Mem. S.A.It. Vol. 91, 167

Memorie della

New candidates for chromopherically young, kinematically old stars

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Abstract. One method for estimating stellar ages is based on the chromospheric activity (CA), a set of phenomena related to rotation and to variations in the magnetic field of stars. Its relation with age arises from the progressive loss of angular momentum a dwarf star experiences over time due to magnetized winds, which decreases stellar rotation. Roughly speaking, high rotation tends to imply intense CA, such that one can infer that chromospherically active objects must be young. At the same time, objects orbiting the Galactic center for long periods tend to increasingly deviate from its initial orbits, determined by the dynamics of the primordial gas that originated them. Thus, parametrizing stellar velocities such that their distributions are zero-centered, stars with high components in space velocities must be old. Our work explores this dichotomy by identifying objects with intense CA – supposed to be young – and high components in space velocities – supposed to be old; we call them chromospherically young, kinematically old objects (CYKOs). A hypothesis that can explain their occurrence is the interaction between stars in short-period binary systems: the outcome of a coalescence between the pair would be an object with intense CA and kinematical features inherited from the former pair. In order to verify this scenario, we investigate lithium depletion in stellar atmospheres, a stellar evolution sensitive phenomenon associated to old stars, by searching for observed spectra in literature and by observing candidates with the coude spetrograph mounted at the Pico dos Dias observatory (MG, Brazil). We have finally yielded a list with 50 CYKOs candidates.

Key words. Stars: ages – Stars: chromospheric activity – Stars: spectroscopy – Galaxy: space velocities

1. Introduction

The chromospheric activity (CA) of a star is a set of phenomena responsible for dumping mechanical energy into the so called chromosphere, a layer just above although hotter than the photosphere. Because of this activity, radiative equilibrium does not explain alone the observed heating. Information on the CA can provide insights on the time evolution of stellar magnetic fields, as well as on mass and radiative fluxes through their complex magnetic topology (Hall 2008).

One of the various methods to measure the CA of a star is through the H and K lines from the singly ionized calcium. Vaughan et al. (1978) introduced the now famous S-index, for the Mount Wilson Observatory HK project, that measured the purely chromospheric emission seen as reversals at the centers of those lines (see e.g. Figure 3 of Schröder et al. 2009). Noyes et al. (1984) updated it into a new index, R'_{HK}, that takes into account not only an intrinsic bias that arises from S due to a star temperature, but also an eventual photospheric contamination in H and K lines reversals, enabling the comparison of the CA of stars with different spectral types.

The relation between CA and age arises from the fact that aging is tightly linked to stellar rotation and magnetic activity, since these features evolve in time (Skumanich 1972). It is well established in literature that for sun-like dwarfs, stellar rotation and magnetic activity tend to decrease with age, due to angular momentum loss through magnetized winds and structural variations on evolutionary timescales, and therefore CA–age relations can be calibrated (e.g. Skumanich 1972; Soderblom et al. 1991; Mamajek & Hillenbrand 2008; Lorenzo-Oliveira et al. 2016). That said, one can state that intense CA is a proxy for youth.

2. Space velocities & age

Since their birth, stars experience kinematical evolution as they age and go through their orbits around the Galactic center. This evolution results in a statistical correlation known as disk heating (Wielen 1977), a net increase in Galactic space motions with time. Almeida-Fernandes & Rocha-Pinto (2018) also summarize some mechanisms that can explain the fluctuations that a star can encounter when traveling around the Galactic center: encounters with giant molecular clouds, interaction with non-axisymmetric Galactic structures, interactions with satellite galaxies, etc.

In order to quantify this behaviour, stellar space velocities can be derived from proper motions and radial velocities, and can be put in a common reference system, in our case namely the Local Stantard of Rest (LSR), valid for stars in the solar neighborhood. In a three dimensional motion, stars move around the Galactic center with velocities u, v and w (respectively pointing towards the center the direction of rotation and the Galactic north pole).

