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STELLAR BIRTHRATE IN THE GALAXY: CONSTRAINTS FROM X-RAY FLUX-LIMITED SURVEYS

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ABSTRACT

The determination of the X-ray luminosity functions of few coeval stellar samples (such as open clusters and stellar associations) with the *Einstein* data has shown that the average level of X-ray emission from coronal source decrease with the age of the emitting stars. We show how the assumed history of the Galactic stellar birthrate (and therefore the number of young X-ray emitting stars today) influences the expected star count distributions in X-ray flux limited surveys. Assuming several different smooth stellar birthrates we have computed model-predicted log (N) − log (S), whose normalization agrees with optical star counts, and have compared them with the actual number of sources detected in the Extended Medium Sensitivity Survey. The comparison covers the $f_x \sim 10^{-12}$–10^{-13} ergs s^{-1} cm^{-2} range where most of the stars have ages less than 10^9 yr, and shows that current X-ray surveys are compatible with high recent stellar birthrate, but incompatible with past stellar formation rates much higher than today's. We discuss the limitations of present application due to available X-ray data, and argue also that stellar detections in X-ray flux limited surveys, when the L_x-age relation will be known with higher time resolution than available now, will become as powerful a method of constraining the stellar birthrate in the Galaxy as the more traditional methods based on kinematic or optical spectroscopic criteria.

Subject headings: galaxy: stellar content — stars: formation — X-rays: stars

1. INTRODUCTION

In this paper we want to point out the role of stellar X-ray counts in understanding the recent star formation history of the Galaxy and in imposing independent constraints on the Galactic stellar birthrate in the past billion years. We show how X-ray flux limited surveys can effectively complement or even replace spatial velocity and metallicity measurements, the means traditionally adopted to investigate the history of star birth in the Galaxy (Mihalas & Binney 1981). We will further discuss why X-ray stellar counts are likely to be a most effective way of picking up a population of young stars and constraining its origin.

The traditional means of studying the history of the stellar birthrate are highly "labor-intensive" and require a large amount of observations: kinematic observations require high-precision astrometric measurements over a long time basis, while metallicity data require high-resolution spectrometry. Both these methods suffer from well known biases, the first toward the nearest and/or higher velocity stars, the second toward relatively nearby and/or luminous stars because of the needed high signal to noise ratio spectra. Furthermore a large number of approaches to constrain the star formation rate (SFR) (see Scalo 1986 for an extensive discussion on the subject) exists. Such methods are based on isochrones (Twarog 1980; Meusinger 1991), on the white dwarf luminosity functions (Noh & Scalo 1990), or on chromospheric age relations (Barry 1988; Soderblom, Duncan, & Johnson 1991). These methods give results often in disagreement or in marginal agreement with each other: in some cases they detect some bumps or lulls in the recent or far past, but in general they cannot rule out a constant or nearly constant SFR. For this reason it is worthwhile, as outlined by Noh & Scalo (1990), to develop independent methods for better constraining the SFR.

On the other hand X-ray stellar counts require the detection of stellar X-ray emission above a given limiting sensitivity. Moreover, modern imaging X-ray detectors coupled with high-resolution X-ray mirrors, such as those of the *Einstein* and *ROSAT* observatories or those planned for the future AXAF and XMM missions, have made and will make possible the detection of tens of X-ray emitting stars in a single observation.

It is evident that the identification and classification of all sources detected in an X-ray flux limited survey is a difficult and time consuming task, requiring, up to date optical spectroscopy of each of the possible counterparts to the X-ray source, since the coronal sources are only a fraction of the sources detected in an X-ray survey. Such work has been pursued, for example, by Stocke et al. (1991) for the Extended Medium Sensitivity Survey (EMSS) sources (Gioia et al. 1990). However, the increase in spectral and spatial resolution of the next generation of X-ray detectors, coupled with the larger spectral coverage and angular resolution of planned X-ray missions, will make the entire process less time consuming, both because of the smaller number of possible counterparts contained in the smaller error circles, and because the identification process will be aided by the information contained in the low-resolution X-ray spectra alone, e.g., as suggested by Collura et al. (1993).

In a more general context the present work is also relevant for the characterization of the diffuse X-ray emission from both our Galaxy and external galaxies. In fact, to account for the diffuse X-ray emission from an external galaxy (see Fabbiano 1993) one has to consider also the properties of stellar coronal emitters, the detailed spatial distribution of stars, and, at least for the Galaxy, the effect of the X-ray absorbing interstellar medium.

To properly account for all these effects (and others to be discussed in the following) one needs to build a model for the X-ray stellar coronal component of the Galaxy. Such a model can be used to predict the expected level of X-ray stellar counts in a survey, and the expected stellar contribution to the diffuse

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X-ray background. With a proper choice of parameters, the expected diffuse X-ray emission from external galaxies can also be computed. In the course of the past years our group has built such model whose details are given in Favata et al. (1992) and in Favata, Micela, & Sciortino (1993c).

