SUPERSOFT ROSAT SOURCES IN THE GALAXIES

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1. Introduction

Before the X-ray surveys performed with EINSTEIN and ROSAT soft X-ray (or EUV) sources were claimed to exist (Iben 1982; Fujimoto 1982); they were looked for in the ultraviolet and indeed such sources were found in the symbiotic systems (which count as CV-like systems) and termed the *hot component* of symbiotics. Although the nature of these hot components has been subject to debate (in terms of either nuclear burning white dwarfs or accretion phenomena) observational facts were in many systems favouring the first scenario (Mikolajewska & Kenyon 1992). Symbiotic binaries require wide orbits in order to keep the big giant star within its Roche lobe. It is natural to look for the short-period counterpart, but it was much more difficult to detect them in the optical due to the faintness of the secondary, which is supposed to be an evolved main-sequence star or even smaller. What turns out in these systems to be predominant is the much brighter accretion disk. It was the unique chance of the satellite borne X-ray imaging instruments to discover these EUV and soft X-ray sources and with the EINSTEIN observatory the first firm candidates were found. However, complete coverage of the soft X-ray sky was needed in order to get them all and ROSAT was the instrument which mapped the whole sky.

Before describing the definition of *supersoft* sources applied to select the sample, we will outline the currently most successful model to explain the phenomenon of supersoft sources, i.e., steady nuclear burning on white

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dwarfs (Van den Heuvel *et al.* 1992). The question, whether supersoft systems comprise a homogenous class or not has not been finally answered: they include close and wide binaries and single stars as well. But two features may be common, a white dwarf (WD) as the hot and compact object, and steady nuclear burning occurring in the envelope of the WD. Stable burning of hydrogen occurs within a narrow range of accretion rates $3.4\ 10^{-7} f \leq \dot{M}\ (\mathrm{M}_\odot\,\mathrm{yr}^{-1}) \leq 8.5\ 10^{-7} f$, dependent on the mass of the WD by $f = M_{WD}[\mathrm{M}_\odot] - 0.52$. The required accretion rates are supplied in short-period ($P \sim 70^m$–2^d) binaries by Roche lobe overflow from a donor star (1.4–2.2 $\mathrm{M}_\odot$) more massive than the WD (0.7–1.2 $\mathrm{M}_\odot$) (Van den Heuvel *et al.* 1992) and in long-period ($P \sim$ 100 days–few years) binaries from a low-mass giant (1–3 $\mathrm{M}_\odot$) to a WD ($\sim$0.5–0.7 $\mathrm{M}_\odot$) (De Kool *et al.* 1986; Sion & Starrfield 1994). From Fujimoto's (1982) theory of hydrogen shell flashes on accreting WDs the main observational features of such supersoft sources become obvious: there is a lower limit to the mass of the envelope of a WD for which the stability criterium is fulfilled, ranging from $\sim 10^{-4}$ to $\sim 10^{-7}\,\mathrm{M}_\odot$ for M_{WD} between $\sim$0.4 $\mathrm{M}_\odot$ and 1.4 $\mathrm{M}_\odot$; the corresponding upper limits are $\sim 3\ 10^{-4}$ to $\sim 10^{-6}\,\mathrm{M}_\odot$. As hydrogen is burnt at a rate $(1\text{–}4)\,10^{-7}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, this envelope will be burnt within $\sim$0.25–1 years for a 1.4 $\mathrm{M}_\odot$ WD, and within $\sim$100–2000 years for a 0.5 $\mathrm{M}_\odot$ WD. Such time scales define systems, in which the envelope is refreshed at an accretion rate below the stable accretion rate of hydrogen burning of $\sim 1\text{–}4\ 10^{-7}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$. If the accretion rate is within the critical range then the lifetime of the system will depend on the thermal time scale of the donor star (cf., Paczynski 1971; Van den Heuvel *et al.* 1992). At very low rates ($\lesssim 10^{-9}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$) nova (like) systems form with ejection of part of the envelope during the nova explosion, drastically reducing the above estimated time scales. Systems accreting at rates in excess of the stability rate may undergo a limit cycle as described in Van den Heuvel *et al.* (1992) of duration $\sim$100 years with visibility in X-rays for $\sim$10 years.

