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PlanetS

Dependence of Solar Activity Signals on the Formation Temperature of Spectral Lines

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Hi, I'm Khaled!
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In a hurry... ? Scan the QR code 👉 to read the full paper which has been accepted for publication in *A&A*.

Introduction

It is evident from the existing literature that the interplay between magnetic fields and multi-scale convection currently prevents radial velocity (RV) precision from reaching the sub-m/s level required to detect Earth-twins around Sun-like stars. In the convective envelope of late-type stars, magnetically active surface regions can inhibit the underlying convective motion, which introduces RV modulations with a period of the stellar rotation.

Previous studies [1,2] have shown that individual spectral lines are affected differently by stellar variability. Here, we present a novel approach to measure how RVs depend on line formation temperatures, which could shed light on the line shifts and asymmetries induced by active regions.

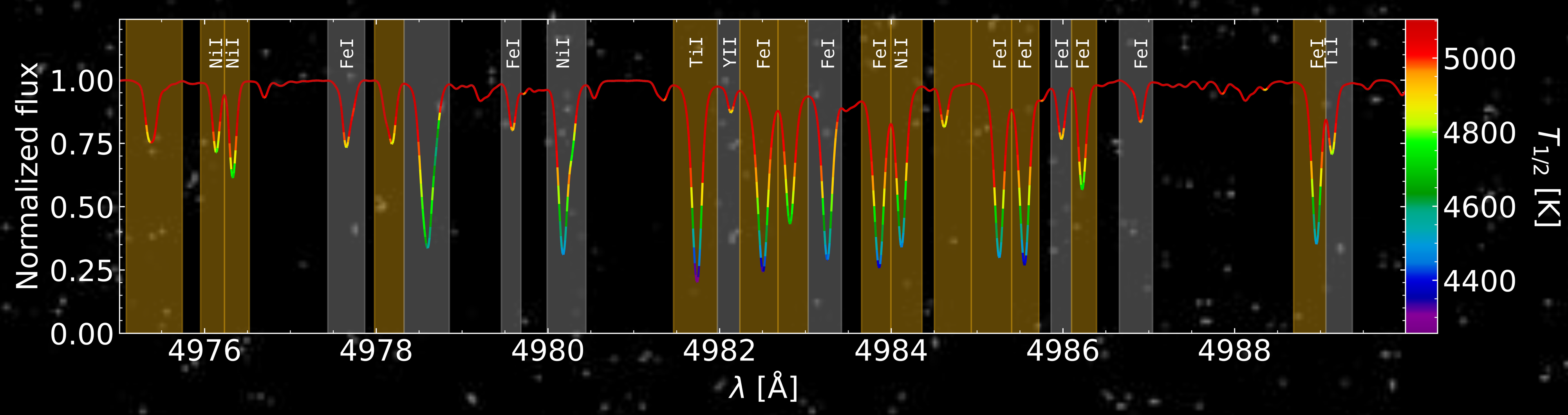

Fig. 1. Spectral window of 15 Å piecewise color-coded according to the average formation temperature, $T_{1/2}$. The shaded areas indicate whether a spectral line is selected (yellow) or rejected (grey). The labels above some spectral lines specify the element and ionization of identified lines.

Method

We use spectral synthesis with `PySME` [3] to derive the average formation temperature, denoted $T_{1/2}$, defined as the temperature below which 50% of the emergent flux originates (see Fig. 1). The reason for using formation temperature rather than flux as a proxy for photospheric depth is that lines of equal line strength yet unequal atomic properties (element, ionization, excitation energy, etc.) do not necessarily have a similar flux contribution function, which depends on the line opacities.

$T_{1/2}$ is derived for each wavelength point of a master spectrum composed of 607 daily-binned solar observations taken with the HARPS-N spectrograph between 2015–2018. Only unblended and accurately synthesized spectral lines are kept in the final selection.

We then compute the RV time series for various line segments based on their formation temperature, by template matching the corresponding segments of individual spectra with the master.

