X-RAY EMISSION FROM YOUNG OPEN CLUSTERS

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ABSTRACT. The rotation–age–X-ray activity connection is a well known and established result. ROSAT observations of several open clusters, together with a large database of rotational data, have given us the chance to refine in greater detail the picture inferred from *Einstein* observations, and to attain a better understanding of both the evolution of X-ray emission and of the rotation – X-ray activity relationship. Incidentally, ROSAT data have permitted to infer X-ray luminosity distribution functions (XLDFs) not only for solar-type stars, but also for X-ray fainter, later-type stars, allowing us to extend the investigation of the age – X-ray activity connection to very low masses.
Rotation is a crucial parameter in determining the level of X-ray activity; the X-ray luminosity of slow rotators increases with rotation rate, although a dispersion is present and the X-ray luminosity – rotation relationship is not a one-to-one relationship. Fast rotators, or stars rotating more rapidly than a given threshold, show saturation of their X-ray emission, and hence their X-ray luminosity depends on mass rather than on rotation. Many of the observed features can be indeed explained based on the phenomenon of saturation.
The XLDFs of stars with different masses in a cluster are mainly determined by the distribution of rotation rates; specifically, by the fraction of stars below and above saturation, and by the distribution of velocities among slow rotators; the evolution of XLDFs with time hence reflects the evolution of the distribution of rotation rates. The spin-down timescales are different for slow and fast rotators, and for stars of different masses. As a consequence, although the inverse activity–age relationship is generally confirmed, the decay of X-ray emission with age in the whole 3×10^7 – 6×10^8 age interval cannot be simply described by a Skumanich-type inverse square root, neither the same decay law holds for stars of different masses. Finally, metallicity also influences dynamo efficiency and X-ray emission.

1. Introduction

X-ray emission in late-type stars originates from a hot corona heated by a dynamo mechanism which depends on rotation and age. Following the early work of Skumanich (1972), several studies have confirmed the age-rotation-activity connection: the youngest is a star, the highest the probability that it is a rapid rotator and chromospherically active; vice-versa, low activity and slow rotation are usually regarded as an indication of old age. *Einstein* observations of the 600–800 Myr old Hyades, of the the 70–100 Myr Pleiades, and of field stars (e.g., Pallavicini et al. 1981; Stern et al. 1981; Micela et al. 1985; Caillault & Helfand 1985; Micela et al. 1988, 1990) extended the age-rotation-activity paradigm to X-ray emission.

A large body of new data has become available in recent years. The ROSAT satellite has provided X-ray data for a variety of open clusters, and, at the same time, optical spectroscopy and photometry have permitted the building of a large database for rotational velocities and/or periods (see the review by Bouvier in this Volume). These data have allowed a deeper insight into the well established and accepted scenario derived from the *Einstein* results.

During its more than seven years of life, ROSAT has carried out deep exposures of several open clusters, giving the possibility to overcome the major limitations of the *Einstein* data, i.e., the small number of clusters which were observed, the restricted age coverage and sampling, the limited area coverage and sensitivity of the observations (which implied incompleteness and severe censoring). In this review I shall use both the ROSAT and rotation databases, together with the results from the numerous papers appeared in the literature, to address some more specific issues within the general framework of the age/rotation/X-ray activity connection. Namely,

- The level of X-ray activity depends on stellar age; but can such a dependence be described by a Skumanich-type inverse square root law? And, is the X-ray emission – age relationship the same for stars of different masses?
- If $\mathbf{X}$ and $\mathbf{V}_{rot}$ denote the generic X-ray emission and rotation level indicators, how is $\mathbf{X}$ related to $\mathbf{V}_{rot}$? Is the relationship the same for slow and fast rotators and for stars of different masses?
- Is the level of X-ray activity predictable only in terms of age and rotation? i.e., *i)* does the dependence on age simply reflect a dependence on rotation (and on its decline with age) or is there an *intrinsic* decrease of X-ray emission with age? If so, what additional parameter(s) play a role? *ii)* Is the evolution with age deterministic, i.e. is a cluster of a given age representative of that age?
- How does metallicity affect the evolution of rotation and hence the level of X-ray emission?