This paper is structured as follows: in the next section we describe the reasons that make stellar age a crucial ingredient in properly interpreting stellar X-ray counts (while this is not generally the case in interpreting optical stellar counts). In § 3 we show the effects of taking into account the age-dependence of X-ray stellar emission on X-ray stellar counts and how X-ray counts can be used to impose constraints on the stellar birthrate in the past billion years in the solar neighborhood. In § 4 we summarize our results and discuss their implication for future observations.

2. THE DEPENDENCE OF STELLAR X-RAY EMISSION ON AGE

Since the early observations of stellar X-ray emission, it was clear that for each given spectral type and luminosity class the level of X-ray emission spans approximately three orders of magnitude (Vaiana et al. 1981). This discovery implies that the level of stellar X-ray emission is not determined by the "classical" parameters yielding the optical characteristics of stars, such as surface gravity and temperature. Other parameters, of which coronal emission is a tracer, must play a fundamental role in determining the level of stellar X-ray emission. The identification of the most important of such parameters has been one of the main objectives of stellar coronal physics over the last decade.

Since 1981 rotational velocity has been identified as important in determining the X-ray emission level of late-type stars (Pallavicini et al. 1981). Other parameters such as the Rossby number, i.e., the ratio between the rotational period and the convective turnover time (Micela, Sciortino, & Serio 1985a; Schmitt et al. 1985; Maggio et al. 1987) or stellar age (Vaiana 1981, 1983; Caillault & Helfand 1985; Micela et al. 1985b, 1988, 1990) have been shown to likely account for most of the spread in X-ray luminosity of late-type stars.

While stellar age by itself cannot be considered as a physical quantity affecting directly the coronal activity level, it is a very convenient parameterization of the evolution of the X-ray emission level during main-sequence lifetime due to the decreasing of stellar magnetic activity with age.

Intense X-ray emission has been associated with young stellar populations since the beginning of imaging X-ray observations. Recent detailed analyses based on the comparison of X-ray luminosity functions of stars in the solar neighborhood (Schmitt et al. 1985; Maggio et al. 1987; Barbera et al. 1993), in the Hyades (Micela et al. 1988) and in the Pleiades (Micela et al. 1990) open clusters, and stars still in the pre–main-sequence phase in the Taurus-Auriga (Damiani et al. 1991) and Chamaeleon (Feigelson & Kriss 1989) star-formation regions, have clearly shown that X-ray luminosity decreases with increasing stellar age, for stars later than spectral type A5 and for each given range of masses. This is clearly shown in Figure 1 for the case of K and M stars where the X-ray luminosity functions for samples of known age are reported. The residual spread present in the X-ray luminosity function of stars of a given age is likely to be due to intrinsic variability (we remind that the X-ray luminosity of the Sun spans one order of magnitude).

Given the span of more than two orders of magnitude of X-ray luminosity during the main-sequence stellar lifetime, the evolution of X-ray luminosity with stellar age cannot be neglected in any realistic attempt to predict or to explain stellar X-ray counts such as those resulting from the analysis of an X-ray flux limited survey. Effects of age on X-ray luminosity are in fact observed to be much more significant than those due to "classical" parameters such as stellar mass or effective temperature (cf. Micela et al. 1988).

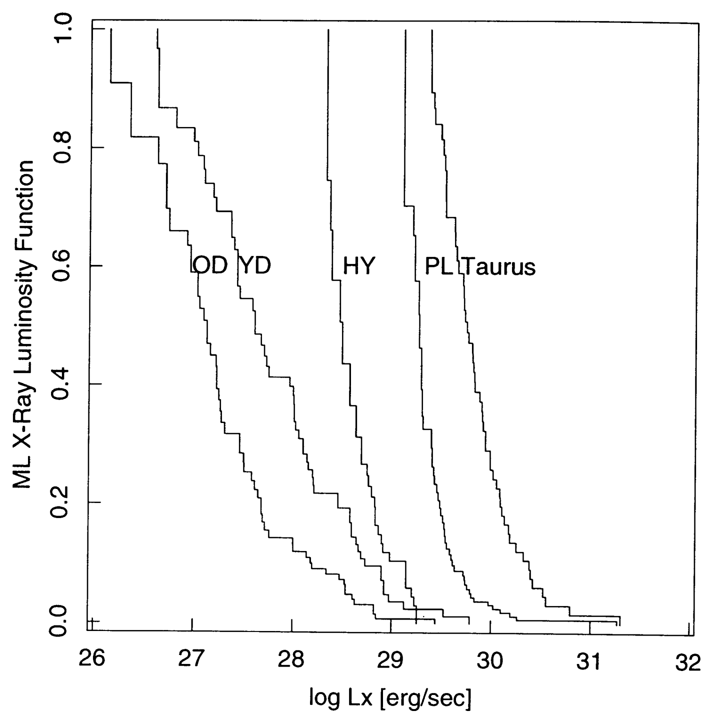

FIG. 1.—Maximum-likelihood integral X-ray luminosity functions for several coeval samples of main-sequence K and M stars of decreasing stellar age: old disk [OD] and young disk [YD] field stars (data form Barbera et al. 1993), Hyades [HY] (Micela et al. 1988), Pleiades [PL] (Micela et al. 1990), and Taurus-Auriga PMS [Taurus] (Damiani et al. 1991) stars. Notice that the spread of X-ray luminosity reduces significantly when considering stellar samples homogeneous by age.

