A&A manuscript no.
(will be inserted by hand later)

Your thesaurus codes are:
05(10.15.2 NGC 3532; 08.03.5; 13.25.5)

ASTRONOMY AND ASTROPHYSICS
March 16, 2000

A $ROSAT$ HRI study of the open cluster NGC 3532

E. Franciosini[1], S. Randich[2], and R. Pallavicini[1]

[1] Osservatorio Astronomico di Palermo "G.S. Vaiana", Piazza del Parlamento 1, I-90134 Palermo, Italy (francio@oapa.astropa.unipa.it, pallavic@oapa.astropa.unipa.it)
[2] Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, I-50125 Firenze, Italy (randich@arcetri.astro.it)

Received / Accepted

Abstract. NGC 3532 is a very rich southern open cluster of age $\sim 200-350$ Myr; it is therefore a good candidate to investigate the X-ray activity–age–rotation relationship at ages intermediate between the Pleiades and the Hyades, where, to our knowledge, X-rays studies exist for only one cluster (NGC 6475). We have performed an X-ray study of NGC 3532 using HRI observations retrieved from the $ROSAT$ archive. The observations have a limiting sensitivity $L_{\rm x} \sim 4 \times 10^{28}$ erg sec^{-1} in the center of the field. We detected ~ 50 X-ray sources above a 4σ threshold, half of which have a known optical counterpart within 10 arcsec; 15 of the X-ray sources have at least one cluster member as optical counterpart.

A comparison of NGC 3532 with the nearly coeval cluster NGC 6475 indicates that the former cluster is considerably X-ray underluminous with respect to NGC 6475. However, because of the existence of possible selection effects, additional X-ray and optical observations are needed before definitively concluding that the X-ray properties of NGC 3532 and NGC 6475 are significantly different.

Key words: open clusters and associations: individual: NGC 3532 – stars: coronae – X-ray: stars

1. Introduction

The $ROSAT$ PSPC and HRI detectors have provided X-ray images for a large number of open clusters sampling the age range from $\sim$ 20 to 600 Myr (e.g., Randich 2000 and references therein; Jeffries 1999 and references therein; see also Belloni 1997, for a review on older open clusters). The data have allowed investigating in great detail the dependence of X-ray activity on mass, age, rotation, and, in particular, to check the validity of the rotation–activity–age paradigm. The overall picture emerging from $ROSAT$ generally confirms that there is a tight dependence of X-ray activity on rotation (or on the so called Rossby number, the ratio of the rotation period over the convective turnover time – e.g., Noyes et al. 1984) and, through rotation, on age: the level of X-ray activity increases with increasing rotation and, since stars spin down as they age, the average or median X-ray luminosity decays with increasing age. However, the X-ray luminosity (or X-ray over bolometric luminosity) does not depend simply on some power of the rotational rate, and the activity–age dependence cannot be described by a Skumanich–type power law. In addition, a few puzzling results have arisen from $ROSAT$ data. For example, the finding that the bulk of the population of Praesepe solar-type stars have a significantly lower X-ray luminosity than the coeval Hyades and Coma Berenices clusters (Randich & Schmitt 1995; Randich et al. 1996) has casted doubts on the common thinking that a unique activity–age relationship holds, and, consequently, that the X-ray properties of a cluster of a given age are representative of all clusters of the same age. A study by Barrado y Navascués et al. (1998) seems to exclude that this result is due to a strong contamination of the Praesepe sample by cluster non-members; at the same time, $ROSAT$ observations of NGC 6633 suggest that this cluster, which is coeval to the Hyades and Praesepe, is more Praesepe–like than Hyades–like (Franciosini et al. 2000; Totten et al. 2000). We also mention that the comparison of the Pleiades (120 Myr) with NGC 6475 (200 Myr) and with other clusters with ages of the order of 100–200 Myr also suggests that a tight/unique age–activity relationship may not hold (e.g. Randich 2000). The issue of the uniqueness of the activity–age relationship is therefore not at all settled. In addition to optical studies that should ascertain cluster membership and provide complete (or close to completeness) lists of members and better defined cluster ages, additional, and possibly deeper, X-ray surveys of samples of coeval clusters are clearly required to further address this problem.

