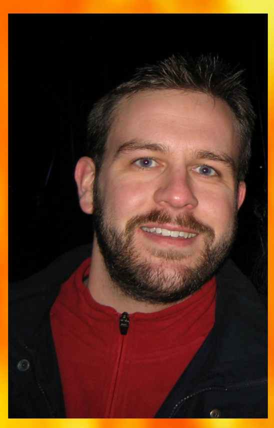
Probing the atmospheric structure of hot Jupiters



Alexis M. S. Smith[1*], David R. Anderson[1], Deepak P. Mahtani[1], N. Madhusudhan[2] and the WASP team[3]

[1]Astrophysics Group, Keele University, UK [2]Princeton University, NJ, USA [3]www.superwasp.org
*amss@astro.keele.ac.uk

When a transiting planet is occulted by its host star, we can detect the emergent flux from the planet. Near-infrared measurements of the occultation depth yield the brightness temperature of the system at a particular wavelength, which can provide an estimate of the efficiency of the heat redistribution to the night-side of the planet. Measurements of the occultation depth at several wavelengths allow the construction of a spectral energy distribution for the planet and enable the atmospheric composition and structure (for instance whether or not the atmosphere has a thermal inversion or stratosphere) to be inferred.

We have ongoing programmes with both the Spitzer Space Telescope and several ground-based telescopes to obtain infrared occultation measurements of a number of planets in order to study their atmospheres. Of particular interest is what determines whether a particular planet's atmosphere exhibits a thermal inversion. Various parameters have been proposed as key to this question, including insolation, stellar activity and stellar metallicity. By characterising the atmospheres of hot Jupiters occupying a range of parameter space, we aim to resolve this question.

Here I present our latest Spitzer results on three systems: WASP-19 (Anderson et al. 2012), WASP-24 (Smith et al. 2012) and WASP-26 (Mahtani et al. in prep.).

Introduction

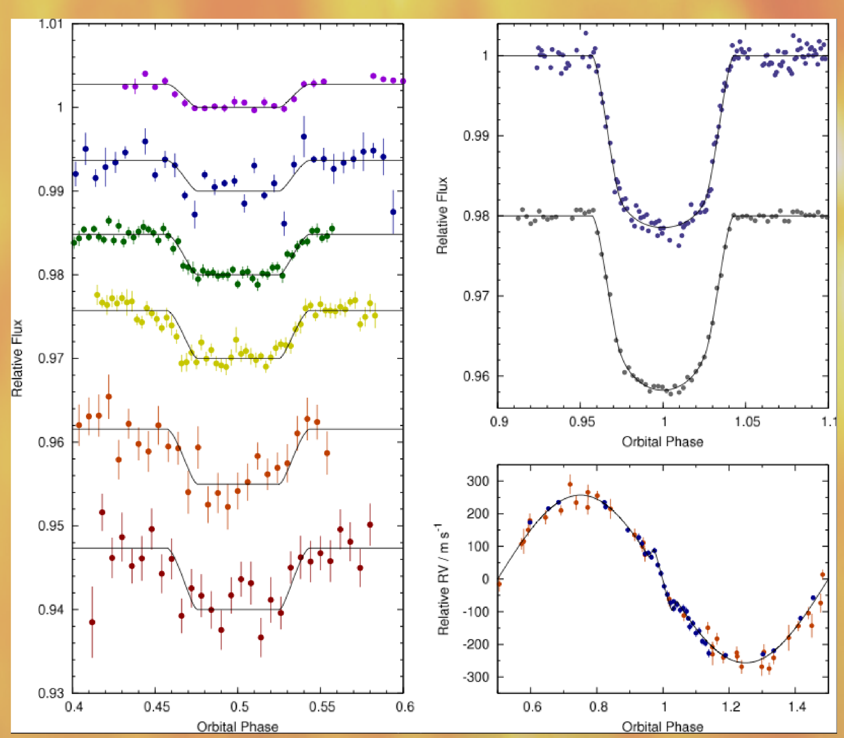
Observing occultations at multiple wavelengths allows us to construct an SED for the planet and fit model atmosphere spectra, we use those of Madhusudhan & Seager (2009, 2010). By comparing SEDs to such models, some atmospheres have been found to have thermal inversions, caused by molecules absorbing heat in the upper atmosphere. An early theory was that only highly irradiated planets have inversions, because high temperatures are needed to keep the absorbers gaseous (Fortney et al. 2008). However, subsequent data (e.g. Machalek et al. 2008) and theory (Spiegel et al. 2009) have challenged this picture. An alternative hypothesis is that high levels of UV flux destroy the species responsible for inversions, resulting in planets around active stars lacking inversions (Knutson et al. 2010).

