Identifying activity-sensitive spectral lines in the CARMENES VIS and NIR spectral range of M dwarfs

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Abstract. We use visible and near-infrared CARMENES spectra of M dwarfs to search for **chromospheric activity-sensitive spectral lines** in addition to the well known **Na I D_1, D_2 He I D_3**, **Hα**, and **Ca II IRT** lines, **He I 10830 Å**, **Paγ** and **Paβ** lines. To identify lines with a significant chromospheric contribution we have used the spectral **subtraction technique**. We confirm the new activity-sensitive lines analysing the correlation with the other well known activity indicators in the same spectra and their temporal evolution in two particular active stars with strong flares EV Lac and YZ CMi. In addition, we analyse line by line the template spectrum (co-added of all the individual spectra available) of these two stars using also the spectral subtraction to search for **magnetically-sensitive lines**, that is lines with detectable Zeeman broadening. These two selection of lines will be used to check the influence in spectral region used to derive radial velocities (RV) and help to solve the problem of stellar activity in RV measurements to search for exoplanets around these stars.

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Context:

- **CARMENES** high-resolution, optical and near-infrared échelle spectrographs @ 3.5 m telescope at the Calar Alto Observatory (Almería, Spain) (Quirrenbach et al. 2018) provide visible and near-infrared spectra of M dwarfs covering the spectral range from 520 to 1710 nm.

- Some spectral lines are well known chromospheric activity indicators: **Na I D_1, D_2 He I D_3**, **Hα**, and **Ca II IRT** lines, **He I 10830 Å**, **Paγ** and **Paβ** lines.

- During **strong flares** additional spectral line goes in emission of filled-in by chromospheric emission.

- The M-dwards of the CARMES GTO (Guaranteed Time Observations) sample include some very active stars that can have strong magnetic field, and some lines with large Landé g-factor can show strong **Zeeman broadening** specially at large wavelength (NIR part of the CARMENES spectra).

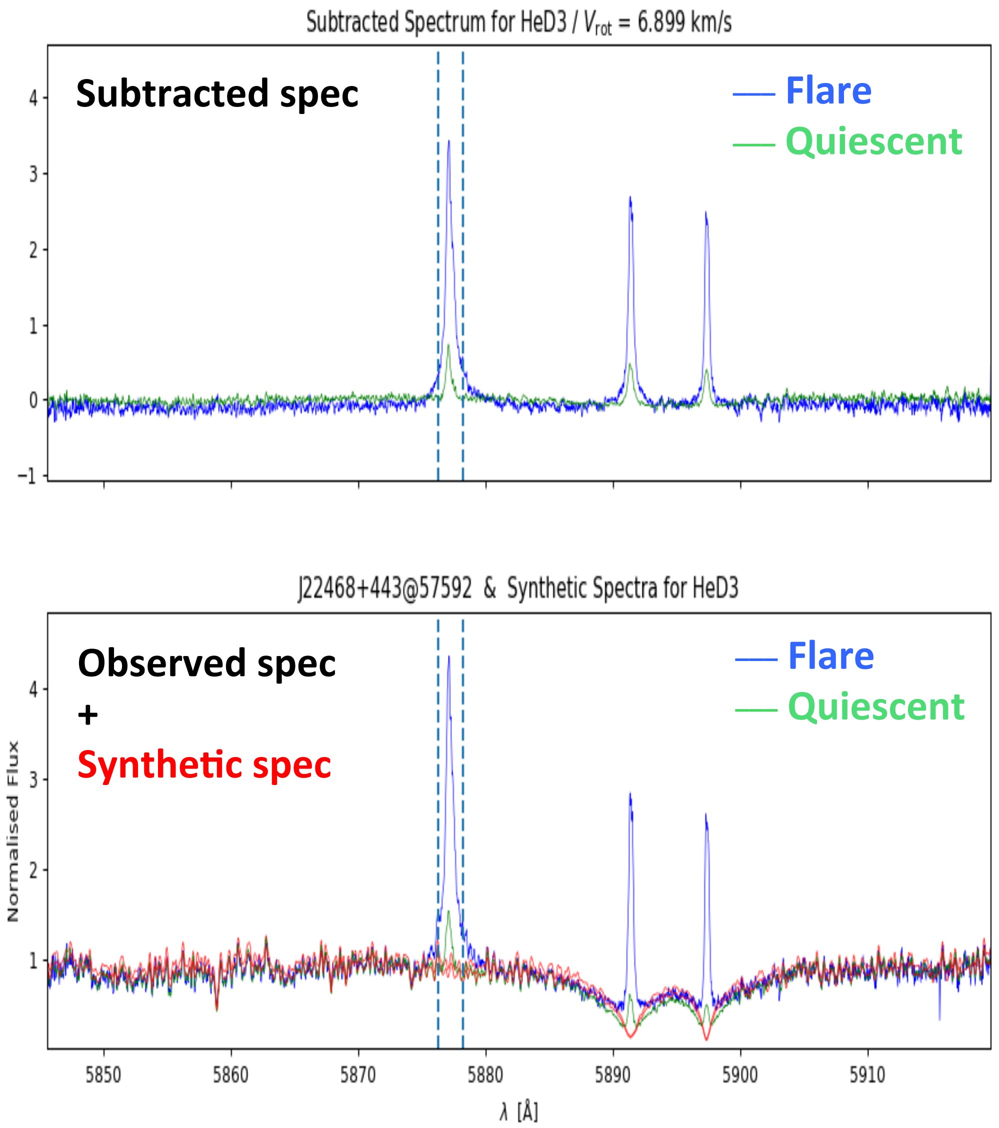
- The spectral **subtraction technique** allowed us to analyse these spectra line by line and identify new chromospheric activity-sensitive lines and the lines with strong Zeeman broadening as well as to study their temporal evolution.

