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Letter to the Editor

A transient supersoft X-ray source in the Large Magellanic Cloud*

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Abstract. We present new X-ray data with an improved position for the supersoft X-ray source RX J0537.7-7034 and propose a candidate for the optical identification. The X-ray source had an "on" and an "off" state and was variable on a time scale of months. The proposed optical counterpart is displaced by only 9 arcsec; it is a blue variable star whith an amplitude modulation in the optical light curve. The optical spectrum shows a blue continuum and the He II λ 4686 emission line.

Key words: Accretion, accretion disks – Stars: binaries: close; white dwarfs – X-rays: stars.

1. Introduction

Supersoft X-ray sources, with a blackbody like spectrum that peaks in the range 20–60 eV and luminosities of 10^{37-38} ergs s^{-1} were first observed with *Einstein* (see Crampton et al. 1987, Wang et al. 1991). They were defined as a class thanks to numerous ROSAT observations (e.g. Greiner et al. 1991). There is evidence that all these intriguing sources might be white dwarfs burning hydrogen in an accreted layer, with a very thin and hot atmosphere on top (see Yungelson et al. 1996). This leaves a number of open possibilities: symbiotic stars (e.g. Jordan et al. 1994), post–nova remnants burning hydrogen for a few years (Ögelman et al. 1993, Krautter et al. 1996), hot PG 1159 stars (Werner 1991, Motch et al. 1993), the hottest planetary nebula nuclei (e.g. Wang 1991), and finaly also close binary systems with a white dwarf accreting from a 1–2 $M_\odot$ main sequence secondary (see van den Heuvel et al. 1991). The latter class, previously unknown, might be the progenitors of type Ia supernovae or of neutron stars born by accretion induced collapse (e.g. Della Valle & Livio 1994). To the present day 34 supersoft X-ray sources have been observed, mostly in M31 and in the Magellanic Clouds where the interstellar absorption is low (Greiner 1996). Excluding two previously known novae the photometric orbital period has been determined only for five sources (see Greiner 1996, Alcock et al. 1996 and references therein). The range of periods varies between 4 and 25 hours. Without a clear optical identification and knowledge of some basic physical properties, the classification of these X–ray objects remains dubious. To put this important piece in the puzzle of close binary stars evolution, we need more observations in the optical and other wavelength ranges. In a 1993 paper, Orio & Ögelman reported the observation of RX J0537.7-7034, a candid supersoft X–ray source in the direction of the Large Magellanic Cloud (hereafter LMC). This source was not previosuly detected with *Einstein*. In May 1992 it was serendipitously observed with the ROSAT PSPC and detected with a lower count rate than most supersoft sources observed by the PSPC in the LMC. All the counts however were below 0.5 keV. The observation was not close to centre of the detector, so the position uncertainty was large. Pakull (1995) found a new Galactic white dwarf inside the previously published PSPC error box. In this article we report new X–ray observations; for a certain time the source was still detected but the X-ray flux varied. This fact seems to exclude a white dwarf as optical counterpart. A better determined position also allows us to propose an optical identification with a blue variable star associated with the LMC. We present photometric data and an optical spectrum of this star.

2. New X-ray observations

The 2000 coordinates of RX J0537.7-7034 , determined again in the longest esposure in December 1993 in which the source was close to the center of the detector, are α = 05 h 37 m 46.3 s and δ = -70^o 33' 44" with an uncertainty of about 30". From the May 1992 data the position was α = 05 h 37 m 43 s and δ = -70^o 34' 40" (Orio & Ögelman 1993) with a much larger uncertainty. Table 1 summarizes the basic results with the ROSAT PSPC. In repeated short archival exposures in June-July 1990 and in November 1991 the source was not detected. It was "perhaps-detected" at a 2.5 σ confidence level in a longer but completly

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* Partially based on observations at ESO, La Silla.

