Hi! My name is Carmen, and I am a 2nd year PhD student at IA involved with the PoET telescope, working on stellar activity and its impact on the detection of Earth twins using the RV method.

If you have any questions I will be around during the conference, or you can contact me at Carmen.SanNicolas@astro.up.pt

Scan this QR code to access my web page, where I talk about the work I do, LBL RVs and more!

SCAN ME

THE PATH TO 10 CM/S RV PRECISION: A NEW LINE-BY-LINE CODE

Carmen San Nicolas Martinez

Nuno C. Santos, Vardan Zh. Adibekyan, André Miguel A. C. V. Silva, Sergio Sousa, Khaled Al Moulla

Faculdade de Ciências da Universidade do Porto (FCUP); Instituto de Astrofísica e Ciências do Espaço (IA-CAUP)

Background

Reaching 10 cm/s radial velocity (RV) precision, needed to detect Earth-like planets around Sun-like stars, remains a major challenge due to stellar "noise" (variability from magnetic activity, granulation, and oscillations) that mimic planetary signals [1].

Despite advanced instrumentation like ESPRESSO [2] and sophisticated RV extraction techniques, current methods still fall short of fully correcting for these effects [3]. Understanding how different spectral lines respond to stellar variability is essential for improving RV precision. This project will tackle this by using high-resolution solar observations from PoET [4] to probe the origin and behavior of stellar noise at unprecedented detail.

Line-by-line code

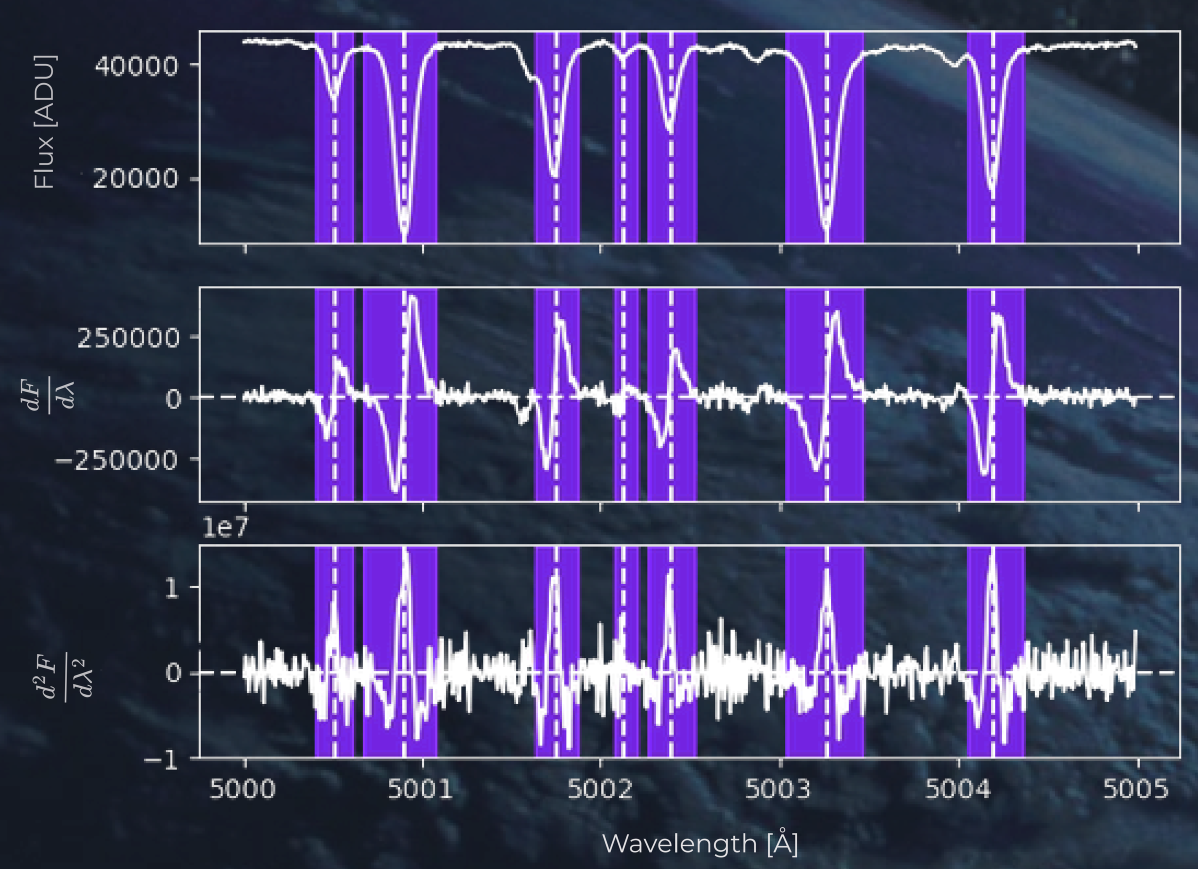
In order for us to measure precise velocities and their variability in PoET solar observations, we are developing a new line-by-line (LBL) code, which differentiates from previous ones by using a template-free approach. The code wraps around ARES [5] to, through a Gaussian fit, calculate the center of the spectral lines, base on a fixed list of ~4400 well-characterized solar spectral lines that we previously computed. It later obtains the RVs using the classical Doppler formula.

