Supersoft sources in M 31: Comparing the XMM-Newton Deep Survey, ROSAT and Chandra catalogues

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To investigate the transient nature of supersoft sources (SSSs) in M 31, we compared SSS candidates of the XMM-Newton Deep Survey, ROSAT PSPC surveys and the Chandra catalogues in the same field. We found 40 SSSs in the XMM-Newton observations. While 12 of the XMM-Newton sources were brighter than the limiting flux of the ROSAT PSPC survey, only two were detected with ROSAT \(\sim 10\) yr earlier. Five correlate with recent optical novae which explains why they were not detected by ROSAT. The remaining 28 XMM-Newton SSSs have fluxes below the ROSAT detection threshold. Nevertheless we found one correlation with a ROSAT source, which had significantly larger fluxes than during the XMM-Newton observations. Ten of the XMM-Newton SSSs were detected by Chandra with \(<1\sim 6\) yr between the observations. Five were also classified as SSSs by Chandra. Of the 30 ROSAT SSSs three were confirmed with XMM-Newton, while for 11 sources other classifications are suggested. Of the remaining 16 sources one correlates with an optical nova. Of the 42 Chandra very-soft sources five are classified as XMM-Newton SSSs, while for 22 we suggest other classifications. Of the remaining 15 sources, nine are classified as transient by Chandra, one of them correlates with an optical nova. These findings underlined the high variability of the sources of this class and the connection between SSSs and optical novae. Only three sources were detected by all three missions as SSSs. Thus they are visible for more than a decade, despite their variability.

1 Introduction

The class of supersoft sources (SSSs), was established by ROSAT and is based on observable characteristics. SSSs show extremely soft spectra with equivalent blackbody temperatures of \(\sim 15\sim 80\) eV. The bolometric luminosities lie in the range of \(10^{35}\sim 10^{38}\) erg s\(^{-1}\). The favoured model for these sources is that they are close binary systems with a white dwarf (WD) primary, burning hydrogen-rich matter at the surface. Symbiotic systems, which contain a white dwarf in a wide binary system, were also observed as SSSs [Kahabka & van den Heuvel1997]. SSSs are often observed as transient X-ray sources [Greiner2000, and references therein]. Pietsch et al. [2005a, 2007, hereafter PFF2005, PHS2007] showed that many SSSs in M 31 correlate with classical novae.

The observations of the ‘Deep XMM-Newton Survey of M 31’ [Stie1 et al.2008a] provide, together with archival observations, a full coverage of the D\(_{25}\) ellipse of M 31 with high spatial and spectral resolution. A description of the observations, the source detection procedure and the full source catalogue will be published in a separate paper [Stiele et al., in preparation]. Here, we discuss the 40 SSSs contained in the Deep XMM-Newton Survey catalogue (hereafter XMM LP-total). The SSSs were selected on the basis of their hardness ratios (HR1<0, HR2\sim EHR2<0.96 or EHR2 not defined; energy bands: B1:0.2\sim 0.5 keV, B2:0.5\sim 1.0 keV, B3:1.0\sim 2.0 keV). The hardness ratios and errors are defined as:

\[ HR_i = \frac{B_{i+1} - B_i}{B_{i+1} + B_i} \quad \text{and} \]

\[ EHR_i = \frac{2\sqrt{(B_{i+1} EB_i)^2 + (B_i EB_{i+1})^2}}{(B_{i+1} + B_i)^2}, \]

where \(B_i\) and \(EB_i\) denote count rates and corresponding errors in energy band \(i\). By cross-correlating with our nova catalogue, we found that 14 out of the 40 sources can be classified as X-ray counterparts of optical novae. The main properties of the four sources that are reported for the first time are given in Table I while the remaining ten were reported in PFF2005, PHS2007 or Smirnova et al. [2006].