Hence, we argue that the dependence of X-ray emission level on stellar age is *the crucial ingredient* for building a model of the X-ray stellar coronal component of the Galaxy. This point is fundamental if one considers that the spatial distribution of disk population stars is almost exclusively determined by their age (Mihalas & Binney 1981; Basu & Rana 1992).

The combination of different spatial distribution and coronal emission levels between "young" and "old" disk stars makes X-ray stellar counts an excellent probe of the recent history of the Galaxy, and can be used to set new, independent constraints on the stellar birthrate in the solar neighborhood as we will show in the following.

To build a model of the coronal X-ray emission of disk population stars in the Galaxy we started from the spatial distribution of stars as adopted in the optical Bahcall and Soneira Galaxy model (Bahcall & Soneira 1980 and Bahcall 1986, hereafter referred to as BS model) which has been shown to agree well with optical star counts in several directions in the sky, in the magnitude ranges ($8 < m_v < 15$) of interest to us in the present work (Bahcall 1986). We have modified the spatial distributions of the disk population in the original model (kindly provided to us by John Bahcall) to include several distinct subpopulations of G, K, and M stars of different ages (similarly to the idea underlying the model of Robin &

Crezé 1986), to introduce an explicit dependence of the stellar spatial distribution and density on stellar age, and have verified, as discussed in detail in § 2.1, that the optical counts predicted by the original and modified versions are in agreement, within the observational error, with the observed stellar counts.

The density of the disk component in the original BS model is exponentially decreasing both with distance from the Galactic center (radial dependence) and from the Galactic plane (vertical dependence). Both the vertical scale height and the density on the plane vary, in the original BS model, as a function of stellar mass. The BS model does not consider any evolutionary effect, so that all its parameters are age-independent. Given the strong variation of X-ray emission characteristics with stellar age, this must be modified in a model which aims to predict X-ray source counts. In particular, the dependence of scale height with stellar mass is an induced effect. Scale height above the Galactic plane is actually only a function of stellar age (Basu & Rana 1992), because all the stars form close to the plane and diffuse away from it during their life. Hence, the scale height of a population is actually a measure of its age, and the variation of scale height with stellar mass is an effect of the variation of the main-sequence lifetime with stellar mass. Therefore, to perform our computations, we have subdivided the late-type (G, K, and M) main-sequence stellar populations in subpopulations of different ages, each with a different vertical scale height (according to its age) and density on the Galactic plane (according to the assumed birthrate).

Various functional forms have been proposed (Vilhu 1984; Catalano & Marilli 1983; Duncan 1981; Simon, Herbig, & Boesgaard 1985; Maggio et al. 1987) to describe the dependence of L_X on age. However, the limited X-ray data available, while preferring an exponential decay of L_X with age, cannot constrain very well the functional form. Hence, we have found it is best, for our purposes, not to fix the functional form for the variation of X-ray luminosity with age. Rather, we consider the three following age groups, 10^7–10^8 yr, 10^8–10^9 yr, and 10^9–10^{10} yr, for each of which we have direct experimental data under the form of maximum-likelihood X-ray luminosity functions for different color ranges. These X-ray luminosity functions are derived from coeval stellar samples, that we assume to be representative of the general Galactic population of stars in the three age intervals considered. Based on Basu & Rana (1992) we have taken as 120, 200, and 400 pc, respectively, the scale heights for these three increasing age ranges. Having fixed the scale heights, assuming a given stellar birthrate, and normalizing to the total space density of stars of a given spectral type, we can determine the star density on the Galactic plane in each of the considered age ranges.

For example, assuming a constant stellar birthrate, having divided the age range in three decades, the total number of young stars will be 10% of the total number of intermediate age stars, which in turn will be 10% of total number of older stars. This allows to write

$$n_{0,(7-8)} = \frac{n_{0,8-9}\,h_{(8-9)}}{10 \times h_{(7-8)}} = \frac{n_{0,9-10}\,h_{(9-10)}}{100 \times h_{(7-8)}}, \quad (1)$$

where the n_0 are the number densities on the Galactic plane in the three considered age ranges, and the h are the corresponding scale heights.

This model implies that, for each spectral type, *the overall X-ray luminosity function depends on the height over the Galactic plane.* In particular, near the Galactic plane where younger population stars are concentrated, the X-ray luminosity function will show a tail at high luminosity, while at large distance from the Galactic plane this tail will disappear because the X-ray luminosity function becomes largely dominated by old population, X-ray faint stars. Figure 2 shows the X-ray luminosity functions for G stars on the Galactic plane, at 500 pc and at 1 kpc over the plane computed assuming a constant birthrate.

We note that the age division we have performed is inevitably coarse, of the order of one decade, and limits the attainable time resolution in constraining the behavior of SFR, due to the lack of more detailed knowledge of the L_X–age relation. This means that we can detect only broad features of the SFR and cannot constrain features such as the peak around 6 Gyr ago found by Twarog (1980) or more complex structures such as those found by Barry (1988). On the other hand we are sensitive to large variations of the SFR in the last 10^7 years with respect to the SFR of one billion years ago.