We computed the per-line RV errors based on the flux errors [6]:

$$\sigma_{\nu_i} = \left|\frac{dF}{d\lambda}\right|^{-1} \cdot \frac{c}{\lambda_i} \cdot \sigma_{Fi} \qquad ; \qquad \sigma_{RV} = \left(\sum \frac{1}{\sigma_{\nu_i}^2}\right)^{-1/2}$$

where $dF/d\lambda$ is the derivative of the flux respect to the wavelength, σ_{Fi} is the error of the flux at a given point, and σ_{ν_i} is the error of the velocity in every point of the line i.

With the first and second derivative of the flux we calculated the windows around the center of the lines to compute the errors:



1st panel: Spectrum of one observation with the center of the spectral lines marked in dashed lines, and the window limiting the region of the spectral line in purple.
2nd panel: First derivative of the flux respect to the wavelength to determine the extremes of the window of the spectral lines based on $dF/d\lambda = 0$.
3rd panel: Second derivative of the flux respect to the wavelength, to confirm the extremes of the line based on $d^2F/d\lambda^2 < 0$.

Then, an iterative 2-sigma clipping is performed on both the errors and the standard deviation of the RVs to exclude outliers. Lastly, by weighting each line based on its sensitivity to stellar activity, the code combines them into a single optimized RV per observation.

This method enables the creation of ultra-precise RV time series, essential for detecting Earth-like exoplanets.

