Retrieving the transmission spectrum of HD209458b using CHOCOLATE

a new Chromatic Line-Profile Tomography Technique

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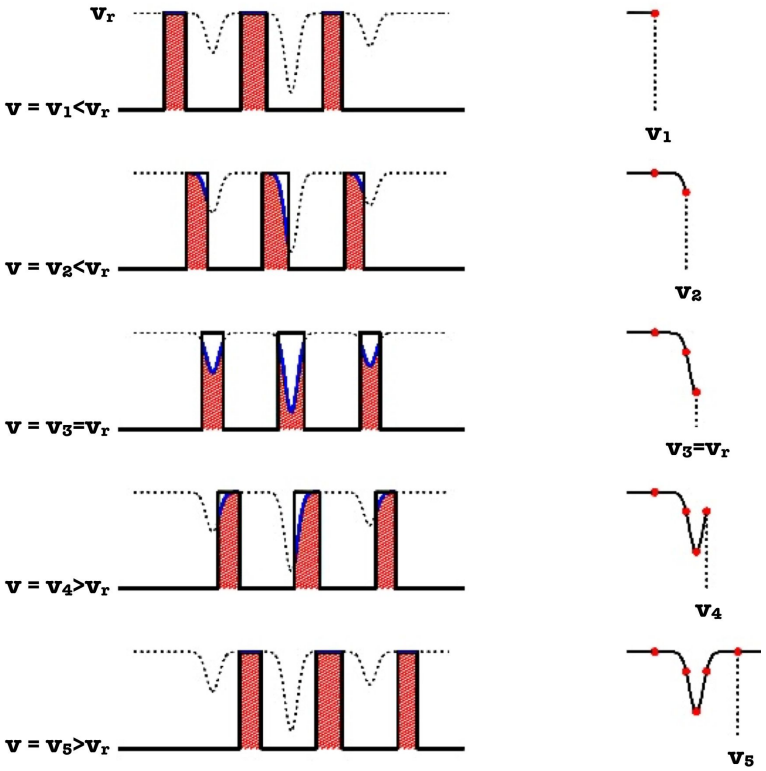
#ATMO2021

Index

CCFs

Cross Correlation Functions



ww.eso.org (Pedro Figueira talk)