2.1. *Coherence of Age Fractioning with Optical Stellar Counts*

The subdivision of the late type star populations into distinct subpopulations with different scale heights, as described before, is tantamount to a modification of the assumed optical Galaxy model. We have studied the impact of this modification on the agreement between the predicted and observed optical star counts for the case of two subpopulations for various values of the relative density of the subpopulations (cf. Table 1 in Favata et al. 1992).

Figure 3 shows the predicted optical star counts for a typical field at $l = 0°$, $b = 90°$ for the "standard" and the modified Bahcall and Soneira model for the three age groups already discussed and for the four distinct birthrates discussed in the next section.

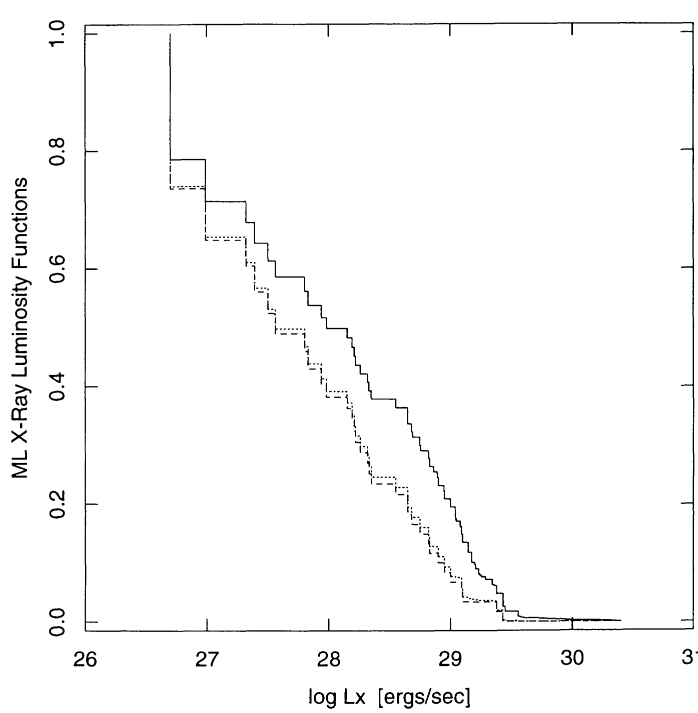

FIG. 2.—X-ray luminosity functions at $z = 0$ (*solid line*), at $z = 500$ pc (*dotted line*), and at $z = 1$ kpc (*dashed line*) for main-sequence G stars, assuming a constant stellar birthrate.

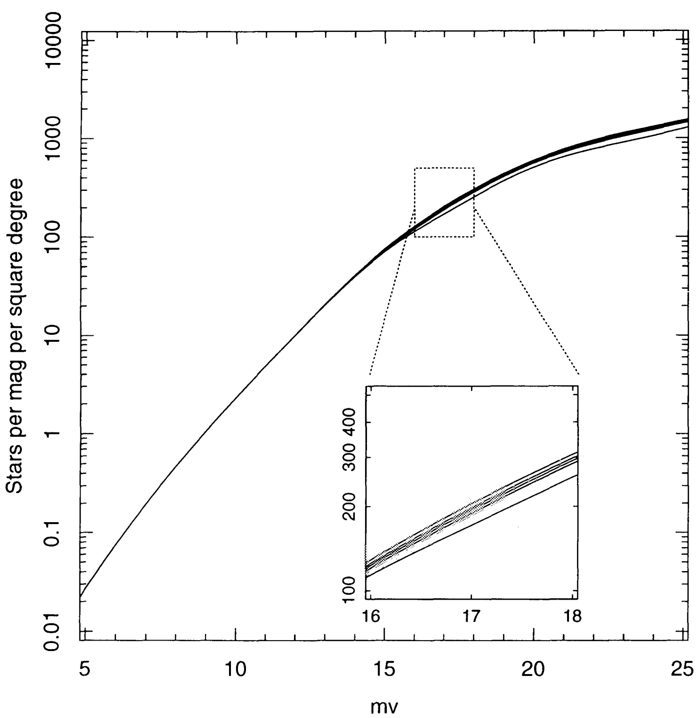

FIG. 3.—Predicted optical star counts at $l = 0°$ and $b = 90°$ for the "standard", and the modified version of Bahcall and Soneira model assuming a birthrate $\Psi \propto e^{-t/\tau}$ with $\tau = \infty$, 15, −15, and 5 Gyr.

It can be seen that our subdivision of late-type stars into subpopulations of different ages does not cause the predicted numbers to vary more than 10%, smaller than the error between predicted and observed optical source counts (see Fig. 2 in Bahcall 1986), we conclude that our modification of the spatial distribution of sources does not influence the coherence between observed and model-predicted optical source counts.

