National Aeronautics and Space Administration

Validating Eclipse Mapping Techniques with Spitzer

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Objectives

- Construct **eclipse maps** of HD 189733b and HD 209458b using eclipse observations with Spitzer at 3.6 and 4.5 microns
- Compare the resulting maps to general circulation models (GCMs) previously produced by PI Kataria
- Use results from GCMs to determine functional forms that can approximate the atmospheric dynamics to fit the resulting 2D temperature maps

Background

- Eclipse mapping is an observational technique that utilizes the ingress and egress of a transiting exoplanet's secondary eclipse
- At infrared wavelengths, this scans the dayside brightness distribution of the planet at an angle related to its impact parameter, yielding a spatially resolved map of the planet's dayside atmosphere (in latitude and longitude, [1], Fig. 1)
- Technique was first demonstrated using multiple Spitzer 8μm eclipses of the ~1300 K hot Jupiter HD 189733b [2,3]
- **JWST will likely be a workhorse for eclipse mapping and understanding 3D atmospheric processes**
  - JWST's greater sensitivity and broader wavelength coverage enable spectroscopic eclipse mapping for some targets from a single eclipse, thus requiring far less observing time than full-orbit phase curves
  - The technique can also be used to map longer-period, cooler Neptune- to Earth-sized planets.
  - ***Motivation: Need to validate data analysis tools and models for eclipse mapping in advance of these observations***

Results/Relevance

- We analyzed Spitzer 3.6 and 4.5 micron eclipses of the hot Jupiters HD 189733b and HD 209458b using proven data reduction analysis methods [4]. This approach determines which combination of reduction, systematic and astrophysical models produce the most robust signal and test the sensitivity of the eclipse maps to such choices (see for example Fig. 2).
- HD 189733b mapping results:
  - Retrieved values are consistent with previous longitudinal offset constraints from previous Spitzer Ch1 and Ch2 phase-curve observations [5] (Fig. 3)
- HD 209458b mapping results (not shown here)
  - Retrieved longitudinal offset of the eclipse map at Ch2 is smaller than that of previous phase curve observations [6]. This can be attributed to the stacking of additional eclipses not analyzed in [6], which shift the offset westward.
- Spherical projections of the eclipse maps are shown in Fig 4.
- This analysis shows that systematics must be carefully treated before stacking multi-epoch observations of transiting exoplanets, as individual eclipses could bias the retrieved latitudinal/longitudinal offset.
- The manuscript presenting these results will compare our results to GCM results published by PI Kataria. These results will serve as benchmark maps to be compared to future HST and JWST observations.
- Because of this funding and the maturity of the Spitzer pipeline, we were also able to make significant progress on additional research projects, including an analysis of Spitzer phase-curve observations of the ultra-hot Jupiter WASP-121b

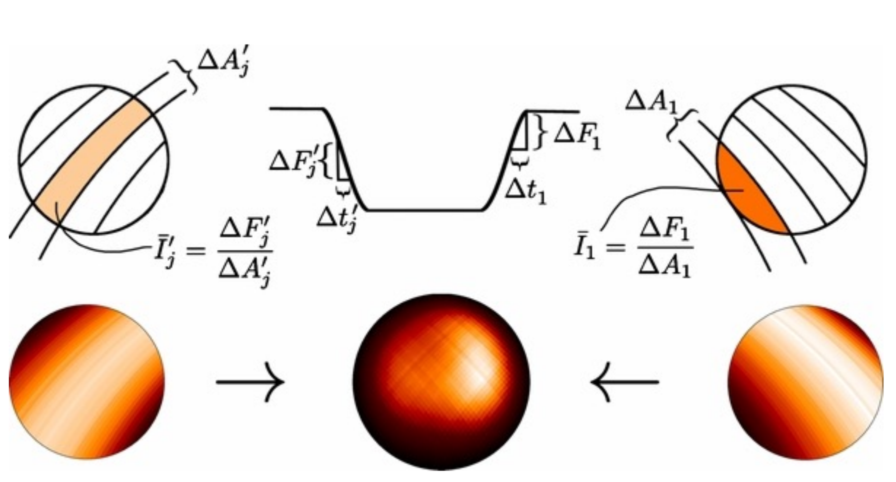

Fig. 1: Cartoon demonstrating the eclipse mapping technique. Bottom: Ingress and egress maps (left and right), as well as a combined map (center) of HD 189733b at 8 μm. The image is centered on the sub-observer point and the black regions are 50% as bright as the white. Figure from [2].

