# SUPERSOFT X-RAY SOURCES IN THE LMC

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## 1. Introduction

Data obtained with ROSAT have established the "supersoft" X-ray sources (SSS) as a separate class of objects. Their unique features include temperatures of ~30 eV and luminosities of $\sim 10^{38}\,\mathrm{erg\,s^{-1}}$. Hasinger (1994) has recently summarized the properties of the SSS presently known in the Galaxy and the Magellanic Clouds (cf., Kahabka & Trümper 1995). The six which are thought to be LMC members are listed in Table 1 and discussed individually, based primarily on optical data we have obtained at CTIO.

## 2. Individual Systems

### 2.1. CAL 83

The prototype of the SSS class, CAL 83, was known as an extremely soft X-ray source from EINSTEIN data (Long *et al.* 1981), a decade before SSS were recognized as a class. The optical spectrum of CAL 83 shows emission lines (primarily He II and H) indicating the presence of a bright accretion disk. The system is a close binary with an orbital period of 1.04 days (Crampton *et al.* 1987; Smale *et al.* 1988; Cowley *et al.* 1991). Mass and luminosity determinations indicate the system is composed of a low-mass dwarf and a degenerate star, but neither star is seen in the optical spectrum.



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TABLE 1. Supersoft X-ray Sources in the LMC

| Source | $V$ | Comments |
|---|---|---|
| CAL 83 | ~17.3 | emission-line binary; P=1.04 days |
| CAL 87 | ~18.9 | emission-line binary; eclipsing; P=0.44 days |
| RX J0439.8–6809 | no id.; $B > 19$ | see Greiner *et al.* 1994 |
| RX J0513.9–6951 | ~16.8 | HV 5682; emission-line star |
| | | 1990 X-ray outburst, but no opt. increase |
| RX J0527.8–6954 | no id.; $B > 18$ | probably not HV 2554; steadily declining X-rays |
| RX J0550.0–7151 | no id. | possibly very blue, ~$18^{th}$ mag. star? |

Crampton *et al.* concluded that the system probably contains a neutron star, however Van den Heuvel *et al.* (1992) have suggested that the compact star is an accreting white dwarf undergoing steady nuclear burning. Both Greiner *et al.* (1991) and Kylafis & Xilouris (1993) explain the SSS by near-Eddington accretion onto neutron stars.

Several spectral characteristics of CAL 83 are unusual. Evidence of very high ionization in the disk is revealed by O VI emission lines at $\lambda\lambda$3881 & 3834. Even more unusual is the very broad emission seen near He II $\lambda$4686, implying radial velocities up to ~2300 km s$^{-1}$. Crampton *et al.* (1987) have shown that this feature shifts from one side of the He II line to the other, with a velocity range of several thousand kilometers per second, in a time scale of months. They suggest an origin in a collimated outflow seen over a range of angles as the disk precesses, analogous to the jets in SS 433 but with lower velocities.

Additionally, CAL 83 is the only known SSS to show a resolved H$\alpha$ and [O III] nebula, extending ~25 pc from the star (Pakull & Motch 1989; Remillard *et al.* 1994). This may indicate a previous period of extensive mass loss from the binary or interaction with the ISM.

## 2.2. CAL 87

CAL 87 is the only SSS presently known to eclipse (Pakull *et al.* 1988; Naylor *et al.* 1989; Cowley *et al.* 1990). The orbital period is 10.6 hours, with the primary optical eclipse lasting almost half the cycle. This indicates the object being occulted (the accretion disk) is very large. Cowley *et al.* concluded the system may contain a black hole, but Van den Heuvel *et al.* interpret the degenerate star as an accreting white dwarf. A brief, shallow X-ray eclipse suggests the X-ray emitting region is an accretion-disk corona which is only partially occulted (Schmidtke *et al.* 1993).

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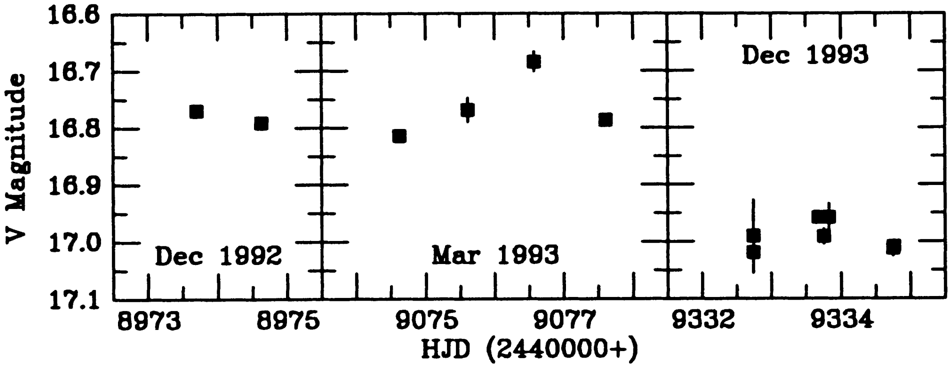


*Figure 1.* Optical light curve of RX J0513.9–6951 for three epochs.