Cross-correlation of a spectrum with a **binary mask**

Degree of similarity along a range of radial velocities

Higher S/N **average line**

Precise **RV measurement** fitting a gaussian to CCF

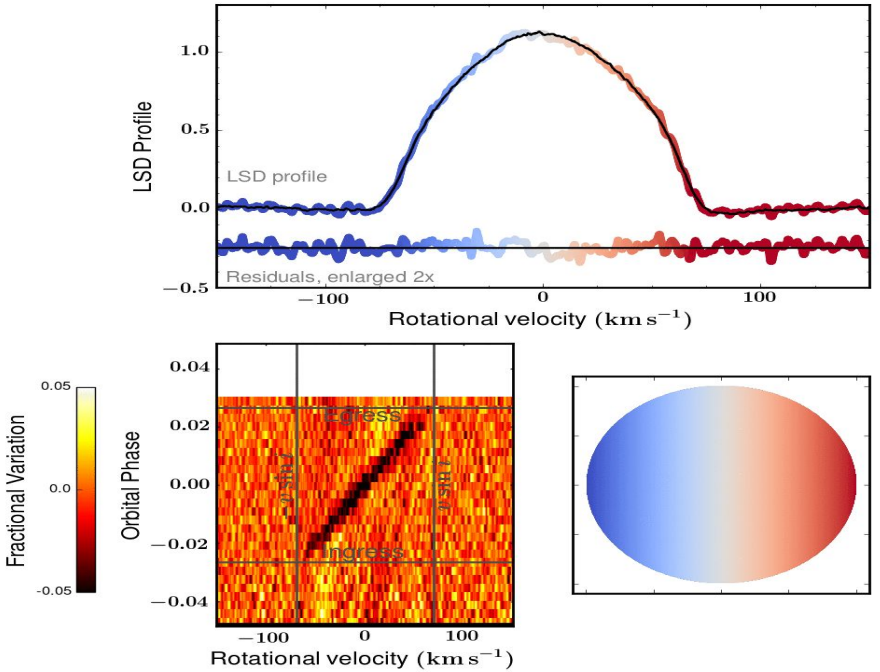
Line-Profile Tomography

Method that analyzes **CCFs temporal sequences**

Reduction of flux from a region affects the stellar line profile

- ➔ Bumps in CCFs
- ➔ Deviations of RV measurements

Anomalies observed in CCFs sequences during transit can be **related to R_p/R_***



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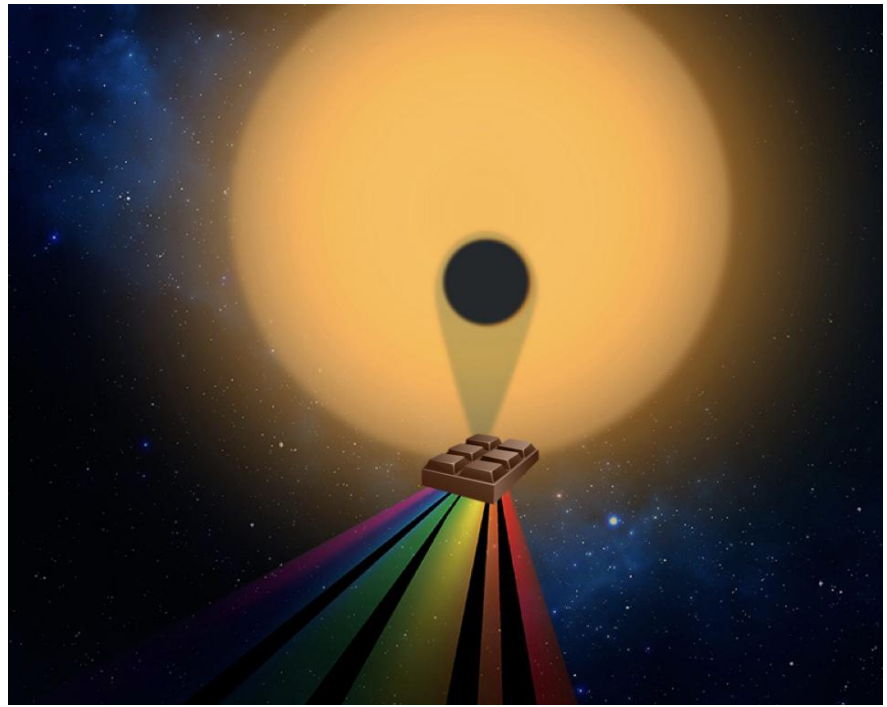
Chromatic Line-Profile Tomography

