Mapping stellar activity indicators across the M dwarf domain

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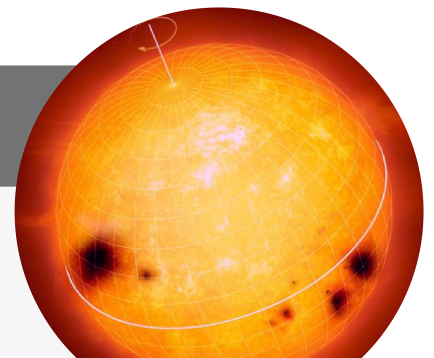
Context



Despite stellar magnetic activity being present in most cool stars, its effects on spectroscopic observations are still not well understood

▸ 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.

▸ Several proxies or indicators of stellar activity are routinely used to identify activity-related signals in RV measurements. However, not all indicators trace exactly the same effects, nor are any of them always effective in all stars.

This work

▸ In this work, we analyse the temporal behaviour of RVs and a set of spectroscopic activity indicators for 98 M dwarfs observed with the CARMENES spectrograph, with the aim of finding a relation between indicator performance and stellar properties (Lafarga et al. 2021, submitted).

Data

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

CARMENES observations

▸ CARMENES high-resolution (R=94600) VIS (520-960 nm) observations [1].

Stellar sample

▸ 98 stars selected from GTO sample of > 300 M dwarfs [2].

- Range of active and inactive stars (pEW'(Hα) ~ 0.1 to -10 Å)
- Most M dwarf subspectral types (M ~ 0.1 to 0.7 $M_{\odot}$)

Activity indicators

- RV [3]
- Cross-correlation function (CCF) full-width-at-half-maximum (FWHM), contrast, and bisector inverse slope (BIS) [4]
- Chromatic index (CRX) and differential line width (DLW) [3]
- pEW' of chromospheric lines Hα and Ca infrared triple IRT-a, b, c [3, 5]

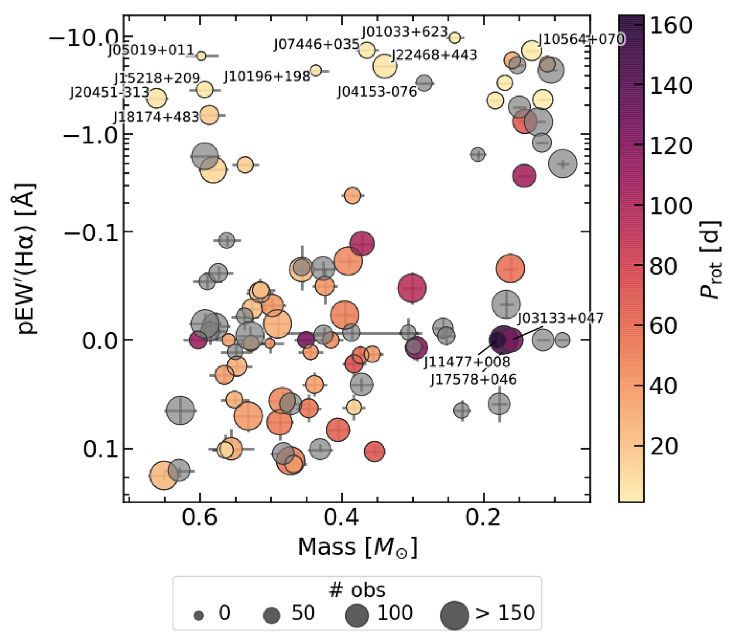


Fig. 1: Stellar sample

Average activity level (measured as the average pEW'(Hα), y-axis, from low- to high-activity level) as a function of the stellar mass (x-axis, from high- to low-mass) of the 98 sample stars.

Data points are colour-coded with the target *Prot* (grey points indicate unknown *Prot*), and their size indicates the number of CARMENES VIS observations available.

All values compiled from Carmencita, the CARMENES input catalogue [7, 8].

Method

▸ Periodogram analysis of RVs and activity indicators time series (generalised Lomb-Scargle, [6]).

▸ Looked for significant periodic signals related to the stellar rotation period of the stars (*Prot*, harmonics, and their 1 day aliases). If unknown *Prot*, identify the same periodic signal in more than one indicator, which we assume to be related to activity.

Results

Rotation signals in activity indicators (Fig. 2)

▸ Find at least one significant activity-related signal in 56 of the 98 stars investigated.

▸ Activity indicators behave differently depending on the mass and activity level of the target star. We observe the following (see **Fig. 2**):

- Most of these 56 stars show an activity signal in RV, which is the most effective tracer of activity.
- Aside from RV, CRX and BIS are the most effective for the active stars in our sample (stars with pEW'(Hα) ≤ −0.3 Å), but they are not as sensitive in the low-activity regime (pEW'(Hα) ≥ −0.3 Å). Low-activity stars tend to be slow rotators, which agrees with the fact that BIS is usually not found to trace activity in such stars.
- For the chromospheric lines, we observe the opposite behaviour. Low-activity stars show a larger fraction of targets with periodic signals in these indicators than the most active ones.
- dLW and FWHM are similarly effective for all stars, but especially in the high-activity, low-mass (M ≤ 0.35 $M_{\odot}$) regime, performing better than any other indicator.

