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# Spectroscopic Survey of Late-type Stars Possible Members of Young Moving Groups

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**Abstract.**
We summarize here our ongoing high resolution echelle spectroscopic survey of late-type stars, identified in our previous studies as possible members of young moving groups. The spectroscopic observations were taken during five observing runs: July 1999 (2.2m-FOCES, CAHA, Almería), November 1999 and 2000 (NOT-SOFIN, La Palma), and January 2000 and August 2000 (INT-MUSICOS , La Palma). Our main goal is to analyse in more detail the membership of these stars to the different young stellar kinematic groups.

## 1. Introduction

Stellar kinematic groups (SKG), (Superclusters (SC) and Moving groups (MG)) are kinematic coherent groups of stars (Eggen 1994) that could share a common origin. In our previous work (Montes et al. 2001a, hereafter Paper I) we have compiled a sample of late-type stars possible members of the youngest and best documented MG: Local Association or Pleiades moving group (20 to 150 Myr); IC 2391 supercluster (35-55 Myr); Castor moving group (200 Myr); Ursa Mayor group or Sirius supercluster (300 Myr); and Hyades supercluster (600 Myr).

Stars have been selected from previously established members of SKG based on photometric and kinematic properties, as well as from new candidates based on other criteria as their level of chromospheric activity, rotation rate and lithium abundance. In order to better establish the membership of these candidate stars to the different young SKG we have started a program of high resolution echelle spectroscopic observations. The spectroscopic analysis of these stars allow us to obtain a better determination of their radial velocity, lithium ($\lambda$6707.8 Å line) equivalent width, rotational velocity and the level of chromospheric activity. We will use all these new data to study in detail the kinematic (Galactic space motions (U, V, W)) of these stars, apply age-dating methods for late-type stars, and in this way analyse in more detail the membership of these stars to the different SKG. We present here the results of our first spectroscopic studies of a sample of single late-type stars selected by us in Paper I as young disks stars or possible member of some of the young SKG above mentioned.

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## 2. Observations

The spectroscopic observations (high resolution echelle spectra) of the stars analysed in this work were obtained during five observing runs (from 1999 to 2000):

From 24–29 July 1999 using 2.2 m telescope at the German Spanish Astronomical Observatory (CAHA) (Almera, Spain) and the Fibre Optics Cassegrain Echelle Spectrograph (FOCES).

From 26–27 November 1999 and 6–9 November 2000 using the 2.56 m Nordic Optical Telescope (NOT) located at the Observatorio del Roque de Los Muchachos (La Palma, Spain) and the Soviet Finnish High Resolution Echelle Spectrograph (SOFIN).

From 18-22 January 2000 and 11–14 August 2000 with the 2.5m Isaac Newton Telescope (INT) at the Observatorio del Roque de Los Muchachos (La Palma, Spain) using the ESA MUSICOS spectrograph. This is a fibre-fed cross-dispersed echelle spectrograph, built as a replica of the first MUSICOS spectrograph and developed as part of MUlti-SIte COntinuous Spectroscopy (MUSICOS) project.

The echelle spectra have been extracted using the standard reduction procedures in the IRAF package. The wavelength calibration was obtained by taking spectra of a Th-Ar lamp. Finally, the spectra have been normalized by a polynomial fit to the observed continuum. The wavelength range covers from 3900 to 10000 Å and the spectral resolution, determined as the full width at half maximum (FWHM) of the arc comparison lines, ranges from 0.06 to 0.42 Å.

## 3. Radial Velocities and Space Motions

Heliocentric radial velocities have been determined by using the cross-correlation technique. The spectra of the program stars were cross-correlated order by order, using the routine FXCOR in IRAF, against spectra of radial velocity standards of similar spectral types taken from Beavers et al. (1979). The velocity is derived from the position of the cross-correlation peak. The orders including chromospheric features and prominent telluric lines have been excluded when determining the mean velocity. Uncertainties in the derived velocities have been estimated from the width of the cross-correlation peak and the inter-order agreement in the derived velocities.