2. Definition

When the EINSTEIN X-ray observatory performed a survey of the LMC in soft X-rays (Long *et al.* 1981) it became obvious that two sources had extremely soft spectra. These sources are numbers 83 and 87 in the Columbia Astrophysics Laboratory catalog, i.e., CAL 83 and CAL 87. A similar soft X-ray survey has been performed of the SMC by Seward & Mitchell (1981). They discovered two sources which were later on found to be supersoft, but at the time the nature of these objects was not yet recognized. In a later comprehensive analysis of the SMC observations by Wang & Wu (1992) these sources were found to be the softest in the sample. The softness was defined in terms of a hardness ratio which in the work of Wang & Wu is defined as $Q = (H - S)/(H + S)$ with S and H the countrates in the soft (0.16–0.8 keV) and hard (0.8–3.5 keV) energy band, respectively. Long *et al.* (1981) used somewhat different energy bands (S = 0.15–1.5 keV, H = 1.5–4.5 keV) but this does not affect the general trends. From the analysis of Long *et al.* (1981) it became clear, that different source types occupy different ranges in hardness ratios Q, −1.0 to 0.0 for supernova remnants, 0.0 to 1.0 for binaries, −0.3 to 0.3 for AGNs. As the LMC supersoft sources had $Q = -0.9$ and -0.7, respectively, it becomes obvious that they form a separate class of objects.

About 10 years after the EINSTEIN observations a complete all-sky-survey in soft (0.1–2.4 keV) X-rays was made with ROSAT; it included the fields of the LMC and SMC with a high sensitivity (Trümper *et al.* 1991; Pietsch & Kahabka 1993; Kahabka & Pietsch 1993). More than 500 X-ray sources were found in a $12^\circ \times 12^\circ$ field centered on the LMC and 72 sources in an $8^\circ \times 8^\circ$ field covering the SMC. Several additional pointed observations towards the Magellanic Clouds (MCs) with considerably deeper exposures complement the survey observations. A hardness ratio criterium has been applied to select candidates for supersoft sources: $HR1 \pm \sigma(HR1) \leq -0.8$, with $HR1 = (H - S)/(H + S)$ and S = 0.1–0.4 keV, H = 0.5–2.1 keV. Six sources have since been found in the LMC and four in the SMC including the 4 sources known from the EINSTEIN observations (cf., Fig. 1 and Table 1). It was recognized, that the extremely soft spectral appearance alone did not yet make a new class of objects as galactic WDs have similar soft X-ray spectra (Fleming *et al.* 1991), and a few AGNs look very soft as well. A second criterium was introduced to better constrain the characteristics of this class, the luminosity criterium. It was claimed, that supersoft sources radiate at or close to the Eddington limit of a 1 $M_\odot$ compact object ($\sim 1.3\ 10^{38}$ erg s^{-1}). This excluded any weak galactic foreground object and luminous background sources. Initially, blackbody spectra were applied to the X-ray data; the inferred (bolometric) luminosities were very uncertain, because of the large bolometric corrections, and the substantial galactic absorption along the line of sight. Also, in most cases the distance to the source was unknown. In case of the MCs the distance is well known and the extent of the Clouds was assumed to be small compared to the distance. However, due to the considerable angle of the sky covered by the Clouds a few galactic WDs or CVs could have a chance superposition. A third criterium necessarily had to be fulfilled to uniquely classify a source as supersoft: an optical counterpart had to be identified which showed the signatures of high excitation (He II λ4686, Hα, Hβ) lines, known from the optical spectra of LMXBs (Van Paradijs 1983) and understood to originate in an irradiated accretion disk.

