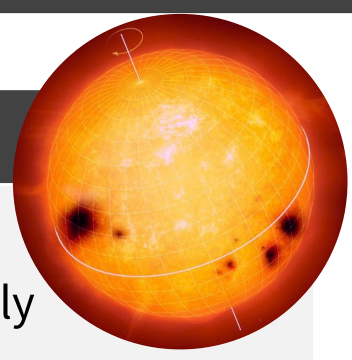
Line-by-line sensitivity to activity in M dwarfs

Marina Lafarga Magro (she/her)
marina.lafarga-magro@warwick.ac.uk

M. Lafarga, I. Ribas, M. Zechmeister, A. Reiners, Á. López-Gallifa, D. Montes, A. Quirrenbach, P. J. Amado, J. A. Caballero, M. Azzaro, V. J. S. Béjar, A. P. Hatzes, Th. Henning, S. V. Jeffers, A. Kaminski, M. Kürster, P. Schöfer, A. Schweitzer, H. M. Tabernero, M. R. Zapatero Osorio

A&A 674, A61
arXiv: 2302.04794

1. Context



- Radial velocities (RVs) measured from the shift of stellar absorption lines are routinely used to study exoplanets.
- **Stellar activity** features such as spots or faculae **distort the line profiles**, challenging exoplanet studies.
- Absorption **lines** are created by several species, which are **non-uniformly affected by stellar activity**.
- Several works are now focusing on activity effects on a **line-by-line** (LBL) basis [e.g. **1-8**], as opposed to classical methods to measure RVs, which *average* all lines.

2. Goal

Study how spectral lines in M dwarfs are independently impacted by stellar activity.

! Note: We use the word *lines* to refer to minima in the spectrum, even though these features are not true atomic lines but blends of several lines or a feature in a molecular band.

3. Data

CARMENES optical spectra of several very active M dwarfs

- 520–960 nm, R = 94600 [**9**]
- 6 early- and mid-type M dwarfs
- pEWHα ~ −2 to −7
- Rotational velocity < 7 km/s
- Activity-dominated RVs (scatter > 20 m/s)

4. Methods

- Select lines in a high S/N template [as in **10**].
- Compute **RV** time series **for each line**.
- Compute **correlation between line RV & activity indicators**. Use Pearson's correlation coefficient R to assess the correlation strength.
- Select lines with a weak correlation (R~0, i.e. *activity-insensitive* lines) and use those lines to recompute global RVs [following **3**].

5. Results

Figure examples for YZ CMi (J07446+035) and EV Lac (J22468+443)

Line RV correlations

- The correlations between line RV & activity indicator allow us to **classify lines with different sensitivities to activity** in 5 stars. See an example of an *active* (strong correlation) and an *inactive* (no correlation) line in **Fig. 1**.
  - Activity proxies used: cross-correlation function (CCF) RV, CCF bisector inverse slope (BIS) [from **10**] and chromatic index (CRX) [from **11**], which show linear-like correlations.

Line selection to mitigate activity effects

- By using activity-insensitive lines in the global RV calculation we are able to
  - **decrease the global RV scatter** from 2 to 5 times (depending on the star), and
  - **decrease the significance of the periodogram peak at the stellar rotation period** P_{rot}.

  See an example in **Fig. 2**.

Line comparison in similar stars

- The same **lines in similar stars** do **not** show the exact **same sensitivity** to activity. See an example in **Fig. 3**.