To study the long term variability of the SSS population of M 31 we performed cross-correlations with the ROSAT...
Table 1 Properties of four newly detected SSSs, which correlate with optical novae

| Name | $t_0$ | $t_f$ | Dist | Perr | $T_{16}$ | $L_{25}^X$ |
|------|-------|-------|------|------|---------|----------|
| M31N | (d)   | (d)   | (") | (") | (eV)    | (10^{-14} erg s^{-1}) |
| 1997-10c | 982  | 1167  | 1.9  | 4.4  | 41      | 5.9       |
| 2005-01b | 535  | 1073  | 4.3  | 5.2  | 45      | 1.0       |
| 2005-01c | 703  | 1144  | 0.9  | 1.8  | 40      | 12        |
| 2005-09b | 299  | 690   | 0.6  | 3.5  | 35      | 54        |

Notes:
* : Time of first detection in X-rays (days after opt. outburst)
† : Time of last detection in X-rays (days after opt. outburst)
‡ : Distance between position of X-ray source and that of optical counterpart
§ : 3σ (99.7%) positional error of the X-ray source
∆ : Temperature derived from a blackbody fit to the X-ray spectrum
& : Unabsorbed 0.2–1.0 keV luminosity, derived from the blackbody fit

PSPC surveys (Supper et al. 1997, 2001, hereafter SHP97 and SHL2001) and with the Chandra source catalogues (Kong et al. 2002, Kaaret 2002, Williams et al. 2006, Voss & Gilfanov 2007, Di Stefano et al. 2004, hereafter DKG2004).

As the ROSAT PSPC observed M 31 more than 10 yr before XMM-Newton EPIC, a comparison of the ROSAT to the XMM-Newton detections probes the long-term variability of SSSs. Lists of SSSs detected in the ROSAT PSPC surveys are given by Greiner (2000) and Kahabka (1999). The selection of these ROSAT SSSs was based on similar selection criteria, as those used for the XMM-Newton data, as the separation energies of the ROSAT bands were ∼0.5 keV and ∼1.0 keV. We ignored all sources of the complimentary sample of Kahabka (1999), which were already classified as foreground stars or SNRs by SHP97. Thus the ROSAT sample contains 34 SSSs.

A list of very soft sources detected with Chandra is given by DKG2004. The observations cover four isolated fields, located in the northern and southern disk and in the centre of M 31. DKG2004 developed an algorithm to select SSSs based on the count rates found in the three energy bands: S, 0.1–1.1 keV; M, 1.1–2 keV; and H, 2–7 keV. The most important difference to our XMM-Newton study is the usage of only one energy band below ∼1 keV. That means that DKG2004 only use cuts that correspond to cuts in HR2 (and not HR1) for XMM-Newton, to select SSSs. From XMM-Newton HR2 cuts we know that – no matter how low the HR2 threshold is chosen – one cannot avoid to select foreground stars and SNRs (Pietsch et al. 2005b, hereafter PFH2005).

2 Results

Table 2 lists all examined sources (40 XMM-Newton SSS candidates from the XMM LP-total catalogue, 34 ROSAT SSS candidates and 43 Chandra very soft sources from Table 1 of DKG2004) and is structured as follows: Column 2 indicates from which source list the examined source is taken, while Col. 3 provides the number (name) of the source in that list. The next three columns (4–6) give information about correlating sources from the other catalogues (and in some cases provide additional information obtained from studies with the same instrument). Sources that are observed as SSSs with more than one instrument are only listed once, reducing the ROSAT and Chandra lists to 31 and 38, respectively. In the last column (7) additional remarks are given. The positions of the sources are indicated in Fig. 1.

3.1 Correlating XMM-Newton SSSs to the ROSAT PSPC surveys and to Chandra catalogues

Three XMM-Newton SSSs correlate with sources that are also classified as supersoft in the ROSAT and Chandra catalogues. Two of them are located in the central field of M 31. The first one (#29) was classified as an SSS by Greiner (2000), but not by SHP97 or SHL2001. The second one (#23) has been known since Einstein. Hence it has been visible for over 25 years. Trudolyubov & Friedhorsky (2008) found that this source varies with a period of 217 s. The third source (#1) is located in the southernmost field of the XMM-Newton survey and correlates with [SHL2001]27 and s2-26 (DKG2004). [SHL2001]27 was detected in the ROSAT PSPC surveys with $F_{X,SHP97} \approx 5.19 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$ and $F_{X,SHL2001} \approx 4.56 \times 10^{-14}$ erg cm$^{-2}$ s$^{-1}$, which is a factor $\sim 22$–25 higher than the fluxes derived from the XMM-Newton observations. DKG2004 detected s2-26 in only one of three Chandra observations obtained between 2000 and 2001 and hence classified the source as variable. With XMM-Newton the source was detected in all three observations, covering the position and did not show signifi-