We present here a $ROSAT$ study of the NGC 3532 cluster: NGC 3532 is a very rich southern open cluster with an estimated age $\sim 200-350$ Myr (Fernandez & Salgado 1980; Johansson 1981; Eggen 1981; Koester & Reimers 1993; Meynet et al. 1993); it is therefore a good candidate to investigate the X-ray activity–age–rotation relationship at ages intermediate between the Pleiades and the Hyades, where, to our knowledge, X-rays studies exist for only one cluster (NGC 6475). The most likely value for the reddening of NGC 3532 is $E(B-V) = 0.04$ (Fernandez & Salgado 1980; Eggen 1981; Schneider 1987; Meynet et al. 1993); the metallicity of the cluster has been estimated to be close to solar ([Fe/H] $\sim$ 0.02;

Send offprint requests to: E. Franciosini

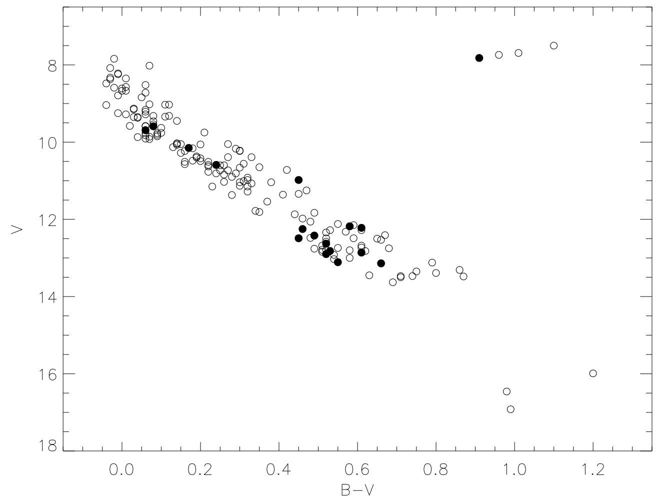

Fig. 1. V vs. $(B-V)$ diagram for the probable and possible members of NGC 3532 included in the HRI field of view. Filled circles indicate stars detected in X-rays

Clariá & Lapasset 1988). The cluster is located at very low galactic latitude ($b = +1.43$ deg). Distance determinations range from 405^{+76}_{-55} pc (from Hipparcos; Robichon et al. 1999) to 500 pc (Eggen 1981); in this paper the most recent value of 405 pc by Robichon et al. (1999) has been adopted.

2. Optical catalog

The first detailed study of NGC 3532 was carried out by Koelbloed (1959), who obtained photoelectric or photographic photometry and proper motions for 255 stars down to a limiting magnitude $V \sim 11.7$. A new proper motion survey of these stars was later performed by King (1978). The most extensive study of this cluster is the photometric study by Fernandez & Salgado (1980), who obtained photoelectric and photographic photometry for 700 stars (including nearly all Koelbloed's stars) down to a limiting magnitude $V = 13.5$. Photoelectric photometry for another 24 stars down to $V = 18.3$ was obtained by Butler (1977). We mention in passing that only 15 G–type and 7 K–type dwarf cluster members are present in the total sample of 724 stars. Additional photometric studies of these stars have been performed by Johansson (1981; UBV, 16 stars), Eggen (1981; Strömgren, 33 stars), Wizinowich & Garrison (1982; UBVRI, 68 stars), Schneider (1987; Strömgren, 164 stars) and Clariá & Lapasset (1988; UBV and DDO, 12 stars). Radial velocities are available for about a hundred stars from the studies by Harris (1976) and by Gieseking (1980, 1981). Gieseking (1981) derived a mean cluster radial velocity $v_{\rm r} = 4.6 \pm 2$ km/s.

Our input catalog is based on the lists of stars by Fernandez & Salgado (1980) and Butler (1977). From these lists, we selected as *probable* members those stars with radial velocity, when available, within 4 km/s (i.e. 2σ) of the cluster mean $v_{\rm r}$, or with membership probability from proper motions greater than 80%, or which were suggested as members in photometric studies. We rejected stars that would be considered members according to either radial velocity or proper motion, but with photometry inconsistent with cluster membership. For stars with no individual membership information, but with UBV photometry available, we accepted as *possible* members those falling in a band between 0.2^m below and 0.7^m above the cluster main sequence.

The resulting catalog contains 248 probable and possible members; 174 of them, including 4 giants, are located within 17 arcmin of the $ROSAT$ nominal pointing position. In Fig. 1 we show the V vs. $(B-V)$ C–M diagram for the probable and possible members in our field of view. It is evident from the figure that the majority of the known members are early-type stars. Except for three very late possible cluster members, the cluster main sequence is truncated at $V = 13.5$, corresponding to G–type stars; only 13 G–type and 5 K–type members (excluding giants) are present in our catalog, compared to 104 B–A and 48 F stars. We also mention that most of the stars with spectral type later than F5 were selected as members only on the basis of photometry.

