A STUDY ON THE FLUX-FLUX AND ACTIVITY-ROTATION RELATIONSHIPS FOR LATE-TYPE STARS MEMBERS OF YOUNG STELLAR KINEMATIC GROUPS

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Abstract

We present here our ongoing study on the spectroscopic properties of young active stars members of the young moving groups Local Association (Pleiades moving group, 20-150 Myrs), IC 2391 supercluster (∼35 Myrs), Ursa Major group (Sirius supercluster, ∼300 Myrs), Hyades supercluster (∼600 Myrs) and Castor moving group (∼200 Myrs). High resolution echelle spectra of 144 late-type stars have been taken during several observing runs from 1999-2004. In this contribution we analyse the flux-flux and activity-rotation relationships for the chromospherically active stars of the sample. Each one of the optical chromospheric activity indicators from Ca II H & K to infrared triplet (IRT), including Balmer series, has been used. Both projected rotation ($v \sin i$) determined by us and photometric period ($P_{\rm phot}$) from the literature have been used in the activity-rotation relationship. We discuss the different behaviour of these relationships in groups of stars with different age and the dependence on stellar parameters of the saturated regime.

Key words: Stars: activity – Stars: chromospheres – Stars: rotation – Stars: spectroscopy: optical – Stars: flare

1. Spectroscopic survey

During four years (1999 - 2003) our group has carried out a spectroscopic survey of late-type active stars selected from our previous study of late-type stars posible members of young stellar kinematic groups (Montes et al. 2001a), where the space motion of 535 cool stars was obtained in order to establish their membership in one of the young moving groups: Local Association (20-150 Myrs), IC 2391 supercluster (∼35 Myrs), Ursa Major group (Sirius supercluster, ∼300 Myrs), Hyades supercluster (∼600 Myrs) and Castor moving group (∼200 Myrs).

A total of 144 objects with declination ranging from -20 to 90 degrees have been observed using high resolution spectrographs in order to simultaneously obtain all of the chromospheric activity indicators from Ca II H & K to the infrared triplet (IRT), including the Balmer series from Hϵ to Hα. In addition, the radial velocity of each star has been determined using cross-correlation technique (López-Santiago et al. 2004) in order to better determine their membership in the stellar kinematic groups.

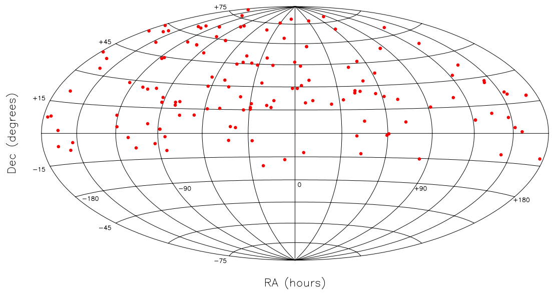

Figure 1. Right ascension and declination of the stars of the sample.

Here we discuss the different behaviour of the flux-flux and activity-rotation relationships with the stars of the sample. The $v \sin i$ have been determined using the cross-correlation technique, while the photometric period ($P_{\rm phot}$) have been obtained from the literature.

2. Flux-flux relationships

Our high resolution spectroscopic observations allow us to study in detail all the chromospheric activity indicators from Ca II K & H to the infrared triplet (IRT) including Balmer lines Hα, Hβ, Hγ, Hδ and Hϵ, as well as Mg I b triplet, He I D_3 and Na I D_1 & D_2 lines. Some of these lines have been widely studied and their absolute surface fluxes ($F_{\rm S}$) relationships obtained. Thus, different linear relationships between $F_{\rm S}$(Hα), $F_{\rm S}$(Hϵ), and $F_{\rm S}$(K) have been found (Herbig 1985; Pasquini & Pallavicini 1991, Montes et al. 1995, 1996) fitting a first order polinomy ($F_{\rm S}({\rm y}) = {\rm a} + {\rm b}F_{\rm S}({\rm x})$) to the data. Other studies show that b grows when increasing the temperature of the region in which the chromospheric lines are formed (Rutten et al. 1991). Ca II K line is the most commonly used although the flux in the blue region of the spectra is lower for late-type stars, specially for late-K and M types. On the contrary, the flux in the continuum near Ca II IRT is higher, and a higher S/N ratio is obtained in the observations of these stars. Taking into account the relation between $F_{\rm S}$(IRT) and $F_{\rm S}$(H & K), the study of the flux-flux relationships between $F_{\rm S}$(IRT) and $F_{\rm S}$ of the other

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chromospheric lines seems to be better. We have found a good correlation between Ca II K and IRT (Fig. 2a), although some dispersion is observed with lower fluxes. Here we present several relationships for the stars of the sample (Fig. 2a-f). The surface flux (F_S) has been determined using the relationships by Hall (1996).