We have used these heliocentric radial velocities together with precise measurements of proper motions and parallaxes taken from Hipparcos (ESA 1997) and Tycho-2 (Høg et al. 2000) Catalogues, to calculate Galactic space-velocity components ($U$, $V$, $W$) in a right-handed coordinated system (positive in the directions of the Galactic center, Galactic rotation, and the North Galactic Pole, respectively). We have modified the procedures in Johnson & Soderblom (1987) to calculate U, V, W, and their associated errors. The original algorithm is adapted here to epoch J2000 coordinates in the International Celestial Reference System (ICRS). The uncertainties of the velocity components have been obtained using the full covariance matrix. We have used the correlation coefficients provided by Hipparcos (ESA 1997). The (U, V) and (W, V) planes (Boettlinger Diagram), for our star sample, are plotted in Fig. 1.

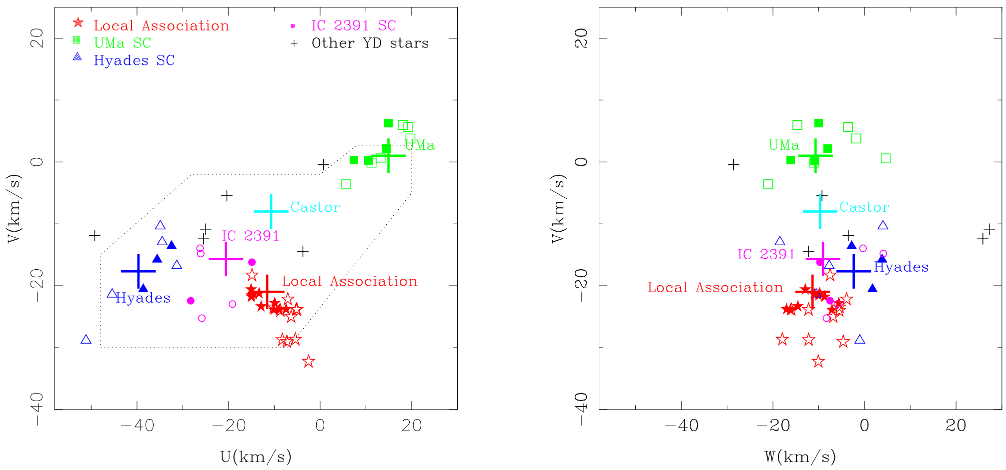


Figure 1. $(U, V)$ and $(W, V)$ planes (Boettlinger Diagram) for our star sample. We plot with different symbols the stars belonging to the different stellar kinematic groups. Filled symbols are stars that satisfied both Eggen's criteria (peculiar velocity, $PV$, and radial velocity, $\rho_c$), open symbols are other possible members. Big crosses are plotted in the central position of each group. The dashed line represents the boundaries that determine the young disk population as defined by Eggen (1984a, 1989).

## 4. The Li I $\lambda$6707.8 Line

The resonance doublet of Li I at $\lambda$6707.8 Å is an important diagnostic of age in late-type stars since it is destroyed easily by thermonuclear reactions in the stellar interior. This line is included in our echelle spectra in all the observing runs. At this spectral resolution and with the rotational velocity ($v \sin i > 8$ km s$^{-1}$) of the observed stars the Li I line is blended with the nearby Fe I $\lambda$6707.41 Å line. We have corrected the total measured equivalent width, $EW$(Li I+Fe I), by subtracting the $EW$ of Fe I calculated from the empirical relationship with $(B–V)$ given by Soderblom et al. (1990). The obtained values are plotted in Fig. 2 versus their spectral type. Spectra in the Li I line region of the stars of the sample with a significant $EW$(Li I) have been plotted in Fig. 3.

