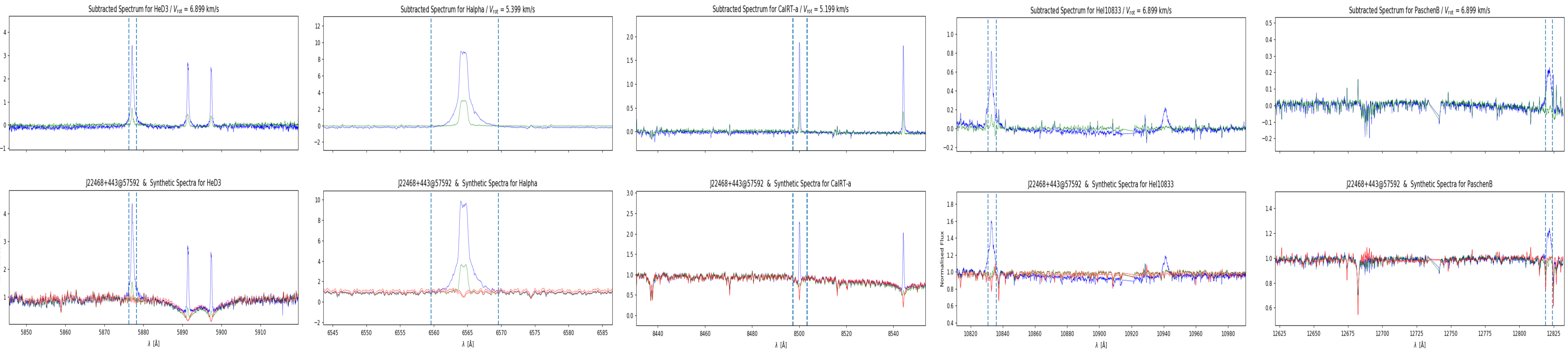
Chromospheric flux-flux relationships of the CARMENES active RV-loud M Dwarfs

F. Labarga[1], D. Montes[1], Á. López-Gallifa[1], J. A. Caballero[2], S. V. Jeffers[3], A. Reiners[3], I. Ribas[4], A. Quirrenbach[5], P. J. Amado[6], and the CARMENES Consortium

[1] Dpto. Física de la Tierra y Astrofísica & IPARCOS-UCM (Instituto de Física de Partículas y del Cosmos UCM), Fac. CC Físicas, Univ. Complutense de Madrid, Madrid, Spain
[2] Centro de Astrobiología (CSIC - INTA), ESAC campus, camino bajo del castillo s/n, 28691, Villanueva de la Cañada, Madrid, Spain
[3] Institut für Astrophysik, Georg-August-Universität, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany
[4] Institut de Ciències de l'Espai (CSIC-IEEC), Campus UAB, c/ de Can Magrans s/n, E-08193 Bellaterra, Barcelona, Spain
[5] Zentrum für Astronomie der Universität Heidelberg, Landessternwarte, Königstuhl 12, D-69117 Heidelberg, Germany
[6] Instituto de Astrofísica de Andalucía (IAA, CSIC), Glorieta de la Astronomía s/n, E-18008 Granada, Spain