Observations from 2006 June 28, 2007 July 24 and 2008 January 2.
Table 2  Overview of SSS detected with ROSAT, Chandra and XMM-Newton.

| Num | 1st | 2nd | XMM-Newton | ROSAT | Chandra | Remarks |
|-----|-----|-----|------------|-------|---------|---------|
|     |     |     |            |       |         |         |
| 1   | X   | 69  | <SSS>      | SI 18 | SII 27  | s2-26 (D,v) | <SSS>   |
| 2   | X   | 92  | <SSS>      |       |         |         |
| 3   | X   | 97  | <SSS>      |       |         |         |
| 4*  | X   | 147 | <SSS>      |       |         | no Chandra |
| 5   | X   | 183 | <SSS>      |       |         |         |
| 6   | X   | 342 | <SSS>      |       |         |         |
| 7   | X   | 408 | <SSS>      |       |         | no Chandra |
| 8   | X   | 454 | <SSS>      |       |         |         |
| 9   | X   | 511 | <SSS>      |       |         |         |
| 10  | X   | 617 | <SSS>      |       |         | no Chandra |
| 11* | X   | 748 | <SSS>      |       |         | M31N 2001-10f |
| 12  | X   | 764 | <SSS>      |       |         | M31N 2005-01b |
| 13  | X   | 821 | <SSS>      |       |         |         |
| 14  | X   | 857 | <SSS>      | SII 156 | <fg Star> |
| 15  | X   | 871 | <SSS>      | SI 160 | <SSS>   |
| 16  | X   | 887 | <SSS>      |       |         |         |
| 17* | X   | 934 | <SSS>      |       |         | M31N 2007-06b |
| 18  | X   | 993 | <SSS>      | Ka 55  | <SSS>   |
| 19* | X   | 1006| <SSS>      | Ka 67, r2-60 (D,t, W6) | <SSS> |
| 20  | X   | 1025| <SSS>      | Ka 86, r2-65 (D,t, W6) | <SSS> |
| 21  | X   | 1046| <SSS>      |       |         | M31N 1999-10a |
| 22  | X   | 1051| <SSS>      |       |         | M31N 1997-08b |
| 23* | X   | 1061| <SSS>      | SI 208, SII 203 | <SSS>   |
| 24  | X   | 1069| <SSS>      | Ka 100, r2-12 (K,v, W, D,v), VG 46 | <SSS>   |
| 25  | X   | 1076| <SSS>      | Ka 106 | <SSS>   |
| 26  | X   | 1087| <SSS>      | Ka 111, r2-63 (W, D, t, W6), r3-128 (W6) | <SSS> |
| 27  | X   | 1100| <SSS>      |       |         | M31N 1995-11c |
| 28  | X   | 1144| <SSS>      |       |         | M31N 1996-08b |
| 29* | X   | 1194| <SSS>      | SI 235, SII 235 | <SSS>   |
| 30  | X   | 1195| <SSS>      | Ka 135, r3-8 (K,v, W6), VG 214 | <SSS>   |
| 31  | X   | 1236| <SSS>      |       |         | <SSS>   |
| 32  | X   | 1242| <SSS>      |       |         | M31N 1998-06a |
| 33* | X   | 1250| <SSS>      |       |         | time variable |
| 34  | X   | 1325| <SSS>      |       |         |         |