In order to obtain an estimate of the ages of our stars we compare their $EW$(Li I) with those of stars in well known young open clusters of different ages. In the $EW$(Li I) versus spectral type diagram (Fig. 2) we have overplotted the upper envelope of the Li I $EW$ of IC 2602 (10-35 Myr), the Pleiades (78-125 Myr), and the Hyades (600 Myr), open clusters which cover the range of ages of the MGs studied here. For the Pleiades we adopt the upper envelope determined by Neuhäuser et al. (1997) with data from Soderblom et al. (1993) and García López et al. (1994) and the lower envelope given by Soderblom et al. (1993). In the case of IC 2602 we have not adopted the upper envelope given by Neuhäuser et al. (1997) with data from Randich et al. (1997) and Stauffer et al. (1997) because they have used $EW$(Li I) not corrected from the $EW$(Fe I) and we have determined a new upper envelope with corrected $EW$(Li I) and using,

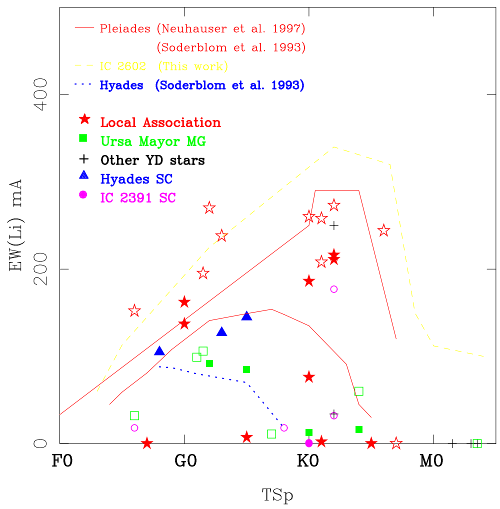


Figure 2. Li I $\lambda$6707.8 Å line equivalent width, $EW$(Li I) versus spectral type for our star sample. Symbols are as in Fig. 1. We have overplot the upper envelope of $EW$(Li I) of IC 2602 (10-35 Myr), the Pleiades (78-125 Myr), and the Hyades (600 Myr), open clusters.

in addition, new data provided by Randich et al. (2001). Finally for the Hyades (600 Myr) we have used the upper envelope of Soderblom et al. (1993).

## 5. Rotational Velocities

We have determined the rotational velocities ($v \sin i$) of our star sample by using the cross-correlation technique. The spectrum of the program star is cross-correlated against the spectrum of a template star (a slowly rotating star of similar spectral type) and the width of the cross-correlation function determined. The calibration of this width to yield an estimate of $v \sin i$ is determined by cross-correlating artificially broadened spectra of the template star for a range of $v \sin i$ with the template star spectrum. We have tested this method with stars of known rotational velocity obtaining a wood agreement.

## 6. Chromospheric Activity Indicators

The echelle spectra analysed in this paper allow us to study the behaviour of the different optical chromospheric activity indicators from the Ca II H & K to the Ca II IRT lines, formed at different atmospheric heights. The chromospheric contribution in these features has been determined using the spectral subtraction technique described in detail by Montes et al. (2000). The synthesized spectrum was constructed using the program STARMOD developed at Penn State University and modified by us. The inactive stars used as reference stars in the spectral subtraction were observed during the same observing run as the active stars. We have determined the excess emission equivalent width ($EW$) for the Ca II H & K, H$\epsilon$, H$\delta$, H$\gamma$, H$\beta$, H$\alpha$, and Ca II IRT lines.

