A new tool for precise radial velocity measurements

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Abstract

One of the most cost-effective, accurate, and cheap methods for radial velocity measurements is the usage of the gas absorption cell (e.g., Iodine cell) method. We present new open-access software for processing spectra obtained with gas cells, the python-based program Viper (Velocity and IP EstimatoR) [2], and recent results obtained with it. It can be used for data obtained with gas cell from multiple instruments (e.g., OES, TCES, CRIRES+) and new can be easily added. When this method was tested on Ondřejov Echelle Spectrograph (OES) data, the achieved rms improved 6 times compared to a classic cross-correlation method. Viper is still under development. One of the new features we are currently working on is employing telluric lines that allow us to use Viper for the analysis without a gas cell.

Viper: Velocity and IP EstimatoR

Viper uses forward modelling based on Butler et al. (1996) [1]. The spectrum of the star I_{stellar} is multiplied by the spectrum of the cell obtained with a Fourier transform spectrometer (FTS) T_{cell} and then convolved with instrumental profile IP and multiplied with normalization k

$$I_{\mathrm{m}} = k[T_{\mathrm{cell}}(\lambda) I_{\mathrm{stellar}}(\lambda + \delta\lambda)] * \mathrm{IP}. \quad (1)$$

This modelled spectrum I_{m} is then by optimizing parameters of normalization, wavelength solution, IP and radial velocity shift ($\delta\lambda$) made to best fit the observation of the star through the gas cell.

Viper is python-based open-access software and can be found on Github:

`https://github.com/mzechmeister/viper`

Figure 1 shows the Graphic User Interface of Viper where several parameters can be set. Furthermore, Viper can be run directly via console commands. Figure 2 shows the fit of the modelled spectrum (blue) and the observed spectrum (red).

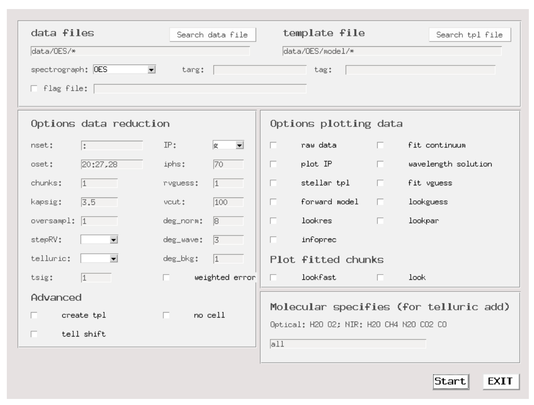

Figure 1: The Graphic User Interface of Viper. Parameters used for OES data are shown.

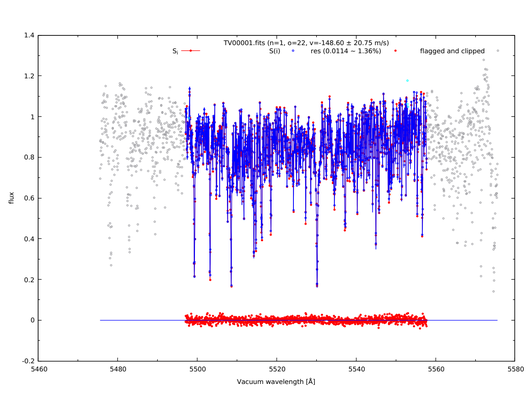

Figure 2: Viper window with observed spectra (red), modelled spectra (blue), clipped/flagged data (light blue/grey) and residuals (observation - model) (bottom red).

Results

- **Sigma Draconis**
  Stability over one night.

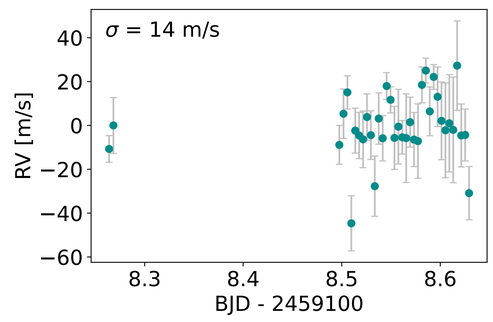

Figure 3: Radial velocities of Sigma Draconis (RV-null standard star). Data from OES.

