# Stellar X-Ray surveys and Galaxy structure

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**Abstract.** Soft X-ray surveys are very effective to study low-mass stellar populations in our Galaxy. Indeed stellar X-ray counts well complement optical stellar counts since they allow us to study spatial distributions and densities of main sequence stars as function of age. This capability is due to the strong dependence of X-ray luminosity on stellar age, especially during the main sequence life. As a consequence X-ray surveys oversample young stars, detectable at large distances, permitting to study the spatial characteristics of these populations and the stellar birthrate in the solar neighborhood in the last billion year. In this context both low and high latitude X-ray surveys play an important role, since low-latitude surveys allow us to determine the stellar density as a function of age on the Plane, while high latitude surveys constrain the scale heights of the different populations. The comparison of the results at various latitudes can constrain the recent star formation history in the solar neighborhood. I will discuss which improvements the Chandra and XMM-Newton surveys can provide in our knowledge of stellar populations, and some preliminary results from new ongoing surveys.

**Key words:** Galaxy: stellar content - Galaxy: structure - stars: activity - surveys - X-rays

## 1. Introduction

X-ray surveys are very effective to study young stars because the X-ray luminosity decreases up to 3 orders of magnitude during the main sequence stellar life while the optical properties remain substantially unchanged. Since in X-rays we observe young stars at distances much larger than old stars, young stars are oversampled in shallow or medium-deep X-ray observations. On the contrary, because of the relatively small scale height of young stellar populations, old stars will dominate the stellar content of deep high latitude X-ray surveys. As a consequence X-ray surveys offer a unique opportunity for constraining global properties of stellar populations.

The comparison of X-ray observations and predictions derived from X-ray galactic models can put strong constraints on properties of stellar populations, in particular on their spatial distributions and on stellar birthrate in the solar neighborhood in the last billion years.

This paper is organized as follow: in Sect. 2 I will discuss why X-ray surveys provide us information on normal stars populations, and which approach we use in order to derive the population characteristics. Then in Sect. 3 I will present some past results obtained with *Einstein* and Rosat telescopes, and in Sect. 4 the contribution that Chandra and XMM-Newton will give to this area, together with some preliminary results from two ongoing projects.

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## 2. X-ray emission and stellar populations

One of the most important results of stellar X-ray astronomy is the evolution of coronal emission during the stellar life in normal late-type stars: the average $L_x$ decreases from $\sim 10^{30}\mathrm{erg/sec}$ to below $10^{27}\mathrm{erg/sec}$ during the main sequence life. Fig. 1 shows the median value of $L_x$ versus stellar age for a set of star formation regions, open clusters, and field stars. The horizontal segments are the uncertainties in age determination and the vertical ones the one-sigma equivalent dispersion of the X-ray luminosity functions. It is interesting to note that most of the decrease of $L_x$ occurs between the Zero Age Main Sequence and the solar age, while the decrease in the first part of the stellar life, between the pre main sequence and the main sequence phase, is very small. This behavior is different than in optical band where most of the luminosity changes occur during the PMS phase, making X-ray emission very effective to identify young main sequence stars that in optical band are essentially indistiguishable from old main sequence stars.

As a consequence X-ray flux-limited surveys preferentially detect young stars up to larger distances than old stars, at least until we can assume nearly spherically symmetric spatial distribution. Hence shallow stellar X-ray selected samples will be dominated by young stars, while deep high latitude stellar X-ray samples will be dominated by old stars, since young stars have smaller scale heights, and even mod-

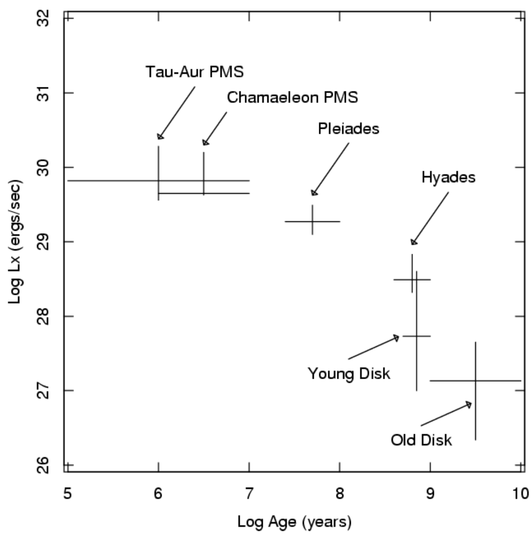


**Fig. 1.** Median value of $L_x$ versus stellar age for a set of star formation regions, open clusters, and field stars. The horizontal segments are the uncertainties in age determination and the vertical one the 1 sigma equivalent dispersion of the luminosity functions. (adapted from Damiani et al. 1995)

erately deep X-ray surveys sample distances beyong scale heights. The relative contributions of young and old stars depend on their spatial distributions, X-ray properties and their density which is a function of stellar birthrate in the solar neighborhood. The comparisons of observations with the predictions derived from stellar galactic models allow us to constrain the spatial population properties.

