Probing the large-scale distribution of X-ray active stars with the RASS-Tycho/Hipparcos samples

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Abstract. We present the RasTyc and RasHip samples which result from the cross-correlation of the ROSAT All-sky survey with the Tycho/Hipparcos catalogs. RasTyc and RasHip are the largest and most comprehensive samples of stellar X-ray sources constructed so far. We discuss briefly the *young star HR diagram* of the 6 200 RasHip stars and show that it fully confirms the quasi-universality of stellar X-ray emission. We report on the analysis of the large-scale sky distribution of the few thousand X-ray brightest RasTyc stars. We detect a density gradient from the galactic plane to the galactic pole and a low galactic latitude enhanced feature with respect to mean plane density. We propose the Gould belt as a possible explanation and show that stars accounting for the observed enhancement towards the third and fourth quadrants display X-ray luminosities typical of very young coronae. The structure can be understood as a *disk-like* distribution of stars having the same inclination on the galactic plane as the Gould belt and extending to its outer boundary. We present a simulation of the *Gould disk* scenario and show that it reproduces satisfactory the observations.

1. Introduction

The discovery that stars of almost all spectral types were X-ray emitters with luminosities in the range 10^{26}-10^{34} erg s^{-1} was one of the major unexpected results of the Einstein mission (Vaiana et al. 1981). Because of their large X-ray luminosities the X-ray brightest stars can then be detected out to a distance of $\sim$300 pc, and hence the study of the large scale distribution of these sources becomes possible with the data provided by the ROSAT all-sky survey (RASS, Voges 1992). Unfortunately, the X-ray data by themselves do not permit a clear and unambiguous identification of an X-ray source with an astrophysical object. The follow-up observational approach is rather time consuming and thus practically restricted to area typically smaller than a few hundred deg^2 for purpose of statistical studies (Motch et al. 1997, Zickgraf et al. 1997) or to identify objects of interest like T-Tauri candidates in star forming regions (Neuhäuser 1997 and references therein). In order to tackle the problem, we decided to cross-correlate stellar catalogs with the RASS X-ray source list in order to construct samples of objects with known X-ray and optical properties.

While ROSAT gathered X-ray photons from X-ray sources over the whole sky, the Tycho mission took advantage of the star mappers on board Hipparcos in order to measure magnitude and position of the brightest one million stars over the whole celestial sphere. This proceeding is a progress report on a research project lying at the crossroad of the RASS and Tycho catalogs, based on two complete sky coverage experiments of the last ten years flown on the ROSAT and Hipparcos satellites respectively.

2. The *RASS - Tycho* and *RASS - Hipparcos* samples

The RASS was carried out during the first six months of the ROSAT mission from 1990 July till 1991 February with the position sensitive proportional counter (PSPC) in the focal plane of the X-ray telescope. The Tycho catalog is based on observations performed during the whole Hipparcos spacecraft mission from November 1989 to March 1993. Resulting of the celestial sphere scanning over than 3 years, the Tycho program performed an all-sky survey of all stars down to about 11 magnitude.

The cross-correlation procedure (see Guillout et al. 1998c for details) consisted to search for Tycho stars within 2 arcmin of each of the $\approx$150 000 X-ray sources of the RASS source list. The output data file of the correlation process between these two catalogs resulted in 38 324 entries. The distribution of the X-ray versus optical offset position (Dxo) of the 32 234 closest matches is shown in Fig.1. Their number per offset bin first increases and then decreases down to a background level suggesting the obvious interpretation of the peak as those objects which are to be physically matched in both catalogs, while the background is ascribed to spurious identifications. The histogram is well peaked around 6-7 arcsec which is known as the uncertainty affecting X-ray positions.

