A ROSAT HRI study of the open cluster NGC 6633

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Abstract. We present a ROSAT HRI study of the open cluster NGC 6633. The observed field contains 52 probable cluster members, including four giants. Our analysis resulted in the detection of 24 X-ray sources of which 6 have an optical counterpart within 10". Of the probable cluster members, we detected 3 F-type stars out of 14, one G-type dwarf out of 5, and one of the giants. None of the seven K dwarfs in our field has been detected. A statistical comparison with the Hyades and Praesepe clusters is shown.

1. Introduction

The ROSAT satellite has provided X-ray data for a large sample of open clusters of different ages. The age–rotation–activity paradigm is generally confirmed (see Randich 1999) but, at the same time, a few puzzling results have emerged from ROSAT data. The most famous “mistery” is the case of Praesepe. X-ray observations of this cluster have shown that the bulk of its population has a lower X-ray luminosity than the coeval Hyades and Coma Berenices (Randich & Schmitt 1995; Randich et al. 1996), casting doubts on the common thinking that the X-ray properties of a cluster at a given age can be considered representative of all clusters of that age. Studies of additional clusters of similar age are therefore required to solve this problem.

We present here ROSAT HRI observations of the open cluster NGC 6633. This cluster is in principle an ideal candidate for such studies: it has a quoted age between 450 and 600 Myr, comparable to that of the Hyades and Praesepe, and a lower metallicity ([Fe/H] \sim –0.1). We anticipate, however, that, given its reddening $E(B - V) = 0.15$ (Jeffries 1997) and its distance $d = 380$ pc (Lyng\AA & A 1987), even a $\sim 120$ ksec HRI exposure was not sensitive enough to allow constraining the X-ray properties of its solar-type members.

2. Observations and data analysis

We have retrieved from the ROSAT archive the data relative to an HRI observation of NGC 6633. The observation was carried out from Sept. 13 to Sept. 26, 1995, for a total exposure time of 118.8 ksec.
The analysis was performed using EXSAS routines in MIDAS and following the usual steps. An X-ray image was obtained from the Photon Event Table using channels 3–15 and a binsize of 5". We first performed a source detection on the image using the Maximum Likelihood (ML) algorithm. This resulted in the detection of 24 sources with ML > 8.5 (3.5 σ), lying within 17" from the image center. The observed field and the X-ray sources are shown in Fig. 1. Six of the sources have a known optical counterpart within 10"; their X-ray and optical properties are listed in Table 1.

We have constructed a catalog of probable cluster members in our field using membership information derived from the recent radial velocity study by Jeffries (1997), or from the proper motion survey by Sanders (1973); additional information was taken from Hiltner et al. (1958) and Mermilliod & Mayor (1989). Stars with radial velocity within ±5 km/sec of the cluster mean $v_r$ (−28 km/sec), when available, or with membership probability greater than 80% were selected as probable members. The resulting catalog contains 52 probable cluster members, including four giants. A ML run on this catalog did not result in any additional detection. For the stars with no associated X-ray source we estimated 3σ upper limits from the background count rates.

3. Results

X-ray luminosities for both detections and upper limits have been computed using a conversion factor of $7.6 \times 10^{-11}$ erg cm$^{-2}$ sec$^{-1}$ per HRI count sec$^{-1}$
Table 1. Detected X-ray sources with an optical counterpart. The star numbering is from Jeffries (1997; J) and Sanders (1973; S)