It is easy to qualitatively visualize this dispersion behaviour when stellar ages are plotted against space velocities u, v, w (corrected for accounting solar motion with respect to the LSR) for stars in the solar neighborhood (e.g. Figure 2 from Rocha-Pinto et al. 2004): there is a clear spread towards older chromospheric ages; also when plotting ages against the dispersion values themselves (e.g. Figure 1 from Almeida-Fernandes & Rocha-Pinto 2018). One can derive an age–velocity dispersion relation, and we can state that high space velocities components, i.e. motions that are way faster (or slower) than the LSR, are more commonly associated with old stars.

3. CYKOs: formation and identification

The occurrence of active old stars seems at first inconsistent, but they could be originated from the coalescence of a short-period pair, as described in Poveda et al. (1996). The authors argued that once the close binary system is tidally locked, it will irreversibly evolve to a contact binary and eventually to a single rejuvenated star, with chromospheric activity levels that would mimic those of a young star. Based on this scenario, Rocha-Pinto et al. (2002) specifically studied active stars with kinematical features associated to old stars, which they called chromospherically young, kinematically old objects (CYKOs), presenteing a list of 29 stars. They proposed a formalism we decided to follow here: after plotting chromospherically active stars in a space velocities diagram, we select the ones lying outside a 3σ limit for dispersion values in each component.

Our dispersion values were found following Almeida-Fernandes & Rocha-Pinto (2018, Table 1), which yielded (in km s^{-1}) σ_U = 29.41; σ_V = 18.21; σ_W = 14.25. The age we used as input was the one associated to $\log R'_{HK} = -4.75$ (2.55 Gy) based on the CA-age calibration presented in equation (3) from Mamajek & Hillenbrand (2008). This is the activity boundary we set in this work based on the so-called Vaughan-Preston gap, where Vaughan & Preston (1980) reported an apparent lack of stars.

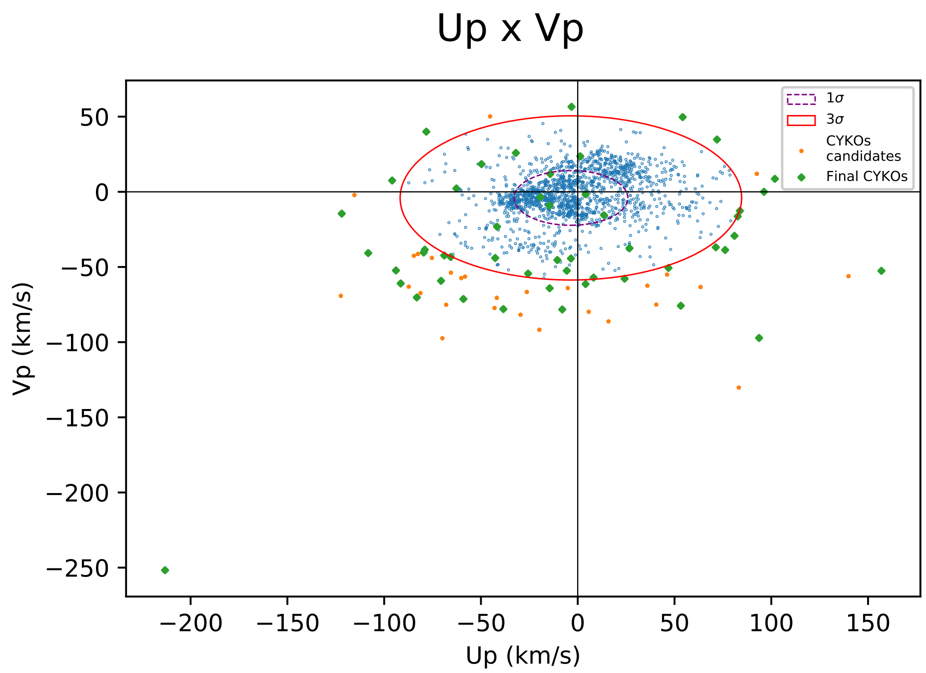

Fig. 1. Space velocities diagram for active stars: the full, outer ellipse represents the 3σ dispersion limit for space velocities components. CYKOs candidates are seen outside this line and the final selected ones are plotted as large diamonds. The ones inside the 3σ ellipse were selected from the w vs. v diagram.