3. EFFECTS OF AGE FRACTIONING ON THE PREDICTED X-RAY SOURCE COUNTS

Predicted optical star counts are not strongly influenced by "reasonable" assumptions on the age distribution of disk populations, because both optical luminosity and color do not vary very much with stellar evolution during the main-sequence lifetime. On the other hand, given the much higher X-ray luminosity of young late-type stars with respect to older stars of the same spectral type, and the different spatial distribution of stars of different age in the Galaxy, the assumed age distribution has a radical influence on the predicted X-ray source counts.

To better illustrate this point we have performed model computations using age-homogeneous X-ray luminosity functions, with relative density on the plane derived assuming various stellar birthrates. We have used the X-ray luminosity functions obtained for the stars in the Pleiades (Micela et al. 1990), in the Hyades (Micela et al. 1988), and in the old disk population (Maggio et al. 1987; Barbera et al. 1993) for the first, second, and third range of ages, respectively.

For the stellar birthrate we have assumed an exponential law:

$$\Psi = A10^{(-t/\tau)} , \qquad (2)$$

where τ can assume the values ∞ (constant birthrate), 15, 5, and −15 Gyr (similar to what has been assumed by Basu & Rana 1992).

The first value of τ implies a constant stellar birthrate during the disk life (Miller & Scalo 1979; Twarog 1980; Carlberg et al. 1985). The second value corresponds to a slow decreasing of birthrate (Tosi & Diaz 1985; Tosi 1988), the third one to a rapid decrease of the stellar birthrate (Rana 1991), and the last one a slow increase of the stellar birthrate (Miller & Scalo 1979).

We have assumed only a smooth shape of the SFR because, at present, the time resolution of the dependence of L_X on age prevent us to test more sophisticated nonsmooth shapes such as those suggested by Twarog (1980), who finds that data are compatible both with a constant SFR and with a broad peak ~6 Gyr ago, or by Barry (1988), who finds a complex SFR with a peak at ~6 Gyr, a dip around 3 Gyr ago, and another peak around 0.2–0.4 Gyr ago.

Assuming the above stellar birthrates, we have computed the predicted stellar X-ray counts at high Galactic latitude for the three discussed ranges of age. Predictions are obtained with the XCOUNT model (Favata et al. 1992) which takes into account the spatial distribution of the stars as described above, the effect of X-ray absorption in the interstellar medium, and the X-ray luminosity functions obtained from optically selected samples.

The adopted X-ray and optical luminosity functions are evaluated for single stars, while in many cases, due to the limited spatial resolution of X-ray imaging observations, X-ray stellar counts do not allow to resolve multiple systems, that are treated as single sources. In a double system with a very low-mass companion, the companion does not significantly contribute to resulting optical magnitude, while it could contribute substantially to X-ray flux, since X-ray emission shows little dependence on stellar mass. We have therefore corrected the log (N) − log (S) evaluated for single stars, assuming that a fraction of stars, f, belongs to binary systems, and that the X-ray luminosity of binary systems is a multiple, κ, of the luminosity of the optically identified star. First of all, we note that if the log (N) − log (S) has a constant slope, α the effect of the binaries is only to change the global normalization of the curve, without effect on the slope. In the most general case, when α changes with S, the log (N) − log (S) curve changes, depending on f, κ, and $\alpha(S)$. Let V be the explored volume assuming all stars are single, then the volume V' in presence of binary systems is

$$V' = \kappa^{\alpha} V f + V(1 - f) , \qquad (3)$$

where the first and second terms represent the accessible volume for the binary systems and single stars, respectively. The density of stellar systems (binary and single) is $\rho' = (1 - f/2)\rho$, where ρ is the density assuming all stars are single. Hence, the correction to the "single" star log (N) − log (S), computed as $C = \rho' V'/\rho V$, is

$$C = (1 - f/2)[f\kappa^{\alpha} + (1 - f)] , \qquad (4)$$

In the following we have chosen $f = 0.61$ (Basu & Rana 1992), and have adopted a value of $\kappa = 2$. This last choice is based on the behavior of X-ray luminosity mean levels with age and masses (cf. Fig. 8*b* of Micela et al. 1990), and on the assumption that the components in a binary system will be coeval. In fact, in each age range, the mean L_X depends little on mass, and F-G stars are usually slightly more intense than

K and M ones. Hence the X-ray luminosity of a combined F/G + K/M system, should be of the order of a factor 2 with respect to that of a single F/G star. Analogously, if one considers the combined X-ray luminosity of a system of two similar mass stars, a factor 2 is a good choice. For α ranging from -1.5 to 0, the correction factor to convert the "single" star log (N) − log (S) to one corrected for the presence of unresolved binaries is at most 1.4.

Further details about the computation and about the sensitivity of the results to other parameters such as coronal temperature and assumed fraction of binary systems are given in Favata et al. (1993c).

