Mitigating stellar activity jitter with a parametric and a randomised line selection for least-squares deconvolution

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Stellar activity

Surface inhomogeneities induced by **stellar magnetic activity plague the search of small exoplanets** with the radial velocity (RV) method, as they mimic or drown planetary signals [1,2]. This is particularly important for M dwarfs, as they are key targets for both current and future missions (e.g., Ariel, [3]), but can manifest high activity levels over long time-scales [4]. Bespoke activity filtering techniques are therefore necessary to remove the activity contamination and disentangle it from planetary signatures.

Knowing from previous studies that different spectral lines are affected differently by magnetic activity [5], **we studied how to mitigate RV jitter by selecting different sets of lines to use in Least-Square Deconvolution** (LSD, [6]).

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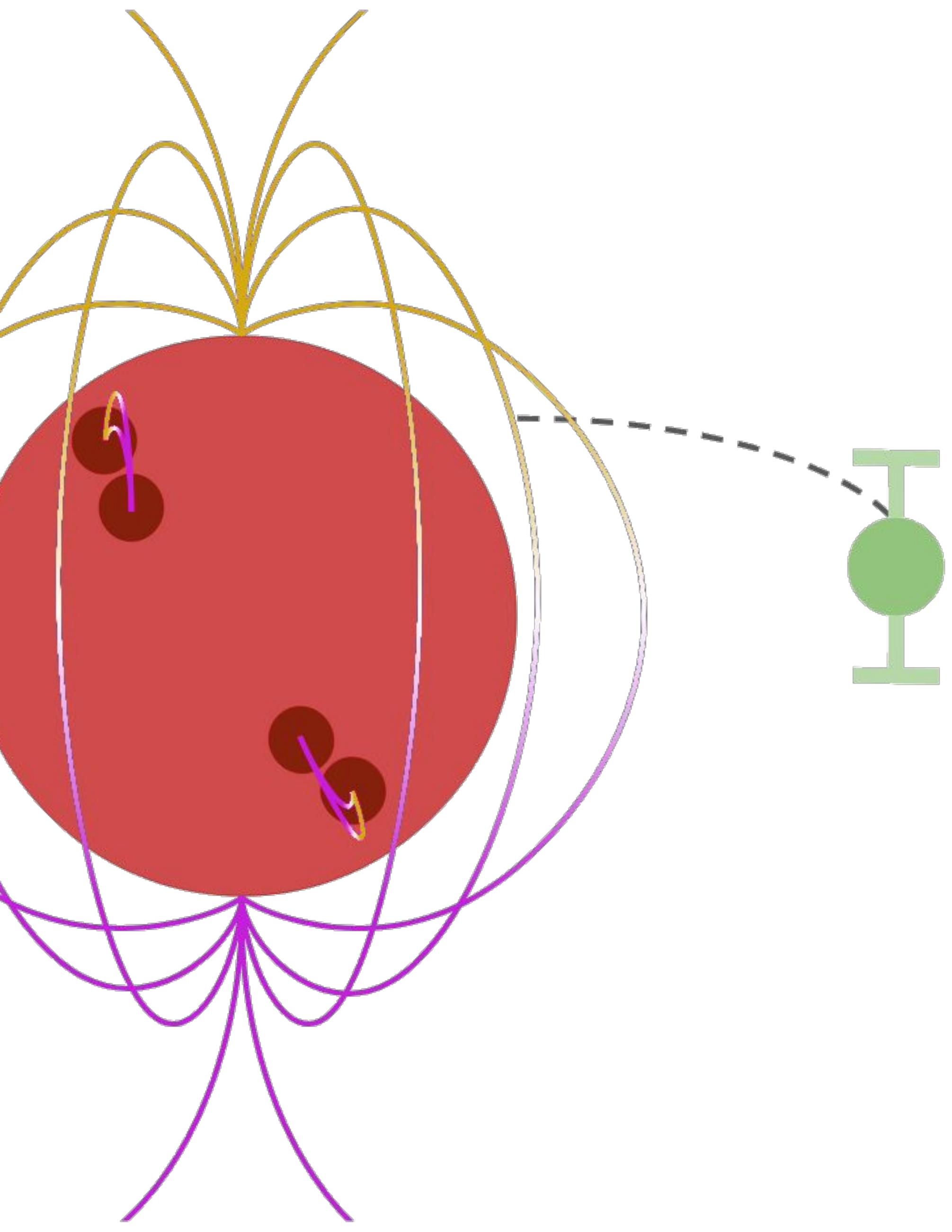

Least-Squares Deconvolution

Assuming the observed spectrum to be the convolution between a line list (i.e. a Dirac comb) and a mean line profile, LSD extracts a **high S/N mean line profile representative of thousands of spectral lines** [6]. This profile can then be fit with canonical methods to measure radial velocities.

Target star

We benchmarked our study on optical spectropolarimetric time series of the active M dwarf **EV Lac** (GJ 873), collected with ESPaDOnS@CFHT and NARVAL@TBL.

