arXiv:astro-ph/0011441v1 23 Nov 2000

X-ray Luminosity Functions of Young Stars in Taurus-Auriga-Perseus

Beate Stelzer

Max-Planck-Institut für extraterrestrische Physik, Giessenbachstrasse 1, D-85741 Garching Germany

Abstract. A detailed discussion of the X-ray luminosity functions of pre-main sequence and young main-sequence objects in the Taurus-Auriga-Perseus region based on the *ROSAT* archive is presented. One of the main conclusions is that the XLF of classical and weak-line T Tauri stars (TTS) are different: weak-line TTS are X-ray brighter than classical TTS. Various possible biases related to the sample selection are described and ruled out as a reason for the observed discrepancies. The X-ray emission of the TTS is compared to that of the Pleiades and the Hyades to examine the influence of stellar evolution on the activity level.

1. Introduction

Within the last years extensive X-ray observations of star forming regions have established that the youngest among the stellar coronal X-ray sources are characterized by the strongest activity levels. A standard picture of stellar magnetic activity has developed in which the activity decreases as the stars evolve from the pre-main sequence (PMS) to the main sequence (MS), and continues to decline during the MS life.

While in some early investigations of the X-ray emission of PMS objects a power-law relation between age and stellar activity was found, other observations seem to indicate that activity remains relatively constant during the PMS and starts to drop rapidly once the MS is reached (Feigelson & Kriss 1989, Walter et al. 1988). Instead of being a pure age effect the decline of activity could be related to the rotational evolution of the objects: Once on the MS the stars spin down and the dynamo should become less efficient. Many observational studies concerning the connection between rotation and X-ray activity have indicated a correlation between X-ray emission and rotational velocity favoring the spin-down scenario (see e.g. Bouvier 1990; Neuhäuser et al. 1995 = N95; Stauffer et al. 1997). However, these results were contradicted by other studies (Gagné et al. 1995; Micela et al. 1996). Thus, despite all efforts, the details of the relation between age, activity, and rotation are still not well understood.

An important tool to assess the strength of the X-ray activity are X-ray Luminosity Functions (XLF), i.e. cumulative distributions of X-ray luminosities $L_{\rm x}$. Previous analyses of XLF of young stars have either focused on individual X-ray exposures of selected sky regions or were based on spatially extended but low-sensitivity observations, such as e.g. the *ROSAT* All-Sky Survey (RASS).

In this contribution a systematic analysis of the XLF of young stars in Taurus-Auriga-Perseus on basis of all publicly available *ROSAT* PSPC observations pointed towards that portion of the sky is presented. The stellar sample includes both PMS objects (T Tauri Stars from Taurus-Auriga), and representatives of young MS stars (the Pleiades and the Hyades cluster). A total of 106 observations are evaluated and more than 800 sources detected. The statistical analysis was performed with the ASURV package (Feigelson et al. 1985) to take proper account of upper limits for non-detections.

2.   XLF of samples with unresolved binary stars

Most of the binary stars in the region under study are unresolved with the *ROSAT* PSPC (spatial resolution $\sim 25''$ on-axis). The emission from unresolved multiples is difficult to interpret because it is not clear which of the components plays the active part. In a study of TTS binaries in the Taurus-Auriga region which are resolved by the *ROSAT* HRI König et al. (2000) found that both components emit X-rays. Therefore, it seems adequate to split the observed L_x in equal amounts on the number of components in each (unresolved) stellar system. As a check of this hypothesis separate XLF for single and binary stars have been computed for each sample (i.e. TTS, Pleiades and Hyades). Because of the known dependence of X-ray emission on spectral type we consider G, K, and M stars separately. Binary stars are treated in two ways: (A) according to the assumption described above, and (B) without taking account of the multiplicity, i.e. by attributing all observed X-rays to the primary in the system. Fig. 1 visualizes the effects this different assumptions have on the XLF. Distributions of binaries treated as in (A) are termed 'b2', and those of type (B) are termed 'b1'. In Fig. 1 the XLF of both types of binary distributions is compared to that of single stars. As expected the distributions 'b1' lie off to the right of the distributions 'b2'. Statistical tests reveal that the latter ones agree with the distributions of singles, but the 'b1' distributions are significantly different.