3. The Magellanic Clouds

The *first light* observation of ROSAT was dedicated to discover X-ray emission from supernova 1987A. While the supernova was not seen, two supersoft sources CAL 83 and RX J0527.8–6954 were detected, the latter for the first time (Trümper *et al.* 1991). CAL 83 is the prototype of supersoft sources. It shows three periodicities, a 1.04 day orbital period, occasional flux variability at ~2 h (Smale *et al.* 1988) and a moving feature in the broad wings of the He II 4686 line with a recurrence time of ~69 d possibly associated with a precessing disk or a jet (Crampton *et al.* 1987). The optical spectrum shows a strong He II 4686 line with a flux of ~4 $10^{33}\,\mathrm{erg\,s^{-1}}$ (Smale *et al.* 1988), two orders of magnitude more luminous than in galactic LMXBs. An intrinsic X-ray luminosity of 5 $10^{39}\,\mathrm{erg\,s^{-1}}$ was estimated, significantly larger than the Eddington limit for accretion onto a $1.4\,\mathrm{M}_\odot$ compact object (Smale *et al.* 1988). Extended emission in O III is seen surrounding the source. This nebula has a shell-like structure and is most likely ionized by X-rays (Pakull & Angebaut 1986). Crampton *et al.* discuss the scenario of a massive post-AGB star collapsing into a WD which has lost the H-rich envelope in a close binary system. However, they argue that the observed fast variability indicates that the system is an interacting binary with mass transfer going on via an accretion disk, and they favour the idea that it is an unusual LMXB system in the LMC. The low X-ray luminosity observed in the EINSTEIN band (0.15–4.5 keV) of ~3.2 $10^{36}\,\mathrm{erg\,s^{-1}}$ and the low ratio of X-ray to optical luminosity $L_\mathrm{X}/L_\mathrm{opt} \sim 0.7$ (compared to values of $\sim 10^2$–10^3 for LMXBs) led Cowley *et al.* to classify CAL 83 as an ADC system similar to X 1822–371 and X 0921–630 (White & Holt 1982; Mason *et al.* 1987). The observed flux would then be due to X rays scattered by an extended disk corona. But it remained unclear how such a corona can generate the observed soft spectrum. The X-ray spectra of CAL 83 measured with ROSAT revealed the very soft ($kT_\mathrm{bb} \sim$ 20–40 eV) and luminous ($L_\mathrm{bol} \sim L_\mathrm{Edd}$ for a $1\,\mathrm{M}_\odot$ compact object) nature of the emission (Greiner *et al.* 1991). Such a soft spectral distribution was hard to be explained by an ADC, and other scenarios like an optically thick cocoon engulfing a NS or near-Eddington accretion onto a NS were invoked (Greiner *et al.* 1991; Kylafis & Xilouris 1993). However, Van den Heuvel *et al.* (1992) demonstrated in a self-consistent way how the manifold observational facts could be reconciled with a ~0.7–$1.2\,\mathrm{M}_\odot$ WD accreting from an evolved main-sequence star transferring mass unstably on a thermal time scale (cf., Pylyser & Savonije 1988) with steady nuclear burning occurring on the WD surface. Heise *et al.* (1994) and Van Teeseling *et al.* (1994) have shown that WD atmosphere spectral fits have to be applied to the X-ray data. Consistency could be obtained with a steady-state burning WD for

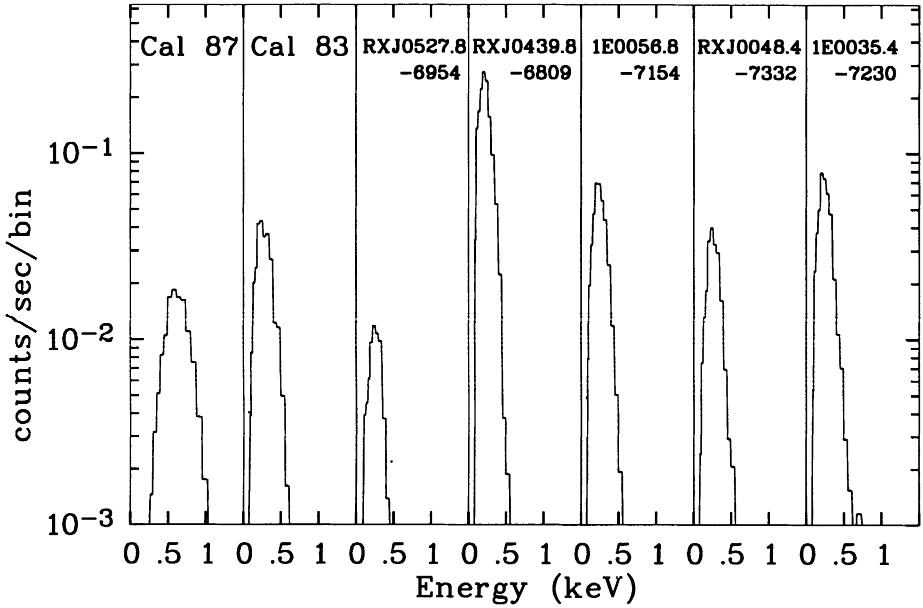

Figure 1. ROSAT PSPC spectra of the LMC & SMC supersoft sources.

CAL 83 (cf., Van Teeseling *et al.*, these proceedings) in full agreement with the model of Van den Heuvel *et al.* CAL 83 was stated to be a prototype of the supersoft sources and the other members may be of a similar nature (as long as the supersofts form a homogenous class). We will further discuss the other MC systems, and concentrate on the X-ray observations as the optical observations are covered by the contribution of A. Cowley to these proceedings.

