XMM-*NEWTON* OBSERVATIONS OF THE PRAESEPE CLUSTER

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Abstract

The Praesepe open cluster represents a puzzle since it has about the same age as the Hyades, and only slightly different metallicity, yet previous *ROSAT* observations resulted in a detection rate of cluster sources significantly lower than for the Hyades. We present a new 50 ksec observation of the Praesepe cluster performed with the EPIC instrument on board XMM-*Newton*, which resulted in the detection of ~ 190 sources, including 44 cluster members. We detected all solar-type (F–G) stars in the field of view, 90% of the K stars and 60% of the M stars. We find that the distribution of X-ray luminosities of solar-type Praesepe members is only slightly below that of the Hyades, in contrast with the previous *ROSAT* results; however, the disagreement between the *ROSAT* and XMM-*Newton* results appears to be mostly due to X-ray faint Praesepe members falling outside the XMM-*Newton* field of view, being considerably reduced when considering only the subsample of stars in the *ROSAT* survey in common with the present observation. The problem of the discrepancy between Hyades and Praesepe therefore remains open.

Key words: Open clusters and associations: individual: Praesepe – stars: coronae – X-ray: stars

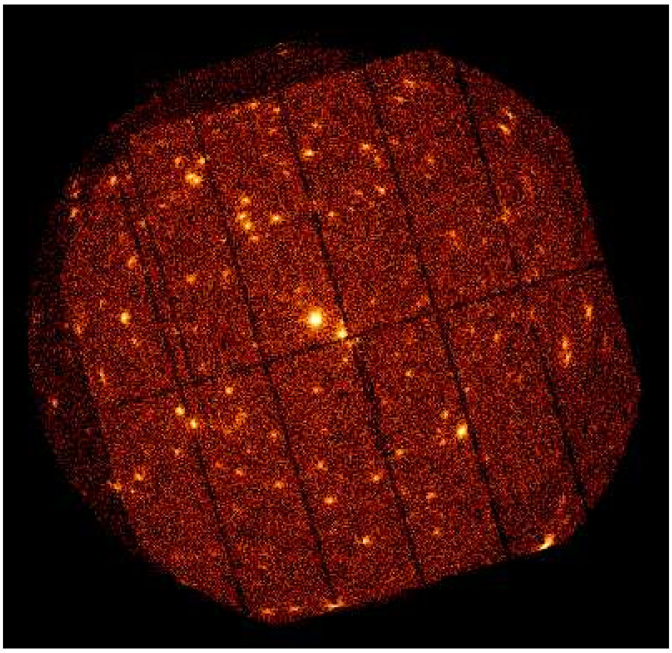

Figure 1. Composite EPIC MOS1+MOS2+PN image of the Praesepe field

1. Introduction

The *ROSAT* satellite has provided X-ray data for a large sample of open clusters of different ages, generally confirming the age-rotation-activity paradigm (ARAP) for solar-type and lower-mass stars (e.g. Randich 1997; Jeffries 1999; Randich 2000). However, a few puzzling results have emerged from the *ROSAT* data that cannot be explained in the global framework of the ARAP. More specifically, the age-activity relationship does not seem to be universal.

Randich & Schmitt (1995) (hereafter RS95), based on a *ROSAT* raster scan survey of the Praesepe cluster, were the first to cast doubts on the common assumption that the X-ray properties of a cluster at a given age are representative of all clusters at that age. Their observations resulted in a rate of detection of solar-type stars in the Praesepe cluster significantly lower than for the coeval Hyades cluster, implying that the bulk of the population of Praesepe solar-type stars was considerably less X-ray luminous than the Hyades. Optical studies seem to esclude that the discrepancy might be due to contamination of the Praesepe X-ray sample by non-members (Barrado y Navascues et al. 1998) or to different distributions of rotation rates in the two clusters (Mermilliod 1997) or to significantly different metallicities. Other exceptions to the ARAP were reported for NGC 6633 (Totten et al. 2000; Franciosini et al. 2000b; Harmer et al. 2001), NGC 3532 (Franciosini et al. 2000a) and NGC 6475 (Prosser et al. 1995; Randich 2000). The issue of the universality of the activity-age relationship is therefore not at all settled.

