Magnetic Fields throughout Stellar Evolution
Proceedings IAU Symposium No. 302, 2013
P. Petit, M. Jardine & H. Spruit, eds.

doi:10.1017/S1743921314001811

Activity and Rotation in the Young Cluster h Per

C. Argiroffi[1,2], M. Caramazza[2], G. Micela[2], E. Moraux[3] and J. Bouvier[3]

[1]Dip. di Fisica e Chimica, Università di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy, email: argi@astropa.unipa.it

[2]INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy

[3]UJF-Grenoble 1/CNRS-INSU, Institut de Plantologie et d'Astrophysique de Grenoble (IPAG) UMR 5274, Grenoble, F-38041, France

Abstract. We study the rotation-activity relationship for low-mass members of the young cluster h Persei, a ~ 13 Myr old cluster. h Per, thanks to its age, allows us to link the rotation-activity relation observed for main-sequence stars to the still unexplained activity levels of very young clusters.

We constrained the activity levels of h Per members by analyzing a deep Chandra/ACIS-I observation pointed to the central field of h Per. We combined this X-ray catalog with the catalog of h Per members with measured rotational period, presented by Moraux *et al.* (2013). We obtained a final catalog of 202 h Per members with measured X-ray luminosity and rotational period. We investigate the rotation-activity relation of h Per members considering different mass ranges. We find that stars with $1.3\,\mathrm{M}_\odot < M < 1.4\,\mathrm{M}_\odot$ show significant evidence of supersaturation for short periods. This phenomenon is instead not observed for lower mass stars.

Keywords. Dynamo, Stars: activity, Stars: pre-main sequence, X-rays: stars

1. Introduction

It is known that late type stars can be magnetically active, becoming therefore bright in the X-rays because of the hot coronal plasmas heated and confined by the stellar magnetic field. Magnetic fields in late type stars are produced by dynamo processes, whose efficiency is related to plasma motions in the stellar interior.

Pallavicini *et al.* (1981) initially evidenced how stellar activity correlates with the stellar rotational velocity. To take into account also the role of the convective envelope in the magnetic field production, Noyes *et al.* (1984) proved that magnetic activity is better determined by the Rossby number, Ro, defined as the ratio between the rotational period $P_{\rm rot}$ and the convective turnover time τ.

Pizzolato *et al.* (2003) and Wright *et al.* (2011), studying large samples of late-type main-sequence (MS) stars, definitely showed that the stellar dynamo is characterized by different regimes. In the non-saturated regime, i.e. for $Ro > 0.1$, the stellar X-ray luminosity, and hence the dynamo efficiency, anticorrelates with Ro. For $Ro < 0.1$, in the so-called saturated regime, MS stars show a constant X-ray emission level, with on average $L_{\rm X}/L_{\rm bol} \approx 10^{-3}$. Both the non-saturated and saturated regimes were well constrained by large sample of MS stars. Randich *et al.* (1996) found that a third regime probably occurs at very low Ro values ($Ro < 0.01$), the supersaturation regime, in fact very fast rotators show $L_{\rm X}/L_{\rm bol}$ lower than the saturated level. This behavior was observed only for very few stars belonging to young cluster ($\sim$30$-$50 Myr), likely because in older cluster the longer rotational periods make such small Ro values not accessible.

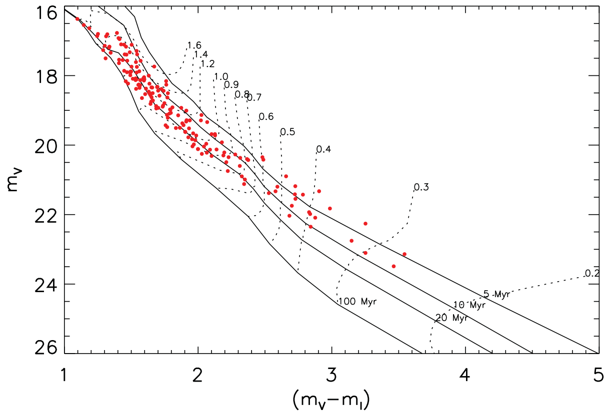

Figure 1. Color magnitude diagrams of the 170 sources that compose our final catalog. Isochrones (solid lines) and evolutionary tracks (dotted lines, with the corresponding mass in solar units) are from Siess *et al.* (2000) and are scaled to the distance of 2300 pc.

