STELLAR CORONAL EMISSION: WHAT WE HAVE LEARNED FROM PRE-ROSAT OBSERVATIONS

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Abstract. Thanks to the success of *Einstein* and, later, of *Exosat*, the past decade has seen the unexpected flowering of the *Study of X-ray Emission from Normal Stars*. At the opening of the "ROSAT-era", when the availability of new data promises exciting advances, I review major accomplishments in the field, such as: i) the unpredicted discovery of coronal emission from nearly all types of stars, ii) the influence of stellar evolution on X-ray emission, iii) the role played by both optically-selected and X-ray-selected stellar samples in our present understanding of coronal emission, and iv) the contribution of coronal emission from late-type stars to the X-ray make-up of the Galaxy.

Key words: Stars: coronae - X-rays: stars -X-rays: diffuse background

1. The Years of Discoveries

The past 15 years have seen the early phase and the mature development of a new frontier in the realm of astrophysical research: *The study of X-ray emission from normal stars*. G.S. Vaiana has been one of the pioneers of this new frontier and was for me a great honor to work with him in the past decade, rich of pleasure for many exciting discoveries. I will try in this review to describe the advancement in this field to which he has given fundamental contributions.

Before 1979 only few stellar coronal sources were known (Figure 1). The coronae of Capella (Catura et al., 1975) and α Cen (Nugent & Garmire, 1978) could still be explained by an acoustic heating mechanism, while the evidence of high temperature components in the coronae of several RS CVn's seen with HEAO-1 (Walter et al., 1980) indicated the need for a non-gravitational confinement. For part of the astrophysical community this last finding was not surprising. In fact, mainly as a result of the program driven by G. S. Vaiana leading to the Skylab S-054 X-ray telescope (see the reviews of Vaiana & Rosner, 1978 and also of Golub, in this volume), the study of the solar corona had clearly shown how complex and structured was the corona of the Sun, pointing toward the need for magnetic confinement of coronal plasma.

With the launch of the *Einstein* Observatory, and since its early observations, our perception of the pervasiveness of stellar X-ray emission has changed drastically. In his memorable paper (Vaiana et al., 1981), based on results of a first round of *Einstein* observations, G.S. Vaiana with his group and several collaborators presented an X-ray survey of about 150 stars, concluding that, with the exception of late-B/early-A and late giants and supergiants, all stars are X-ray emitters. This discovery was a breakthrough in stellar coronal physics. It ruled out, as essentially incorrect, all those models that tried to predict/explain stellar X-ray emission without taking into account the critical role played by the magnetic field both in structuring and heating the stellar coronae.

Since these early results, the Palermo-Cfa stellar group has been engaged in the homogeneous analysis of all stellar data gathered with the Imaging Proportional Counter (Giacconi et al., 1979; Gorenstein et al., 1981) on board the *Einstein* Observatory, which covered approximately 10% of the sky with $\sim$ 4000 images. The task of extracting quantitative information for more than 35000 stars from IPC images has been made possible by the final highly-sophisticated IPC data processing

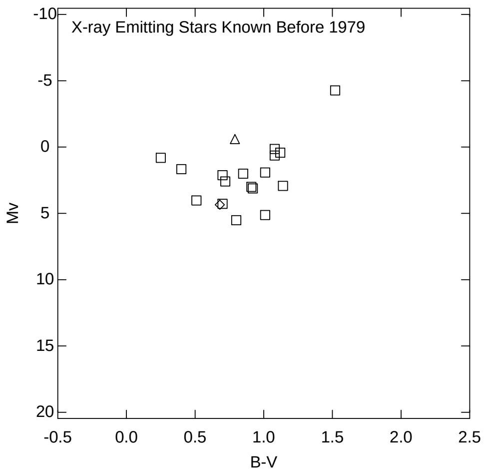

Fig. 1. HR diagram of the stellar coronal sources known up to 1979. Except for Capella (filled triangle) and α Cen (filled diamond), all other stars were RS CVn-like systems (squares). Based on these spare data no clear answer could have been given about the mechanism responsible of X-ray emission. However, already at those early days RS CVn's coronal temperatures gave indication for a non-gravitational confinement of emitting plasma.

system (Harnden et al., 1984), while handling all the available information has called for the realization of the Einstein Stellar X-ray Database (Sciortino et al., 1988; Harnden et al., 1990). This effort has resulted in the *Einstein* Stellar Survey (Vaiana, 1990; Vaiana et al., 1990).

The result of this effort is illustrated in figure 2, showing the HR diagram of most (*but not all !*) of the stars with, at least, an X-ray flux (or upper limit) measured with the *Einstein* Observatory.

Among the stars surveyed but not shown in figure 2 are those listed in the SAO catalog with magnitude fainter than 6.5 (the limiting magnitude of the Bright Stars Catalog). This sample is largely composed of yellow main sequence and giant stars up to distances of 100-200 pc, and likely contains a population of young intense X-ray sources (Micela et al., 1992a; Favata et al., 1992a). The space density of this population is quite small and their discovery is virtually impossible exploring only the volume inside the sphere of 25 pc radius made accessible by available catalogs of nearby stars. This explains why their existence has not been recognized in the *Einstein* dG survey of Maggio et al. (1987).