2. Observations and data analysis

In order to further address this problem, we have performed a new observation of the Praesepe cluster with the EPIC cameras on board XMM-*Newton*. The cluster was observed on November 7-8, 2000 (ID 0101440401) as part of the GT programme; the observation lasted ~ 47 ksec, for an effective exposure time of 45.5 ksec in MOS1/MOS2

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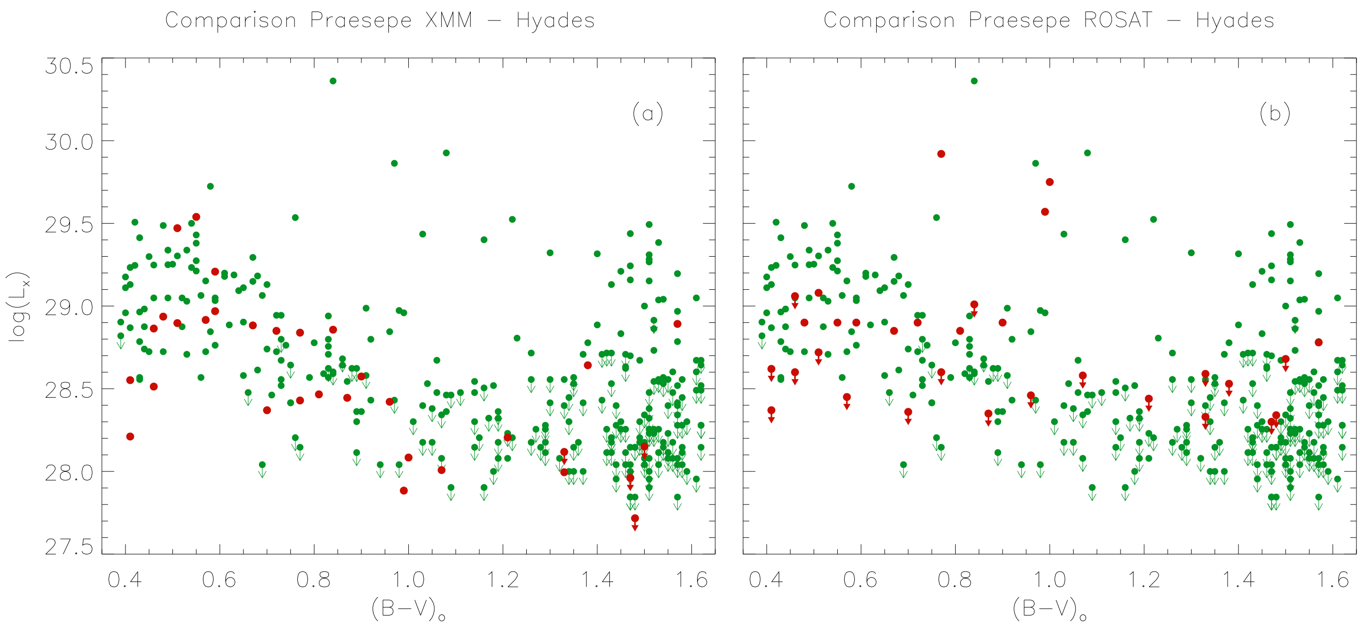

Figure 2. *Comparison of the* $\log L_X$ *vs.* $(B-V)_\circ$ *distribution of Praesepe (red points) with that of the Hyades (green points). In panel (a) we plot the Praesepe X-ray luminosities derived from the present XMM-Newton observation; panel (b) shows the Praesepe X-ray luminosities derived from the ROSAT observations of the same sample of stars. The Hyades data are from the ROSAT All-Sky Survey observations by Stern et al. (1995)*

and 43 ksec in PN. The thick and the medium filters were used for MOS and PN, respectively.

Data analysis was carried out using the standard tasks in SAS v.5.2. After checking the relative alignment of the three cameras by comparing the positions of common sources, we merged the three event files into a single dataset. A combined exposure map was obtained by summing the individual exposure maps of the single instruments with an appropriate scaling factor for PN, in order to take into account the different sensitivities of MOS and PN. The scaling factor was derived by measuring the ratio of PN to MOS count rates for the detected sources: we found a median ratio PN/MOS ~ 4.3 in the 0.3-8 keV energy band. This implies for the merged dataset an equivalent MOS exposure time of 248 ksec. The combined EPIC image is shown in Fig. 1.

We have constructed a catalogue of probable and possible cluster members based on the proper motion surveys by Klein-Wassink (1927), Jones & Cudworth (1983), Jones & Stauffer (1991), Hambly et al. (1995) and Wang et al. (1995); additional stars from the radial velocity study by Mermilliod et al. (1990) and from the photometric surveys of low-mass stars by Williams et al. (1995) and Pinfield et al. (1997) were added. Photometry and radial velocity information was retrieved from several studies. We selected as probable or possible members those stars with radial velocity within 5 km/s of the cluster mean v_r (34.5 km/s), when available, or with membership probability from proper motions greater than 50%, and having photometry consistent with cluster membership.

