centrifugal barrier.

In later years the source has been mostly quiescent. Weak outburst activity at two to three orders of magnitude below the early observations was found in the *ROSAT* All-Sky Survey end 1990 (Mavromatakis & Haberl 1993) and in an *ASCA* observation in 1995 (Corbet et al. 1997); for details see Table 1. Campana et al. (2002) observed the source 1999 in quiescence with *BeppoSAX* finding very different results than in the previous observations.

We have observed A 0535–66 in the quiescent state in April 2002 with *XMM-Newton*. The goal of the observation was to use the unique collecting power of this satellite in order to obtain spectral data allowing to distinguish between different models of the quiescence emission

2 Data Analysis

The data were extracted with the *XMM-Newton Scientific Analysis Software*, version 5.4. The data were extracted from circles centered on the source, and from a background region of same area. Separate spectra were extracted for single and double events, which allows to gauge potential calibration uncertainties.

3 Results

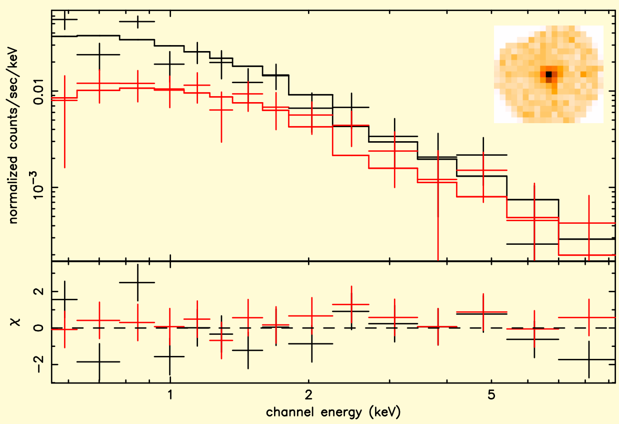

FIGURE 1: Observed *XMM-Newton* spectra for single (black) and double (red) events, together with the best fit power law spectrum. The inset shows the source image.

Given the low flux from the source, the obtained spectra do not allow to distinguish between complex spectral models.The amount of photoelectric absorption is not strongly constrained and consistent with zero. We used a fixed value of $N_H = 0.08 \times 10^{22}$, as found by Corbet et al. (1997) and consistent with the ranges given in Mavromatakis & Haberl (1993) and Campana et al. (2002).

The spectra can be well fitted either by a power law with α=1.9±0.3 and $I_{1\,\mathrm{keV}}$=(4.9±0.6)×10^{-5} or a bremsstrahlung spectrum with kT=3.9+3.9-1.7 keV and I=6.3+1.1-0.8×10^{-5}. A blackbody spectrum is not consistent with the data, showing clear systematic devations above ∼2 keV.

The spectrum reported by Corbet et al. (1997) (see also Tab. 1) for a weak outburst is not at all compatible with our data – even after allowing for free scaling the χ^2_{red} ≈6.75 for 29 d.o.f. We can exclude any significant contribution from an additional soft component or an iron line to the best fit spectra – at most such components could contribute 2–3% to the total flux. In summary our results match very well those obtained by Campana et al. (2002) for but with the source in an even lower luminosity state.

Authors	Time of Observation	Luminosity [ergs/s]	Energy range
Ponman et al. (1984)	Dec 1980 & Feb 1981	(2-5)×10^{38}	1.5–20 keV
blackbody with kT=2.4 keV *or* Wien law with kT=2.4 keV			
Mavromatakis & Haberl (1993)	Nov 1990	4×10^{37}	0.1–2.4 keV
blackbody with kT=0.25±0.04 keV *or* bremsstrahlung with kT=0.9+0.9-0.3 keV *or* power law with α=2.6±0.7			
Mavromatakis & Haberl (1993)	Dec 1990	2×10^{37}	0.1–2.4 keV
blackbody with kT=0.22±0.02 keV *or* bremsstrahlung with kT=0.7+0.1-0.2 keV *or* power law with α=2.9±0.3			
Campana (1997)	Oct 1993	1×10^{36}	0.1–2.4 keV
blackbody with kT=0.22+0.07-0.04 keV *or* power law with α=2.5+1.2-0.9			
Corbet et al. (1997)	Feb 1995	∼5.5×10^{36}	0.3–10 keV
power law (α=2.04±0.15) plus blackbody (kT=2.69±0.15 keV) and Fe line at 6.52±0.04 keV, *or* power law (α=2.05±0.15) plus blackbody (kT=2.69±0.15 keV) and Fe lines at 6.4 and 6.7 keV, *or* power law (α=0.73±0.05) plus bremsstrahlung (kT=0.58±0.35 keV) and Fe line at 6.52±0.04 keV			
Campana et al. (2002)	Sep 1999	(1-3)×10^{35}	0.1–10keV
power law with α=2.1±0.6, *or* bremsstrahlung with kT=5.5+9.6-2.9 keV			
This study	**April 2002**	**(6-8)×10^{34}**	**0.3–10 keV**
power law with α=1.9±0.3, *or* bremsstrahlung with kT=3.9+3.9-1.7 keV			

TABLE 1: Comparison of spectral fit results with previous observations of A 0535–66. While in the outbursts soft spectra or spectral components were observed, the available data in quiescence shows hard spectra without the need for any soft component. Over the years the maximum observed luminosities have decreased.

