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# Soft X-rays from the intermediate-age open cluster NGC 752

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**Abstract.** A ROSAT PSPC observation of NGC 752 detects 49 sources. Seven sources are tentatively identified with optical cluster members, of which three are short-period binaries, one is a blue straggler, and one a rapid rotator. The eclipsing binary DS And – also a cluster member – is probably detected as well. The X-ray properties of these sources are similar to those of RS CVn binaries with the same absolute magnitude and colour in the galactic disk.

**Key words:** stars: activity – open clusters and associations: individual: NGC 752 – X-rays: stars

## 1. Introduction

Stellar chromospheric and coronal activity is believed to be connected to rotation (as reviewed in Pallavicini 1989). In the course of their lives stars spin down because of magnetic breaking. For this reason, X-ray studies of open clusters have concentrated on clusters younger than 600 Myr (see *e.g.* Pye et al. 1994, Stern et al. 1993). The only old systems which exhibit rapid rotation are close binaries, whose stars are forced into corotation by tidal interaction. The binary motion is thus providing the angular momentum to keep a high rotation rate, allowing the stellar activity and consequently the X-ray emission to remain strong at an older age.

A *ROSAT* observation of the old open cluster M67 led to the detection of 22 X-ray sources, 7 of which have been identified with cluster members (Belloni, Verbunt and Schmitt 1993). Among these, 4 are known short period binaries, one is a cataclysmic variable and one is a blue straggler. Optical follow-up observations have allowed the detection of signs of stellar activity from most of the optical candidates (Pasquini and Belloni 1994, 1995). Moreover, a soft ROSAT source has been identified with a DA white dwarf, probably a member of M67 (Pasquini, Belloni and Abbott 1994).

To further investigate the X-ray emitting stellar population of old open clusters, we observed NGC 752. At $\sim$ 2 Gyr, this cluster is intermediate in age between the Hyades and M67. Its distance of $\sim$ 400 pc, roughly half of the distance to M67, and the low value for the interstellar absorption (E(B-V)=0.035, Daniel et al. 1994) make it an ideal target for a soft X-ray observation. A comprehensive photometric and spectroscopic study of NGC 752 has been published by Daniel et al. (1994).

## 2. Observations

NGC 752 was observed in pointing mode with the ROSAT X-ray telescope in combination with the Position Sensitive Proportional Counter (PSPC), between 21h31m UT on 11 Aug 1992 and 13h58m on 13 Aug 1992, for a total of 15596 seconds. A description of the satellite, the X-ray telescope and detector are given by Trümper (1983) and Pfeffermann et al. (1986).

The X-ray data have been analyzed with the Extended Scientific Analysis System (EXSAS, Zimmermann et al. 1994). In this study we followed the standard detection procedure. This procedure first produces a background map by removing the possible sources and running a spline fit to the remaining data. Then a maximum likelihood (ML) algorithm is applied to the data (see Cruddace, Hasinger and Schmitt 1988) to test for significant deviations of the observed photon distribution from that expected from background only. The threshold for a detection has been set to a likelihood value of 10, corresponding to a probability of a chance detection of $4.54\times10^{-5}$, for a single trial. The detection procedure has been applied to the data for the whole energy band of the PSPC (0.1–2.4 keV) and for the soft band (channels 11–40, roughly corresponding to 0.1–0.4 keV) and the hard band (channels 41–240, 0.4–2.4 keV) separately. Because of the degrading of the PSPC point spread function outside the inner area of the detector (a circle with a radius of approximately 20′) we limit our analysis to this region. After combining the lists of sources corresponding to the three different detection runs (total, soft and hard), we detected a total of 49 sources above threshold: 47 of them have been detected in the total band, 7 in the soft band, and 48 in the hard band. The selected threshold is so high that none of these sources is

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**Table 1.** Sources detected in the NGC 752 field. The columns give the position of the source, the 90% confidence radius, the countrate, the channel band to which the count rate corresponds (T=11–240, H=41–240), and the hardness ratios. The positions have been corrected for the offset between the pointings of the optical and X–ray telescopes. The hardness ratios are defined as HR1≡ $(B - A)/(A + B)$ and HR2≡ $(D - C)/(C + D)$, where $A, B, C, D$ are the counts detected in the channel intervals 11-40, 41-240, 41-100, and 101-240, respectively.