CHOCOLATE

CHrOmatiC line prOfiLe tomograAphy TEchnique

Line-Profile Tomography in
different Δλ



Transmission Spectroscopy

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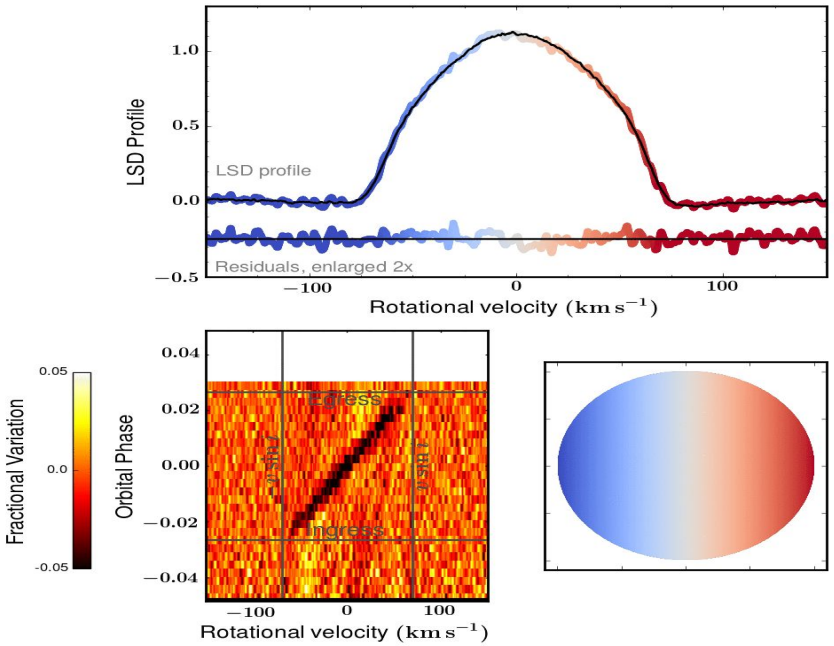

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CHOCOLATE

CHrOmatiC line prOfiLe tomogrAphy TEchnique

Based on the spectral line distortions caused by the planet shading parts of the rotating stellar surface

Outline

Obtain transmission spectroscopy via Chromatic L-P Tomography

Model

Obtained a functional model of chromatic line-profile tomography extending SOAP tool

Data Reduction

Reduced ESPRESSO data and prepared it for a chromatic fitting

Fitting

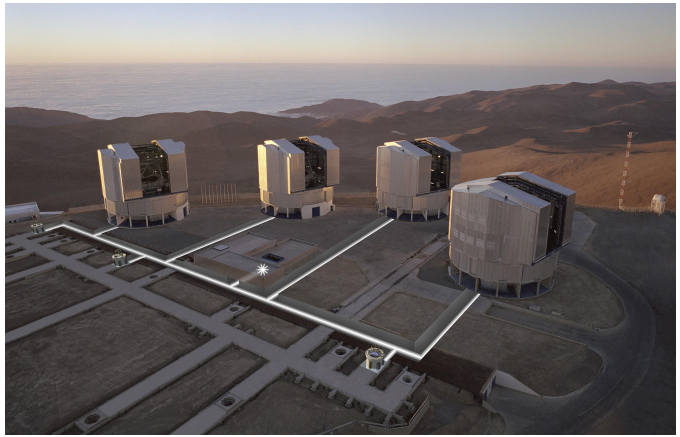
Developed an MCMC fitting procedure to estimate the planet radius in different $\Delta\lambda$

HD 209458 b

Applied the fitting procedure to the planet HD209 as a reliability test of our procedure and to check if it is possible to retrieve the transmission spectra using this method