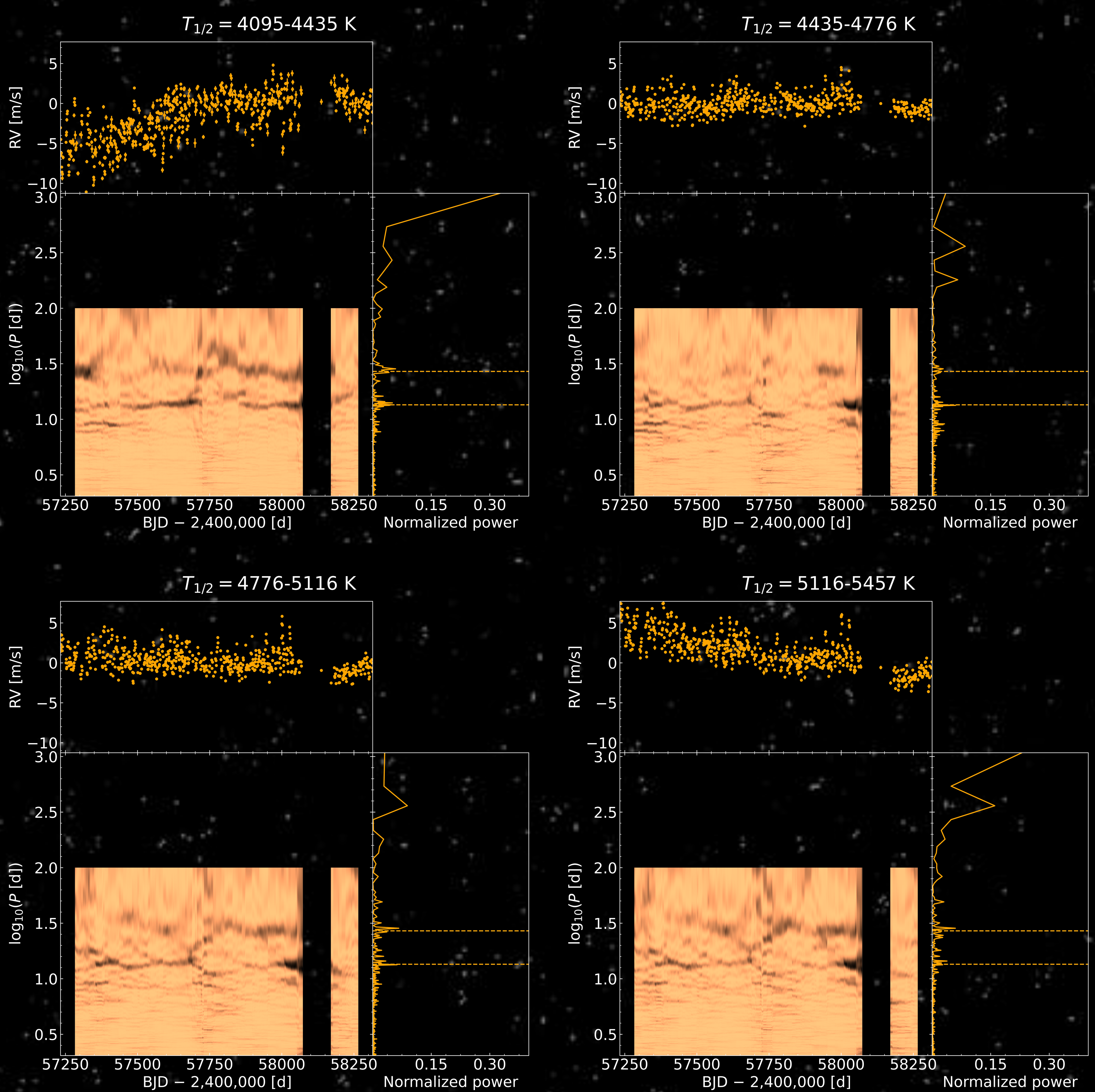

Fig. 2. Sliding periodogram of the temperature-binned RV time series of the Sun. The upper and rightmost panels show the total RV time series and their GLS periodograms, with the solar rotation period and its 1st harmonic indicated by the dashed lines. The columns of the central color maps show the GLS periodogram of every 100-day window, where darker color indicates stronger power. The window is shifted in steps of 1 day.

Results

Our method is applied on both the entire time interval (presented here) and a short-term interval (see full paper [4]) when the Sun showed a heightened level of activity, as seen in e.g. the Ca H&K index. By changing the number of temperature bins, we observe that the measured RVs have varied sensitivity to activity.

When dividing the entire temperature range into 4 equal bins (see Fig. 2), we find the most extreme temperature bins (the coolest and hottest) to be dominated by the long-term magnetic cycle, and they are apparently oppositely affected. The intermediate bins are less affected by low-frequency signals, but still show relatively strong amplitudes at the solar rotation period and its 1st harmonic.

From solar simulations on short timescales, we find that convection and its inhibition inside active regions due to strong magnetic fields is responsible for most of the observed effect. This dominant contribution is primarily measured in line segments formed at higher temperature ranges, that is, deeper parts of the photosphere where convective velocities are expected to be higher and their suppression more noticeable. However, for the lower temperature ranges (high in the photosphere), we detect an effect that does not seem to be explained by convection and is likely due to a change of the physical conditions.

References

[1] Dumusque 2018, A&A, 620, A47
[2] Cretignier et al. 2020, A&A, 633, A76
[3] https://github.com/AWehrhahn/SME
[4] Al Moulla et al. 2022, arXiv:2205.07047

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