| 35  | X   | 1355| <SSS>      | SI 262, SII 269 | <SNR> |
| 36  | X   | 1356| <SSS>      |       |         | no Chandra |
| 37* | X   | 1381| <SSS>      |       |         | no Chandra |
| 38* | X   | 1416| <SSS>      |       |         |         |
| 39  | X   | 1435| <SSS>      |       |         |         |
| 40* | X   | 1675| <SSS>      |       |         | M31N 2005-01c |
| 41  | R   | SI 3 | <SSS>      |       |         | outside FoV |
| 42  | R   | SI 12| <SSS>      |       |         |         |
| 43  | R   | SI 35| 188 <fg Star> | SI 43 |         |
| 44  | R   | SI 39| 240 <hard>  |       |         |         |
| 45  | R   | SI 45| <SNR>      | SI 51  | <SSS> |
| 46  | R   | SI 58| 304 <GCI>   | SI 60  | <SSS> |
| 47  | R   | SI 62| 325 <fg Star> |       | <SSS> |
| 48  | R   | SI 78| <SNR>      |       |         |         |
| 49  | R   | SI 88| <SNR>      |       |         |         |
| 50  | R   | SI 114| <SNR>      |       |         |         |
| 51  | R   | SI 128| <SNR>      |       |         |         |
| 52  | R   | SI 129| 737 <fg Star> | SI 123 | <SSS> |
| 53  | R   | SI 156| 842 <fg Star> | SI 151 | <SSS> |
| 54  | R   | SI 171| <SNR>      |       |         |         |
| 55  | R   | SI 183| 10 XMM ents | SI 185 | <SSS> |
| 56  | R   | SI 185| 969 <SNR>   | SI 186 | <SSS> |
| 57  | R   | SI 245| <SNR>      |       |         | s1-84 (W) |
| 58  | R   | SI 252| 1297 <hard> | SI 258 | <SSS> |
| 59  | R   | SI 259| 1331 <fg Star> |       | <SSS> |
| 60  | R   | SI 268| <SNR>      |       |         | M31N 1990-09a |
| 61  | R   | SI 271| SI 282     |       |         | outside FoV |
| 62  | R   | SI 280| 1442 <fg Star> | SI 287 | <SSS> |
| 63  | R   | SI 307| <SNR>      |       |         |         |
| 64  | R   | SI 309| SI 324     |       | <SSS>   |
| 65  | R   | SI 322| <SNR>      |       | <SSS>   |
| 66  | R   | SI 330| <SNR>      |       | <SSS>   |
| 67  | R   | SI 335| <SNR>      |       | <SSS>   |
| 68  | R   | SI 341| <SNR>      |       | <SSS>   |
| 69  | R   | SI 342| <SNR>      |       | <SNR>   |
| 70  | R   | SI 374| <SNR>      |       | <SNR>   |
| 71  | R   | SI 376| <SNR>      |       | <SNR>   |
| 72  | C   | s2-7 | 52 <fg Star> | <DR> | <SSS>   |
| 73  | C   | s2-10| <fg Star>   | <DR> | <SSS>   |
| 74  | C   | s2-27| <fg Star>   | <DR> | <SSS>   |
| 75  | C   | s2-28| 32 <fg Star> | <DR> | <SSS>   |
| 76  | C   | s2-29| 23 <fg Star> | <DR> | <fg Star> |
| 77  | C   | s2-37| 237 <fg Star> | SI 40, SII 47 | <SSS> |
| 78  | C   | s2-46| 13 <fg Star> | <DR> | <fg Star> |