2.1. Flare stars

Some of the dMe stars of our sample are flare stars. In addition, six stars with types ranging from K2 to K7 show flare events (see contribution by Montes et al. in this book). During a flare, the emission in Balmer lines grows more than in Ca II ones, and the position of the stars in the flux-flux diagrams changes. In fact, in the $\log F_S$(Hα) vs. $\log F_S$(Ca II λ8542) diagram they situated out of the tendency for the rest of the stars (see Fig. 2d). Usually, dMe stars have short duration flares which happen very frequently (see contribution by Crespo-Chacón et al. in this book). The exposure time needed for these stars in our observations, typically 1500 s, is larger than the time between flares, and the spectra of these stars can be affected by a flare.

2.2. Prominences and plage-like material

In Fig. 2e and 2f we show the $\log F_S$(Ca II λ8498) vs. $\log F_S$(Ca II λ8542) and F_S(Hβ) vs. F_S(Hα) relationships for the stars of the sample with emission in these chromospheric lines. The ratio E_{8498}/E_{8542} is commonly used for discriminating between the presence of plages and prominences on the stellar surface, following the results of Hall & Ramsey (1992), who found that values of 1 - 2 are indicative of optically thick emission in plage-like regions, in contrast with the prominence-like material inferred by the $E_{H\alpha}/E_{H\beta}$ ratio (corrected from the absolute flux density of these lines). Values of 1 - 2 in $E_{H\alpha}/E_{H\beta}$ can be achieved both in plages and prominences viewed against the disk, but high ratios (~3 - 15) can only be achieved in extended regions viewed off the limb. In Fig. 2e, almost all the stars of the sample are situated between the lines $E_{8498}/E_{8542} = 1$ and $E_{8498}/E_{8542} = 2$, but some of them are out of these limits suggesting that the emission comes from prominences.

3. Activity-rotation relationship

The relation between activity and rotation has been studied for the stars of our sample using the Ca II K and Hα lines as chromospheric activity indicators. In Fig. 3a-d we have plotted $\log F_S$(Ca II K) and $\log F_S(H\alpha)$ vs. $\log P_{\rm phot}$ for the stars with known photometric periods. In addition we have plotted the binary stars from (1996). In order to compare results, the value of $\log F_S$(Ca II K) and $\log F_S(H\alpha)$ for the stars from (Montes et al. 1995 & 1996) has been again determined using the relationships by Hall (1996). One of the main results is the dichotomy between single and binary stars for $\log P_{\rm phot} > 1$ days in the $\log F_S$(Ca II K) vs. $\log P_{\rm phot}$ diagram. When the Rossby number ($Ro = P_{\rm phot}/\tau$) is used the dispersion decrease and the difference between binary and single stars dissapears. At high rotation rates, the flux is saturated and even super-saturated for rapid rotators (Fig. 3a). The same result is obtained with other chromospheric lines (see Figs. 3c).

3.1. Estimation of age

In order to estimate the age for the stars of the sample, the equivalent width of the resonance doublet of Li I at λ6707.8 Å has been measured, taking into account that lithium abundance is an important diagnostic of age in late-type stars since it is easily destroyed by thermonuclear reactions in the stellar interior. This line is included in our high resolution echelle spectra in all the observing runs.

We compare the EW(Li I) of our stars with those of stars in well-known young open clusters of different ages: IC 2602 (~10 Myrs), Pleiades (~78 Myrs), and Hyades (~630 Myrs) using a EW(Li I) vs. spectral type diagram (see Montes et al. 2001b; López-Santiago et al. 2003) where the upper envelopes of the EW(Li I) of the clusters, and the lower envelope of Pleiades, have been over-plotted. Thus, the stars have been classified in four groups: $EW >$ Pleiades, $EW \sim$ Pleiades, $EW \sim$ Ursa Major and $EW \sim$ Hyades, if the EW(Li I) is higher than that of the members of the Pleiades, similar to that of the members of this cluster, similar to the EW(Li I) of the members of the Ursa Major moving group, and similar to the values of the Hyades members. In Figs. 3b and d we have used different symbols for the different groups.