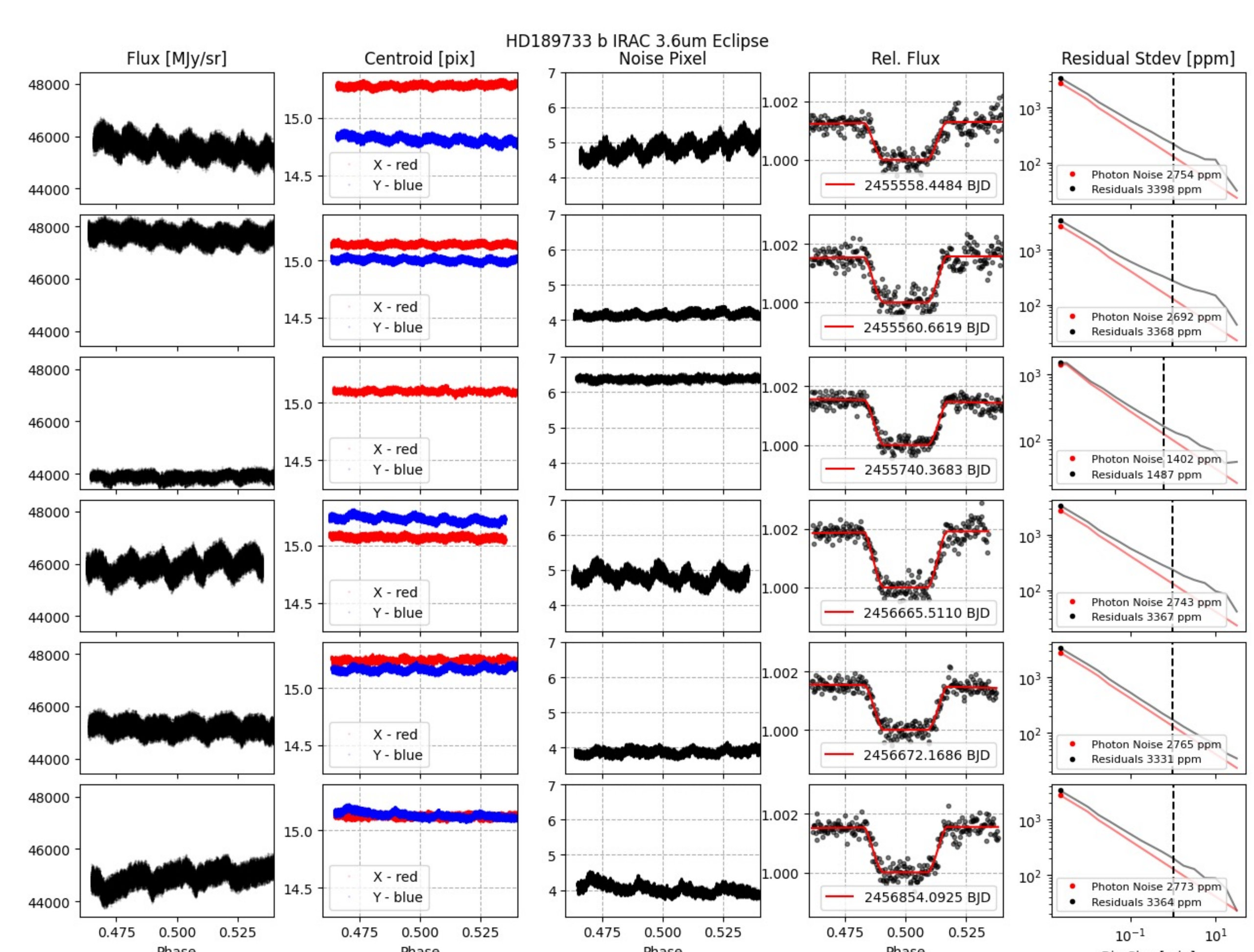

Fig. 2: Example analysis of Spizter eclipses for HD 189733b at 3.6 microns. Each column shows overall flux, XY centroid, noise pixel level, planet-to-star flux and residuals, all as a function of orbital phase.