- XMM-Newton: X-ray observation
- ROSAT: X-ray observation
- Chandra: X-ray observation
- Remarks: Not detected, detected, no Chandra, outside FoV, time variable
Table 2  Overview of SSS detected with ROSAT, Chandra and XMM-Newton. (continued)

| Num | I* | Cont* | XMM-Newton† | ROSAT‡ | Chandra§ | Remarks¶ |
|-----|----|-------|-------------|--------|----------|----------|
| 79  | C  | s2-62 | (D,i)       | <QSS>  |          |          |
| 80  | C  | s1-18 | (D-x)       | <SSS>  |          |          |
| 81  | C  | s1-20 | 696 fg Star | SI 121, SII 112 | <fg Star> | (D)      |
| 82  | C  | s1-27 | (D-x)       | <QSS>  |          |          |
| 83  | C  | s1-41 | 673 <Gal>   | (D)    | <GIC>    |          |
| 84  | C  | s1-42 | 668 SNR     | SI 116 | SNR      |          |
| 85  | C  | s1-45 | 603 <fg Star> | SI 107, SII 99 | <fg Star> | (D-W)    |
| 86  | C  | s1-69 | (D,i)       | <SSS>  |          |          |
| 87  | C  | r3-11 | 1172 <hard> | (K, D) | VG 161   | <QSS>    |
| 88  | C  | r3-113 | 1136 <XRB> | (W, D,t, W6), Ka 125, VG 128 (t) | <SSS> |
| 89  | C  | r3-122 | 826 <fg Star> | SI 147 | <fg Star> |          |
| 90  | C  | r2-19 | 1000 (K, W, D), Ka 63, VG 72 (t) | <SSS> |
| 91  | C  | r2-42 | 960 <fg Star> | SI 181, SII 182 | <SSS> |
| 92  | C  | r2-54 | (D)         | <SSS>  |          |          |
| 93  | C  | r2-56 | 1050 SNR    | (K,p, D) | VG 36, | SNR      |
| 94  | C  | r2-61 | (D,i)       | <SSS>  | M31N2000-08a² |          |
| 95  | C  | r2-62 | (D,i)       | <SSS>  |          |          |
| 96  | C  | r2-66 | (D)         | <SSS>  |          |          |
| 97  | C  | r1-9  | 1010³    | <XRB>  |          |          |
| 98  | C  | r1-20 | 1534 <XRB> | (K, W, D), Ka 89, VG 23 (t) | <SSS> |
| 99  | C  | r1-30 | (D,i)       | <SSS>  | M31N1995-09b² |          |
| 100 | C  | n1-1  | 1106 <fg Star> | (D) | <SSS> |
| 101 | C  | n1-8  | 1773 <fg Star> | (D) | <SSS> |
| 102 | C  | n1-13 | 1747 <fg Star> | (D) | <SSS> |
| 103 | C  | n1-15 | 1742 <fg Star> | SI 127 | <SSS> |
| 104 | C  | n1-26 | (D-x)       | <SSS>  |          |          |
| 105 | C  | n1-29 | (D)         | <SSS>  |          |          |
| 106 | C  | n1-31 | 672 <hard> | (D)    | <SSS>    |          |
| 107 | C  | n1-46 | (D)         | <SSS>  |          |          |
| 108 | C  | n1-48 | 1741 <SNR> | (D)    | <SSS>    |          |
| 109 | C  | n1-66 | (D)         | <SSS>  | outside FoV |          |

Notes: *: Correlated SSS taken from the XMM LP-total catalogue, ROSAT SSS lists [Greene 2001, Kahabka 1999] (given is the source name from SHP97 or SHL2001) and very soft sources from Table 1 of DKG2004; The used lists are marked in the instrument column (I): X: XMM-Newton, C: Chandra, R: ROSAT
†: Sources and classification from the XMM LP-total catalogue [Stiele et al., in preparation]
‡: Sources from Chandra catalogues: D: [Di Stefano et al. 2004b], K: [Kong et al. 2002], W: [Williams et al. 2002], W6: [Williams et al. 2007], Ka: [Kaastra 2003], v: variable, t: transient, r: ROSAT HRI source, f: foreground star, p: planetary nebula; and classification of Chandra sources from DKG2004; ◊: apart from r3-8 which was classified as SSS by Kong et al. 2002; †: listed as <SSS> or <QSS> in Table 1 of DKG2004
§: Sources from ROSAT catalogues SI: SHP97, SII: SHL2001 and classification of ROSAT sources from [Greene 2001, Kahabka 1999], SHP97 and SHL2001
¶: “outside FoV” means ROSAT or Chandra source is located outside the area covered by the Deep XMM-Newton Survey of M 31; “no Chandra” means that the location of the source was not covered by any Chandra observation (included in the used literature), TF: [Trinchieri & Fabbiano 1991]
†: XMM-Newton SSSs with 0.2–4.5 keV flux above ROSAT PSPC detection threshold
‡: chance coincidence; ♦: Trudolyubov & Priedhorsky 2008; ♣: Osborne et al. 2001; ○: more details in PFF2005 or PHS2007; ²: counterparts
cant variability. Detection of this source in our survey suggests that it has been active for about 20 years.

Another three XMM-Newton SSS candidates (#19, #20, #27) have counterparts in the Chandra catalogues, that were classified as Chandra SSSs (DKG2004, Kong et al. 2002).

Of the 40 SSS candidates found in the XMM-Newton observations 12 have 0.2–4.5 keV fluxes above the ROSAT PSPC detection threshold of $\sim 5.3 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$. They are marked with an “s” in Table 2. Nevertheless 10 of them do not have ROSAT counterparts. One of them (#30) is a supersoft transient that shows variability with a periodicity of 865.5 s [Osborne et al. 2001]. Another one (#33) was detected in only one XMM-Newton observation. Upper-limits to its flux obtained in three other XMM-Newton observations indicate variability by a factor of $F_{var} \gtrsim 6.9$ ($\sigma = 2.8$). Another six sources correlate with recent optical novae, which explains why they were not detected by ROSAT.

