Recovering low-amplitude planetary signals in nIR RV data using Wapiti, a wPCA-based telluric correction method

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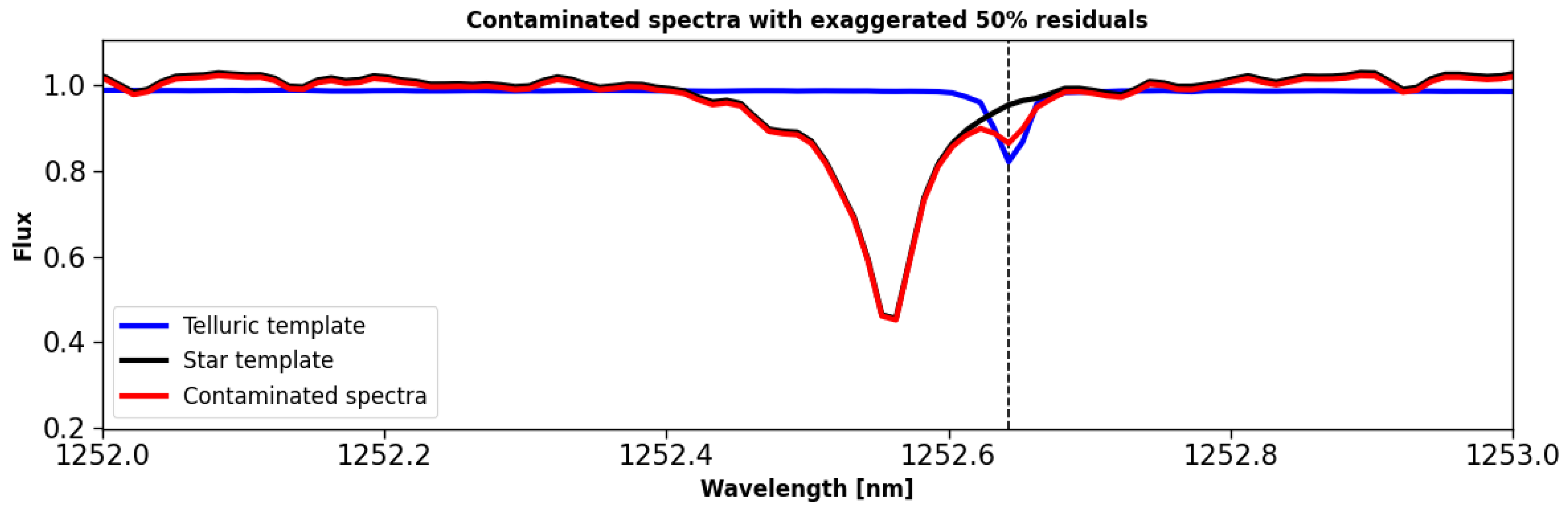
Introduction

In recent years, radial velocity (RV) searches for exoplanets have extended into the near-infrared (nIR), notably to observe M dwarfs. These stars are favorable targets: their low mass amplifies planetary RV signals, they host more rocky planets than FGK stars, and they emit most of their flux in the nIR, where stellar activity may be lower.

