National Aeronautics and Space Administration

THE ROLE OF HAZE IN EXOPLANET TRANSIT SPECTRA

Principal Investigator: Robert West (322)
Gaël Roudier and Mark Swain (both 326)
Program: Exoplanetary Science Initiative

Project Objective:

As the steady accumulation of exoplanet transit spectra and secondary eclipses becomes available it is increasingly clear that condensate cloud or photochemical haze opacity plays an important role in shaping the nature of the spectra. In the most extreme cases such as for GJ 1214b, the spectrum is flat with no spectral features from gas. In order to interpret spectra to infer gas mixing ratios, especially C/O, it is necessary to take into account the effects of clouds and haze. Up to now models to fit transit spectra include only condensate clouds and the aerosol distribution is only crudely modeled. Here we use a Jupiter photochemical haze profile as a starting point to better understand how photochemical haze can influence transit spectra.

FY18/19 Results:

Part 1: Retrieval for WASP 79b using WFC3 data

This study makes use of the transit spectra pipeline Excalibur designed by Mark Swain's group, and, as part of that, the Cerberus retrieval package that uses the MCMC (Monte Carlo Markov Chain) and Bayesian formalism implemented by Gaël Roudier. We augmented the retrieval procedures to include haze parameters (perturbations on the Jupiter haze profile) as listed in Table 1 below. We retrieved these parameters as well as the usual ones for gas composition for the planet WASP 79b using spectra obtained by the Wide Field Camera 3 (WFC3) on the Hubble Space Telescope. Figure 1 shows the data and the fit to the data. For this case the haze needs to be spread over many scale heights and its pressure at peak density needs to be about a factor of 10 less than for the Jupiter case. The retrieval procedure also revealed detection of HCN with high probability as shown in Fig. 2.

Part 2: Forward model extension relevant to JWST and HST STIS Visible

We can anticipate that data expected from instruments on the James Web Space Telescope will significantly advance the state of the art for transit spectra thanks to increased sensitivity and spectral range, out to 5 μm. Accordingly, we computed a suite of forward models over a broader spectral range. A sample of these are shown in Figure 3. Panel A shows the best-fit model from Fig. 1 over the broader wavelength range. The other panels have the same set of parameters except for one, as indicated in the caption. Of particular note is the spectral behavior at and below 1.1 μm. Because of its very broad vertical distribution the best-fit haze profile produces a very large rise in to the visible. The rise toward short wavelengths is not nearly as great when the only short-wave opacity is Rayleigh scattering from H2 and He (Panel B), and we see a notch just below 1.1 μm. Also of interest are an intermediate case in Panel C (haze has a vertical spread the same as for Jupiter but at a higher altitude) and Panel D where the haze is spectrally flat.

Significance of results:

This work expands current state of the art for transit spectral modeling by revealing the ways that a high-altitude photochemical haze can shape transit spectra. It also puts us in a position to take advantage of new data expected from JWST.

Retrieval Results for WASP-79b

Table 1. Haze Parameters For the Retrieval

Parameter	Range	Description	Retrieved Value
Haze	$2.5X10^{-4}$ – 1.0	Haze cross section multiplier (1 = Jupiter)	0.0025
HZTOP	$1.6X10^{-5}$ – 1.6	Pressure (mbar) at peak haze density	1.6
HZSCALE	0.1 – 4.5	Vertical (Log Pressure) scale multiplier (1 = Jupiter)	4.5
HZSLOPE	-4.0 - 0.0	Wavelength Exponent Rayleigh scattering corresponds to -4.0	-4.0

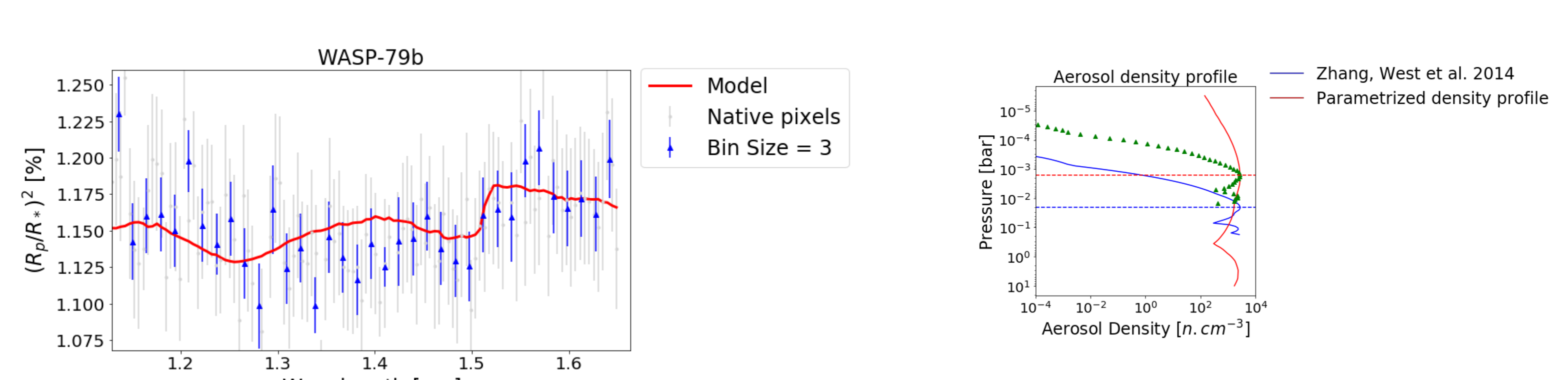

Figure 1 Retrieval results for WASP 79b. Left panel: WFC3 data with uncertainties. R_p/R_* is the ratio of the planet to star radius. The model spectrum is derived from gas and haze parameters as indicated in Table 1. The best-fit haze profile is shown in the right panel along with the Jupiter profile from Zhang et al. The green symbols show the Jupiter profile moved to higher altitude for referencing with the more extended best-fit profile in red.

