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Kahabka, P.

**Publication date**  
1995

**Published in**  
Advances in Space Research

[Link to publication](#)

**Citation for published version (APA):**

Kahabka, P. (1995). Supersoft X-ray sources in the Magellanic Clouds. *Advances in Space Research*, 16(3), 149-153.

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## SUPERSOFT X-RAY SOURCES IN THE MAGELLANIC CLOUDS

P. Kahabka\*,\*\*

\* *Astronomical Institute, University of Amsterdam, Kruislaan 403,  
NL-1098 SJ Amsterdam, The Netherlands*

\*\* *Max-Planck-Institut für extraterrestrische Physik, D-85740 Garching,  
Germany*

### ABSTRACT

The Magellanic Clouds (MCs) have been mapped at soft X-rays (0.1–2.4 keV) with *ROSAT* during an all-sky survey and numerous pointed observations. A distinct class of *supersoft* X-ray sources (SSS) was discovered radiating with blackbody temperatures of a few times  $10^5$  K and with bolometric luminosities  $\sim 10^4$  times solar. A detailed study of these sources in X-rays, UV and the optical spectral regime has just started. The nature of these sources was in debate with a black hole (Cowley et al. 1990), neutron star (Kylafis & Xilouris 1993) and white dwarf (Van den Heuvel et al. 1992) origin. The identification of SSS in the Small Magellanic Cloud with the hot central star of a planetary nebula (Wang 1991) and the hot component of a symbiotic nova (Kahabka et al. 1994) are in favor for a white dwarf (WD) origin. Van den Heuvel et al. 1992 have shown, that Cal 83 and Cal 87 in the Large Magellanic Cloud are close binaries with a WD accreting at high rates and stable burning hydrogen. Systems of a similar nature may be RXJ0513.9–6951 and 1E0035.4–7230. SSS are observed to be stable burning already for a period of  $\sim 10$  years or are of transient nature or even recurrent. Such a behaviour is predicted for accreting and nuclear burning WDs if the accretion rate is within or below a critical range (Fujimoto 1982).

### INTRODUCTION

From stellar evolution calculations WDs in close and wide binary systems experiencing high mass overflow rates and stable burning hydrogen have been predicted to show up as bright EUV sources (Iben 1982, Fujimoto 1982). They have been looked for in the regime of ultraviolet radiation and found in the *hot component* of symbiotic systems. It was natural to look for them in the close binary systems as well. But it was much more difficult to detect them there due to the faintness of the optical counterpart which is supposed to be an evolved main sequence star (Van den Heuvel et al. 1992). In these systems the accretion disk will be predominant in the optical. One had to wait for the soft X-ray surveys of *Einstein* and *ROSAT* to discover the hot component in these systems, the nuclear burning WD. *Einstein* found the first 4 candidates in the Clouds (Long et al. 1981, Wang et al. 1991, Wang & Wu 1992) and *ROSAT* added in the meantime 6 further discoveries (c.f. Fig.1, Tab.1 and references given there).

### THE SAMPLE

Which systems do we observe in the MCs and what are their characteristics? They are obviously close and wide binaries and central stars of planetary nebulae. But they are also recurrent EUV (or soft X-ray) sources and transients which could be recurrent sources in case the recurrence period is quite long compared to the time these systems are observed (years). In Tab.1 we give a summary of the MC *supersoft* sample as it is presently known and published in the literature. All

the systems listed in the table can be reconciled with nuclear burning WDs. Not all necessarily need hydrogen-rich matter (or helium-rich matter) being supplied by accretion (e.g. the planetary nebula nuclei) but obviously the big majority. This rises the question whether the PNe objects are close binaries as well (c.f. Iben & Tutukov 1993, Heise et al. 1994). The optical spectra of these systems contain valuable information about the chemical composition and the state of ionisation of the accreted matter (exposed by the bright accretion disk, the optical companion or a nebula if present). A clue in understanding these systems may come from the determination of the mass of the WD, the mass of its envelope, the accretion rate onto the WD, the chemical composition of the accreted matter and the characteristics of mass-loss due to a wind ejected from the WD and/or the inner accretion disk in form of a jet. All these physical parameters have yet to be determined or are in the course of being determined. We refer as one example to the work of Heise et al. 1994 and Van Teeseling et al. 1994 where LTE model atmosphere spectral fits have been applied to the X-ray data and WD masses have been determined. Surely information from X-ray, UV and optical data has to be combined in order to come to a consistent description of these laboratories. *Supersoft* systems have also been found in the Galaxy. Two are close binary systems, RXJ 0925.7-4758 (Motch et al. 1994) and RX J0019+21 (Reinsch et al. 1993). A review of the observations is given in Hasinger 1994, Kahabka & Trümper 1995, Cowley et al. 1995.

