

Activity on individual lines from CARMENES M dwarfs

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Context

Stellar activity poses one of the main challenges to detect and characterise exoplanets

- ▶ Stellar activity features on the stellar photosphere such as **granulation**, **spots** or **faculae**, display strong magnetic fields that inhibit convective motions and change the temperature on these regions.
- ▶ These features **deform** the **absorption line profiles** of spectroscopic observations, which we use to measure **Doppler shifts** caused by orbiting companions.
- ▶ Radial velocities (RVs) end up containing activity signals, which can hide or mimic the presence of true exoplanets because they can have **amplitudes well above a few m/s**, and be **modulated with the stellar rotation period**.

New methods to compute RVs by selecting lines

- ▶ Stellar spectral lines are created by different elements and molecules, which react differently to changes in the magnetic field, temperature and velocity caused by activity, so **not all the lines are affected by activity in the same way**. Several efforts are being made to identify activity-sensitive and insensitive lines [0-6].
- ▶ Traditional methods to compute RVs and assess activity effects rely on measurements of the whole observed spectrum, which wash out the different effects of activity on different lines. Recently, it has been shown that an accurate selection of the lines used mitigates the effect of activity in the RVs of the K1 dwarf α Cen B observed with HARPS [7, 8].

This work

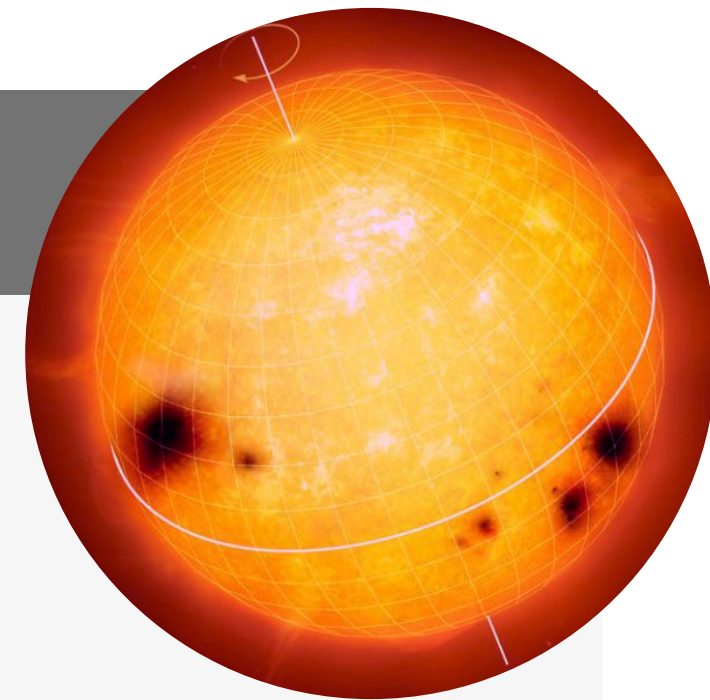
- ▶ Inspired by [7], which presents a method to select lines based on their sensitivity to activity and recompute RVs mitigating or boosting activity, we study the feasibility of a similar approach but with CARMENES observations of M dwarfs.

Data

CARMENES observations

Calar Alto high-Resolution search for M dwarfs with Exo-earths with Near-infrared and optical Echelle Spectrographs

- ▶ Pair of fibre-fed, high resolution ($R > 80000$) VIS (520-960 nm) and NIR (960-1710 nm) echelle spectrographs at the 3.5 m telescope at Calar Alto [9].
- ▶ Survey of > 300 M dwarfs with the goal of detecting exoplanets [10].
- ▶ 6 early- and mid-M dwarfs selected (VIS spectra)
 - Range of active stars ($pEW_{H\alpha} \sim -2$ to -7)
 - Relatively low rotational velocity ($v \sin i < 7$ km/s)
 - Activity dominated RVs (scatters > 20 m/s)



Method

Procedure applied to each star separately

- ▶ Find, characterise and select absorption lines in a high S/N spectral template, as in [11].
- ▶ Compute the time series RV for each line individually. Estimate the position of the line by fitting a Gaussian and compare it with the line position in the template.
- ▶ Compute the correlation between the time series of the line RV and an activity indicator. We use the Pearson's correlation coefficient R to assess its strength.
- ▶ Select lines that show a weak correlation ($R \sim 0$) with the activity indicators to recompute the time series RVs. We just compute the average of the lines RVs.