The ROSAT non-detection of the remaining two sources implies a much weaker source flux at the time of the ROSAT observations. Therefore both sources are likely to be transient or at least variable.

Among the remaining 28 XMM-Newton SSSs that have fluxes below the ROSAT detection threshold, we detected four correlations of which three, however, have to be considered as chance coincidences: In two cases a second (not supersoft) XMM-Newton SSS source correlates with the ROSAT counterparts. The third XMM-Newton SSS source correlates with an optical nova, that was detected in the optical $\sim$6 yr after the ROSAT observations.

Of the 30 XMM-Newton SSSs that do not have Chandra counterparts, five lie in regions that were not covered in the Chandra catalogues. Another ten sources correlate with optical novae, which either had their optical outburst after the Chandra observations were obtained (so they could not
Figure 1  Image of the deep XMM-Newton survey of M 31 over plotted with the sources from Table 2. SSSs from the XMM LP-total catalogue are marked in red, from DKG2004 in green and from the ROSAT PSPC surveys in blue. Chandra and ROSAT SSSs with XMM-Newton counterpart not classified as SSS are marked in magenta. The image in the upper right corner shows a zoom-in to the central region of M 31, marked by the yellow box.

be visible during the Chandra observations), or for which Chandra observations, if at all, can only provide upper limits (PFF2005 and PHS2007). In addition, source #33 was found to be variable in our XMM-Newton survey.

3.2 Correlating ROSAT SSSs to the XMM-Newton Deep Survey catalogue

Of the 34 ROSAT SSS candidates four are located outside the field of M 31 covered with XMM-Newton observations. 11 correlate with XMM LP-total sources with other classifications (see Table 2). Source [SHP97] 183 correlated with ten XMM-Newton sources, due to the large position error, rendering identification with a single source impossible.

We examined the variability of the correlated sources between the ROSAT and XMM-Newton observations following the method used in Stiele et al. (2008b). Many of the sources show rather low variability and are classified as foreground star, SNR, or background galaxy candidates from XMM-Newton data. As sources of the afore mentioned classes (excluding flaring foreground stars) are expected to be hardly variable on time scales of several years (in contrast to SSSs), the detected lack of variability is consistent with the XMM-Newton classifications.

Sixteen ROSAT SSSs are left without a corresponding source from the XMM LP-total survey. One ([SHP97] 268) source correlates with the optical nova M31N 1990-09a (PFF2005). The remaining 15 sources have to be classified as transient or at least highly variable and may well represent the SSS phase of optical novae that have not been detected in the optical. In the years before the ROSAT observations, there were no systematic searches or monitoring campaigns for optical novae in M 31. Hence, the number of known optical novae per year was very low (Pietsch, this issue).

3.3 Correlating Chandra very-soft sources to the XMM-Newton Deep Survey catalogue

Table 1 of DKG2004 lists 43 very soft sources detected with Chandra, of which 20 are classified as SSSs. For five of them Table 3 of DKG2004 already lists correlations with known SNRs or foreground stars. This information is taken into account for the entries in the Chandra classification column of Table 3. The XMM-Newton counterparts of 10 Chandra SSSs, do not show a supersoft spectrum (in the XMM-Newton observations) and thus received a different XMM-Newton source classification (see Table 3). Two sources are especially interesting as they are classified as X-ray binary (XRB) candidates in the XMM LP-total catalogue. The first one (r3-115) has been noted to have an uncommon behaviour and was discussed in detail in PFF2005. In early X-ray observations that transient source shows a supersoft spectrum. As the source luminosity increases, its spectrum becomes hard (in the XMM-Newton observation from 2002 January 06). Based on its hard spectrum and transient behaviour the source was classified as an XRB candidate. The soft to hard transition suggests a black hole (BH) primary (PFF2005), although an optical nova or a symbiotic star cannot be excluded. The second Chandra SSS (r1-25) with an XMM-Newton counterpart classified as XRB candidate, shows a very similar behaviour. It was detected with an X-ray 0.3 – 7 keV luminosity of \( \sim 5 \times 10^{35} \) erg s\(^{-1}\). HR\(_{\text{kong}}\) = −0.79, HR\(_{\text{gong}}\) = 0.00. Two sources were not visible in the 2000–2002 XMM-Newton observations of the centre of M 31. A correlating source was detected in observations of July 2004, with an 0.2–4.5 keV luminosity of \( \sim 3.7 \times 10^{36} \) erg s\(^{-1}\) and a hard spectrum. The XMM-Newton long-term variability analysis (Stiele et al. 2008b) gives a maximum variability factor of \( F_{\text{var}} = 9.35 \) and \( \sigma_{\text{var}} = 28.02 \) (Voss & Gilfanov (2007) reported a Chandra detection of a correlating source ([VG2007]23) in observation 4 682, taken on 2004 May 23, 2000 Oct 13, 1999 Dec 11, 1999 Dec 27, 2000 Jan 29, 2000 Feb 16, 2000 Jul 29, 2000 Aug 27, 2001 Jun 10 and XMM-Newton: 2000 Jun 25, 2000 Dec 27, 2001 Jun 29).
which is about two months before the 2004 XMM-Newton observations, at a luminosity of $1.26 \times 10^{37}$ erg s$^{-1}$ and found a variability factor of 50.3. An optical source located within 1'2 of the XMM-Newton source position is listed as a ‘regular or semi-regular red variable’ in Fliri et al. (2006).