Pye et al. (1994) and Stern et al. (1995) have discussed the XLF of Hyades stars based on a smaller set of *ROSAT* observations. They found that among the Hyades stars of spectral type K the binaries are stronger X-ray emitters than the single stars. The distributions derived in these earlier studies correspond to our type 'b1' distribution. This indicates that a proper treatment of the binary character is important in understanding the XLF if the sample includes unresolved multiples. In view of the above result all XLF discussed furtheron in this paper are based on choice (A).

3.   XLF of cTTS and wTTS

In an analysis of RASS observations in Taurus-Auriga Neuhäuser et al. (1995) found that cTTS and wTTS are statistically different concerning the amount of X-rays emitted: wTTS show stronger X-ray emission than cTTS. This can in principle be explained in terms of rotational evolution, because the wTTS – having lost their disks – can spin up and drive a more efficient dynamo, while for the cTTS the rotation rate is restrained by magnetic coupling between the star and its accretion disk. Contrary to this obvious explanation, X-ray studies
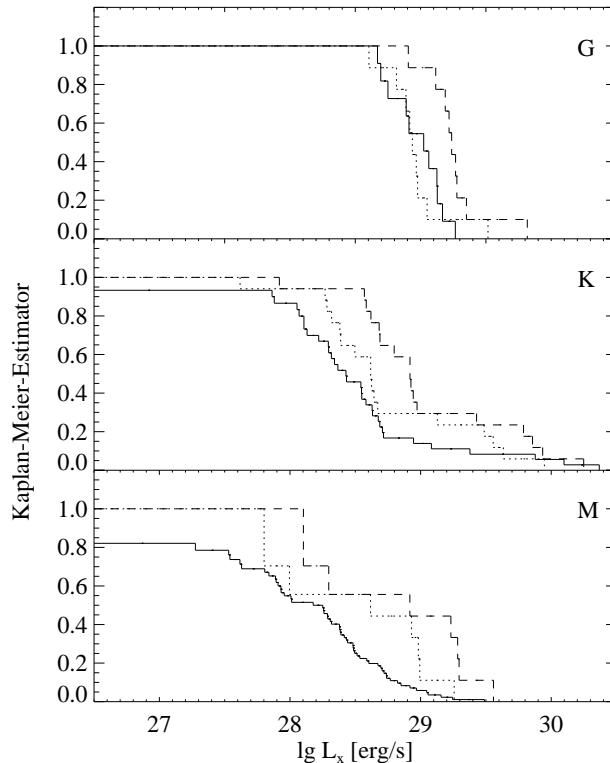
Figure 1.   XLF of single and binary stars in the Hyades. *solid* - single stars, *dotted* - binaries 'b2', and *dashed* - binaries 'b1' (see text for a description of the samples). Separate XLF have been compiled for G, K, and M stars, and demonstrate the trend towards lower L_x for cooler stars.

in other star forming regions (Feigelson et al. 1993; Grosso et al. 2000) do not show differences between the activity of cTTS and wTTS.

In order to test the XLF for various contaminating effects a systematic analysis of pointed *ROSAT* observations in the Taurus-Auriga region (including the Pleiades and Hyades) is performed. The resulting XLF for cTTS and wTTS are displayed in Fig. 2. The distributions derived from this study of pointed PSPC observations are similar to those obtained earlier by N95 from the RASS at the high luminosity end, but demonstrate the better sensitivity of the pointed observations in the low-luminosity regime. The wTTS are found to be stronger X-ray emitters than the cTTS, confirming the result of N95. The remainder of this paper will be focused on the discussion of several effects that could be responsible for the observed differences.