| no. | $\alpha$(2000) | $\delta$(2000) | $\Delta r$ | cts/ksec | B | HR1 | HR2 |
|---|---|---|---|---|---|---|---|
| 1 | 1h58m16.6s | 37°57′21" | 26.5" | 2.5± 0.6 | H | >0.37 | -0.17±0.23 |
| 2 | 1h57m20.0s | 37°56′40" | 19.4" | 3.8± 0.7 | H | >0.65 | -0.07±0.16 |
| 3 | 1h57m20.8s | 37°56′32" | 17.8" | 3.8± 0.7 | H | >0.62 | -0.04±0.17 |
| 4 | 1h57m34.0s | 37°54′11" | 13.2" | 2.9± 0.5 | H | >0.72 | -0.23±0.18 |
| 5 | 1h57m51.4s | 37°53′04" | 3.2" | 23.7± 1.3 | T | 0.21±0.06 | -0.35±0.07 |
| 6 | 1h57m39.8s | 37°52′31" | 8.9" | 3.9± 0.6 | H | >0.26 | 0.02±0.18 |
| 7 | 1h57m35.9s | 37°49′34" | 7.8" | 3.4± 0.6 | H | >0.36 | -0.38±0.17 |
| 8 | 1h58m48.9s | 37°49′34" | 23.6" | 1.6± 0.5 | T | >-0.24 | |
| 9 | 1h57m49.7s | 37°49′10" | 10.0" | 2.5± 0.5 | H | >0.56 | -0.45±0.18 |
| 10 | 1h58m15.3s | 37°48′42" | 6.6" | 5.4± 0.7 | H | >0.56 | -0.21±0.13 |
| 11 | 1h57m58.0s | 37°48′20" | 10.0" | 2.0± 0.4 | H | >0.37 | <-0.53 |
| 12 | 1h58m20.3s | 37°47′31" | 9.1" | 3.0± 0.5 | H | >0.44 | -0.21±0.18 |
| 13 | 1h57m10.2s | 37°45′31" | 15.8" | 1.3± 0.4 | H | >0.10 | |
| 14 | 1h58m01.8s | 37°45′27" | 13.0" | 0.8± 0.3 | H | >0.22 | >0.44 |
| 15 | 1h57m50.8s | 37°45′16" | 3.2" | 13.0± 1.0 | H | 0.55±0.07 | -0.12±0.08 |
| 16 | 1h57m36.3s | 37°45′12" | 5.9" | 4.5± 0.6 | H | >0.36 | -0.38±0.14 |
| 17 | 1h57m26.2s | 37°43′37" | 8.0" | 2.2± 0.5 | H | >0.45 | -0.30±0.21 |
| 18 | 1h56m51.5s | 37°43′03" | 7.8" | 4.4± 0.6 | H | 0.40±0.16 | -0.66±0.13 |
| 19 | 1h58m42.9s | 37°42′20" | 20.8" | 1.5± 0.4 | T | >0.03 | <-0.51 |
| 20 | 1h57m45.8s | 37°41′48" | 9.6" | 2.1± 0.5 | H | >0.14 | -0.46±0.22 |
| 21 | 1h56m55.0s | 37°41′36" | 16.2" | 0.7± 0.2 | H | >0.13 | >-0.17 |
| 22 | 1h59m09.2s | 37°41′11" | 19.2" | 1.6± 0.5 | H | >0.26 | <0.01 |
| 23 | 1h58m51.2s | 37°40′57" | 18.7" | 1.3± 0.4 | H | >0.21 | <-0.75 |
| 24 | 1h58m12.0s | 37°40′48" | 9.1" | 2.0± 0.5 | H | >0.51 | -0.17±0.22 |
| 25 | 1h57m59.9s | 37°40′42" | 11.4" | 1.4± 0.4 | H | >0.26 | <-0.26 |
| 26 | 1h58m18.8s | 37°40′36" | 12.3" | 1.6± 0.4 | H | >0.20 | <-0.16 |
| 27 | 1h57m37.8s | 37°39′21" | 13.0" | 1.1± 0.4 | H | >0.16 | <-0.33 |
| 28 | 1h56m38.1s | 37°37′57" | 7.5" | 7.7± 0.8 | T | 0.01±0.11 | -0.39±0.14 |
| 29 | 1h57m22.2s | 37°36′29" | 7.1" | 3.8± 0.6 | H | >0.32 | -0.36±0.16 |
| 30 | 1h58m53.6s | 37°34′44" | 6.6" | 6.2± 0.7 | H | >0.64 | -0.55±0.11 |
| 31 | 1h56m41.9s | 37°34′44" | 14.6" | 1.4± 0.4 | H | >0.35 | <-0.27 |
| 32 | 1h58m10.7s | 37°34′29" | 11.5" | 1.6± 0.4 | H | >0.54 | <-0.35 |
| 33 | 1h57m58.2s | 37°33′56" | 11.0" | 1.2± 0.4 | H | >0.47 | 0.10±0.29 |
| 34 | 1h57m18.5s | 37°33′50" | 14.4" | 1.5± 0.4 | H | >0.42 | <-0.47 |
| 35 | 1h58m18.1s | 37°33′34" | 8.0" | 3.6± 0.6 | H | >0.22 | -0.35±0.17 |
| 36 | 1h59m12.9s | 37°33′19" | 24.4" | 2.4± 0.6 | T | >-0.23 | |
| 37 | 1h57m22.9s | 37°32′57" | 12.3" | 1.7± 0.4 | T | >-0.02 | <-0.28 |
| 38 | 1h57m59.2s | 37°32′24" | 7.3" | 5.6± 0.7 | H | 0.48±0.13 | -0.10±0.14 |
| 39 | 1h57m11.9s | 37°31′40" | 26.5" | 0.8± 0.3 | H | >0.62 | |
| 40 | 1h58m11.8s | 37°31′02" | 14.6" | 2.4± 0.5 | H | >0.31 | 0.30±0.22 |
| 41 | 1h57m11.4s | 37°30′15" | 17.6" | 1.2± 0.4 | H | >0.42 | >-0.18 |
| 42 | 1h58m22.7s | 37°29′50" | 5.9" | 10.2± 0.9 | H | 0.51±0.09 | -0.34±0.10 |
| 43 | 1h58m02.5s | 37°29′37" | 9.4" | 6.3± 0.8 | T | -0.43±0.11 | <-0.46 |
| 44 | 1h58m32.9s | 37°29′14" | 20.0" | 1.6± 0.5 | H | >0.11 | >-0.30 |
| 45 | 1h57m37.4s | 37°29′14" | 13.7" | 1.8± 0.5 | H | >0.64 | >0.14 |
| 46 | 1h57m09.9s | 37°27′32" | 13.7" | 3.6± 0.6 | H | >0.25 | -0.40±0.18 |
| 47 | 1h57m51.2s | 37°26′18" | 24.0" | 1.6± 0.5 | T | | |
| 48 | 1h57m42.6s | 37°24′27" | 22.8" | 2.7± 0.6 | T | >0.07 | -0.17±0.25 |
| 49 | 1h57m26.0s | 37°23′55" | 16.0" | 3.9± 0.7 | H | >0.71 | -0.12±0.16 |

