X-RAY SURVEY OF THE PLEIADES: DEPENDENCE OF X-RAY LUMINOSITY ON STELLAR AGE

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The study of X-ray emission of stellar clusters, allows to decouple the influence of some individual stellar parameters, as initial conditions, composition and age, on the stellar X-ray luminosity function.

In order to be studied in the soft X-ray band, a cluster must be sufficiently near for its stars to be detected in "normal" observations times (10^3 - 10^4 sec); this means that the cluster must have a maximum distance ≤ 150 pcs. The clusters which meet this requirement are only a few, namely: the Hyades, Ursa Major, Coma and the Pleiades.

A detailed study on the central region of the Hyades has been done by Stern et al. (1981). They have detected X-ray emission above a threshold of 10^{23.5} ergs/sec from ~ 50% of the cluster stars. The median X-ray luminosity for dwarfs G Hyades stars resulted to be ~ 30 times the luminosity of the Sun which is ~ 1 order of magnitude older. Since the Pleiades are even younger than Hyades, a survey of this cluster can improve our knowledge of the dependence between X-ray luminosity and stellar age.

We report here preliminary results from an Einstein X-ray survey of the Pleiades. We have analysed, using the standard Einstein Observatory software a 1° x 1° exposure centered over one of the more luminous stars of the cluster (20 TAU, [B7-III]), taken with Imaging Proportional Counter (IPC) (Giacconi et al., 1979) which is sensitive to X-rays in the energy band .15 - 4.0 KeV with a energetic resolution (ΔE/E) of ~ 1 at 1.0 KeV and a spatial resolution of ~ 1'.

This field contains ~ 62 cluster members out of a total of ~ 270 stars with magnitude lower than 14^m. (Hertzsprung, 1947).

The exposure time of the observation sets a detection threshol of ~ 10^{29.5} ergs/sec. With this threshold we have detected 17 distinct X-ray sources; 16 sources are identified with a cluster stars within a distance less than 1'. The probability of a chance identification is ≤ 2 10^{-3}. X-ray emission from 2 (out of 8) B stars, 1 (out of 9) A star, 3 (out of 6) F stars, 8 (out of 19) G stars, 2 (out of 20) K stars has been detected. The brightest X-ray sources is Hz 303‡ (spectral type G1), which has Log L_X ~ 30.3.

We give in Table 1 the X-ray luminosities, together with the optical properties, of the detected sources.

The estimated error on the values of the X-ray luminosity is ~ 40% compounded by a statistical error ranging from 10 % to 30%, sismatic errors in instrument calibration < 20% (Harnden et al., 1979), error in the individual cluster member

‡ In the following will use the numeration of Hertzsprung, 1947.
TABLE 1

<table>
<thead>
<tr>
<th>X-ray Source #</th>
<th>$L_X$ [ergs/sec]</th>
<th>Counterpart Hz II #</th>
<th>Sp</th>
<th>$m_V$</th>
<th>B - V</th>
<th>Note*</th>
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<tr>
<td>1E 0340.9+2404</td>
<td>7.2</td>
<td>193</td>
<td>G7*</td>
<td>11.29</td>
<td>+0.81</td>
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<tr>
<td>1E 0341.1+2406</td>
<td>6.3</td>
<td>263</td>
<td>G8*</td>
<td>11.54</td>
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<tr>
<td>1E 0341.3+2356</td>
<td>19.0</td>
<td>303</td>
<td>G9*</td>
<td>10.48</td>
<td>+0.89</td>
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<tr>
<td>1E 0341.4+2437</td>
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<td>320</td>
<td>G5*</td>
<td>11.04</td>
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<tr>
<td>1E 0341.5+2425</td>
<td>9.3</td>
<td>345</td>
<td>G8*</td>
<td>11.65</td>
<td>+0.86</td>
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<tr>
<td>1E 0342.2+2419</td>
<td>5.5</td>
<td>563</td>
<td>B6*</td>
<td>4.31</td>
<td>-0.11</td>
<td>19 TAU</td>
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<td>1E 0342.6+2355</td>
<td>6.6</td>
<td>708</td>
<td>G0*.</td>
<td>10.13</td>
<td>+0.82</td>
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<tr>
<td>1E 0342.6+2408</td>
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<td>686</td>
<td>K2*</td>
<td>13.62</td>
<td>+1.04</td>
<td>f v</td>
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<tr>
<td>1E 0342.7+2403</td>
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<td>F9.</td>
<td>9.70</td>
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<td>v</td>
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<tr>
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<td>956</td>
<td>F0*.</td>
<td>7.96</td>
<td>+0.32</td>
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<tr>
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<td>980</td>
<td>B6IV*</td>
<td>4.18</td>
<td>-0.06</td>
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<td>1100</td>
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<td></td>
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</tbody>
</table>

* v indicates variable star, f flare star, d binary system.
† Spectral type determined from B-V values (Johnson & Mitchell, 1958; Jones, 1973; Landolt, 1979; Stauffer, 1980) corrected for reddening, using as mean E(B-V)=0.04 (Crawford & Perry, 1976).

Fig. 1 - Dependence of median X-ray luminosity from age for different samples of G stars: a) pre-main sequence stars (Ku & Chanan, 1979; Feigelson & De Campili, 1981); b) main sequence G stars in the Pleiades (present work); c) main sequence G stars in the Hyades (Stern et al., 1981); d) local disk population G dwarfs (Vaiana et al., 1981; Topka et al., 1981; Rosner et al., 1981). Solid line indicates the median value and the error bar represents the uncertainty in age determination. The range of observed luminosities is indicated by •; the lower limit is always fixed by the best detection treshold for each group.
distance < 3\%, and a systematic error in converting counts to flux < 20\% due to the assumed hydrogen column density and source temperature ($N_H = 10^{20.3}$ atoms/cm$^2$, $T = 10^5.6$ K).

Only 5 stars (~3\% of the stars with comparable limiting magnitude) in the Hyades survey have been detected as X-ray sources with a luminosity above the threshold for the present Pleiades survey. Since the Pleiades are ~1 order of magnitude younger than the Hyades, this different behaviour can be attributed to the age difference of the two clusters.

Since have been detected in X-rays ~42\% of dwarfs G the value of the median of the X-ray luminosity function is not far from $10^{20.5}$ ergs/sec. We have plotted in figure 1 this value together with the median of the X-ray luminosity of T Tauri stars, of main sequence G stars in the Hyades, of local disk population G dwarfs. This plot provide evidence of a dependence of the level of the X-ray emission for G stars from stellar age. Fitting a relationship of the type $L_X \propto \tau^{1.8}$, $\beta$ is of the order of 1. The absence of sources identified with M stars, except perhaps the one source without optical counterpart, may indicate a dependence of X-ray luminosity from age more complex than a simple law of monotonic decrease for all spectral types. In fact, in the nearby sample, the median X-ray luminosity of M stars is higher than that of G stars, while in the Pleiades the upper limit to the X-ray luminosity of M stars is lower than the median luminosity of G stars.

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REFERENCES


\footnote{The optical catalog is complete to $m_\nu < 14^m$, i.e. to late K stars.}
DISCUSSION

Richer: Did you detect any X-ray sources that were not visible as stars on the plates? Did you detect the supposed white dwarf member of the Pleiades in the X-ray region?

Micela et al: One of the X-ray source detected in our X-ray observation is not identified with a Pleiades member. However, the published optical catalogue is complete until 14° magnitude (i.e. late-K main sequence stars). The nature of the unidentified X-ray source should be object of more detailed investigation to clear if we are looking at an M main-sequence star belonging to the cluster, or a field star or an object of different nature.