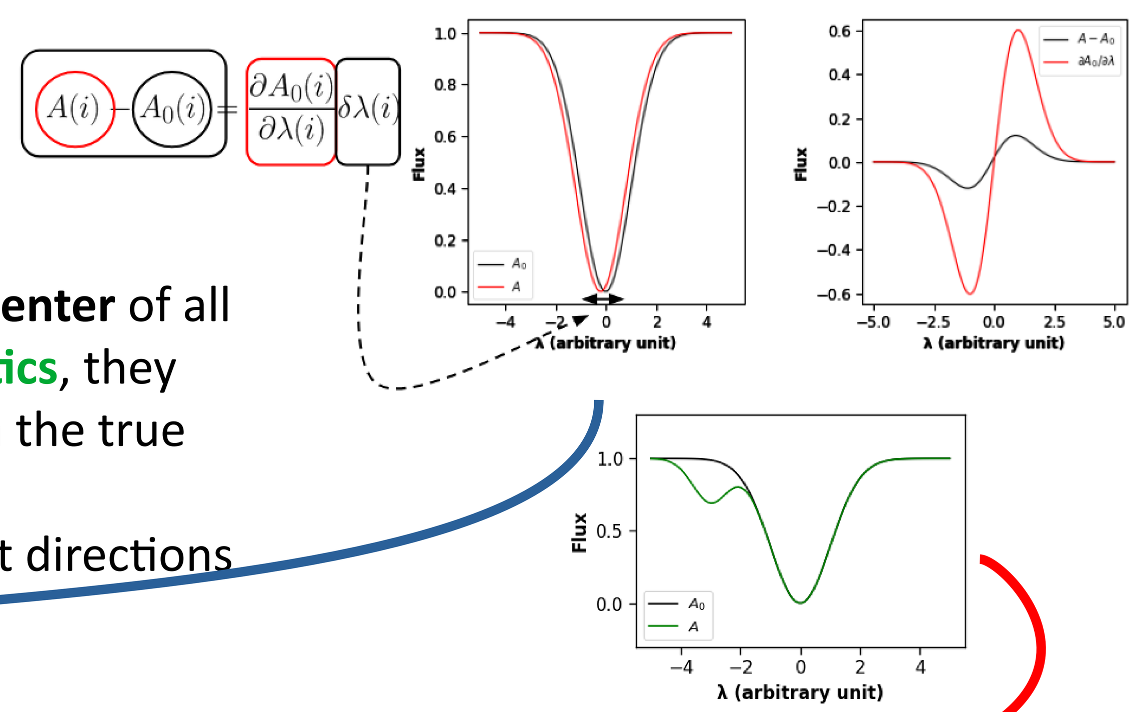
Key challenges: Telluric absorption from Earth's atmosphere strongly contaminates nIR spectra. Even after correction, residuals at the 1–3% level can induce systematic RV signals of 1–2 m/s at yearly timescales, hampering the detection of low-mass planets.



Objective*:* We aim to mitigate telluric-induced systematics using Wapiti, a data-driven, weighted PCA method applied to line-by-line RVs, and recover low-amplitude planetary signals otherwise buried in systematics.

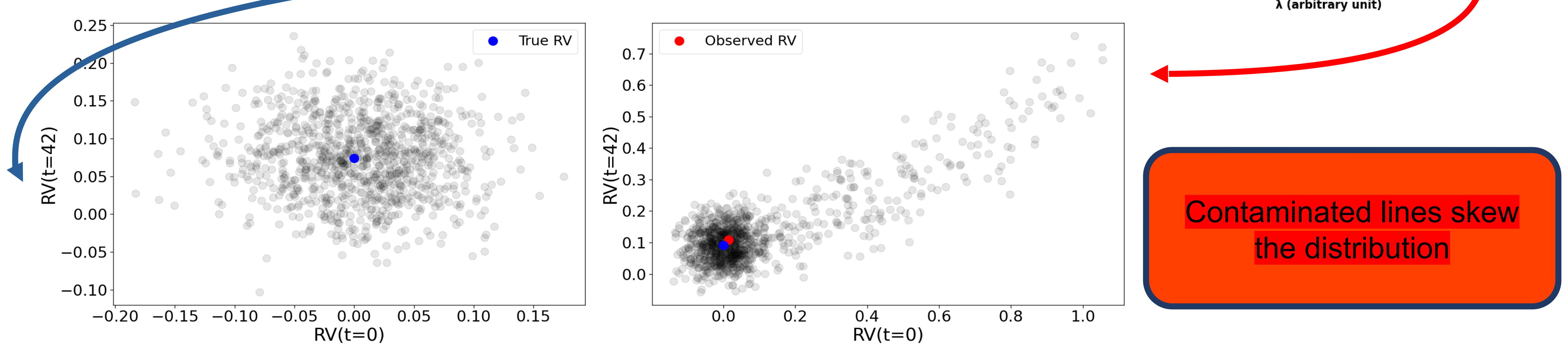
PCA in the context of line contamination

Line-by-line (LBL): We use the LBL algorithm to extract RVs by measuring the Doppler shift of individual spectral lines independently.



In the absence of contamination, the global RV is the **barycenter** of all per-line RVs. But when some lines are affected by **systematics**, they skew the distribution, **shifting the measured RV** away from the true value.

Principal Component Analysis (PCA) can give the dominant directions of this variability.



