X-RAY EMISSION AT LOW-MASS END OF THE MS: RESULTS FROM AN EXTENSIVE EINSTEIN OBSERVATORY SURVEY

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Abstract

Using all available Einstein Observatory Imaging Proportional Counter (IPC) data and a critical compilation of catalogued optical data, we have measured the 0.16 – 4.0 keV X-ray emission of K and M stars of luminosity class IV, V and VI within 25 parsecs of the Sun. We have detected 54 of 88 K stars, 70 of 138 M stars with $M_v$ less than 13.4 (corresponding approximately to M6), and 15 of 31 fainter M stars. Homogeneously recomputed U, V, W space velocity components for the surveyed stars, with a kinematical criterion based on, we have subdivided them in old-disk, young-disk and halo population stars. We have selected a subsample of surveyed star that is statistically representative of the population of K and M stars in the solar neighborhood. On the basis of this subsample, we constructed unbiased Maximum Likelihood X-ray luminosity functions for K, early M and late M stars. Our investigation of the X-ray luminosity behavior in various spectral-type and populations subsamples reveals a drop in X-ray luminosity for M stars later than approximately M6, and confirms, both for K and M stars, the decrease of X-ray luminosity with increasing stellar age in the range of ages of disk population stars.

Introduction

Since the first analysis of the X-ray data from the Einstein satellite (Giacconi et al. 1979), many stellar X-ray surveys have been carried out to characterize the X-ray emission of star populations selected according to spectral type, age or evolutionary state.

Within this framework we have carried out a detailed statistical analysis of the X-ray emission of low mass stars (spectral types K and M and luminosity classes IV, V and VI) in the solar neighborhood, using a wider and better known optical volume-limited sample, using all available Einstein Observatory Imaging Proportional Counter (IPC) data homogeneously reduced with the REV-1B processing system (Harnden et al. 1984), and accurately investigating the possible occurrence of sample selection effects.

Sample selection and data reduction

We have compiled a volume-limited sample comprising all optically-known low mass dwarfs (spectral types K and M and luminosity classes IV, V and VI) within 25 parsecs of the Sun and have extracted an X-ray sample of such stars which fall, either serendipitously or as targets, in at least one of the IPC fields (cf. Table 1).
To minimize the incompleteness suffered, at faint magnitudes, by volume-limited samples, we have merged data from three optical catalogues, namely: the Near Star Catalogue (Gliese 1969), its supplement (Gliese and Jahreiss 1979), and the Catalogue of Stars within 25 Parsecs of the Sun (Woolley et. al 1970).

We have subdivided the X-ray sample stars in young disk, old disk and halo population stars according to a statistical method based on the U and V velocity components (Eggen 1969, 1973).

Under the working hypothesis that stars are uniformly distributed in the solar neighborhood, we have computed, for each bin of absolute visual magnitude of the optical sample, the volume within which the subsample of stars may be considered complete and have estimated the expected density of the stars in the solar neighborhood. The subsample of stars with $M_v \leq 9$ may be considered complete within 25 parsecs. Stars with $9 < M_v < 14$ are incomplete by a factor 2-3, while for greater $M_v$, the known sample is up to ten times less than the expected one. The optical sample of M stars is, therefore, not uniformly sampled in $M_v$.

The X-ray sample comprises 257 stars, which represent about 16% of the optical parent sample, a percentage larger than the $\sim 10\%$ sky coverage of the IPC fields due to the presence of a great number of targeted stars (148) (cf. Table 1).

We have identified the X-ray subsample composed of all K and M stars within 10 parsecs, and of serendipitous K and M stars at greater distances, as representative of the population of the optical parent sample. To compute the X-ray luminosity in the IPC broad band (0.16 - 4.0 keV) we have adopted the conversion factor $2 \cdot 10^{-11} (\text{erg} \cdot \text{cm}^{-2} \cdot \text{cnt}^{-1})$ from count rate to X-ray flux (Vaiana et. al 1981).