Figure 4 shows the contributions to the X-ray counts of the young, intermediate, and old stars for the case of constant birthrate ($\tau = \infty$). Errors bars shown in the figure are due to the uncertainty in the X-ray luminosity functions (especially large in the high luminosity tails). Uncertainties due to the stellar density can be estimated to be of the order of the discrepancy between observed and predicted optical stellar counts in the Bahcall and Soneira Galaxy model (see Fig. 2 in Bahcall 1986), that in the typical magnitude range we are working (8–15) is at most of 30%. At high fluxes the counts are dominated by the young and intermediate age stars. At intermediate flux the Hyades-like stars (10^8–10^9 yr) dominate the X-ray counts, while at fluxes fainter than 10^{-14} ergs s^{-1} cm^{-2} the contribution of old stars becomes relevant. The present uncertainty in the age of the Galactic disk, ranging between 10 and 13.5 Gyr, according to various recent determinations (cf. § 2.6 of Basu & Rana 1992, and references therein), introduced a large uncertainty in the number of old disk population stars. This would result in a systematic shift of stellar counts at faint

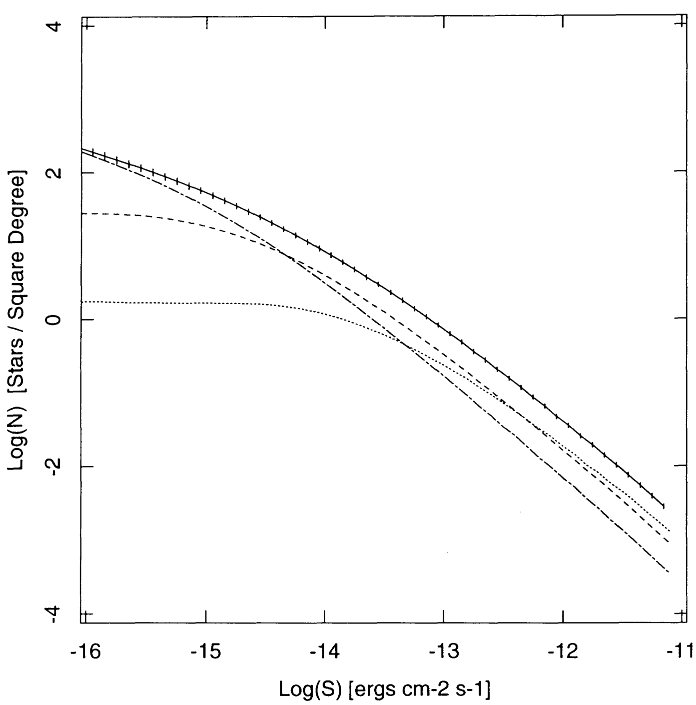

FIG. 4.—Predicted log (N) − log (S) in the 0.16–4.0 keV band at high galactic latitude for disk population stars assuming a constant stellar birthrate (*solid line*). In figure are shown the contributions of young stars (*dotted line*), intermediate age stars (*dashed line*), and old stars (*dotted-dashed line*). log (N) − log (S) has been corrected for the presence of unresolved binary systems. The indicated 1 σ error bars take into account the uncertainty in the knowledge of X-ray luminosity functions.

X-ray fluxes. We note also that at these faint fluxes a contribution of halo stars could appear. These are not presently included in our model calculation, because we lack enough X-ray data for attempting their modeling; however, their contribution is irrelevant at the presently explored X-ray flux level ($f_X \sim 10^{-13}$–10^{-12} ergs s^{-1} cm^{-2}).

At the typical *Einstein* sensitivity, $\sim 2 \times 10^{-13}$ ergs s^{-1} cm^{-2} the detected stars are mostly young stars. A similar age composition should occur in the *ROSAT* survey, while we expect that stellar sources detected by the deepest *ROSAT* observations or by the next generation X-ray observatories, such as AXAF or XMM, will be, at least at high latitude, mostly old disk (and maybe Population II) stars. This behavior is common to the cases $\tau = 15$ Gyr and $\tau = -15$ Gyr, i.e., for those cases with enough young stars to dominate the high flux region. On the contrary, in the case with $\tau = 5$ Gyr the young stars are very rare and do not dominate at any flux.

Figures 5*a* and 5*b* show the log (N) − log (S) obtained in the 0.16–4.0 keV band for the four studied birthrates without and with considering the effect of unresolved binary systems, respectively. The comparison of these plots clearly show that at any given flux the effect of taking into account the binary systems increases the number of expected X-ray coronal sources of a factor between 10% and 40% with the effect being larger at highest fluxes. The greatest differences are at high fluxes, where the effect of the presence of young stars is dominant. Also shown in the figures are the experimental points obtained from the EMSS (Gioia et al. 1990), excluding peculiar stars, such as W UMa, FK Com, RS CVn's, or BY Dra type stars. The lack of detections in the EMSS at higher fluxes is most likely due to the selection effects present in the EMSS itself, from which all the targets of the observations (typically bright sources) have been excluded. Points on intermediate flux ($f_X \sim 10^{-13}$–10^{-12} ergs s^{-1} cm^{-2}) are in agreement with a nearly constant stellar birthrate (upper three log (N) − log (S) of Fig. 5*b*). This result is in agreement with that obtained by Basu & Rana (1992) who reject the star-formation rate with $\tau = 5$ Gyr on the base of their computations of neutron star and white dwarf formation rates. Notice that both allowed models imply the presence of a large young population in the X-ray detected star sample. We stress that our results are based on comparison between the number of stars detected in the 10^{-13}–10^{-12} ergs s^{-1} cm^{-2} flux range, mainly young stars, and the number of sources predicted by various birthrate histories, whose normalization agrees with optical star counts. Since we have assumed SFR laws whose analytic form is determined by two parameters only (cf. eq. [2]) with the normalization, A, fixed by requiring the agreement with optical star counts, we are able to constrain the e-folding time, τ, just from stars with age less than 10^9 yr.