In general, K and M-type stars with higher values of EW(Li I) show higher levels of activity and rotation rates (see Figs. 3b and d), which agree with the fact that younger stars rotate more rapidly than the older ones. On the contrary, F and G-stars of the sample show a great dispersion and no relation can be achieved from their position in the diagrams, at least in the short range of ages we are working on. This effect is more noticeable in the Hα line (Figs. 3d) since the level of activity decrease more rapidly than the abundance of lithium. On the other hand, Ca II K and IRT show similar results, due the good correlation found between their level of activity (see Fig. 2a).

3.2. $v \sin i$

As in the case of $\log P_{\rm phot}$, when $v \sin i$ is used, a clear relation between the rotation and the activity level is observed, in spite of the great dispersion of the data. Those stars with higher $v \sin i$ show higher level of activity in the chromospheric lines. Again, K young stars show higher

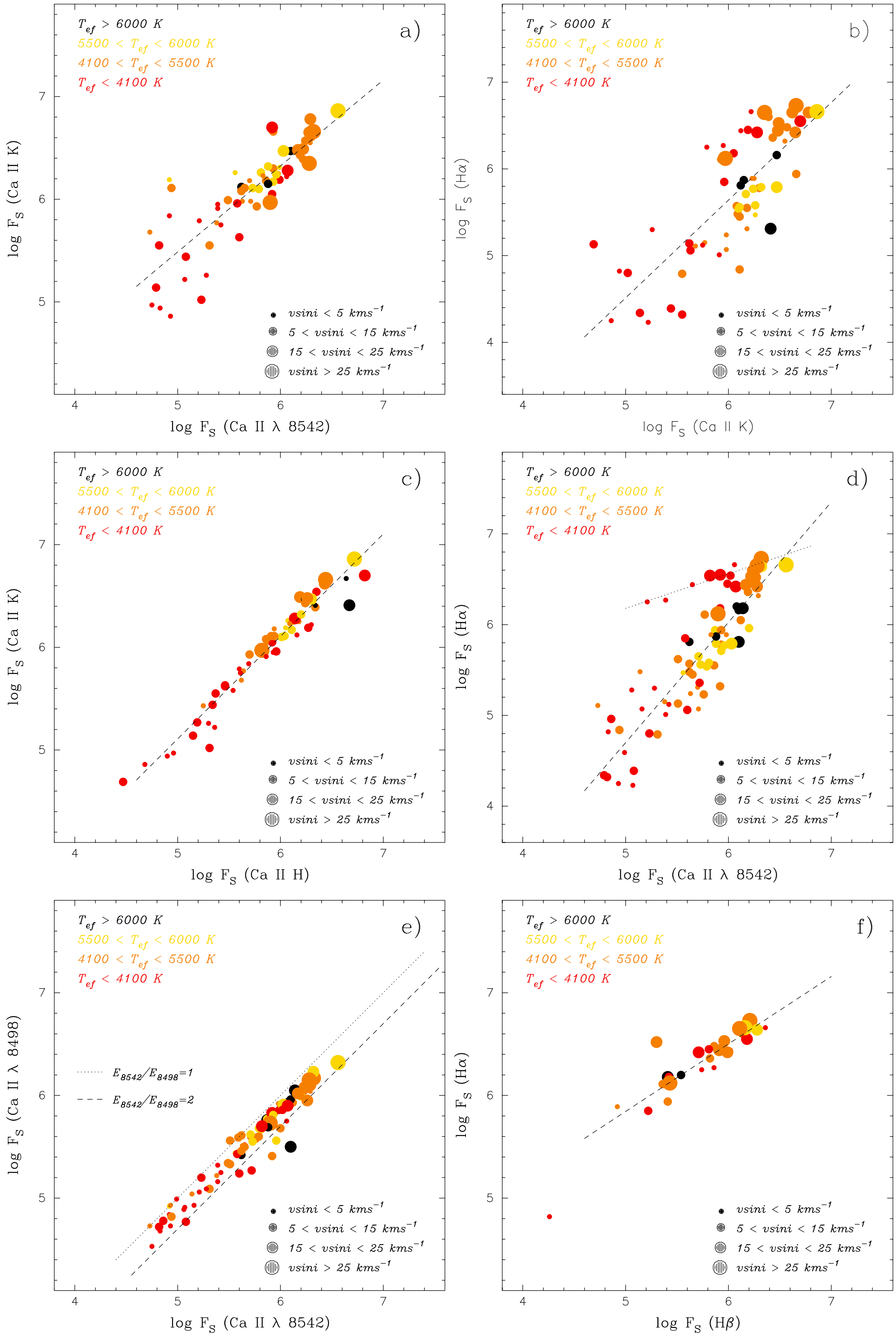

Figure 2. Flux-flux relationships of the stars of the sample. In the $\log F_S$ (Hα) *vs.* $\log F_S$ (Ca II λ8542) *plot, the tencence of the flare stars is clearly different from the rest of the stars*