## DISCUSSION

As the phenomena involved with SSS are very manifold, we will restrict on a few aspects which in the present understanding appear to be of peculiar interest. There may be other features like possible jets present in these binary systems (c.f. Cowley et al. 1995) or the nature of the donor star which in the future turn out to be of high interest, but the present knowledge forwards the attention towards the hot nuclear burning WD. This has been outlined in the work of Fujimoto 1982, who set up a theory of hydrogen shell flashes on accreting WDs. One needs to supply a minimum envelope mass (e.g. by accretion) to ignite the burning and then burn this envelope with a constant burning rate of  $\sim 1 - 4 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$  for a period dependent on the mass of the WD. Such systems can be either short ( $\sim 1$  yr) or quite long ( $\sim 10^3$  yr) lived for high mass ( $> 1 M_{\odot}$ ) or

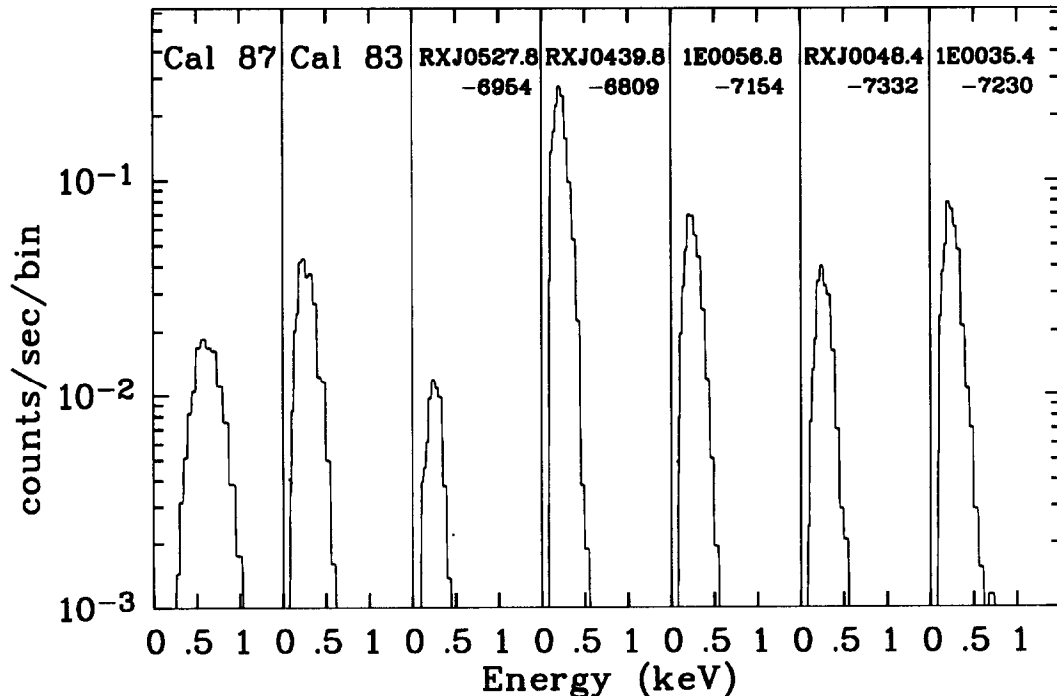


Figure 1: ROSAT PSPC spectra of the LMC and SMC supersoft sources.

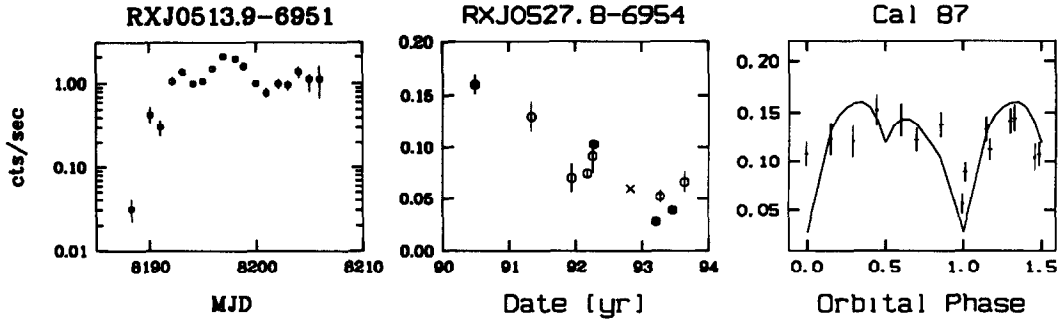


Figure 2: ROSAT PSPC X-ray lightcurves of RXJ0513.9-6951 (from Schaeidt et al. 1993), RXJ0527.8-6954 (Hasinger 1994) and Cal 87 (Kahabka et al. 1994).