RV scatter, activity, and mass (Fig. 3)

▸ As expected, RV scatter increases with the activity level, especially in the high-activity regime, where it can reach values as high as ~100 m/s (see **Fig. 3 left**). In the low-activity regime, the RV scatter is in general lower than ~10 m/s. Lower RV scatter corresponds to stars with no activity detections.

▸ Most of the targets for which we cannot identify any activity-related signal are stars at the low-mass end of the sample, where stars are fully convective, and also show the lowest RV scatter (see **Fig. 3 right**). This could potentially hint at different manifestations of activity compared to higher-mass stars. Moreover, ultracool M dwarfs could be better candidates for planet searches than earlier types, which display higher levels of RV variability.

Outlook

Overall, this study highlights the fact that, depending on the properties of the stars considered, different indicators of stellar activity will behave differently. In our M dwarf sample, which covers a relatively large range of masses and activity levels, each type of indicator performs best in specific ranges of mass and activity. None of the indicators are effective activity tracers for all stars. Therefore, an analysis of a large set of indicators is necessary to obtain a complete picture of stellar activity variability. This becomes critical when assessing the origin of RV signals, as not using the most effective indicators considering the characteristics of the star may lead to false planet claims.

References

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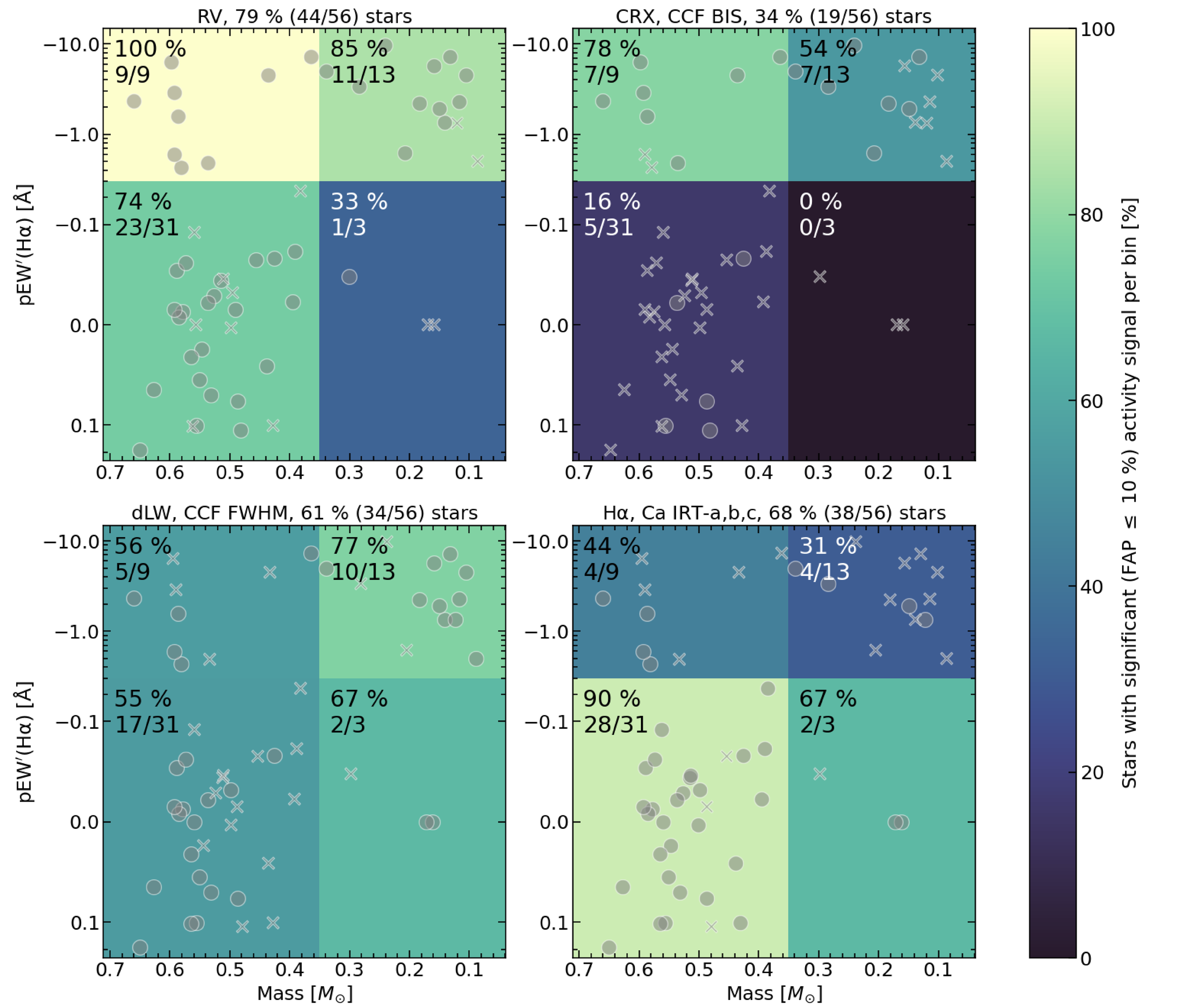

Fig. 2: Detected activity-related signals in RVs and indicators.