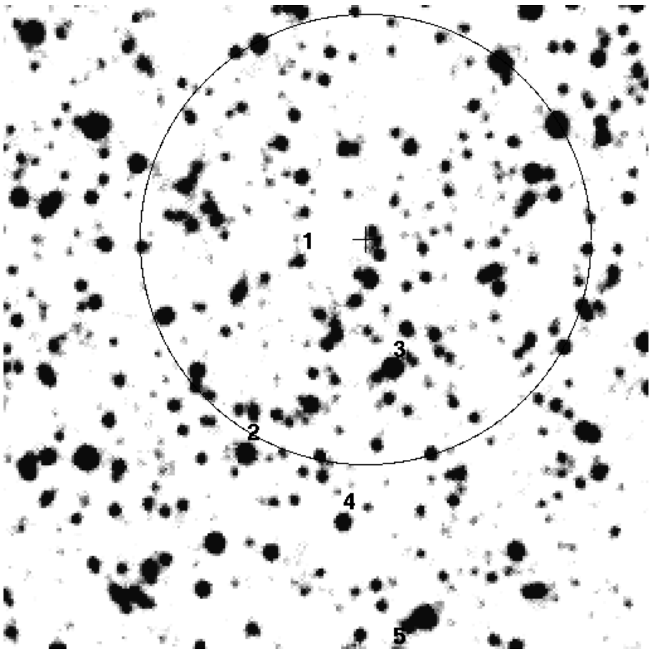

Fig. 1. The field of RX J0537.7-7034 as it appeared on November 8 1993 with the Thompson CCD at the 1.5 m Danish ESO telescope with the B filter. The size of the chart is about 1.4 arc min. The best X-ray position with the position error circle is shown. Identification numbers are above the stars. The star no. 1 is at 2000 coordinates α = 05 h 37 m 44.61 s and δ = -70^o 33' 46.7".

off-axis exposure in January 1992. The X–ray flux must have peaked between January and May 1992 and decreased from May 1992 to 1993. In the three detections since May 1992 *all counts above the background* were below 0.5 KeV. Reasonably good fits to the spectra observed in May and December 1992 are obtained only with a blackbody model. The source was not detected in June 1993, and the 1 σ upper limit 0.0023 cts/s is lower than the count rate observed half a year later. RX J0537.7-7034 was then observed by the ROSAT HRI in March 1994. The HRI 1 σ upper limit to the count rate, only 7.5 10^{-4} cts/s, can be roughly translated into a PSPC upper limit 0.002 cts/s. It seems therefore that the source has been most of the time in an "off" state in which either the bolometric luminosity, or the effective temperature, or both, decreased significantly.

The X–ray flux and the column density of neutral hydrogen N(H) are unfortunately not well constrained with the poor statistics of the PSPC observations. It is more appropriate therefore to talk about confidence contours in the F_{bol} – T_{BB} plane with fixed neutral hydrogen column density N(H). Orio & Ögelman (1993) reported that the observed X–ray spectrum in May 1992 could be fitted at the 2 σ confidence level with a blackbody temperature in the range 18–30 eV assuming N(H)=8–9 $\times 10^{20}$ cm^{-2}. The results in this paper differ somewhat, mainly because of the choice of the background. The 2 σ confidence level of the minimum X-ray luminosity is lower. In Table 1 we give indications of the applicable parameter space for the spectral fits. The contours of acceptable values in the bolometric flux versus blackbody temperature plane form a banana shape starting with higher temperatures at the minimum fluxes and ending with lower temperatures and super–Eddington luminosities (e.g. Ögelman et al. 1993). In column 4 we report the *lowest* blackbody temperature obtained at the 2 σ confidence level for the luminosity L_{bol} = 10^{38} (Eddington luminosity for a $M_\odot$ star, assuming the distance 55 Kpc to the LMC) with a fixed N(H)= 0.8–0.9 $\times 10^{21}$ cm^{-2} (see discussion by Greiner et al. 1991). Assuming the same N(H) and distance, in column 4 and 5 we report respectively the *highest possible* blackbody temperature and corresponding *lowest possible* bolometric luminosity at the 2 σ confidence level. For the three detections, the results are compatible with a supersoft X–ray source in the LMC. However, we caution that due to the poor statistics we cannot rule out that the bolometric luminosity might have been even by two order of magnitudes lower than in other supersoft X-ray sources studied and classified.