Results

Find lines with different sensitivities to activity for 5 stars

- ▶ **Fig. 1**: Example of line that has a strong correlation with several indicators (6661.25 Å), and another one with no clear correlations (7855.92 Å).
- ▶ We tested several spectroscopic activity indicators and found that only with the **total RV**, the **CCF bisector inverse slope (BIS)** and the **chromatic index (CRX)** some lines displayed **linear-like correlations**. In general, the correlation strength of the same line with these 3 indicators was similar.

Mitigate the activity signal present in the RVs using lines with $|R| \sim 0$

We also discarded a large number of lines with $R \sim 0$ but large RV scatters (wstd RV), which mostly contribute to noise, probably because being weak.

- ▶ **Fig. 2** shows the results obtained for YZ CMi (J07446+035) and the correlations with the CCF BIS. **Colours** represent different sets of selected lines, and black is the original data.
 - **RV time series scatter decreases** as we restrict the lines used.
 - **Periodogram peak at the stellar rotation period decreases its power** as we restrict the lines used, until becoming non-significant for the **blue** data set.
 - ➔ Effectively reduce the activity signal present in the RVs.

- ▶ Of the different data sets tested, the "best" one is the one that includes lines with $|R| \leq 0.2$ and $wstd RV \leq 200$ m/s. The "best" set depends on the indicator and the star, but in general, it occurs for lines with $|R| \leq 0.1-0.3$ and $wstd RV \leq 150 - 300$ m/s.

Cannot generalise the "active"/"inactive" lines to other stars

- ▶ **Fig. 3** shows an example where we compare the R values of YZ CMi (J07446+035) and EV Lac (J22468+443). The correlation between them is relatively high, of $R \sim 0.6$, but using the sets of lines based on the R values of the other star results in a worse mitigation of activity than using the sets selected based on the R values of the star itself.
- ▶ For the other pairs of stars, the correspondence between the correlation strengths is even lower, with $R \sim 0.2$ and 0.3 .
- ▶ We are not able to obtain a general set of lines that mitigates the activity in several stars of similar characteristics.

Outlook

- ▶ Our method could be improved in several ways.
 - More precise RVs by improving the RV computation method (now individual line RVs typical error is of ~ 300 m/s) ➔ More reliable R values.
 - Identify the lines in atomic and molecular catalogues to further study their properties.
- ▶ Further studies about activity effects on spectral lines and how to mitigate it will clearly improve RV measurements, which is key as state-of-the-art instruments reach the smaller RV precision needed to detect Earth-like planets.

