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Dectection of Thermal Emission from WASP-3b

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Abstract. We report secondary eclipse detections of the transiting hot Jupiter WASP-3b at 3.6, 4.5 and 8.0μm using the *Spitzer Space Telescope's* Infrared Array Camera. We find planet-to-star flux ratios of $0.210^{+0.043}_{-0.029}$, $0.281^{+0.012}_{-0.011}$ and $0.332^{+0.050}_{-0.034}$% in the three bands respectively. Comparisons with 1D atmospheric models show these values strongly favour inefficient redistribution of heat around the planet and also favour the presence of a temperature inversion. In addition, WASP-3 probes the cut-off region of a proposed activity-inversion correlation and we find evidence of atmospheric differences between this system and a similarly active system, WASP-4.

1. Observations and analysis

We obtained secondary eclipse observations of the exoplanet WASP-3b using the *Spitzer Space Telescope* at 3.6, 4.5 and 8.0μm. Fluxes, measured using simple aperture photometry, displayed well know systematics due to intra-pixel sensitivity variations and detector 'ramps'. These effects were removed using simple detrending functions based on the image centroid positions and time. We used a Markov Chain Monte Carlo χ^2 minimisation algorithm to simultaneously determine the WASP-3 system parameters and detrending model parameters. Eclipse depth errors were found using a 'prayer bead' method (Gillon *et al.* 2007) to account for systematic noise present in the detrended lightcurves.

2. Results and discussion

We find planet-to-star flux ratios (eclipse depths) for WASP-3 of $0.210^{+0.043}_{-0.029}$%, 0.282 ± 0.012% and $0.332^{+0.050}_{-0.034}$% at 3.6, 4.5 and 8.0μm respectively. These correspond to planetary brightness temperatures of 2200-2400 K, confirming WASP-3b is very hot.

Comparisons of our eclipse depths with 1D atmospheric models (Fortney *et al.* 2008) suggest inefficient heat redistribution is favoured, as one would expect from the high brightness temperatures (Fig. 1). For reference the equilibrium temperature with total absorption of the irradiating stellar flux and instantaneous re-radiation is 2600 K. Our data also favour the presence of a thermal inversion, with this conclusion being driven by the increase in planetary flux seen from 3.6 to 4.5 μm, and the poor agreement of our 4.5 μm measurement with the non-inverted model prediction (3σ). Indeed, our value for an empirical measure of the change in planetary flux from 3.6 to 4.5 μm (Knutson *et al.* 2010) puts WASP-3 into a class of planets which generally favour inverted atmospheres.

A caveat to this is the K_s band eclipse measurement by Zhao *et al.* 2012. The very deep eclipse depth found may suggest a very hot lower atmosphere from where flux can escape due to opacity windows across the K_s band (de Mooij *et al.* 2011). Such a high flux is not reproduced in either of the models that do fit the *Spitzer* data.

Using the empirical 3.6–4.5 μm spectral slope measurement, we can evaluate how WASP-3 fits in with a proposed correlation between this quantity and the activity of the host star (Fig. 2). The system forms an interesting pair with WASP-4b near the

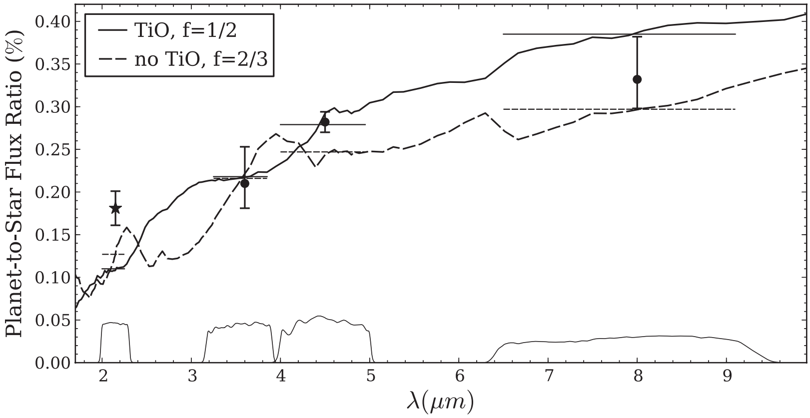

Figure 1. WASP-3b flux ratios along with 1D model atmosphere predictions (Fortney *et al.* 2008). The solid line ('TiO') is for an atmospheric model which exhibits a temperature inversion, while the dashed line ('no TiO') model does not. Horizontal lines are the corresponding passband integrated predictions (also showing the extent of the passbands). The starred point is the previously measured K_S band eclipse depth. 'f' describes the extent of heat redistribution around the planet. f = 1/2 is for models where there is only redistribution on the planet's dayside, and f = 2/3 is for instantaneous re-radiation. Thus inefficient heat redistribution is favoured in both models. Our *Spitzer* data also favours the inverted model case - particularly at 4.5μm.

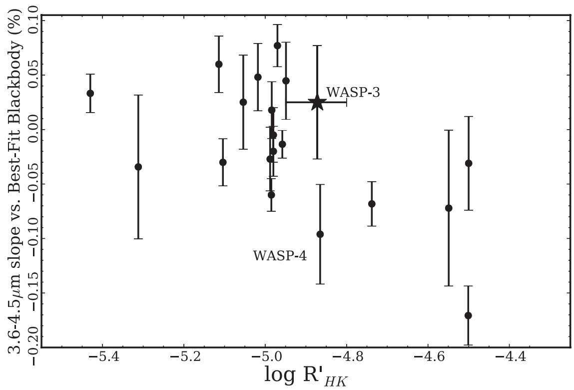

Figure 2. Empirical 3.6-4.5 μm spectral slope measure vs host star activity (log R'_{HK}). The proposed idea is that the enhanced UV flux irradiating planets around active stars (with log R'_{HK} above about -4.9) will act to suppress temperature inversions, indicated by a shallower 3.6-4.5 μm spectral slope.

proposed activity cut-off. The host activities are similar, but the spectral slope is steeper for WASP-3, perhaps indicating a fundamental difference in the nature of the planetary atmospheres. In addition, WASP-3 is now the most active star found to host a planet with a 3.6-4.5 μm slope consistent with an atmospheric inversion.

References

Gillon, M., Demory, B.-O., Barman, T., Bonfils, X., Mazeh, T., Pont, F., Udry, S., Mayor, M., & Queloz, D. 2007, *A&A*, 471, L51

Fortney, J. J., Lodders, K., Marley, M. S., & Freedman, R. S. 2008, *ApJ*, 678, 1419

Knutson, H. A., Howard, A. W., & Isaacson, H. 2010, *ApJ*, 720, 1569

Zhao, M., Milburn, J., Barman, T., Hinkley, S., Swain, M. R., Wright, J., & Monnier, J. D. 2012, *ApJ*, 748, L8

de Mooij, E. J. W., de Kok, R. J., Nefs, S. V., & Snellen, I. A. G. 2011, *A&A*, 528, A49