2. The ROSAT database

The 'young'[1] open clusters which, to my knowledge, have been observed by the ROSAT PSPC or HRI detectors are listed in Table 1 in order of increasing age. I list clusters' names and the estimated ages in columns 1 and 2, and refer to the papers in column 3 for detailed information on the various studies. NGC 2516, the only cluster known to have a metallicity significantly different from solar ([Fe/H]= -0.32), is marked with an asterisk. The sensitivity of the observations varies from cluster to cluster, basically depending on the distance and on the reddening, on whether PSPC or HRI detector has been used and on the effective exposure time. Typical sensitivities are in the range of a few 10^{28} erg/sec to a few 10^{29} erg/sec. Analogously, the number of cluster members covered by ROSAT observations, and hence the completeness of the X-ray surveys, is different for the various clusters, depending on the ROSAT detector used and its field of view, on the observations mode (i.e., single pointing, All-Sky Survey, or raster scan), and on the distance of the cluster. To this respect, it is important to note that, for a large fraction of the investigated clusters, complete and/or reliable membership lists

[1] With young I mean clusters in the 20×10^7 – 600-800 $\times10^7$ yrs. I refer to the contribution by Belloni in this Volume for clusters older than the Hyades.

for solar-type and low mass members were not available prior to ROSAT: this implies, on one hand, that X-ray data had to be complemented by optical photometry and spectroscopy, and, on the other hand, that the X-ray data may be biased towards active stars. Incidentally, ROSAT observations proved to be a very powerful tool, even in the best studied clusters, to identify cluster candidates which had not been selected through conventional proper motions surveys (e.g., Prosser et al. 1996a; Randich et al. 1996a; Prosser & Randich 1997; Prosser et al. 1997).

Table 1 indicates that ROSAT data enable us to cover both the age gap between the pre-main sequence phase and the Pleiades, and the one between the Pleiades and the Hyades. More than one cluster per age bin was observed, allowing us to address the question of whether all clusters of a given age behave similarly. The Hyades and the Pleiades have been re-observed, with a better sensitivity and completeness than with *Einstein* (the RASS data for the Hyades constitute a complete survey of the cluster). I mention in passing, and refer to Stern (1997) for details, that new observations of the Hyades and the Pleiades have given also the possibility of investigating long term variability of coronal emission (see also Stern et al. 1995; Micela et al. 1996).

Tab. 1 - The cluster database

Cluster	Age (Myr)	Reference
NGC 2232	20	Prosser (PI)
IC 2602	30	Randich et al. 1995
IC 2391	30	Patten & Simon 1996
IC 4665	35	Giampapa et al. 1997
α Per	50	Randich et al. 1996b
"	"	Prosser et al. 1996b
Blanco 1	50	Micela et al. 1997
NGC 2422	< 70	Barbera et al. 1996
Pleiades	70-100	Schmitt et al. 1993
"	"	Stauffer et al. 1994
"	"	Micela et al. 1996
"	"	Harnden et al. 1996
NGC 2451	100?	Schmitt (PI)
NGC 2516*	100	Dachs & Hummel 1996
"	"	Jeffries et al. 1997
NGC 6475	200	Prosser et al. 1995
"	"	James & Jeffries 1997
Coma Berenices	500	Randich et al. 1996c
Hyades	600	Pye et al. 1994
"	"	Reid et al. 1995
"	"	Stern et al. 1995
Praesepe	600	Randich & Schmitt 1995
IC 4756	800	Singh (PI)

