Methods to measure exoplanet phase curves, and absolute masses.

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Why do we do this?

High-resolution cross-correlation techniques are standard tools to detect atmospheres of hot and ultra-hot Exoplanets.

- **high signal-to-noise data** allow tests of exoplanet model atmospheres including winds and spatial distribution of molecules.
- Allow tracing of species over several parts of the **planetary orbit**.

- We **develop `Saltire to`**
  - Model the 2D shape of the Cross-correlation signal of such observations,
  - Model exoplanet observations, and
  - model phase-dependent atmospheric signals.
- We measure precise Masses of **high-contrast binaries,**
  - define conditions for high-SNR **Exoplanet phase curve** observations

Applications

Modelling exoplanet CCF signals Sebastian et al. 2024a.

- **`Saltire` model**
- Predict phase-dependent CCF shape in K_c-V_{sys} plane
- We model the CO detection in τ Boötis b using CRIRES data from Brogi et al. 2012
- Full **2D CCF shape** of CO detection is recovered.

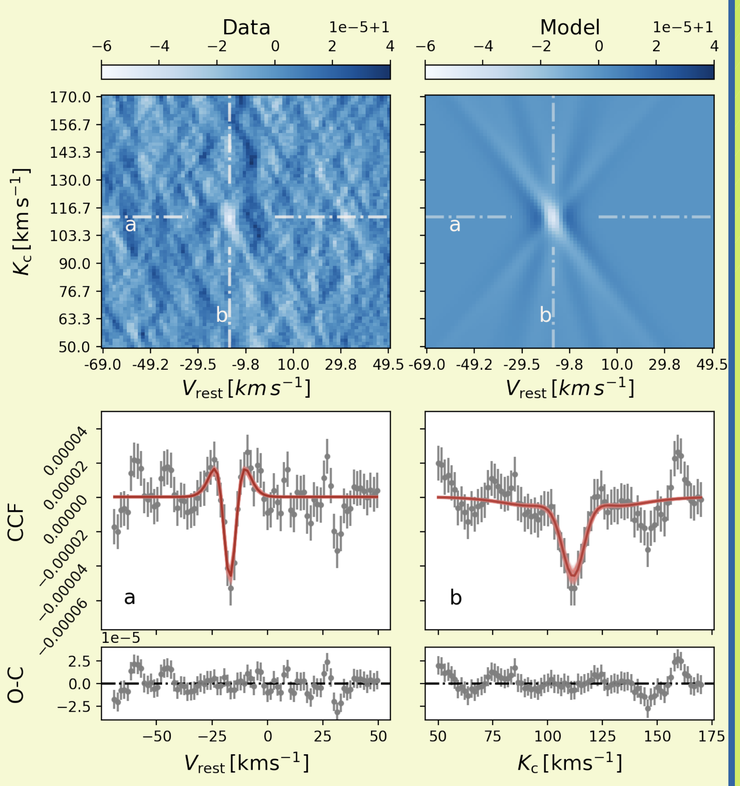


Figure 1

Left: The CCF map of τ Boötis b. *Right*: Saltire model map of the same observation
Lower panels: Comparison of data and best fitting model.

Dynamical masses of TOI-1338 Sebastian et al 2024b.

- First time, application to a **high-contrast binary.**
- **Dynamical** (model independent) **masses** of TOI-1338/BEBOP-1
- Mass **accuracy:**
  - 2% for the primary
  - **1% for the secondary**