CAL 87 is another outstanding supersoft source in the LMC. A binary orbital period of 10.6 hr could be established (Callanan *et al.* 1989; Cowley *et al.* 1990). The system shows optical (Pakull *et al.* 1988; Cowley *et al.* 1990) and X-ray eclipses (Schmidtke *et al.* 1993; Kahabka *et al.* 1994) indicative of a high inclination (70°–90°). The primary eclipse shows asymmetry in ingress with variability from cycle to cycle similar to pre-eclipse variations known from LMXBs. The observed (0.5–2.4 keV) X-ray luminosity is low ($\sim 10^{36}\,\mathrm{erg\,s^{-1}}$) but has to be high ($\sim 10^{38}\,\mathrm{erg\,s^{-1}}$) in order to explain the X-ray heating of the secondary seen in the optical light curve (Van den Heuvel *et al.* 1992). An optically thick disk has been invoked to shield the X-ray source. The X-ray spectrum was poorly constrained by EINSTEIN observations (cf., Brown *et al.* 1994). ROSAT observations showed that the X-ray source has a very soft spectrum ($kT_{\rm bb} \sim$ 30–55 eV), is luminous ($\geq 5\ 10^{38}\,\mathrm{erg\,s^{-1}}$) and suffers a large absorption ($N_{\rm H} \sim 10^{22}\,\mathrm{cm^{-2}}$

(Schmidtke *et al.* 1993; Kahabka *et al.* 1994) which probably cannot be accounted for by galactic foreground ($\sim 8\ 10^{20}\,\mathrm{cm}^{-2}$) and LMC intrinsic ($\sim 3\ 10^{21}\,\mathrm{cm}^{-2}$) absorption. However, WD atmosphere spectral fits are consistent with CAL 87 being located at the far side of the LMC. Then the absorption contribution by an accretion disk would be minor. This raises the question, whether the X-ray source is extended or not. The WD model atmosphere fits are consistent with the X-ray emission originating from a region of the size of the surface of a high-mass steady-state nuclear burning WD. On the basis of radial-velocity variations of the He II 4686 line it has been suggested that CAL 87 harbours a black hole (Cowley *et al.* 1990); however, the origin of the line more probably is connected with a strong wind from the optical star (cf., Van den Heuvel *et al.* 1992), arguing against the black-hole nature.

ROSAT observations added four further supersoft sources to the LMC sample. RX J0513.9–6951 was discovered during the ROSAT all-sky survey (Schaeidt *et al.* 1993) and was observed for 22 days. Within a few days the count rate increased by a factor of ~ 20 and oscillated on a time scale of several days (cf., Fig. 2). The source was not detected in calibration data taken 4 months before, confirming the transient nature of the source. Monitoring of the source every three months revealed a second outburst about 1 year and 9 month after the first outburst. This makes RX J0513.9–6951 the first recurrent supersoft X-ray transient (Hasinger 1994). The X-ray spectrum is very soft ($kT_{\mathrm{bb}} \sim 40\,\mathrm{eV}$) and the bolometric luminosity is high ($L_{\mathrm{bol}} \sim 2.3\ 10^{38}\,\mathrm{erg\,s^{-1}}$) (Schaeidt *et al.* 1993). WD atmosphere spectral fits are consistent with a steady-state nuclear burning WD (Van Teeseling *et al.* 1994). Optical and IUE observations of RX J0513.9–6951 (Pakull *et al.* 1993) imply the presence of a luminous ($\sim 3\ 10^{37}\,\mathrm{erg\,s^{-1}}$) accretion disk indicating a very high mass transfer rate ($\dot{M} \gg 10^{-8}\,\mathrm{M_{\odot}\,yr^{-1}}$). Such rates occur on a thermal time scale from a donor star that is more massive than the WD (Paczynski 1971; Van den Heuvel *et al.* 1992). The outburst was not accompanied by optical brightening of the companion star and therefore appears to be fundamentally different from that of X-ray novae. Pakull *et al.* proposed that the outburst corresponds to an episode of reduced mass transfer that lead to a considerable contraction of the WD envelope, decreasing the radius and increasing the temperature from $<20\,\mathrm{eV}$ (most radiation unobservable) to 40 eV. The binary nature of the source is indicated by radial-velocity variations of the optical emission lines.

RX J0527.8–6954 was discovered during the *first light* observation of ROSAT of the LMC (Trümper *et al.* 1991). The source is soft ($kT_{\mathrm{bb}} \sim 30\,\mathrm{eV}$), luminous ($L_{\mathrm{bol}} \sim L_{\mathrm{Edd}}$) (Greiner *et al.* 1991) and transient (Trümper *et al.* 1991), as it was not seen 10 years before with EINSTEIN. Orio & Ögelman (1993) found the source intensity to have decreased by a factor of