If all stars would emit X-rays at the same level of the Sun, then the study of X-ray emission from normal stars would have been a very meager affair. As shown in figure 3, only a handful of stars, all inside 10 pc, have been detected at the solar X-ray emission level: $L_X \sim 10^{27}$erg s^{-1}, while the majority of stars have been detected at significantly higher (up to three orders of magnitude) L_X. In other words, it has been only the surprising discovery of the wide spread of L_X for each spectral type and luminosity class, evident since early days (Vaiana et al., 1981), that has allowed the rapid growth of our knowledge. **This large spread shows that "classical" stellar parameters cannot explain the X-ray emission level**, indicating that coronal emission is a manifestation of "stellar activity" determined by "non-classical" stellar parameters. Since 1979, it has been

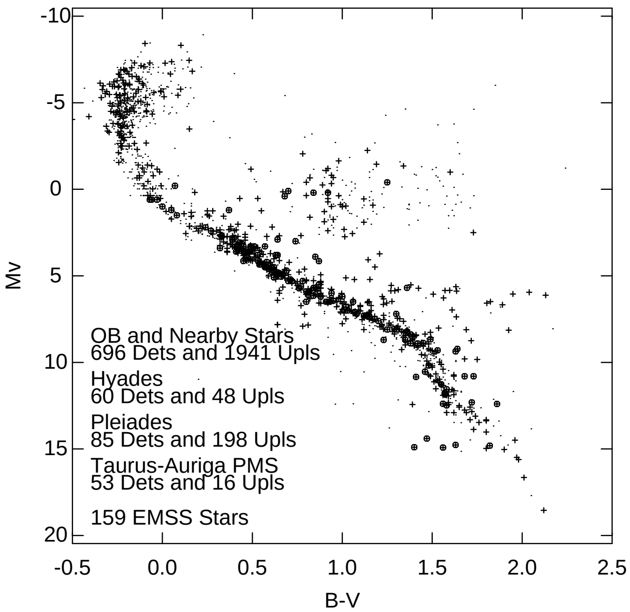

Fig. 2. HR diagram of stars surveyed with the *Einstein* Observatory, based on X-ray surveys of optically selected samples of O stars (Chlebowsky et al., 1989; Sciortino et al., 1990), B stars from SAO (Grillo et al., 1992), nearby field dA (Schmitt et al., 1985), dG (Maggio et al., 1987), dK and dM (Barbera et al., 1992b) stars, Pleiades (Micela et al., 1990), Hyades (Micela et al., 1988), and optically and X-ray selected Taurus-Auriga PMS stars (Damiani & Micela, 1992). Detections are indicated by pluses, while stars with measured upper limits are indicated by dots. The X-ray selected stars (bullets) are taken from the Extended Medium Sensitivity Survey stars (Fleming, 1988; Stocke et al., 1991).

clear that the magnetic field is a crucial ingredient (Rosner & Vaiana, 1980). Its interplay with stellar rotation rate, spin-down with increasing stellar age, depth of convection zone would result in stellar dynamos of various efficiency. In this interpretational framework, the spread in the observed X-ray luminosity will mainly reflect that of the efficiency of the stellar coronal heating. It is hypothesized that the heating mechanism is mainly due to the interaction between stellar magnetic fields and coronal plasma, a mechanism clearly at work on the Sun. In the past ten years this picture has passed many observational tests, as I will briefly discuss in the following. I will not discuss evidence coming from temporal variations of coronal emission level, since this subject has been reviewed by Pallavicini, in this volume.

2. What Parameters does L_X Depend upon in Late-type Stars ?

2.1. L_X and Stellar Dynamos

Stellar magnetic fields have to be continuously regenerated by dynamo action (see Weiss, in this volume and references therein), and a more intense dynamo action will result generally in a more intense X-ray emission (but see the caveat in the following). If this scenario is correct, there are various predicted trends and relations that should occur between the X-ray emission level and other stellar parameters,

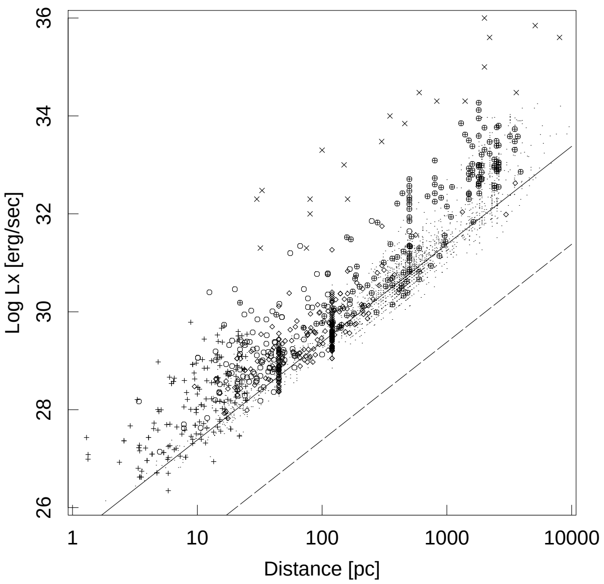

Fig. 3. L_X vs. distance for various stellar samples. Detected sources are indicated with different symbols as follows: Main sequence G, K, M stars (plus), main sequence A-F stars and yellow giants (circles), Orion, Pleiades, Hyades and EMSS stars (diamonds), OB stars (bullets), HEAO-1 compact sources (crosses). Small dots indicate upper limits to the X-ray luminosity. The lines represent limiting sensitivities of 2 10^{-13}erg cm^{-2} s^{-1} (solid), typical of Einstein observations, and of 2 10^{-15}erg cm^{-2} s^{-1} (dashed), expected for the majority of AXAF-I observations.

such as: (i) stellar rotation rate; (ii) dynamo efficiency at A/F type boundary, as a result of the depth of the convection zone; (iii) ineffectiveness of $\alpha - \omega$ dynamo action at the low-mass end, where stellar models predict a completely convective structure.

2.1.1. $\mathrm{L_X}$ *and Rotation Rate*

Pallavicini et al. (1981) have shown that the X-ray luminosity of late-type stars, independently of spectral type and luminosity class, correlates with stellar rotation rate, as $\mathrm{L_X} \propto (\mathrm{v}\sin\mathrm{i})^2$ (cf. figure 5 in Pallavicini et al. paper). Adopting a somewhat larger sample of dwarf G stars, and considering both detections and upper bounds, Maggio et al. (1987) have confirmed this finding. Micela et al. (1985a,1990) and Caillault & Helfand (1985) have pointed out that this relation breaks down for the fast rotating, intense X-ray emitting Pleiades dK stars (see figure 4).