3. Observations and data analysis

The X-ray data used in this study have been retrieved from the $ROSAT$ public archive (obs. IDs 202075h, 202075h-1, 202075h-2). NGC 3532 was observed with the HRI during three separate pointings on January 21, 1996, July 28, 1996, and June 19, 1997. The net exposure times were respectively 30.5 ksec, 37 ksec, and 34 ksec. The nominal pointing position for all observations was RA $= 11^{\rm h}5^{\rm m}43.2^{\rm s}$, DEC $= -58^\circ 43' 12''$ (J2000).

The analysis was performed using EXSAS routines within MIDAS. We first checked the alignment of the three single images by comparing the positions of common sources; since the shifts between the images are very small (less than 1 image pixel), we did not apply any correction to the data. The three Photon Events Tables (PET) were then merged into a single PET, from which an image with a total exposure time of 101.5 ksec was generated. We then followed the standard steps for data reduction. A background map was created from the global image by removing outstanding sources previously detected with the LOCAL/DETECTION algorithm and then smoothing with a spline filter. Source detection was performed using the Maximum Likelihood (ML) algorithm. The ML algorithm was first run on a provisional list of sources obtained from the Local and Map Detection, resulting in the detection of 47 sources with ML > 10 (corresponding to a significance of 4σ), lying within 17 arcmin from the image center; two additional sources (nos. 48 and 49) were detected above the same threshold by running the ML on the input optical catalog. Of these sources, 15 have at least one cluster member counterpart within 10 arcsec, 13 have an optical counterpart which is probably a cluster non-member, and 21 do not have any known optical counterpart (additional positions of non-member stars from the survey of Andersen & Reiz 1983 and from the Guide Star Catalog have also been considered). The X-ray and optical properties

Table 1. Detected X-ray sources identified with cluster members within $10''$. Star numbering for cluster members is from Fernandez & Salgado (1980)

No.	$\alpha_{\rm x}$ (2000)	$\delta_{\rm x}$ (2000)	ML	count rate (10^{-5} s^{-1})	$L_{\rm x}$ (10^{29} erg/s)	Optical ident.	Δr ($''$)	Memb. pm v_r ph	V	B-V	Notes
4	11 05 53.07	-58 35 34.2	14.6	45 ± 10	2.3 ± 0.5	FS243	4.9	y - y	10.98	0.45	
5	11 05 46.99	-58 36 47.3	22.0	40 ± 8	2.0 ± 0.4	FS242	2.1	y - y	12.18	0.58	
8	11 06 33.24	-58 37 45.7	32.9	67 ± 11	3.4 ± 0.6	FS229	3.9	- - y	13.14	0.66	
11	11 04 37.02	-58 39 05.5	17.8	57 ± 12	2.9 ± 0.6	FS146	4.1	- - y	12.63	0.52	
12	11 05 33.78	-58 39 08.9	12.7	31 ± 8	1.6 ± 0.4	FS128	2.6	y - y	12.42	0.49	
18	11 05 35.15	-58 40 37.5	12.7	31 ± 8	1.5 ± 0.4	FS129	0.8	y - y	10.59	0.24	
21	11 04 52.84	-58 40 53.9	37.3	78 ± 12	3.9 ± 0.6	FS149	2.4	- - y	12.86	0.61	
22	11 06 23.06	-58 40 59.3	13.7	27 ± 7	1.4 ± 0.4	FS102	2.4	- - y	12.90	0.52	
						FS103	7.8	- - y	12.49	0.45	
25	11 04 33.38	-58 41 37.1	25.4	66 ± 12	3.4 ± 0.6	FS152	5.2	y ? y	7.82	0.91	g, SB?
27	11 05 49.99	-58 42 18.1	10.2	28 ± 8	1.4 ± 0.4	FS21	5.9	y - y	9.59	0.08	
37	11 05 18.25	-58 46 16.4	27.7	39 ± 8	2.0 ± 0.4	FS8	2.4	y - y	9.69	0.06	
40	11 04 35.32	-58 48 26.6	60.7	127 ± 16	6.5 ± 0.8	FS169	2.6	- - y	12.25	0.46	
						FS170	8.7	y - y	10.15	0.17	
42	11 05 28.75	-58 49 29.3	12.6	37 ± 9	1.9 ± 0.5	FS57	1.7	- - y	13.11	0.55	
48	11 04 14.02	-58 45 52.6	11.2	69 ± 17	3.5 ± 0.9	FS277	0.0	- - y	12.82	0.53	
49	11 05 52.18	-58 55 35.5	10.5	63 ± 16	3.2 ± 0.8	FS314	0.0	y - y	12.22	0.61	

Note: for proper motion membership, 'y' means $P \geq 80\%$, '?' means $65\% \leq P < 80\%$
A '-' in the membership columns indicates that no information is available

of the sources with an optical counterpart are listed in Tables 1 (cluster members) and 2 (non-members); the list of unidentified sources is given in Table 3. For the cluster members without associated X-ray sources we estimated 3σ upper limits from the background count rates at the optical position.

