WASP-121 b's transmission spectrum observed with JWST/NIRSpec G395H reveals partially dissociated atmosphere

Cyril Gapp[1] (gapp@mpia.de), Thomas M. Evans-Soma[2,1], Joanna K. Barstow[3], Joshua D. Lothringer[4,5], David K. Sing[6,7], Duncan Christie[1], Laura Kreidberg[1], Nathan J. Mayne[8]

WASP-121 b

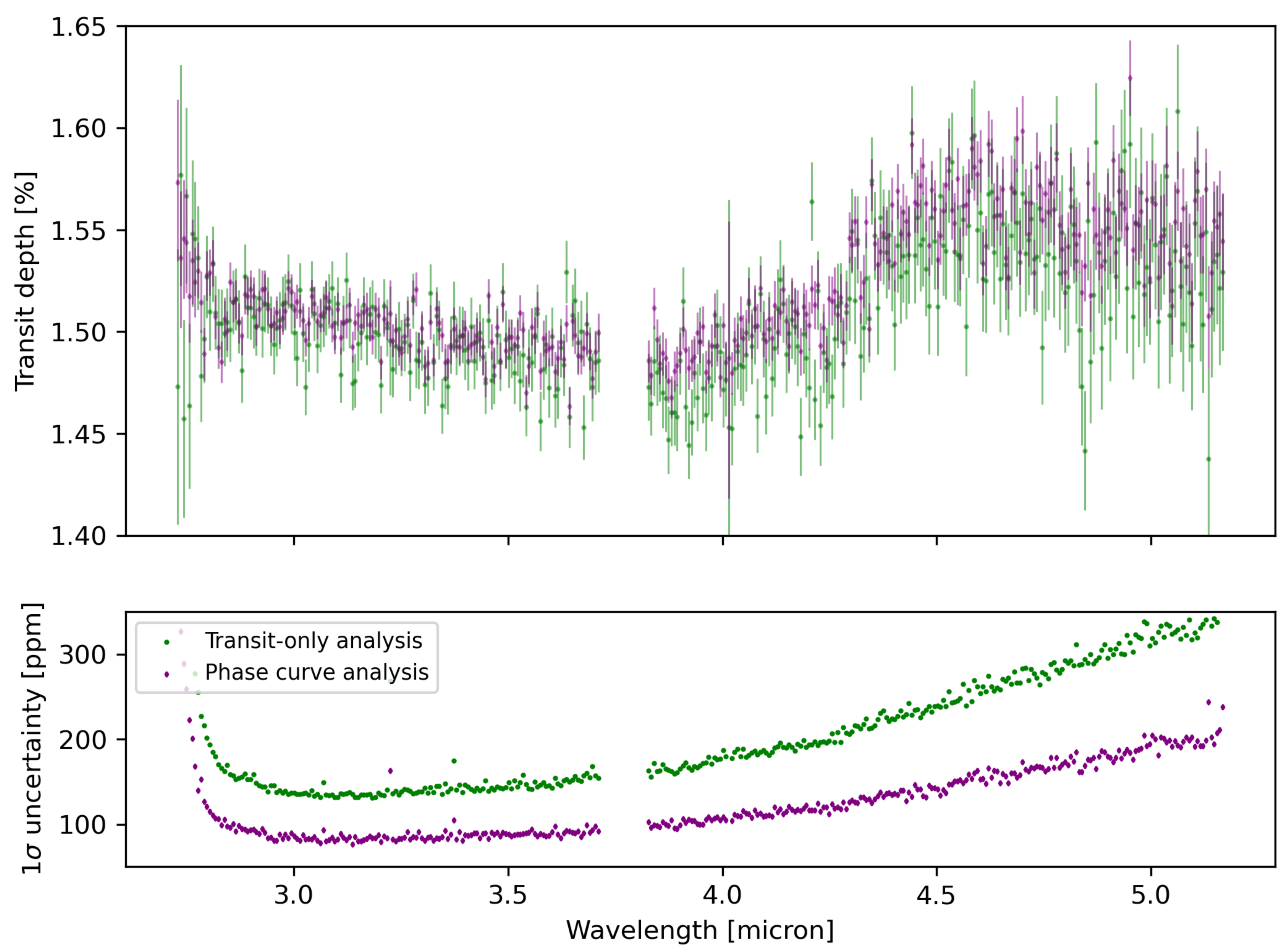
Basic data:

$1.2\,M_J$	$P_{rot} = 1.27$ d	$a/R_s = 3.81$
$1.8\,R_J$	$T_{14} = 2.91$ h	$T_{eq} \approx 2400$ K

WASP-121 b is an Ultra-Hot Jupiter (UHJ) that orbits its F-type host star in extremely close proximity. Its atmospheric temperatures are high enough to vaporize most elements, yielding the opportunity to investigate the planet's complete chemical inventory and subsequently to constrain its formation and migration to its current orbit.

WASP-121 b's dayside is hot enough to dissociate most molecules, including H_2, but excluding CO, in the atmosphere. On the nightside, temperatures are low enough for molecules to recombine, leading to a substantial chemical heterogeneity between hemispheres (Parmentier et al. 2020). Therefore, this heterogeneity must be carefully accounted for to quantify the planet's chemistry.

Transmission Spectrum



We took two different approaches to model the light curves:

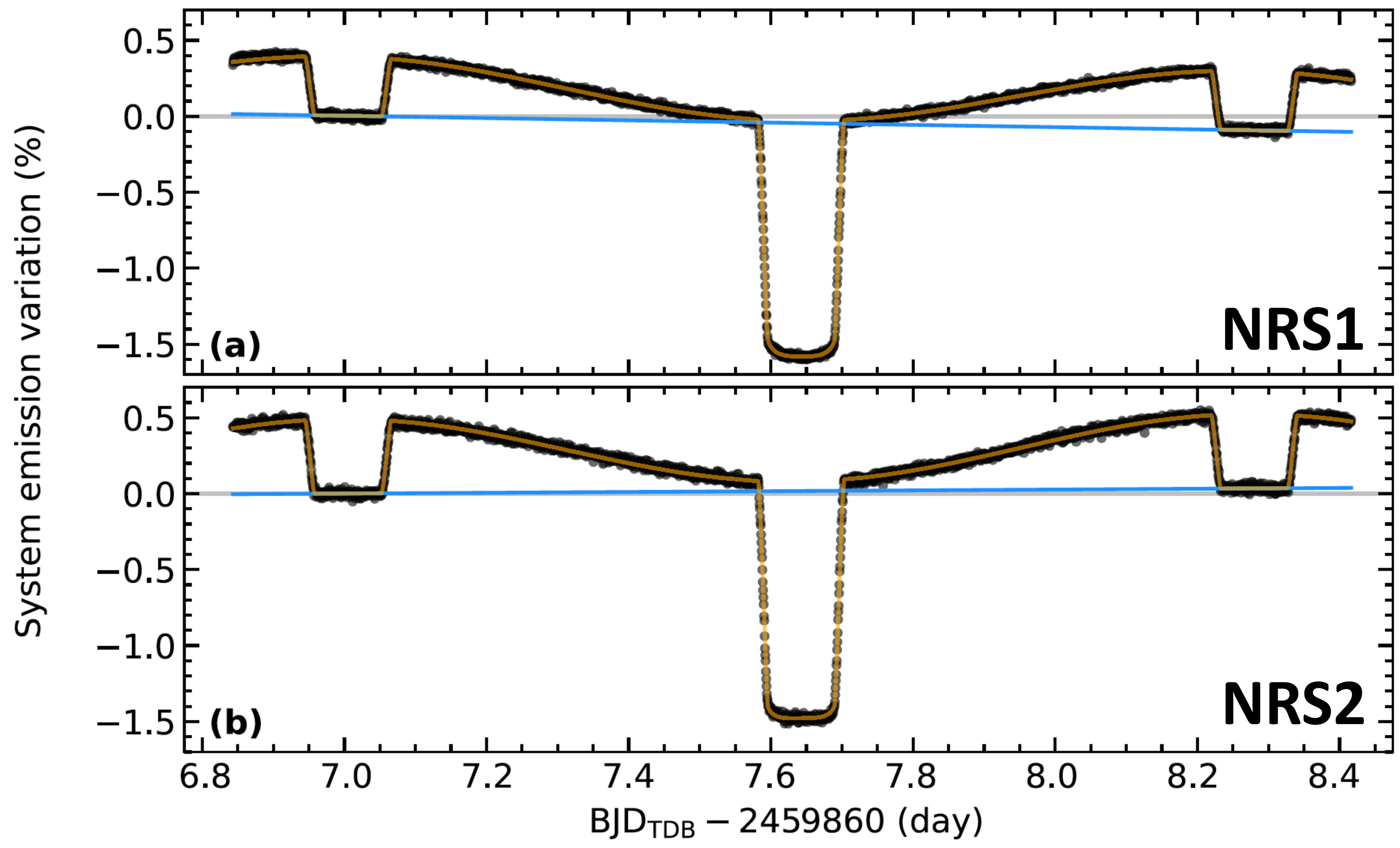
1. Transit-only analysis: We analyzed the transit by cutting out the data from 3.5 h before to 3.5 h after the transit midtime
2. Phase curve analysis: A full analysis of the phase curve