These results rest on the assumption that the majority of the EMSS stellar sample is actually composed of normal coronal sources. In Favata et al (1993c) we show that the majority of stars detected in the EMSS are young Population I stars, with very little contamination from, for example, an RS CVn-like population, at variance from what was suggested by Favata et al. (1988) as an alternative explanation for the yellow star excess in the Medium Sensitivity Survey (Gioia et al. 1984).

To further discriminate between these two interpretations we have conducted an optical observational campaign of high-resolution spectroscopy to determine the Li abundance from Li 6708 Å line (Favata et al. 1993a, b); analysis of these observations suggest that a large part of the active yellow stars

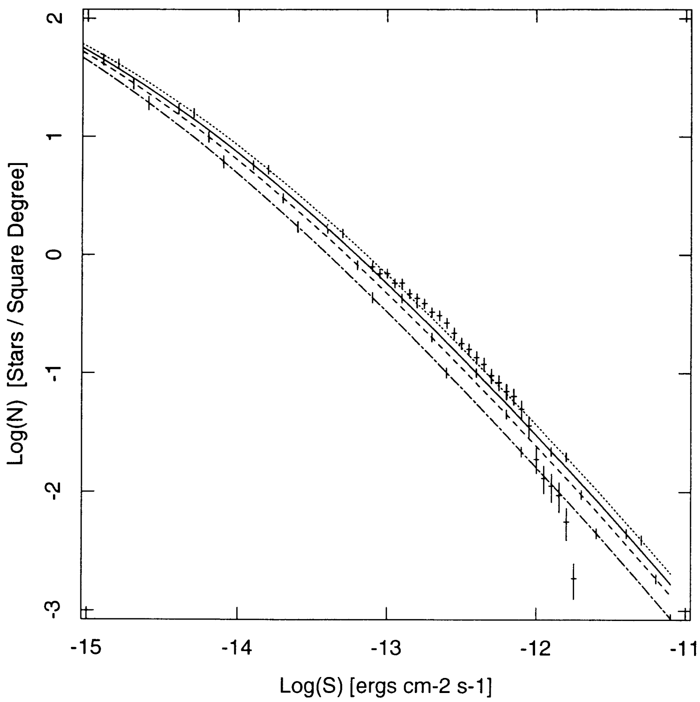

FIG. 5a

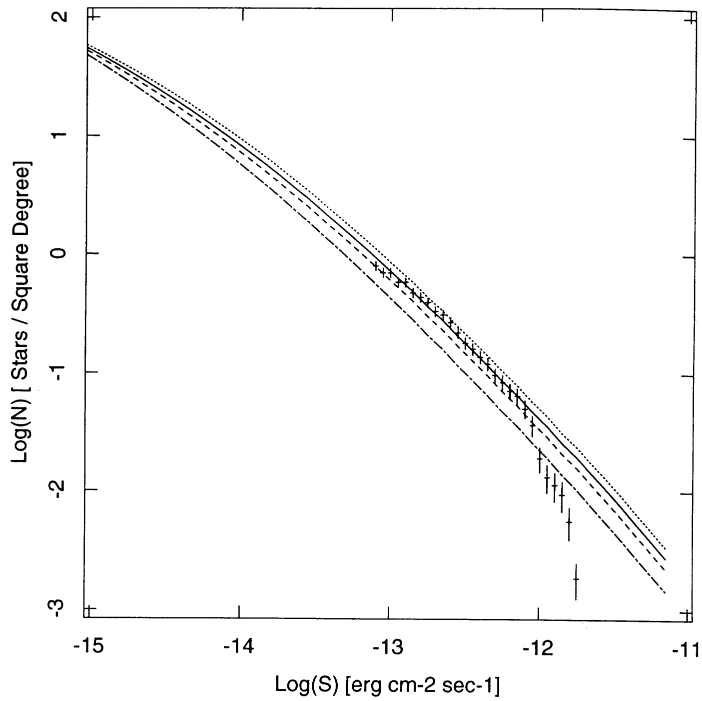

FIG. 5b

FIG. 5.—(*a*) log (*N*) − log (*S*) in the 0.16–4.0 keV band without binary correction predicted in the direction $l = 90°$ and $b = 90°$ assuming $\tau = \infty$ (*solid line*). $\tau = 15$ Gyr (*dashed line*), $\tau = -15$ Gyr (*dotted line*), and $\tau = 5$ Gyr (*dotted-dashed line*). Error bars meaning as in Fig. 4. Crosses indicate the experimental points (with error bars) obtained from the stellar content of the EMSS. (*b*) Same as panel (*a*) but corrected for the occurrence of binary systems. The EMSS experimental data points are indicated by crosses. The size of the error bars (not shown for readability) are of the same order of those shown in panel (*a*).

detected in the EMSS are objects with high content of Li, and therefore likely to be young objects. Analogous indications have been obtained from Li observations of a sample of stars detected serendipitiously in X-ray by *EXOSAT* (Tagliaferri et al. 1993).