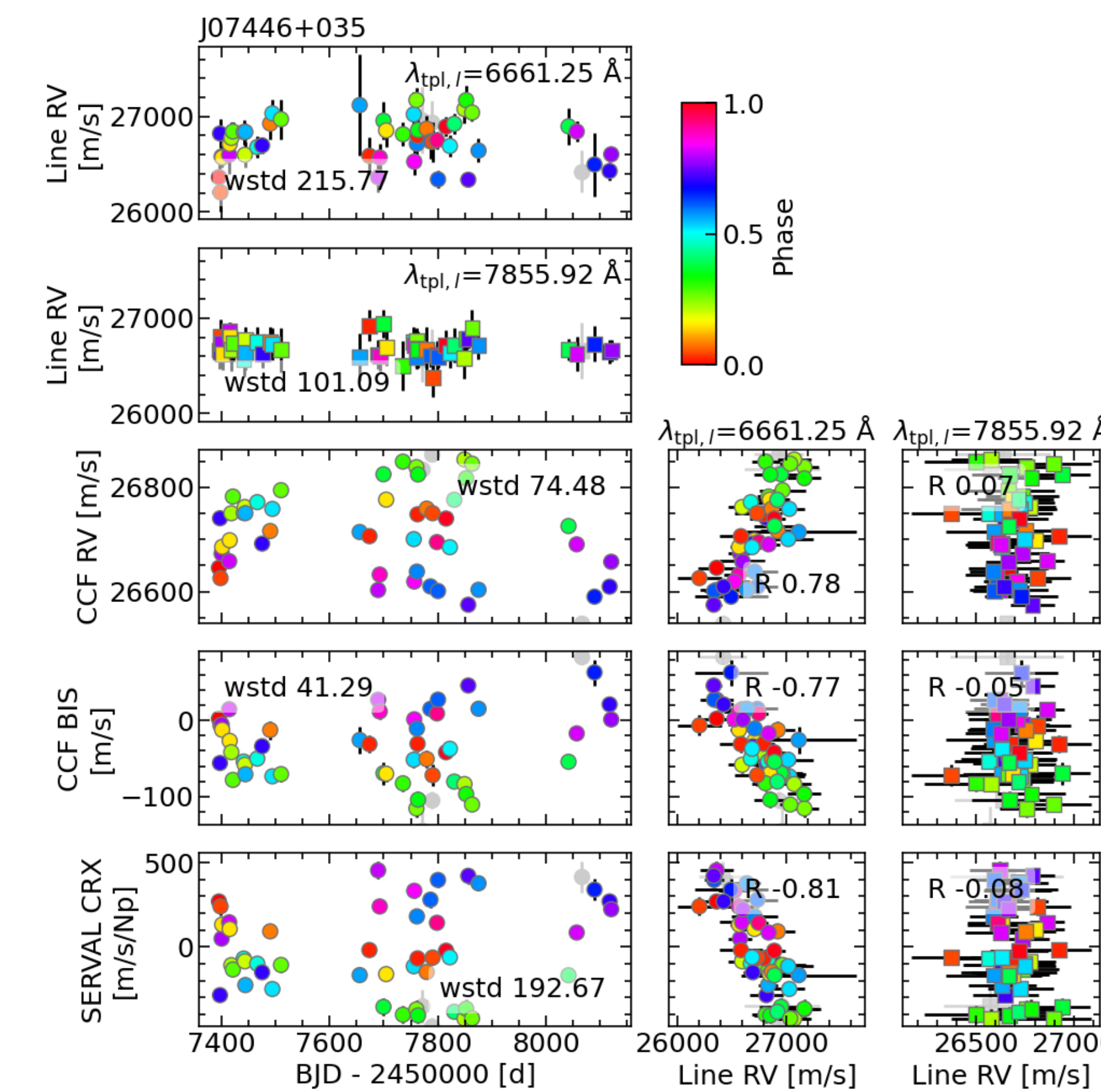


Fig. 1: Example of 2 lines with different sensitivities to activity. The 2 top panels show the RV time series of the line located at 6661.25 Å (dots) and the line at 7855.92 Å. The panels below show the time series of 3 activity indicators: the total RV, the CCF BIS, and the CRX. The central and right panels show the correlation of these indicators with the RVs of the 2 lines. The data points are colour-coded with the stellar rotation phase.