A similar break is clearly evident also among the stellar coronal sources discovered with the Extended Medium Sensitivity Survey (Fleming et al., 1989), the majority of which have rotational velocities much higher than those of nearby field stars (see Figure 4). These results can be naturally interpreted (cf. Rosner, 1989) as the existence of a saturation level in stellar coronal emission occurring when the entire stellar surface is covered with solar-like active regions. In such a case a further increase of the stellar rotation rate cannot result in an increase of the stellar X-ray emission level.

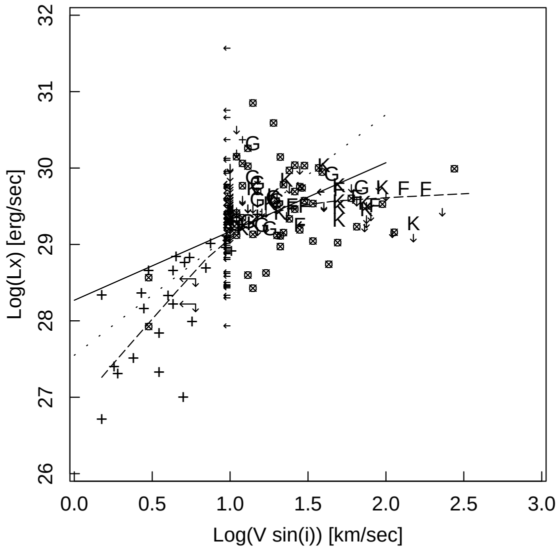

Fig. 4. L_X vs. rotation rate for (i) a sample of late type stars (pluses) from Maggio et al. (1987), (ii) a sample of Pleiades stars from Micela et al. (1990), each letter indicates the corresponding spectral type, (iii) a sample of EMSS stellar sources (filled squares) from Fleming (1988). The dotted line is the $L_X \propto (v \sin i)^{2.1\pm0.5}$ relation, found for the late-type stars (Pallavicini et al. 1981; Maggio et al. 1987) and holding also for the entire class of RS CVn's (not shown in the figure). The solid line is the regression fit, $L_X \propto (v \sin i)^{1.21\pm0.13}$ to the Pleiades data (Micela et al. 1990), while the dashed line is a robust local fit to both the field and Pleiades star samples. It is evident that the local fit provides also a good description of the coronal emission of the EMSS stellar sources.

2.1.2. L_X *and Depth of Convection Zone*

The two principal ingredients determining the efficiency of an $\alpha - \omega$ stellar dynamo are the rotation rate and the structure of the convection zone. Dynamo efficiency is usually expressed with a single parameter, the dynamo number, $N_D \propto \alpha(\nabla_r\Omega)d^4/\eta^2$, where α is the mean elicity of convective velocity times convective turnover time (τ_c) at the base of convection zone, $\nabla_r\Omega$ is the radial gradient of angular velocity, d is the scale length of convection, and η is the turbulent magnetic diffusivity. Assuming $\alpha \sim \Omega d$ and $\eta \sim d^2\tau_c$ (Durney & Latour, 1978), and making the further naive assumption $\nabla_r\Omega \sim \Omega/d$ then $N_D \sim (\Omega\tau_c)^2 \sim R_o^{-2}$. The so-called Rossby number, R_o, is a parameter that gives a measure of dynamo efficiency in terms of measured rotational rate and of τ_c as derived from models. Noyes et al. (1984) have shown that in a wide range of spectral types the intensity of Ca h&k lines is well correlated with R_o. A similar results has been obtained correlating X-ray luminosity with R_o (Micela et al., 1985b; Schmitt et al., 1985; Maggio et al., 1987), **indicating a common magnetic origin for many manifestations of stellar activity.**

Since convection is an essential ingredient for stellar dynamos, and stellar interior models predict the growth of the convection zone at late-A spectral types, no coronae should develop on normal late-B/early-A stars (but see Linsky, in this volume, for a discussion of peculiar B/A stars) while X-ray emission should smoothly increase together with the depth of convection zone in the late-A/early-F spectral type range. Schmitt et al. (1985) have performed a detailed study of the X-ray emission level among A and early-F stars showing (i) that early A stars as a class are not X-ray emitters, and (ii) that the X-ray emission level of late-A/early-F stars correlate better with the Rossby number than with the rotational velocity, as expected in the region of rapid change of the depth of convection zone with spectral type.

2.1.3. L_X *at the Low-Mass End*

The expectation of a lower X-ray emission level in low-mass stars (later than M5) has been recently addressed by Barbera et al. (1992a,b,c), based on the final data processing of the full set of *Einstein* observations and on a detailed analysis to investigate and to remove at the best the biases of the optically-selected stellar sample. This work shows with high statistical significance the existence of a drop in X- ray emission level (as indicated both by X-ray luminosity and surface flux) at spectral type later than $\sim$ M5. This drop was previously indicated by Bookbinder (1985) on the basis of a smaller, less optically characterized stellar sample and an early version of the *Einstein* data analysis system.

2.2. L_X and Stellar Age

One of the most important results of stellar X-ray astronomy has been the discovery that the X-ray luminosity level decreases with increasing stellar age (Vaiana, 1981, 1983; Caillault & Helfand, 1985; Micela et al., 1985a, 1988, 1990).

Young pre-main sequence stars where recognized as a class of intense X-ray emitters ($L_X \sim 10^{29-30}$erg s^{-1}) since early observations (Ku & Chanan, 1979; Ku et al., 1982; Gahm, 1980; Feigelson & Decampli, 1981; Walter & Kuhi, 1981; Feigelson & Kriss, 1981), but only the systematic analysis of various coeval stellar samples (for a recent review see Vaiana et al.,1992 and references therein), with the adoption of survival analysis techniques (Avni et al., 1980; Schmitt, 1985; Feigelson & Nelson, 1985) to retain upper limits as well as detections information, has clearly shown the decrease of the X-ray emission level from the PMS stage and along the entire MS lifetime. This can be explained as an effect of stellar spin-down with age (for recent reviews, see Soderblom 1991, Bovier 1991, Stauffer 1991) resulting from the magnetic braking (Collier-Cameron et al. 1991) due to intense stellar magnetic activity associated with high rotational velocity.