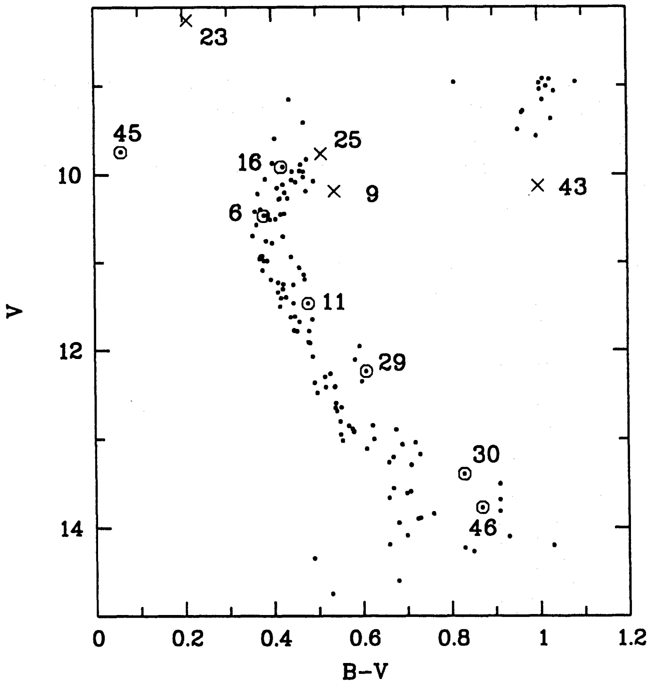


**Fig. 1.** Color–magnitude diagram of NGC 752. The dots are members of the cluster (from Daniel et al. 1994). The circles indicate the X-ray sources identified with members, the crosses the identifications with non-members. The numbers correspond to the entries in Table 1

