Chromospheric flux-flux relationships of the CARMENES active RV-loud M Dwarfs

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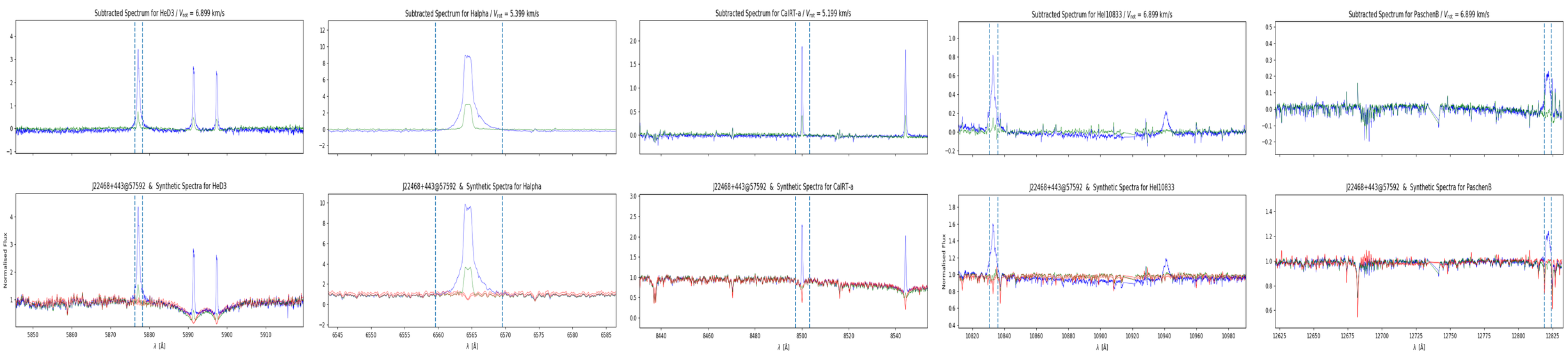
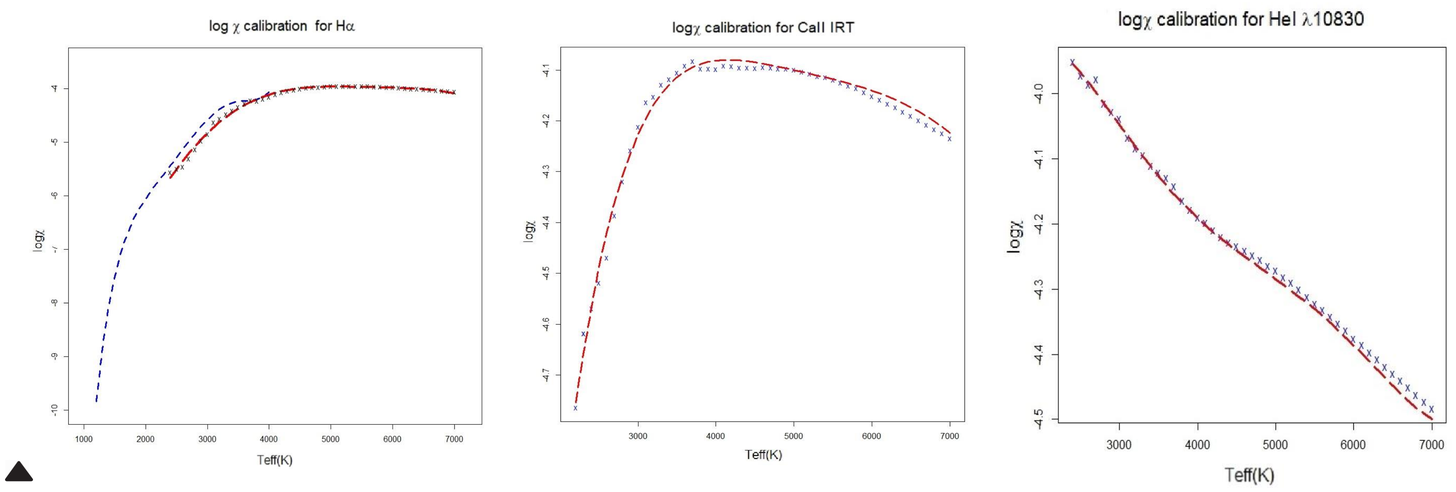
ABSTRACT: The main objective of this work within **CARMENES** survey is the extraction of all available information on the chromospheric activity and its variability (rotational modulation, flares, etc.) using for that all the chromospheric indicators included in the spectral range of the spectrograph, ranging from visible (VIS), including the **Na I D_1**, **D_2 He I D_3**, and **H** lines to near-infrared (NIR) that include the **Ca II IRT**, **He I 10830 Å**, **Paschen α**, **Paschen β** and **Paschen δ** lines. We study in detail the behavior of the flux-flux relationships of lines formed at different chromosphere layers in order to a better understanding of the magnetic activity of M-type dwarf stars. For this task we have selected the CARMENES active RV-loud M Dwarfs (Tal-Or et al. 2018) and apply the spectral subtraction technique using **iSTARMOD** to derive te equivalent width (EW) of the chromospheric excess emission of the different lines that is converted to surface flux using the χ factor methodology defined by Walkowicz et al. (2004) and implemented as Reiners & Basri (2008), using the set of BT-Settl-CIFIST [Fe/H] = 0 synthetic spectra as in Cifuentes et al. (2020). The ongoing results extends the frame of the work done for FGK stars in Martinez-Arnáiz et al. (2011) and confirms the non-universality of the flux-flux relationship presented there, with two or more distinct chromospheric emitter populations.

