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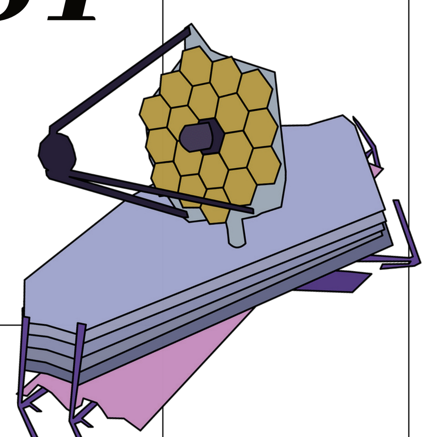
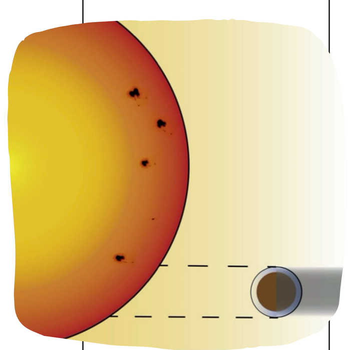
Disentangling Planetary and Stellar Features of Transits in the Era of JWST

Near-Infrared Transmission Spectroscopy of HAT-P-18 b and WASP-52 b with NIRISS/SOSS



1.



INTRODUCTION

Active K dwarfs such as HAT-P-18 and WASP-52 are known to possess surface heterogeneities (i.e., spots and faculae), which can introduce spurious spectral features in transmission spectra through the *transit light source effect*[1] (TLSE).

OBJECTIVE

We aim to disentangle stellar and planetary atmosphere signals by including stellar heterogeneities in transit light curve fits and atmospheric retrievals.

OBSERVATIONS

The JWST ERO program included a transit of the warm Saturn-mass exoplanet HAT-P-18 b, while the transit of the inflated hot Jupiter WASP-52 b was part of the NIRISS team GTO program, both observed from 0.6–2.8 μm using NIRISS/ SOSS. Spot-crossing events are clearly present in the light curves.

METHODOLOGY

We employ *spotrod*[2] for the transit model. We use different treatments (e.g., spots only, spots and faculae) for the TLSE in the retrievals. We also implement new model considerations designed to fit the local surface gravity of stellar heterogeneities, thereby attempting to capture the effects of magnetic pressure.[3]

2.

STANDARD LIGHT CURVE FITTING & SPOT-CROSSING MODELLING

We use a standard two-step approach. First, a transit model is fitted to a white light curve to infer the values of the model parameters that should be independent of wavelength (e.g., impact parameter, spot's position and radius). Then, with those parameters held fixed, a transit model is fitted successively to the spectroscopic light curves to infer the values of wavelength-dependent parameters (e.g., transit depth, spot contrast).

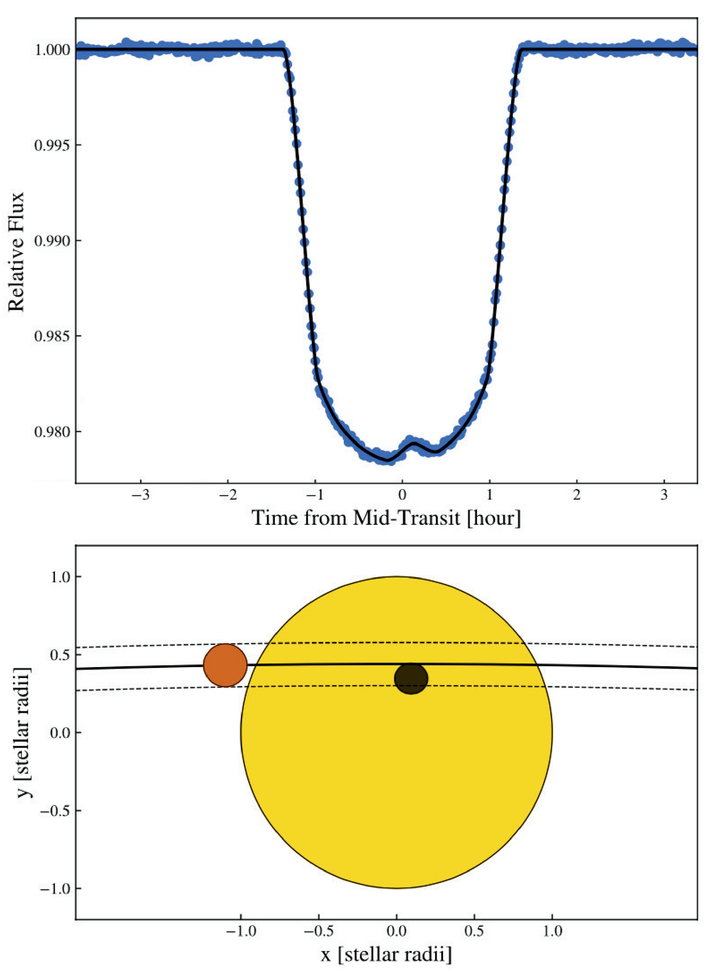


Figure 1. Modelling of the spot-crossing event with the standard approach for HAT-P-18 b.