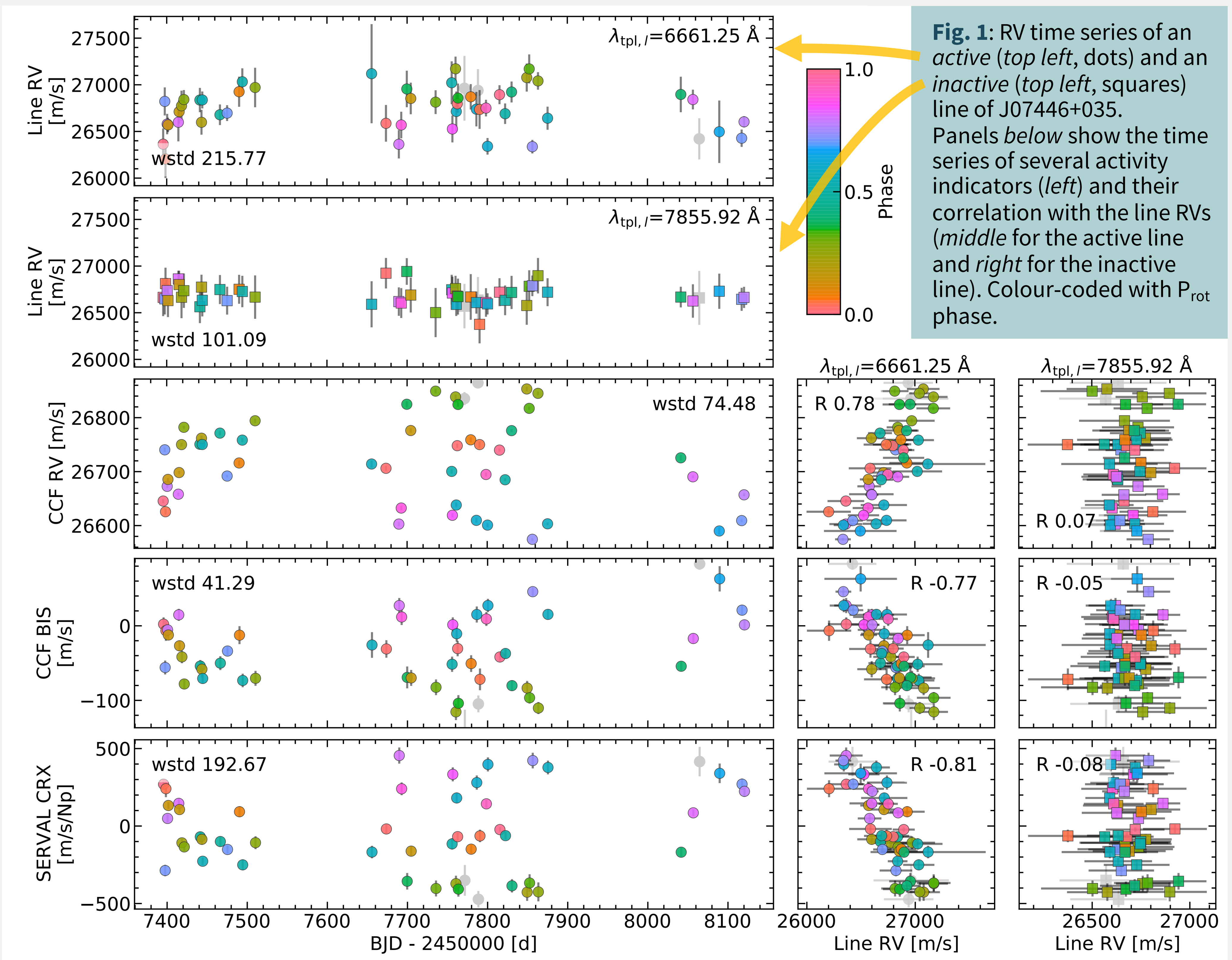


Fig. 1: RV time series of an *active* (*top left*, dots) and an *inactive* (*top left*, squares) line of J07446+035. Panels *below* show the time series of several activity indicators (*left*) and their correlation with the line RVs (*middle* for the active line and *right* for the inactive line). Colour-coded with P_{rot} phase.