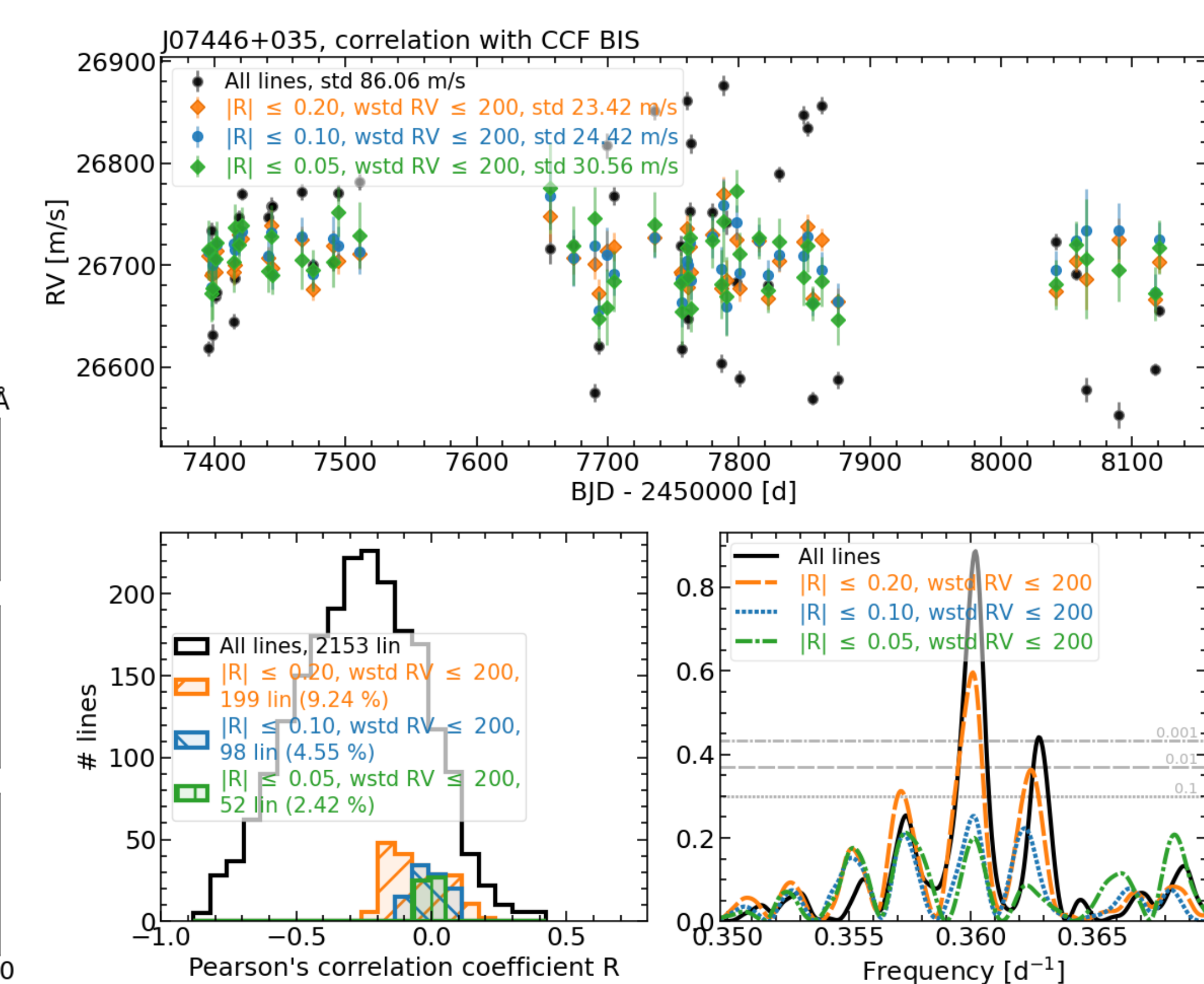


Fig. 2: Example of the decrease of the activity signal present in the RVs. The top panel shows the RV time series obtained using different sets of lines (colours), and the original one using all the lines (black). The bottom left panel shows the distribution of R obtained from the correlation between the line RVs and the CCF BIS. The coloured areas show the data sets used to compute the RVs above. The bottom right panel shows the periodogram of the RVs above (same colours) around the frequencies close to the stellar rotation period, 2.78 d.