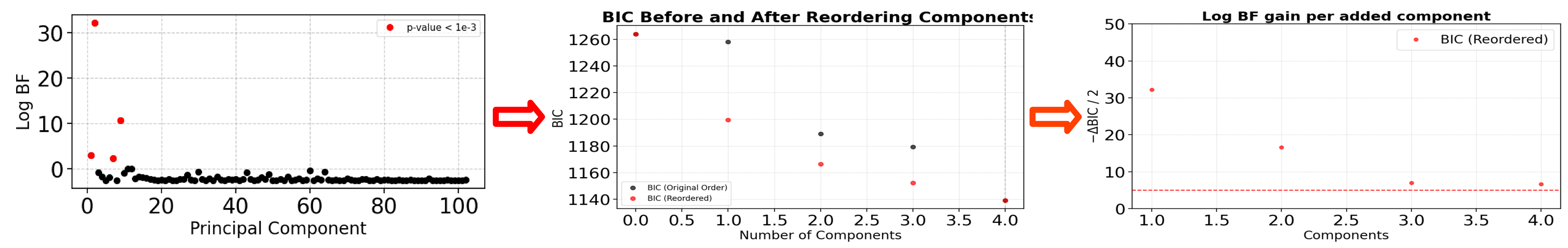
WAPITI

Wapiti (*Weighted principAl comPonent analysIs reconsTructIon*) uses a **weighted** PCA to identify and remove systematics from per-line RVs. The method selects the most relevant components in three steps:

1/ **Permutation test:** Each principal component is tested by comparing model fits using Bayes Factor

2/ **Reordering:** The selected components are reordered by how much they improve the model when added sequentially.

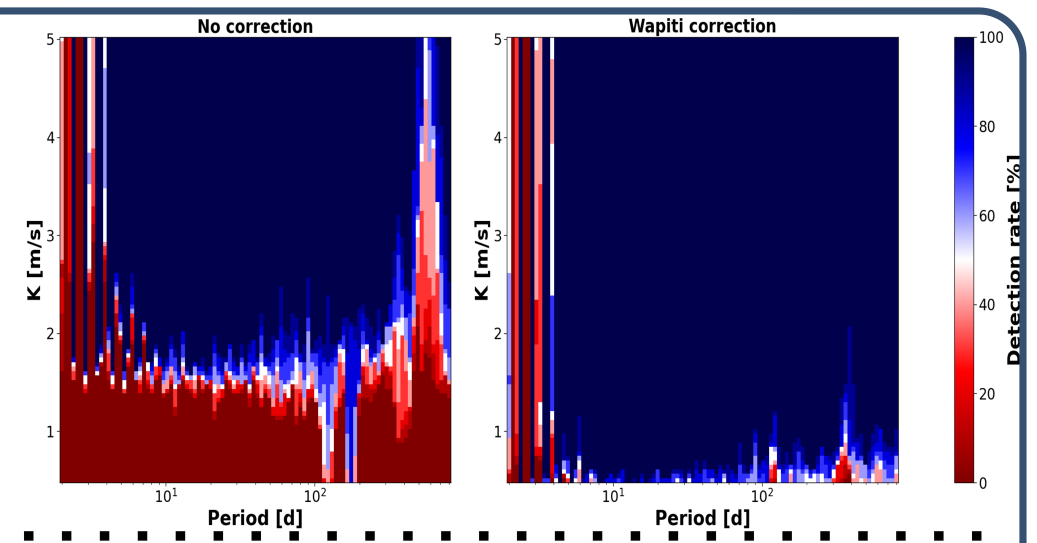
3/ **Component selection:** To decide how many components to include, we add them one by one (ordered by BIC) and stop when the improvement drops below a log BF threshold of 5.



Results

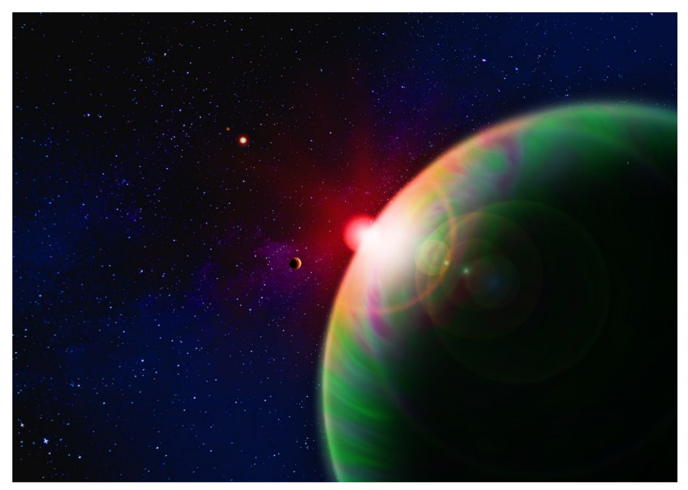
Simulations

We **simulated** systematics originating from **3% telluric residuals** and injected signals over a grid of semi-amplitudes (K) and periods (P). This allowed us to quantify the detection rate and assess how **Wapiti** improves signal recovery in the low-amplitude regime.