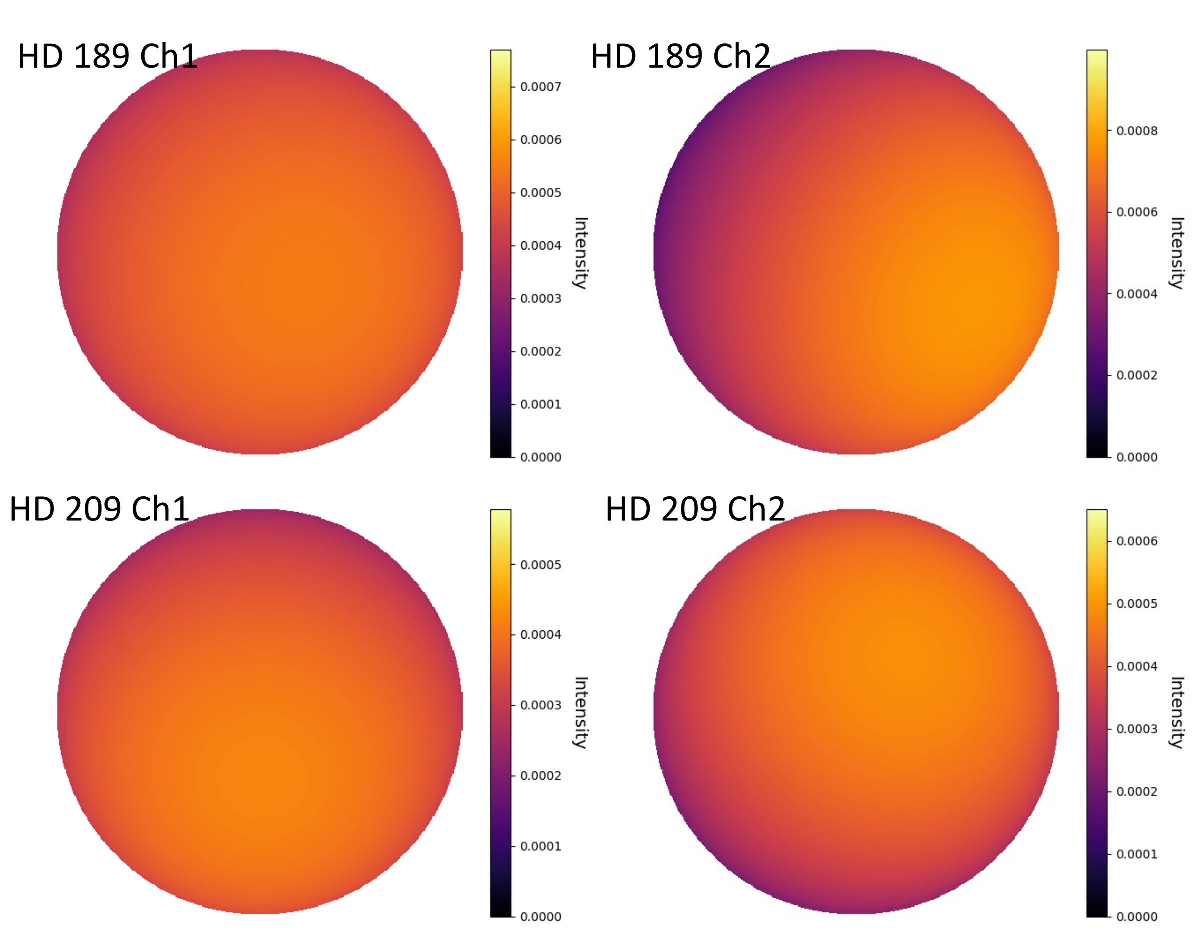

Fig. 3: Spherical projection of retrieved maps for HD 189 and HD 209 at 3.6 microns (left column) and 4.5 microns (right column).