Number of stars with activity detections in RV (*top left*), CRX and BIS (*top right*), dLW and FWHM (*bottom left*), and chromospheric lines Hα and Ca IRT-a,b,c (*bottom right*). The stars are divided into four bins, depending on their average activity level and mass. Axes are the same as in Fig. 1. The colours of each bin indicate the number of stars (in percentage) for which we found an activity-related signal with FAP ≤ 10 %. The text in each bin also shows that percentage, together with the absolute number of stars with a detection. The title of each panel shows the same numbers, but for all the stars. Grey data points indicate the position of the 56 stars considered in the activity-mass space, with large circles representing the stars with a detection in the specific indicator, and crosses, stars with no detection.

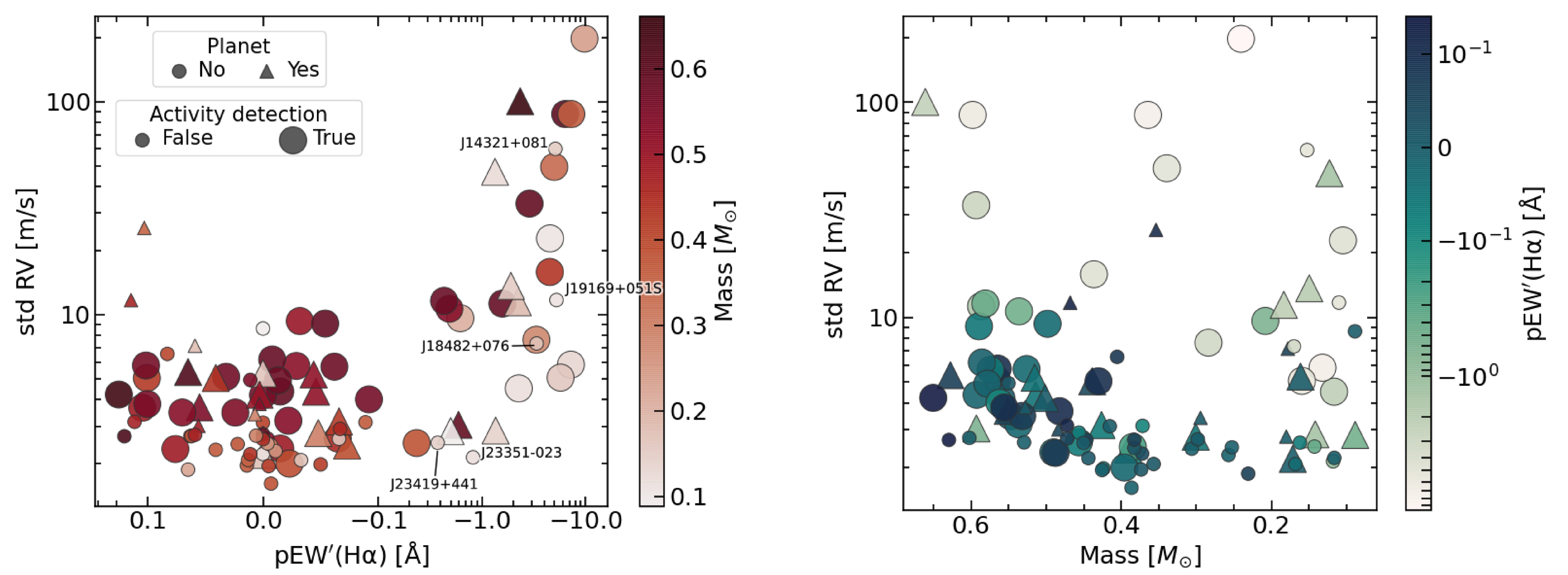

Fig. 3: RV scatter, activity level, and mass.

Left: RV scatter (std RV) as a function of the activity level (pEW'(Hα)) of the 98 sample stars, colour-coded with the stellar mass. Stars with no known planetary companions are indicated with circles, while triangles indicate those with confirmed planetary companions. Large data points correspond to the 56 stars with activity-related signals, and small data points correspond to those with no detection.

Right: RV scatter as a function of the stellar mass of the 98 sample stars, colour-coded with the average activity level (pEW'(Hα)). Same symbols and sizes as in the left panel.