The resulting catalogue contains a total of 141 stars falling in the XMM-*Newton* field of view, of which 59 are probable or possible members, including two giants.

3. Results

We performed a source detection on the combined dataset using the Maximum Likelihood (ML) algorithm: this resulted in the detection of 167 sources with $ML > 10$ (corresponding to 4σ); 22 additional sources were detected above the same level on the single instrument datasets, giving a total number of 189 sources. Of these sources, 44 have a cluster member counterpart within 10″, including the two giants. Nine additional sources have been identified with cluster non-members. For the remaining members with no associated X-ray source we estimated 3σ upper limits from the background count rates.

X-ray luminosities for both detections and upper limits have been computed using a conversion factor of 6.0×10^{-12} erg sec^{-1} cnt^{-1} for a single MOS camera (derived using PIMMS for a Raymond-Smith plasma with $\log T = 7$ and $N_H = 5 \times 10^{19}$ cm^{-2}) and a distance of 170 pc. The sensitivity reached in the central 10 arcmin of the field is $L_X \sim 5 \times 10^{27}$ erg sec^{-1}, i.e. a factor ~ 4 lower than the previous *ROSAT* observations.

The distribution of X-ray luminosities of Praesepe compared to that of the Hyades is shown in Fig. 2.

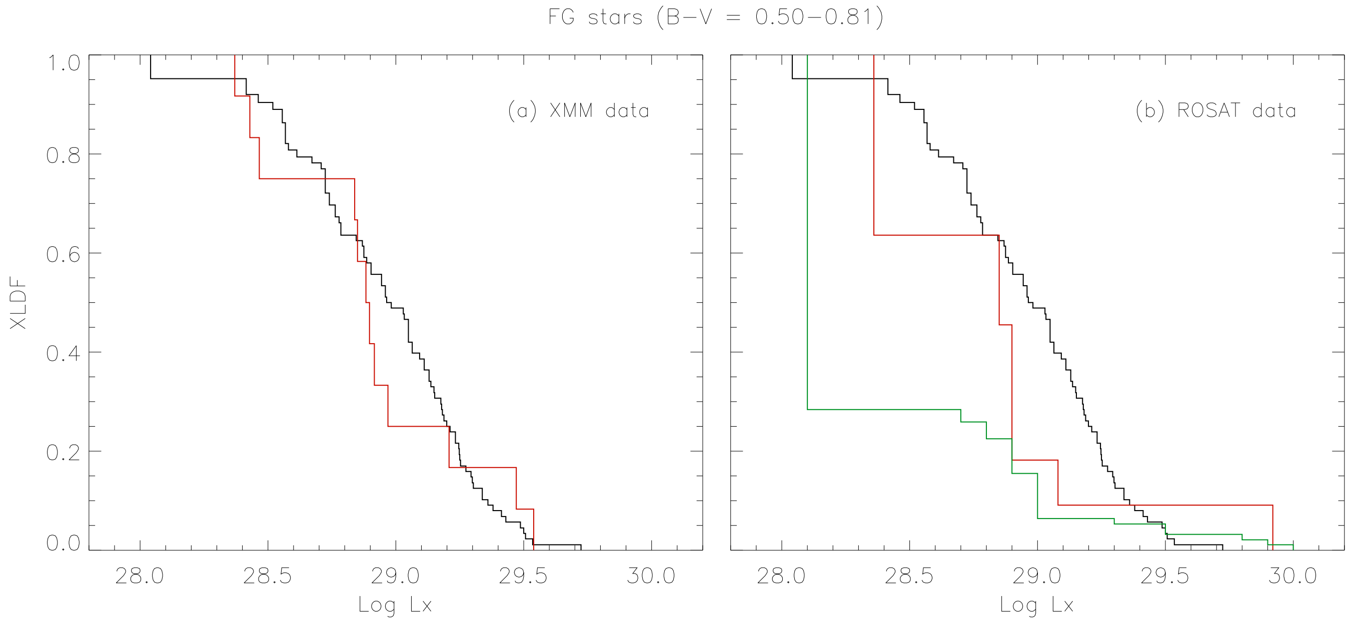

Figure 3. Comparison of the X-ray luminosity distribution function (XLDF) of Praesepe (red line) and the Hyades (black line) for F-G dwarf stars in the colour range $0.50 \leq (B-V)_\circ \leq 0.81$*. In panel (a) we show the Praesepe XLDF obtained from the present XMM-Newton data. Panel (b) shows the XLDF derived, for the same sample of stars, from the previous ROSAT observations; for comparison, we also show in green the Praesepe XLDF derived from the entire ROSAT sample. The Hyades XLDF was derived from the ROSAT All-Sky Survey observations by Stern et al. (1995)*