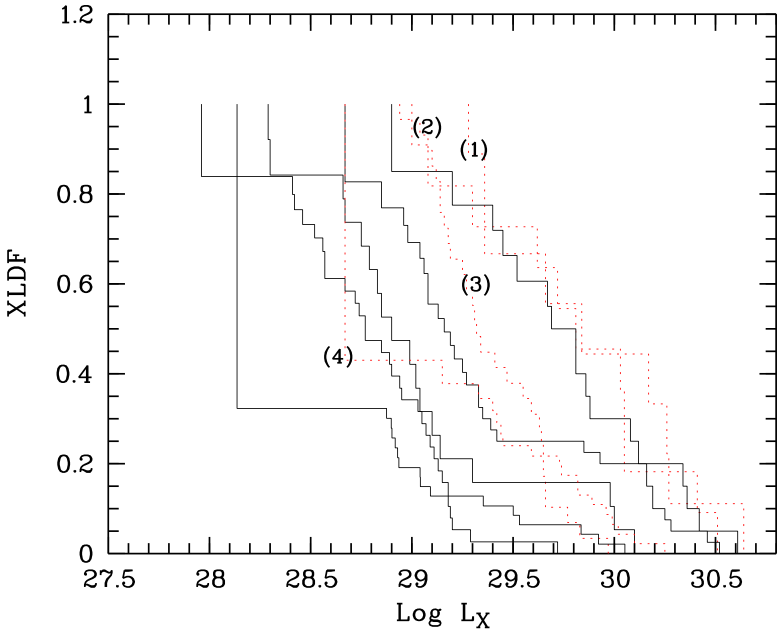

Fig. 1. XLDFs for G-type stars in nine open clusters. The solid, thick curves represent the clusters for which good membership lists existed prior to ROSAT. From the right to the left the clusters are: α Per (50 Myr), the Pleiades (70–100 Myr), Coma Berenices (500 Myr), the Hyades (600 Myr), Praesepe (600 Myr). The dotted curves represent: (1) IC 2391 (30 Myr); (2) IC 2602 (30 Myr); (3) NGC 6475 (200 Myr); (4) NGC 2516 (100 Myr).

3. The empirical picture from ROSAT observations

3.1. General results

A few general features that are common to all clusters observed by ROSAT are summarized below; part of these confirm early results from *Einstein*, whereas others are completely new.

1. Stars have been detected in X-rays all along the main sequence. The detection rates for stars of different masses in the various clusters depend, as expected, on the intrinsic X-ray luminosity function and on the sensitivity of the observations. The detection rates for late F, G, and K-type stars in the younger clusters are close to 100% in the high sensitivity regions of the ROSAT surveys. About 90 % of the Hyades G dwarfs were detected in the RASS survey by Stern et al. (1995), whereas

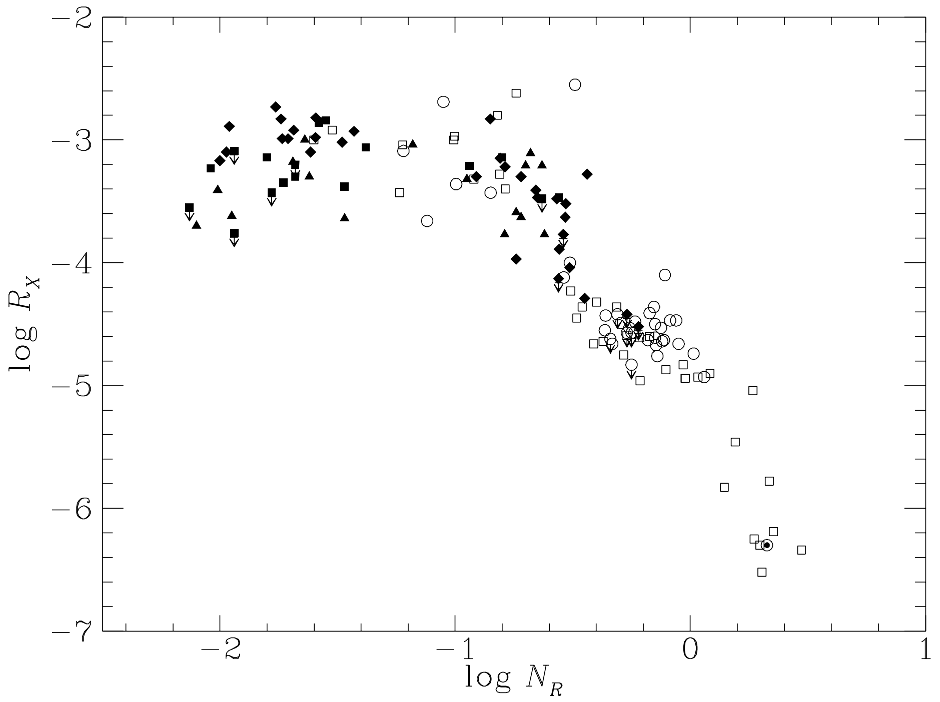

Fig. 2. log L_X/L_{bol} (log R_X) vs. log Rossby number for: IC 2391 (filled triangles), α Per (filled squares), the Pleiades (filled diamonds), the Hyades (open circles) and main sequence stars (open squares). The Sun is also plotted.

