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New Candidates for Chromospherically Young, Kinematically Old Stars

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Abstract. Roughly speaking, young stars are associated to intense chromospheric activity (CA), whereas it decreases with stellar aging. However, some objects that show high kinematical components – in turn, associated to older stars – reveal CA similar to that of young ones; we call these stars chromospherically young and kinematically old (CYKOs). One hypothesis that could explain their occurrence is the merge of a short-period binary, from which the outcome would be a chromospherically active, kinematically evolved star. Considering that they evolved separately, we expect them to be lithium depleted, and therefore we look for CYKO stars by analyzing their lithium content (λ 6707 Å). We present a preliminary list of 48 stars matching this criteria, aiming to either confirm or discard the coalescence of a short-period pair hypothesis.

Keywords. late type stars, stars: chromospheric activity, space velocities, stars: spectroscopy

1. Chromospheric activity as a proxy for youth

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, after projecting two triangular filters in order to measure the purely chromospheric emission seen as reversals at the centers of those lines. Aiming to normalize this emission to stellar continuum, other two neighbor continuum bandpasses were also designed by these authors. These features can also be seen in more recent works, e.g. in Figure 3 by Schröder *et al.* (2009). However, due to this continuum normalization, the S-index is color-dependent, hence Noyes *et al.* (1984) updated it into a new index, R'_{HK}, that takes into account both the continuum normalization and an eventual photospheric contamination in H and K lines reversals, enabling the comparison of the CA of different stars.

The relation between CA and age arises from the fact that it is tightly linked to stellar rotation and magnetic activity, since these features evolve in time (Skumanich 1972). It is well established in literature (e.g. Skumanich 1972; Soderblom *et al.* 1991; Lorenzo-Oliveira *et al.* (2018) 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 a CA–age relation can be calibrated. A relation derived by Lorenzo-Oliveira *et al.* (2018) can be seen in left panel of their Figure 7, showing that intense chromospheric activity is associated to young stars.

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2. Kinematical features as a proxy for old ages

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) 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, stellar space velocities can be derived from proper motions and radial velocities, and can be put in a common reference system, such as 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 (pointing towards the center), v (pointing towards the rotation direction) and w (pointing towards Galactic north pole).

In Figure 2 from Rocha-Pinto *et al.* (2004), it is easy to qualitatively visualize this dispersion behaviour: space velocities u, v, w (with respect to LSR and corrected for accounting solar motion) for stars in the solar neighborhood show a clear spread towards older (in this case, chromospheric) ages; this is seen to be true for any of the tree components. 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. Identifying CYKOS

Here we revisit the work of Rocha-Pinto *et al.* (2002) (hereafter RP+02) and follow the same formalism introduced by these authors. We used 3 samples of stars having known chromospheric activity: a list assembled by one of us (Rocha-Pinto) in the course of other various studies; the largest CA compilation we found in the literature, from Boro-Saikia *et al.* (2018); and a catalogue build by Murgas *et al.* (2013), in an investigation on comoving groups, which ended up providing space velocities components as well. For the first two samples, with no kinematical data available from the source, we used the Geneva-Copenhagen Survey (Holmberg *et al.* 2009) to retrieve u, v, w. In order to have zero-centered values, we took solar motion into account by using Almeida-Fernandes & Rocha-Pinto (2018) results.

After crossing and merging these samples into one list, we plotted the chromospherically active stars in a space velocities diagram, from which we selected objects lying outside a 3σ dispersion limit, yielding a final list of 48 CYKOs candidates, 15 more than in Rocha-Pinto *et al.* (2002). The result of applying this methdology can be seen in Figure 1, where small dots, inside the full ellipse, are stars with normal space velocities components, whereas larger dots, outside the full ellipse, represent our candidates.

In an effort to explain the ocurrence of these stars, we perform spectroscopic observations and compare them to normal objects, under the hypothesis explained in the next section.

