Changing Phases of Kepler Exoplanets: Evidence for Clouds and Winds

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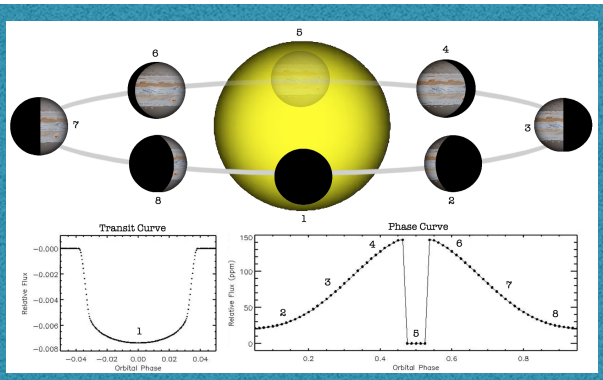
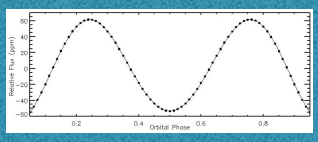
Using 18 quarters of data from the Kepler Space Telescope we analyze the transit and phase curve of 14 systems with significant detections in each of the phase curve components: the planet's phase function, Doppler boosting and ellipsoidal variations. We model the full phase curve simultaneously, including primary and secondary transits, and derive albedos, day- and night-side temperatures, planet masses and planetary light peak offsets.

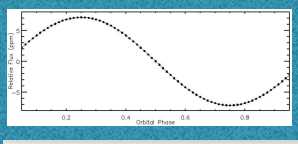


The **phase function** is a combination of reflected and thermally emitted light from the planet, whose amplitude varies as the planet changes phases (i.e. change in the visible area of planet's day-side). For a planet with a symmetrical day-side surface brightness the phase curve would also be symmetric (as seen above).

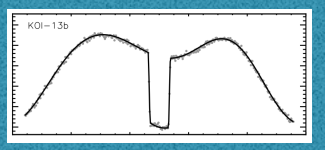
Ellipsoidal variations are periodic changes in observed stellar flux caused by fluctuations of the star's visible surface area as the stellar tide, created by the planet, rotates in and out of view of the observer.



The **Doppler boosting** signal is the result of non-relativistic Doppler beaming of the stellar light in the direction of the star's radial velocity.

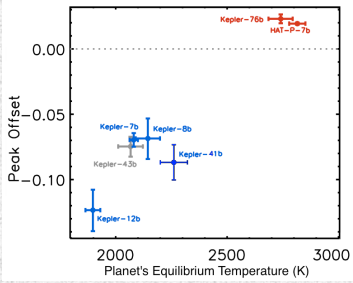


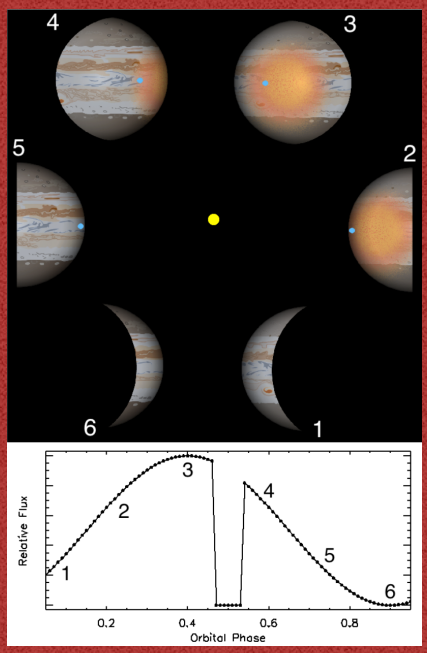
Combined



Peak Offset of Planetary

For seven planets, we find that the planetary light peak is offset from the substellar point. Of these the hottest two (Kepler-76b and HAT-P-7b) exhibit shifts eastward or to the evening-side, while the cooler five (Kepler-7b, -8b, -12b, -41b and -43b) peak westward or on the morning-side.

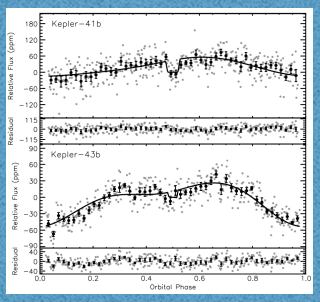




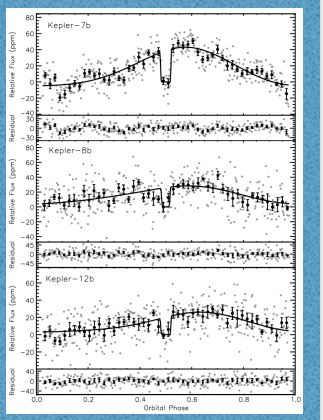
Eastward Offset for Hotter Planets

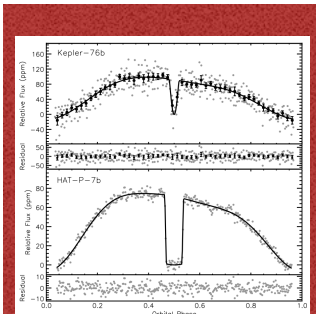
For tidally locked planets, an eastward shift in the substellar hot-spot is predicted by circulation models (e.g. Cooper et al. 2005; Heng et al. 2011).

- Could be caused by **winds** moving in the direction of planetary rotation.

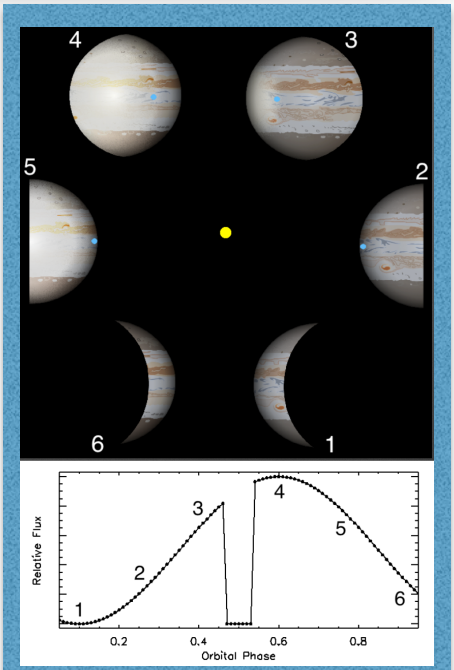


Westward Peak Offset of Phase Curve





Eastward Peak Offset of Phase Curve



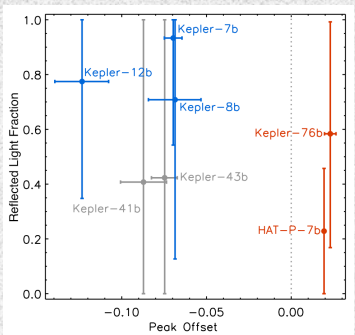
Westward Offset for Hotter Planets

Possibly caused by **clouds** on the morning-side (as seen for Kepler-7b; Demory et al. 2013).

- Could have condensed on the night-side, when temperatures are cooler.
- Thickest at sunrise then gradually disperse throughout the day as the atmosphere heats up.

Calculated **reflected light fraction** is marginally consistent with:

- Cooler Planets
  - Mostly Reflected Light Clouds
- Hotter Planets
  - Mostly Thermal Emission Hot-Spot



For more information:
Esteves, De Mooij and Jayawardhana. arXiv:1407.2245, (2014)

References

Cooper et al. 2005, ApJ, 629, L45
Demory et al. 2013, ApJ, 776, L25
Heng et al. 2011, MNRAS, 413, 2380

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