This ageing effect is so relevant to be one of the crucial ingredients for a realistic modeling of the stellar coronal content of the Galaxy. It influences substantially stellar X-ray counts (Favata, Micela and Sciortino 1992a,b), is a sensible diagnostics of stellar birthrate in the Galaxy in the last billion years (Micela et al., 1992a), and gives a natural explanation of the origin of the diffuse soft X-ray background feature called the Galactic Ridge (cf. §5.1).

2.3. L_X and Evolution Toward The Red Giant Branch

Changes of stellar structure with evolution toward the red giant branch, especially stellar angular momentum redistribution and development of the convection zone, influence the level of "stellar activity" (for a review of some of the theoretical aspects see Rosner, in this volume). Based on IUE data of 22 stars, Linsky and Haisch (1979) have suggested the existence of an UV dividing line going from the K2III to the G8Ib spectral types, separating earlier stars having line emission coming from transition regions from later ones showing mainly evidence of strong winds.

The final, detailed analysis of the entire sample of late giants and supergiants listed in the BSC and surveyed with the *Einstein* Observatory (Maggio et al., 1990) has demonstrated on firm statistical grounds the existence of an X-ray dividing line, originally suggested on more sparse data (Ayres et al., 1981), occurring for stars of spectral type later than K3III. The analysis of a substantially larger sample has confirmed the existence of the UV dividing line likely at the same position of the X-ray one (Haisch et al., 1990).

Using both X-ray and IUE data, our group has recently studied the evolution of stellar activity in early post-main-sequence phases for stars with 1.1-1.9 $M_\odot$. Available data are consistent with a picture in which the onset of convection when stars leave the main sequence accounts for the raise of X-ray luminosity. However, the rotational velocity of stars with $M < 1.6$ $M_\odot$, already declined during the main sequence life-time, due to intense magnetic activity, keeps declining until the dynamo ceases to be effective, and the X-ray emission consequently drops (for more details see Maggio et al., in this volume).

3. Low-Resolution Spectroscopy of Stellar Coronae

Medium/high resolution spectra are available only for a handful of stars (cf. Mewe, in this volume). Hence, most of the knowledge on the physical conditions of stellar coronal plasma is based on low resolution spectra, such as those gathered with the *Einstein* IPC, or on broad band measurements, such as those of the *Exosat* CMA. The analysis of about 170 IPC spectra of nearby stars (Schmitt et al., 1990) has shown that: (i) coronal temperatures are in the range $10^6 - 10^{7.5}$ K with dF-dK stars being cooler than dM stars; RS CVn systems have very hot coronae (see figure 2 of Schmitt et al. 1990), (ii) often a two-temperature model, as well as a continuous emission measure distribution model, gives a better fit to high S/N spectra (see figures 7, 8 and 9 of the cited paper). A comparison of *Einstein* IPC and *Exosat* fluxes for a sample of $\sim$ 15 stars detected with both instruments has also indicated the existence of multi-temperature components in coronal emitting plasmas (Pallavicini et al., 1988).

4. X-ray Emission from Early-type Stars

One of the most unpredicted discovery of the *Einstein* Observatory has certainly been the recognition that OB stars are intense X-ray emitters with X-ray and bolometric luminosities being roughly proportional (Harnden et al., 1979). Based on a small sample of OB stars, Pallavicini et al. (1981) have shown that X-ray luminosity do not correlate with rotation rate. Hence, X-ray emission from massive stars is not associated with dynamo action. Given the lack of a convection zone in OB stars, this is not really surprising.

With the availability of the final catalog of O stars surveyed with *Einstein* imaging instruments (Chlebowsky et al., 1989) we have carried out a detailed study of X-ray emission from O stars (Sciortino et al., 1990) concluding that: (i) the majority of O stars have X-ray luminosity between 10^{31-32}erg s^{-1}, (ii) $\log L_X/L_{Bol}$ ranges between -6 and -7, (iii) L_X/L_{Bol} seems to correlate with $\dot{M}V_\infty^2$, (iv) none of the stellar and wind parameters considered, including L_{Bol}, accounts for the large spread of L_X, (v) there is no evident relation between L_X and association membership and/or position in the Galaxy.

Many models have been proposed to explain the intense X-ray emission from OB stars. They belong mainly to two classes: those where a hot corona lies near the stellar surface, at the base of a cooler high-speed wind (Cassinelli & Olson, 1979; Waldron, 1984), and those where shocked X-ray emitting matter is distributed throughout the wind, and the shocks are due to the instability of a radiatively-driven wind to density perturbations (Lucy & White, 1980; Lucy, 1982).

A very crucial test of all those models is the comparison between predicted and observed spectra (Cassinelli & Swank, 1983). Only Lucy's model, with an ad-hoc choice of shock intensity distribution, seems to match the observations (cf. figure 5 of Cassinelli & Swank, 1983), while all models assuming the existence of a corona at the base of the wind are ruled out by the lack of the predicted strong absorption feature below 0.5 keV (cf. figures 3, and 4 of the cited paper). S. Owoki and collaborators, and Pauldrak and collaborators have undertaken long term projects for studying the physics of wind-induced instability. This study should make possible to predict the resulting X-ray emission. For further details the reader is referred to the paper by Kudritzki, in this volume.

5. Stellar Coronal Emission and the Origin of Diffuse Soft X-ray Background (DXRB)

Since the seminal paper of Rosner et al. (1981), several authors have evaluated the contribution of stellar coronal sources to the DXRB (Kahn & Caillault, 1986; Caillault et al., 1986; Caillault, 1990). In the following I will limit myself to consider only the most recent results (see Table 1) based on a detailed stellar spatial distribution taken from the Bachall & Soneira Galaxy model (Bahcall & Soneira, 1980; Bahcall, 1986) and a detailed description of interstellar absorption at X-ray wavelenghts.