CAL 87 is very faint (outside eclipse, $V \sim 19$), so that the optical spectra we obtained are low quality. They show a disk-dominated system with He II strongly in emission. In spite of the fact that the system eclipses (indicating a high inclination angle for the orbit), the emission lines exhibit only a low velocity amplitude. This was one factor which lead Cowley *et al.* to infer a large mass for the compact star.

### 2.3. RX J0439.8–6809

This source was discovered by Greiner *et al.* (1994) using ROSAT All-Sky-Survey data. X-ray spectral fitting gives $kT_{\rm bb} = 20\,\rm eV$ for $N_{\rm H} = 0.43\ 10^{21}\ \rm cm^{-1}$. Within the error circle ($\pm 15''$) they found no suitable optical candidates brighter than $19^{th}$ magnitude. Our only optical spectrum in this field is for star 'D' (see Greiner *et al.*) which lies well outside their error circle. It is a late B star in the LMC.

### 2.4. RX J0513.9–6951

This source was not detected with EINSTEIN but had a remarkable X-ray outburst in 1990 which was observed with ROSAT (Schaeidt *et al.* 1993). Although the X-ray count rate increased by >200 times, optical photometry shows the $B$ magnitude did not brighten during the same period (Pakull *et al.* 1993). The star appears to be HV 5682 which historically has shown variations of about a magnitude (Leavitt 1908). Our photometry of RX J0513.9–6951 shows small changes ($\pm 0.1$ mag) on a night-to-night basis and $\pm 0.3$ magnitude variations on a time scale of months (see Fig. 1). This is broadly in agreement with the behavior observed by Pakull *et al.* (1993).

Like CAL 83 and CAL 87, the optical spectrum of RX J0513.9–6951 is dominated by a luminous accretion disk with strong emission lines of He II

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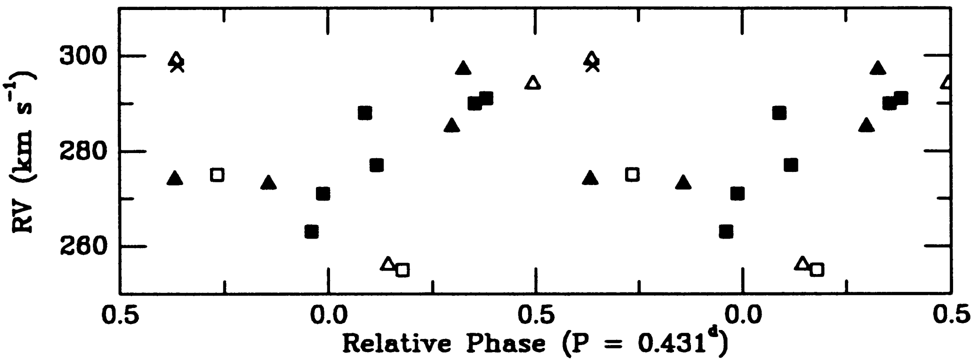


*Figure 2.* Radial velocities of RX J0513.9–6951 folded on a 0.431-day period. Different symbols represent data from five consecutive nights in Dec. 1993.

and H. Its spectrum bears many similarities to that of CAL 83, including relative line strengths, a broad emission near 4686 Å, and presence of O VI lines in the near ultraviolet (Pakull *et al.* 1993). A comparison of spectra of these two stars is shown in figure 2 of Cowley *et al.* (1993).

A series of 15 spectra obtained at CTIO in Dec. 1993 reveal ~40 km s$^{-1}$ nightly velocity variations in the emission lines. Our data are insufficient to define the period uniquely, but $P$ =0.43 days gives a reasonable orbital fit. Fig. 2 shows the velocities folded on this period. More data are needed to better define the period, to rule out alias periods (e.g., 0.32 or 0.77 days), and to determine other system parameters.

Numerous weak, unidentified lines are present in most spectra. Some can be identified assuming they are high velocity components of He II and H, shifted by ~+4200 and −3700 km s$^{-1}$. This implies a bipolar, collimated outflow may be present. Pakull (1994) has reached a similar conclusion based on entirely independent data. Recall that such a high velocity outflow may also be responsible for the changing broad He II wing in CAL 83. Thus, it is possible that such flows may be an additional characteristic of SSS.