the detection rate among K dwarfs was only 40 %. A significant fraction of M dwarfs have been detected by ROSAT in α Per, the Pleiades, and the younger IC 2391 and 2602 clusters; Stern et al. (1995) detected only $\sim$ 30 % of the M dwarfs in their RASS survey of the Hyades, but Pye et al. (1994) detected 23 out of 32 of them in a deeper exposure of the cluster. I remind that one of the unsolved problems from *Einstein* observations was the very low detection rate ($\sim$ 10%) of M dwarfs in the Pleiades. The high detection rate in ROSAT surveys of both young and old clusters indicates that coronal emission is a common phenomenon also among low mass dwarfs: the stars detected by *Einstein* were not peculiar objects, but only the high luminosity tail of a population most of which was below the sensitivity threshold.

Finally, in all clusters a not negligible fraction of A-type stars has been detected. Since the focus of this review is on late-type stars (later than $\sim$ F0), I shall not discuss here the detection of these stars which lack both a convective zone (and thus cannot generate an efficient dynamo) and massive winds (which are thought to be responsible for the X-ray emission of O and early B stars). The most likely explanation is that X-rays from the detected A-type stars are coming from an unseen late-type companion;

2. In X-ray luminosity (L_X) vs. color or magnitude plots a dispersion in L_X is seen; such a spread may be as large as two orders of magnitude;
3. The maximum L_X at a given age decays with spectral-type;
4. X-ray emission in clusters stars saturates. Saturation indicates that the radiation released in X-rays cannot exceed, in a quiescent state, about 1/1000 of the total radiation released by a star, i.e., the ratio of X-ray to bolometric luminosity L_X/L_{bol} is always lower than 10^{-3}. The concept of saturation is not new, although it still lacks a generally accepted interpretation; saturation of X-ray emission was observed previously to ROSAT in the most active field stars (e.g., Fleming et al. 1989); moreover, saturation is observed not only in X-rays, but also e.g., in transition line fluxes (Vilhu 1984; Simon 1990; Ayres et al. 1996). As discussed below, ROSAT observations have shown that saturation is a crucial parameter for understanding the X-ray properties of clusters.

3.2. X-ray emission vs. stellar age

In Figure 1 I plot the X-ray luminosity distribution functions for G-type stars in several open clusters surveyed by ROSAT. A first look at the figure shows that the overall decline of X-ray activity with time is confirmed and strengthened by the use of a larger sample of clusters. Moving from the youngest clusters to the oldest ones, the XLDFs shift from the right to the left of the diagram and, correspondingly, the median X-ray luminosity decreases. A closer inspection of the figure evidences a few additional interesting features. More specifically, **i)** there is no significant decrease of the level of X-ray activity from ~ 30 to ~ 50 Myr as indicated by the comparison of IC2602/IC2391 and α Per. On the contrary, the decline between the latter cluster and the Pleiades is very steep: if one assumes that the decay of the median luminosity is described by a power law $(L_X)_{med.} \propto t^{-\alpha}$, α is greater than 2 from α Per to the Pleiades. The decay is much less steep from the Pleiades to the Hyades, with α being close to 0.5; **ii)** at each age the spread around the median is significant and the high luminosity tails of the XLDFs do not follow in all cases the same decay law as the bulk of the population: for example, the most luminous stars in the Pleiades are as luminous as those in the younger clusters, in spite of the steep decrease of the median luminosity; **iii)** within the general trend, a few 'anomalous' features are evident: the Praesepe XLDF falls far below that of the approximately coeval Hyades; about 30 % of the G dwarfs were detected by Randich & Schmitt (1995) in Praesepe, in contrast with the 90 % detection rate in the Hyades. Note that the high luminosity tail of the Praesepe XLDF is even more luminous than the Hyades XLDF. NGC 6475 appears more X-ray luminous than the younger Pleiades: more specifically, the high luminosity tail of the Pleiades XLDF (about 30 % of the population) is above that of NGC 6475, but the bulk of the Pleiades population seems less active than the Pleiades.