- These selection of lines are very important for **magnetic activity** studies and also to be discarded in the the selection of lines used for **stellar parameters** determinations and **precise radial velocities** determinations to search for exoplanets around these stars.

Methodology

- To identify activity-sensitive spectral lines we have used the **spectral subtraction technique**, that is by subtraction of a synthesized stellar spectrum constructed using artificially rotationally broadened and radial-velocity shifted spectrum of an inactive star chosen to match the spectral type and luminosity class of the active star under consideration.

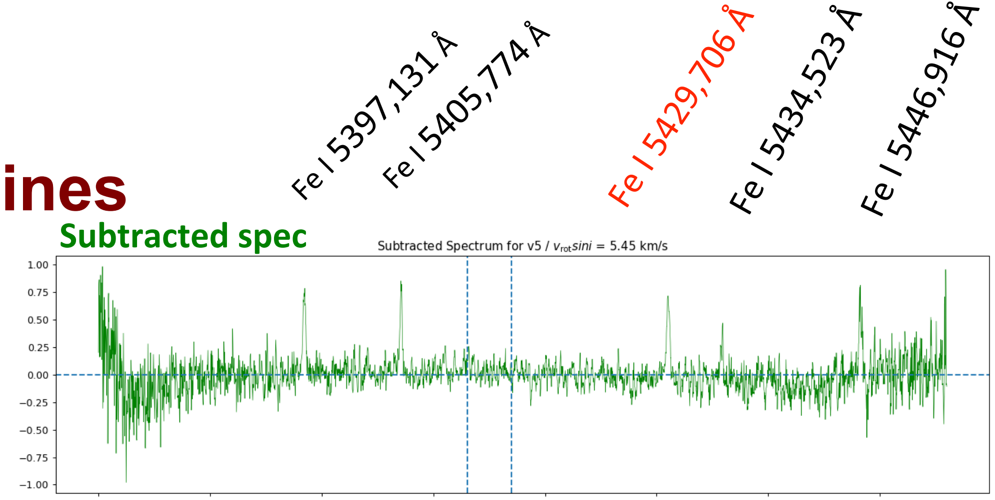
- The **spectral subtraction** have been performed by means of the *Python* code ***iSTARMOD***. This code is based on a former code *STARMOD* (Barden 1985; Montes et al. 2000). The code has been adapted to the particular features and formats of the CARMENES spectra and include improvements as the determination of the equivalent widths (*EW*) and automation, in order to perform time series analysis of the set of spectra (see Labarga & Montes SEA 2020 contribution).



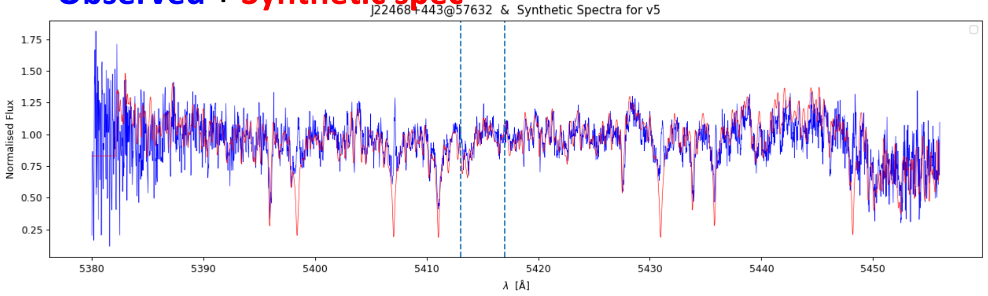
Results

→ New chromospheric activity-sensitive spectral lines (at a flare maximum)

The spectral subtraction was applied to all the CARMENES spectral orders (VIS + NIR) of the very active stars **EV Lac** and **YZ CMi** and compared the subtracted spectra at **Quiescent** state and at **Flare maximum** to identify new chromospheric activity-sensitive lines.

