X-Ray Emission, Stellar Populations and Determination of IMF

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Abstract

X-ray observations allow investigation of the relation among coronal emission level and other stellar parameters, still poorly considered in the standard evolutionary models, such as rotation rate, rotational braking due to angular momentum loss, etc. They also are a very effective way to find late-type members of young open clusters/associations. Indeed young stars are intense X-ray emitters and have been detected with past and current X-ray observatories up to distances of $\sim$ 1 kpc. Because of their effectiveness, X-ray observations are becoming a choice method for the study of the Initial Mass Function (IMF) at the low-mass end, where more traditional methods such as ground-based proper motion studies encounter difficulties in discriminating cluster/association members from the older field population stars. As an example of this approach we will discuss some recent results obtained by studying young clusters and associations.

Observations of open clusters/associations with AXAF and XMM on which we are highly involved mainly through the reserved time of Palermo's Observatory scientists will allow us to identify and study their late-type members, to constrain and compare their IMFs as well as to study open clusters/associations at distances greater than 1 kpc. The proposed X-ray mission for a Wide Area X-ray Survey (WAXS) with a Wide Field X-ray Telescope (WFXT) with its unique characteristics will provide an important step forward in studying the large scale structure and the characteristics (scale height, stellar birthrate) of the young stellar population of the Milky Way.

1 X-ray Emission: Generalities

Since the early eighties *Einstein* observations have shown that X-ray emission is common through the entire H-R diagram with the only exception of the very late supergiants and the late B-early A stars (Vaiana et al. 1981). These observations show i) a clear relationship between stellar rotation rate and X-ray luminosity level ($L_X \propto (\mathrm{v} \sin \mathrm{i})^2$, Pallavicini et al. 1981) for late-type slow rotating stars ($v \sin i <$ 15 km/sec), ii) a break of the above relation for fast rotating young stars (Micela et al. 1985, 1990), and iii) the increase of the X-ray luminosity level with decreasing stellar age (Micela et al. 1985, 1988, 1990). This latter is likely due to the decrease of the stellar dynamo efficiency related to the decrease of stellar rotation-rate with increasing stellar age due to the braking effect of magnetized wind. These results have been confirmed, extended and re-enforced by the more recent, and deeper pointed *ROSAT* observations, especially by the very extensive observations of open cluster of various ages and metallicity (cf. for a review Randich 1997) together with the availability of rotation rates for large samples of open cluster stars (for a review see Bouvier 1997). The observed stellar coronal activity patterns show the *very crucial role* played by magnetic phenomena and specifically of stellar dynamo, whose efficiency is thought to be regulated by the rotation rate and its radial gradient as well as by the depth of the convection zone.

While in general stellar coronal phenomena are considered "small" perturbations of the stellar "machine" ($L_{\rm X}/L_{\rm bol}$ usually ranges between 10^{-6} and 10^{-3}), still very big X-ray flares have been observed in some late K–M stars during which the total X-ray luminosity has become comparable to the stellar bolometric luminosity. Finally it is worth to mention that stellar activity clearly influences photometric colors, the more X-ray active stars having photometric indices that make them appear less metallic than they really are (Morale et al. 1996, Favata et al. 1997).

In summary, X-ray observations show that **stellar rotation rate and its evolution history should be taken into account for better understanding stellar physics and evolution, especially of the young stellar population.**

2 X-Ray Observations and Stellar Populations

Young stars (age $<$ 100 Myr) have X-ray luminosity level a factor 10^{2-3} times higher than the Sun ($L_{\rm X} \sim 10^{27}$ erg/sec) making it possible to "see" young stellar population stars at distances of few hundreds of parsec (incidentally if the above age dependence was not there, the *Einstein* and the *ROSAT* stellar observations would have been a meager affair). This explains why flux limited surveys carried out with *Einstein*, EXOSAT and ROSAT typically contain a large fraction of active stars, either young stars or RS CVn binaries (Favata et al. 1993, 1995; Tagliaferri et al. 1994; note that for RS CVn binaries the high rotation and high coronal activity is due to tidal interaction rather than young age). X-ray observations thus provide a unique way to investigate the distribution of active stars, and in particular of young stars, throughout the Galaxy, provided we can also estimate, at least in an approximate way, their distances. This makes it possible to use X-ray surveys to investigate the stellar birthrate in the Galaxy in the last billion year (Micela et al. 1993).

Taking advantage of the high X-ray emission level of young stars it is possible to discriminate them on the basis of their coronal emission, i.e. X-ray emission can be adopted as an independent membership criterion for late-type members of young open clusters/associations. Such a criterion has been show to be very effective in the case of the $B-V>0.5$ members of IC 2602 (Randich et al. 1995) and IC 2391 (Simon & Patten 1996), especially if we take into account the intrinsic difficulty of other techniques, such as ground based proper motion studies in discriminating late-type members from (older) field stars.

