Tracing day-night atmospheric gradients in ultrahot Jupiters via transit spectroscopy

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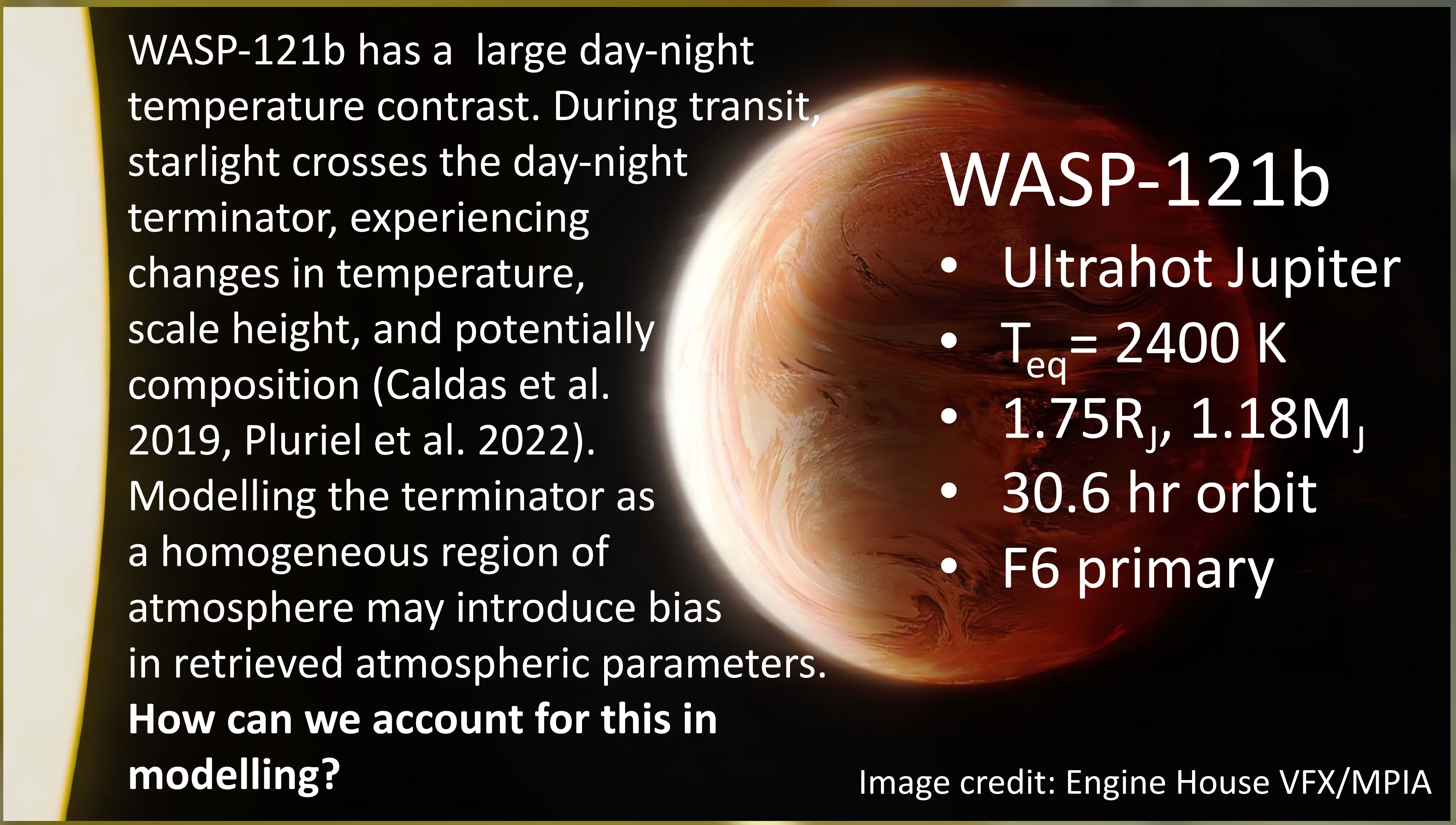
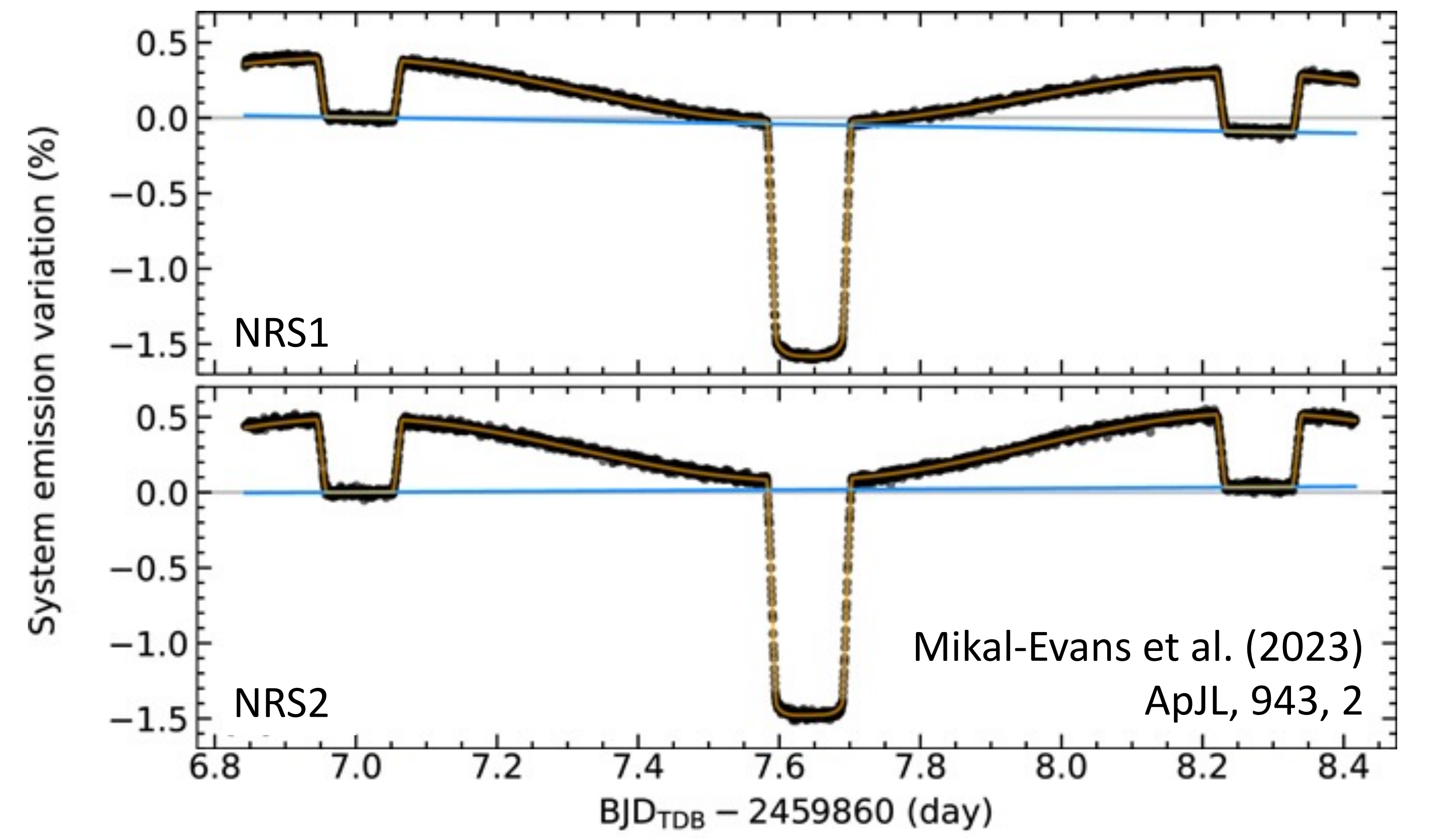