3. The proposed optical counterpart

Considering that the effective temperature of the source even in a "off" state should remain quite high, we searched a blue, possibly variable object with emission lines. We propose the identification with an optical counterpart that is only 9 arcsec distant from the PSPC position determined in December 1993. Fig. 1 shows the finding chart of the object, star no. 1.

3.1. Photometry

We observed the star from ESO–La Silla on November 8 and 10 1993 with the 1.5m Danish telescope and the imager–spectrograph DEFOSC and on January 5 1995 with the 2.2m ESO/Max-Planck telescope and EFOSC2. On January 4 1995 the star was observed to be at V=19.66 at UT 3^h, 36^m, 20^s. Two subsequent observations in U and V, performed respectively 6 and 16 minutes later, allowed us to measure the colour indexes B–V = -0.03 and U–B = -0.69 (the measurement in B was done for the second observation in Figure 2a). In Table 2 we report the values obtained also for four comparison stars, indicated in Fig. 1. For comparison CAL 83 was observed at variable visual magnitude V=17.1–14.8 and with B–V = -0.025$\pm$0.034 (Crampton et al. 1987, Smale et al. 1988), and CAL 87 at V$\simeq$18.3 and with colour indexes B–V = 0.140$\pm$0.056 and U–V = -0.742$\pm$0.075 (Cowley et al. 1990). The star was observed six times with the R filter on November 8 and November 10 1993 but no absolute magnitude calibration was made with standard stars. The data reduction for the relative magnitudes was done with the photometric software package DAOPHOT (Stetson 1987). The few R data points seem to indicate some variability. The B light curve observed in November 1993 and January 1995, shown in Fig. 2, indicates clear variability that could be interpreted as the occurence of an eclipse (see Fig. 2a and 2c). As an exercise we tried to fit to the observations a sinusoidal curve of the type $m = a - b \times sin(c\times t)$ where m is the magnitude and t the time. For the observations of November 8 the light curve can be fitted at a 68.3% confidence level by the curve plotted in Fig. 2a with the following parameters:

Table 1. The ROSAT PSPC count rate. The distance from the center of the detector, the lowest blackbody temperature with L_{bol} = 10^{38} ergs/s and the highest blackbody temperature and lowest bolometric luminosity in ergs/s admitted at the 2 σ confidence level. We assume a distance to the LMC 55 Kpc and N(H)=0.8–0.9 $\times 10^{21}$ cm^{-2}.

Observation date	Count rate	Off-axis angle (arcmin)	T_{BB} (eV) (at $L_{Edd.}$)	L_{bol} ergs/s (lowest)	T_{BB} (eV) (highest)
1990 June 16	$\leq$0.0104	52			
1990 June 18	$\leq$0.0068	40			
1990 June 18	$\leq$0.0070	37			
1990 June 19-23	$\leq$0.0063	38	<20	$\leq 10^{36}$	<100
1990 July 10	$\leq$0.0090	51			
1991 Nov 29	$\leq$0.0097	52			
1992 Jan 17-24	0.0149$\pm$0.0061	52	18	6×10^{35}	64
1992 May 9–16	0.0213$\pm$0.0010	29	20	1.7×10^{36}	56
1992 Dec 18–26	0.0163$\pm$0.0042	29	20	6.5×10^{35}	75
1993 June 15–27	$\leq$ 0.0023	29	< 20	$\leq 3.5 \times 10^{35}$	< 95
1993 Dec 15–16	0.0035$\pm$0.0008	13	18	7×10^{35}	64

a=19.709$\pm$0.048, *b*=0.174$\pm$0.060, *c*=0.0272$\pm$0.0045 (this latter value corresponds to a period 140$\pm$31 min). The light curve of Fig. 2c, of January 1995, can be fitted at the same confidence level with the following parameters: *a*=19.729$\pm$0.014, *b*=0.066$\pm$0.021, *c*=0.0296$\pm$0.0022 (corresponding to a photometric period 153$\pm$12 min). The evidence is not conclusive in any way because there are other possible parameters. Also short time scale flickering might make very good statistics necessary for believable results. However, we notice the possibility to fit the data with a period of a little less than 3 hours, shorter than all the orbital periods of supersoft X–ray sources. New photometric observations are necessary.

