STELLAR CONTRIBUTIONS TO THE DIFFUSE SOFT X-RAY BACKGROUND

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I. INTRODUCTION

One of the results of the EINSTEIN/C.f.A. x-ray stellar survey was a determination of the contribution of the disk stellar population to the galactic component of the diffuse soft (0.28 - 1.0 keV) x-ray background. Our analysis employed both binned and unbinned nonparametric statistical methods that have been developed by Avni et al. (1980). These methods permitted us to make use of the information contained in both the 22 detections and 4 upper bounds on the luminosities of 26 dM stars in order to derive their luminosity function. We have not as yet developed luminosity functions for earlier stellar types, which leads us to use a delta-function approximation for their true luminosity functions. For these earlier stellar types, we have used the median luminosities as determined by Vaiana et al. (1981), which underestimates their contribution to the background. We find that it is the M dwarfs that dominate the disk population stellar contribution to this background.

To calculate the contribution of the stellar sources to the background, we have made use of simple models both for the spatial distribution of the stars and for the properties of the intervening interstellar medium. We choose a model in which all stellar classes have the same functional form for their spatial distribution: an exponentially decreasing distribution above the galactic equatorial plane, and a uniform distribution within the galactic plane for a region of several kiloparsecs centered on the sun. In the same spirit of keeping our model simple, we assume that it is sufficient to choose a uniform interstellar medium, characterized by a single relevant parameter, r_o, which is the energy weighted mean free path of an x-ray photon. This quantity is regarded as a free parameter, and our calculations span the range of r_o ~ 200 pc to r_o ~ 10 kpc. We believe that these values of r_o are the correct order of magnitude for ISM absorption at high galactic latitudes (|b| > 30°), and since they cover the range from strong absorption to essentially free propagation, we will be able to estimate the effect of interstellar absorption on the stellar component of the x-ray

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background. Since we assume a uniform ISM that is characterized by average quantities, whereas the real ISM is both quite inhomogeneous and has an exponential density profile perpendicular to the galactic plane, our model can be compared only with the average properties of the soft x-ray background, such as observed with a wide field of view.

II. DISCUSSION

We present our first result, the integral x-ray luminosity function for dM stars, in Figure 1. Among these M dwarfs, the ratio of their x-ray to visual luminosity, $f_x/f_\nu$, varies from $10^3$ to $10^{-1}$ (Rosner and Vaihara 1980). As we will see below, probably only in the case of dM stars is it necessary at present to construct a detailed x-ray luminosity function; and for this purpose we have used the data from the Einstein Observatory/CfA Stellar Survey of nearby stars. Stars that were included in the pointed survey for a priori reasons of noted activity (i.e. flare stars) were not included in the construction of the luminosity function, as they would tend to bias the function towards the high luminosity tail. The stars that are included in the construction are all members of the survey of dM stars within a 6 pc radius, selected solely by the distance criterion.

**Figure 1.** Integral x-ray luminosity function for dwarf M stars. Also indicated are the values of x-ray luminosity detections and upper bounds (top of the figure), and the mean x-ray luminosity for dM stars.
To reduce the information contained in the survey to a luminosity function, we use a non-parametric statistical approach developed by Avni et al. (1980) that can, as a special case, be applied to volume-limited samples. This method is quite different from the standard procedures, which involve observations of 'complete' samples. The complete samples are most often flux-limited, and one traditionally develops the luminosity function based solely on those objects whose fluxes are higher than the sample threshold. This paper uses a method which permits the use of objects which have been observed down to a limiting-flux level, whether they have been positively detected or not; the flux limit may also be different for each object. The maximum-likelihood technique that is employed allows us to combine data sets that were acquired with quite different sensitivities. Moreover, this method does not waste the information that can be obtained by considering those objects whose fluxes fall below the observational thresholds.