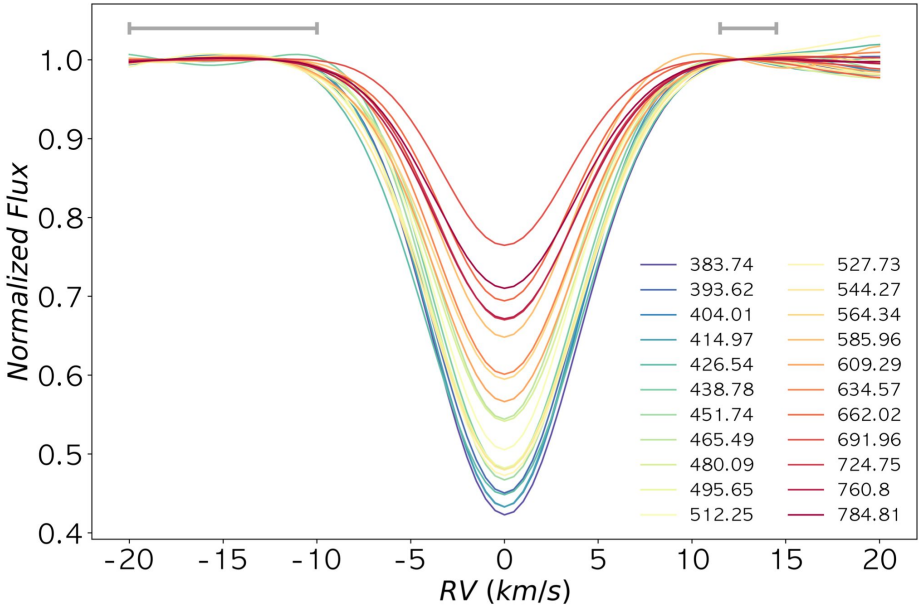
HD 209458b data

	ESPRESSO N1	ESPRESSO N2
Date	2019-11-15	2019-11-16
Airmass	1.886	1.930



ESPRESSO @ VLT, Paranal

Data Reduction

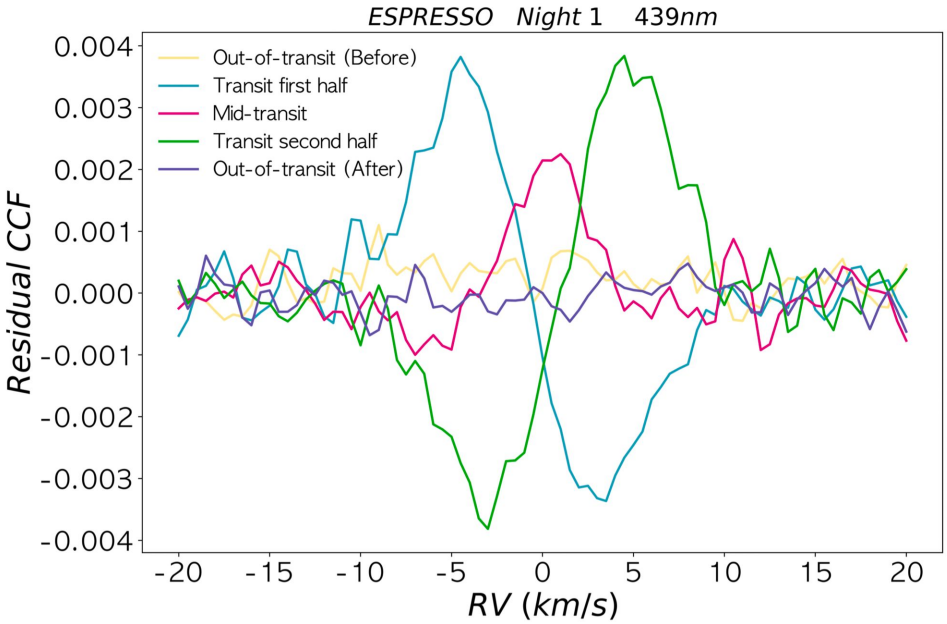


8-orders bins

Steps

1. **CCF flux normalization**
2. **Keplerian motion subtraction**
3. **Wavelength bins definition**
4. **Master CCF generation**
5. Subtraction of the Master CCF
6. Error estimation

Data Reduction



Steps

1. CCF flux normalization
2. Keplerian motion subtraction
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5. **Subtraction of the Master CCF**
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Data Reduction