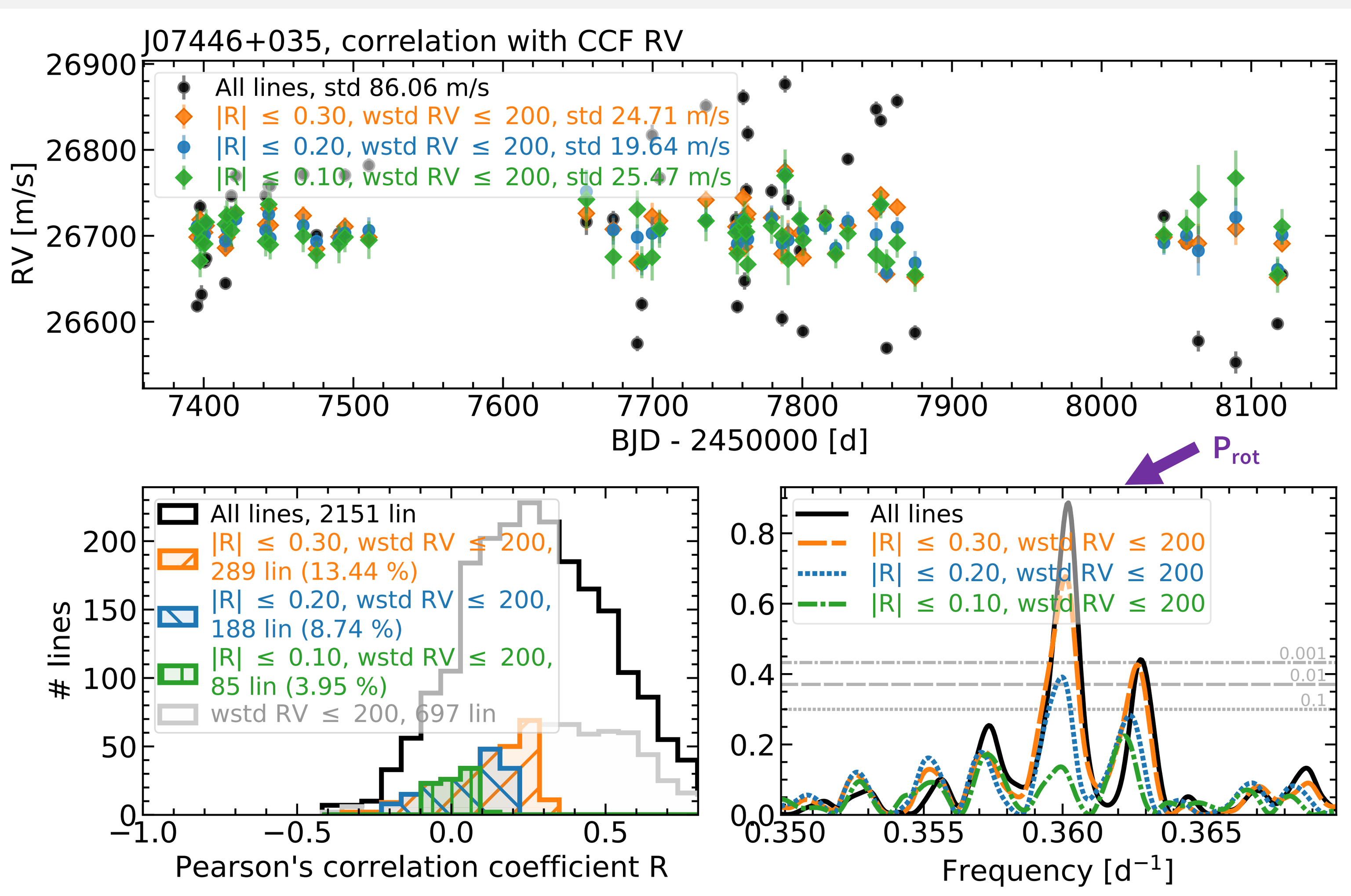


Fig. 2: Decrease of the activity signal in the global RVs by using inactive lines.
Top: RV time series for 3 subsets of inactive lines (colours) and all lines (black), scatter in legend. Note the decrease in RV scatter when using inactive lines.
Bottom left: Distribution of Pearson's correlation coefficient R values for all lines (black) and selected subsets (colours).
Bottom right: Periodogram of the inactive lines RV (colour) and all lines (black) close to the stellar rotation period P_{rot}. Note the decrease in significance of the P_{rot} peak for the inactive lines RV sets.