### Table 1 - Survey composition

<table>
<thead>
<tr>
<th>Dist.(pc)</th>
<th>Kstars</th>
<th>Mstars</th>
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<tbody>
<tr>
<td>$&lt; 25$</td>
<td>646</td>
<td>51</td>
</tr>
<tr>
<td>$&lt; 25$</td>
<td>1035</td>
<td>196</td>
</tr>
<tr>
<td>$&lt; 10$</td>
<td>88</td>
<td>24</td>
</tr>
<tr>
<td>$&lt; 25$</td>
<td>169</td>
<td>70</td>
</tr>
<tr>
<td>Detected</td>
<td>54</td>
<td>21</td>
</tr>
<tr>
<td>X-ray</td>
<td>85</td>
<td>49</td>
</tr>
<tr>
<td>Up.limits</td>
<td>34</td>
<td>3</td>
</tr>
<tr>
<td>Targeted</td>
<td>84</td>
<td>21</td>
</tr>
<tr>
<td>Serendip.</td>
<td>50</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>98</td>
<td>66</td>
</tr>
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<td></td>
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<td>2</td>
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<tr>
<td></td>
<td>71</td>
<td>4</td>
</tr>
</tbody>
</table>

**Figure 1:** X-ray luminosity vs. absolute visual magnitude for the representative sample (points = detections, arrows = upper limits). The vertical line, corresponding to $M_v = 8.5$, separates K and M stars.

### Results and Conclusions

Indications that stars later than M5 present a sharp drop in X-ray emission level have been previously presented on somewhat smaller size samples (Golub 1983,
Rosner, Golub and Vaiana 1985, Bookbinder 1985). We have reconsidered this problem with our larger, less biased, better known, and statistically representative sample of M stars in the solar neighborhood. The plot of the X-ray luminosity vs. absolute visual magnitudes for the entire representative sample [cf. fig 1] shows a clear drop in the X-ray luminosity at $M_v \approx 13.4$. Assuming that the M stars later than $M_v = 13.4$ have the same X-ray luminosity function as the earlier M stars, we have evaluated the expected number of detections of late M stars above four given thresholds of $\log(L_x)$, namely: 27.5, 28, 28.5 and 29, and have found that the number of observed detections of late M stars is lower than expected, with high statistical significance.

This result shows that a single X-ray luminosity function is not adequate to describe both early and late M stars and confirms that the steep drop in X-ray luminosity is a real effect.

In view of this evidence, we have subdivided the M star sample in two subsamples: late M ($M_v > 13.4$) and early M ($8.5 < M_v \leq 13.4$). In figure 2 we show the X-ray cumulative luminosity functions of K stars (solid line), early M stars (long dashed line) and late M stars (short dashed line).

There is clear evidence that age plays a fundamental role in accounting for the wide spread in X-ray luminosity of late type stars. We have computed separate cumulative X-ray luminosity functions for young disk and old disk stars for K, early M and late M stars. The derived mean values of $\log(L_x)$ with associated 1σ confidence level uncertainties are:

<table>
<thead>
<tr>
<th></th>
<th>young disk</th>
<th>old disk</th>
</tr>
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<tbody>
<tr>
<td>K</td>
<td>27.8 ± 0.1</td>
<td>27.5 ± 0.1</td>
</tr>
<tr>
<td>early M</td>
<td>27.7 ± 0.1</td>
<td>27.1 ± 0.2</td>
</tr>
<tr>
<td>late M</td>
<td>27.3 ± 0.1</td>
<td>26.8 ± 0.2</td>
</tr>
</tbody>
</table>

Hence the mean X-ray luminosity is systematically higher for the young disk stars, even for late M stars.

In figure 3 we plot the early M stars in the U-V velocity plane with two symbols for stars brighter (full circles) and fainter (crosses) than $\log(L_x) = 27.4$. Most of the luminous objects fall inside the polygon which, according to the adopted kinematical criterion (Eggen 1969), delimits the region populated by kinematically young
stars while the faint objects are mainly located in the external region populated by kinematically old stars (stars outside the ellipse are suspected halo stars). This plot demonstrates the power of the X-ray luminosity, by itself, to subdivide a sample of stars of the same spectral type into different age groups.

Although direct measurements of rotation are very difficult for late M stars, the evidence that the X-ray luminosity decreases with age suggests that rotation still plays a fundamental role in the mechanisms of X-ray emission for the late M stars.

As the most numerous stars and as intense X-ray emitters, K and M stars account for a large fraction of the stellar contribution to the soft X-ray background (Rosner et al. 1981, Schmitt and Snowden 1990, Kashyap et al. 1992, Micela 1991). The exact determination of this contribution is critically dependent on the correct determination of the X-ray luminosity functions. In this perspective we note that the maximum likelihood cumulative X-ray luminosity functions we have presented here are the least biased that can be constructed, prior to the advent of the ROSAT full sky-survey.

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Bibliography