Analyzing Spectral Features in the JWST/NIRSpec Transmission Spectrum of LTT 9779b

DEPARTMENT OF PHYSICS & ASTRONOMY

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Introduction

LTT 9779b is a planet in the Hot Neptune Desert, a region with few Neptune-mass planets that have orbital periods shorter than 4 days [1, 2]. LTT 9779b has a mass of 29.32 Earth masses (or about 1.71 Neptunian masses), a radius of 4.72 Earth radii (or about 0.4 Jupiter radii), and an orbital period of 0.792 days [3]. This planet is the hottest ultrahot Neptune exoplanet we know of with a T_{eq} of ~1978 K, and the only hot Neptune we know of that has retained an atmosphere [3-5].

We observed two secondary eclipses, one transit, and a full-orbit phase curve. These observations were conducted as part of the GO 3231 program (JWST Cycle 2, PI: Crossfield). Observations occurred from October 17, 2024, 07:35:52 UT to October 18, 2024, 05:10:30 UT.

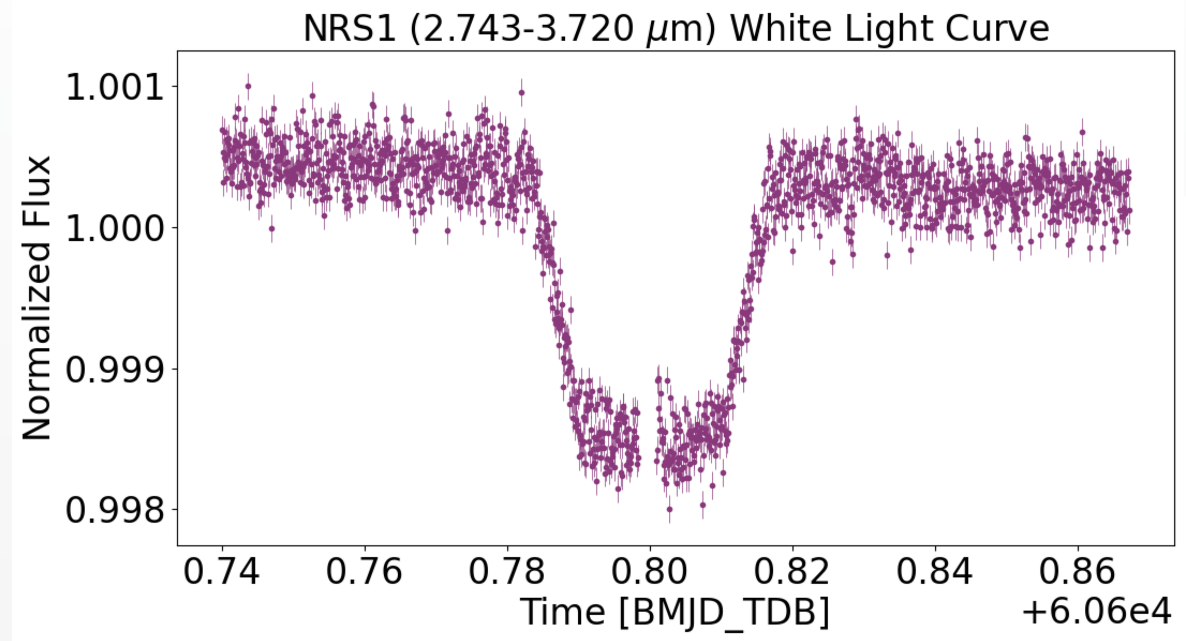
We present a transmission spectrum obtained using the James Webb Space Telescope (JWST) Near-Infrared Spectrograph (NIRSpec) PRISM in the Bright Object Time Series (BOTS) mode.