In order to estimate the Dxo distribution of the spurious population, we computed the cross-correlation of about 150 000 positions distributed uniformly over the sky (simulating the RASS source list) with an artificial catalog (mean surface density of 25 $\star/\mathrm{deg}^2$) simulated in a square degree around each positions. The mean Dxo distribution of the spurious population for 20 experiments is over-plotted as the grey-shaded area in Fig.1. Next we fitted a lognormal to the distribution of *true* matches i.e. the total histogram minus the mean distribution of the spurious population. The best fit is over-plotted as the solid curve in Fig.1. We decided to define the *RASS-Tycho* sample (hereafter RasTyc) as the 13 875 matches with Dxo ≤ 30 arcsec, thus reducing the fraction of the spurious population to a level of about 7%. We emphasize that *RasTyc is the largest sample of stellar X-ray sources with homogeneous and accurate data constructed so far.*

The 6 301 Hipparcos stars not observed by Tycho were included in the Tycho catalog with a special flag reffering to Hipparcos. Hipparcos being thus a subsample of Tycho, the RASS-Tycho matching procedure also consisted in a RASS-Hipparcos cross-correlation. We define the *RASS-Hipparcos* sample (hereafter RasHip) as the 6 200 RasTyc stellar X-ray sources with an entry in the Hipparcos catalogue. Compared to RasTyc, RasHip provides us with optical data about 10 times more accurate but on the other hand is reduced to 45% of the former sample.

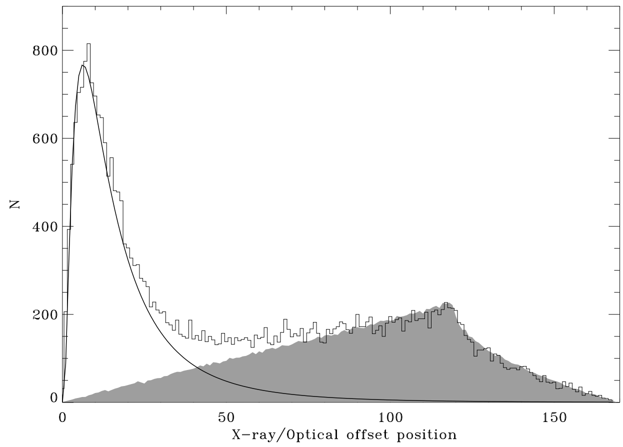

Fig. 1. Distribution of the X-ray/Optical offset position Dxo for the 32 234 closest matches resulting from the cross-correlation process of the RASS and Tycho catalogs. It is noticeable that the simulation of the expected spurious population (grey shaded area) perfectly reproduce the decrease of the matches beyond 2 arcmin which is due the box pattern adopted for the correlation of the catalogs. The full line is the best fit of a lognormal to the distribution of the expected physical matches. We defined the *RASS-Tycho* sample as the 13 875 matches with associated offset position ≤ 30 arcsec.

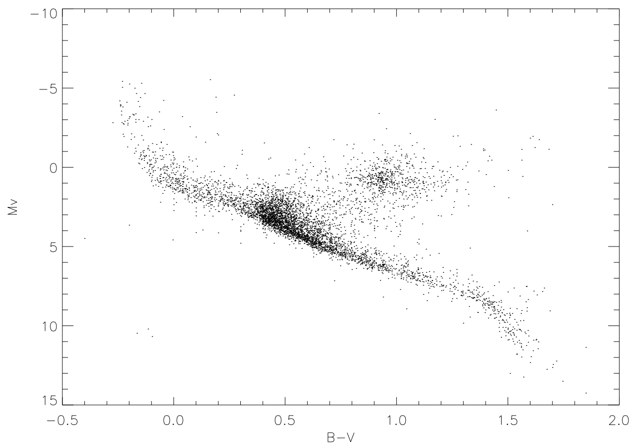

Fig. 2. HR diagram of the 6 200 RasHip stars.