In addition to the features observable in Fig. 1, there are a few other major dependences of X-ray properties on age (see also Caillault 1996). Namely,

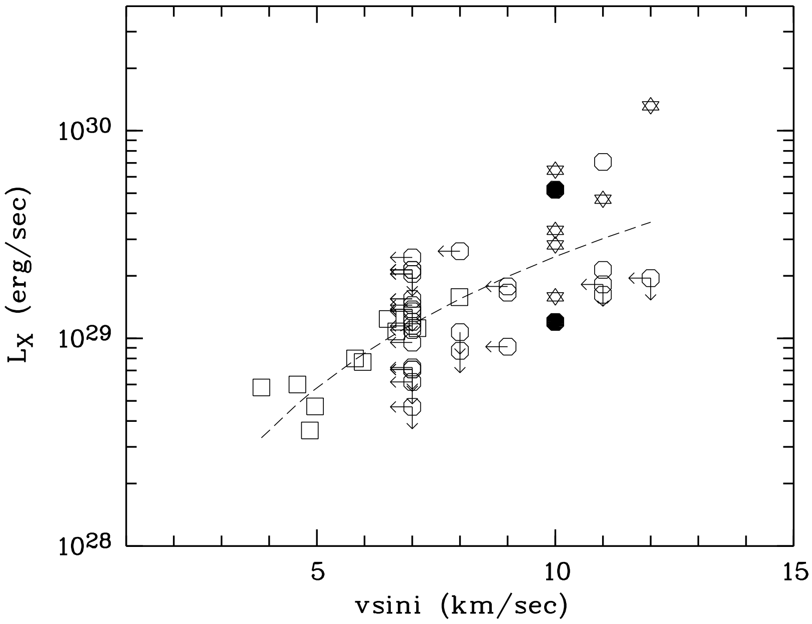

Fig. 3. L_X vs. vsin i for G-type ($0.58 \leq (B-V)_0 \leq 0.82$) slow rotators in various clusters: namely, IC 2602 (filled circles), α Per (stars), the Pleiades (open circles), and the Hyades (open squares) are shown. The dotted curve represent the best-fit regression to the data.

1. The decline of the median L_X with age is progressively less pronounced for lower masses. Whereas the median L_X for G dwarfs drastically decreases between α Per and the Pleiades, the XLDFs for K-type stars are much closer, and those for M dwarfs are, within errors, the same; in other words, *not only the whole decay from 30 Myr to 600 Myr cannot be described with a single power law, but the timescales of the decline are different for different masses*;

2. The color at which saturation is first seen increases with increasing age (e.g., Prosser et al. 1995; Giampapa et al. 1997): it is around $(B-V)_0$=0.6-0.7 for IC 2602, IC 2391, α Per, IC4665 and the Pleiades, $(B-V)_0\sim 1$ for NGC 6475, and $(B-V)_0\sim 1.4$ for the Hyades and Praesepe;

3. Finally, the spread around the median is smaller in younger clusters, in particular when considering K-type stars.

3.3. X-ray emission vs. stellar rotation

Caillault & Helfand (1985) and Micela et al. (1990) found that rapidly rotating K-type stars in the Pleiades have L_X below what expected by extrapolating the $L_X \propto v\sin i^2$ law of Pallavicini et al. (1981). Stauffer et al. (1994) first showed that this is due to the fact that rapid rotators with $(B-V)_0 \geq 0.6$ in the Pleiades exhibit saturation of their X-ray emission. Subsequent studies of other clusters confirmed that late-type stars rotating faster than a threshold velocity are saturated and, therefore, their L_X does not depend on rotational velocity (e.g., Randich et al. 1996b; Prosser et al. 1996b; Stauffer et al. 1997ab).

The rotation – activity connection and, in particular, the existence of a saturation effect can be illustrated considering Rossby numbers rather than rotational velocities or periods themselves; the use of the Rossby number (e.g., Noyes et al. 1984), the ratio of rotational period to convective turnover time ($N_R = P/\tau_C$), allows taking into account at the same time both rotation and depth of the convective zone, which are key parameters in the dynamo mechanism. Figure 2, which was kindly provided by Brian Patten, shows $\log L_X/L_{bol}$ vs. $\log N_R$ for stars in various clusters. The existence of saturation is evident in the figure: the level of activity increases with decreasing $\log N_R$ (i.e., decreasing period or increasing convective turnover time), until saturation is reached for $\log N_R \approx -0.6$ – -0.8 [2]. As well known, the depth of the convective zone and the convective turnover time increase with spectral-type: therefore, the existence of a threshold Rossby number, above which saturation is seen, implies that the threshold period (velocity) for saturation depends on mass, becoming progressively longer (smaller) for lower masses.