low mass ( $\sim 0.5M_{\odot}$ ) WDs. The long lived systems obviously are observed in the symbiotic (slow) novae and it has been claimed, that symbiotic systems contain low-mass WDs. The short-lived systems obviously just got discovered by *ROSAT* in the supersoft transient and recurrent sources (c.f. Fig.2) and favor high mass WDs involved. It strongly depends on the mass accretion rate what these systems look like. Van den Heuvel et al. 1992 have shown, that systems like Cal 83 and Cal 87 may experience accretion at a rate within the critical accretion rate for steady-state nuclear burning. He claims, that such accretion rates are supplied by donor stars (evolved main sequence stars) that are more massive than the WD accretors. That's the case for the close binary systems. In the wide systems (the symbiotics) a giant is involved with high mass loss (c.f. de Kool et al. 1986, Sion and Starrfield 1994) providing such high accretion rates.

## CONCLUSIONS

From evolutionary calculations (Rappaport et al. 1994)  $\sim 120$  steady-state nuclear burning SSS are expected in the LMC and  $\sim 15$  in the SMC. This does not yet consider the recurrent SSS which add another significant number. The fact, that only about 10 systems are observed may be related to SSS being hidden from our view due to substantial absorption in the Clouds.

Table 1: Supersoft X-ray sources - the Magellanic Clouds Sample

Name	PSPC [c/s]	kT [eV]	opt. ID	opt. mag	Orb. Period [d]	Remarks	Ref. <sup>a</sup>
<b>LMC</b>							
RXJ0439.8-6809	1.38	18	-	B>19			1,15
RXJ0513.9-6951	<0.06-2	40	HV 5682	V~17	0.43?	recurrent	2-4,15
RXJ0527.8-6954	0.03-3	30	-			transient	4-8,15
Cal 83	0.98	40	+	V>17	1.04	persistent	6,9,10
Cal 87	0.12	31	+	V~19	0.44	eclipsing	9-13
RXJ0550.0-7151	0.9	32	-				4,15
<b>SMC</b>							
1E0035.4-7230	0.38	41	+	V~20		eclipping?	14,16
RXJ0048.4-7332	0.19	20	SMC3	V~15.5		slow nova	13
RXJ0058.6-7146	0.025	42	-			outburst	13
1E0056.8-7154	0.33	28	N67	V~16.6		PN	14,17

<sup>a)</sup> Ref.:

- (1) Greiner, Hasinger & Thomas, 1994; (2) Schaeidt, Hasinger & Trümper, 1993; (3) Pakull et al. 1993;
- (4) Cowley et al. 1993; (5) Trümper et al. 1991; (6) Greiner, Hasinger & Kahabka 1991;
- (7) Orio & Ögelman 1993; (8) Hasinger 1994; (9) Long, Helfand & Grabelski 1981; (10) Smale et al. 1988;
- (11) Pakull et al. 1988; (12) Schmidtke et al. 1993; (13) Kahabka, Pietsch & Hasinger 1994;
- (14) Wang & Wu 1992; (15) Cowley et al. 1995; (16) Orio et al. 1994; (17) Heise et al. 1994.

*Supersoft* sources have been discussed as progenitors of supernovae type Ia and as systems that eventually may undergo accretion induced collapse (AIC). This topic has extensively been discussed in Livio 1994 and references therein. It is concluded, that *supersoft* systems having CO degenerates of mass  $0.7-1.2M_{\odot}$  will, if they grow due to accretion beyond the Chandrasekhar limit, experience carbon deflagration and henceforth a type Ia supernova event but are not a case for the AIC (initial WD masses in excess of  $1.2M_{\odot}$  are required). As type Ia supernovae comprise a rather inhomogenous class (c.f. Della Valle & Livio 1994), the progenitors may be found among the *supersofts*, recurrent novae but also among WD mergers. In late type galaxies CV like systems like the *supersofts* and recurrent novae are favored and in early type galaxies double degenerates (Della Valle & Livio 1994). It is interesting to note, that *supersofts* in which the WD does not grow beyond the Chandrasekhar limit, will become double degenerates (c.f. Iben & Tutukov 1984).

#### ACKNOWLEDGEMENT

P. Kahabka is a Human Capital and Mobility fellow.

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