3.1.   An X-ray selection bias in the sample of wTTS ?

One argument that can be put forth against results of the type shown in Fig. 2 is that the wTTS sample may be biased towards strong X-ray emitters, because
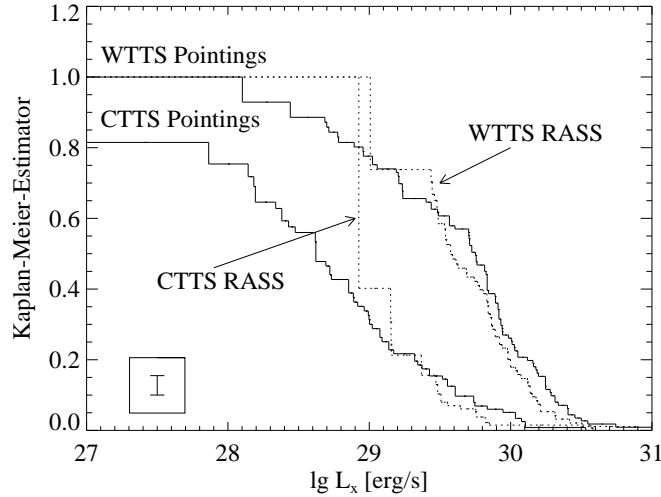
Figure 2.   XLF of cTTS and wTTS in Taurus-Auriga as derived from the RASS (dotted lines) and from pointed PSPC observations (solid lines).

the main identification method for wTTS are indeed their X-rays. cTTS are not affected by this bias because most of them have been identified by optical surveys (e.g. Hα). A possible selection bias in the wTTS sample is examined by computing separate XLF for wTTS discovered by X-ray satellites (*Einstein* and *ROSAT*) and those discovered by other methods, e.g. proper motion studies. The comparison of these distributions (displayed in Fig. 3 on the left) shows that there is no significant difference. This leads to the conclusion that the total sample of wTTS is not biased towards strong X-ray emitters.

3.2.   Age segregation

A large fraction of the TTS discovered in the RASS are wTTS at the outer edge of well-known star forming regions. Although the individual ages of the stars are subject to large uncertainties, there is a tendency of these objects to be somewhat older than stars in the central parts of the molecular clouds. In this sense the differences between the XLF of cTTS and wTTS could be the result of comparing samples with different ages. XLF from wTTS on the clouds should then be similar to the XLF of cTTS (most of which are on the clouds). Fig. 3 on the right shows a comparison of the XLF of cTTS and wTTS in the L1594 E cloud, the region of densest concentration of molecular material in the Taurus-Auriga complex. The data are taken from a long pointed observation (*ROR* 200001-0 and 200001-1). The X-ray luminosities of the on-cloud cTTS are lower than those of the on-cloud wTTS ruling out that the observed difference in the total sample is an effect of age segregation.
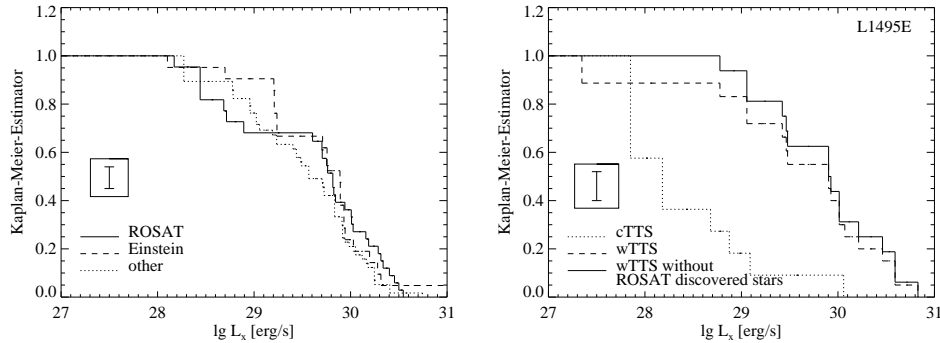
Figure 3. *left* - XLF for subsamples of wTTS in Taurus-Auriga: *ROSAT* discovered wTTS, *Einstein* discovered wTTS, and wTTS discovered by other means, i.e. not by X-ray emission. *right* - XLF of cTTS and wTTS in L1495 E, a cloud in the central part of the Taurus star forming complex.
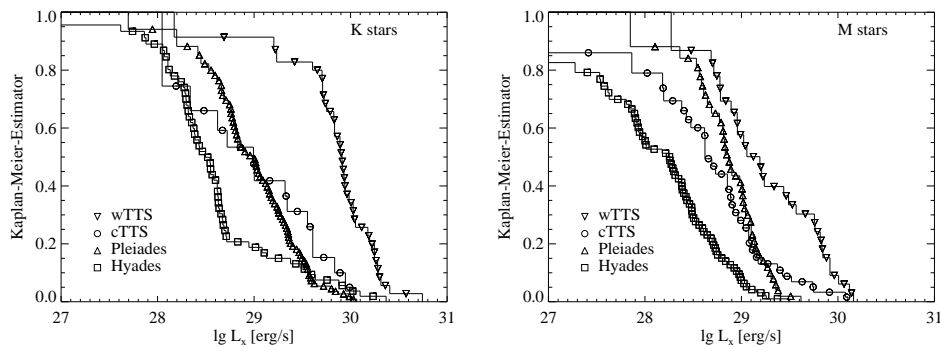