For the transit-only analysis, we modeled the out-of-transit flux using a second-order polynomial in time to grasp the curvature caused by the planet's phase curve around the transit. The phase curve curvature, however, is correlated with the transit depth, as a stronger curvature would reach lower fluxes during transit. This leads to **larger uncertainties on the transmission spectrum** compared to the full phase curve analysis which constrains the phase curve curvature more tightly.

Conclusions

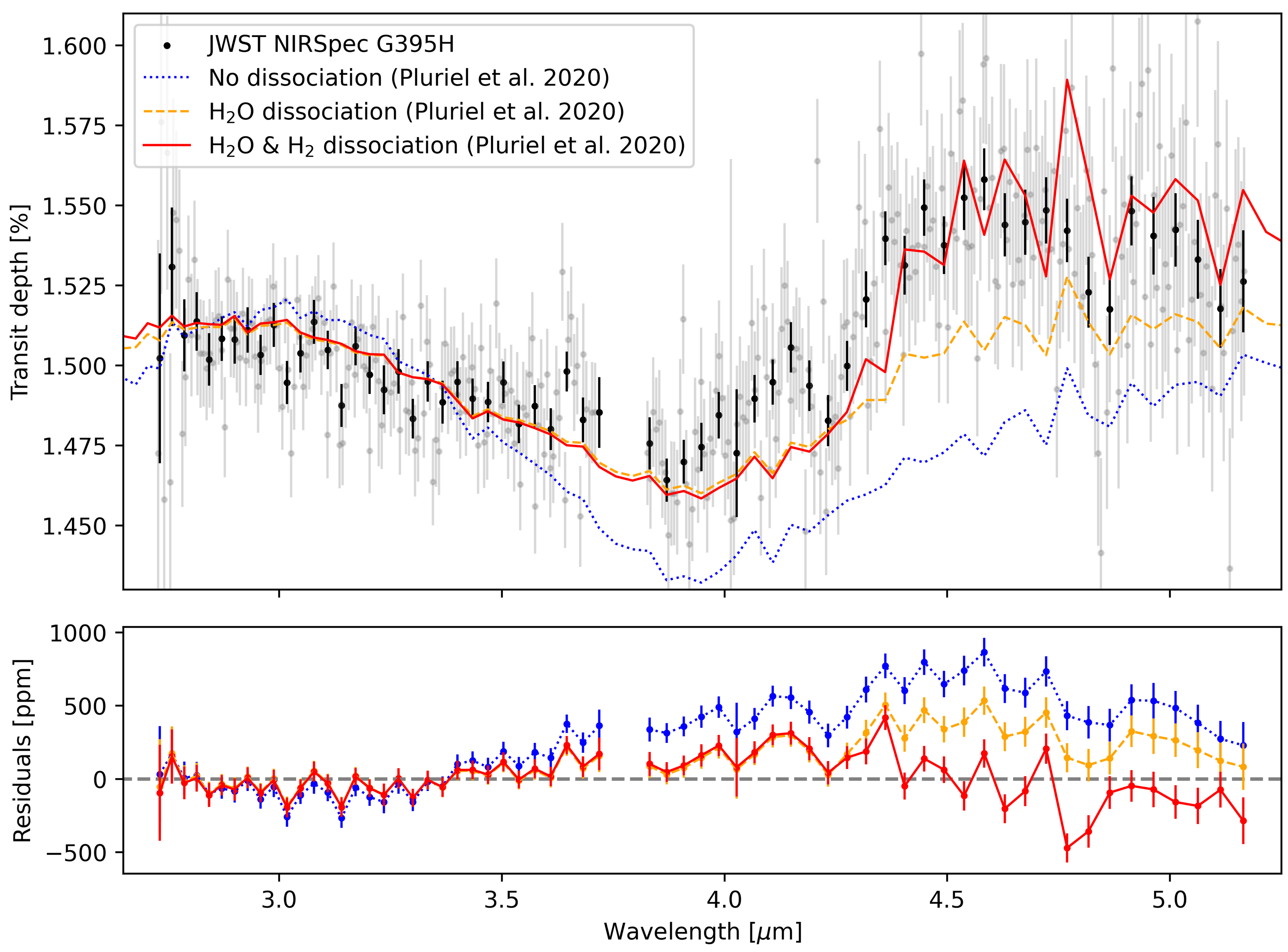
1. At JWST's wavelengths, WASP-121 b's phase curve is strongly curved and **tight constraints on the curvature are needed** to obtain a high-precision transmission spectrum.
2. Including **thermal dissociation of both H_2O and H_2** in GCM spectra is needed to match the observations.
3. In NIRSpec's wavelength range, the **transmission spectrum is a composite of atmospheric opacities on both the dayside and the nightside** due to absorption by H_2O (dissociated on the dayside) and CO (abundant on both hemispheres).