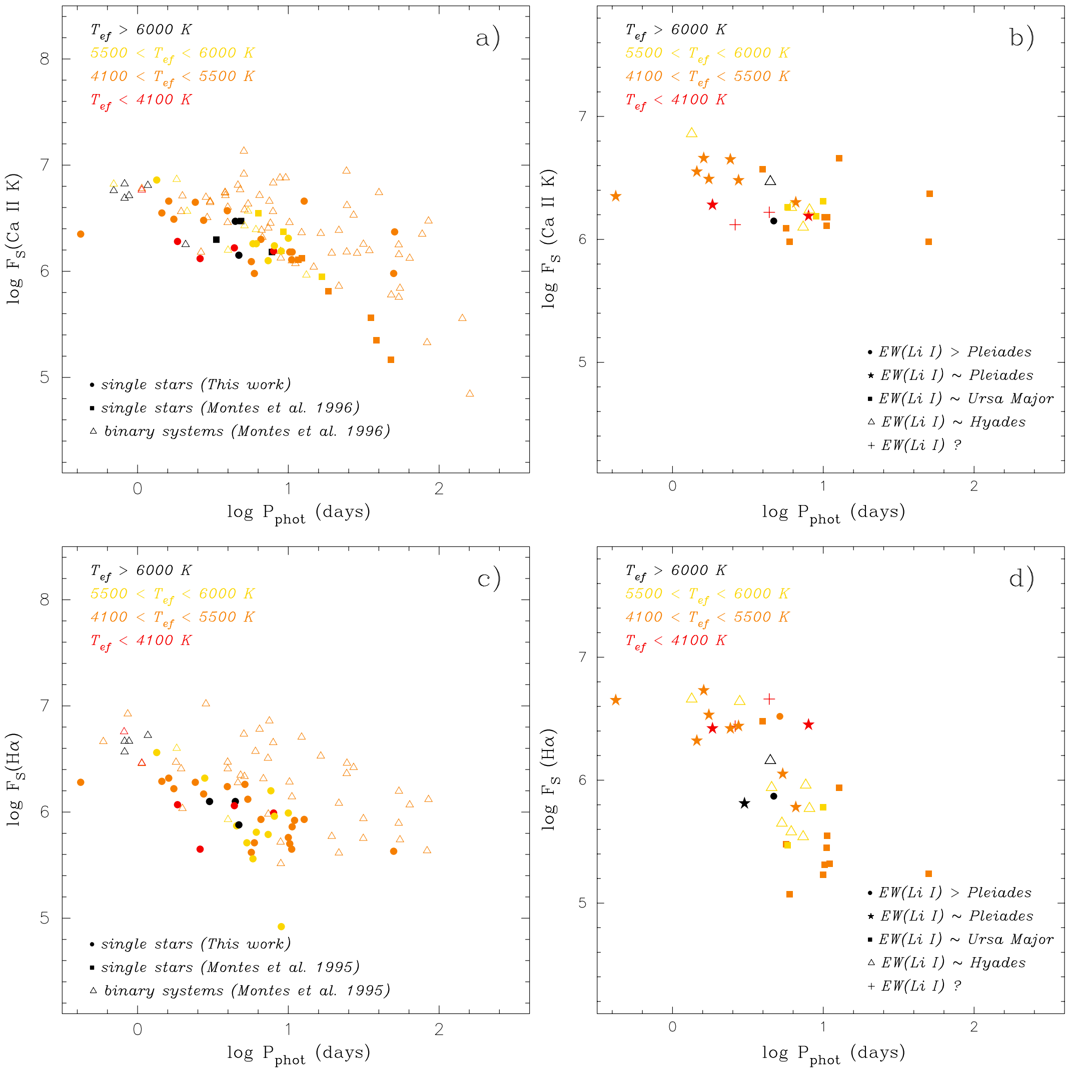

Figure 3. Activity-rotation relationships for the stars of the sample. A clear dichotomy between single and binary stars for $\log P_{\rm phot} > 1$ *days in the* $\log F_{\rm S}$ *(Ca II K) vs.* $\log P_{\rm phot}$ *diagram (figure a) is observed.*

level of rotation rates. However, M stars show lower values of $v \sin i$.

Acknowledgements

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