Figure 4. XLF for cTTS, wTTS, Pleiades, and Hyades of spectral type K and M.

3.3. Distribution of spectral types

The X-ray luminosity of active stars scales with spectral type. This implies that differing spectral type distributions of cTTS and wTTS may have an effect on the XLF. However, XLF computed separately for three spectral type bins show that from G to M stars wTTS are stronger X-ray emitters than cTTS. Fig. 4 shows the XLF of K and M TTS together with Pleiades and Hyades stars of the same spectral type, and demonstrate the continual decline of L_x for stars on the MS. The corresponding XLF for G stars (not shown) have similar shape but low statistics in the sample of cTTS.

4. Conclusions

A study of the XLF from a large sample of PMS and ZAMS objects was performed on basis of pointed *ROSAT* PSPC observations.

This analysis shows that the XLF are sensitive to the way in which unresolved binaries are dealt with. Two cases have been considered, in which the observed luminosity is either all attributed to the primary or distributed equally onto all components in multiples. A comparison shows that the latter assumption is consistent with the XLF of single stars. If all X-rays are assumed to come from the primary instead, the XLF of binaries are too bright.

In Taurus-Auriga the wTTS show higher $L_{\rm x}$ than the cTTS in agreement with earlier studies in the same star forming region, but in contrast to results from other regions (e.g. Cha I, ρ Oph). A detailed analysis was undertaken to examine possible explanations for the discrepancy of the XLF of cTTS and wTTS in Taurus-Auriga. Effects which could be ruled out are

- an X-ray bias in the wTTS sample,

- different age distributions of cTTS and wTTS,

- different spectral type distributions of cTTS and wTTS,

- uncertainties in the X-ray emission from unresolved binaries (not discussed in the text).

The only obvious parameter left with a possible influence on the X-ray emission is rotation. A comparison of slow to fast rotating wTTS in Taurus-Auriga indicates that fast rotators show higher $L_{\rm x}$. However, the sample of stars with measured rotation periods is small (16 fast versus 12 slow rotators among the wTTS).

For a more detailed discussion of the XLF and the rotation-activity relation we refer to Stelzer & Neuhäuser (2000).

References

Bouvier J. 1990, AJ, 99, 946

Feigelson E. D., Nelson P. I., 1985,ApJ, 293, 192

Feigelson E. D., Kriss G. A. 1989, ApJ, 338, 276

Feigelson E. D., Casanova S., Montmerle T., et al. 1993, ApJ, 416, 623

Gagné M., Caillault J.-P., Stauffer J. R. 1995, ApJ, 445, 280

Grosso N., Montmerle T., Bontemps S., et al. 2000, A&A, 359, 113

König B., Neuhäuser R., Stelzer B. 2000, A&A, submitted

Micela G. , Sciortino S., Kashyap V., et al. 1996, ApJS, 102, 75

Neuhäuser R., Sterzik M. F., Schmitt J. H. M. M., et al. 1995, A&A, 297, 391 (N95)

Pye J. P., Hodgkin S. T., Stern R. A., et al. 1994, MNRAS, 266, 798

Stauffer J. R., Hartmann L. W., Prosser C. F., et al. 1997, ApJ, 479, 776

Stelzer B., Neuhäuser R. 2000, submitted to A&A

Stern R. A., Schmitt J. H. M. M., Kahabka P. T. 1995, ApJ, 448, 683

Walter F. M., Brown A., Mathieu R. D., et al. 1988, AJ, 96, 297