Our sample is composed by stars with known chromospheric activity from three sources:

(i) a list gathered by one of us (Rocha-Pinto) in the course of other studies, with 1235 entries;
(ii) the sample presented in Murgas et al. (2013), with 2529 entries;
(iii) the largest compilation we found in literature, by Boro-Saikia et al. (2018), with 6962 entries.

Merging those together yielded a final list of 5175 unique stars with mean CA values. We selected the active ones (2121) to cross against the Gaia DR2 astrometric solution catalogue (*Gaia Data Release 2. The astrometric solution* 2018) from *The Gaia mission* (2016), and found 1692 having kinematical information, which we used to calculate their space velocities components (U, V, W). Finally, following the formalism described in Rocha-Pinto et al. (2002), we plotted these stars in the space velocities diagram shown in Fig. 1. The inner and outer ellipses represent dispersion values (1σ and 3σ) for each component, and objects lying beyond both are the selected 93 CYKOs candidates. Finally, we filtered only the stars of spectral types F, G and K, and removed the ones with binarity flag from SIMBAD. After this process, 50 candidates remained, which are represented by large diamonds marks, and this is our final CYKOs list. It may be important to mention that not all of them are UV CYKOs (i.e., beyond the outer ellipse in Fig. 1); the ones seen insde the 3σ limit are objects selected in the diagram with velocities w vs. v.

4. Lithium in CYKOs

In order to confirm whether coalescence scenario can explain CYKOs' formation, we analyze their lithium content, assuming they're old stars which coalesced. Lithium depletion is a well established phenomenon that takes place in stellar atmospheres, characterized by this el-

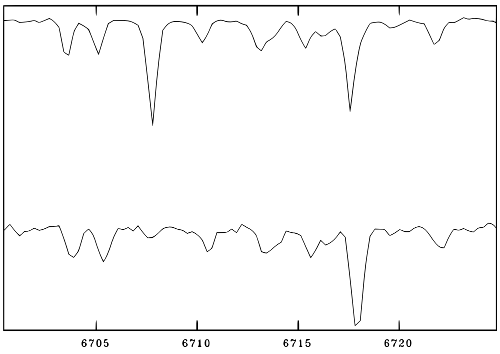

Fig. 2. Representative comparison between spectra of a normal young star (top) and a CYKO star (bottom): in the former, the Li I line λ 6707.8 Å is proeminent, indicating youth as expected; in the latter, this line is nearly absent, which may corroborate to a coalescence scenario.

ement's fragility: it can be destroyed in environments hotter than $T \sim 10^6 K$. As a rule, it's safe to say that old main sequence stars must be lithium depleted, given the fast timescale of the destruction process (Skumanich 1972, cf van den Heuvel & Conti 1971) compared to overall stellar evolution.

Spectroscopic observations of CYKOs in the region of the λ 6707.8 Å Li I line allow us to confirm whether the coalescence scenario is reasonable, since we detect no or low lithium content in these stars. We observed 5 candidates with the coude spectrograph mounted at 1.6m Perkin-Elmer telescope at the Pico dos Dias Observatory (data currently in reduction phase) and we have other two observation runs to perform. The signal-to-noise ratio (S/N) and resolving power (R) we will reach in these observations ($S/N \gtrsim 100$, $R \gtrsim 10,000$) will not allow us to retrieve abundances, such that we will only be able to discriminate which stars show a relevant amount of lithium in their atmospheres, instead of actually determining how much of this element is present there.

We show in Fig. 2 a preliminary result with a representative spectrum as expected for a normal young star compared to that of a CYKO. For the in one in the top (normal young star), there is a strong feature in the Li region, whereas for the one in the bottom (CYKO), no substantial lithium content was detected. With the remaining observing runs to be performed, we expect to confirm this lack of lithium behaviour in CYKOs, as well as with spectroscopic data available from other databases, e.g. HARPS, FEROS, Gaia-ESO survey, etc.

Acknowledgements. This research was supported, in part, by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001, by the Astronomy Postgraduate Programme at the Valongo Observatory and by the National Science Foundation under Grant No. PHY-1430152 (JINA Center for the Evolution of the Elements). Data was aqcquired in observation runs taken at the Pico dos Dias observatory / LNA.

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (`https://www.cosmos.esa.int/gaia`), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, `https://www.cosmos.esa.int/web/gaia/dpac/consortium`). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

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