We note that sources no. 27 in Table 1 and nos. 24 and 31 in Table 2 are barely visible above the background on the X–ray image (as indicated also by their low ML) and therefore could be not real. However, since two of them are identified with cluster non-members (nos. 24 and 31) and the other with an A-type cluster member (no. 27), including or excluding them from our source list would not change our main results/conclusions.

We estimated the number of spurious identifications due to chance coincidences, following Randich et al. (1995). Such a number ($N_{\rm s}$), is given by:

$$N_{\rm s} = D_{\rm c} \times N_{\rm X} \times A_{\rm id.} \tag{1}$$

where $D_{\rm c}$ is the density of cluster candidates within the surveyed area (i.e., the number of clusters candidates divided by the HRI field of view), $N_{\rm X}$ is the number of X–ray sources, and $A_{\rm id.}$ is the area of our identification circle. Considering $D_{\rm c} = 174/(289 \times \pi)$ arcmin^{-2}, $N_{\rm X} = 49$, and $A_{\rm id.} = 0.028 \times \pi$ arcmin^2, we obtain $N_{\rm s} = 0.83$, i.e., less than one spurious identification.

X–ray luminosities were derived as follows. We assumed a conversion factor (CF) of 2.6×10^{-11} erg cm^{-2} sec^{-1} per HRI count sec^{-1}, estimated using PIMMS (version 2.7) assuming a Raymond-Smith plasma with $T = 10^6$ K and a column density $\log N_H = 20.3$ cm^{-2}; higher temperatures do not significantly affect the value of the conversion factor, and the same is true if a two-temperature model is assumed. X-ray luminosities for both detections and upper limits were then computed assuming a cluster distance of 405 pc. The resulting sensitivity in the center of the field is $L_{\rm x} \sim 3.6 \times 10^{28}$ erg sec^{-1}, a factor ~ 2 higher than the limiting sensitivity of the X-ray studies of the coeval cluster NGC 6475 (Prosser et al. 1995; James & Jeffries 1997). Had we assumed a 10% larger distance to the cluster ($d = 450$ pc), the X-ray luminosities and upper limits would have been a factor of 20% larger, not introducing any significant change in our results. Note that, due to the relative short exposure times of the three individual images, we are not able to put stringent constraints on source variability. We just mention that for the few X-ray sources that were detected in the single images we obtained count rates very similar to the ones that we inferred from the global image.

4. Results

As mentioned in the previous section, 15 sources have been identified with cluster members. For two sources (nos. 22 and 40) two cluster members are found within the identification radius. Our analysis resulted in the detection of 11 F–type cluster stars out of 48 (detection rate 23%), one G–type dwarf out of 13 (detection rate 8%), and one of the four giants. None of the five K dwarfs in our field has been detected. Four A–type stars were also detected. The detected stars are indicated as filled symbols in Fig. 1. The issue of X-ray emission from early-type (i.e., earlier than F0) stars which, due to the lack of a convective zone, cannot generate magnetic fields (and thus magnetic activity) via the dynamo process, has been discussed at length in several papers (e.g., Micela et al. 1996 and references therein); the most likely possibility is that their X-ray emission is due to unseen binary companions. Therefore, we focus the following discussion on solar-type (namely, F and G-type) stars only.

Table 2. Detected X-ray sources with an optical counterpart within $10''$ which is probably a cluster non-member