What about slow rotators, i.e., stars with rotational velocity below the saturation threshold? Fig. 2 shows that, below saturation, L_X/L_{bol} steeply decreases with increasing $\log N_R$. But: is there a one-to-one, unambiguous relationship between rotation velocity itself and L_X? In other words, would one be able to predict L_X of a star, knowing its rotation rate? In Figure 3 I plot L_X vs. projected rotational velocity for slow rotating G-type stars in IC 2602, α Per, the Pleiades and the Hyades; Figure 4a is the same as Fig. 3, but K-type stars are shown. In Figure 4b K-type stars are considered again, but L_X is plotted vs. period. Both Figs. 3 and 4 indicate that there is a general trend of declining L_X with decreasing $v\sin i$. The best-fit regression line for G dwarfs is $\log L_X = 27.3(\pm 0.2) + 2.09(\pm 0.3) \log v\sin i$, which is in very good agreement with the relationship originally found by Pallavicini et al. (1981) for field stars. Note that, whereas the Hyades data points lie very close to the best fit relationship and exhibit very few scatter, a larger dispersion is seen for the younger clusters. Stars which, at a given $v\sin i$, have L_X above the average trend are easily explainable by projection effects; more surprising are objects with L_X significantly below the best-fit line, although, in most cases, only $v\sin i$ upper limits are available rather than actual measurements, and thus low L_X stars could actually be very slow rotators. The dispersion is apparently more pronounced for K dwarfs, but Fig. 4b suggests that at least part of it can be removed by using periods. In particular, the majority of the low $v\sin i$/high L_X points turn out to be rapid rotators seen at small inclination angles. The best-fit regression

[2] I refer to Randich (1997) for the discussion of the phenomenon of supersaturation, i.e. a further decline below the saturated value which occurs for very low Rossby numbers.

line of L_X vs. P for K-type stars is somewhat steeper than that for G-type stars.

4. Towards a global understanding

Many of the observational results discussed in the previous sections can be interpreted using the Rossby diagram shown in Fig.2, the saturation relation, and the well known phenomenon of the stellar spin-down during main sequence evolution (see again the review by Bouvier in this Volume).

As originally suggested by Patten & Simon (1996), one can imagine the Rossby diagram as an evolutionary diagram; at a given age t_0, part of the stars lie on the saturation plateau, whereas the remaining ones lie along the declining part of the diagram. Stars on the plateau do not contribute to the observed dispersion in L_X (whatever their dispersion in rotation is), whereas such a spread originates, as Figs. 3 and 4 show, from not-saturated stars. The first consequence is that, if a large fraction of stars in a cluster is saturated, a relatively small spread should be seen; on the contrary, if most of the stars are below saturation (and, in addition, are characterized by a dispersion in rotation) the spread should be larger. This explains why in old clusters, where there are fewer rapid rotators, the dispersion grows larger. Secondly, the maximum L_X at each color in young clusters is traced by saturated stars; $L_{X\mathrm{max}}$, therefore, is proportional to L_{bol} and obviously decreases with increasing color. Third, saturation at a given color will be seen only if at the age under consideration there are stars of that color (mass) with V_{rot} > threshold velocity (V_{thr}). In the younger clusters (including the Pleiades) there are solar-type stars with $V > V_{\mathrm{thr}}$, and thus saturation is already seen at $(B-V)_0 \approx 0.6$; all G-type stars have already spun-down to velocities below the threshold at the age of NGC 6475, and at the Hyades age not even K dwarfs rotate faster than the saturation threshold, explaining why saturation in these two clusters is seen only for stars later than $\sim$ K2 and M0, respectively.

As a star gets older, it spins down and, assuming that the convective turnover time does not change during main sequence lifetime, it starts moving towards the right in the Rossby diagram. Stars along the saturation plateau remain saturated until they become old enough to reduce their velocity below the threshold; at that time, they undergo an abrupt decrease of their L_X. On the other hand, stars which start below the plateau experience a more continuous decline of their L_X with time. The evolution of the median luminosity is the combination of the evolution of the two initial populations, the fast rotators, which slow down until they eventually de-saturate, and the slow rotators, which also spin down and shift further to the right (and to lower log L_X/L_{bol} values) in the Rossby diagram. Given this, and given that spin down timescales are different for rapid and slow rotators, is not surprising that the decay of the median L_X with time cannot be described by an unique power law.

