



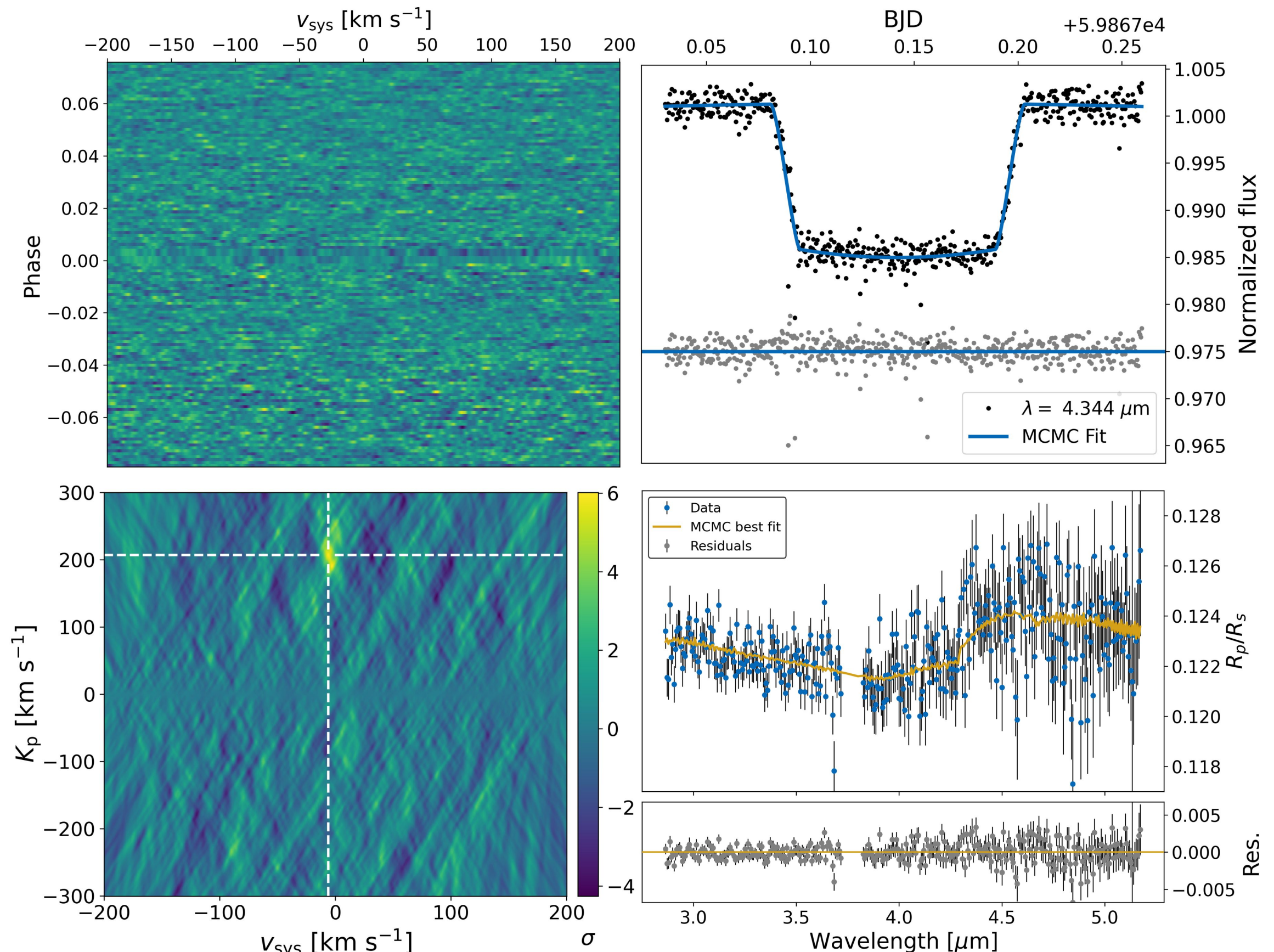
Combining JWST & Ground-based Spectroscopy

Atmospheric retrievals of the extrasolar planets have traditionally been performed separately for high- and low-resolution spectroscopy. However, they both probe different parts of the atmosphere and are sensitive to different physics. High-resolution spectroscopy is sensitive to weaker spectral lines and their Doppler shift, allowing for the study of dynamics such as atmospheric winds. Low-resolution spectroscopy offers a broad view of the spectral continuum, leading to the study of thermal structure and exoplanetary climate.