No.	α_x (2000)	δ_x (2000)	ML	count rate (10^{-5} s^{-1})	Optical ident.	Δr ($''$)	Memb. pm v_r ph	V	B-V	Notes
1	11 06 16.23	-58 33 32.9	259.8	307 ± 21	FS388	2.9	n - n	11.52	0.76	
7	11 05 03.49	-58 37 27.6	64.6	101 ± 13	GSC8627-2833	3.6	- - -	12.46		
13	11 05 22.34	-58 39 10.9	15.1	28 ± 7	FS132	1.1	n - n	11.30	0.53	
15	11 04 17.75	-58 39 42.5	34.1	112 ± 17	FS268	0.9	- - n	13.22	1.02	
16	11 05 53.74	-58 39 45.8	25.5	42 ± 8	FS115	1.6	n - y	8.51	-0.11	
19	11 05 45.68	-58 40 38.1	884.2	504 ± 24	FS122	1.8	? - n	8.20	0.93	*a*
24	11 06 45.78	-58 41 22.1	11.7	35 ± 9	FS219	2.1	n - n	11.23	0.53	
26	11 05 06.37	-58 42 09.4	20.6	44 ± 9	FS35	0.5	- - n	13.36	0.42	
31	11 06 08.79	-58 43 27.3	10.9	20 ± 6	FS90	1.0	n - n	11.78	0.63	
33	11 06 52.76	-58 44 58.3	89.3	130 ± 14	FS354	1.3	n - n	12.42	0.34	
36	11 06 08.98	-58 45 52.4	36.2	47 ± 8	FS84	0.9	n - y	12.03	0.53	
41	11 05 54.92	-58 49 02.0	97.0	111 ± 13	FS67	1.9	n - y	9.81	0.16	
43	11 06 01.14	-58 50 26.6	27.5	52 ± 10	FS196	1.7	y - n	11.96	0.74	

a) extended source. No known optical extended sources are present at the X-ray position

Table 3. Unidentified X-ray sources

No.	α_x (2000)	δ_x (2000)	ML	count rate (10^{-5} s^{-1})
2	11 06 03.56	-58 35 08.8	27.7	60 ± 11
3	11 05 42.97	-58 35 23.6	39.0	71 ± 11
6	11 06 29.65	-58 37 07.4	195.9	203 ± 17
9	11 05 09.88	-58 38 29.2	19.5	38 ± 8
10	11 05 02.23	-58 38 58.9	12.1	34 ± 9
14	11 06 05.99	-58 39 35.7	14.8	30 ± 7
17	11 05 25.66	-58 40 09.0	13.0	26 ± 7
20	11 06 19.93	-58 40 46.7	34.7	46 ± 8
23	11 06 18.71	-58 41 03.0	14.8	33 ± 8
28	11 05 12.42	-58 42 18.5	28.6	44 ± 8
29	11 06 54.20	-58 42 23.0	13.7	53 ± 12
30	11 05 52.48	-58 42 59.0	32.8	51 ± 9
32	11 05 06.18	-58 44 42.9	11.8	36 ± 9
34	11 04 50.82	-58 45 46.1	17.8	46 ± 10
35	11 07 03.09	-58 45 50.1	13.2	55 ± 13
38	11 05 45.86	-58 47 29.0	10.5	21 ± 6
39	11 05 20.57	-58 47 58.3	31.9	64 ± 11
44	11 05 10.28	-58 50 33.0	16.1	43 ± 10
45	11 05 43.34	-58 50 55.6	32.7	68 ± 11
46	11 05 52.01	-58 51 11.7	21.6	53 ± 11
47	11 05 53.15	-58 54 24.6	14.9	63 ± 14

As to the X-ray sources identified with non-members, they do not warrant much further discussion. Most of them, as indicated by their position on the C–M diagram are most likely G/early–K type foreground stars. Given that the cluster is basically located on the galactic plane, it is not surprising to find such a large contamination from cluster non-members among X-ray sources.

4.1. Comparison with other clusters

In Figs. 2a–2b we compare the $\log L_x$ vs. $(B-V)_0$ distribution of NGC 3532 with those of the supposedly coeval NGC 6475 cluster and the older Hyades. The comparison with NGC 6475 (Fig. 2a) suggests that the bulk of NGC 3532 F and G-type stars may be less X-ray luminous than NGC 6475. The few detections have X-ray luminosities comparable to the luminosities of similar stars in NGC 6475, but the majority of NGC 3532 solar-type stars were not detected; most important, the upper limits we derived for a very large fraction of the late–F and G–type stars in NGC 3532 are as low as or even below the luminosities of the least X-ray luminous stars of NGC 6475.

Given the low number of detections, a direct comparison of the X-ray luminosity distribution function (XLDF) of NGC 3532 with the XLDF of the coeval cluster NGC 6475 would not be of much help. In Fig. 3 we show instead the X-ray luminosity distribution function (XLDF) for G–type stars with $0.59 \le (B-V)_0 < 0.81$ in NGC 6475 with vertical bars indicating the upper limits and the one detection in this spectral range for NGC 3532. The figure seems to confirm that the population of solar-type stars in NGC 3532 is less X-ray active than NGC 6475. Such a conclusion is supported by a statistical comparison of the X-ray properties of G dwarfs in the two clusters, carried out using various two-sample tests as implemented in the Astronomy SURVival Analysis (ASURV) Ver. 1.2 software package (see Feigelson & Nelson 1985; Isobe et al. 1986); the tests indicate that the hypothesis that NGC 3532 and NGC 6475 solar-type stars are drawn from the same parent population can be rejected with a confidence level higher than 99.9 %. In addition, considering the XLDF of NGC 6475 and using the method described by Randich et al. (1998) for IC 4756, we estimate that the probability of getting the observed ULs distribution of NGC 3532 if the XLDF of NGC 3532 were the same as the one of NGC 6475 is virtually 0.