Steps

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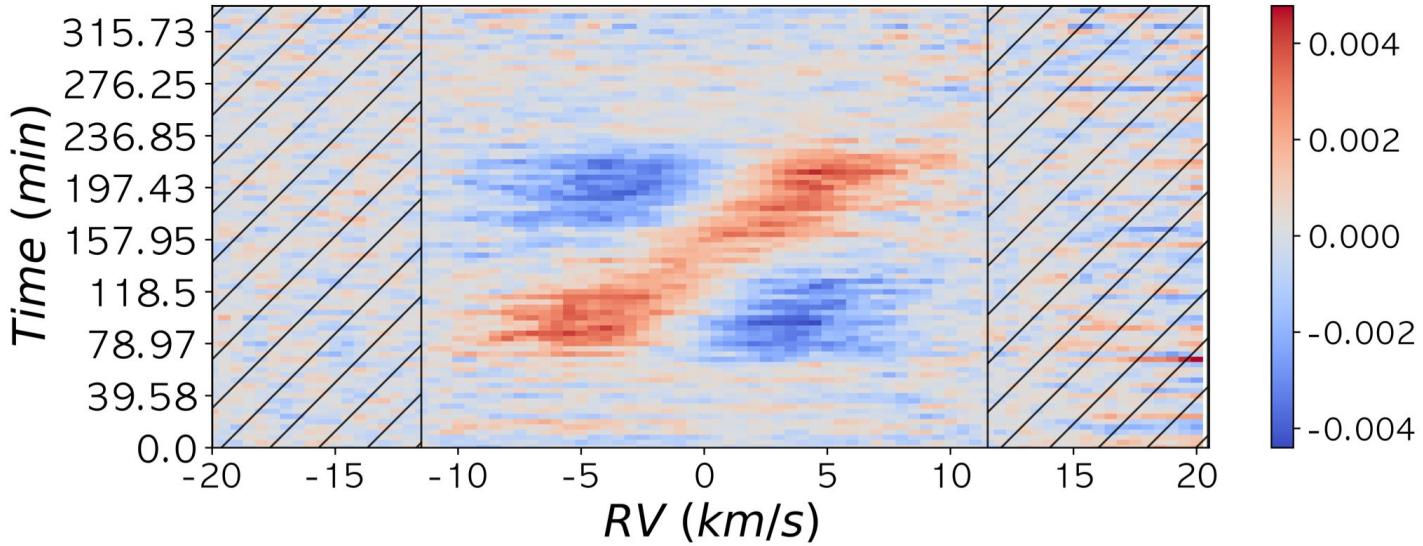
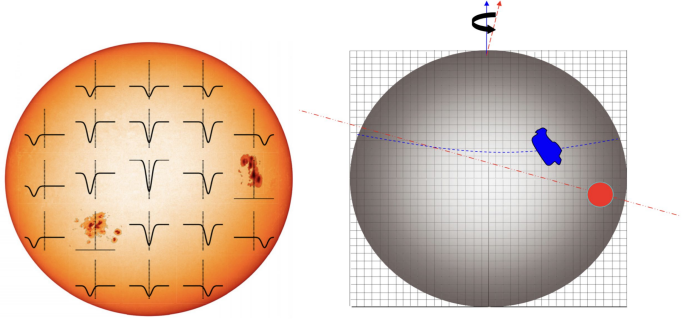
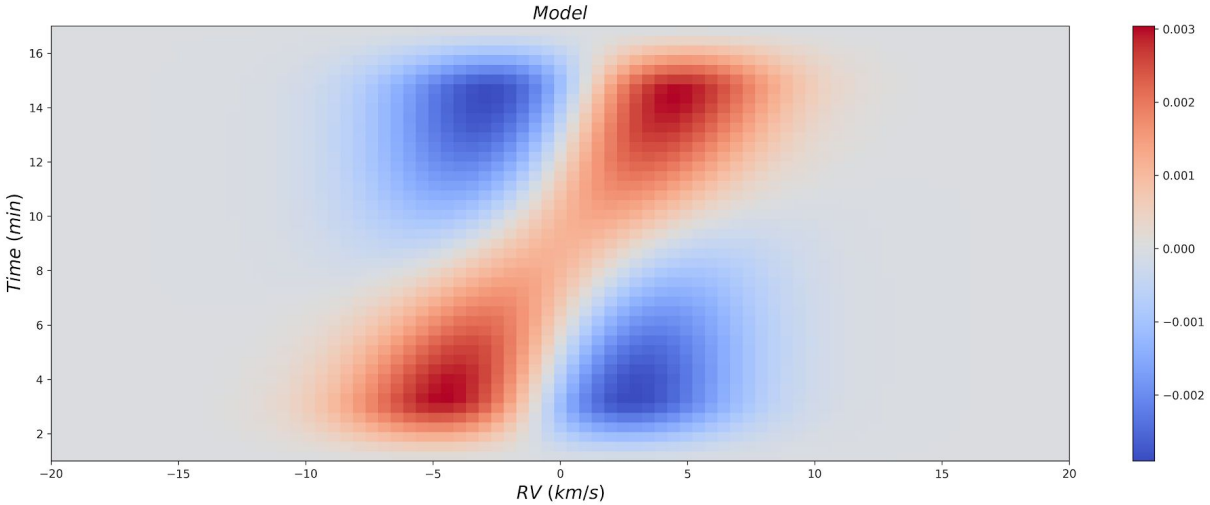