We found for HAT-P-18 b that the spot's y-position is not well constrained, and a degeneracy between the spot's y-position, radius and temperature leads to four slightly different solutions. As the spot's position and radius can show different spectral dependencies, the wide-bandpass averaging inherent to the white light curve might bias the values found for the achromatic parameters, which are retained for the chromatic fits. That appears to be the case based on testing with synthetic light curves.

3.

NEW APPROACH FOR THE LIGHT CURVE FITTING

In the single-step approach, all spectral light curves are simultaneously and jointly fit using both wavelength-dependent and wavelength-independent parameters. We used the two approaches for WASP-52 b and found a similar solution for the second spot, but two different solutions for the first spot. The retrieved transmission spectra with both approaches are consistent within 1 σ.

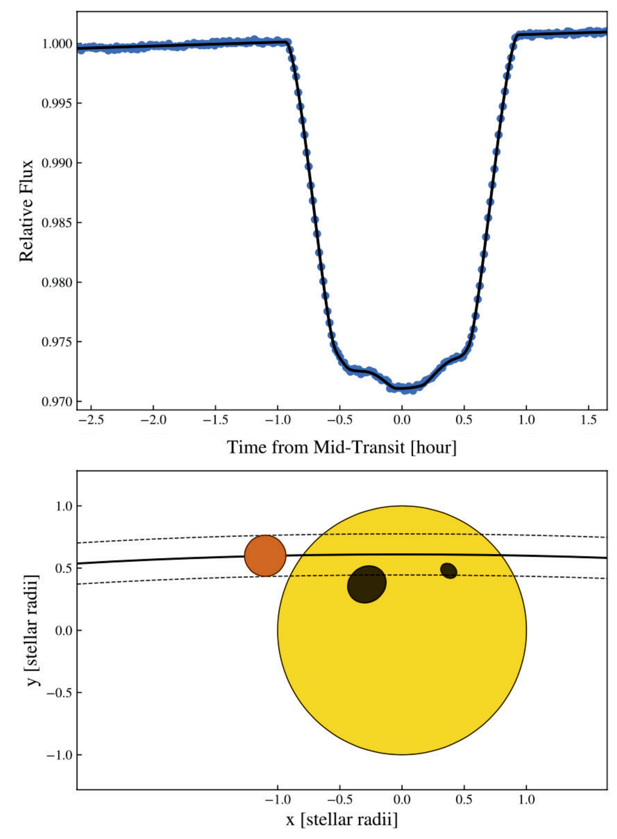


Figure 2. Modelling of the spot-crossings with the standard approach for WASP-52 b.

Approach	Spot 1 Standard	Spot 1 Single-step	Spot 2 Standard	Spot 2 Single-step
x_{spot} [R_*]	-0.283 ± 0.009	-0.20 ± 0.01	0.372 ± 0.009	0.37 ± 0.01
y_{spot} [R_*]	0.33 ± 0.07	0.86 ± 0.02	$0.47^{+0.02}_{-0.04}$	0.47 ± 0.01
R_{spot} [R_*]	0.19 ± 0.06	0.23 ± 0.02	$0.08^{+0.04}_{-0.02}$	0.07 ± 0.01
T_{spot} [K]	4670 ± 20	4000 ± 200	4590 ± 20	4540^{+70}_{-90}

Table 1. Best-fitting spots' parameters for WASP-52 with the two approaches.