CARMENES (http://carmenes.caha.es/) is a ultra-stable, double- channel spectrograph at the 3.5 m Calar Alto telescope for radial-velocity surveys of M dwarfs (Quirrenbach et al., 2020) with the aim of detecting Earth-mass planets orbiting in the habitable zones of their host stars. The CARMENES survey, which began in January 2016 and is still ongoing, aims to observe over 300 M-type dwarf stars, spread over the complete M spectral range. The task carried out in this study, on chromospheric activity indicators, is intended to be carried out applying the spectral subtraction technique, and to this end it has been used the *Python* code **iSTARMOD** (Labarga & Montes, 2020). The detailed analysis of these activity indicators is important from one side in order to confirm or discard all the possible planets around these stars and by the other studying its dependency with other stellar parameters as rotation, age and depth of the convective zone.

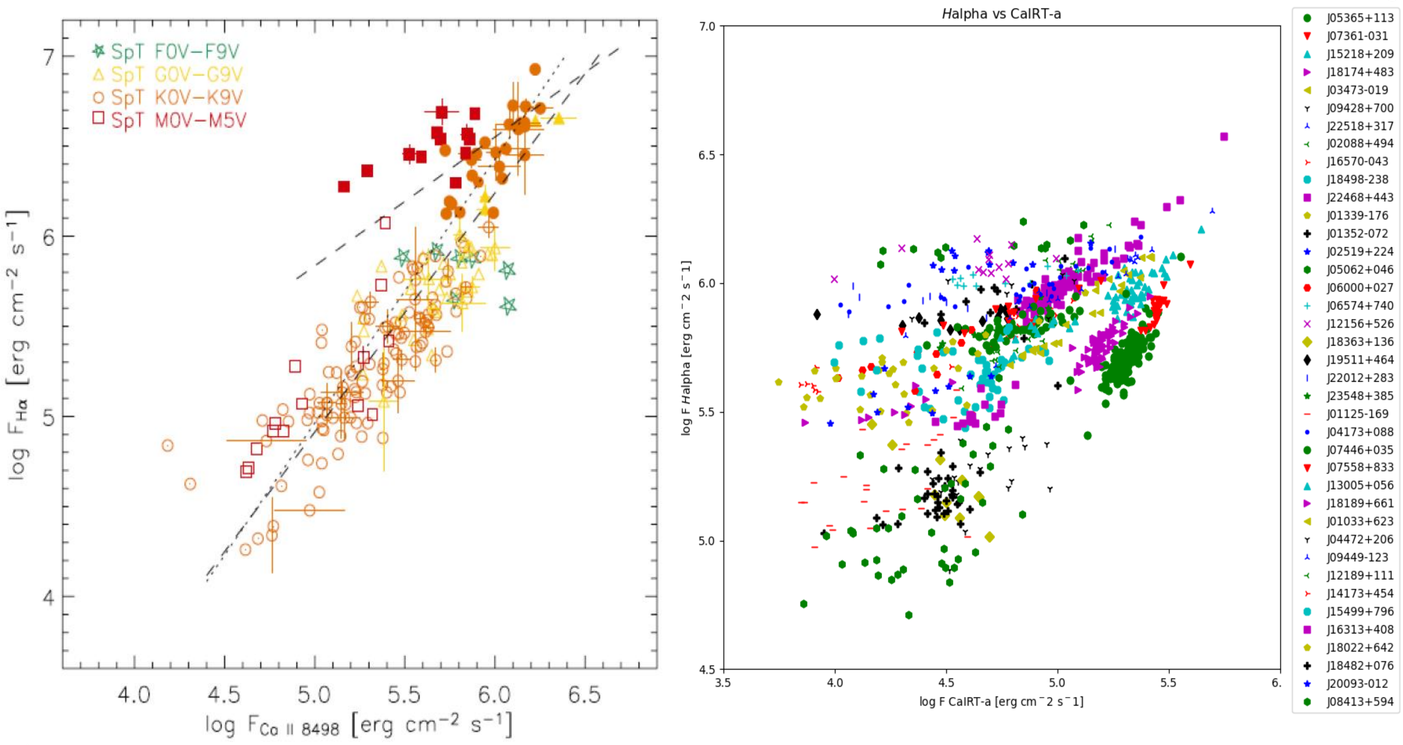


▲**Fig. 1:** Showing the results of the spectral subtraction for the chromospheric activity indicators (He I D_3, Na I D_1, D_2, Hα and the first two of three Ca II IRT lines in the VIS and He I 10830 Å, Pγ and Pβ lines in the NIR) for the CARMENES spectra of J22468+443 **(EV Lac)** at the **maximum level** of chromospheric activity (Flare) and in a previous **quiescent phase** as well as the **synthetic spectrum** obtained with a M3.5 V reference star (J22096-046). The spectra to perform the subtraction are shown at the bottom and the obtained subtracted spectra at top from where we derived the EW of the chromospheric contribution. The algorithm makes use of the python code **iSTARMOD** as described in a Labarga & Montes (2020).

In order to convert the measures of the chromospheric excess emission (*pEW*) into line fluxes it has been followed the method of χ factor, defined by Walcowicz et al. (2004) and implemented as in Reiner & Basri (2008). As mentioned in the latter paper, this χ factor is calculated by means of a polynomial fit to