3.1. Early-type stars

Eight A- and early F-type stars have been detected in our observation. These stars, due to the lack of a convection zone, cannot generate magnetic fields via the dynamo process, and thus should not be X-ray emitters. The most likely possibility is that their X-ray emission is due to an unseen late-type companion. Indeed, three of these stars (KW224, KW268 and KW279) are known SB1 binaries.

3.2. Solar-type stars

We detected all solar-type stars ($0.5 \leq \mathrm{B-V} \leq 0.81$) included in the field of view. The detection rates for F and G-type stars separately are of 100 %.

The comparison of the XLDF of the Praesepe solar-type members in our field of view with the Hyades does not evidence a discrepancy as large as found by RS95 (Fig. 3); nevertheless, the XLDF of Praesepe still lies somewhat below that of the Hyades. Correspondingly, the median luminosity ($\log L_\mathrm{X} = 28.88$) as well as the 25th and 75th percentiles ($\log L_\mathrm{X} = 28.97$ and 28.47, respectively) are smaller (note that the median luminosity of the Hyades is equal to the 25th percentile of Praesepe). Due to the small size of the present Praesepe sample this may be due to low number statistics. To carry out a more quantitative comparison between the two cluster populations, we performed various two-sample tests, that, however, were all inconclusive.

Our results for solar-type stars seem to contradict the previous results by RS95 based on the *ROSAT* raster scan survey of Praesepe. However if one considers only the subsample of Praesepe stars in the survey of RS95 in common with the present sample, the disagreement between XMM-*Newton* and *ROSAT* based results is considerably reduced. More specifically:

- seven out of the 11 solar-type stars in common were detected by RS95; except for one case, *ROSAT* luminosities are in general similar to those derived by us (see Fig. 4);
- for three of the four undetected stars the upper limits inferred by RS95 are comparable to our estimate of the X-ray luminosities. Only for one star (KW208) the upper limit of RS95 is smaller than our luminosity. The difference in the detection rates is then due to the different sensitivities of the two surveys;
- the median luminosity that we derive based on *ROSAT* luminosities (or upper limits) for the 11 stars in common is comparable to the median luminosity that we derive from the present XMM-*Newton* observations.

In other words, the overall discrepancy between the X-ray properties of the Hyades and Praesepe pointed out by RS95 seems mostly due to X-ray faint Praesepe members outside our XMM-*Newton* field of view (see Fig. 3).

Holland et al. (2000) made the hypothesis that Praesepe is formed by two merging clusters. They found that the X-ray brightest sources are almost exclusively located in the "main" cluster and suggested a difference in age

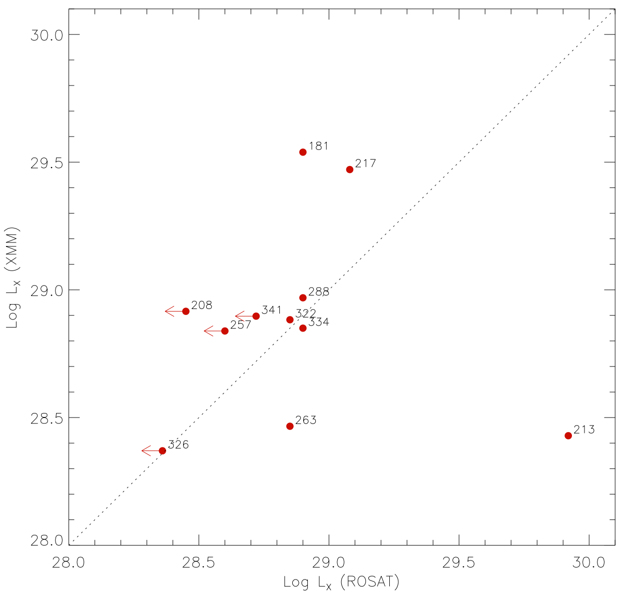

Figure 4. Comparison of the X-ray luminosities of F-G stars in the XMM-Newton field of view derived from XMM-Newton and ROSAT. Numbers are star numbers from Klein-Wassink (1927)

between the main cluster and the subcluster as an explanation for the *ROSAT* based results. Our XMM-*Newton* observation indeed covers a small area of the main cluster and thus presumably includes the X-ray brighter cluster population.

