Exoplanet phase curves from TESS: Results from the Primary Mission and future prospects

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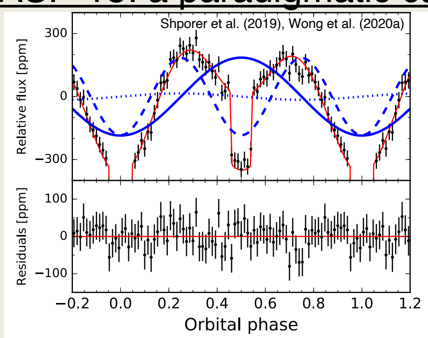
Abstract

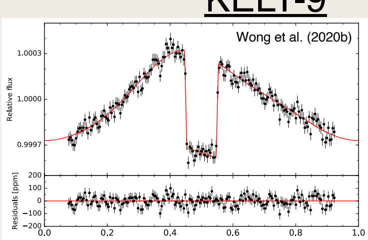
Throughout the Primary Mission, TESS observed almost the entire sky, providing high-cadence, long-baseline photometry for over 200,000 stars. ***We carried out a systematic, uniform analysis of TESS phase curves, targeting both previously-known and newly-discovered transiting systems.*** These light curves offer a glimpse into the atmospheric properties of a broad ensemble of exoplanets. Our phase curve study has also identified promising targets for future intensive atmospheric characterization.

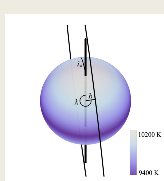
WASP-18: a paradigmatic case



- Deep secondary eclipse (~340 ppm), large day-night flux contrast, and no phase shift
  - ***Inefficient day-night heat recirculation***
- ***All three phase curve components detected*** (solid: atmospheric, dashed: ellipsoidal, dotted: Doppler)
  - Amplitudes consistent with predictions
- Very low albedo ($A_g < 0.048$; 2σ)

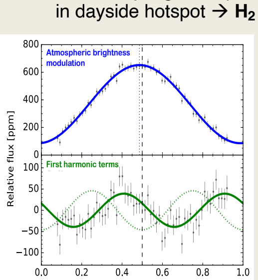
KELT-9

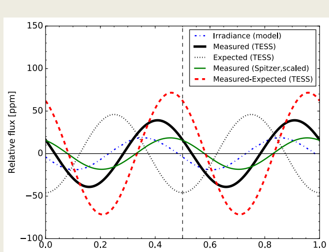




Hottest known planet on near-polar orbit around rapidly-rotating A-star (Ahlers et al. 2020)

- Very deep TESS-band secondary eclipse (~650 ppm)
- Muted day-night temperature contrast with 5° eastward offset in dayside hotspot → H_2 **dissociation**





Total first harmonic signal inconsistent with expected ellipsoidal distortion (also seen in Spitzer photometry; Mansfield et al. 2020):

- Additional signal due to **variable stellar irradiation** from KELT-9b's misaligned orbit and the star's gravity-darkening

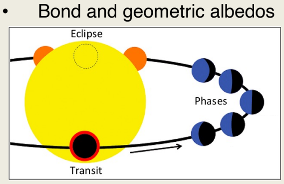
Phase curve components

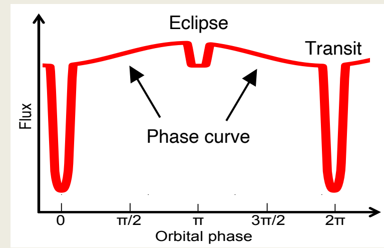
(e.g., Shporer 2017)

Atmospheric brightness modulation + secondary eclipse

Constraints on:

- day-night temperature contrast
- longitudinal heat transport
- Bond and geometric albedos

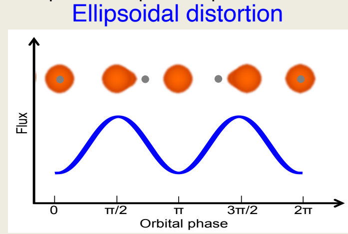




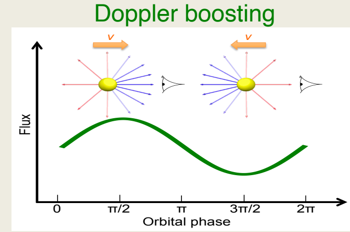
Gravitational interaction components

Amplitudes depend on planet-star mass ratio

Ellipsoidal distortion



Doppler boosting



Systematic phase curve study

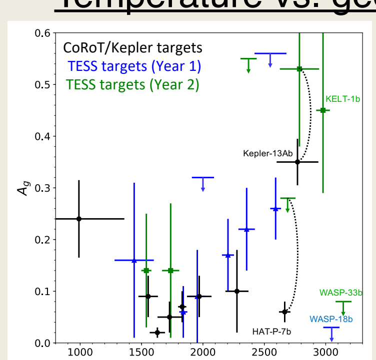
Target selection:

- Previously-known or newly-discovered systems with TESS mag < 12.5
- Predicted secondary eclipse depth > 100 ppm / √(number of Sectors)
- Predicted ellipsoidal and/or Doppler amplitudes > 50 ppm

Year 1 detections:	*Year 2 detections:*	*New planets:*
[Wong et al. (2020a)] HIP-65A, TOI-503, WASP-18, WASP-19, WASP-30, WASP-72, WASP-100, WASP-111, WASP-121, WASP-122	[Wong et al. (2021a)] HAT-P-7, KELT-1, KELT-9, KELT-16, KELT-20, Kepler-13A, WASP-12, WASP-33	HAT-P-70 (Zhou et al. 2019), TOI-1431 (Addison et al. 2021), TOI-1518 (Cabot et al. 2021), TOI-2109 (Wong et al. 2021b), etc…

Extended Mission: (1) revisit previous systems and improve sensitivity, (2) obtain additional phase curve detections, (3) probe for atmospheric variability, (4) search for orbital decay, etc…

Temperature vs. geometric albedo trend



We fit the measured TESS/Kepler/CoRoT and Spitzer 3.6/4.5 µm secondary eclipse depths to blackbody emission spectra with reflected starlight in the visible:

- ***~5σ correlation between visible geometric albedo and dayside temperature (1500<T_{day} < 3000 K)***
- Hottest ultra-hot Jupiters have near-zero geometric albedos → systematic change in atmospheric properties around T_{day}~3000 K

Other possible explanations for trend:

- Partial condensate cloud cover
- Additional short-wavelength opacity (e.g., H^-, TiO, Fe)
- Strongly non-isothermal T-P profiles

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