It is known that pre main-sequence (PMS) stars, like MS stars, are magnetically active, having strong magnetic field and showing intense coronal emission. The relation between *Ro* and fractional X-ray emission in PMS, studied in very young cluster (age < 5 Myr), shows much larger scatter than in MS stars (e.g. Preibisch *et al.* 2005). It still unclear which stellar parameters, other than $P_{\rm rot}$ and τ, determine the magnetic activity levels in PMS stars. A substantial difference between MS and PMS stars is that, at very young ages, PMS stars do not yet have a radiative core, being therefore fully convective. This different internal structures likely indicates that different dynamo mechanisms determine magnetic activity in PMS and MS stars.

To bridge the gap between the well constrained case of MS stars and the puzzling case of very young PMS stars, we studied the activity-rotation relation in young cluster h Persei. h Per is a rich cluster, ~ 13 Myr old, located at 2300 pc, and characterized by a $E(B-V) \sim 0.55$. Because of its age the h Per cluster offers us several advantages: it contains both fast and slow rotators, allowing us therefore to test the different regimes of stellar dynamo; accretion processes already ended; all the stars with $0.5\,M_\odot < M < 1.5\,M_\odot$ already developed a radiative core, having therefore an inner stellar structures similar to that of MS stars.

2. Analysis

The h Per cluster was observed with the Chandra satellite for 200 ks. This observation, in which we detected 1010 X-ray sources, allowed us to constrain the magnetic activity level of h Per members.

We compared the X-ray source catalog with the catalog of h Per members with measured period presented by Moraux *et al.* (2013). We obtained a catalog of 202 h Per members with detected X-ray flux and measured rotational period. 170 of these 202 members have also measured optical photometry from Currie *et al.* (2010).

We derived stellar X-ray luminosities $L_{\rm X}$ from the observed X-ray flux. Stellar masses and rotational periods are from Moraux *et al.* (2013). Bolometric luminosities, $L_{\rm bol}$, needed to compute the fractional X-ray luminosity, were evaluated starting from the V magnitude and $V-I$ color, and correcting for interstellar absorption. We estimated the empirical turnover times τ inferring the $B-V$ colors from the observed $V-I$, and then applying the empirical relation derived by Wright *et al.* (2011).

https://doi.org/10.1017/S1743921314001811 Published online by Cambridge University Press

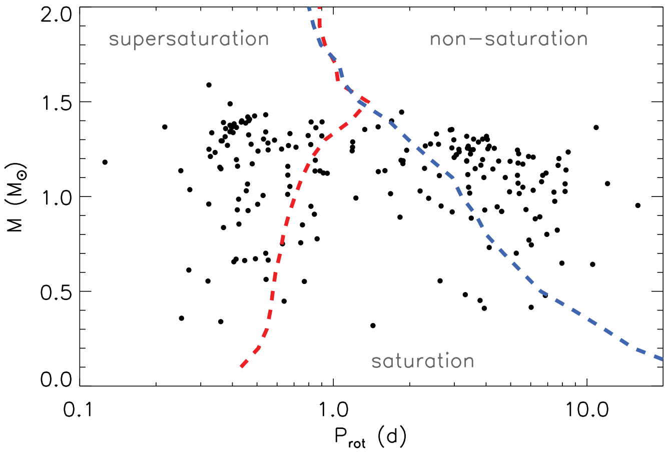

Figure 2. Mass vs period of the h Per members with measured $P_{\rm rot}$ and $L_{\rm X}$. The regions corresponding to the different dynamo regimes are separated dotted lines. The red dotted line marks the transition from saturated to supersaturated regime. This threshold is obtained assuming that supersaturation is caused by coronal stripping occurring at $R_{\rm cor}/R_* = 3$, note that a similar threshold is obtained considering the coronal updrafts mechanism instead of coronal stripping, as indicated by Wright *et al.* (2011). The blue dotted line marks the transition from saturated to non-saturated regime expected to occur at $Ro = 0.13$.

Our final sample is composed of stars with: X-ray luminosity ranging 2.4×10^{29} to $5.8 \times 10^{30}\,{\rm erg\,s^{-1}}$; mass ranging from ~ 0.3 up to $\sim 1.6\,{\rm M_\odot}$; rotational period ranging from ~ 0.13 and ~ 15.9 d; convective turnover time τ ranging from 9 and 96 d.

In fig. 1 we show the color magnitude diagram of our catalog. In in fig. 2 we show the mass vs period plot, with superimposed the line marking the transitions between the different regimes. From this plot it is clear how our stellar sample allows us to investigate the behavior of stars expected to be in the supersaturated, saturated, and non-saturated regimes.

3. Results

We investigated the relation between $\log L_{\rm X}/L_{\rm bol}$ vs Rossby number Ro. We separated our stellar sample into different mass bins because the predicted Ro values separating the different regimes of stellar dynamo are expected to vary with stellar mass. In fig. 3 we show the fractional X-ray luminosity vs Rossby number for different mass bins.

