The Astrophysics of Planetary Systems: Formation, Structure, and Dynamical Evolution
Proceedings IAU Symposium No. 276, 2010
A. Sozzetti, M. G. Lattanzi & A. P. Boss, eds.

doi:10.1017/S1743921311020862

Hot Jupiter secondary eclipses measured by *Kepler*

Brice-Olivier Demory[1] **and Sara Seager**[1]

[1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, USA. email: demory@mit.edu

Abstract. Hot-Jupiters are known to be dark in visible bandpasses, mainly because of the alkali metal absorption lines and TiO and VO molecular absorption bands. The outstanding quality of the *Kepler* mission photometry allows a detection (or non-detection upper limits on) giant planet secondary eclipses at visible wavelengths. We present such measurements on published planets from Kepler Q1 data. We then explore how to disentangle between the planetary thermal emission and the reflected light components that can both contribute to the detected signal in the *Kepler* bandpass. We finally mention how different physical processes can lead to a wide variety of hot-Jupiters albedos.

Keywords. techniques: photometric, eclipses, planetary systems

1. Background and motivation

The reflected light component of the hot-Jupiter population is critical to constrain planetary energy budgets and to explore the upper atmosphere properties. While Jupiter has a geometric albedo of 0.5 in the visible, HD209458b's is surprisingly low : <0.08 (3-σ upper limit, Rowe *et al.* 2008. The planetary to stellar flux ratio of hot Jupiters at visible wavelengths is of the order of 10^{-5}, making it very challenging to measure. After just 1.5 years of operation, *Kepler* has proven to be a facility able to achieve a few parts per million (ppm) photometric precision (e.g. Jenkins *et al.* 2010).

2. Geometric albedo determination

We performed Markov Chain Monte-Carlo analyses on the 6 hot Jupiters that have been observed by *Kepler*, including two previously known exoplanets : TrES-2b and HAT-P-7b. Public data from the first quarter were used to derive the systems parameters.

Results from this preliminary study appear in Table 1 and depict a wide variety of geometric albedos, ranging from 0.06 to 0.35. A single secondary eclipse is also shown on Fig. 1 for HAT-P-7b. Similar analysis has been performed by Kipping & Bakos (2010) and results show good consistency with those presented here.

3. Disentangling thermal emission and reflected light

Hot-Jupiter thermal emission could have a significant contribution to the planetary flux measured in the *Kepler* bandpass. Comparing the range of possible equilibrium temperatures to the brightness temperature corresponding to the secondary eclipse depth allows an estimate of the upper bound for the thermal emission, and thus also an estimate of the reflected light fraction. This simple approach is however challenged by the departure from blackbody radiation of hot Jupiter thermal emission spectra. Moreover, the structure of the atmospheric temperature profile might cause visible band measurements

Table 1. Geometric albedos and equilibrium temperatures (assuming no redistribution) for *Kepler* published giant planets from public data (Q1).

Planet	Geometric Albedo	$T_{eq}[K]$
Kepler 5b	0.21 ± 0.10	1557
Kepler 6b	0.18 ± 0.09	1411
Kepler 7b	0.35 ± 0.11	1370
Kepler 8b	0.21 ± 0.10	1567
TrES-2b	0.06 ± 0.05	1464
HAT-P-7b	0.20 ± 0.03	2085

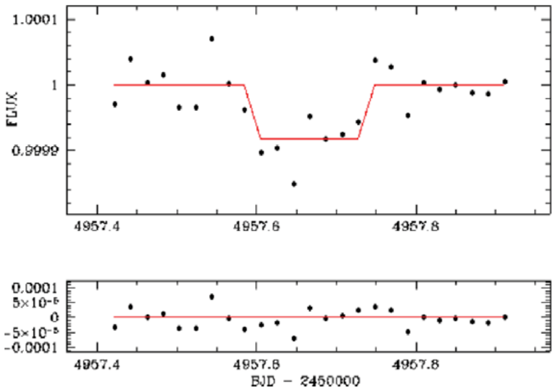

Figure 1. Top : Kepler single long-cadence (30min) secondary eclipse lightcurve of the 2.2-day period hot Jupiter HAT-P-7b with the best fit model superimposed. **Bottom** : residuals of the fit. The occultation depth is 82 ± 12 ppm. Obtained from Kepler Q1 public data.

to probe thermal emission from deep layers of the atmosphere. Brightness temperature estimates at other wavelengths might definitely help in constraining the energy budget and sample the planetary spectral energy distribution.

4. Conclusions

While alkali metal absorption lines and TiO and VO molecular absorption bands are expected to shape the spectrum of hot Jupiters in the *Kepler* bandpass, the planetary thermal emission is an important contributor for the most irradiated hot-Jupiters. Additionally, clouds are expected to form at the intersection of enstatite and iron compound condensation curves with the planetary temperature structure profile (Sudarsky *et al.* 2000). The altitude of iron and enstatite cloud decks in hot Jupiter atmospheres significantly affects the geometric albedo (Seager *et al.* 2000). How representative are giant irradiated planets harboring high altitude reflective clouds and hazes is one of the several points *Kepler* will be able to address, shedding light on the properties of hot Jupiter atmospheres.

References

Jenkins, J. M., Caldwell, D. A., Chandrasekaran, H., & Twicken, J. D., *et al.* 2010, *ApJ*, 713, L120

Kipping, D. M. & Bakos, G. A. 2011, *ApJ*, 730, id.50
Rowe, J. F., Matthews, J. M., Seager, S., Miller-Ricci, E., & Sasselov, D., *et al.* 2008, *ApJ*, 689, 1345
Seager, S., Whitney, B. A., & Sasselov, D. D. 2000, *ApJ*, 540, 504
Sudarsky, D., Burrows, A., & Pinto, P. 2000, *ApJ*, 538, 885