Several possibilities can explain our results: **a)** first, and most obviously, the reddening to the cluster could be significantly wrong; a higher reddening would mean a higher column density of absorbing material and would eventually imply that our upper limits (as well as the X–ray luminosities of the detected stars) are underestimated. However, all the sources in the literature, using different methods, agree in deriving a redden-

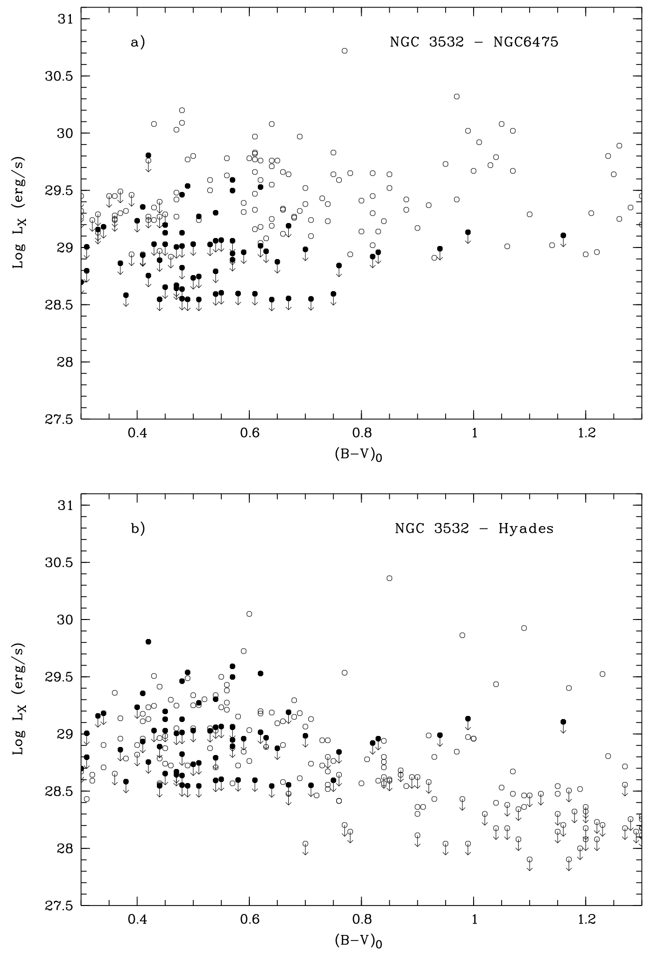

Fig. 2. Comparison of the relation $\log L_{\rm x}$ vs. $(B-V)_0$ of NGC 3532 with NGC 6475 (panel a) and the Hyades (panel b). Filled symbols denote NGC 3532 members, while open symbols indicate NGC 6475 and Hyades stars

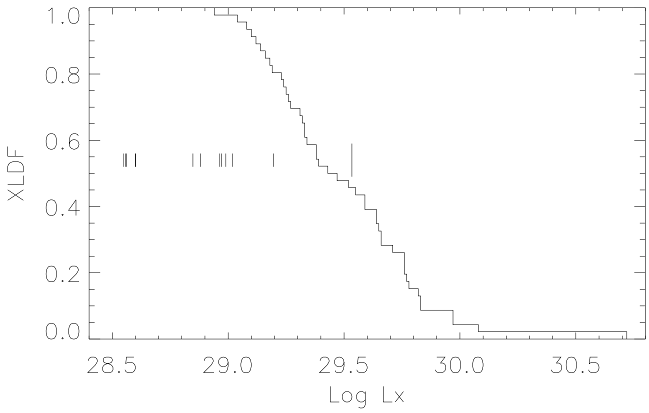

Fig. 3. Comparison of the X-ray luminosity distribution function (XLDF) for G dwarfs ($0.59 \le (B-V)_0 < 0.81$) in NGC 6475 (solid curve) with the upper limits (short vertical bars) and the one detection (long vertical bar) derived for NGC 3532. The XLDF for NGC 6475 has been constructed using the data from Prosser et al. (1995) and James & Jeffries (1997)