4. CONCLUSIONS

We have discussed the sensitivity of the stellar X-ray log (*N*) − log (*S*) to the relative density of young stars resulting from the assumed stellar birthrate. We have shown that given the sensitivity of X-ray model predicted log (*N*) − log (*S*) to the stellar birthrate, X-ray flux limited survey can be used to impose relevant constraints on the history of the star-formation rate in the Galaxy.

In principle, the method we have presented is a very powerful one and could be used independently by other methods based on kinematics (Gomez et al. 1990), isochrones (Twarog 1980; Noh & Scalo 1990; Meusinger 1991) or chromospheric activity (Barry 1988; Soderblom et al. 1991). A relevant characteristic of the presented method is the selection of the sample used, that is *complete* in the sense that is made by all the stars with an X-ray flux greater than a given threshold in a given field of view. At this moment the main limitation of the method is due to the coarse knowledge of L_X-age relation, that is fundamental in building an appropriate X-ray Galaxy model. This is a crucial point: until a more detailed dependence will be known, the method presented here, cannot give a better resolution in the SFR history. For this region we have adopted only smooth birthrate, refraining from searching for irregularities such as bumps or lull as those suggested by Twarog (1980) or Barry (1988). The knowledge of L_X-age dependence would be increased by *ROSAT* observations of clusters that will allow to sample the L_x-age relation with higher resolution. We prefer not to use stars with age determination based on more uncertain methods (such as lithium abundances) given the uncertainty of such age determination. Furthermore, because stars of a given age do not have a fixed L_X, but a range of possible values described by the X-ray luminosity function, it is important to use the entire X-ray luminosity function and not a single L_X value.

We want to stress that our present results do not exclude the existence of irregularities in the SFR evolution. In particular bumps or dips such as those suggested by Barry (1988), with present data, would be smeared over an entire decade and would mimic a small increase or decrease in the SFR. We notice, however, that the existence of bumps or dips still need a firmer confirmation (see Soderblom et al. 1991).

The smaller scale height of young stars with respect to that of older stars should make the effect more relevant at low Galactic latitudes. Nevertheless, even at high latitude and at typical X-ray fluxes of *Einstein* observations, (10^{-13} ergs s^{-1} cm^{-2}), available observations (EMSS stellar content) are capable of discriminating between different star-formation rate histories, excluding a rapid decrease in the stellar birthrate in the past billion years.

We note that due to the flux limited nature of the EMSS (and future similar X-ray surveys), observations can extend to a distance that will depend primarily on the intrinsic stellar X-ray luminosity. The maximum X-ray luminosity observed for the most active late-type stars is of the order of $L_X = 10^{29.5-30}$ ergs s^{-1}; taking a typical EMSS limiting sensitivity, $f_X \sim 10^{-13}$ ergs s^{-1} cm^{-2}, the radius of the spherical volume already explored is, for the most luminous stars, between 150 and 500 pc. This implies that while at low Galactic latitude (near or below $b = 20°$) we are still far from reaching distances comparable to the scale height of young active stars (ranging between 120–180 pc), at high Galactic latitude ($b > 60°$) even present-day observations allow to sample distances comparable or larger than the scale height of young stars. A similar behavior we expect will be obtained with the *ROSAT* survey observations. Hence, with more sensitive observations, such as the deep *ROSAT* exposures or the future observations of AXAF and XMM, we expect to detect an even larger number of young active stars at low Galactic latitude than at high Galactic latitude.

Major difficulties in testing this very specific prediction with available or future X-ray surveys are (i) the determination of stellar distances; (ii) the patchiness of the X-ray absorbing interstellar medium at low Galactic latitudes (which makes the intrinsic source luminosity difficult to determine, although this effect should be sensibly less severe above 1 keV); (iii) the limited sky coverage; and (iv) the difficulties of unique optical identifications in the Galactic plane with instruments of limited (1′) spatial resolution which has so far prevented a detailed analysis of stellar content at low latitudes where we expect young stars to be concentrated.

The results of the ongoing source identification programs for the *ROSAT* all-sky survey should increase the number of stellar sources at low Galactic latitude and allow to better constrain the properties of the young disk population. We predict that future more sensitive and higher spatial resolution X-ray missions should detect an excess of young disk population stars at low Galactic latitude. On the contrary, at high Galactic latitudes the new X-ray detected stars will belong largely to an old disk population of relatively X-ray inactive stars with scale height greater than that of young more active stars.

We expect that large improvements in angular resolution, such as that attainable with the AXAF-HRC, will allow to extend this type of analysis to the low Galactic latitude region. Future observations will allow to better determine the scale heights of stars as functions of their X-ray luminosity (i.e., their age), and to further exploit this technique as an independent, new way of measuring the stellar age and birthrate in our Galaxy.

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