3.2. The optical Spectrum

The spectrum of star no. 1 was observed first in January 1995 with the 2.2m ESO/Max Planck telescope at La Silla and the spectrograph–imager EFOSC2 and in March 1995 with NTT. In the 2.2m telescope spectrum the emission line HeII 4686 can be detected above the noise. The NTT spectrum is shown in Fig. 3 and it is dominated by the steep blue continuum. The resolution is about 9 Å. The measurements of the possible spectral features together with the observed flux and full width at half maximum are given in Fig. 3. We clearly recognize again only the He II line at 4686 Å, red–shifted by almost 5 Å as expected for a LMC membership. This feature is very rare in normal stars, yet it is common to all the identified binary supersoft sources, to some CV's and polar systems, and it is usually indicative of accretion at high rates. The full width at half maximum for this line is 28 Å, well above the 9 Å value of the spectral resolution of the instrument. This implies a velocity of about 900 Km s^{-1} and it could indicate rotation, possibly of an accretion disk. Table 3 shows also the measurements of the Hγ and Hδ lines, that appear in absorption, and confirm the redshift of 4–5 Å. These are the only Balmer lines that can be measured with acceptable S/N. .

Table 2. The absolute V magnitude and the B–V and U–B colour indexes measured for star no. 1 (proposed optical counterpart) and for the four reference stars marked in Fig. 1.

Reference Star	V	B–V	U–B
1	19.66	-0.03	-0.69
2	16.99	+0.92	+0.86
3	17.67	+0.10	+0.07
4	18.42	-0.02	-0.22
5	16.00	-0.07	-0.51

We speculate that the hydrogen lines in absorption are produced in the atmosphere of the donor star while the HeII feature in emission should be due to accretion onto the white dwarf. We cannot detect the Hα line, but the S/N ratio is poor.

4. Discussion

Of all the orbital periods measured up to now for supersoft X-ray sources, only the ones of 1E0035.4-7230 and RX J0439.8-6809 are as short as for CV's, about 4 hours (Kahabka & Ergma, 1997, and references therein). These systems and RX J0537.7-7034 might be with a long post–outburst hydrogen burning phase. However, the Magellanic Clouds have been monitored quite well for nova detection since about 1955, and *very efficiently* in the last 10 years. These sources do not overlap with the position of any known nova. The counterpart should even be a *recent* nova, since ROSAT observations of post-outburst novae rule out that the constant bolometric luminosity, hydrogen burning phase lasts for longer than 10 years (Orio & Ögelman, 1997). 1E0035.4-7230 and RX J0439.8-6809 might however be CV's undergoing hydrogen flashes (Kahabka & Ergma 1997).

Finally, the X-ray variability of RX J0537.7-7034 is very interesting and poses a question concerning the true statistics of such transient sources. We remind that also RX J0527-6954 was not observed with *Einstein* and later showed a declining X-ray