Observation



Program GO-1729 (PI: Evans-Soma, co-PI: Kataria) was dedicated to observing a **full phase curve** of WASP-121 b using JWST/NIRSpec G395H, including one transit. Over the 37.8 hour long observation, the spectra were dispersed over the instrument's NRS1 and NRS2 detectors ranging from 2.54 − 3.72 µm and from 3.82 − 5.15 µm, respectively. An analysis of the white light curves of the observations (see Fig. above) was published by Mikal-Evans et al. (2023).

Comparison to GCM spectra



Post-processed GCM spectra including varying degrees of thermal dissociation (Pluriel et al. 2020) reveal that both H_2O and H_2 dissociation are required to match the observations, because:

1. H_2O dissociation flattens out the H_2O absorption feature on NRS1 due to the decrease of H_2O's abundance on the dayside. Thus, the observed absorption feature mainly probes the planet's nightside.
2. H_2 dissociation inflates the CO absorption feature at $\lambda > 4.3$ µm. The increase of the atmospheric scale height caused by H_2 dissociation boosts absorption features of any molecule residing on the dayside. As CO, unlike H_2O, is abundant on the dayside, H_2 dissociation inflates CO's absorption feature but leaves the H_2O absorption signal unchanged.

Therefore, the transmission spectrum is a **composite of atmospheric opacities on both the planet's dayside and nightside**, as the H_2O absorption feature mostly originates from the nightside while the CO feature samples both hemispheres.

Retrieval study

Check out poster #1223 by Joanna Barstow for an atmospheric retrieval study on this data set.

References: *Mikal-Evans*, T., Sing, D. K., Dong, J., et al. 2023, ApJL,943, L17, doi: 10.3847/2041-8213/acb049; *Parmentier*, V., Line, M. R., Bean, J. L., et al. 2018, A&A, 617, A110, doi: 10.1051/0004-6361/201833059; *Pluriel*, W., Zingales, T., Leconte, J., & Parmentier, V. 2020, A&A, 636, A66, doi: 10.1051/0004-6361/202037678

Affiliations: [1]Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany; [2]School of Information and Physical Sciences, University of Newcastle, Callaghan, NSW, Australia; [3]School of Physical Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK; [4]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA; [5]Department of Physics, Utah Valley University, 800 W University Pkwy, Orem, UT 84058, USA; [6]Department of Earth & Planetary Sciences, Johns Hopkins University, Baltimore, MD, USA; [7]Department of Physics & Astronomy, Johns Hopkins University, Baltimore, MD, USA; [8]Department of Physics and Astronomy, Faculty of Environment, Science and Economy, University of Exeter, Exeter EX4 4QL, UK