Supersaturated regime: We find that stars with $1.3\,{\rm M_\odot} < M < 1.4\,{\rm M_\odot}$ and with $Ro \leqslant 0.07$ display a significant correlation between their fractional X-ray luminosity and Rossby number. In fig. 3 the dotted gray line indicate the observed correlation. The limiting Ro value of 0.07 perfectly fits with the value predicted by coronal stripping assuming $R_{\rm cor} = 3R_\star$. Conversely lower mass stars do not show any clear evidence of supersaturation, even at the lowest Ro values, as instead expected considering the threshold shown in fig. 3. This difference indicates that for different stellar masses something different happens in the threshold between saturation and supersaturation.

Saturated regime: We observe that the fractional X-ray luminosity of saturation regime varies for different stellar masses, with lower masses displaying the larger fractional X-ray luminosity. In fact for $Ro < 0.13$ stars in the range $0.3-0.9\,{\rm M_\odot}$ show $\log(L_{\rm X}/L_{\rm bol})_{\rm mean} = -2.8$, while stars in the range $0.9 - 1.3\,{\rm M_\odot}$ show $\log(L_{\rm X}/L_{\rm bol})_{\rm mean} = -3.3$.

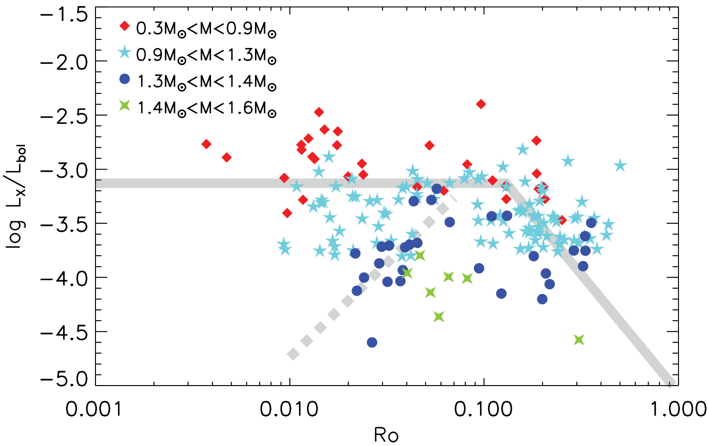

Figure 3. $\log L_X/L_{\rm bol}$ vs Rossby number *Ro*. Solid gray line marks the relation derived by Wright *et al.* (2011) for saturated and non-saturated region. Dotted gray line indicated the correlation found for stars with $1.3\,{\rm M}_\odot < M < 1.4\,{\rm M}_\odot$ in the supersaturation region.

Non-Saturated regime: Even if we have a significant fraction of stars having *Ro* corresponding to the non-saturated regime we do not find any clear trend indicating non-saturation, probably because of the large intrinsic scatter of the fractional X-ray luminosity.

4. Conclusion

In this work we present the study of the activity-rotation relation for PMS stars at 13 Myr. We find that the activity-rotation relation at this age varies significantly for different stellar masses. We observe that at 13 Myr the intrinsic scatter in the $\log L_X/L_{\rm bol}$ vs *Ro* plot is lower than that observed at younger ages. The very low *Ro* values accessible at this age allowed us to observe the first clear detection of supersaturation for PMS stars with mass ranging between 1.3 and $1.4\,{\rm M}_\odot$.

References

Currie, T., Hernandez, J., Irwin, J., *et al.* 2010, *ApJS*, 186, 191
Moraux, E., Artemenko, S., Bouvier, J., *et al.* 2013, *A&A*, in press
Noyes, R. W., Hartmann, L. W., Baliunas, S. L., Duncan, D. K., & Vaughan, A. H. 1984, *ApJ*, 279, 763
Pallavicini, R., Golub, L., Rosner, R., *et al.* 1981, *ApJ*, 248, 279
Pizzolato, N., Maggio, A., Micela, G., Sciortino, S., & Ventura, P. 2003, *A&A*, 397, 147
Preibisch, T., Kim, Y.-C., Favata, F., *et al.* 2005, *ApJS*, 160, 401
Randich, S., Schmitt, J. H. M. M., Prosser, C. F., & Stauffer, J. R. 1996, *A&A*, 305, 785
Siess, L., Dufour, E., & Forestini, M. 2000, *A&A*, 358, 593
Wright, N. J., Drake, J. J., Mamajek, E. E., & Henry, G. W. 2011, *ApJ*, 743, 48