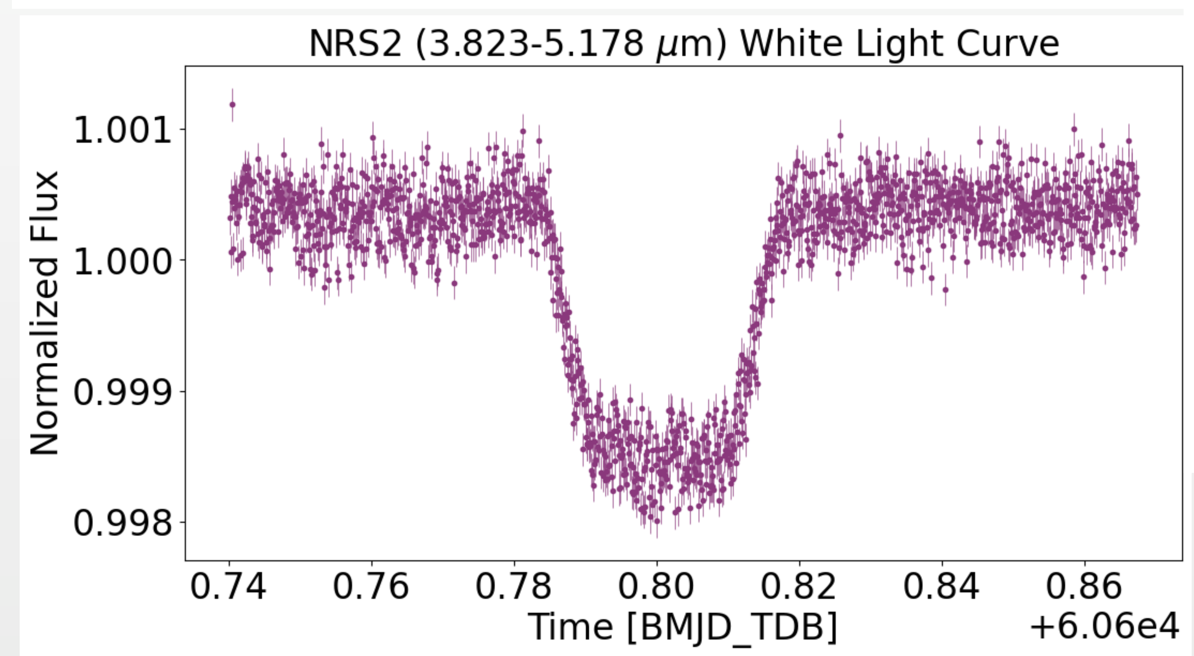
Data Reduction and Analysis

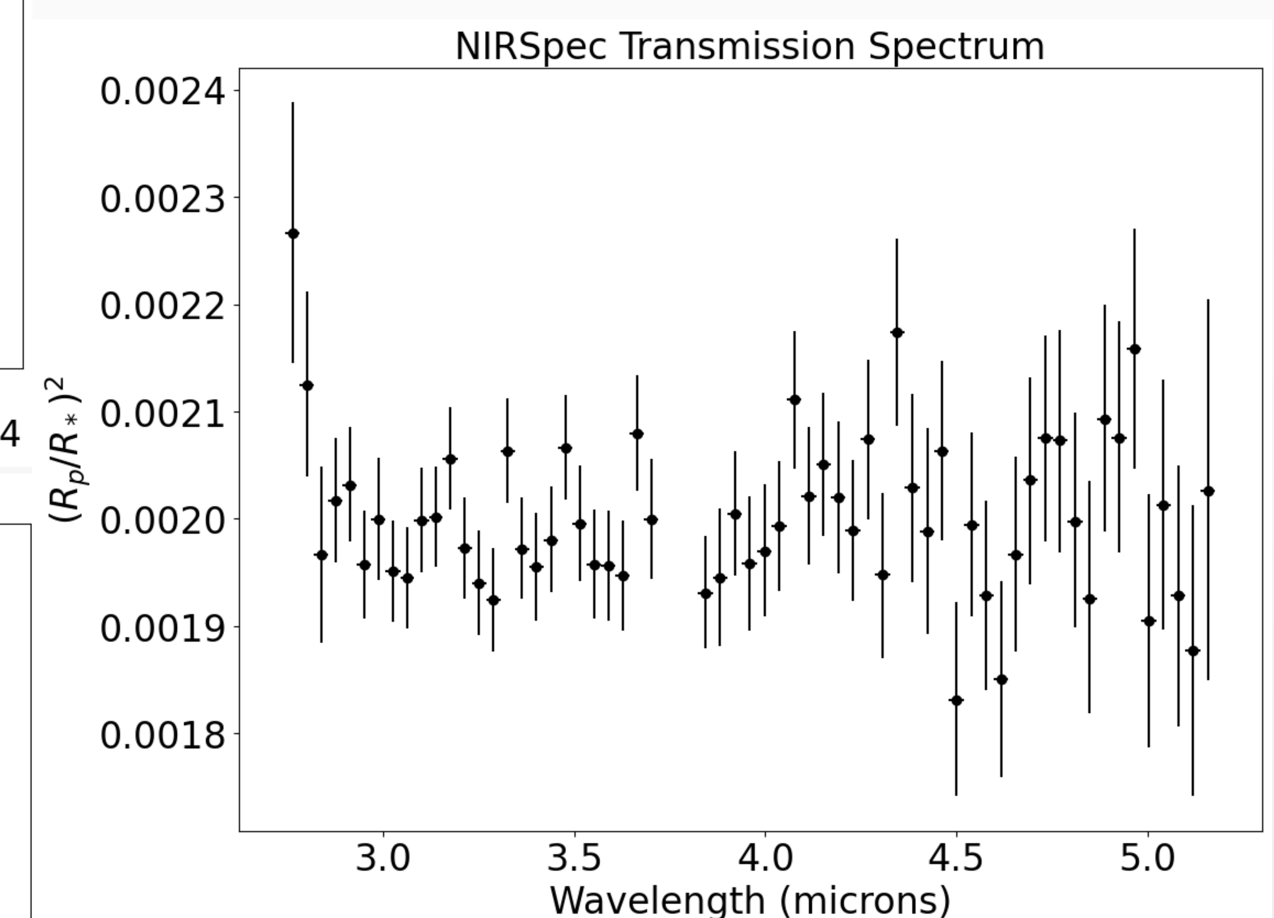
We reduced the NRS1 and NRS2 transit data and generated spectroscopic light curves and a final transmission spectrum using the Eureka! pipeline [6]. Stages 1–2 wrap the JWST pipeline; Stage 3 performs background subtraction and optimal spectral extraction using a smoothed spatial profile and Median Absolute Deviation subtraction, masking <0.7% of pixels. Stage 4 generates white and spectroscopic light curves (2.743–3.720 μm for NRS1, 3.823–5.178 μm for NRS2), applies 5σ outlier rejection, and computes wavelength-dependent limb-darkening parameters with ExoTiC-LD. In Stage 5, we jointly fit the NRS1 and NRS2 white light curves to refine orbital parameters (shared t_0, a, and i) before fitting spectroscopic light curves using batman and emcee (2500 steps, 200 walkers). Free parameters per channel include r_p, polynomial baseline terms (0^{th} and 1^{st} order), and a noise multiplier. Stage 6 yields the final transmission spectrum.

We used petitRADTRANS [7, 8] for forward modeling and retrievals. We began with forward modeling to gain intuition about what molecules should be present and obtain initial abundances. We then performed atmospheric retrievals on the spectrum using those molecules, first with an opaque cloud deck and then Mg_2SiO_4 and $MgSiO_3$ clouds using f_{sed} and K_{zz} values from [9].