Recent advances in performing high-resolution retrievals have opened up the possibility to simultaneously retrieve parameters from both types of data, in principle allowing us to probe these planets in more detail. Potentially, this approach can allow us to:

- Improve abundance constraints
- Reduce degeneracies
- Detect trace species
- Measure winds and rotation

The aim of my PhD project is to create a framework to simultaneously analyze JWST and ground-based high-resolution spectroscopy, with the overall aim of providing better constraints on atmospheric parameters.



Top left image: Cross-correlation of spectral template at each orbital phase of WASP-121b

Bottom left: Detection of Fe line in WASP-121b spectra using UVES high-resolution spectrograph at VLT

Top right image: Transit curve of WASP-121b at 4.344 μm observed with JWST/NIRSpec

Bottom right: Transmission spectrum of WASP-121b with best fit model and residuals.

High-Resolution Spectroscopy

- Resolution $\geq 50,000$
- Ground-based facilities (e.g. ESPRESSO or CRIRES+ on ESO VLT or HARPS on La Silla)
- Probes higher in the atmosphere (lower pressures)

Pros:

- Ability to resolve individual lines and their Doppler shifts
- Sensitive to line shapes
- Large number of detectable species¹
- Useful for study of atmospheric composition and dynamics, i.e. winds or jet streams²

Cons:

- Telluric lines / Earth atmosphere's contamination
- Limited information on the continuum
- Exoplanet spectrum cannot be directly inspected

Low-Resolution Spectroscopy

- Resolution usually $\leq 1,000$
- Space-based observation (e.g. JWST)
- Probes lower in the atmosphere (higher pressure levels)

Pros:

- Broad spectral coverage (study of the continuum)
- Detection of the most dominant species³
- No telluric lines contamination from space, more sensitive for small planets
- Useful for T/P profile and climate study²

Cons:

- Individual lines are not resolved: subject to confusion of atmospheric species
- Not sensitive to line shapes or positions
- In case of JWST – less sensitive in the optical part of the spectrum

Joint Retrieval Framework

We are developing a Bayesian retrieval framework capable of simultaneously fitting JWST transmission spectra and ground-based high-resolution transit spectroscopy.

It is based on the same high-resolution atmospheric model and the same chemical composition described by the joint parameter vector. Both datasets have individual wavelength grids. High-resolution data are also fitted for the cross-correlation Doppler-shifted model.

Joint posterior is created as a combination of two separate likelihoods:

$$\ln \mathcal{L}_{\text{joint}} = \ln \mathcal{L}_{\text{LRS}} + \ln \mathcal{L}_{\text{HRS}}$$

Current Target & Setup

Our main target is an ultra-hot Jupiter **WASP-121b**. With its parameters ideal for observations and atmospheric studies ($M_p = 1.18 M_J$, $R_p = 1.81 R_J$, $T_{\text{eq}} \sim 2400 \text{ K}$, $P = 1.275 \text{ day}$)⁴, and numerous archival data, it is an ideal benchmark for development of joint retrieval framework.

We are using **JWST/NIRSpec** transit spectra for low-resolution and **VLT/UVES** echelle transit spectra for high-resolution spectroscopy. Our forward model is generated with resolution $R = 100,000$, and for low-res data, it is binned down to the spectra resolution.

We are performing a free chemistry retrieval using MCMC framework with 13 free parameters (4 for CC-model, 3 for T/P profile, P_0 , P_{cloud} , and **H₂O**, **CO**, **SiO**, and **Fe** opacities).

Acknowledgements

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¹Gibson, N.P. et al. 2020, MNRAS, 493, 2215

²Smith, P. C.B. et al. 2024, AJ, 167, 110

³Gapp, C. et al. 2025, AJ, 169, 341

⁴Delrez, L. et al. 2016, MNRAS, 458, 4025

Contact: dupkalad@tcd.ie



Right: Retrieved T/P profile of WASP-121b from joint retrieval of JWST/NIRSpec and VLT/UVES data with marked contribution functions.