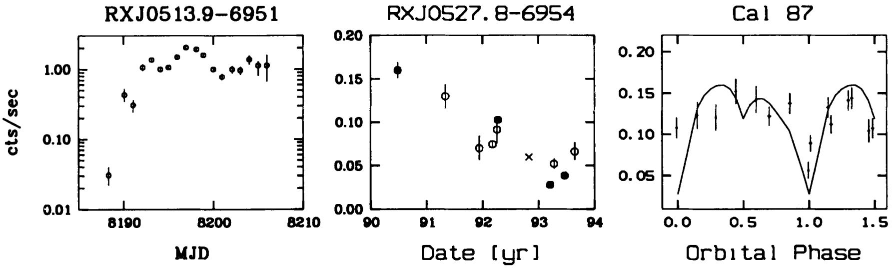

Figure 2. X-ray light curves of RX J0513.9–6951 (from Schaeidt *et al.* 1993), RXJ 0527.8–6954 (Hasinger 1994) and CAL 87 (Kahabka *et al.* 1994).

4 two years after the ROSAT observations. A complete record of the source intensity spanning a period of ~3.5 years covering the all-sky survey and numerous dedicated and serendipitous observations (cf., Fig.2) revealed an almost linear decrease of the count rate by a factor of ~4 (Hasinger 1994). This gives the source the appearance of a slow nova. Any optical counterpart has to be fainter than 17^m (Hasinger 1994).

In the SMC two supersoft sources were known from EINSTEIN observations. 1E 0056.8–7154 coincides within 4″ with the bright $V = 16.6$ nebula N67 in the SMC (Seward & Mitchell 1981; Wang 1991). The extremely soft spectrum and strong emission were explained by the radiation from the surface of the central star of N67 which is evolving into a WD. In a typical evolutionary model for a planetary nebula the duration is less than 10^3 years. The deduced temperature ($T_{\rm eff} \sim 3 \pm 1 \times 10^5$ K) and luminosity ($L_{bol} \sim 4\ 10^{38}\,{\rm erg\,s^{-1}}$), although quite uncertain, place the source at the location of a high-mass (~$0.9\,{\rm M_\odot}$) WD in the Hertzsprung-Russell diagram of planetary nebula nuclei (Wang 1991). IUE observations of the nebula show strong lines of NV and He II indicating high excitation by a hot nucleus (Aller *et al.* 1987). ROSAT observations of 1E 0056.8–7154 confirm the presence of a hot ($T_{\rm bb} = 1.6$–$4\ 10^5$ K) and luminous ($\sim 2\ 10^{38}\,{\rm erg\,s^{-1}}$) X-ray source (Kahabka *et al.* 1994). This shows that the source temperature and luminosity have remained constant for ~10 years, in agreement with the track of a planetary nebula nucleus. Heise *et al.* (1994) have shown, that the luminosity of 1E 0056.8–7154 is overestimated by a factor of ~10 if a blackbody description is used. They applied WD atmosphere model fits with $\log g{=}8$ to the data and deduce a temperature of $4.5\ 10^5$ K and a luminosity of $2\ 10^{37}\,{\rm erg\,s^{-1}}$. Although a single hot nucleus explains the observations in a consistent way, a possible close binary system nature of the central source of N67 has been considered (cf., Iben & Tutukov 1993) but no decision on this can be drawn from the X-ray data alone. A search for a weak optical counterpart and/or an accretion disk in the hypothetical binary system should be initiated.

1E 0035.4–7230 is the second source in the SMC known from EINSTEIN observations (Seward & Mitchell 1981). The source appeared point like in the HRI image, an extremely soft spectrum with $T_{\rm eff} \leq 4\ 10^5$ K and a luminosity in the EINSTEIN band of $\sim 10^{37}$ erg s^{-1} were deduced. ROSAT observations confirm the source to be soft ($T_{\rm bb} \sim 4\ 10^5$ K) and luminous ($\sim 2\ 10^{37}$ erg s^{-1}) (Kahabka *et al.* 1994). The source appears not to have varied drastically since the EINSTEIN observations. From WD atmosphere model fits it follows that 1E 0035.4–7230 is consistent with a steady-state nuclear burning WD (Van Teeseling *et al.* 1994). A possible optical counterpart at $V \sim 21$ was claimed by Jones *et al.* (1985). Orio *et al.* (1993) report about the identification of 1E 0035.4–7230 with a variable star of magnitude $B = 19.9$–20.2. The star shows strong UV excess, a blue continuum and weak lines of high excitation. A variation of ~0.2 mag within ~2 h of observations was detected and a possible eclipse event was considered. This would indicate that the source is a binary with an orbital period of order hours to tens of hours. The existence of two possible eclipse events in this source has been claimed from X-ray data (Kahabka *et al.* 1994) and an upper limit of 30 d was estimated for an orbital period. 1E 0035.4–7230 has a similar optical brightness as CAL 87, and if eclipsing may be seen under a similar inclination. The high absorption seen in the X-ray data of CAL 87 is absent in 1E 0035.4–7230.