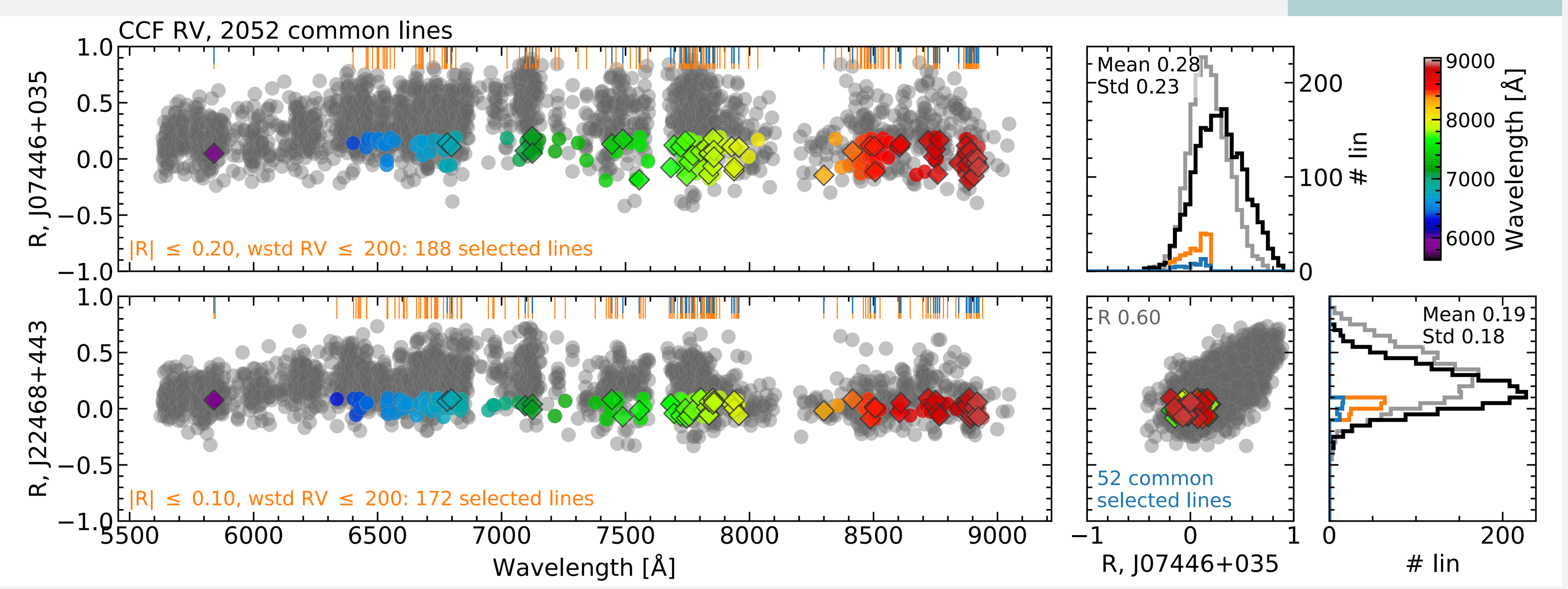


Fig. 3: Comparison of the R values of two similar stars (all lines, grey). Coloured dots show inactive lines, and coloured diamonds show inactive lines common for both stars.

6. Conclusions

- LBL RVs from (active) M dwarf spectra are sensitive to activity to varying degrees.
- By selecting activity-insensitive lines we can mitigate activity effects in RVs.
- Activity effects vary in the same insensitive lines from star to star, making a generalisation of insensitive lines challenging.
- This work can be expanded in many ways!
  - Improve line (and global) RV computation
  - Expand correlation quantification (beyond linear correlations)
  - Apply line selection to CCF/template matching
  - Study line physical parameters

References

[1] Davis et al. 2017
[2] Thompson et al. 2017
[3] Dumusque 2018
[4] Wise et al. 2018
[5] Cretignier et al. 2020
[6] Siegel et al. 2022
[7] Bellotti et al. 2022
[8] Artigau et al. 2022
[9] Quirrenbach et al. 2016
[10] Lafarga et al. 2020
[11] Zechmeister et al. 2019

WARWICK THE UNIVERSITY OF WARWICK
Institute of Space Sciences CSIC IEEC
carmenes