Parametric selection

We selected subsets of spectral lines based on their properties: wavelength (λ), depth (*d*), magnetic sensitivity (g_{eff}), etc.

We computed RV time series for each subset and compared the RMS with the case of using all the lines, looking for a substantial decrease.

We kept track of the precision associated with the selected set of lines to understand whether it is photon noise limited, considering that the S/N decreases with the number of lines adopted.

Selection	num of lines	Precision [m s^{-1}]	RMS [m s^{-1}]
Full	3240	5	167
$d < 0.6$	1058	22	208
$0.6 < d < 0.8$	926	10	183
$d > 0.8$	1231	8	157
λ > 550 nm	314	8	168
λ < 550 nm	2872	7	173
$g_{eff} > 1.2$	1649	8	199
$g_{eff} < 1.2$	1495	7	151

Table 1. Results of the parametric selection.

Randomised selection

We selected a sample of n_{sample} lines randomly, derived the RV time series and stored the RMS. We iterated until all lines were selected n_{stop} times to obtain a distribution of RV RMS over different line subsets.

We kept only the subsets below the 1st, 5th and 10th percentiles of the RMS distribution and built three line lists out of them, respectively. With the latter, we re-applied LSD and inspected the RV RMS.

The algorithm was optimised for n_{sample} = 50 and n_{stop} = 100 and it was tested on the 2010 data set of EV Lac. The performance of the line subsets is always referred to the case when using the full line list. Combining the best line subsets from different runs allows the reduction of the jitter without affecting the precision significantly.

Case	num of lines	Precision [m s^{-1}]	RMS [m s^{-1}]
Full on 2010	3300	4	182
10th percentile	666	11	79
5th percentile	636	19	79
1st percentile	198	14	67
Union of best	721	8	68

Table 2. Results of the randomised selection. The last row corresponds to the union of the best subsets from three different runs.

Conclusions

- A direct parametric selection is not sufficient to mitigate RV jitter
- **The randomised algorithm allows improvements of at least 50%**
- The following tests are successful: (i) portability to data sets from other years, (ii) portability to other stars with similar (AD Leo) or lower (DS Leo) activity level, (iii) applicability in the opposite direction, i.e. to find lines sensitive to activity, and (iv) applicability with planet signals.

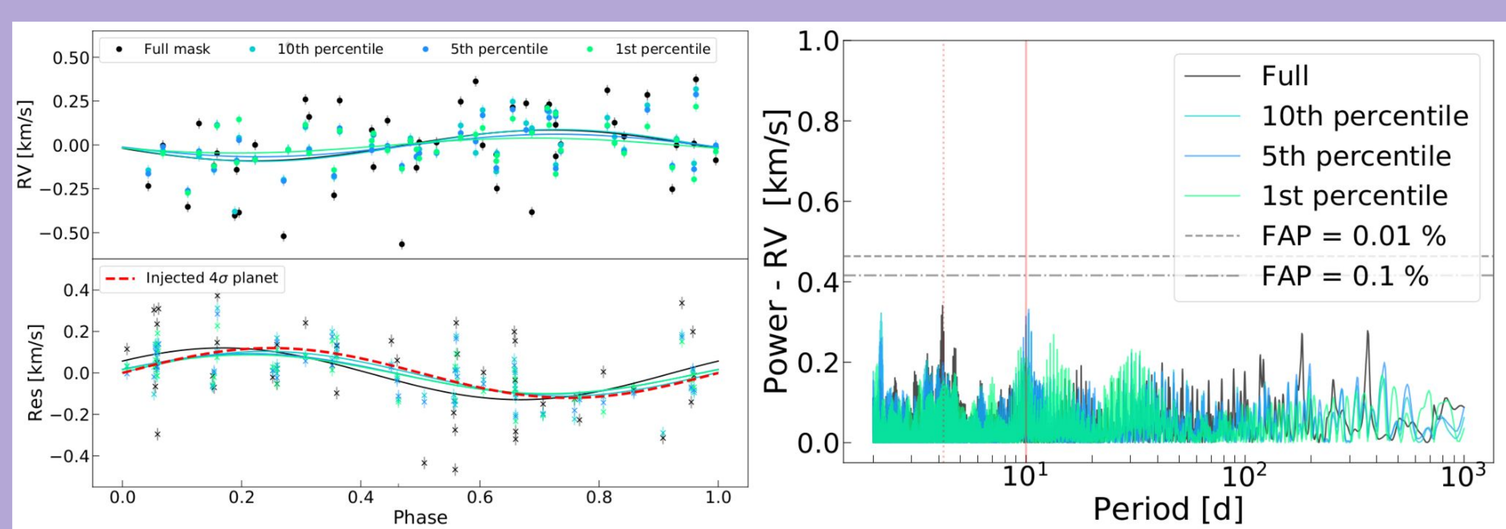

Fig 1. Results from the planet injection tests. When a 0.6 M_J mass planet on a 10 days orbit is simulated in our spectra, the output line subsets from our algorithm enables us to retrieve its signal within uncertainties, contrarily to the full line list.

References

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