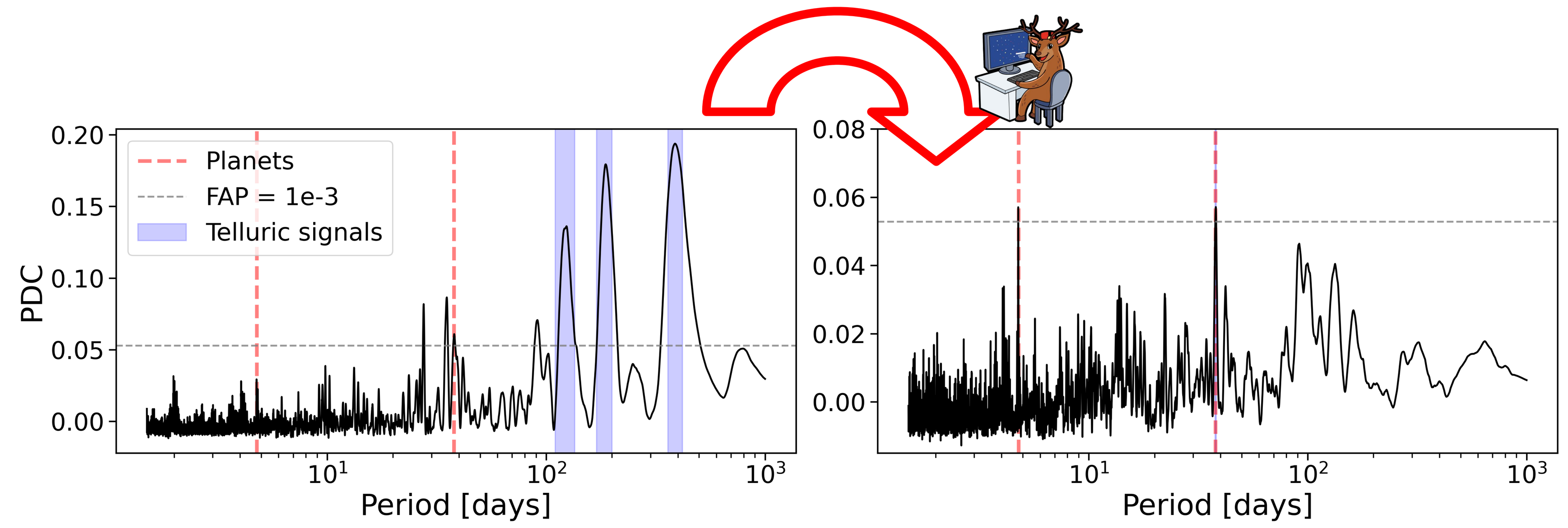


GL 725 B

Applied to the M dwarf Gl 725 B — strongly affected by tellurics — **Wapiti** enables the **detection of two signals at 4.77 and 37.9 days**, with semi-amplitudes of respectively 1.4 ± 0.4 and 1.7 ± 0.4 m/s, corresponding to **≥1.4 and ≥3.5 $M_{\oplus}$**. The outer planet being **located in the habitable zone** of its host star.



Credit : Aurore Bouchet, OMP - Université de Toulouse



CONCLUSION AND PERSPECTIVES

Wapiti significantly improves the detection of **low-amplitude planetary signals** in nIR d RV data by removing **telluric-induced systematics** using a **wPCA** approach. Applied to **Gl 725 B**, Wapiti enables the detection of **two low-mass planets**, including one in the **habitable zone**, that would be otherwise hidden by telluric contamination.S

Future work will consist in applying **Wapiti** to other RV instruments and explore replacing PCA with autoencoders to capture non-linear effects in the RV space.

Weighted principal component analysis: a weighted covariance eigendecomposition approach, Delchambre, L., Monthly Notices of the Royal Astronomical Society, vol. 446, no. 4, OUP, pp. 3545–3555, 2015.

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