With this aim in mind we have built a stellar X-ray galactic model – XCOUNT (Favata et al. 1992, Micela et al. 1993) – that allows us to predict the number and the properties, in terms of magnitude, color, population, and $f_x/f_v$ ratio distributions of the stellar coronal sources detected with a given instrument and sensitivity in a given sky direction. Main ingredients of such a model are the stellar spatial distribution, a spatial model of interstellar gas, responsible for the absorption in X-ray and in optical band, and the X-ray stellar properties, parameterized through X-ray luminosity functions.

The present version of the model include only the disk component; this choice is justified by the very low density and very low X-ray luminosity of halo stars. The disk is modeled by a set of exponential disks as in the original Bahcall & Soneira model (BS, Bahcall & Soneira 1980), but, with the crucial modification that the scale heights of stellar populations are function not only of the stellar mass – as in the original BS model – but also of stellar age. This change in practice does not affect optical counts, but is very important for X-ray counts (Micela et al. 1993), since young stars are much brighter in X-rays than old stars, and their scale heights are smaller than that of old stars. Presently, for old dM stars we have also implemented a different spatial distribution that takes into account the results derived by Gould et al. (1997) from HST observations.

We have considered three age ranges: The first includes young main sequence stars, with age between $10^7$ and $10^8$ years. The scale heights we attribute to these stars is 120 pc, and we assume that their X-ray emission is well represented by the luminosity functions of the Pleiades (for each spectral type), and a coronal temperature of 1 keV (Stauffer et al. 1994, Micela et al. 1996). The intermediate range include stars with age between $10^8$ and $10^9$ years. Their scale height is 200 pc, and we attribute to them the X-ray luminosity functions of the Hyades, with a coronal temperature of 0.5 keV (Stern et al. 1995). The last range of age includes stars older than $10^9$ years with a scale height of 400 pc and the X-ray luminosity functions of nearby old disk stars with a temperature of 0.34 keV (Schmitt et al. 1985, Maggio et al. 1987, Barbera et al. 1993). Unfortunately, we do not have X-ray luminosity functions for normal stars derived from old clusters with age greater than $10^9$ years, since they are typically quite distant and X-ray faint and we are forced to adopt X-ray luminosity functions derived from old field stars that include a mixture of age. Only with the new planned Chandra and XMM-Newton observations will be possible to derive X-ray luminosity functions of normal stars of old open clusters.

## 3. Previous results

One of the first results derived from the comparison between predictions and observations of the Extended Medium Sensitivity Survey of *Einstein* (EMSS, Gioia et al. 1984), was the detection of an excess of yellow stars in the observations (Favata et al. 1988, Sciortino et al. 1995). Optical follow up allowed us to determine the properties of this population which appears to be young (Favata et al. 1993). The presence of an excess of X-ray detected young stars in the solar neighborhood was confirmed by Exosat and Rosat surveys (eg. Tagliaferri et al. 1994).

Another relevant aspect of stellar X-ray surveys is their capability to put constraints on stellar birthrate in the last billion years in the solar neighborhood. Fig. 2 shows the expected stellar log(N)-log(S) at high galactic latitude assuming constant stellar birthrate. The dotted line marks the contribution of young stars to the log(N)-log(S). They provide a large contribution at high flux, while can be neglected at low flux, since the sampled distances reach and go beyond the scale height of young stars. The intermediate age stars, marked by the dashed line, dominate at intermediate flux, while old stars continue to increase at low flux where they dominate the stellar population. If we change the stellar birthrate, we affect the relative contributions to the log(N)-log(S) from stars of different age, modifying the overall shape. The analysis of the EMSS observations allowed us to exclude scenarios with decreasing stellar birthrate in the last billion years, while it was unable, because of the limited sample size, to discriminate between a constant and an increased stellar birthrate hypotheses (Micela et al. 1993).