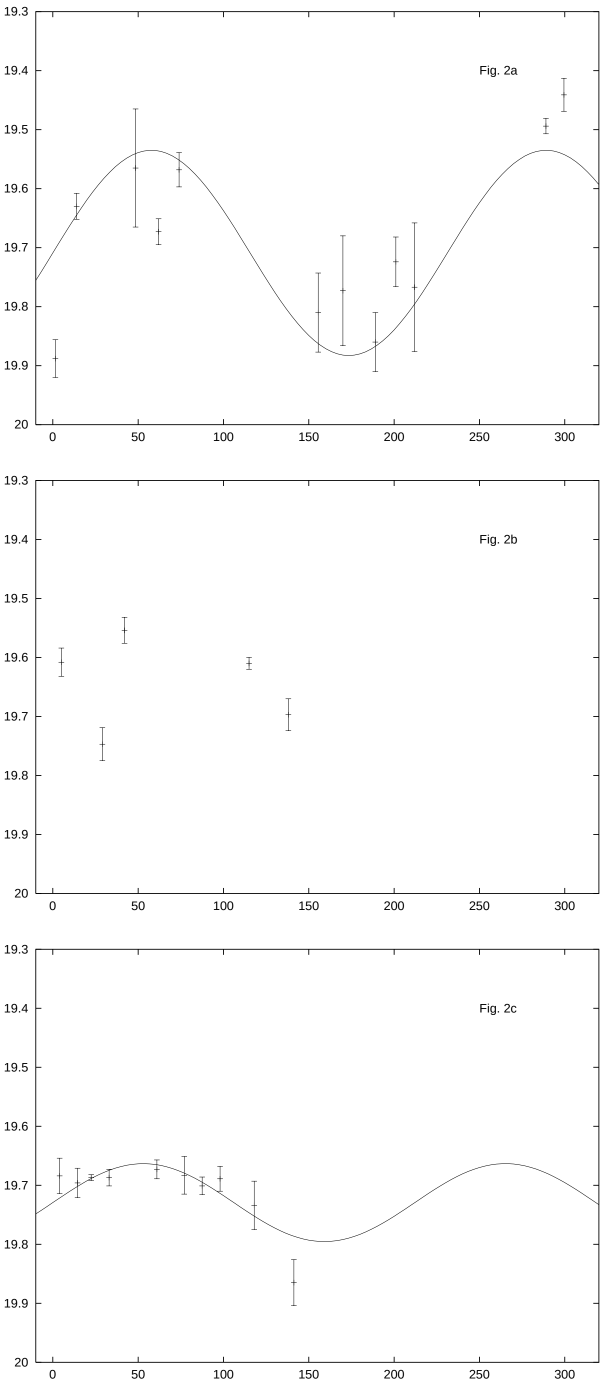

Fig. 2. The light curve of star no. 1 on November 8 1994 (2a), on November 10 1994 (2b) and on January 5 1995(2c). Each point represents the middle of an exposure of length variable from 3 to 10 min. The 1σ error bars and the possible fits with a sinusoidal light curve are shown.

flux (Greiner et al., 1996). Whether the variability mechanism and the nature of the two sources are really similar should be determined with future observations.

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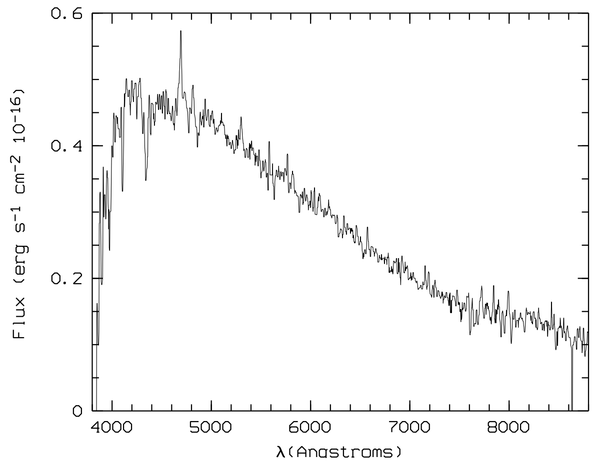

Fig. 3. Mean flux calibrated spectrum of the proposed optical counterpart of RX J0537.6-7033, obtained on March 3 1995.

Table 3. The proposed identification, the observed flux and the full width at half maximum, for the emission lines appearing in the spectrum in Fig.3.

Observed λ (Å)	Proposed Identification	Observed flux (10^{-16} ergs/cm^2/s)	FWHM (Å)
4106.8	Hδ(4101.7)	2.02	
4344.6	Hγ(4340.5)	6.63	
4690.6	HeII(4685.7)	3.30	28.2

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