fifth degree obtained using synthetic spectra (here *BT-Settl-CIFIST* [Fe/H]= 0 as in Cifuentes et al. 2020) to perform a calibration. The novelty of this study lies in the application of the χ factor methodology not only for the **Hα** line, but also for the rest of activity indicators, ranging from the **He I D_3 to Na I D_1 & D2** lines in the visible to **Ca II IRT, He I λ10830Å** and **Paschen** lines in the NIR.



▲**Fig. 2:** Example of the results of the calibrations performed for effective temperature range [2400, 7000 K], except the case of the Hα line that covers the range [1200, 7000 K] for comparison with the fit obtained in Reiners & Basri (2008).



▲ **Fig. 3:** Showing the results of the calculation of the flux-flux relationship of **Hα vs. Ca II IRT-a**. A similar figure, provided in Martinez-Arnáiz et al. (2011) for FGKM Stars is shown for comparison purposes. The right figure, showing the preliminary results of our study, come from data taken in the CARMENES survey. At least two branches are clearly visible in both figures, showing the non-universality of flux-flux relationships, providing evidence to the existence of two distinct chromospheric emitter populations.

The ultimate goal of this work is to obtain flux-flux relationship for the RV loud sample within the whole CARMENES survey. Here is shown the ongoing calculation of flux-flux relationship between **Ca II IRT-a** and **Hα** lines. The different branches in the flux-flux relationship are clearly seen, resembling the dichotomy in the Hα emission found by López-Santiago et al. (2010) and Martinez-Arnaiz et al. (2011). Stars in the "upper branch" in the flux-flux relationships are the stars above the *Vaughan-Preston gap* (believed to be young stars probably with a different dynamo, Hartmann et al. 1984; Bohm-Vitense 2007). Similar analysis will be made, extending to the NIR range of the CARMENES spectra, in order to obtain a better understanding of the magnetic activity of M-type stars

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