3. The young stars HR diagram

Fig.2 shows the HR diagram constructed from the Hipparcos data for the 6 200 RasHip stars. First we note that this picture fully confirms the quasi-universality of stellar X-ray emission throughout the HR diagram discovered seventeen years ago by Vaiana et al. (1981, see their Fig.1) from a sample of 143 stellar counterparts of Einstein X-ray sources (see also Fig.4 of Micela et al. 1997). Fig.2 shows a well defined main sequence (MS) extending from very hot (around spectral type B0) to very cool (around M5-6) objects. Stars in the giant branch extending from B - V ≈ 0.7 towards the cooler and brighter part of the diagram are also detected as X-ray sources. The distinct group of objects within the giant branch known as the "clump" (around B - V = 1.0, Mv = 1.0) clearly shows up. Compared with the non X-ray selected sample (see for example Fig.6 of Perryman et al. 1995), Fig.2 shows a thinner MS (0.4 mag scatter) located very close to the theoretical Zero Age Main Sequence (ZAMS) isochrone over-plotted as the thick full line. This is especially noticeable in the 0.5 - 1.0 B - V range, outside the MS turnoff which is responsible for the prominent kink in the blueward upper envelope of the MS at about B - V = 0.4, Mv = 2.5. We thus confirm the conclusion of Perryman et al. (1995) that the width of the MS in the non X-ray selected sample is attributable to intrinsic dispersion due primarily to age and evolutionary effects above B - V = 0.8. At a given color index, a additional scatter likely attributable to unresolved binaries (0.75 mag) and possibly to very young (PMS) stars is clearly visible. Last we note that a lack of detection in the A-type stars and late-type giant regions of the HR diagram, is a major difference between X-ray and non X-ray selected samples. We refer to Guillout et al. (1998c) for a detailed discussion of the X-ray selected HR diagram.