ing to the cluster $E(B-V) \le 0.1$, with the most quoted value being in fact $E(B-V) = 0.04$. If we assume a reddening as high as $E(B-V) = 0.1$ (Johannson et al. 1981), we get a factor 1.5 higher CF for $T = 10^6$ K (CF $= 4.0 \times 10^{-11}$ instead of 2.6×10^{-11} erg cm^{-2} sec^{-1} per HRI count sec^{-1}) and the same CF for higher temperatures; similar results are found using two-temperature models. Therefore, it seems rather unlikely that the use of an incorrect value for the reddening is the major cause of the discrepancy between NGC 6475 and NGC 3532; **b)** second, NGC 6475 is an X-ray selected sample, i.e. most of its solar–type and lower mass members were not known until X–ray surveys of the cluster were carried out and they were detected in X-rays. Therefore, we cannot exclude that a low activity (with X-ray luminosities below 10^{29} erg sec^{-1} – see Fig. 2a) population exists that was not detected in the two $ROSAT$ surveys of this cluster. The comparison of the XLDF of NGC 6475 with that of the Pleiades or other young clusters indeed suggests that this is a very likely possibility. Such a population would contribute to the low luminosity tail of NGC 6475 distribution function; nevertheless, Fig. 2a indicates that, as a matter of fact, NGC 3532 also lacks the high luminosity population that is present in NGC 6475. We conclude that, although the presence of an X-ray faint population in NGC 6475 would partly reduce the inconsistency between the two clusters, it could not completely cancel it, unless one assumes that the low X-ray luminosity population of NGC 6475 is 5–10 times more numerous than the high luminosity one; **c)** the NGC 3532 sample is incomplete and the membership for most of the late-type cluster members is based on photometry only. Therefore, on the one hand, our optical sample could be highly contaminated by non-members and, on the other hand, several other optically unknown members could exist. If all or most of the 21 X-ray sources without a known optical counterpart turn out to be solar-type (or later) cluster members and, at the same time, part of the optically selected members turn out to be non-members, the discrepancy between NGC 6475 and NGC 3532 would possibly be solved. The 21 unidentified X-ray sources if located at the cluster distance would have X-ray luminosities in the range $1.1 \times 10^{29} - 1.0 \times 10^{30}$ erg sec^{-1}; if all these sources were G–type cluster members, the XLDF for NGC 3532 would have indeed a median $\log L_{\rm x} = 29.3$, slightly lower than the median for NGC 6475 (29.4). Therefore we cannot exclude that the results presented here are due, at least in part, to the incompleteness of the presently known optical cluster sample; nevertheless, if this were true, it would be difficult in any case to explain why virtually all the currently known solar-type cluster members are X-ray faint; **d)** if neither point **b)** or **c)** (or both together) were proven to explain entirely why NGC 3532 is less X-ray luminous than NGC 6475, then the conclusion could be drawn that there is a *real* difference between the X-ray properties of the two clusters. In this case, two hypothesis could be made: *i)* NGC 3532 is actually older than NGC 6475; *ii)* NGC 6475 and NGC 3532 are about coeval, and our result represents an additional piece of evidence that the age–activity relationship is not unique. Fig. 2b indeed indicates that the X-ray properties of NGC 3532 may be more similar to those of the Hyades than to NGC 6475. Using again the two sample tests, we find that the hypothesis that NGC 3532 and Hyades solar-type stars are drawn from the same parent population can be excluded with a confidence level ranging between 95 and 98 %, depending on the adopted test. We mention that the age of NGC 3532 has been generally estimated using C–M diagram fitting or, in two cases, from the magnitude of the turn-off. As mentioned in the introduction different methods result in an age between 200 Myr (Fernandez & Salgado 1980; Johansson 1981) and 350 Myr (Eggen 1981); the most recent determinations give ~ 300 Myr (Koester & Reimers 1993; Meynet et al. 1993). Note that Meynet et al. (1993) using the same method/isochrones derived an age of ~ 220 Myr for NGC 6475; it seems, therefore, that NGC 3532 might be slightly older than NGC 6475, but not as old as the X-ray data would suggest.