With a similar approach Guillout et al. (1996), using a model based on the Besançon galactic model, analyzed the

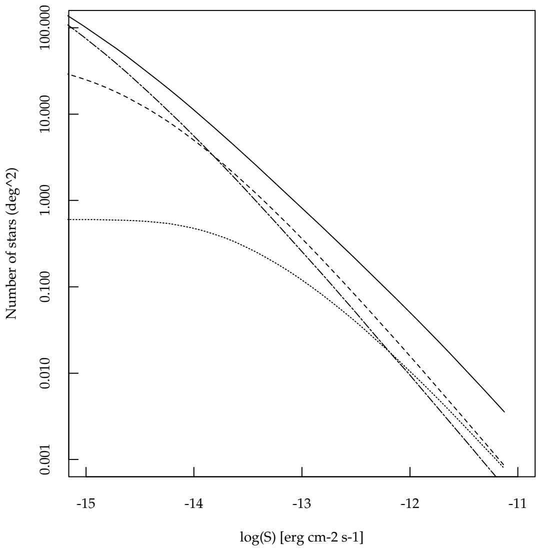


**Fig. 2.** Expected log(N)-log(S) predicted with XCOUNT assuming constant stellar birtrate (solid line) at $b = 90°$. The contribution of Pleiades-like (dotted line), Hyades-like (dashed line) and old stars (dashed-dotted line) are shown. (adapted from Micela et al. 1993)

stellar content of Rosat All Sky Survey. Furthermore the cross-identifications between the Rosat sources and Tycho stars has revealed a physical structure of young stars in the solar neighborhood coincident with the Gould Belt (Guillout et al. 1998)

In this context Galactic Plane surveys play a crucial role, since they contrain the stellar density on the Plane, an important parameter for stellar X-ray galactic models. The comparison of predictions with observations of Pointed Rosat Galactic Plane Survey (Morley et al. 2001) shows that the density of active stars on the Galactic Plane is larger than assumed in the XCOUNT model in the hypothesis of constant stellar birthrate. This result is consistent or with an increased star formation rate in the last billion year or with a different spatial distribution, more concentrated on the Plane, than assumed in XCOUNT (see e.g. Haywood, Robin & Crézé 1997) and constant stellar birthrate. Chandra and XMM-Newton surveys will be able to discriminate between these two possible scenarios, thanks to their high sensitivity.

## 4. The Chandra and XMM-Newton contribution

Chandra and XMM-Newton will give a novel and unique contribution to the study of stellar populations. Their high sensitivity allows us to reach and go beyond the scale heights of the young stars. They are hence able to detect all the young and intermediate age stars at high latitude and stellar X-ray samples will be dominated by old stars, allowing for the first time to investigate in the X-ray regime the old stellar population.

Fig. 3 shows the predicted log(N)-log(S), expressed in ACIS-I count rates, in the direction of the Chandra Deep Field North, with the contributions of the different stellar populations as in Fig. 2. Vertical lines indicate the range of sensitivity of the observation. The curves relative to the young and intermediate age stars are constant at the sensitivity of the Chandra deep field; at fainter flux we do not detect new young or intermediate age stars. On the contrary, the contribution of old stars continues to increase even for deeper observations. The Chandra Deep Field North is the longest Chandra exposure for a total of 2 Msec (Brandt et al. 2001) and offers a unique opportunity to test the X-ray stellar Galaxy models at the faint fluxes. The stellar content of the X-ray detections is the subject of a thorough study in order to characterize the properties of the detected stellar population (Feigelson et al. in preparation). This sample is very well suited to be compared with the predictions and presently (September 2002) the identifications program for the detections found in the first 1 Msec exposure is complete at $V = 22$. The identified sample consists of 12 stars, 8 dM, 2 dK, 2 dG, respectively. Fig. 4 shows the comparison between predictions and observations. The number of observed dM stars agrees very well with the predictions while there is an excess of dF, dG, dK stars in our predictions. The observed lack of yellow stars is the opposite direction of the discrepancy observed in previous shallow surveys in which an *excess* of observed yellow stars was detected, but we have to stress that with the Chandra Deep Field we are observing old stars, while the yellow excess was observed in surveys dominated by young stars. This different behavior could be due to a non constant stellar birthrate, or to wrong assumptions on the stellar spatial distribution and its dependency on age. For details on stellar content of Chandra Deep Field North see the contribution on these proceedings (Micela et al. 2003a).