SCAN ME

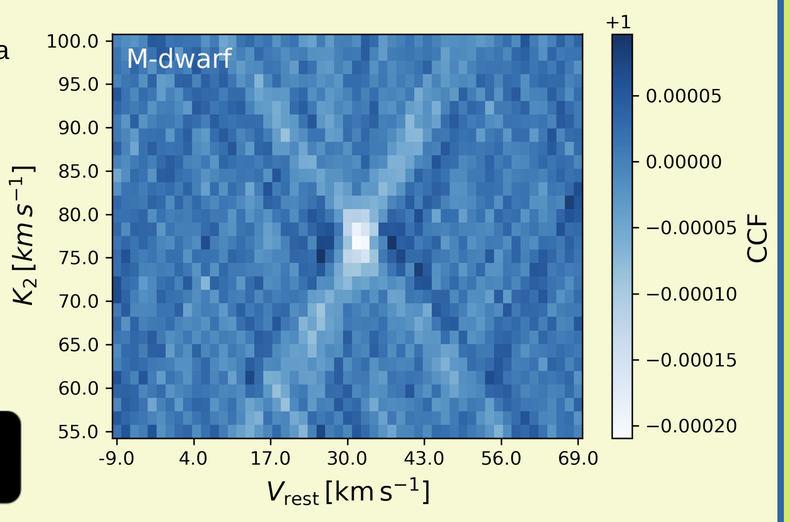


Figure 2

The process to derive a CCF map in the K_c-V_{sys} plane (**K-focusing**).
Secondary's CCFs align at best matching orbit (best K_c)
`Saltire` model takes K-focusing process into account.

Read on...
... on ADS

Highlights

Detecting a spectroscopic phase curve

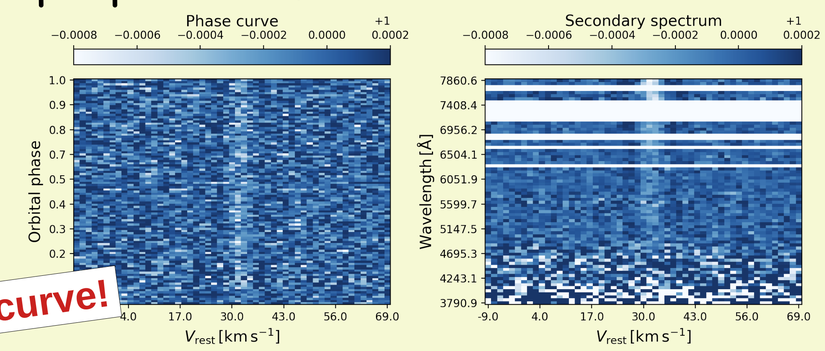
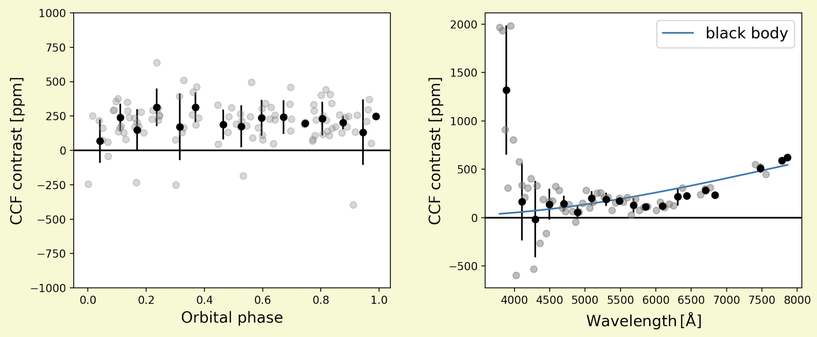


Figure 3

The CCF signal is clearly recovered in the Secondary's rest frame. *Left:* phase dependent CCF signal showing a flat phase curve, *Right:* wavelength dependent CCF signal matching the black body spectra of both stars.

Phase curve!

- Spectroscopic phase curve measured for TOI-1338 B
- **No** phase-dependent degradation from Primary Component Analysis (**PCA**)!