<table>
<thead>
<tr>
<th>No.</th>
<th>$\alpha_x$ (2000)</th>
<th>$\delta_x$ (2000)</th>
<th>ML</th>
<th>count rate (10^{-5} cts/s)</th>
<th>$L_x$ (10^{29} erg/s)</th>
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<tr>
<td>1</td>
<td>18 28 17.66</td>
<td>+6 46 05.3</td>
<td>48.6</td>
<td>209 ± 25</td>
<td>27.2 ± 3.2</td>
</tr>
<tr>
<td>2</td>
<td>18 27 43.35</td>
<td>+6 41 15.4</td>
<td>18.1</td>
<td>39 ± 8</td>
<td>5.1 ± 1.1</td>
</tr>
<tr>
<td>10</td>
<td>18 27 26.29</td>
<td>+6 34 18.5</td>
<td>33.7</td>
<td>38 ± 7</td>
<td>4.9 ± 0.9</td>
</tr>
<tr>
<td>15</td>
<td>18 28 00.53</td>
<td>+6 31 47.4</td>
<td>9.2</td>
<td>22 ± 7</td>
<td>2.9 ± 0.9</td>
</tr>
<tr>
<td>18</td>
<td>18 27 45.46</td>
<td>+6 29 22.4</td>
<td>206.2</td>
<td>141 ± 12</td>
<td>18.3 ± 1.6</td>
</tr>
<tr>
<td>20</td>
<td>18 27 07.37</td>
<td>+6 27 55.9</td>
<td>8.6</td>
<td>25 ± 7</td>
<td>3.3 ± 1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>Optical ident.</th>
<th>offset (&quot;)</th>
<th>V</th>
<th>$B - V$</th>
<th>$u_r$ (km/s)</th>
<th>Prob. (%)</th>
<th>Notes</th>
</tr>
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<tr>
<td>1</td>
<td>BD+06 3796</td>
<td>5.7</td>
<td>8.95</td>
<td>1.01</td>
<td>-29.1</td>
<td>43</td>
<td>gK</td>
</tr>
<tr>
<td>2</td>
<td>J25</td>
<td>4.1</td>
<td>11.36</td>
<td>0.54</td>
<td>-56/-12</td>
<td>89</td>
<td>SB</td>
</tr>
<tr>
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<td>J34</td>
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<td>12.44</td>
<td>0.62</td>
<td>-25.15</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>S407</td>
<td>2.1</td>
<td>10.91</td>
<td>0.55</td>
<td></td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>S359</td>
<td>0.8</td>
<td>10.88</td>
<td>0.42</td>
<td></td>
<td>69</td>
<td>non member?</td>
</tr>
<tr>
<td>20</td>
<td>J27</td>
<td>2.2</td>
<td>13.47</td>
<td>0.79</td>
<td>-26.9</td>
<td>93</td>
<td></td>
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</table>

(which was obtained using PIMMS and assuming a Raymond-Smith plasma with $kT = 1$ keV and $\log N_H = 21$ cm$^{-2}$) and a cluster distance of 380 pc.

As mentioned in the Introduction, we find that the observation is not deep enough to constrain the cluster solar-type stars X-ray luminosity function: the sensitivity in the center of the field is in fact $L_x \sim 7 \times 10^{28}$ erg sec$^{-1}$, slightly below the median luminosity of the Hyades G dwarfs. However many cluster members lie at large off-axis distances and, therefore, considerably higher upper limits to their luminosities were inferred.

Our analysis resulted in the detection of 3 F-type cluster stars out of 14 (detection rate 21%), one G-type dwarf out of 5 (detection rate 20%), and one of the giants. None of the seven K dwarfs in our field has been detected.

Given the low number of detections and the relatively high upper limits, it is impossible to compare directly the X-ray luminosity distribution function (XLDF) of NGC 6633 with the XLDFs of the Hyades and Praesepe. In Fig. 2 we show the XLDF for F-G type stars with $0.43 \leq (B - V)_o < 0.81$ in the Hyades and Praesepe; vertical bars indicate the upper limits and the two detections in this spectral range for NGC 6633. A statistical comparison of the X-ray properties of solar-type stars in NGC 6633 and in the Hyades and Praesepe shows that the probability that they are drawn from the same population are 0.027 and 0.341 respectively. Therefore it appears that F-G stars in NGC 6633 are less X-ray active than the Hyades; nothing can be said about Praesepe.

All the detected dwarfs in NGC 6633 have an $L_x$ comparable to the high-luminosity tail of the XLDF of the Hyades. Since most of the high-luminosity stars of the Hyades are known active binaries, it is likely that also our detections are binaries. Indeed, J25 is a known spectroscopic binary; the others have no sufficient radial velocity measurements to derive information on binarity. We
also note that the detected giant (BD+06 3796), with \( L_x = 2.7 \times 10^{30} \) erg/sec, is among the most active giants observed so far in other clusters of similar age. Finally, we mention that a similar study (using the same data!) has been carried out by Briggs et al. (1999) and Totten et al. (1999). Although in their study they claim a limiting sensitivity comparable to ours, they detected a larger number of X-ray sources (32). Note that this is not due to the choice of a different detection threshold, but the images themselves appear to be different. Efforts to understand the discrepancy are being carried out at present.

References

Randich, S. 1999, these Proceedings
Sanders, W.L. 1973, A&AS, 9, 213