Moreover, the timescales for a shift from $N_R(t_0)$ to $N_R(t_1)$, where $N_R(t_0)$ and $N_R(t_1)$ are the Rossby numbers at the times t_0 and t_1 (with $t_1 > t_0$), depend both directly and indirectly on stellar mass. Directly, since spin down timescales are longer for lower masses; indirectly, since for a given interval in N_R, the difference in period is larger for larger τ_C, i.e., for lower masses. As a consequence, the evolution of X-ray emission with time is slower for low mass stars than for solar-type stars.

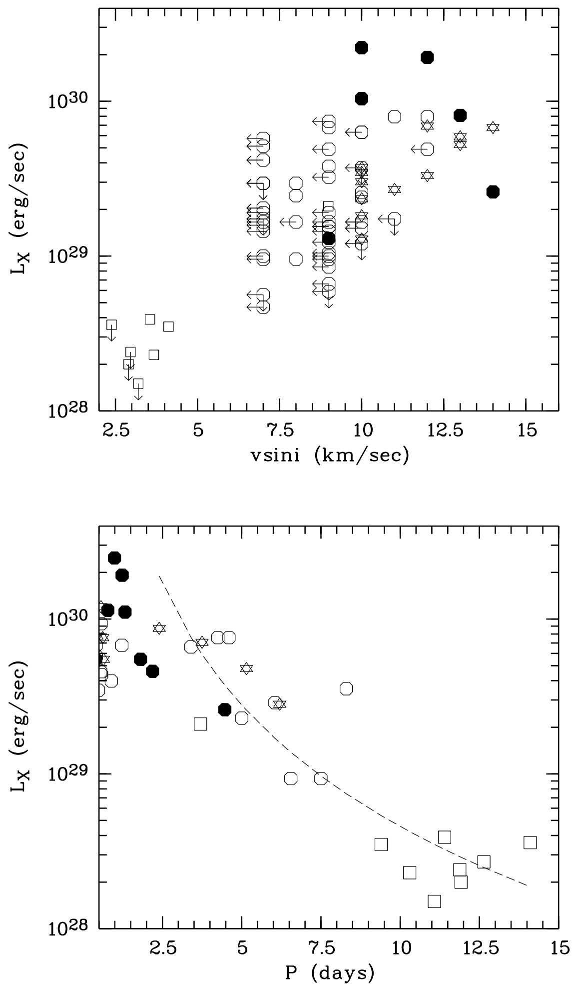

Fig. 4. **Upper panel:** L_X vs. $v\sin i$ for K-type slow rotators in the same clusters plotted in Fig. 3. The symbols are the same as in Fig. 3. **Lower panel:** L_X vs. period is plotted for a subsample of the objects (i.e., those stars with measured periods) shown in the upper panel. The dotted curve represent the best-fit regression to the data.

To conclude, I would try to answer some of the questions mentioned in the Introduction and outline a few problems which deserve further investigation.