5. Conclusions

We have analyzed $ROSAT$ archive data of the open cluster NGC 3532. The comparison of the X-ray properties of solar-type stars in the cluster with those of the supposedly coeval NGC 6475 cluster indicates that NGC 3532 is considerably X-ray underluminous with respect to NGC 6475. If this result is not due to selection effects and biases in the two cluster samples, it would provide an additional piece of evidence that the X-ray activity–age relationship is not unique and that other parameters, in addition to rotation, determine the level of coronal emission. However, before such a conclusion can be accepted, additional X-ray and optical observations should be performed. Namely, **I.** an additional X-ray survey of NGC 6475 should be carried out; the survey should be deeper than the $ROSAT$ ones so that, if present, an X-ray faint population of cluster members could be detected; **II.** additional photometric and spectroscopic studies of NGC 3532 should be carried out in order to confirm cluster membership for the optical candidates known at present and to detect still unidentified solar-type and lower mass stars in the cluster. These studies would also provide information on rotation for cluster members; **III.** If possible, an effort should also be done, once more low-mass cluster members are known, to provide a definitive estimate of the cluster age using also low main-sequence fitting.

Besides the 15 cluster members, the X-ray survey resulted in the detection of 13 foreground/background stars – which is not surprising given the low cluster galactic latitude – and of 21 objects without any known optical counterparts. Priority should be given to optical observations aimed at determining the nature of these sources, and, in particular, at ascertaining whether they are cluster members or not.

Acknowledgements. We thank the referee, Dr. F. Verbunt, for useful comments and suggestions.

References

Andersen, T.B., Reiz, A., 1983, A&AS 53, 181

Barrado y Navascués, D., Stauffer, J.R., Randich, S., 1998, ApJ 506, 347

Belloni, T., 1997, Mem. SAIt 68, 993

Butler, C.J., 1977, MNRAS 178, 159

Clariá, J.J., Lapasset, E., 1988, MNRAS 235, 1129

Eggen, O.J., 1981, ApJ 246, 817

Feigelson, E.D., Nelson, P.I., 1985, ApJ 293, 192

Fernandez, J.A., Salgado, C.W., 1980, A&AS 39, 11

Franciosini, E., Randich, S., Pallavicini, R., 2000, in: Stellar Clusters and Associations: Convection, Rotation, and Dynamos, ASP Conf. Ser., R. Pallavicini, G. Micela & S. Sciortino (eds.), in press

Gieseking, F., 1980, A&AS 41, 245

Gieseking, F., 1981, A&A 99, 155

Harris, G.L.H., 1976, ApJS 30, 451

James, D.J., Jeffries, R.D., 1997, MNRAS 291, 252

Jeffries, R., 1999, in: Solar and Stellar Activity: Similarities and Differences, C.J. Butler and J.G. Doyle (eds.), ASP Conference Series 158, p. 75

Johansson, K.L.V., 1981, A&AS 43, 421

Isobe, T., Feigelson, E.D., Nelson, P.I., 1986, ApJ 306, 490

King, D.S., 1978, Sydney Obs. Pap. no. 79

Koelbloed, D., 1959, Bull. Astr. Inst. Neth. 14, 265

Koester, D., Reimers, D., 1993, A&A 275, 479

Meynet, G., Mermilliod, J.-C., Maeder, A., 1993, A&AS 98, 477

Micela, G., Sciortino, S., Kashyap, V., Harnden, F.R. Jr., Rosner, R., 1996, ApJS 102, 75

Noyes, R.W., Hartmann, L.W., Baliunas, S.L., Duncan, D.K., Vaughan, A.H., 1984, ApJ, 279, 763

Prosser, C.F., Stauffer, J.R., Caillault, J.-P., Balachandran, S., Stern, R.A., Randich S., 1995, AJ 110, 1229

Randich, S., 2000, in: Stellar Clusters and Associations: Convection, Rotation, and Dynamos, ASP Conf. Ser., R. Pallavicini, G. Micela & S. Sciortino (eds.), in press

Randich, S., Schmitt, J.H.H.M., 1995, A&A 298, 115

Randich, S., Schmitt, J.H.H.M., Prosser, C.F., Stauffer, J.R., 1995, A&A 300, 134

Randich, S., Schmitt, J.H.H.M., Prosser, C.F., 1996, A&A 313, 815

Randich, S., Singh, K.P., Simon, T., Drake, S.A., Schmitt, J.H.H.M., 1998, A&A 337, 372

Robichon, N., Arenou, F., Mermilliod, J.-C., Turon, C., 1999, A&A 345, 471

Schneider, H., 1987, A&AS 71, 147

Totten, E.J., Jeffries, R.D., Harmer, S., Pye, J., 2000, in: Stellar Clusters and Associations: Convection, Rotation, and Dynamos, ASP Conf. Ser., R. Pallavicini, G. Micela & S. Sciortino (eds.), in press

Wizinowich, P., Garrison, R.F., 1982, AJ 87, 1390