Two additional SMC sources were found with ROSAT. RX J0048.4–7332 was discovered in the ROSAT all-sky-survey data (Kahabka & Pietsch 1993) and monitored with several pointed SMC observations (Kahabka *et al.* 1994). The count rate remained essentially constant for ~2 years. The source may have been missed in the EINSTEIN survey of the SMC as it lies in an unexposed small region between two fields (Wang & Wu 1992). Blackbody fits yield $kT_{\rm bb} \sim 10$–40 eV and $L_{\rm bol} \geq 0.2\,{\rm L_{Edd}}$ (for a $1\,{\rm M_\odot}$ compact object). The spectrum shows substantial absorption additional to the galactic foreground which may either be due to the SMC or related to the system itself (Kahabka *et al.* 1994). The X-ray source coincides with the symbiotic star SMC 3 which is located in, or in front of, the SMC cluster NGC 269. The optical star is of spectral type M0. The hot component had an outburst sometime between 1980 December and 1981 November, increasing by 3 mag in the U band. In the infrared band no outburst was detected. The intensity of the hot component has stayed nearly constant since this outburst (Morgan 1992). Recent IUE observations of SMC 3 (Vogel & Morgan 1994) show an enrichment of N similar to galactic novae, which was related to a (possible) recent thermonuclear event connected with the optical outburst. A pronounced Si overabundance deduced from the IUE spectrum was explained by collisional ionization due to a highdensity ($N_e \geq 10^9\,\mathrm{cm}^{-3}$) symbiotic nebula in the system (Vogel & Morgan 1994; Nussbaumer & Stencel 1987). Such a nebula of size ~1 AU would result in a line of sight absorbing column in agreement with the column of ~2–3 $10^{21}\,\mathrm{cm}^{-2}$ deduced from the X-ray observations. RX J0048.4–7332 is most likely a symbiotic (slow) nova. This would imply a low-mass (~0.5–0.7 $\mathrm{M}_\odot$) nuclear burning WD. RX J0048.4–7332 is the first and only symbiotic nova seen in X-rays and identified in the Magellanic Clouds. As the giant M star in such systems is easily detectable in the optical any similar system might already have been found.

RX J0058.6–7146 is another ROSAT discovery (Kahabka *et al.* 1994). The source was seen in outburst during one pointed observation. Several additional observations before and after the outburst (Kahabka *et al.* 1994; Hasinger 1994) did not reveal the source; it varies by at least a factor of 50. During the detection observation the source luminosity increased from below the detection limit to ~3 $10^{36}\,\mathrm{erg\,s}^{-1}$ within ~2 days (Kahabka *et al.* 1994). Unfortunately, a possible further increase of the source flux could not be followed as the observation ended. A very soft (~40 eV) and absorbed (~4 $10^{20}\,\mathrm{cm}^{-2}$) spectrum was deduced. As no optical identification has yet been made SMC membership of the transient remains open. The source resembles the low-luminosity globular-cluster X-ray source 1E 1339.8+2837 in M3 (Hertz, Grindlay & Bailyn 1993). A soft ($kT_{\mathrm{bb}} \sim 20\,\mathrm{eV}$) outburst with a luminosity $L_{\mathrm{bol}} \sim 1.2\ 10^{36}\,\mathrm{erg\,s}^{-1}$ has been detected with ROSAT in this source, which may be a CV with steady nuclear burning of accreted material on the WD surface. Both the SMC and M3 globular cluster source may be recurrent EUV sources (Fujimoto 1982).

4. The Galaxy

As the supersoft X-ray sources have been recognized as a new class of objects which have been found in the MCs, it was natural to look for them in other galaxies and the closest galaxy is our Galaxy itself. A clear definition of this source type has been set up (cf., Section 2), the whole sky has been mapped in soft X-rays with ROSAT and a first version of a point source catalog with ~50,000 entries has been worked out (Voges 1992). A selection according to the hardness ratio criterium and a count rate threshold has been applied to the catalog and this subset has been further considered as input for an optical identification program (Greiner *et al.* 1994; Motch *et al.* 1994). Motch *et al.* started a galactic-plane survey within $b^{\mathrm{II}} = \pm 20°$. As supersoft sources will be significantly absorbed due to the galactic column concentrated towards the galactic plane, Motch *et al.* found by simulations a somewhat different hardness ratio criterium to be appropriate, i.e., $HR1 \geq -0.4$ (for $N_{\mathrm{H}} \geq 5\ 10^{20}\,\mathrm{cm}^{-2}$) and $HR2 \leq -0.8$ (for $N_{\mathrm{H}} \leq 4\ 10^{22}\,\mathrm{cm}^{-2}$). An