- **HD 182572**
  Long-term stability.

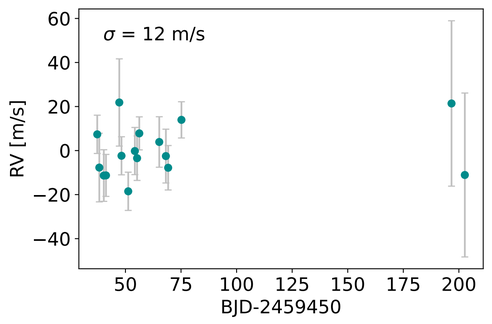

Figure 4: Radial velocities of HD 182572 (RV-null standard star). Data from OES.

- **51 Pegasi**

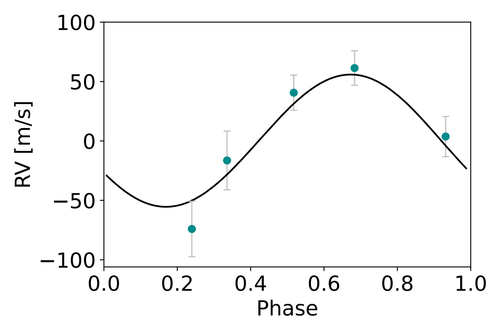

Figure 5: Radial velocities of 51 Pegasi obtained from data from OES (green) with radial velocity curve obtained with known exoplanet parameters (black line).

- **HD 189733**

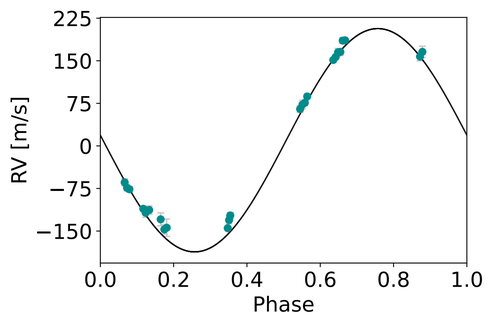

Figure 6: Radial velocities of HD 189733 obtained from data from TCES (green) with radial velocity curve obtained with known exoplanet parameters (black line).

Future work

Current work on Viper is focused on incorporating telluric lines into the code to be used as an additional wavelength calibration besides of the present cell lines. This feature is now tested for optical and also infrared regions of the spectrum.

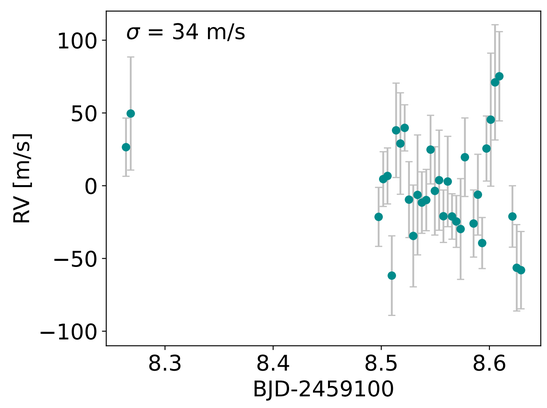

Figure 7: Radial velocities of Sigma Draconis (RV-null standard star) obtained using only telluric lines as wavelength calibration. Data from OES.

Acknowledgements

MV and MS acknowledge the support by Inter-transfer grant no LTT-20015.

References

[1] R. P. Butler, G. W. Marcy, E. Williams, C. McCarthy, P. Dosanjh, and S. S. Vogt. Attaining Doppler Precision of 3 M s-1, June 1996.

[2] M. Zechmeister, J. Köhler, and S. Chamarthi. viper: Velocity and IP EstimatoR. Astrophysics Source Code Library, record ascl:2108.006, Aug. 2021.

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