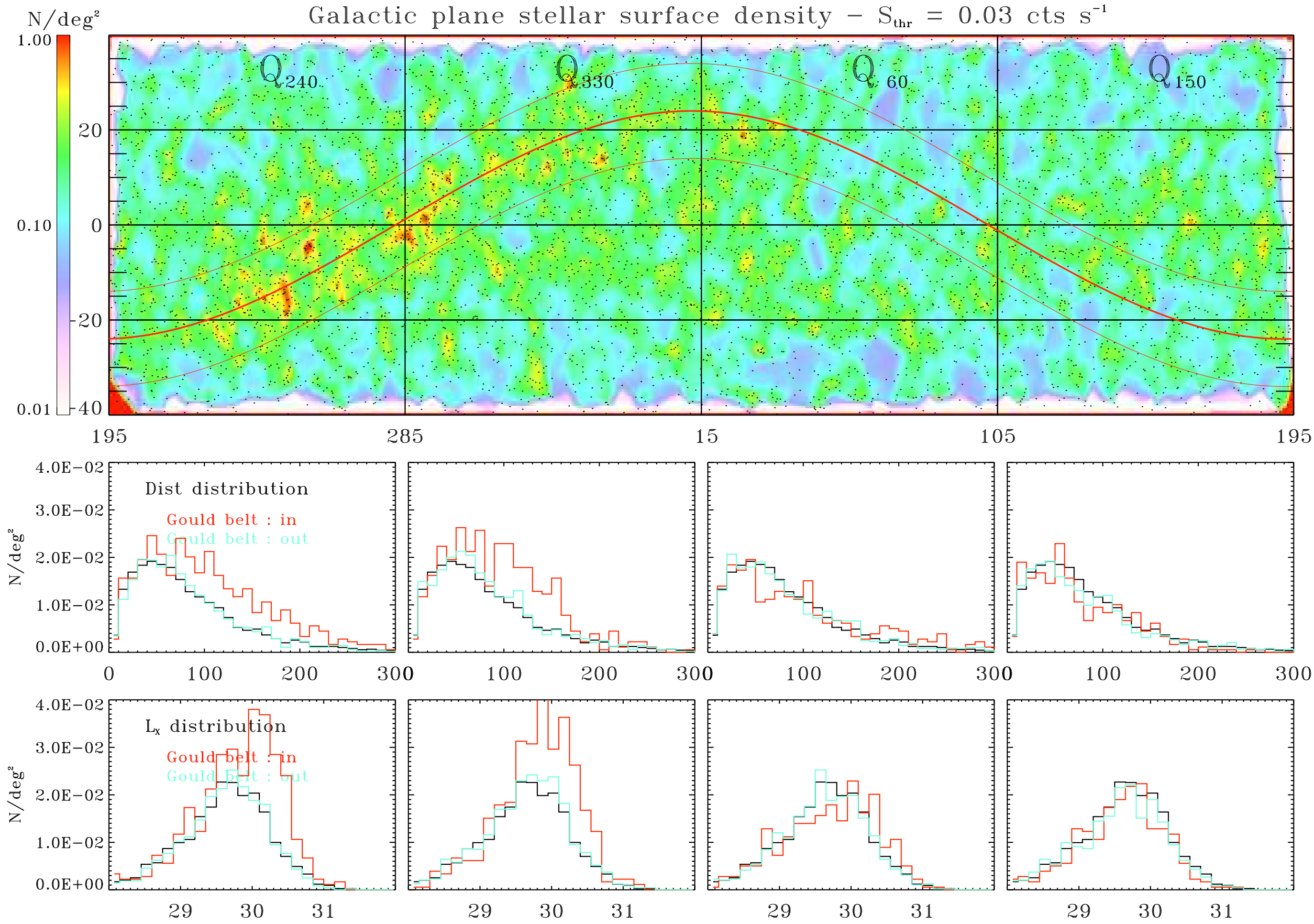

Fig. 3. Simulation of the surface density, distance and X-ray luminosity distributions of the Galactic plane + GB populations. In the simulated *Gould disk* scenario, stars in excess of the ambient population are distributed *not* along a belt (*Gould belt* scenario) but rather in a disrupted disk, as indicated with the grey shaded area in Fig.1 of Guillout et al. 1998b. The simulation is computed to be directly comparable with Fig.5 of Guillout et al. 1998b. See their Fig.4 for a detailed caption.

4. The large scale distribution of X-ray active stars in the solar neighborhood

4.1. Observations and data analysis

The analysis of the whole sky stellar surface density of the 8 593 RasTyc stars detected at a PSPC count-rate threshold $S = 0.03\,\mathrm{cnt\,s^{-1}}$ (see Fig.3 of Guillout et al. 1998a) shows a gradual decrease from low to high galactic latitude. This gradient is attributed to the scale height of the ambient Pleiades-like population of the Galactic disk preferentially detected in soft X-ray survey.
Detailed investigations reveal a noticeable asymmetry with respect to the galactic plane. Interpreting then the observed density enhancement as a coherent feature, we fitted the X-ray stellar surface density with a simple model consisting of a constant background component plus an exponential disk and derived for the best fit an inclination $i = 27.5°$ and an ascending node $l_\Omega = 282°$ with respect to the Galactic plane. Both values are very close to those quoted in the literature for the Gould belt (hereafter GB) and in fact consistent with them. Detailed analysis of the surface density, distance and X-ray luminosity distributions led us to introduce a slightly modified scenario in which the GB is not a "belt" but rather a disk composed of young stars, disrupted near the Sun (see Guillout et al. 1998b for details). This scenario is suitable to explain the wide radial distance distribution observed for GB stars in excess of the ambient population.

4.2. Modeling approach

Stellar X-ray population models (Micela et al. 1993, Guillout et al. 1996) are powerful tools to predict and interpret the characteristics (number, distribution in distance, color, magnitude, kinematic properties...) of stellar X-ray sources. So far X-ray data have only been rarely used to test galactic evolution and structure parameters, mainly because of the absence of a sufficiently large (and