TABLE 1. System parameters of supersoft sources

Name	log ($T_{\rm eff}$ [K])•	log ($L_{\rm bol}$ [$L_\odot$])•	log g•	binary/ single	$P_{\rm orb}$ [d]	variab. class
LMC						
RX J0439.8−6809	5.4–5.5	3.2–3.6	7.0–8.3	?		persistent?
RX J0513.9−6951	5.6–5.8	3.5–4.1	7.3–9.3	b?		recurrent
RX J0527.8−6954	5.5–5.9	2.0–3.9	7.0–9.9	b?		variable
CAL 83	5.6–5.8	3.0–4.1	7.3–9.9	b	1.04	persistent
CAL 87	5.9–6.0	3.5–4.4	8.3–9.9	b	0.44	eclipsing
RX J0550.0−7151				?		variable
SMC						
1E 0035.4−7230	5.6–5.8	3.0–3.5	7.5–9.8	b	0.1–2?	eclipsing
RX J0048.4−7332°	5.0–5.2	3.1–3.5		b	> 100?	slow nova
RX J0058.6−7146				b?		transient
1E 0056.8−7154	5.5–5.7	3.6–4.0	7.0–9.0	s?	–	persistent
Galaxy						
GQ Mus	~5.5	~4.4		b	0.059	post-nova
RX J0925.7−4758	5.7–5.8			b	3.5	
RX J0019+21	5.4–5.5	4.1–3.4		b	0.658	recurrent?
1E 1339.8+2837 (M3)	~5.4	~2.5		b?		recurrent?
RR Tel	5.2	3.5	≥6.5	b		slow nova
AG Dra				b	554	slow nova
RX J2117.1+3412	5.2	4.0	5.6–6.3	s	–	persistent

•)values for LMC & SMC sources from Van Teeseling *et al.* (1994), °) parameters determined from IUE observations (Vogel & Morgan 1994).

additional count rate criterium ($\geq$0.1 cts s^{-1}) was applied and 98 candidates were found, from which all but 6 were rejected due to an association with a late-type star.

The brightest remaining candidate source RX J0925.7−4758 was selected for follow-up X-ray and optical studies. A ROSAT pointed observation showed the source to be soft ($kT_{\rm bb}$ ~30–55 eV) and heavily absorbed ($N_{\rm H} \sim$ 1.3 10^{22} cm^{-2}). The large column indicates that RX J0925.7−4758 may be located behind the nearby Vela sheet molecular cloud. A maximum source distance of ~2 kpc is deduced for a source luminosity of 2×10^{38} erg s^{-1}. Optical photometric monitoring of the 17.1 mag counterpart suggest a possible (orbital) period of 3.5 days. This source appears to be quite similar to

CAL 87 in the LMC (Motch *et al.* 1994). From the absence of further bright ($>0.27\,\mathrm{cts\,s^{-1}}$) candidates in the galactic plane Motch *et al.* conclude, that sources may be more concentrated to the galactic plane than the LMXBs which may show a wider distribution due to a kick obtained during the NS formation.

RX J0019+21 is the second close binary ($P_{\rm orb} = 15.8\,\mathrm{h}$) supersoft X-ray source discovered in the Galaxy (Reinsch *et al.* 1993). The optical/UV continuum is reminiscent of a bright accretion disk with strong He II and Balmer emission lines.

RR Tel is a symbiotic nova (Jordan *et al.* 1994) that started an outburst in 1944. Symbiotic novae are wide binaries (orbital periods 10^{2-3} days) with an evolved late-type star and a very hot companion, a WD undergoing nuclear burning (of hydrogen-rich matter) during outburst. They may be embedded in a dense nebula due to the cool giant's wind. The outbursts last of the order of decades, i.e., much longer than classical novae. The giant in RR Tel is of spectral type M5 and a Mira variable with heavy mass loss ($\dot{M} \approx 5\ 10^{-6}\,\mathrm{M_\odot\,yr^{-1}}$). The UV spectrum indicates $T_{\rm eff} \geq 140,000\,\mathrm{K}$ and $\log g \geq 6.5$ for the WD; the X-ray data are consistent with $T_{\rm eff} = 142,000\,\mathrm{K}$ and $L = 1.3\ 10^{37}\,\mathrm{erg\,s^{-1}}$. An additional hard X-ray component of low luminosity ($\sim 10^{33}\,\mathrm{erg\,s^{-1}}$) may be due to hot plasma from a colliding wind in the interacting binary (Jordan *et al.* 1994).