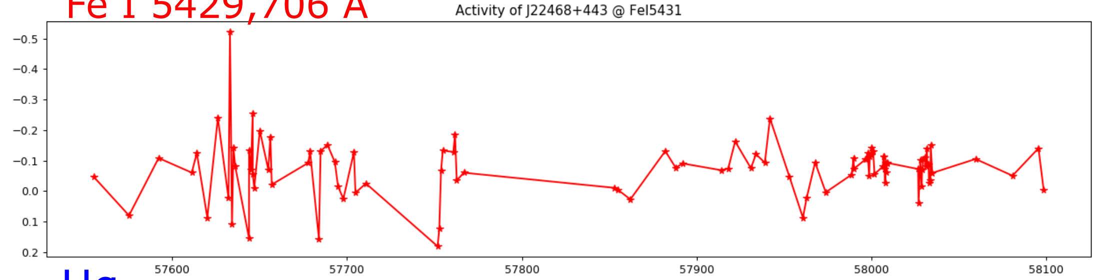


Observed + **Synthetic spec**

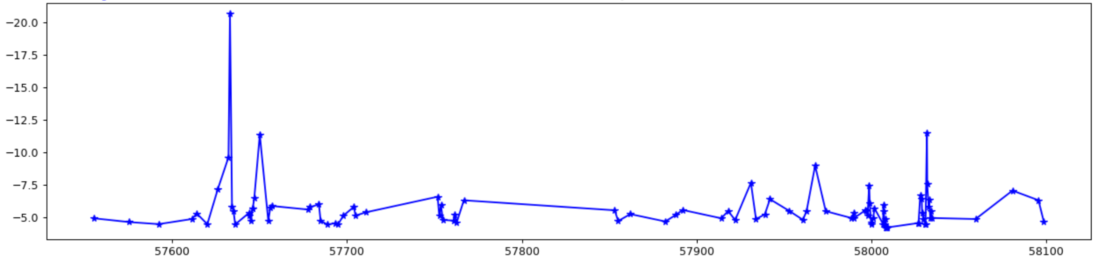


J22468+443 **EV Lac** M3.5 V Flare maximum

Fe I 5429,706 Å



Hα



Flare maximum

An example of ***EW* time variation** for **EV Lac** for one of the new activity-sensitive lines (Fe I 5429,706 Å) and for the Hα line to confirm that follows the same behaviour. It is clearly seen a strong **flare** where the *EW* measures reaches the maximum of the whole time series in both Hα and the new activity-sensitive line.

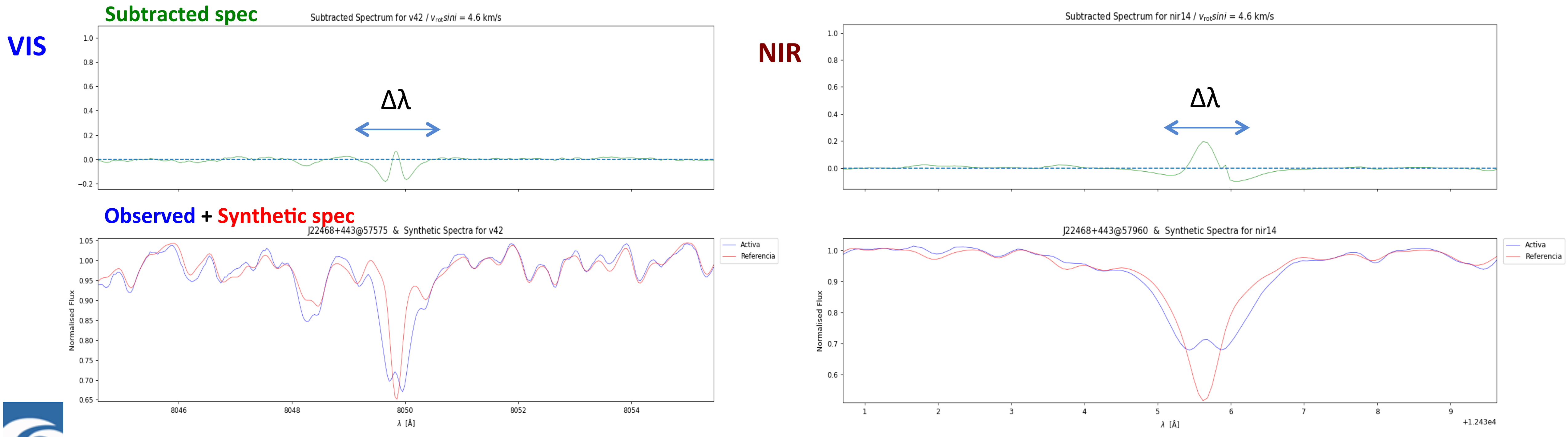
Results

$$\Delta\lambda = 4.67\text{x}10^{-13}\,\lambda^2 gB$$

λ(Å)
g: effective Landé - factor
B(G)