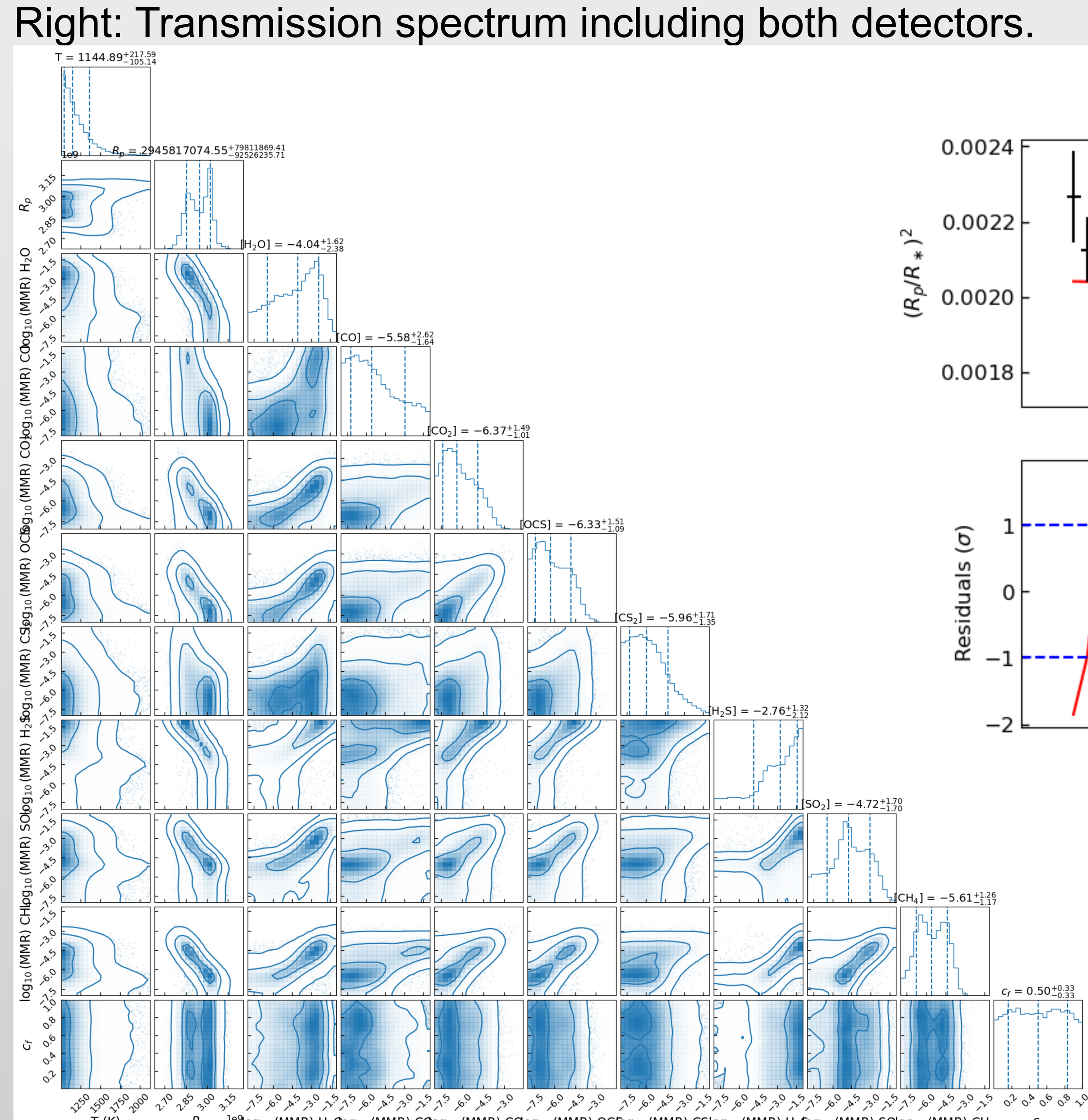
Results

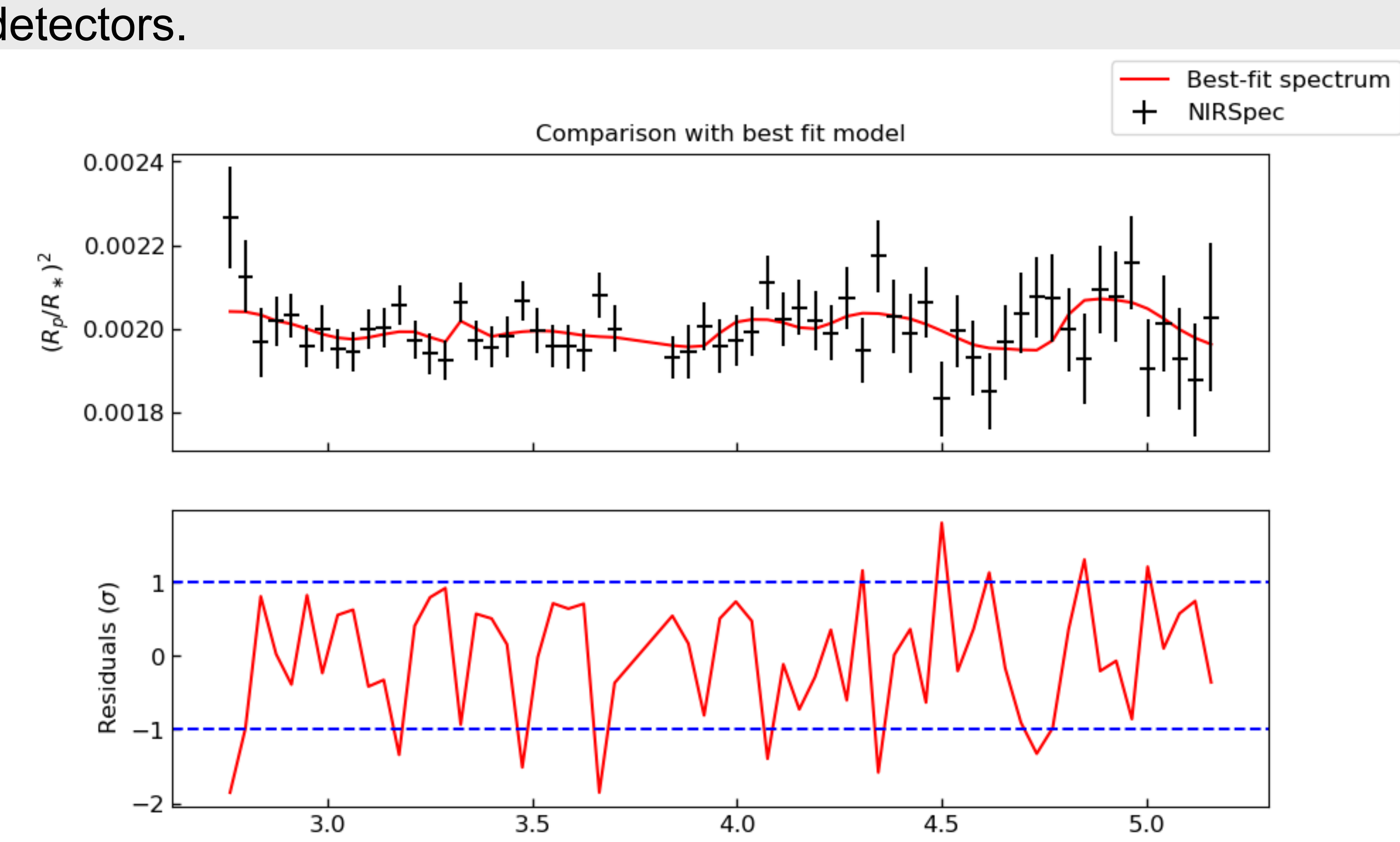






Left: **Un-detrended** transit white lightcurves for NRS1 (upper panel) and NRS2 (lower panel). These are outputted from Eureka Stage 4.
Right: Transmission spectrum including both detectors.





Left: Corner plot from the petitRADTRANS retrieval on the transmission spectrum.
Right: Transmission spectrum with the best-fit model from the retrieval overplotted on the upper panel, and a plot of residuals between the data and the retrieval on the lower panel.

Conclusions

Our JWST/NIRSpec transmission spectrum for LTT 9779b reveals clear evidence for atmospheric absorption across the 2.7–5.2 μm range. Our retrievals yield well-constrained estimates for the planet's atmospheric properties, including its temperature, and confident detections of several molecular species. We find strong evidence for H_2O, CO, and CO_2, which is consistent with a moderately metal-enriched atmosphere. Additionally, we detect sulfur-bearing species including H_2S, and tentative signatures of SO_2 and CS_2. The retrieved cloud fraction points to partial cloud coverage, which may contribute to the muted amplitude of the spectral features. The best-fit retrieval reproduces the observed spectrum well, with residuals largely within one standard deviation.

Future work will aim to finalize the transmission spectrum through tests comparing different free parameters for modeling the transit, constrain atmospheric metallicity and molecular abundances through continued retrievals, and validate pressures and cloud types through additional retrievals incorporating different cloud species. We also intend to perform joint fits with the NIRISS/SOSS data previously analyzed in [10], as well as joint fits with the secondary eclipse and phase curve data obtained from this NIRSpec observation, to determine what molecules dominate in the atmosphere and obtain information on the molecular abundances as a function of atmospheric pressure.

Acknowledgements and References

The authors would like to thank the developers of Eureka! for their assistance and helpful conversations.

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