GQ Muscae is the first classical nova detected in X-rays (with EXOSAT) during outburst (Ögelman *et al.* 1987). ROSAT observations 9 years after the outburst revealed a soft X-ray source (Ögelman *et al.* 1993). Assuming Eddington luminosity for a $1\,\mathrm{M_\odot}$ WD a temperature of $\sim 3.5\ 10^5\,\mathrm{K}$ was deduced. It was concluded, that GQ Mus is burning hydrogen-rich matter. As the other 25 recently detected novae were not detected in X rays GQ Mus either has not ejected its envelope during outburst or is burning recently accreted material (Ögelman *et al.* 1993).

The probably recurrent EUV source 1E 1339.8+2837 in M3 has been discussed together with RX J0058.6–7146 in the SMC which may be of a similar nature.

5. M31 and other galaxies

A soft X-ray (0.1–2.4 keV) survey of M31 has been performed with the ROSAT PSPC in July 1991 (Supper *et al.* 1994). A total of 396 X-ray sources have been detected with luminosities from 10^{35} to $3\ 10^{38}\,\mathrm{erg\,s^{-1}}$ (690 kpc). 15 sources were considered to belong to the class of supersoft sources. For the brightest source (# 309) a blackbody fit was applied, and a temperature $kT \sim 30\,\mathrm{eV}$ and a luminosity $L_{\rm bol} \sim 10^{38}\,\mathrm{erg\,s^{-1}}$ deduced. From evolutionary calculations (Rappaport *et al.* 1994; Rappaport, these proceedings) ~1000 supersoft sources are expected to exist in M31, but obviously most of them will be highly absorbed.

A systematic search for supersoft sources in other nearby galaxies has not yet been completed. There may be detectable candidates in M101, NGC 253 and probably M33.

6. Conclusions

Of the 17 supersoft systems observed in the MCs and in the Galaxy 4 have been identified as close binaries with orbital periods of 0.4–3.5 days (cf., Van den Heuvel *et al.* 1992), 2 further sources (RX J0513.9–6951 and 1E 0035.4–7230) may turn out to belong to the same class, 3 supersoft systems are symbiotic (wide) binaries, and 2 are hot central stars of PNe or PG1159 stars. Among the 6 remaining sources are post-novae (1) and recurrent EUV sources (3). The two LMC sources RX J0439.8–6809 and RX J0550.0–7151 can presently not yet be classified. This gives a ratio of close to wide binaries of 1–2 and shows the importance of the close binary systems contributing to the supersoft systems. The ratio of binary to single stars is 4–7 and may reflect the longer lifetime of binaries compared to planetaries.

The question arises whether there are (predominantly) helium accreting systems among the supersoft sources as discussed in Iben & Tutukov (1993, 1994). Such systems are expected to have orbital periods above 10 min (cf., Savonije *et al.* 1986) and may be characterized by strongly suppressed hydrogen Balmer lines (Hα and Hβ) in the optical spectra of the accretion disks in these systems. In a few systems (CAL 87 and RX J0925.7–4758) Hβ is missing (Pakull *et al.* 1988; Cowley *et al.* 1990; Motch *et al.* 1994).

Supersoft sources have been discussed as progenitors of type Ia supernovae and as systems that eventually may undergo accretion induced collapse (AIC). Livio (1994) concludes that supersoft systems with CO degenerates of mass 0.7–1.2 $M_\odot$ will, if they grow beyond the Chandrasekhar limit due to accretion, experience carbon deflagration and hence a type Ia supernova event, but they do not undergo AIC (initial white-dwarf masses in excess of 1.2 $M_\odot$ are required). As type Ia supernovae comprise a rather inhomogeneous class (cf., Della Valle & Livio 1994), their progenitors may be found among the supersofts, and recurrent novae but also among WD mergers. In late-type galaxies CV-type supersofts and recurrent novae are favoured, 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 (cf., Iben & Tutukov 1984).

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Discussion

V. M. Lipunov: Some supersoft superluminous sources (about several percent as determined from our calculations) must be related with super-accreting neutron stars. This is confirmed by the discovery of the supersoft source in the X-ray pulsar in the SMC by Hughes (1994, ApJ 427, L25).

R. Sunyaev: It is obvious that the spectrum of a WD with a steady burning hydrogen envelope must be very different from a black body. Therefore the luminosity might strongly differ from that estimated using the black body approximation. UV or even optical measurements might be useful for the comparison of the more realistic WD atmosphere radiation spectrum with the observed one.