4. CYKOS's nature: coalescence and lithium depletion

We look for objects that, at first, seem inconsistent: chromospherically active stars with high space velocities components, firstly noticed by Soderblom (1990). Rocha-Pinto *et al.* (2002) dedicated a whole paper to study these objects, and concluded that they could be single stars formed out of the coalescence of short-period binaries. The star should look chromospherically younger — since the orbital angular momentum of the former binary is transformed into rotational angular momentum of the new single star — and keep

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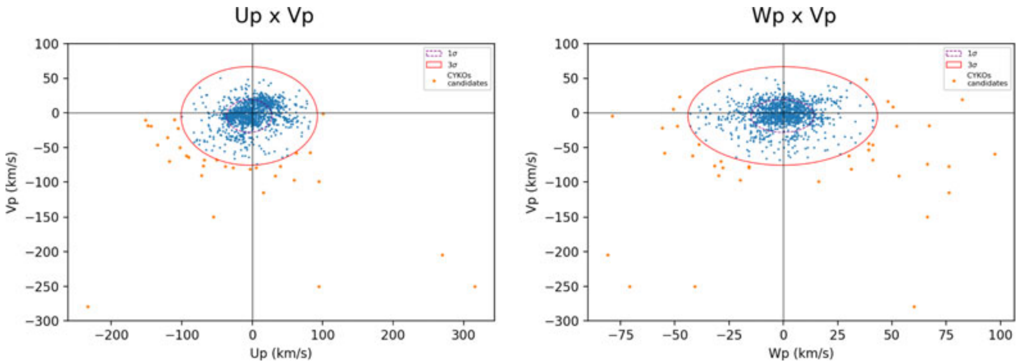

Figure 1. Space velocities diagram with chromospherically active stars: the full, outer ellipse represents the 3σ dispersion limit for space velocities components. CYKOS candidates are seen outside this line, shown by larger dots than those inside.

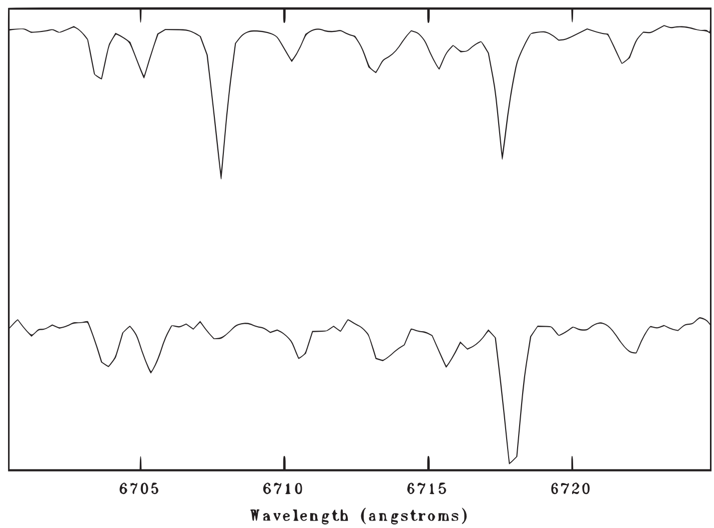

Figure 2. For comparison, two representative stars that we observed for this work. Top: a normal chromospherically active star, showing a strong lithium line (λ 6707 Å); bottom: a CYKOS candidate selected from our list, showing almost no lithium content.

the kinematical signatures of an advanced age — since the movement of the binaries' center of mass around the Galactic center is inherited by the new single star. In this way, CYKOs would be formed by stars that evolved individually until coalescence.

We can confirm this hypothesis by analyzing the lithium content in these objects, more specifically through the absorption line 6708 Å: it is well known that Sun-like stars deplete their surface Li abundances over time (e.g. Soderblom 2010, and references therein), and thus the presence of this element in stellar spectra can be used as a youth indicator. Assuming the coalescence scenario, we expect to find no or low presence of lithium, as these are individually evolved objects.

In Figure 2 we compare spectra for two representative stars that we observed up to date: at the top, a normal active star with ordinary space velocities components, showing a proeminent lithium line at λ 6707 Å; at the bottom, a CYKOS candidate, with high space velocities components, showing almost no lithium content. The vertical axis must

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be read as arbitrary flux units, and it was not made explicit merely because this figure is for comparison means only.

We are currently finishing observational reduction phase and awaiting for other two observing runs to be performed in 2020. We also want to take advantage of already existing databases (e.g. ESO-HARPS, Gaia-ESO, California-Kepler Survey, etc.) that have available spectra in that spectral region. Aditionally, GAIA data is part of our plans to enhance our kinematical data, considering it could provide precise measurements for proper motions and radial velocities. The results and conclusions achieved in this work will be presented as a M.Sc. thesis of one of us (Machado-Pereira) in July 2020.

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