thus statistically representative) stellar X-ray catalog. The RasTyc and RasHip samples in conjunction with stellar X-ray population models provide us with a powerful "data catalog - interpretation tool" which could yield valuable informations on the star formation rate in the solar neighborhood during the last billion years, the slope of the initial mass function (at the low mass end), the scale height and the dynamical state of the youngest population of the Galactic disk. Stellar X-ray population models are especially well adapted to show deviations from a pure Galactic plane population. Moreover, one of the major advantage of the modeling approach is its capability to test various scenari and to reproduce observational bias, allowing thus to compute synthetic diagrams directly comparable to observational ones.
As mentioned in the previous subsection, there is evidence that the RASS young stellar population is at least not everywhere, compatible with expectations from standard galactic models. We thus used the modeling approach to test if the GB is a realistic explanation of these RasTyc stars which are seen in excess of the Galactic plane population. For a preliminary study we modeled the ambient Galactic plane population by 3 sub-populations of increasing age and scale height with adequate X-ray luminosity functions (for the final step the Besançon Xcount model should play this role). An additional structure whose parameters (shape, position, stellar density, age...) need to be defined is then imposed on the 'global' model. Here we test the *Gould disk* scenario proposed by Guillout et al. 1998b (see the grey shaded area of their Fig.1). The parameters defining the *simulated* GB are chosen to reflect the actual knowledge on its position and shape. The center of the structure is located at $l=130°$, $b=-15°$, and $d=190$ pc. Semi major and minor axes of the ellipse (about half filled of stars) are respectively 500 and 340 pc, the major axe pointing towards $l=30°$. The inclination is $i=25°$. Fig.3 shows our first results. All biases (X-ray and optical flux limits) that are present in the RasTyc sample are taken into account, Fig.3 is thus directly comparable with the observations (see Fig.5 of Guillout et al. 1998b). According to these preliminary results, the *Gould disk* scenario perfectly reproduce the overall observations, i.e. the enhancements of stellar surface density towards the third and fourth quadrants, but also the D and Lx distributions. Note that the *Gould disk* scenario allows to explain the presence of stars in excess of the ambient Galactic plane population within 100 pc from the Sun towards the closest part of the GB. The comparison of observed and simulated maps like Fig.3 will allow us to put better constrains on the free parameters of the *synthetic* GB. When the shape and position will be derived more accurately, the synthetic approach will help to predict in which direction and range of PSPC count-rate the GB is expected to show up in that part of the structure having the largest distance towards us.

5. Conclusions

The cross-correlation of the RASS and Tycho/Hipparcos catalogs provided us with the largest sample of stellar X-ray sources statistically identified so far. This drastically improved the quality of the optical parameters and also supplied homogeneous parallaxes and accurate proper motions for X-ray sources that were successfully cross-correlated with stars. The young stars HR diagram derived from the RasHip sample fully confirm the quasi-universality of stellar X-ray emission discovered seventeen years ago. It also shows a significant lack of detection in the A-type stars and late-type giant regions.
We analyzed the large scale distribution of the RasTyc and RasHip stars. A surface density gradient between low and high galactic latitude regions expected from X-ray galactic models clearly appears in our data. In addition a broad over-density tilted with respect to the Galactic plane shows up at low galactic latitude. We interpret these observations as the first detection of the Gould belt late type stars population born within the last 30-80 Myrs. We are led to a slightly modified scenario i.e. *Gould disk*, in which Gould belt members are distributed in a disk disrupted near the Sun, but with the same inclination and orientation of the traditionally assumed picture. Preliminary simulations strongly support this interpretation. Comparison of the properties of the RasTyc and RasHip sample with the predictions of stellar X-ray population model is likely to give new insight on the galactic structure and evolution parameters as well as on the dynamical state of the young stellar population of the galactic disk preferentially detected in soft X-ray survey.

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References

Guillout, P., Haywood, M., Motch, C., Robin, A.C., 1996, A&A, 316, 89
Guillout, P., Sterzik, M.F., Schmitt, J.H.M.M., Motch, C., Egret, D., Voges, W., Neuhäuser, R. 1998a, A&A 334, 540
Guillout, P., Sterzik, M.F., Schmitt, J.H.M.M., Motch, C., Neuhäuser, R., 1998b, A&A 337, 113
Guillout, P., Schmitt, J.H.M.M., Voges, W., Egret, D., Motch, C., Sterzik, M.F., 1998c, A&A, to be submitted
Micela, G., Sciortino, S., Favata, F., 1993, Ap.J., 412, 618
Micela, G., Favata, F., Sciortino, S., 1997, A&A, 324, 998
Motch, C., Guillout, P., Haberl, F., Pakull, M., Pietsch, W., Reinsch, K., 1997, A&A 318, 111
Neuhäuser, R., 1997, Science, 276, 1363
Perryman, M.A.C., et al., 1995, A&A, 304, 69
Vaiana, G.S., et al., 1981, Ap.J., 244, 163
Voges, W., 1992, in Proceedings of Satellite Symposium 3, "International Space Year Conference", ESA ISY-3, p9
Zickgraf, F.-J., et al., 1997, A&AS, 123, 103