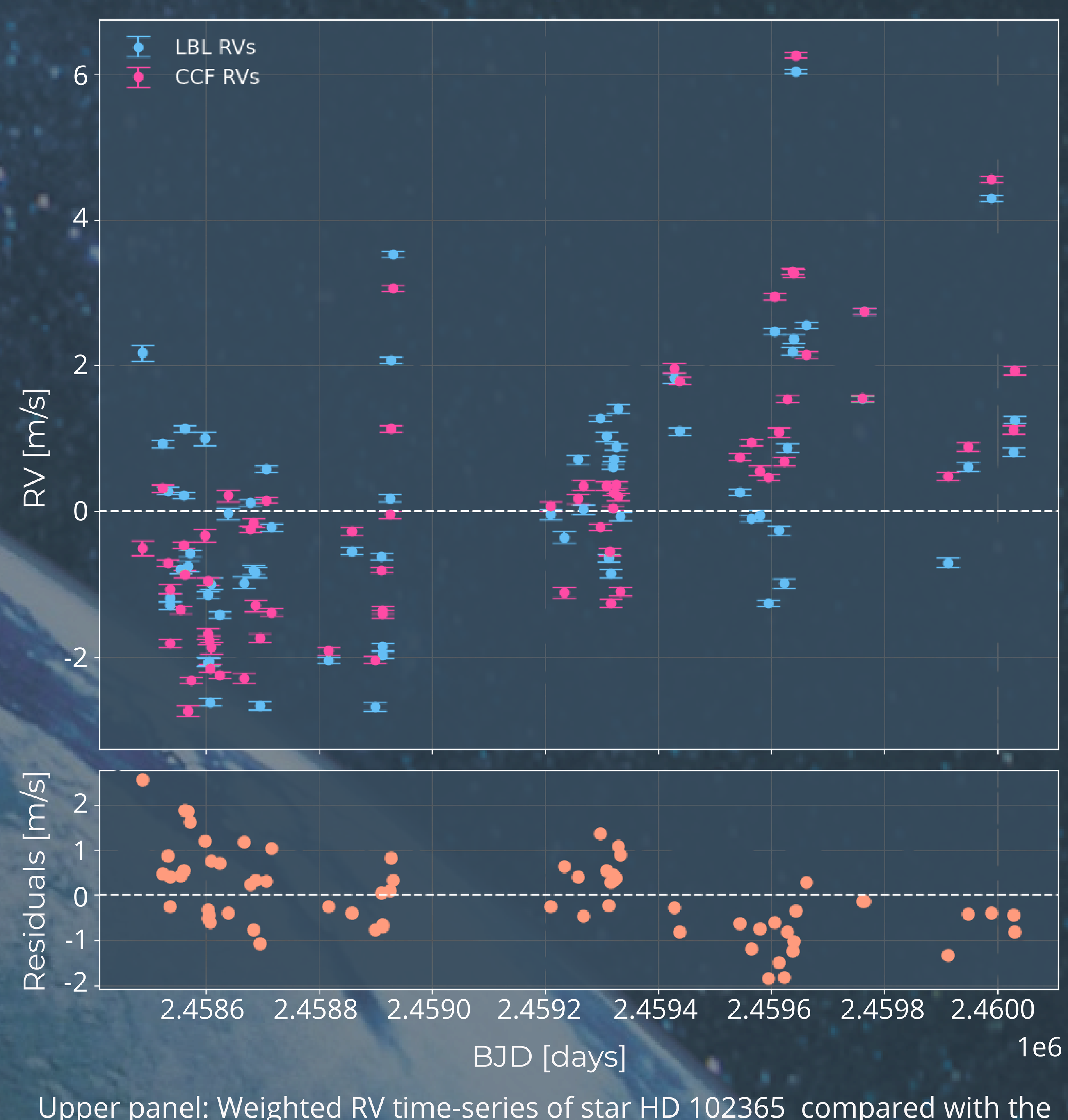
Results: Application to HD102365

The code has been tested so far with the nearby Sun-like star HD 102365 (G2V) [7], which is know for hosting a Neptune-like planet [8]. We used 527 ESPRESSO observations, spanning from January 2019 to March 2023, with a mean SNR of 267.

We computed the RV time-series and compared our results with the values derived using the official ESPRESSO pipeline (based on the CCF method).

Our LBL values (binned by night):
Standard deviation of RVs: 1.637 m/s
Average RV error bar: 5.453 cm/s

CCF values (binned by night):
Standard deviation of RVs: 1.734 m/s
Average RV error bar: 5.445 cm/s



Upper panel: Weighted RV time-series of star HD 102365 compared with the RVs from the CCF (all binned by nights).
Lower panel: Residuals of the RVs binned by nights.

Take-home messages

- We developed a template-free LBL code to retrieve precise RVs.
- The code will be applied to PoET observations in order to study different solar activity phenomena.
- So far it has been tested with the Sun-like star HD102365. We obtained a smaller standard deviation than the CCF, and similar average error bar.
- Our methodology will now be applied to other Sun-like stars.
- The paper accompanying the LBL code is in preparation. Stay tuned!

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