- The X-ray activity – age dependence cannot be described by a single decay power law. The decline is faster/slower depending on stellar mass and time interval considered;
- the $\mathbf{X} = f(\mathbf{V}_{rot})$ relation is not the same for fast and slow rotators. Fast rotators at a given color have virtually the same L_X, being their emission saturated; the relationship for slow rotators is not completely clear. As indicated by both the Rossby diagram and Figs. 3 and 4, there is an overall decrease of L_X with decreasing velocity or increasing period. However, the L_X vs. vsin i or P relationship does not appear to be the same for e.g. G-type and K-type stars, and a dispersion is present. Part of the dispersion can be due to projection effects and to the fact that in most cases upper limits, rather than actual measurements of vsin i, are available for slow rotators. A larger sample of stars with measured periods is needed to discern to which extent the dispersion can be explained by projection effects or, more in general, by measurement uncertainties. Patten & Simon (1996) discussed additional possible reasons for this dispersion in young clusters and concluded that it is probably caused by long term variability and by confusion due to binarity. An additional reason may reside in the pre-main sequence/early main sequence rotational history and, ultimately, on the internal rotation profile of a star. To this respect, I refer to the review by Bouvier in this volume where the implications of differential internal rotation or solid body rotation on the nature of stellar dynamo are discussed.
- The previous two points partly answer the third question. I believe that the dependence of X-ray activity on age mostly reflects the dependence of rotation (and rotational history) on age. At each age a spread in rotation and activity is observed, and nor the X-ray–rotation, neither the X-ray–age relationships are one-to-one relationships. In this sense the evolution of activity is not strictly predictable. Nevertheless, XLDFs for G-type stars -which are complete for most of the observed clusters- allows us to define a range of L_X values where a single star [3] at a given age *is expected* to be found. For cooler stars, in particular in the old clusters, this L_X range becomes progressively more difficult to predict, both because XLDFs are not complete (and thus it is not possible to derive the lowest L_X and not even the median in some cases), and because no evolution of the maximum luminosities with age is seen, i.e., the most luminous M dwarfs in the Hyades are saturated as the ones in the Pleiades and younger clusters.

  The anomalous case of Praesepe is discussed in detail by Barrado y Navascués et al. in this Volume. I only mention that the discrepancy between this cluster and the Hyades, which does not fit at all into the age-activity scheme, is not easily explainable. The most obvious idea that Praesepe G dwarfs have on average

[3] I refer to Pye et al. (1994) and Stern et al. (1995) for a discussion on the relationship between binarity and X-ray emission.

lower velocities than the Hyades has been discarded by measurements of v$\sin i$ (see Mermilliod, this Volume). The alternative explanation could be reduced metallicity (see below), although it is not clear whether the difference in [Fe/H] between Praesepe and Hyades is large enough to explain the discrepancy seen in X-rays. Whatever the reason, this result suggests that one cannot consider a cluster of a given age as completely representative of that age.

The other apparently puzzling feature in Fig. 1 is the fact that only $\sim$ 25-30 % of the Pleiades G dwarfs seem more X-ray active than the older NGC 6475, but most of the Pleiades XLDF lies below that of NGC 6475. This result, however, can be interpreted based on the rotation – X-ray emission relationship. According to Bouvier (this Volume) rapid rotators slow down quickly on the main sequence, whereas the spin-down timescales for slow rotators are longer. James and Jeffries (1997) indeed found that all the very fast rotating Pleiades G dwarfs have spun down by the age of NGC 6475, but a population of moderate rotators (6 km/sec $<$ v$sini$ $<$ 13 km/sec) is still present in this cluster. This, on turn, implies that an evolution of the high luminosity tail of the XLDF is expected -and indeed it is observed- between the Pleiades and NGC 6475, but that no major changes should occur in the X-ray properties of the bulk of the population. In other words, the XLDF of NGC 6475 should not be very different from that of the Pleiades. Fig. 1 indicates that NGC 6475 XLDF is, on the contrary, above the one of the Pleiades; however, the NGC 6475 sample is X-ray selected and, therefore, biased towards active stars: the comparison between the XLDF of NGC 6475 and the XLDF which one would get for the Pleiades if this cluster had been observed with the sensitivity of Prosser et al. (1995) survey of NGC 6475, shows indeed a good agreement, supporting the above suggestion. A deeper X-ray survey of NGC 6475 will help definitively clarifying this issue.

- Only one cluster with a metallicity significantly different from solar has been observed with ROSAT (NGC 2516, Jeffries et al. 1997). Jeffries et al. have found that, in contrast with the age-activity paradigm, NGC 2516 G-type stars are less active than expected (see also Fig. 1). They interpreted this result based on the fact that lower metallicity implies a thinner convective zone, and, for a given period, a larger Rossby number. If one looks again at the Rossby diagram, for similar initial conditions, lower metallicity stars would be located more to the right of the diagram, suggesting that they would de-saturate (and thus have a lower L_X) at earlier ages than solar metallicity stars. The effect of different metallicity should be noticeable also among slow rotators, since, again, under-abundant stars would have, at a given period, larger Rossby numbers. This issue has to be further investigated, both on observational and theoretical grounds and rotational velocities should be derived for metal poor clusters to check how the evolution of rotation compares with that of solar metallicity stars.

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