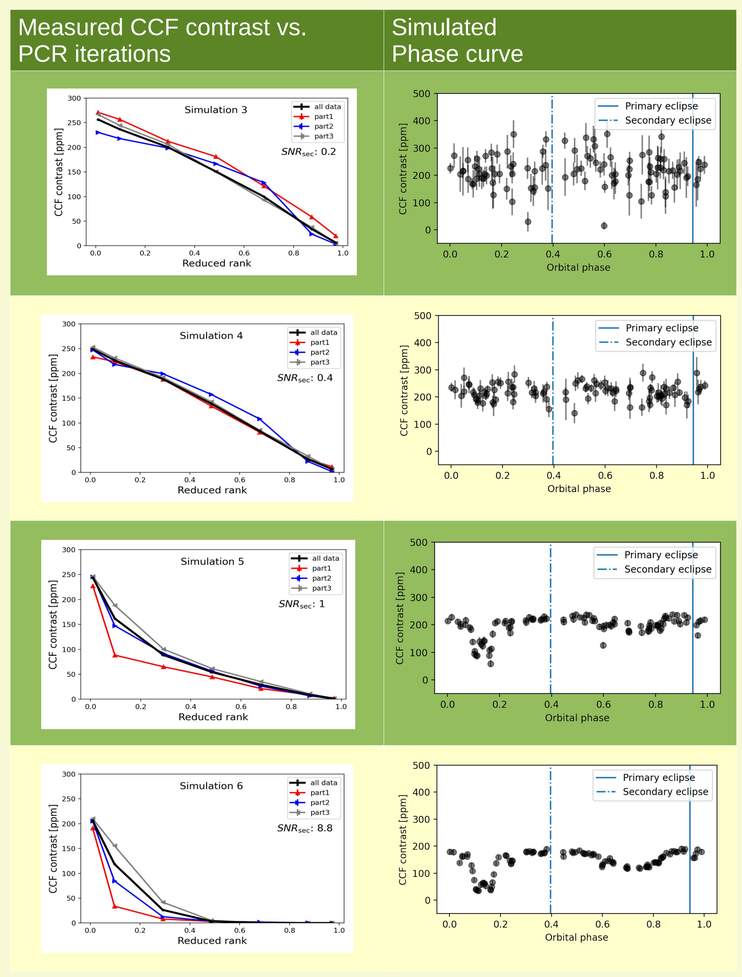
PCA - a great tool - for noisy data

- Effects of PCA on simulated spectroscopic binary
- Measured CCF contrast decreases
  - **with number of PCA** iteration
  - **with SNR** of companion signal
- **Phase-dependent degradation?**
  - for **SNR ~ 1** and higher!

Figure 4

Left: The CCF contrast measured with **`Saltire`** for simulated data of different secondary SNR.
Colours: phases with different velocity changes in primary rest frame: **Red (part1):** smallest velocity change, **Blue (part2):** average velocity change, **Grey (part3):** large change (close to conjunction).

Right: Phase dependent CCF contrast for same data.



How much signal is left?

- Observed signal degradation depends on
  - 1.) Number of PCA iterations
    - **Reduced rank** (iterations/max possible iterations)
  - 2.) SNR of companion – for individual spectra
- For TOI-1338
  - **Signal degradation** from PCA **< 5%**!
- But: **PCA will degrade high-SNR data**
  - Better use different tools for high-SNR?

Table1

Results from simulations. Average, fractional CCF contrast after PCA detrending, compared contrast without PCA.

Retrieved CCF contrast		
SNR Secondary \ Reduced rank	**0.01**	**0.1**
0.1 [TOI-1338]	99.6 %	95.4 %
0.2	96.9 %	89.4 %
0.4	94.1 %	85.6 %
1.0	92.3 %	61.1 %
8.8	77.9 %	44.9 %
∞ (noiseless)	76.1 %	31.1 %

References

Sebastian et al. (2024a), 'Saltire - A model to measure dynamical masses for high-contrast binaries and exoplanets with high-resolution spectroscopy', MNRAS submitted
Sebastian et al. (2024b), The EBLM project – XIII. TOI-1338 - Measuring dynamical Masses of EBLM binaries.
Brogi, M., Snellen, I. A. G., de Kok, R. J., et al. (2012) "The signature of orbital motion from the dayside of the planet τ Boötis b," Natur, 486, 502-504 - 2012Natur.486..502B

Fancy using **`Saltire`**?