**Table 2.** Tentative optical identifications for sources in the NGC 752 field. Given are the number of the X-ray source, the number of the optical object in Heinemann (1926), the distance Δ between X-ray and optical position in arcseconds, $V$ and $B-V$ of the optical object (from Daniel et al. 1994), the membership (+: member, -:non-member, 0: probable member; from Daniel et al. 1994), and remarks

| X–ray no. | H no. | Δ ″ | $V$ | $B-V$ | M | remarks |
|---|---|---|---|---|---|---|
| 5 | 226 | 1.3 | 11.3 | | ? | $m_v$ from GSC |
| 6 | 214 | 6.4 | 10.47 | 0.38 | + | |
| 9 | 225 | 3.4 | 10.19 | 0.54 | - | |
| 11 | 235 | 3.0 | 11.47 | 0.48 | + | |
| 14 | 242 | 11.0 | 14.2 | | ? | $m_v$ from GSC |
| 16 | 205 | 2.5 | 9.92 | 0.42 | + | |
| 23 | 309 | 11.6 | 8.25 | 0.21 | - | |
| 25 | 240 | 3.8 | 9.77 | 0.51 | - | |
| 29 | 182 | 5.7 | 12.24 | 0.61 | + | |
| 30 | 313 | 3.8 | 13.39 | 0.83 | + | |
| 31 | 101 | 11.3 | 11.3 | | ? | $m_v$ from GSC |
| 43 | 246 | 0.9 | 10.13 | 1.00 | - | |
| 45 | 209 | 13.6 | 9.75 | 0.06 | + | |
| 46 | 156 | 8.8 | 13.77 | 0.87 | 0 | |

considered spurious. A summary of the detected sources with their positions, count rates, and hardness ratios in Table 1. If a source is detected in more than one energy band, the position corresponding to the detection with the highest value of ML is given.

The positions of the X–ray sources given in Table 1 have been corrected for the offset between the X–ray detector and the optical star sensor. The uncertainty of the X–ray position is expressed as the 90% radius, the radius of the circle within which the source is expected to lie with a 90% probability. This 90% confidence radius is mainly determined by the photon statistics, but also contains a 3″ systematic error.

The ML algorithm is able to discriminate between point-like and extended sources, keeping into account the effects introduced by the point spread function. Source X 2 has a high probability of being extended. The gaussian fit provided by the algorithm gives a FWHM of 100±40 arcsecs.

We produced light curves for all the sources, looking for variability or flares, with negative results.

## 3. Results

### *3.1. Identifications*

To identify optical counterparts for the X–ray sources we use the Space Telescope Guide Star Catalogue (Lasker et al. 1990). We consider as possible identification an optical object which falls within the 90% error circle of one of the X–ray sources. A total of 14 X–ray sources have been identified using this procedure. Table 2 lists these tentative optical counterparts, with their optical magnitudes and colors, and the membership flags from Daniel et al. (1994) and Platais (1991). Fig. 1 shows the colour magnitude diagram of NGC 752, in which we also indicate those identified sources for which a $B-V$ value is available.

To estimate the number of spurious identifications we simulated 10000 source positions within 20′ from the PSPC pointing direction, with an average error radius and ran the identification algorithm on the Guide Star Catalogue. Roughly 1% of the simulated error boxes contains an entry in the Guide Star Catalogue. Thus, the probability of a chance identification in Table 2 is low.

One source, X 45, is identified with the star H209, which is the only blue straggler known in the cluster (see Fig. 1). Of the remaining six detected members, four are located close to the main sequence and two around the turn-off point (see Fig. 1). Remarkably, all these stars are displaced upwards from the main sequence, indicating a possible binary nature. From Daniel et al. (1994) we find that two of them (H235 and H205) are indeed double-lined spectroscopic binaries, H313 is a single-lined spectroscopic binary, and H214 is probably rapidly rotating, which makes it difficult to establish its possible binary nature (although any rapidly rotating star in an old cluster is likely to be a binary member). The periods of these systems are rather short. H235 has a photometric period of ~0.41 days (Milone & Schiller 1991), H313 of 1.95 days (Twarog, personal communication), and H205 of 1.45 days (Mermilliod, personal communication).