WASP-121b has a large day-night temperature contrast. During transit, starlight crosses the day-night terminator, experiencing changes in temperature, scale height, and potentially composition (Caldas et al. 2019, Pluriel et al. 2022). Modelling the terminator as a homogeneous region of atmosphere may introduce bias in retrieved atmospheric parameters. **How can we account for this in modelling?**

WASP-121b

- Ultrahot Jupiter
- T_{eq}= 2400 K
- 1.75R_J, 1.18M_J
- 30.6 hr orbit
- F6 primary

Image credit: Engine House VFX/MPIA



Mikal-Evans et al. (2023) ApJL, 943, 2

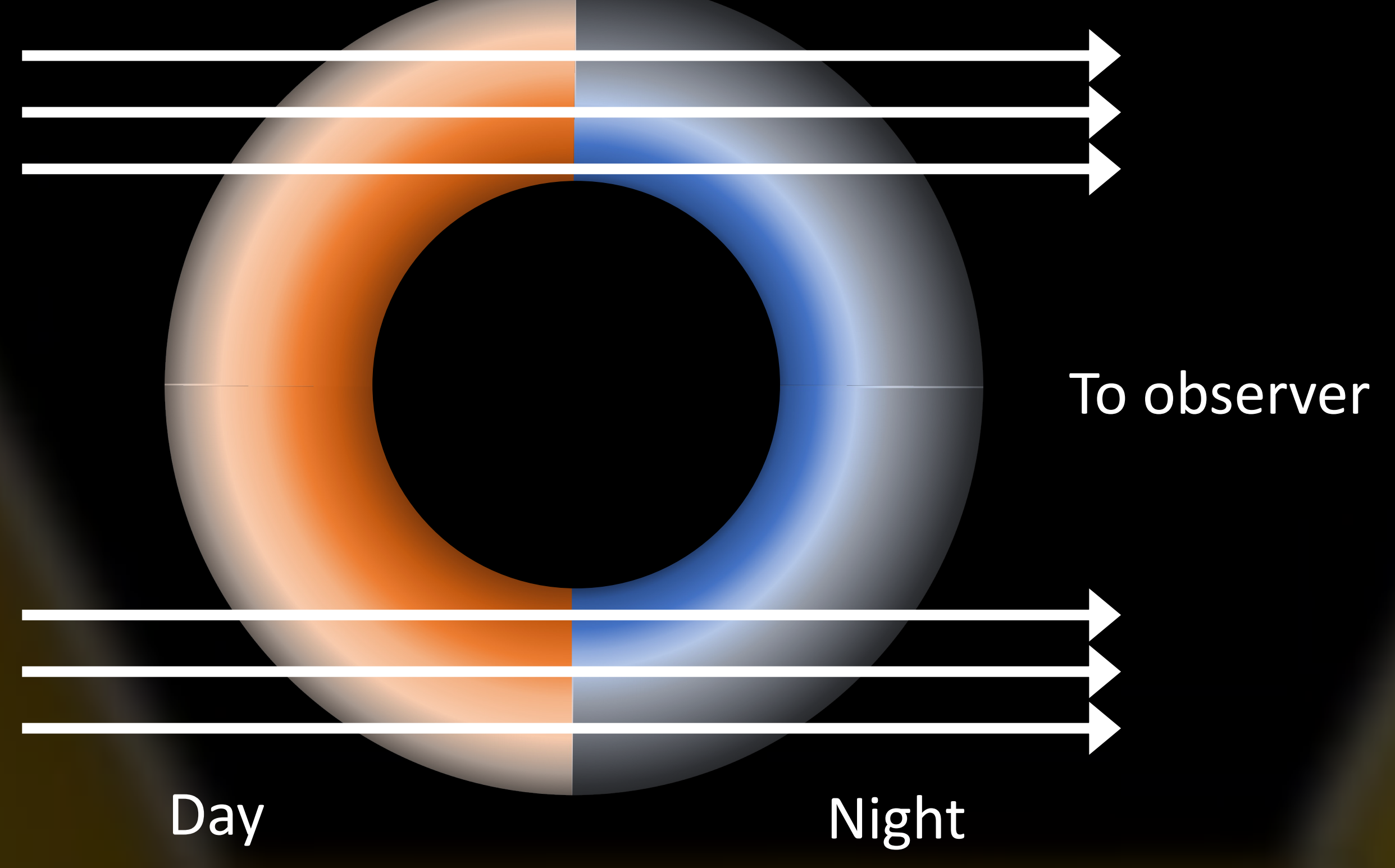
38-hour phase curve observation with NIRSpec/G395H. Includes 1 transit . Day-night temperature contrast > 1000K.

The model:

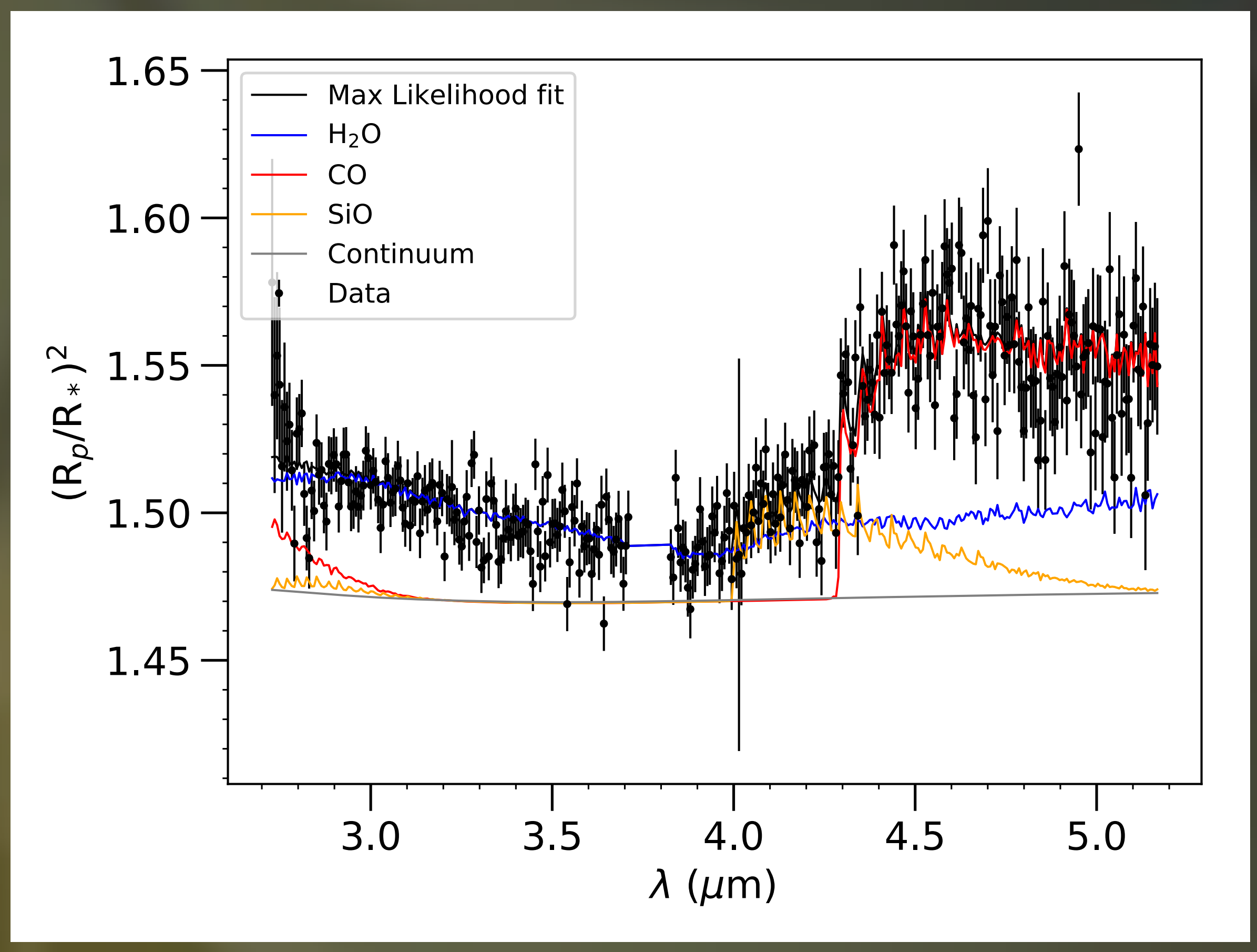
- Uses NEMESIS retrieval framework (Irwin et al. 2008) + PyMultinest (Feroz & Hobson 2008, Feroz et al. 2009, Feroz et al. 2019, Buchner et al. 2014)
- Simplest possible approach – divide between day and night regions along the terminator.
- Day and night T-p profiles use modified Guillot profile (Guillot et al. 2010). Dayside is described by 3-parameter Guillot profile, nightside is described as follows assuming no incoming radiation at the top of the atmosphere:

$$T(p) = \left(\frac{3}{4}\left(T_{\mathrm{int}} + a^{1/4}\,T_{\mathrm{day}}\right)^4 \left(\frac{2}{3} + \frac{\kappa_{\mathrm{night}}p}{g}\right)\right)^{1/4}$$

where T_{int} is internal temperature, T_{day} is the temperature at the bottom of the model atmosphere on the dayside, a represents day-night heat transport, κ_{night} is the infrared opacity on the nightside, p is pressure and g is the gravitational acceleration.