SOAP 3.0

Pixelation approach to simulate a transiting planet in front of a rotating host star



Model



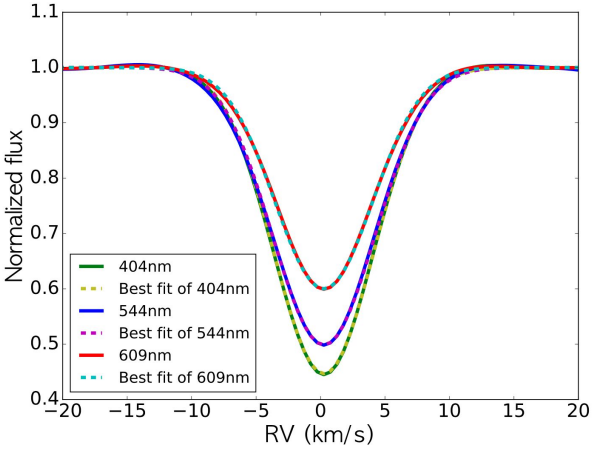


Fig. Example of the SOAP CCF fitting to the Master CCF in different wavelength bins, which leads to determination of the Gaussian standard deviation and depth parameters. The solid lines represent the Master CCFs from the observations in 440 nm (green), 544 nm (blue) and 609 nm (red) bins. The SOAP modelled CCF resulting from the best fit Gaussian parameters is shown by the dashed lines.

4. Master CCF generation
5. Subtraction of the Master CCF

MCMC

MCMC approach: *emcee*

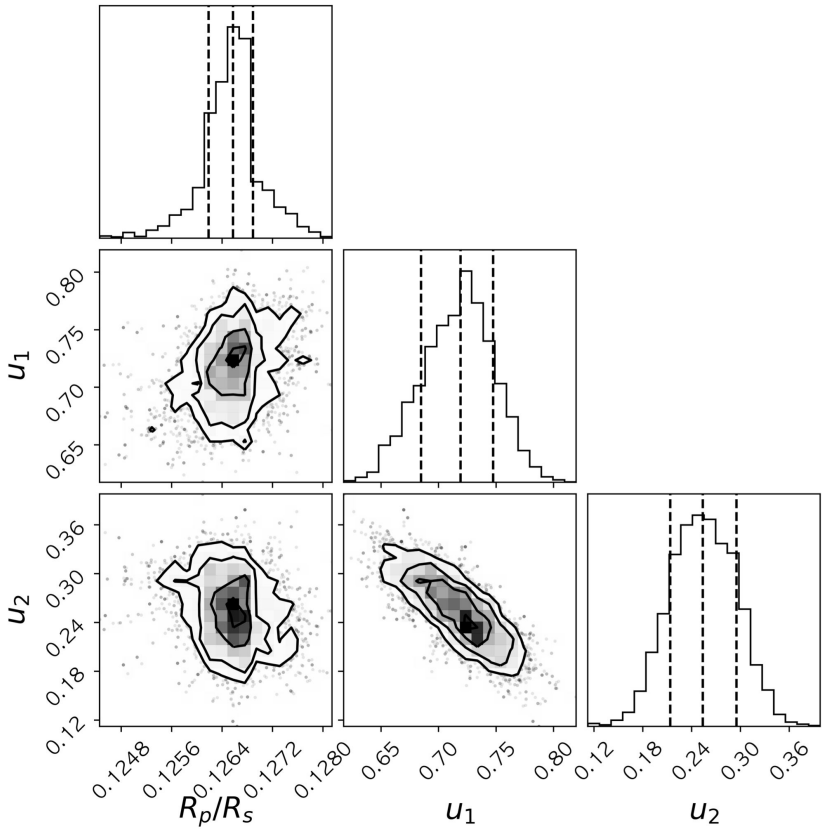
(Foreman-Mackey et al., 2013)