### 2.5. RX J0527.8–6954

Trümper *et al.* (1991) discovered this supersoft source in a PSPC survey of the LMC. The X-ray luminosity is variable. It was not detected with EINSTEIN but was a prominent source when first observed with ROSAT. Its X-ray count rate has steadily declined since 1990 (Hasinger 1994). Although its X-ray position was shown on a finding chart (Cowley *et al.* 1993), this needs correction to take into account a small field rotation (0.4°) announced by the ROSAT group (Kuerster 1993) after publication of our paper. Our revised position is shown on the finding chart in Fig. 3 (marked

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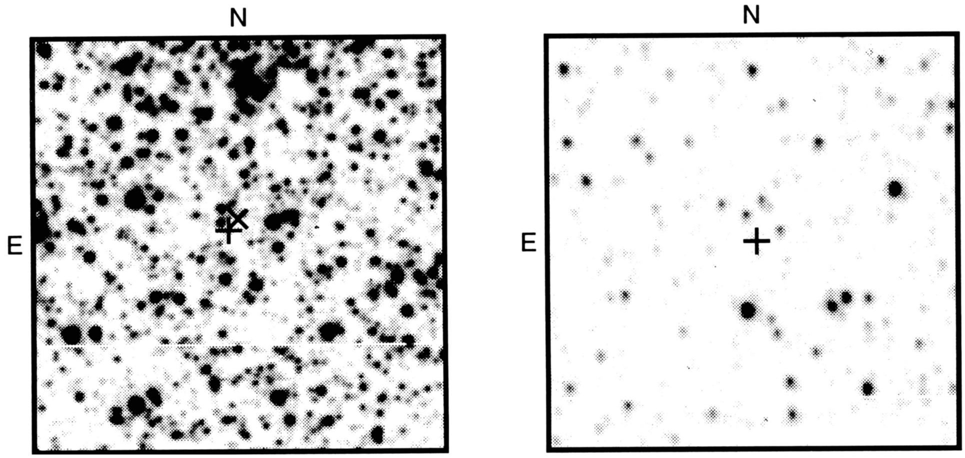


*Figure 3.* Finding charts for two SSS ($1.5' \times 1.5'$). Left: RX J0527.8–6954, '+' marks the position derived from a single HRI pointing and '×' marks the average position given by Hasinger (1994). Right: RX J0550.0–7151, '+' is the X-ray position from an off-axis PSPC observation.

by a '+'). Also shown is Hasinger's (1994) position (marked with a '×') which is based on an average of one HRI and four PSPC pointings. It is unlikely that HV 2554 (the easternmost star of the pair $\sim 10''$ west of the X-ray position) is the optical counterpart since it is too far from the new position. Furthermore, the spectrum of HV 2554 shows it is an ordinary A5 star with nothing to indicate it might be an X-ray source. Spectra of several other blue stars brighter than $19^{th}$ magnitude near the X-ray position reveal normal B or A stars in the LMC and hence unlikely candidates. Thus, this source is still optically unidentified.

## 2.6. RX J0550.0–7151

The X-ray spectrum of RX J0550.0–7151 is very soft and similar to that of RX J0439.8–6809. A black-body fit to the ROSAT data gives $kT_{\rm bb} \sim 32$ eV. The position is based on an off-axis PSPC image, so it is probably only accurate to $\sim \pm 1'$ (larger than the field shown in the finding chart in Fig. 3!). Spectra were obtained for seven candidate blue stars in Dec. 1993. Most appear to be normal LMC early-type stars. One star in the field shows very broad lines and may be a galactic white dwarf. However, Beuermann (1994) reports that RX J0550.0–7151 is variable and was not detected in an HRI observation his group obtained. This makes it unlikely that the source could be a white dwarf. If the source brightens again, an HRI observation is essential to obtain an accurate X-ray position for making a more concentrated search for the optical counterpart.

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## 3. Concluding Remarks

Three of the six supersoft X-ray sources in LMC have been identified with disk-dominated, close binaries whose absolute magnitudes range between $M_V \sim -1.6$ and $+0.5$. We note that the orbital periods for these systems are longer than the ones for typical low-mass X-ray binaries. Two of the systems (CAL 83 and RX J0513.9–6951) show evidence of high-velocity outflows or possibly collimated, precessing jets. optical counterparts for three systems have not been found, but they must be considerably fainter than those already identified. Not only is there a range in absolute magnitudes, but some of the X-ray spectra differ (e.g., X-ray emission in CAL 87 extends to much higher energies than in other SSS). The nature of the component stars in the supersoft sources is not yet resolved, but models include white dwarfs, neutron stars, or black holes as the collapsed star. It seems likely that the SSS include several types of systems, and more than one model may be needed to understand them.

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