From the 23 quasi-soi-soft sources (QSSs) of Table 1 in DKG2004 (4 with correlations in Table 3 of DKG2004), 13 correlate with XMM-Newton sources. The correlation with r1-9 has to be regarded as chance coincidence as XMM-Newton cannot resolve this source, which is located in direct vicinity of the central source of M 31 and a nearby XRB. In Table 3 of DKG2004 the correlation of s1-41 with the globular cluster candidate B251 (RBC V3.5) is indicated. Caldwell et al. (2009) found that B251 is more likely to be a background galaxy than a globular cluster candidate.

4 Discussion and conclusions

Of the 40 SSSs detected with XMM-Newton only three sources are visible for at least one decade. The additional six sources that were visible in XMM-Newton and Chandra observations were all located in the central area of M 31. The Chandra and XMM-Newton observations of that area were taken at about the same time (within several weeks to a few months, whereas in the outer regions there is at least a five year gap between the Chandra and XMM-Newton observations). From all XMM-Newton SSSs 12 have a flux above the ROSAT detection threshold. Nevertheless only two were detected in the ROSAT PSPC surveys. These findings underline the long term variability of the class of SSSs (cf. Greiner et al. 2004).

From the 34 ROSAT SSSs (selected from Greiner 2000 and Kahabka 1999) four are outside the field observed with XMM-Newton. We assigned other source types to the XMM-Newton counterparts of 11 ROSAT sources, which means that 19 ROSAT SSS candidates are left. Subtracting the three SSSs that were confirmed by XMM-Newton and the correlation with an optical nova, there are 15 sources left which must be considered as transient or at least variable. Due to the few optical novae, observed in the years before the ROSAT observations, several of these 15 sources may be the X-ray counterpart of a nova, where the optical outburst has been missed.

DKG2004 report on 20 Chandra SSSs, of which three are classified as foreground stars and two as SNRs. From the remaining sources two XMM-Newton counterparts are classified as foreground star candidates, one as SNR candidate and two as XRB candidates. The latter two sources are very interesting as they were found as SSSs in Chandra observations, but showed a “hard” spectrum in XMM-Newton observations. This indicates a transition from a supersoft to a hard spectral state, which is consistent with the behaviour of BH XRBs. However other source types, like e.g. symbiotic stars, cannot be excluded. Five Chandra sources do not have counterparts in the XMM-Newton observations. The fact that half of the Chandra SSSs are not XMM-Newton SSSs underlines the missing selection sensitivity in the Chandra studies, as only one band below $\sim 1$ keV was used. Of the 23 Chandra quasi-soft sources (DKG2004), about half (12) have counterparts in the XMM-Newton Deep Survey observations. However none of these 12 XMM-Newton sources had hardness ratios consistent with SSSs.

In conclusion our comparative study of SSS candidates in M 31 detected with ROSAT, Chandra and XMM-Newton demonstrated that strict selection criteria have to be applied to securely select SSSs. It also underlined the high variability of the sources of this class and the connection between SSSs and optical novae.

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