Schmitt & Snowden (1990) have computed the contribution of M stars assuming that: (i) their coronal spectra can be modeled with a continuous emission measure distribution with log $T_{max} = 7.1$ and $\alpha = 0.9$ (Schmitt et al., 1990); (ii) their X-ray luminosity function can be parametrically described with a log-normal distribution of given $< L_X >$. With a similar approach Ottman & Schmitt (1992) have evaluated the contribution of RS CVn's whose spectra have been modeled with log $T_{max} =$ 7.5 and $\alpha = 3$.

Kashyap et al. (1992) have evaluated the contribution of all spectral types (including RS CVn's), giving also an estimate of the contribution of halo population stars. In their calculations (i) they have modeled coronal spectra both in terms of the same continuous emission measure distribution model adopted by Schmitt and Snowden (1990), and in terms of a two-temperature description with $T_{low} = 1.4\ 10^6$ K and $T_{high} = 1.74\ 10^7$ K, derived from the stellar coronal temperature survey of Schmitt et al. (1990), where the emission measure of the high-T component, EM_{high}, increases with increasing total L_X, in analogy with the solar case; (ii) they have adopted the full set of maximum likelihood X-ray luminosity functions derived from the *Einstein* Stellar Survey as available at the end of 1990. Due to the limited knowledge on X-ray luminosity functions at high L_X, from which the major part of stellar contribution to DXRB derives, those authors have obtained confidence intervals for the predicted stellar contribution through a bootstrap analysis.

A comparison of the predictions of the above two models is shown in table 1 for a limiting sensitivity of 10^{-10}erg s^{-1} cm^{-2}, namely that of the all sky survey of McCammon et al. (1983). The discrepancies can be explained (i) by the tails of X-ray luminosity functions retained by Kashyap et al. (1992) in their calculation, and

TABLE 1
Comparison of Recent Predictions of Stellar Coronal Source Contribution to Soft DXRB for a Limiting Sensitivity of 10^{-10} erg sec^{-1} cm^{-2}

Schmitt and Snowden (1990) and Ottman and Schmitt (1992)

Energy	/ Band	High Galactic Latitude dM	All MS	RS CVn[(a)]	Low Galactic Latitude dM	All MS	RS CVn[(a)]
< 0.3	C	...	-	...	...	-	...
0.45-0.65	M_1	5%	-	...	9%-18%	-	-
0.65-0.85	M_2	10%	...	1%	20%-40%	...	5%
0.85-1.15	I	8%	...	1%	20%-40%	...	14%
1.15-2.0	J	< 3%	...	1%	7%-14%	...	16%
2.0 - 6.0	HEAO1[(b)]	...	...	-	...	...	6%

Kashyap et al. (1992)[(c)]

Energy	/ Band	High Galactic Latitude dM	All MS	RS CVn	Low Galactic Latitude dM	All MS	RS CVn
< 0.3	C	...	< 3%	-	...	< 3%	...
0.45-0.65	M_1	...	4%-8%	$\sim$ 1%	...	7%-16%	...
0.65-0.85	M_2	...	7%-17%	$\sim$ 1%	...	14%-34%	...
0.85-1.15	I	...	12%-30%	$\sim$ 1%	...	29%-71%	...
1.15-2.0	J	...	9%-22%	$\sim$ 1%	...	27%-66%	...

(a) Notice that the limited knowledge on space density, scale height and X- ray luminosity function of RS CVn's makes the calculation of their contribution to DXRB much more uncertain than that of main sequence stars (cf. Ottman and Schmitt, 1992).
(b) The 6% contribution in the 2-6 keV band accounts for $\sim$ 27% of the Galactic Ridge excess, however this prediction leaves unexplained the strong Fe 6.7 Kev line seen in the Ridge and in stars formation regions with Ginga (Koyama 1988a,b).
(c) M stars account for $\sim$ 60%-75% of the overall stellar contribution, the exact amount depending on energy band and assumed stellar spectra. The intensity of the stellar contribution to DXRB decreases by a factor 2 when the limiting sensitivity becomes 10^{-14}erg cm^{-2} s^{-1}.

(ii) by differences in the assumed model stellar spectrum. Future 100 eV resolution observations, such as those which will be possible with CCD instruments, should better constrain stellar spectra, and allow a further advancement in the field.

5.1. The Origin of the Galactic Ridge

Our group in Palermo has re-evaluated the stellar contribution to DXRB to investigate the origin of the Galactic ridge (Micela, 1991; Micela et al., 1992b).

The predictions shown in figure 5 have been evaluated in the [0.16 - 3.5] keV energy band and for a limiting flux, $f_x \sim 10^{-13}$ erg cm^{-2} s^{-1}, typical of *Einstein* observations, assuming that:

- The nearby dA-dF field stars are representative of the dA-dF stars in the entire Galaxy and have coronal temperatures of 0.3 keV.
- The dG, dK, dM stars have been divided into 3 age ranges with scale heights, X-ray luminosity functions, and coronal temperatures as listed below, and

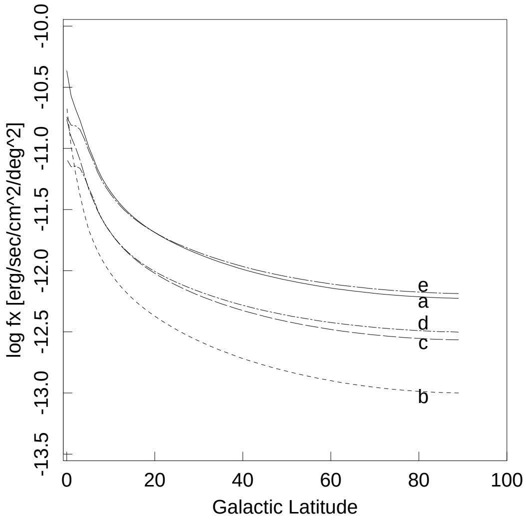

Fig. 5. Predicted contribution of disk population stars to DXRB as a function of galactic latitude for a limiting X-ray flux of 10^{-13}erg cm^{-2} s^{-1} (line *a*). The contributions from stars of the three distinct age ranges considered are also shown: "Pleiades-age" (line *b*), "Hyades-age" (line *c*), and "Old-Disk age" (line *d*) stars. For comparison, we shows also the predicted contribution assuming that all stars belong to the "Old-Disk age" group (line *e*).