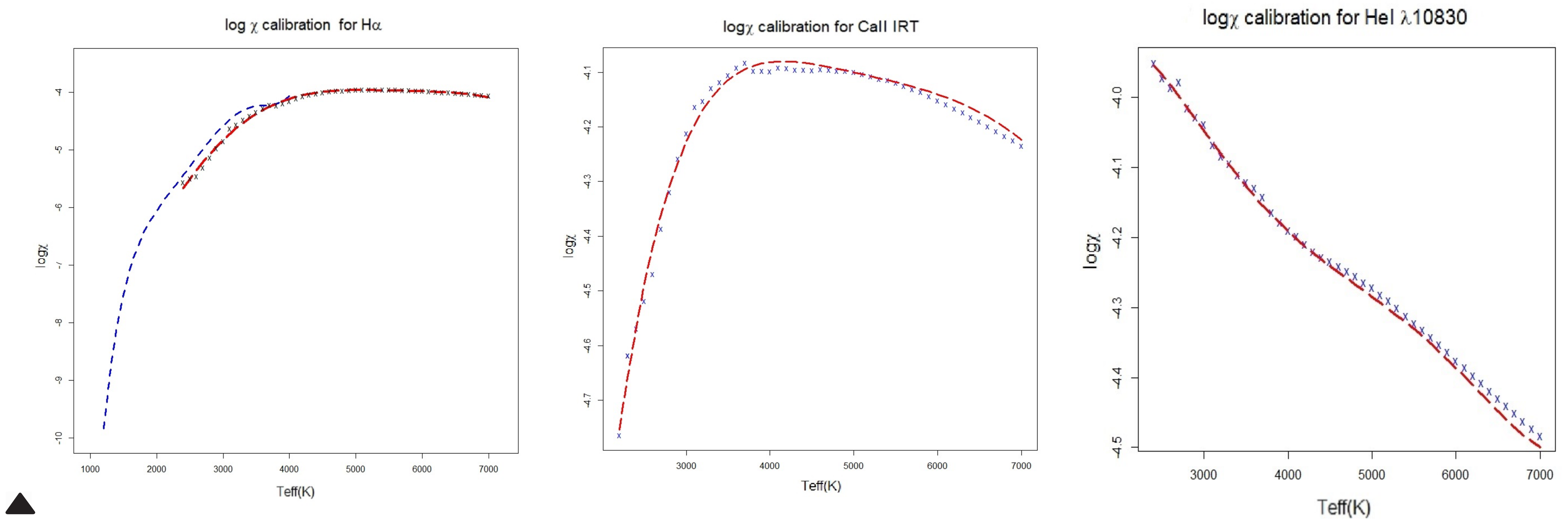
ABSTRACT: The main objective of this work within **CARMENES** survey is the extraction of all available information on the chromospheric activity and its variability (rotational modulation, flares, etc.) using for that all the chromospheric indicators included in the spectral range of the spectrograph, 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 our *Python* code **iSTARMOD** (Labarga & Montes 2020) 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 in Walkowicz et al. (2004) and implemented as in 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. (2010) 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 former Spanish-German 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 still ongoing, aims to observe approximately 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.