3.3. K- and M-type dwarfs

RS95 detected a very small fraction of the K and M dwarfs covered by their raster scan observations. The higher sensitivity of our present XMM-*Newton* observation resulted in the detection of 10 of the 11 K-dwarfs (91%) and 12 of the 20 M dwarfs (60%) in the field of view. The X-ray luminosities that we derive for the detected stars are of the same order of the upper limits inferred by RS95 and thus our results are consistent with theirs. The X-ray properties of K and M dwarfs in Praesepe are similar to the Hyades, although the XLDFs of Praesepe lack the high luminosity tail ($\log L_{\rm X} \geq 29$) which is instead evident in the XLDFs of the Hyades. We mention the detection of the very low-mass star WRS4 which is well below the fully convective boundary (it has an estimated mass equal to 0.13 $M_\odot$). For this star we derived an X-ray luminosity $L_{\rm X} = 2.37 \times 10^{28}$ erg sec^{-1}.

4. Conclusions

Our results are not inconsistent with those of RS95. Our improved sensitivity has allowed us to detect, and better constrain the luminosities of, X-ray faint solar-type and lower-mass stars in the field of view. The X-ray properties of our small sample of Praesepe solar-type stars show a better agreement with the Hyades, although the latter still remain somewhat more X-ray luminous. The rather small field of view of our observation, however, does not allow us to discern whether our sample stars are indeed representative of the whole Praesepe population. The problem of the discrepancy between Praesepe and the Hyades, which apparently shows up only when considering a much larger area of the Praesepe cluster, remains open. Additional XMM-*Newton* pointings across the cluster are required to settle this issue and check the hypothesis that Praesepe may be formed by two merged clusters.

References

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

Franciosini, E., Randich, S., Pallavicini, R. 2000a, A&A 357, 139

Franciosini, E., Randich, S., Pallavicini, R. 2000b, in ASP Conf. Ser. 198, Stellar Clusters and Associations: Convection, Rotation, and Dynamos, eds. R. Pallavicini et al. (San Francisco: ASP), 447

Hambly, N. C., Steele, I. A., Hawkins, M. R. S., Jameson, R. F. 1995, A&AS 109, 29

Harmer, S., Jeffries, R. D., Totten, E. J., Pye, J. P. 2001, MNRAS 324, 473

Holland, K., Jameson, R. F., Hodgkin, S., Davies, M. B., Pinfield, D. 2000, MNRAS 319, 956

Jeffries, R. D. 1999, in ASP Conf. Ser. 158, Solar and Stellar Activity: Similarities and Differences, eds. C. J. Butler & J. G. Doyle, (San Francisco: ASP), 75

Jones, B. F., Cudworth, K. 1983, AJ 88, 215

Jones, B. F., Stauffer, J. R. 1991, AJ 102, 1080

Klein-Wassink, W. J. 1927, Publ. Kapteyn Astron. Lab. Groningen 41, 1

Mermilliod, J.-C. 1997, Mem. Soc. Astr. It. 68, 853

Mermilliod, J.-C., Weis, E. W., Duquennoy, A., Mayor, M. 1990, A&A 235, 114

Pinfield, D. J., Hodgkin, S. T., Jameson, R. F., Cossburn, M. R., von Hippel, T. 1997, MNRAS 287, 180

Prosser, C. F., Stauffer, J. R., Caillault, J.-P., et al. 1995, AJ, 110, 1229

Randich, S. 1997, Mem. Soc. Astr. It. 68, 971

Randich, S. 2000, in ASP Conf. Ser. 198, Stellar Clusters and Associations: Convection, Rotation, and Dynamos, eds. R. Pallavicini et al. (San Francisco: ASP), 401

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

Stern, R. A., Schmitt, J. H. M. M., Kahabka, P. T. 1995, ApJ 448, 683

Totten, E., Jeffries, R., Harmer, S., Pye, J. 2000, in ASP Conf. Ser. 198, Stellar Clusters and Associations: Convection, Rotation, and Dynamos, eds. R. Pallavicini et al. (San Francisco: ASP), 451

Wang, J. J., Chen, L., Zhao, J. H., Jiang, P. F. 1995, A&AS 113, 419

Williams, D. M., Rieke, G. H., Stauffer, J. R. 1995, ApJ 445, 359