35 sources remain unidentified. The observed field is located outside the plane of our galaxy ($l_{II} \sim -23°$), so we can expect a significant contribution by extragalactic sources, mainly Active Galactic Nuclei. To estimate the number of extragalactic sources

expected in the central region of the PSPC, we assume that a typical extragalactic source emits a power law X-ray spectrum $f_\nu(\mathrm{erg\,cm^{-2}s^{-1}Hz^{-1}}) \propto \nu^{-2.4}$, and use a value for the total interstellar absorption column of $N_{\rm H} = 5 \times 10^{20}\mathrm{cm^{-2}}$, derived from radio data (Dickey & Lockman 1990). For these parameters, the count rate limit of $\sim 10^{-3}$cts/s is converted into a flux limit of $\sim 10^{-14}\mathrm{erg\,cm^{-2}\,s^{-1}}$. Comparing with the log N–log S function derived from the ROSAT deep survey (Hasinger 1992) we estimate that ~28 extragalactic sources are expected to be detected in our field. Therefore, most of the unidentified sources are likely to be background objects. Source X 2, being extended, is most likely a background cluster of galaxies. Source X 43 has a rather soft spectrum, and is probably very nearby.

### *3.2. X–ray properties of proposed members*

The tentative identifications for the X-ray sources are mostly binaries. We therefore adopt a spectral model suitable for RS CVn binaries. Dempsey et al. (1993a) describe the data of RS CVn binaries observed in the ROSAT All Sky Survey data with a sum of two thermal emission models (according to Raymond & Smith 1977), one with a low temperature, and one with a higher temperature. Characteristic values of the two temperatures and of the ratio between the two corresponding emission measures are $T_{low} = 0.175$ keV, $T_{high} = 1.4$ keV, and $EM_{low}/EM_{high} = 6.0$. With this spectral distribution, and an interstellar absorption of $2.3 \times 10^{20}\mathrm{cm^{-2}}$ (derived from E(B–V)= 0.035; Daniel et al. 1994), 1 PSPC ct/ksec detected in the total channel range 11–240 corresponds to an X–ray flux of $1.5\times10^{-14}\mathrm{erg\,cm^{-2}s^{-1}}$ in the 0.1–2.4 keV band. If the count rate corresponds to a detection in the hard band only, the 0.1–2.4 the flux is $1.9\times10^{-14}$erg $\mathrm{cm^{-2}s^{-1}}$.

All the tentatively identified members of NGC 752 have hardness ratios HR1 and HR2 that are compatible with the values expected for RS CVn binaries. The blue straggler, the faintest of the sources identified with a member of NGC 752, has a somewhat harder spectrum, with HR2> 0.14.

## 4. Discussion

The seven X-ray sources tentatively identified with members of NGC 752 are listed in Table 3, with more information on the optical counterparts culled from Daniel et al. (1994). Three of the sources are spectroscopic binaries, all with orbital periods less than 2 days. One other source is a rapidly rotating star, which indicates (in this old cluster) that it is a member of a short-period binary. Source X 45 is identified with the blue straggler H209. This is the second blue straggler detected in X–rays, the other one being the star S1082 in M67 (Belloni, Verbunt & Schmitt 1993). The latter one is known to be short-period binary (P~1.07 days, Goranskij et al. 1992).

The high incidence of known and suspected short-period binaries in our sample of tentative identifications is rather similar to the situation in M67 (Belloni, Verbunt and Schmitt 1993). We take this as confirmation of our hypothesis that the X-ray sources are stars that have been brought to rapid rotation by tidal interaction in a close binary.