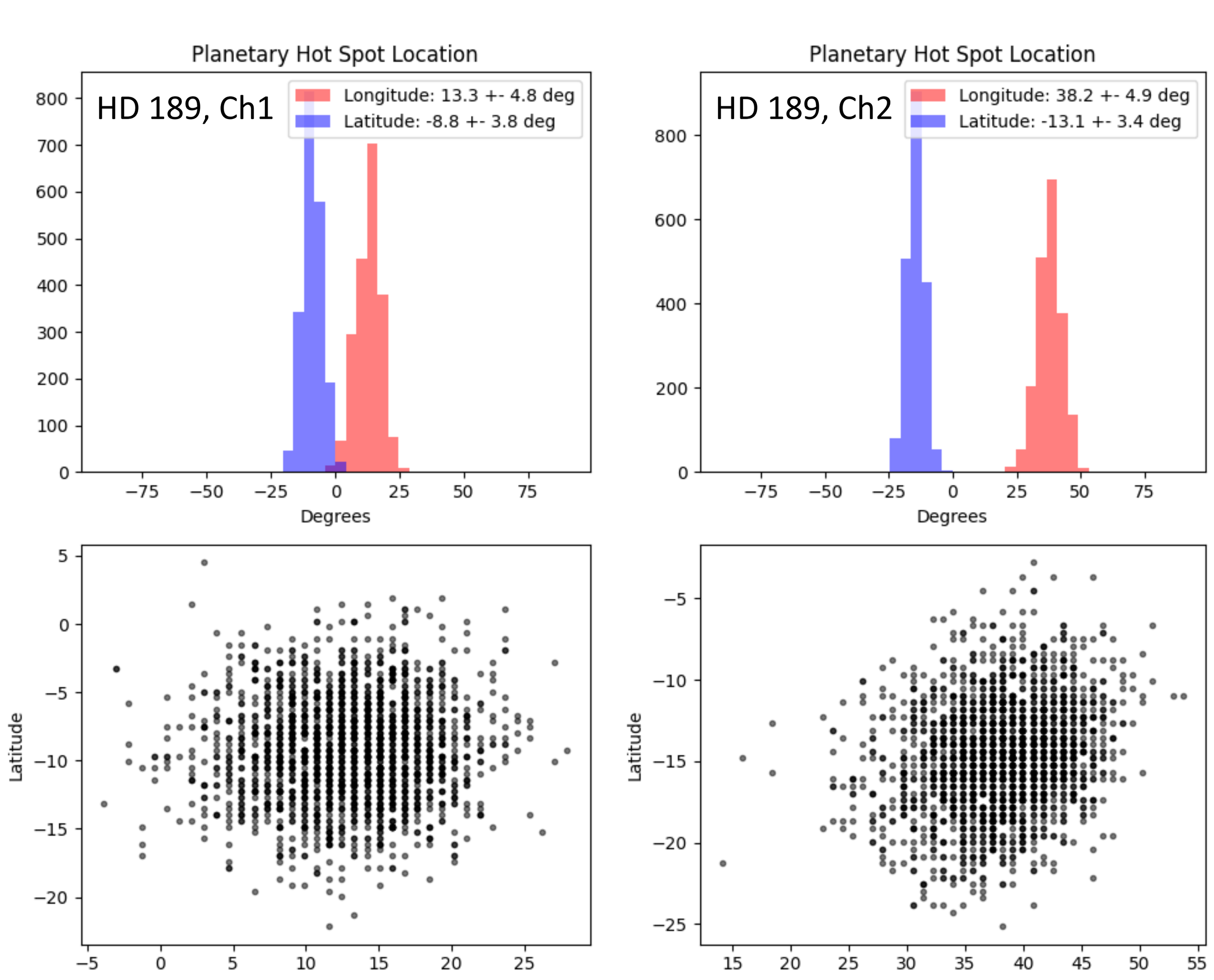

Fig. 4: Retrieved latitude and longitude for maps for HD 189733b in 3.6 microns (left column) and 4.5 microns (right column).

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Publications:
Kataria, Pearson, Zellem, Lewis, ApJ, in prep.
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