→ Identification of magnetically-sensitive lines (Zeeman broadening)

The spectral subtraction was applied to all the CARMENES spectral orders (VIS + NIR) of the the template spectrum (co-added of all the individual spectra available) of **EV Lac** and **YZ CMi** to search for magnetically sensitive lines, that is lines with detectable Zeeman broadening.



Impact and prospects for the future

- We provide the list of lines that are affect by **chromospheric activity** (emission or filled-in) and by **magnetic field** (Zeeman broadening) in the full spectral range of the CARMENES spectra (VIS + NIR).
- These lines are useful to take into account for **magnetic activity** analysis and to be discarded in **stellar parameters** determinations (see Tabernero et al. and Marfil et al. SEA 2020 contributions).
- We are comparing this selection of lines with the selection found by other recent works (Wise et al. 2018; Dumusque et al. 2018; Lisogorskyi et al. 2019; Ning et al. 2019) in the spectral ranges in common. The final selection of lines will be used to check the influence in spectral region used to derive *RV* and help to solve **the problem of stellar activity in *RV* measurements** to search for exoplanets around the CARMENS sample of stars.

Chromospheric activity-sensitive lines (VIS) - truncated table

λ measured	λ theoretical	Element	Ref.	Star
5227.241	5227.189	Fe I	Wise/Johns-krull	EV Lac
5269.541	5269.537	Fe I	Wise/Johns-krull	EV Lac / YZ CMi
5270.294	5270.170	Ca I	Johns-Krull	EV Lac / YZ CMi
5276.029	5276.030	Cr I	ILLSS moore	EV Lac / YZ CMi
5283.509	5283.628	Fe I	ILLSS moore	YZ CMi
5316.630	5316.609	Fe II	Mochnacki	EV Lac / YZ CMi
5328.057	5328.038	Fe I	Johns-krull/Mochnacki	EV Lac / YZ CMi
5328.557	5328.531	Fe I	Johns-krull/Mochnacki	EV Lac
5340.974	5341.023/5341.050	Fe I/ Mn I	Johns-krull	EV Lac / YZ CMi
5362.818	5362.781	Co I	ILLSS moore	EV Lac / YZ CMi
5371.435	5371.492	Fe I	Wise / Johns-Krull	EV Lac / YZ CMi
5397.180	5397.131	Fe I	Johns-krull	EV Lac / YZ CMi
5405.798	5405.774	Fe I	Wise/Johns-krull	EV Lac / YZ CMi
5409.820	5409.790	Cr I	Lisogorskyi	EV Lac / YZ CMi
5415.118	5415.192	Fe I	Johns-Krull	EV Lac / YZ CMi
5424.055	5424.072	Fe I	ILLSS moore	YZ CMi

Magnetic field-sensitive lines (VIS) - truncated table

λ measured	λ theoretical	Element	Ref.	Ref2.	Landé g-factor	Star
7364.083	7364.101	Ti I	VALD3		0.67	EV Lac
7400.173	7400.179	Cr I	VALD3		1.96	EV Lac / YZ CMi
7462.306	7462.309	Cr I	VALD3		1.37	EV Lac / YZ CMi
7664.901	7664.293	Fe I	VALD3		0.99	EV Lac / YZ CMi
7698.962	7698.964	K I	VALD3		1.33	EV Lac / YZ CMi
7800.295	7800.22/.227	F I/ Rb I	ILLSS Moore			EV Lac / YZ CMi
7912.854	7912.866	Fe I	VALD3		0.92	EV Lac
7947.605	7947.56/.60	O I/ Rb I	ILLSS Moore			EV Lac / YZ CMi
7949.114	7949.152	Ti I	VALD3		0.98	EV Lac
8024.844	8024.843	Ti I	VALD3		1.06	EV Lac
8047.627	8047.617	Fe I	VALD3		1.50	EV Lac / YZ CMi
8068.232	8068.239	Ti I	VALD3		0.75	EV Lac
8075.160	8075.149	Fe I	VALD3	Marfil et al.	0.76	EV Lac
8116.799	8116.789	V I	VALD3		1.42	EV Lac / YZ CMi
8144.571	8144.560	V I	VALD3		1.51	EV Lac / YZ CMi
8161.027	8161.062	V I	VALD3		1.35	EV Lac / YZ CMi
8183.261	8183.256	Na I	ILLSS Moore			EV Lac

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