with densities derived assuming a constant stellar birth rate:

Age (yr)	Scale Height (pc)	Prototype X-ray Lum. Fun.	Coronal Temp. (keV)
$10^7 - 10^8$	140	Pleiades	1.1
$10^8 - 10^9$	240	Hyades/Young Disk	0.5
$10^9 - 10^{10}$	400	Old Disk	0.3

This model seems capable to explain the Galactic Ridge in terms of unresolved coronal emission from young disk population stars (line *a*), and predicts a stellar contribution toward galactic poles of only few percent of the observed diffuse soft X-ray background in the [0.16 - 3.5] keV energy band. For comparison we show in figure 5 (line *e*) a calculation performed assuming a single stellar age, and a coronal temperature equal to 0.3 keV. At high galactic latitude this single age, single T model is essentially indistinguishable from the other (line *a* of Fig. 5), while at low galactic latitude the predicted emission accounts only for $\sim$ 25% of the observed excess X-ray emission in the Galactic ridge.

In figure 6 we compare as a function of galactic longitude a model prediction and the actual IPC background measurements in the Galactic ridge region. The points are measurements taken from the *Einstein* IPC survey of soft X-ray background (Micela et al., 1991), and the lines are the predicted profiles computed for $b = 0°$ (lower) and $b = 5°$ (upper) including the average level of non-astrophysical background (dashed line).

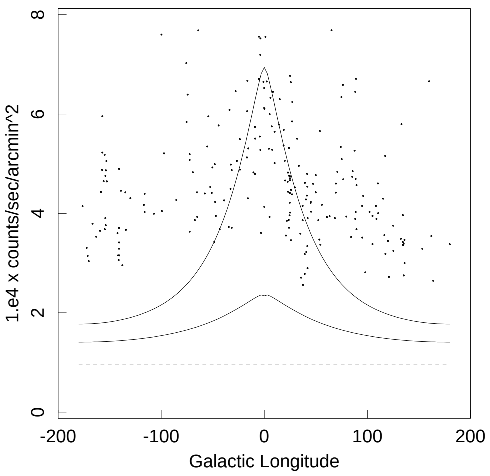

Fig. 6. Comparison of a model prediction of the [.16 - 3.5] keV X-ray background with *Einstein* Observatory IPC measurements, in the region of sky with $|b| < 5°$, namely toward the Galactic ridge. The dashed line is the average level of non-astrophysical contamination. The lower and upper solid lines are the predicted profiles computed for $b = 0°$ and $b = 5°$, respectively.

6. A Glance into the Future

Since many of the new exciting results from ongoing ROSAT stellar surveys are reported in many other papers of this volume (Bromage, 1992; Casanova et al., 1992; Caillault et al., 1992; Fleming, 1992; Harnden, 1992; Pye, 1992; Schmitt, 1992), I will not even attempt to discuss them. Looking at the stellar X-ray astronomy of the next decade I want to notice that future more sensitive, high resolution observations covering the energy range up to $\sim$ 10 keV, such as those that will be available with ASTRO-D, Jet-X, AXAF and XMM, will allow to better probe the origin of the Galactic Ridge. In particular, the origin of the iron 6.7 keV emission line, seen both in Galactic Ridge and in star formation regions with the few degrees spatial resolution instrument of Ginga (Koyama, 1988a; Koyama, 1988b), is an open and intriguing research problem.

As a result of stellar density scale heights, and shape of X-ray luminosity functions, if we had a very high X-ray sensitivity, we would expect a *clustering of stars* in the f_x/f_v vs. m_v plane for each pointing direction. Based on the Palermo-ESA X-ray Galaxy model (Favata et al. 1992c), and taking into account the effect of stellar age as discussed by Micela, Sciortino and Favata(1992a) and Favata, Micela and Sciortino (1992a,b), one can calculate the predicted positions of the centroids of the distributions in the f_x/f_v, m_v plane.

Figure 7 shows the contour plot of number density (number of star per unit m_v, and unit f_x/f_v) for the dA, dG, dM0-dM5 stars at $b = 20°$ and $l = 90°$. Centroid positions depend on latitude: at the poles they move towards smaller m_v (apparently more luminous stars), and on the plane they move towards larger m_v (less luminous stars). The limiting flux required to observe the centroids is very low: for instance, at $b = 20°$, we predict $f_x \sim 10^{-(17 \div 18)}$ erg cm^{-2} s^{-1}, that becomes $f_x \sim 10^{-(16 \div 17)}$ erg cm^{-2} s^{-1} at the pole. At this sensitivity, the number of stars per square degree is very high and obviously there will be source confusion at any

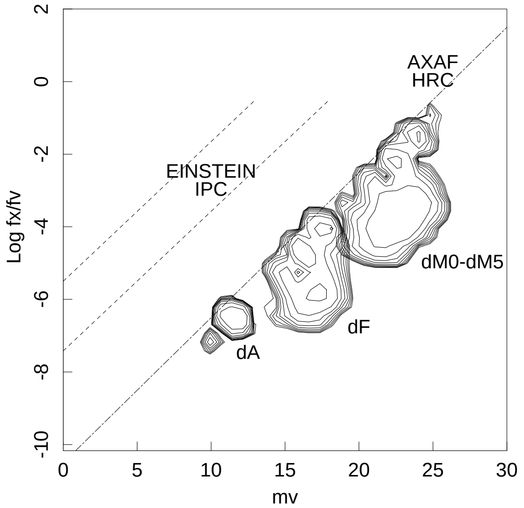

Fig. 7. Contours of model-predicted stellar number density in the log f_x/f_v - m_v plane, for dA, dG and dM0-dM5 stars at $b = 20°$, and $l = 90°$. The number density of each group has been normalized to its maximum value. Contours cover the range between 1 and 1/10 of the maximum value. The range of limiting sensitivities achieved by the *Einstein* IPC observations, and the foreseeable limiting sensitivities for the AXAF HRC observations are shown. Even a mission with sensitivity such as that of AXAF will not be able to sample the centroid of the distribution of M stars.