We have recently studied some young open cluster/associations detecting tens of X-ray sources that are likely late-type cluster members. In the case of the high-latitude open cluster Blanco 1 (also known as ζ Sculp, cf. Micela et al. 1998) the analysis of two medium deep ROSAT HRI pointings has resulted in the detection of 134 X-ray sources, 42 of which identified with known cluster members, 2 with field stars, while 90 sources have no previously catalogued optical counterparts. At most 20 out of these 90 X-ray sources can be explained with field galactic and (mainly) extragalactic objects on the basis of the $\log N - \log S$ derived from deep *ROSAT* surveys (Hasinger et al. 1993; Branduardi-Raymont 1994). Hence the remaining 70 are likely to be cluster members with V > 15 (i.e. late K and M stars). Preliminary follow-up spectroscopy of few optical counterparts seems to confirm this working hypothesis. The recognition of these late-type members is obviously crucial for a proper determination of the Blanco 1 IMF. The analysis of ~ 3 sq. deg. of the Upper Sco-Cen region (Sciortino et al. 1998) using archive *Einstein* IPC, *ROSAT* PSPC images and a deep, purposely taken, ROSAT HRI image has allowed us to increase by a factor ~ 10 the census of the known emitters in the surveyed region, most of them being too faint to have been detected in previous less sensitive X-ray observations. Models predict that only 1 field star and 7 extragalactic objects should fall in the surveyed area. Again most of the new sources have to be faint coronal emitters, late-type members of Upper Sco-Cen. The follow-up observations we have recently obtained (Favata et al. 1998, in preparation) shows indeed that the sample of PMS (most WTTS) stars in this region extends toward significantly lower mass than previously thought. These observations are crucial for deriving an accurate estimate of the IMF in the Upper Sco Cen association. As a final example, we have recently studied medium-deep ROSAT HRI images toward the southern part of the NGC 2264 star forming region (Flaccomio et al. 1997) detecting 78 distinct X-ray sources with X-ray luminosity, $L_X \sim 10^{30-31}$ erg/sec. The majority of these sources are, based on our own CCD photometry (Flaccomio et al. 1998), associated with late-type (K7–M0) PMS members of NGC 2264. The joint analysis of X-ray and optical data has allowed us to derive the IMF of NGC2264 down to M ~ 0.6 $M_\odot$ and to derive an hint that stars above and below 1 $M_\odot$ form at different epochs, the high mass stars before the low mass ones.

3 Some Hints on Future Observations

By the end of 1999 both AXAF and XMM should be in operation for the next decade. These two large X-ray observatories will open a new era of great opportunities for studies both of stellar coronal physics and of stellar populations in cluster/associations. In particular, the already planned observations of the Orion central region (with AXAF HRC and ACIS), of NGC 2516 (with AXAF HRC), of the Pleiades, of Upper Sco-Cen, of IC 2391, of α Per (with XMM-EPIC) and of many other open clusters/association either with AXAF and XMM, will allow improving the limiting sensitivity of *Einstein* and *ROSAT* observations by at least a factor 10 and in many cases by a factor 100. In particular AXAF with its superb resolution (less than 1" in the center of the field of view) will allow the detection, without source confusion problem, of late-type faint coronal emitters in young clusters (5 [!] counts are [conservatively] predicted to be necessary for detecting a source). These observations will allow to investigate on more solid observational basis important question as the "universality" of the IMF. However both AXAF and XMM because of the pointed nature of their operations will hardly allow to investigate the large scale structure and related physics, such as the determination of the stellar birthrate in the last billion years, of young stellar population in the Milky Way. A very important and unique advancement in this field will be offered by the Italian mission for a Wide Area X-ray Survey (WAXS) using a Wide Field X-ray Telescope (WFXT) selected by ASI for a pre-phase A study (PI G. Chincarini, co-PI S. Murray). Thanks to the use of a new X-ray mirror having a revolutionary uniform image quality over the entire ~ 1 sq. deg. field of view, this mission will perform an unprecedented high latitude medium-deep 1000 sq. deg. survey and a deep 100 sq. deg. *contiguous area* survey as well as a galactic latitude medium-deep 500 sq. deg. *contiguous area* survey. The scientific outcome and strategy of the mission has been studied, evaluated and proposed by an international committee (Chair S. Sciortino) organized in 6 international panels and including scientists from the four involved countries: Italy, US, UK, Germany. While being devoted mainly to the study the large scale structure of the Universe as outlined by clusters, galaxy groups, and AGNs, the joint analysis of the stellar contents of these three surveys (including the follow-up optical photometry and spectroscopy of properly selected sub-samples) will offer the *unique* opportunity to study the young stellar population of the Galaxy, including the recently proposed existence of a late-type population associated with the Gould Belt (Guillout et al. 1998a,1998b), and in particular will make it possible to determine the stellar birthrate in the solar vicinity in the last billion year.

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