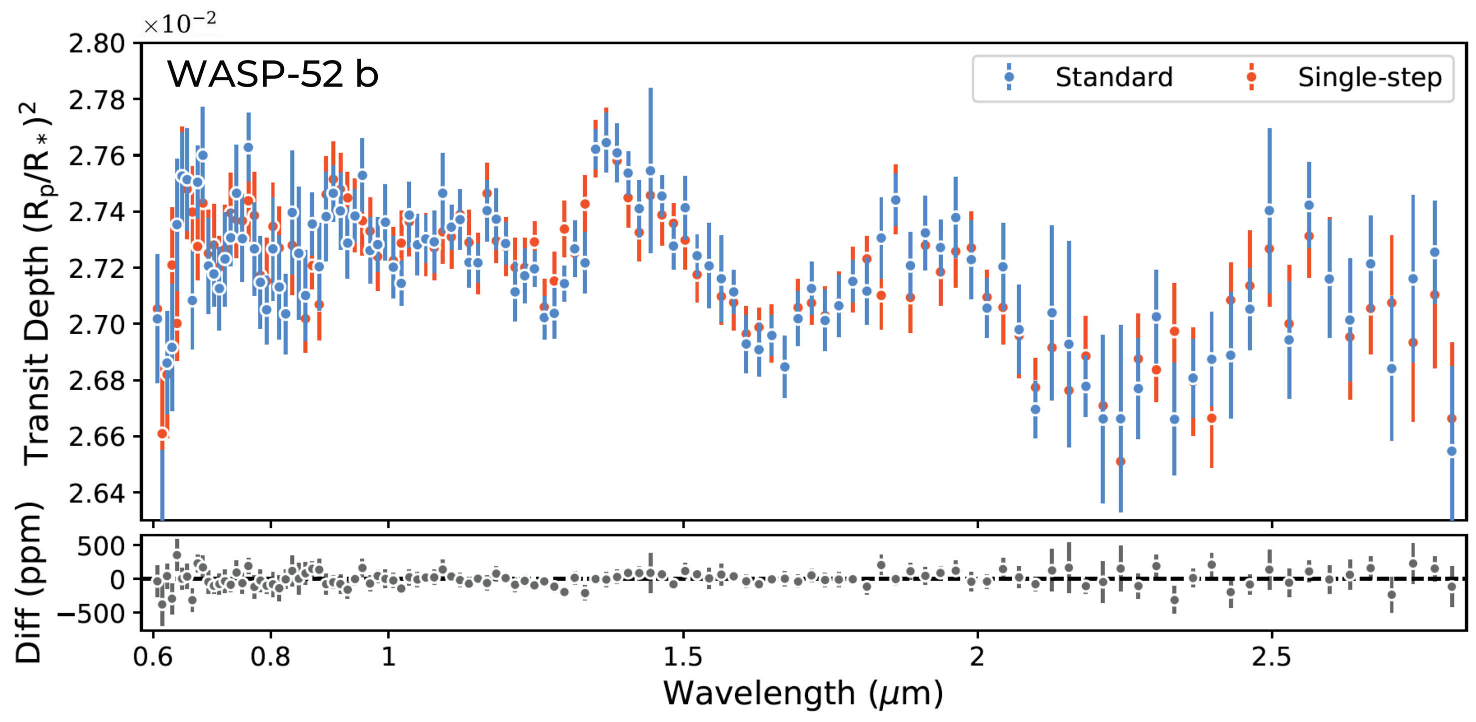


Figure 3. Transmission spectra retrieved with the two approaches for WASP-52 b.

4.

RETRIEVAL ANALYSIS

Our results highlight the exceptional promise of simultaneous planetary atmosphere and stellar heterogeneity constraints in the era of JWST and emphasize the risk of biasing atmospheric inferences when joint retrievals are not performed.