foreseeable sensitivity and resolution that instruments will reach in near future. As shown in figure 7, **AXAF will detect only the tail of the stellar distribution of M stars. Hence, even AXAF (or AXAF-like missions) will not be able to resolve the stellar soft X-ray background.**

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References

Avni, Y., Soltan, A., Tananbaum, H., and Zamorani, G. 1980, ApJ, 238, 1800.
Ayres, T. R., Linsky, J. L., Vaiana, G. S., Golub, L., and Rosner, R. 1981, ApJ, 250, 293.
Bahcall, J. N. 1986, ARA&A, 24, 577.
Bahcall, J. N. and Soneira, R. M. 1980, ApJS., 44, 73.
Barbera, M., Micela, G., Sciortino, S., Vaiana, G. S., F. R. Harnden, J., and Rosner, R. 1992a, Mem. Soc. Astr. It., in press.
Barbera, M., Micela, G., Sciortino, S., Harnden, F. R., Jr., and Rosner, R. 1992b, ApJ, submitted.
Barbera, M., Micela, G., Sciortino, S., Harnden, F. R., Jr., and Rosner, R. 1992c, In *This volume*.
Bookbinder, J. 1985, PhD Thesis, Harvard University.
Bouvier, J. 1991, In *Angular Momentum Evolution of Young Stars*, S. Catalano and J. Stauffer, editors, page 41, Kluwer Academic Publisher.

Bromage, G. 1992, In *This volume.*
Caillault, J. P. 1990, PASP, 102, 989.
Caillault, J. P. and Helfand, D. J. 1985, ApJ, 289, 279.
Caillault, J. P., Helfand, D. J., Nousek, J. A., and Takalo, L. O. 1986, ApJ, 304, 318.
Caillault, J. P., Gagne, M., Stauffer, J. 1992, In *This volume.*
Casanova, S., Feigelson, E. D., Montmerle, T. 1992, In *This volume.*
Cassinelli, J. P. and Olson, G. L. 1979, ApJ, 229, 304.
Cassinelli, J. P. and Swank, J. H. 1983, ApJ, 271, 681.
Catura, R. C., Acton, L. W., and Johnson, H. M. 1975, ApJL, 196, 47.
Chlebowsky, T., Harnden, F. R., Jr., and Sciortino, S. 1989, ApJ, 341, 427.
Collier-Cameron, A., Jianke, L., and Mestel, L. 1991, In *Angular Momentum Evolution of Young Stars*, S. Catalano and J. Stauffer, editors, page 297, Kluwer Academic Publisher.
Damiani, F. and Micela, G. 1992, In *This volume.*
Durney, B. R. and Latour, J. 1978, Geophys. Ap. Fluid. Dyn., 9, 241.
Favata, F., Micela, G., and Sciortino, S. 1992a, In *This volume.*
Favata, F., Micela, G., and Sciortino, S. 1992b, A&A, submitted
Favata, F., Micela, G., and Sciortino, S., Vaiana, G. S. 1992c, A&A, 256, 86.
Feigelson, E. D. and Decampli, W. M. 1981, ApJL, 243, 89.
Feigelson, E. D. and Kriss, J. A. 1981, ApJL, 248, 35.
Feigelson, E. and Nelson, P. L. 1985, ApJ, 257, 695.
Fleming, T. H. 1988, PhD Thesis, University of Arizona.
Fleming, T. H. 1992, In *This volume.*
Fleming, T. H., Gioia, I., and Maccacaro, T. 1989, ApJ, 340, 1011.
Gahm, G. F. 1980, ApJL, 242, 163.
Giacconi, R. et al. 1979, ApJ, 230, 540.
Gioia, I. M., Maccacaro, T., Schild, R. E., Wolter, A., Stocke, J., Morris, S., and Henry, J. P. 1990, ApJS., 72, 567.
Golub, L. 1992, In *This volume.*
Gorenstein, P., Harnden, F. R., Jr., and Fabricant, D. G. 1981, page 869.
Grillo, F., Sciortino, S., Micela, G., Vaiana, G. S., and Jr., F. R. H. 1992, ApJS, in press.
Haisch, B., Bookbinder, J., Maggio, A., Vaiana, G. S., and Bennett, J. 1990, ApJ, 361, 570.
Harnden, F. R., Jr. et al. 1979, ApJL, 234, 51.
Harnden, F. R., Jr., Fabricant, D. G., Harris, D. E., and Schwarz, J. 1984, SAO Special Report 393, Smithsonian Astrophysical Observatory.
Harnden, F. R., Jr., Sciortino, S., Micela, G., Maggio, A., Vaiana, G. S., and Schmitt, J.H.M.M. 1990, In Elvis, M., editor, *Imaging X-ray Astronomy*, page 313. Cambridge University Press.
Harnden, F. R., Jr. 1992, In *This volume*
Kahn, S. M. and Caillault, J. P. 1986, ApJ, 305, 526.
Kashyap, R., Rosner, R., Micela, G., Sciortino, S., Vaiana, G. S., and Harnden, F. R. 1992, ApJ, 391, 667.
Koyama, K. 1988a, Comments Astrophys., 12, 287.
Koyama, K. 1988b, ISAS Res. Note, 391.
Ku, W. H.-M. and Chanan, G. A. 1979, ApJL, 234, 59.
Ku, W. H.-M., Righini-Cohen, J., and Simon, M. 1982, Science, 215, 61.
Kudritzki, R. P. 1992, In *This volume.*
Linsky, J. 1992, In *This volume.*
Linsky, J. L. and Haisch, B. 1979, ApJL, 229, 27.
Lucy, L. B. 1982, ApJ, 255, 286.
Lucy, L. B. and White, R. L. 1980, ApJ, 241, 300.
Maggio, A., Sciortino, S., Vaiana, G. S., Majer, P., Golub, L., Bookbinder, J., Harnden, F. R. J., and Rosner, R. 1987, ApJ, 315, 687.
Maggio, A., Vaiana, G. S., Haisch, B. M., Stern, R. A., Bookbinder, J., Harnden, F. R., and Rosner, R. 1990, ApJ, 348, 253.
Maggio, A., Sciortino, S., Bianchi, L., Harnden, F. R., Jr., and Rosner, R. 1992b, In *This volume.*
McCammon, D., Burrows, D. N., Sanders, W. T., and Kraushaar, W. L. 1983, ApJ, 269, 107.
Mewe, R. 1992, In *This volume.*
Micela, G. 1991, PhD Thesis, Universita' di Palermo.
Micela, G., Sciortino, S., Serio, S., Vaiana, G. S., Bookbinder, J., Golub, L., Harnden, F. R. J.,