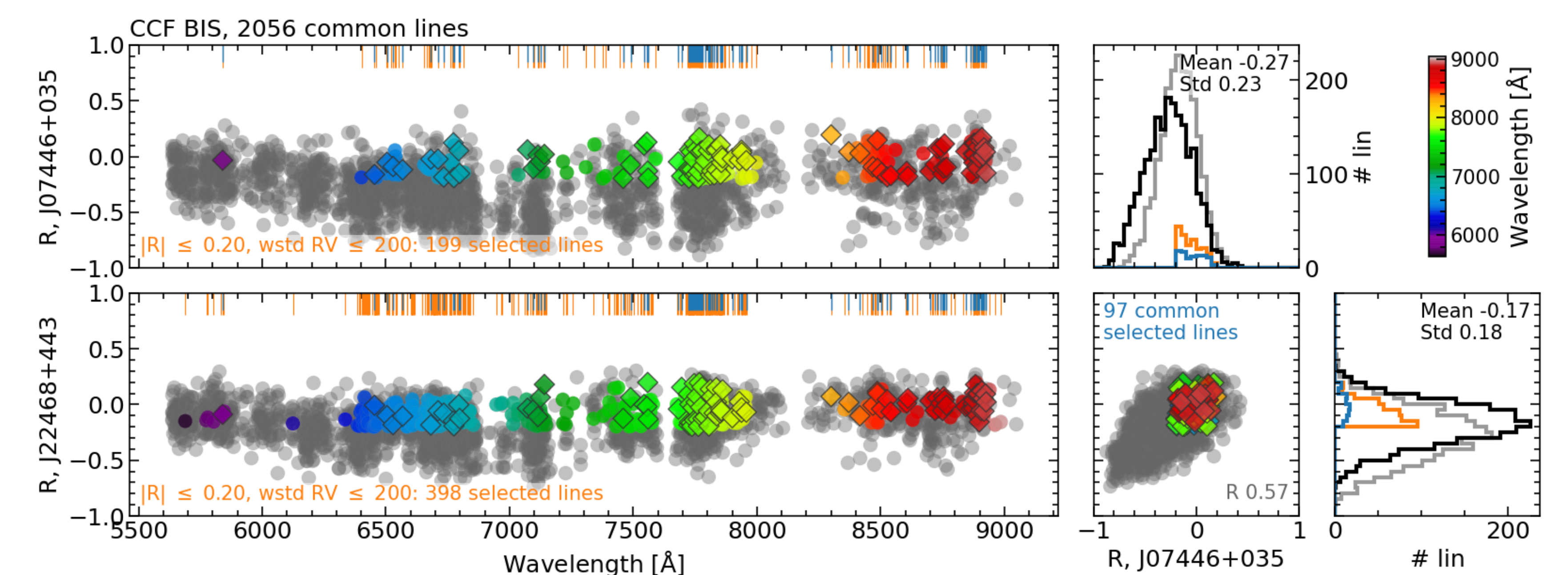


Fig. 3: Example of the difference in correlation strengths of 2 stars. The left panels show the R values as a function of wavelength for YZ CMi (J07446+035) and EV Lac (J22468+443), for the correlation with the CCF BIS. The coloured dots indicated the lines in the "best" data sets, and the diamonds, the lines in the "best" sets common in the 2 stars. The right panels show the correlation between the R values of the 2 stars and their distribution, where again the common selected lines are highlighted in coloured diamonds.

References

- [1] Davis, A. B., et al. 2017, ApJ 846, 59
- [2] Thompson, A. P. G., et al. 2017, MNRAS, 494, L16
- [3] Wise, A. W., et al. 2018, AJ, 156, 180
- [4] Lisogorskyi, M., et al. 2019, MNRAS, 485, 4804
- [5] Ning, B., et al. 2019, ApJ, 158, 5
- [6] Thompson, A. P. G., et al. 2020, MNRAS, 494
- [7] Dumusque, X. 2018, A&A, 620, A47
- [8] Cretignier, M. et al. 2020, A&A, 633, A76
- [9] Quirrenbach, A. et al. 2016, Ground-Based and Airborne Instrumentation for Astronomy VI, Int. Soc. Opt. Photon., 9908, 990812
- [10] Reiners, A., et al. 2018, A&A, 612, A49
- [11] Lafarga, M., et al. 2020, A&A, 636, A36