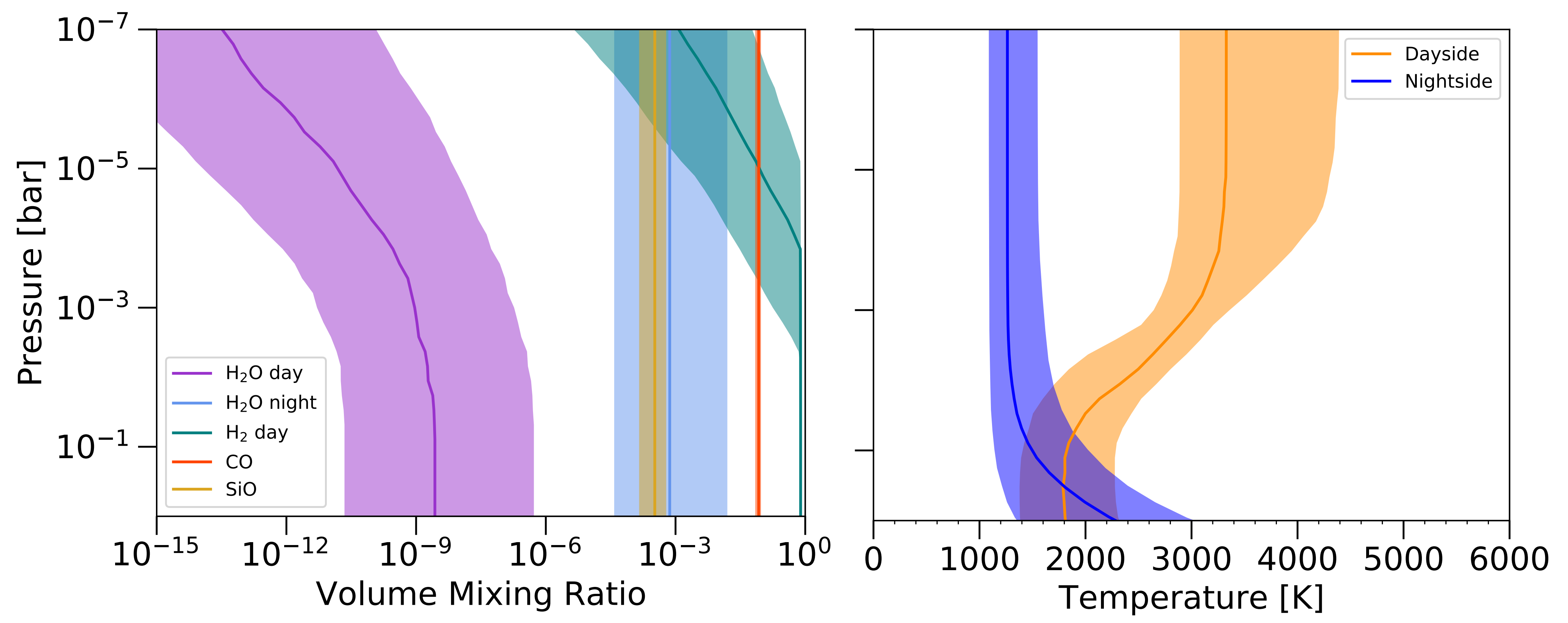
- Gases retrieved: H_2O(day), CO_2(day), H_2O(night), CO_2(night), CO, SiO, SiH, H^-(day)
- H_2 and H_2O are both allowed to dissociate on the dayside, parameterized with a variable knee pressure and a power law index for the rate of decrease at $p < p_{\mathrm{knee}}$.
- Grey cloud is included with scaled opacity.



Spectrum from Gapp et al. (2024) with NEMESIS best fit model and gas contributions highlighted.

The spectrum:

- For more details on the spectrum and data reduction see poster 1190 (Cyril Gapp).
- Fit includes contributions from CO, H_2O (mostly from nightside) and SiO. No CO_2 or SiH detected.
- Retrieved CO abundance is a few % of the atmosphere.
- H^- unconstrained (free-free absorption in G395H range is weak) and cloud properties unconstrained.



Left: retrieved volume mixing ratios of constrained gases H_2O, CO and SiO plus dayside H_2. Dissociated H is assumed to be converted to atomic H. Right: retrieved dayside and nightside T-p profiles.

Take-home points:

- Dayside atmosphere has temperature inversion as expected and retrieval favours thermal dissociation of H_2. Dayside H_2O abundance is low overall but transit spectrum insensitive to pressures > 10 mbar.
- Nightside H_2O is constrained at ~solar abundances but 1σ confidence interval spans 2 orders of magnitude.
- Dual atmosphere method only marginally favoured over retrieval assuming homogeneous terminator – information content in NIRSpec/G395H alone possibly does not justify this. Tests with G395H+WFC3 ongoing, NIRISS/SOSS data from programme 1201 may also provide more constraint.

References:
Caldas et al. 2019 A&A 623 A161; Pluriel et al. 2020 A&A 636 A66; Irwin et al. 2008 JQSRT 109 1136; Feroz & Hobson 2008 MNRAS 384 449; Feroz et al. 2009 MNRAS 398 1601; Feroz et al. 2019 OJA 2 10; Buchner et al. 2014 A&A, 564, A125; Mikal-Evans et al. 2023 ApJL 943 2; Guillot et al. 2010 A&A 520 A27; Gapp et al. (2024, under review)