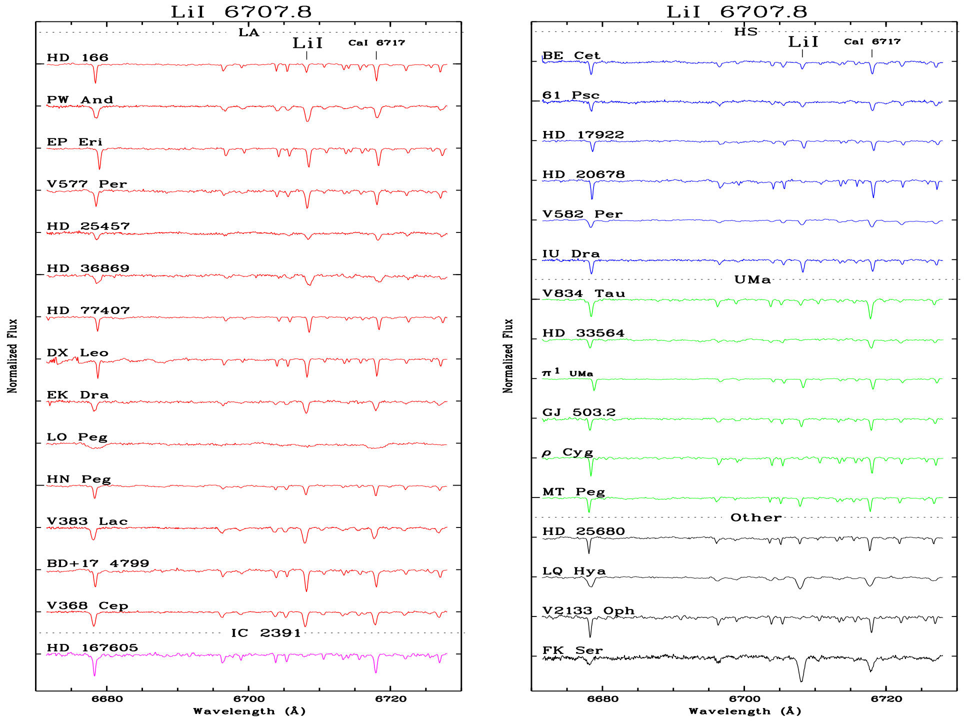


Figure 3. Spectra in the Li I $\lambda$6707.8 Å line region for our star sample

## 7. Results

We have used high resolution echelle spectroscopic observations to test out the membership of a sample of 60 single late-type stars to young SKGs. We have determined accurate heliocentric radial velocities, rotational velocities, equivalent width of the Li I doublet at $\lambda$6707.8 Å, and the level of chromospheric activity using different indicators from the Ca II H & K to the Ca II IRT lines (the values obtained for some of these stars can be found in Montes et al. 2001b). All these data allow us to apply both, kinematic (position in the (U, V) and (W, V) planes and Eggen's criteria, see Paper I) and spectroscopic (rotation, chromospheric activity, and $EW$(Li I)) criteria.

Our results confirm the membership of several previously established members of SKG, but in other cases the kinematic and spectroscopic criteria indicate the membership to a different SKG or that the star should be considered only as a young disk star with no clear membership to any SKG.

Some stars have been observed at different nights and at different epochs, covering several rotational periods. The radial velocities that we have determined in these spectra show no evidence of variability and are in good agreement with the range of values previously reported by other authors, supporting the single nature of these stars. For some of these stars (with several spectra available) we have also found low level variability of the chromospheric emission, which can be attributed to low level flaring or rotational modulation of chromospheric active regions. The stars with the highest levels of chromospheric activity have the H$\alpha$ line in emission above the continuum and also have the highest excess emissions in the Ca II H & K and Ca II IRT lines. These stars are also the most rapidly-rotating stars of the sample with rotation period, $P_{\rm phot}$ $< 2$ days. When we analyse in detail the behaviour of the chromospheric excess emissions with the star rotation (characterized by their photometric period, $P_{\rm phot}$ or their projected rotational velocity, $v \sin i$) a clear trend of increasing activity with increasing rotation is showed up.

A more detailed analysis of chromospheric activity of some of these stars including additional spectroscopic observations, will be the addressed in forthcoming papers. An additional age estimation of these stars can be obtained by isochrone fitting on the color-magnitude diagram. We are carrying out this kind of study in our ongoing project dedicated to the detailed study of each young SKG and the results will be addressed in forthcoming papers, for preliminary results see López-Santiago et al. (2001).

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