Preliminary analysis of one field of the HELLAS2XMM survey (Fiore et al. 2003, these proceedings, Baldi et al. 2002) suggests a similar discrepancy. The analysis of photometric observations of a large fraction of one of the lowest latitude field of the survey suggests that at most 35 sources can be identified with stellar counterparts, corresponding to about 40% of the number of stars predicted by XCOUNT (Micela et al. 2003b, these proceedings). The optical observations of the entire survey have to be completed in order to verify the nature of the candidate counterparts and if the observed discrepancy is restricted to yellow stars as in Chandra Deep Field North survey.

There are some possible explanations for the observed discrepancy: It is possible that the spatial distribution assumed in XCOUNT is uncorrect, and in particular that stellar density drops with the distance from the Galactic Plane more rapidly than assumed in XCOUNT (as in the Besançon model in Haywood, Robin & Crézé 1997). The complete analysis of the stellar content of the HELLAS2XMM survey will be of help, since it will allow us to explore the existence and the nature of the discrepancy as a function of the galactic latitude, that is related to the scale heights of stellar populations. Another possibility is that the stellar density on the Plane is overestimated. This possibility seems to be excluded from the

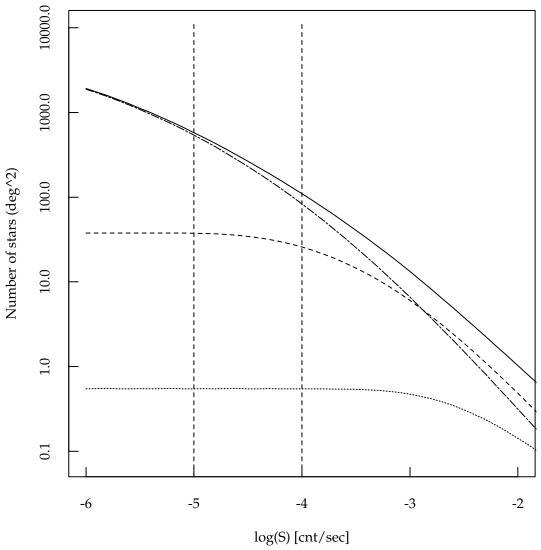


**Fig. 3.** Expected log(N)-log(S) in ACIS-I count rate predicted with XCOUNT in the Chandra Deep Field direction. Contributions to the log(N)-log(S) as in Fig. 2. Vertical lines mark the typical sensitivity of the observation.

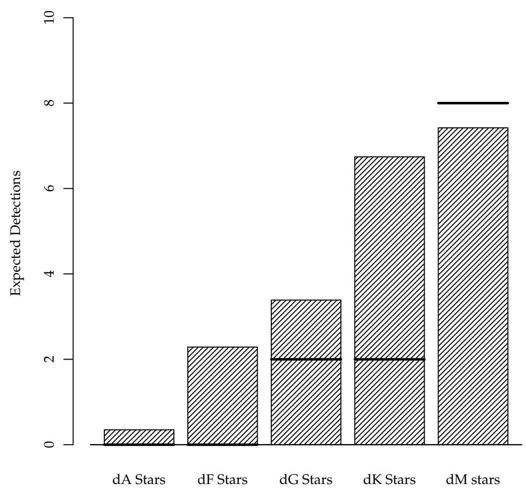


**Fig. 4.** Expected spectral type distribution in the Chandra Deep Field North with 1 Msec of exposure for stars with $V < 22$. The horizontal segments mark the actual observations.

Rosat pointed galactic plane surveys (Morley et al. 2001), but the stellar population of this Rosat intermediate-flux survey has significant contribution from young and intermediate age stars, while Chandra and deep XMM-Newton fields are dominated by old stars. A further explanation of the observed discrepancy is that the X-ray luminosity functions of old dG and dK stars are wrong and overestimate the contributions of high luminosity stars, which dominate the X-ray stellar counts. In particular, we have to remind that the X-ray luminosity functions of old stars are derived from nearby field stars whose age is determinated only by kinematics. Since kinematics can be used only as statistical age indicator, the sample can be contamined by young stars affecting the bright tails of luminosity distributions of old stars. Deep X-ray observations of old open clusters or of old field stars for which accurate age determination can be obtained could clarify this point.

The complete analysis of Chandra and XMM-Newton stellar surveys at various latitudes and sensitivities will allow us to discriminate between these scenarios.

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