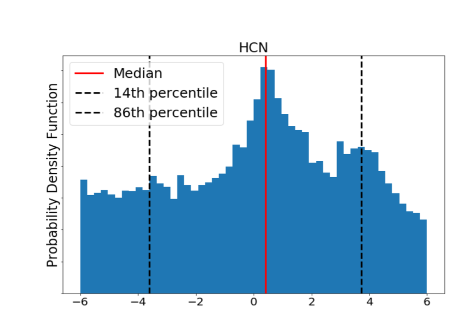

Figure 2. Probability distribution for detection of HCN in the spectrum of WASP 79b

Forward Models for JWST

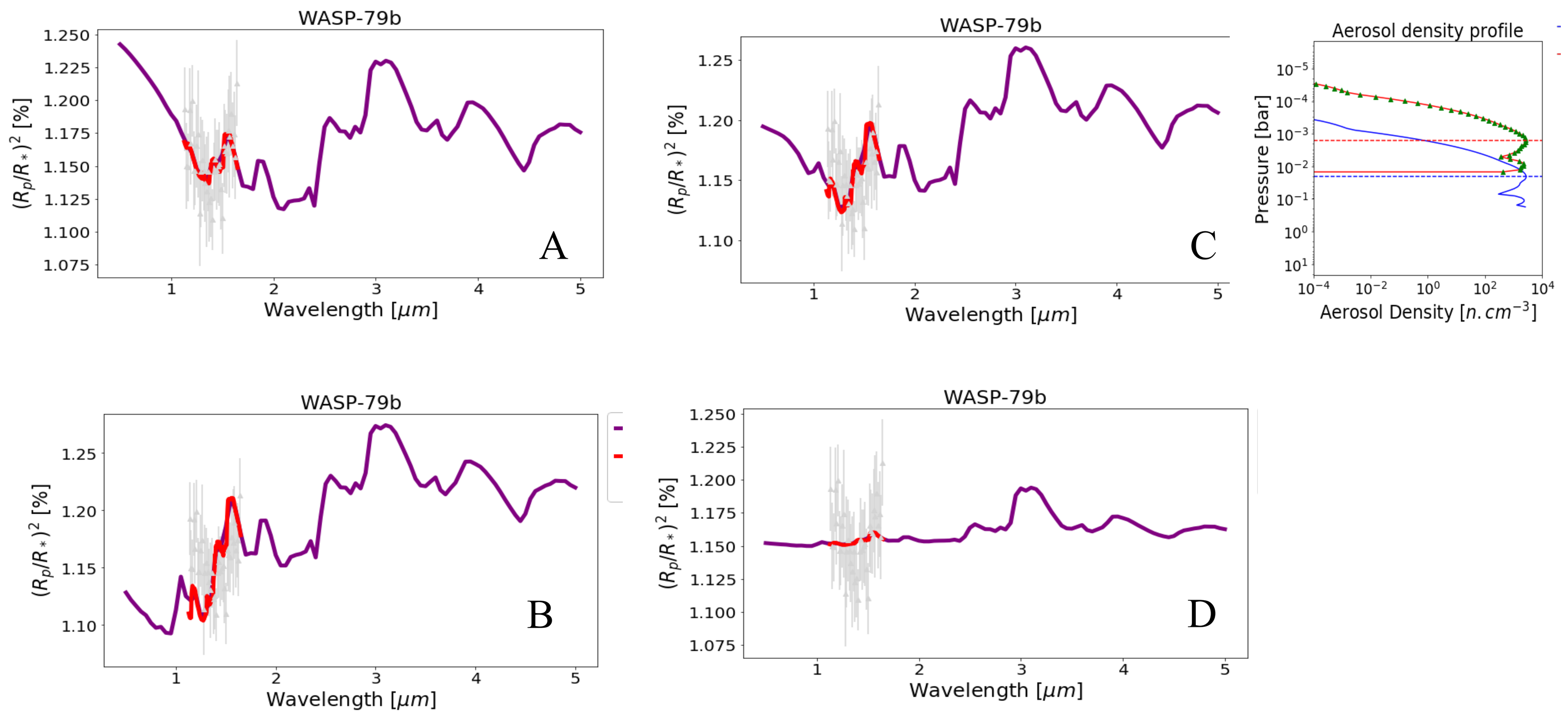

Figure 3. Panel A: Extended synthetic spectrum calculated using best-fit haze and gas parameters listed in Table 1 with results shown in Figs 1 and 2. Panel B: Same as panel A, but without haze. Panel C: Same as panel A except the haze now has the Jupiter profile but moved to have a peak at 1.6 mbar pressure as in panel A (red curve and green symbols). The haze profile is shown to the right of this panel (compare with Fig. 1 right panel). Panel D: same as panel A except the haze has no spectral slope. In all panels the red segment covers the spectral range of the WC3 measurements which are show as gray vertical bars.

Publication status:

West, R., G. Roudier and M. Swain, Photochemical Haze in Hydrogen-Rich Exoplanet Atmospheres: Lessons from Jupiter's Polar Haze (in preparation as of 9/26/2019; to be submitted to The Astrophysical Journal)

PI/Task Mgr. Contact Information:
818 354 0479 Robert.A.West@jpl.caltech.edu

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

Poster No. RPC-036