From the integral luminosity function we obtain a mean x-ray luminosity for dwarf M stars: \( \bar{L} = 2.3 \times 10^{28} \) ergs s\(^{-1}\). The two-\(\sigma\) error bars are (+2.6, -1.2). We are now able to calculate the integrated stellar flux \( f_i(|\beta|) \) (in the range of 0.28 - 1.0 keV) as a function of galactic latitude:

\[
f_i(|\beta|) = n_i(0) \bar{L}_i / 4\pi \gamma_i \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}
\]

where \( \bar{L}_i \) is the mean x-ray luminosity of the ith source class and \( \gamma_i = r_o^{-1} + \sin|\beta|/\beta_i \) is the effective inverse scale height. The stellar parameters given in Table I are used to generate Figure 2, where we show results using an interstellar absorption parameter of \( r_o = 200 \) pc (solid curve) and \( r_o = 10 \) kpc (dashed curve). We note that the integrated flux has a considerable dependence on the ISM absorption. Because most of the flux is due to distant sources, the result of decreasing \( r_o \) is to decrease the flux by a factor of nearly three. Several other aspects of this plot are of interest as well. First, concurrent with the decrease in the flux as the absorption is increased, comes a decrease in the latitude dependence of the flux. Examination of the figure shows essentially no latitude dependence of the flux when \( r_o = 200 \) pc and \( |\beta| > 30^0 \). Secondly, M dwarfs dominate the x-ray background in this bandpass. The next most important contributors are dF stars, whose contribution to the soft x-ray flux is a factor of five less than that of the dM stars.

We are now able to compare our model's predictions with the observations of Tanaka and Bleeker (1977), whose total average soft x-ray background flux in the M-band is:

\[
f_{\text{obs}}(0.28 - 1.0 \text{ keV}) \sim (0.4 - 2.6) \times 10^{-8} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}
\]

These integrated energy flux values are indicated for both the low-flux and high-flux regions (excluding known point sources), though it is important to note that the high- and low-flux regions in different energy bands are not
Table I

<table>
<thead>
<tr>
<th></th>
<th>( \log L_x ) (^{(1)})</th>
<th>( n(0) [\text{pc}^{-3}] ) (^{(2)})</th>
<th>( b(\text{pc}) ) (^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>dF</td>
<td>29.0</td>
<td>0.003</td>
<td>190</td>
</tr>
<tr>
<td>dG</td>
<td>27.8</td>
<td>0.006</td>
<td>340</td>
</tr>
<tr>
<td>dK</td>
<td>27.8</td>
<td>0.01</td>
<td>350</td>
</tr>
<tr>
<td>dM</td>
<td>28.36</td>
<td>0.065</td>
<td>350</td>
</tr>
</tbody>
</table>

1. Estimated median \( L_x \) (ergs s\(^{-1}\)) from Vaiana et al. 1981, for spectral classes dF, dG, and dK. The mean \( L_x \) for dM stars is derived from the integral luminosity function that is shown in Figure (1).

2. Stellar space densities and the galactic scale height are the values given by Allen (1973).

![Figure 2](image.png)

Figure 2. Predicted contribution to the diffuse soft x-ray background (0.28 - 1.0 keV) from stars [solid: \( r = 200 \text{ pc} \); dashed: \( r = 10 \text{ kpc} \)]. Also shown is the range of observed background fluxes obtained from the results of Fried et al. (1980) for the (0.28 - 1.0 keV) band for \(-90^\circ < b < -30^\circ\), and the corresponding flux range quoted by Tanaka and Bleeker (1977). The 1-\( \sigma \) error bounds on the M dwarf contribution (which dominates by far) are also indicated.
always coincident. For a choice of model parameters \(|b|=30^\circ\) and \(r_o=200\) pc, we predict a total stellar contribution to the M-band flux of 2.5 \((^{+1.1}_{-0.8}) \times 10^{-9}\) ergs cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\), or 7\% to 14\% of the maximum observed flux. The error bars, here as elsewhere, reflect only the uncertainty in the x-ray luminosity function, but not in the assumed stellar distribution or ISM absorption properties. If we observe an area of the sky that is characterized by a low value of interstellar absorption, then the stellar contribution rises to 1.0 \((^{+0.5}_{-0.3}) \times 10^{-8}\) ergs cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\), corresponding to between 27\% and 58\% of the maximum M-band flux.

We can perform the same comparisons with the more recent Wisconsin results (Fried et al., 1980). Because of the strong possibility that the North Polar Spur is an (independent) x-ray source, we will confine our attention to the Southern Galactic hemisphere, at latitudes \(|b|>30^\circ\). Note that the range of the Wisconsin data is comparable with, and overlaps, that quoted by Tanaka and Bleecker (1977). For the same stellar parameters that we used above, the comparison suggests that the stellar contribution may account for 11\% to 24\% of the minimum flux and 6\% to 12\% of the maximum observed flux. Again, for region of low absorption, the contribution rises to 23\% to 48\% of the maximum observed flux.

References