and Rosner, R. 1985a, ApJ, 292, 172.
Micela, G., Sciortino, S., and Serio, S. 1985b, In Oda, M. and Giacconi, R., editors, *X-Ray Astronomy '84*, page 43, Bologna.
Micela, G., Sciortino, S., Vaiana, G. S., Schmitt, J. H. M. M., Stern, R. A., Harnden, F. R., and Rosner, R. 1988, ApJ, 325, 798.
Micela, G., Sciortino, S., Vaiana, G. S., Harnden, F. R., Rosner, R., and Schmitt, J. H. H. M. 1990, ApJ, 348, 557.
Micela, G., Harnden, F. R., Rosner, R., Sciortino, S., and Vaiana, G. S. 1991, ApJ, 380, 495.
Micela, G., Sciortino, S., and Favata, F. 1992a, ApJ, submitted.
Micela, G., Sciortino, S., and Favata, F. 1992b, in preparation.
Noyes, R. W., Hartmann, L. W., Baliunas, S., Duncan, D. K., and Vaughan A. H 1984, ApJ, 279, 763.
Nugent, J. and Garmire, G. 1978, ApJL, 226, 38.
Ottman, R. and Schmitt, J. 1992, A&A, 256, 421.
Pallavicini, R. 1992, In *This volume.*
Pallavicini, R., Golub, L., Rosner, R., Vaiana, G. S., Ayres, T., and Linsky, J. L. 1981, ApJ, 248, 279.
Pallavicini, R., Monsignori-Fossi, B. C., Landini, M., and Schmitt, J. H. M. M. 1988, A&AS, 191, 109.
Pye, J. 1992, In *This volume*
Rosner, R. 1989, In *Highlights of Astronomy*, Vol. 8, page 521
Rosner, R. 1992, In *This volume.*
Rosner, R. and Vaiana, G. S. 1980, In Giacconi, R. and Setti, G., editors, *X-Ray Astronomy*, page 129.
Rosner, R. et al. 1981, ApJL, 249, L5.
Schmitt, J. H. M. M. 1985, ApJ, 293, 178.
Schmitt, J. H. M. M. 1992, In *This volume.*
Schmitt, J. H. M. M., Golub, L., Harnden, F. R. J., Maxson, C. W., Rosner, R., and Vaiana, G. S. 1985, ApJ, 290, 307.
Schmitt, J. H. M. M., Collura, A., Sciortino, S., Vaiana, G. S., Harnden, F. R., Jr., and Rosner, R. 1990, ApJ, 365, 704.
Schmitt, J. and Snowden, S. L. 1990, ApJ, 361, 207.
Sciortino, S., Harnden, F. R., Jr., Maggio, A., Micela, G., Vaiana, G. S., Schmitt, J., and Rosner, R. 1988, In Murtagh, F. and Heck, A., editors, *Astronomy from Large Databases.*
Sciortino, S., Vaiana, G. S., Morossi, C., Ramella, M., Harnden, F. R., Jr., Schmitt, J.H.M.M, and Rosner, R. 1990, ApJ, 220, 361.
Soderblom, D. R. 1991, In *Angular Momentum Evolution of Young Stars*, S. Catalano and J. Stauffer, editors, page 151, Kluwer Academic Publisher.
Stauffer, J. R. 1991, In *Angular Momentum Evolution of Young Stars*, S. Catalano and J. Stauffer, editors, page 117, Kluwer Academic Publisher.
Stocke, J. T. et al. 1991, ApJS, 76, 813.
Vaiana, G. S. 1981, The Institute of Space and Astronautical Science, Report N. 597
Vaiana, G. S. 1983, In *Solar and Stellar Magnetic Fields: Origins and Coronal Effects*, Stenflo, J. O., editor, p. 165, Dordrecht: Reidel.
Vaiana, G. S. 1990, In *Imaging X-ray Astronomy*, Elvis, M., editor, p. 61, Cambridge University Press.
Vaiana, G. S. and Rosner, R. 1978, ARA&A, 16, 393.
Vaiana, G. S. et al. 1981, ApJ, 245, 163.
Vaiana, G. S. et al. 1990, in *The Einstein Observatory Astrophysical Databases*, Vol. 3 (on floppy disk).
Vaiana, G. S., Maggio, A., Micela, G., and Sciortino, S. 1992, Mem. Soc. Astr. It., page in press.
Waldron, W. 1984, ApJ, 282, 256.
Walter, F. M. and Kuhi, L. V. 1981, ApJ, 250, 573.
Walter, F. M., Cash, W., Charles, P. A., and Bowyer, C. S. 1980, ApJ, 236, 212.
Weiss, N. 1992, In *This volume.*