4 Discussion

The observations reported here found A 0535–66 in a state of very low luminosity – the lowest state for which spectral results have been reported up to today. The results found by Campana et al. (2002) for the quiescent state are confirmed and extended to even lower luminosity.

Several mechanisms to produce the residual luminosity of an accreting X-ray pulsar in quiescence are discussed in the literature:

- Residual accretion onto the neutron star surface at very low rates (e.g. Stella et al. 1994).
- Accretion down to the centrifugal barrier caused by the rotating magnetic field (Illarionov & Sunyaev 1975) with the main emission coming from the material outside or just at the magnetosphere boundary (Campana & Stella 2000).
- Thermal emission of the neuton star surface due to cooling of the core heated during phases of strong accretion (Brown et al. 1998).
- Rotational energy release via an activated radio pulsar either with a directly observed pulsar wind or X-ray emission originating in a shock front between the pulsar wind and the inflowing matter (e.g. Burderi et al. 2002; Campana et al. 2002).

From an observational point of view two groups of sources emerge: The majority of the reported results has a significant soft component, usually modeled as a blackbody spectrum, and sometimes a high energy tail, represented by a power law of photon index ∼1–2 (e.g. Asai et al. 1998). Only three neutron star systems have been observed with a quiescent spectrum dominated by hard power law: SAX J1808.4–3658 (Campana et al. 2002), EXO 1745–248 (Wijnands et al. 2004) and A 0535–66. It is interesting to note that two of these systems have a fast spin period: 69 ms for A 0535–66 and 2.5ms for SAX J1808.4–3658.

Assuming that the low luminosity emission is caused by centrifugal inhibition of accretion, i.e. a kind of "propeller" mechanism at work in A 0535–66, one would at first expect the spectrum to be dominated by a thermal component from a residual accretion disk up to the magnetospheric radius. Its absence is an indication that indeed a pulsar mechanism may be at work driven by the fast spinning neutron star.

References

Alcock C., Allsman R.A., Alves D.R., et al., Mar. 2001, Mon. Not. R. Astron. Soc., 321, 678
Asai K., Dotani T., Hoshi R., et al., Dec. 1998, Publ. Astron. Soc. Jpn., 50, 611
Brown E.F., Bildsten L., Rutledge R.E., Sep. 1998, Astrophys. J., Lett., 504, L95
Burderi L., Di Salvo T., Stella L., et al., Aug. 2002, Astrophys. J., 574, 930
Campana S., 1997, Astron. Astrophys., 320, 840
Campana S., Stella L., Oct. 2000, Astrophys. J., 541, 849
Campana S., Stella L., Gastaldello F., et al., Aug. 2002, Astrophys. J., Lett., 575, L15
Charles P.A., Booth L., Densham R.H., et al., Feb. 1983, Mon. Not. R. Astron. Soc., 202, 657
Corbet R.H.D., Charles P.A., Southwell K.A., Smale A.P., Feb. 1997, Astrophys. J., 476, 833
Illarionov A.F., Sunyaev R.A., 1975, Astron. Astrophys., 39, 185
Johnston M.D., Griffiths R.E., Ward M.J., May 1980, Nature, 285, 26
Mavromatakis F., Haberl F., Jul. 1993, Astron. Astrophys., 274, 304
Pakull M., Parmar A., Sep. 1981, Astron. Astrophys., 102, L1
Ponman T.J., Skinner G.K., Bedford D.K., Apr. 1984, Mon. Not. R. Astron. Soc., 207, 621
Skinner G.K., Nov. 1980, Nat, 288, 141
Skinner G.K., Shulman S., Share G., et al., Sep. 1980, Astrophys. J., 240, 619
Skinner G.K., Bedford D.K., Elsner R.F., et al., 1982, Nature, 297, 568
Stella L., Campana S., Colpi M., Mereghetti S., Tavani M., 1994, Astrophys. J., 423, L47
White N.E., Carpenter G.F., Apr. 1978, Mon. Not. R. Astron. Soc., 183, 11P
Wijnands R., Heinke C., Pooley D., et al., 2004, submitted to ApJ, astro-ph/0310144

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