Fitting

Priors imposed on the free-parameters of the fitting.

Free parameter	Prior
R_P/R_*	$\mathcal{U}(0.1; 0.2)$
u_1	$\mathcal{N}(\mu_{\texttt{LDTk}}; 0.05)$
u_2	$\mathcal{N}(\mu_{\texttt{LDTk}}; 0.05)$

Notes: $\mathcal{U}(a; b)$ is a uniform prior with lower and upper limits of a and b. $\mathcal{N}(\mu; \sigma)$ is a normal distribution with mean μ and width σ.



MCMC

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(Foreman-Mackey et al., 2013)

Fitting

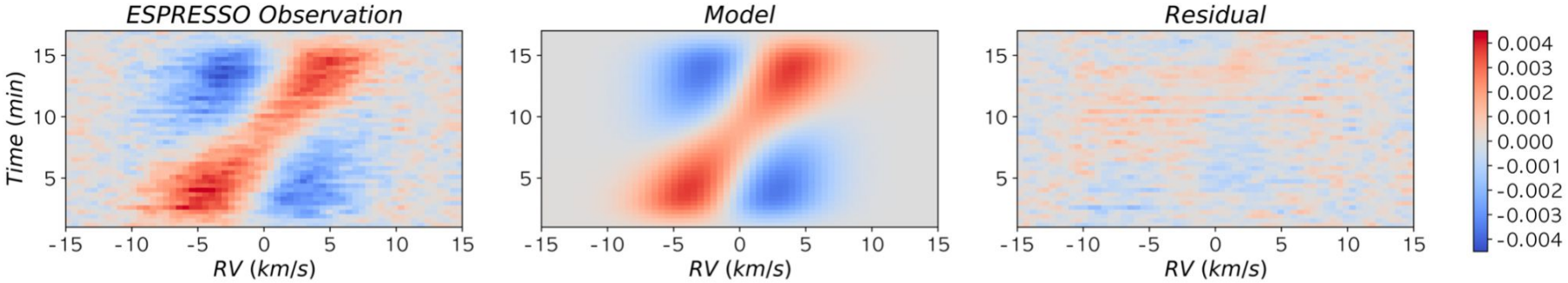


Fig. Comparison between the observed *CCF residual matrix* for the 439 nm-centered bin (left), the best-fit SOAP-modelled *CCF residual matrix* (center) and the residuals of the fitting (right).