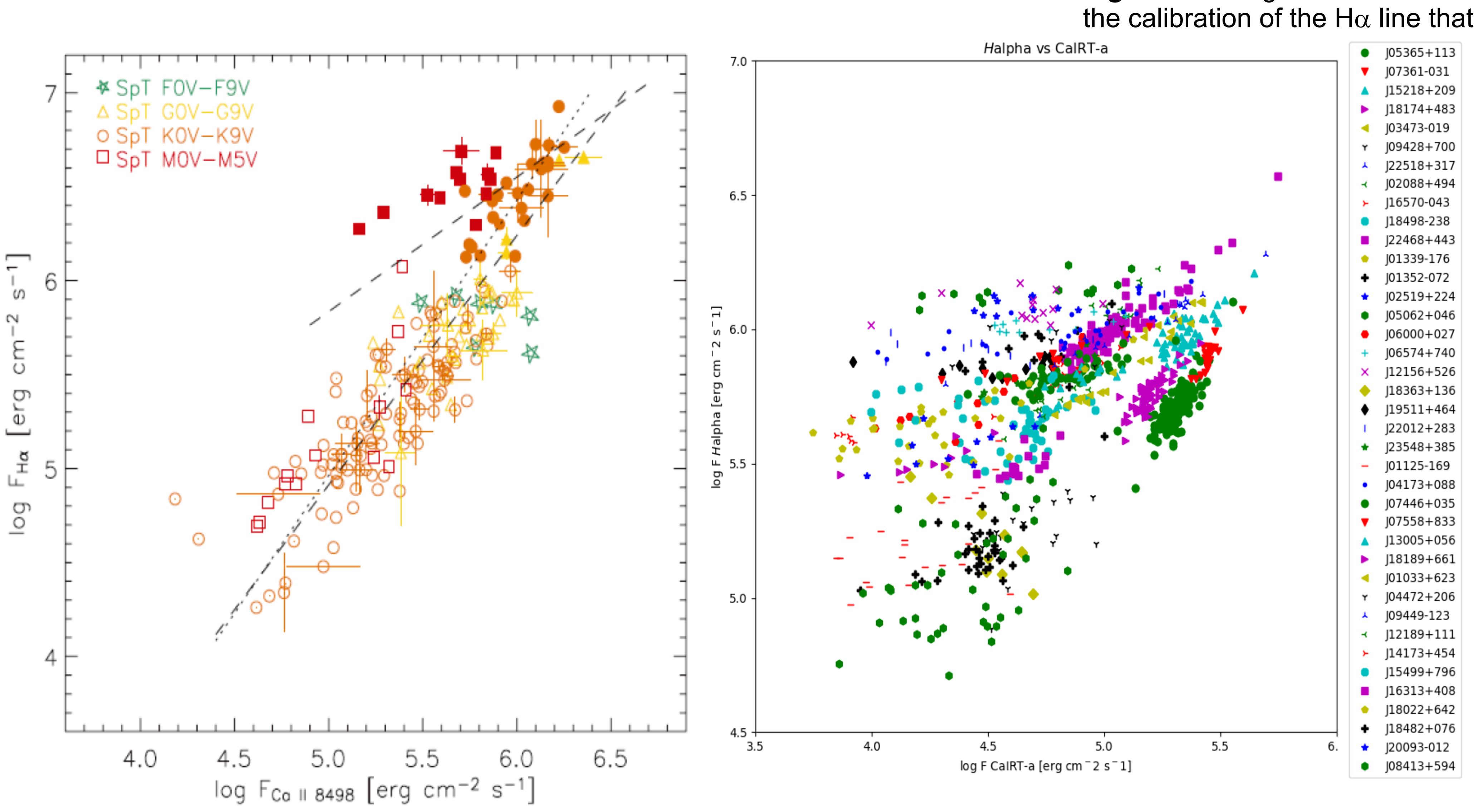


▲**Fig. 1:** Showing the results of the spectral subtraction for the chromospheric activity indicators (He I D_3, Na I D_1, D_2, Hα and the first two of three Ca II IRT lines in the VIS and He I 10830 Å, Pγ and Pβ lines in the NIR) for the CARMENES spectra of J22468+443 **(EV Lac)** at the **maximum 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, as defined in 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 λ10830** and **Pachen** lines in the NIR.



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



▲ **Fig. 3:** Showing the results of the calculation of the flux-flux relationship of **Hα vs. Ca II IRT-a**. For comparison purposes it is provided the similar provided in Martinez-Arnáiz et al. (2011) for FGKM Stars. 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.

As mentioned above, 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. There are clearly seen the different branches in the flux-flux relationship, 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 younger 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

References:

Barden, S. C. 1985ApJ...295..162B
Böhm-Vitense, E. 2007ApJ...657..486B
Cifuntes, C. et al. 2020A&A...642A.115C
Labarga, F. & Montes, D. 2020sea..confE.153L
López-Santiago, J., et al. 2010A&A...514A..97L
Montes et al. 1995A&A...294..165M
Montes et al. 2000A&AS..146..103M
Martinez-Arnáiz et al. 2011MNRAS.414.2629M
Quirrenbach, A., et al. 2020SPIE11447E..3CQ
Reiners, A. & Basri, G. 2008ApJ...684.1390R
Tal-Or, L. et al. 2018A&A...614A.122T
Walkowicz, L. M., et al. 2004PASP..116.1105W

Acknowledgements:

Based on data obtained from the CARMENES project, the German-Spanish priority program at Calar Alto Observatory. This research is supported by the Universidad Complutense de Madrid (UCM), the Spanish Ministerio de Ciencia e Innovación through project PID2019-109522GBC51,54/ AEI/10.13039/50110001103.

MAX-PLANCK-GESELLSCHAFT CSIC ICE Institut für Astrophysik Göttingen TLS hs Unión Europea Fondo Europeo de Desarrollo Regional "Una manera de hacer Europa" Calar Alto Bundesministerium für Bildung und Forschung KTS DFG DLR