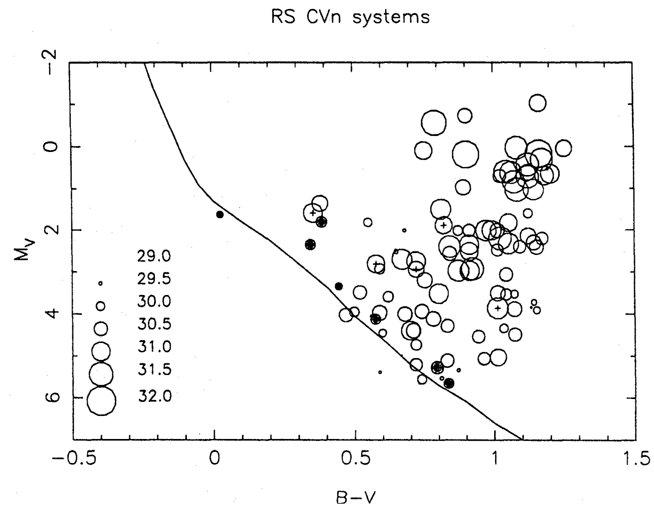


**Fig. 2.** Comparison of the X-ray luminosities as a function of location in the color–magnitude diagram of field RS CVn's (open circles; data from the ROSAT all-sky survey, Dempsey et al 1993b), X–ray sources in NGC 752 identified with cluster members (filled circles), and X–ray sources in M 67 (circles marked with +; data from Belloni, Verbunt and Schmitt 1993; source M67-11 has been excluded, see text). The size of the circle indicates the X-ray luminosity. The solid line is the zero-age main-sequence (Mihalas & Binney 1981, Table 3-1)

One other short-period binary in NGC 752 is the eclipsing binary DS And = H219, with a period of 1.01 days, and zero eccentricity (Schiller & Milone 1988). This star is located just outside the inner region of the PSPC detector, and was not included in the analysis discussed above. An X–ray source is detected $\sim 1'$ away from it, with a formal 90% radius of $\sim 40''$. Given the uncertainties of the point spread function outside the inner $20'$ of the field of view, it is possible that we detected DS And. The source is weak: a search for evidence of an X–ray eclipse has been made, with negative results.

Two other known binaries in NGC 752 are H300, with an eccentric orbit of 6.593 days (Pilachowski et al. 1986), and H110, which has a circular orbit of 127 days (Pilachowski et al. 1989). Neither is detected.

To further investigate our hypothesis that the X-ray sources are active, RS CVn type binaries, we compare their properties with those of the RS CVn binaries studied in the ROSAT All Sky Survey by Dempsey et al. (1993 a,b) in Fig. 2. In this figure we also show the sources detected in the old open cluster M67. We have recalculated the fluxes for these sources, assuming the same intrinsic spectrum used for the sources in NGC 752, and adopting $N_H$=$4\times10^{20}\mathrm{cm^{-2}}$ and $d$ = 785 pc for M67. The values thus found are higher by a factor of $\sim 2$ with respect to the values reported in Table 1 of Belloni, Verbunt & Schmitt (1993). X-ray source M67-11 is not included, as its flux is contaminated by a nearby source (Belloni and Verbunt, in preparation).

Fig. 2 shows that the brightest X-ray sources among the RS CVn binaries in the galactic disk are those that are furthest from

**Table 3.** Summary of the detected members of the cluster. The X–ray luminosities have been calculated assuming a distance of 400pc. The notes *ROTATOR, SB1, SB2, ORB* are from Daniel et al. (1994)

| X–ray no. | H no. | $L_X$ (erg/s) | Binarity |
|---|---|---|---|
| 6 | 214 | $1.5 \times 10^{30}$ | ROTATOR |
| 11 | 235 | $7.4 \times 10^{29}$ | SB2 (P=0.4118 d, Milone & Schiller 1991) |
| 16 | 205 | $1.7 \times 10^{30}$ | SB2, (P=1.45 d, Mermilliod, priv. comm.) |
| 29 | 182 | $1.4 \times 10^{30}$ | |
| 30 | 313 | $2.3 \times 10^{30}$ | SB1, (P=1.95 d, Twarog, priv. comm.) |
| 45 | 209 | $6.7 \times 10^{29}$ | Blue Straggler |
| 46 | 156 | $1.3 \times 10^{30}$ | |
| – | 219 | $2.9 \times 10^{30}$ | DS And (P=1.01 d, Schiller & Milone 1988) |

the main sequence. This is in agreement with the suggestion, by Vilhu (1987), that the X-ray flux per unit area of the star saturates at high rotation rates, so that the largest X-ray luminosities are emitted by the largest rapidly rotating stars (see also Fig. 3 in Verbunt 1995). The X-ray sources in both NGC 752 and M67 fit this general pattern. Due to higher interstellar absorption and a larger distance our detection limit for M67 is higher than for NGC 752, which explains our failure to detect systems located close to the main sequence in M67. The non-detection of stars further from the main sequence in NGC 752 must be due to slow rotation of the relatively few evolved stars that are known in NGC 752.

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