HD209458b

ESPRESSO observations

Results

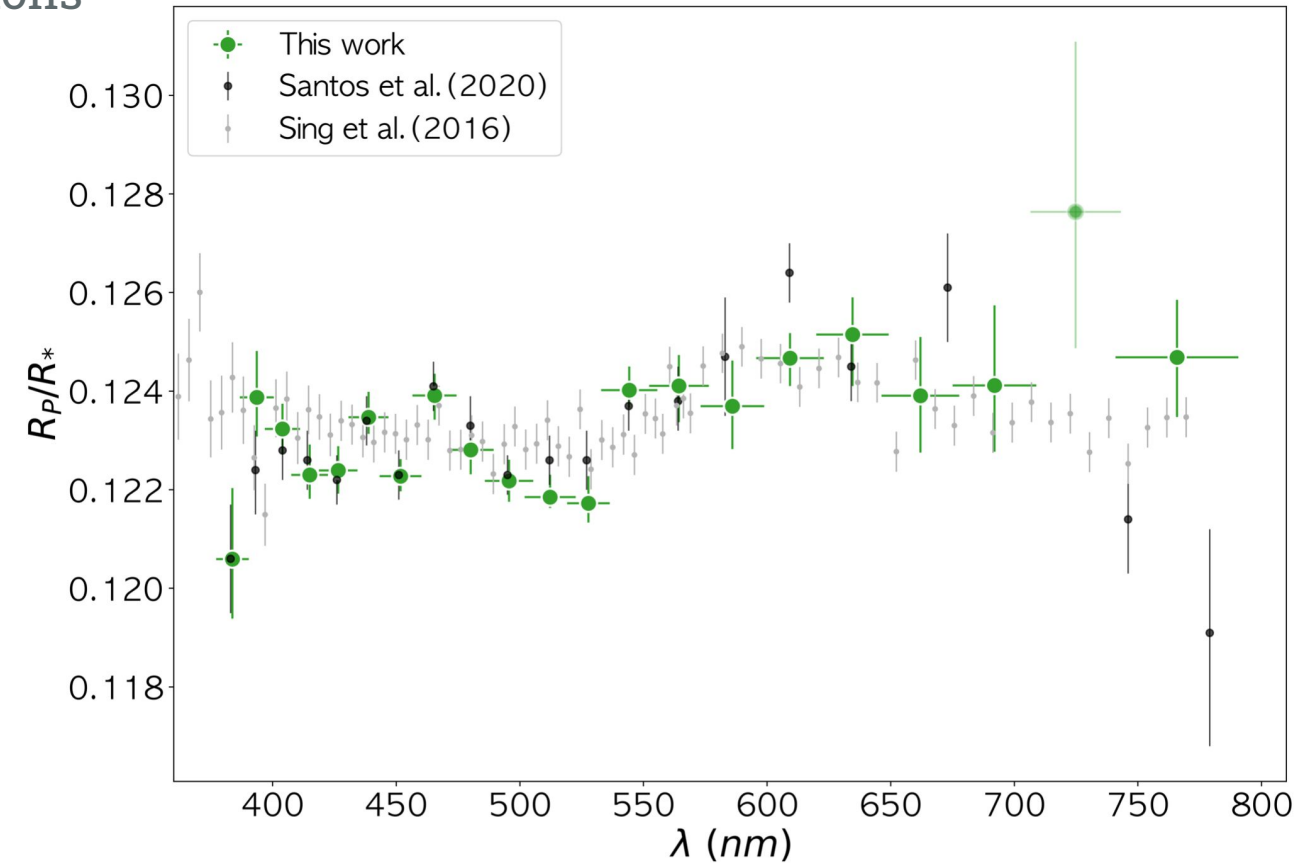
Esparza-Borges et al. (2021), submitted

Santos et al. (2020):

- Chromatic R-M
- ESPRESSO data

Sing et al. (2016):

- Multiband photometry
- HST (STIS) data



Retrieving transmission spectrum of HD209458b using CHOCOLATE

Conclusions

- We developed CHOCOLATE method, based on physical modeling of obs. data (SOAP).
- Validated its performance on HD209458b data.
- Transmission spectrum agree with previous results (Sing et al. 2016; Santos et al. 2020), obtaining similar precision using similar data and different methodology.

- Hint of H_2O and NH_3 detection after performing atmospheric retrieval on the results
- Particularly interesting for exoplanets around young and active stars or moderate/fast rotating stars

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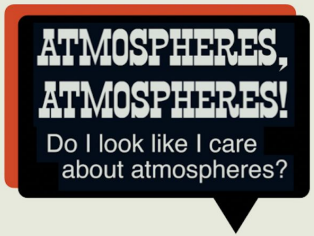
Conclusions



THANKS

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