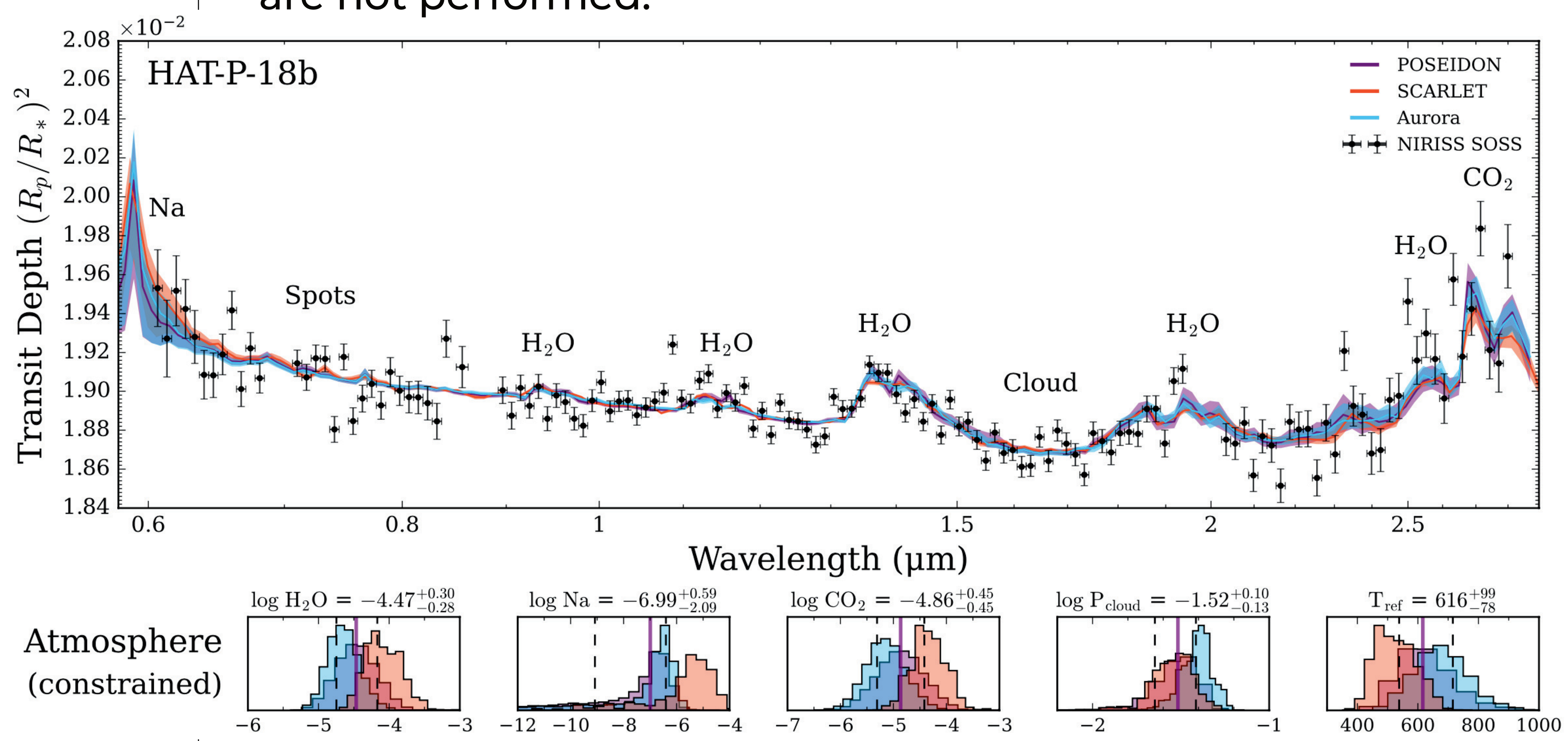


Figure 4. Atmospheric retrieval results for HAT-P-18 b.

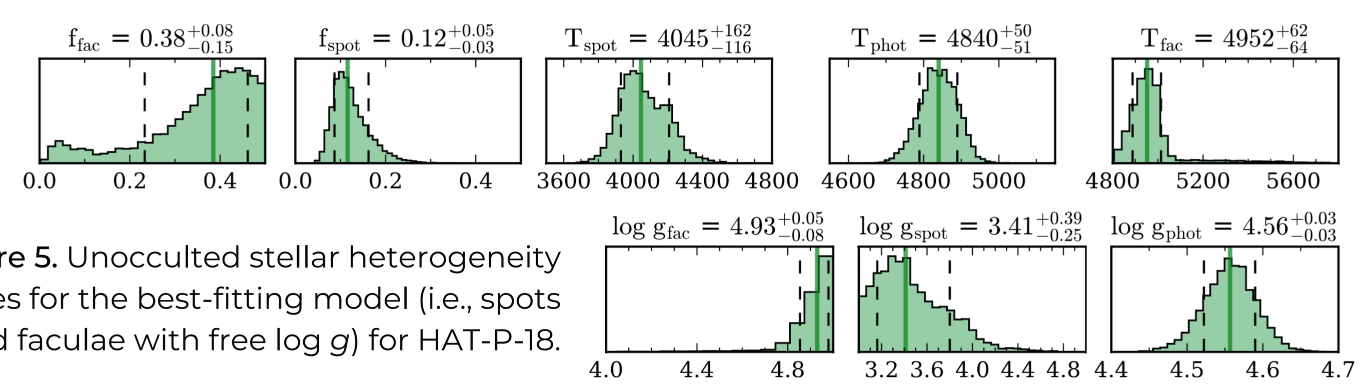


Figure 5. Unocculted stellar heterogeneity properties for the best-fitting model (i.e., spots and faculae with free log g) for HAT-P-18.

5.

CONCLUSION

Our results demonstrate that JWST transit observations may warrant more complex treatments of stellar heterogeneities in both transit light curves and transmission spectra.

REFERENCE [1]Benjamin V. Rackham *et al* 2018 *ApJ* **853** 122, [2]Bence Béky *et al* 2014 *MNRAS* **442** 4, [3]Giovanni Bruno *et al* 2022 *MNRAS* **509** 4