Spitzer data reduction

We present occultation data obtained with the InfraRed Array Camera (IRAC) of the Spitzer Space Telescope. This instrument operated in four channels during Spitzer's crygenic mission (1: 3.6 µm, 2: 4.5 µm, 3: 5.8 µm, 4: 8.0 µm). After 2009 May, when the cyrogen ran out, IRAC has operated in channels 1 and 2 only in Spitzer's warm mission.

We employ the custom pipeline described in Anderson et al. (2011) to perform aperture photometry on the Spitzer data. We de-trend for systematics within our MCMC code, trying a range of functional forms. The channel 1 & 2 data presented here are de-trended for the pixel-phase effect (Knutson et al. 2008) with a quadratic function in pixel position, in addition to a linear function in time. The channel 3 & 4 data are de-trended for the ramp effect (Knutson et al. 2008) with a quadratic function in ln(time).

WASP-19b (Anderson et al. 2012)

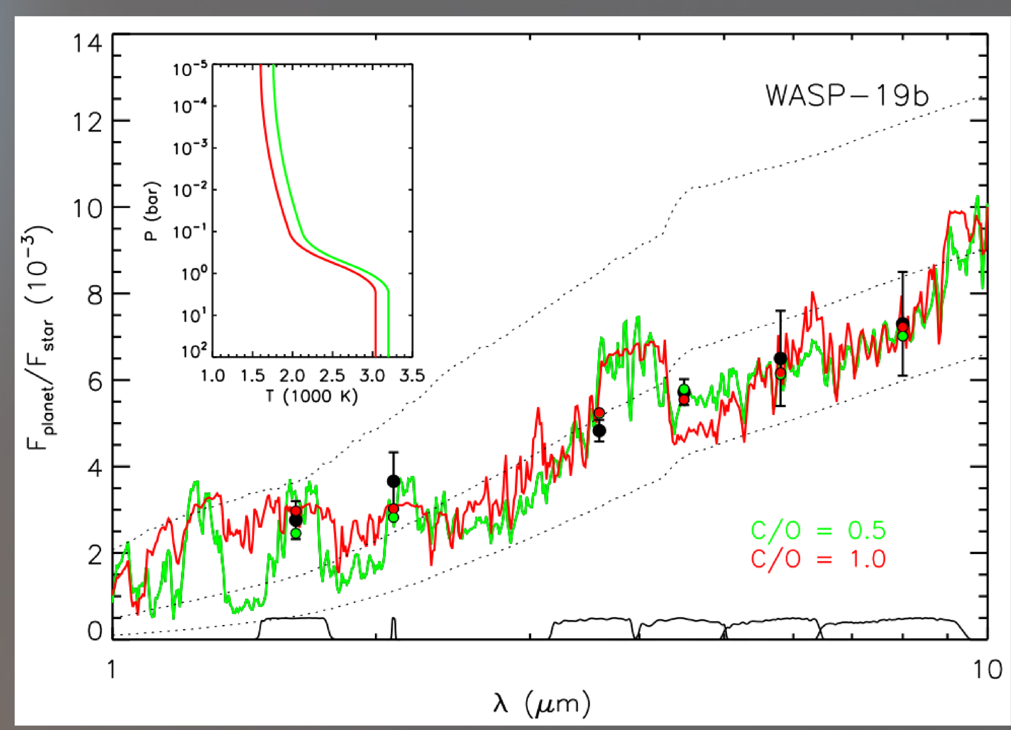


From top to bottom: H-band, K-band, 3.6, 4.5, 5.8, 8.0 µm

WASP-19b orbits a G8 star in an extremely close orbit, with a period of just 0.79 days (Hebb et al. 2010). Ground-based near-IR occultation observations with VLT/HAWK-I have been reported in both the H and K-bands (Anderson et al. 2010, Gibson et al. 2010).

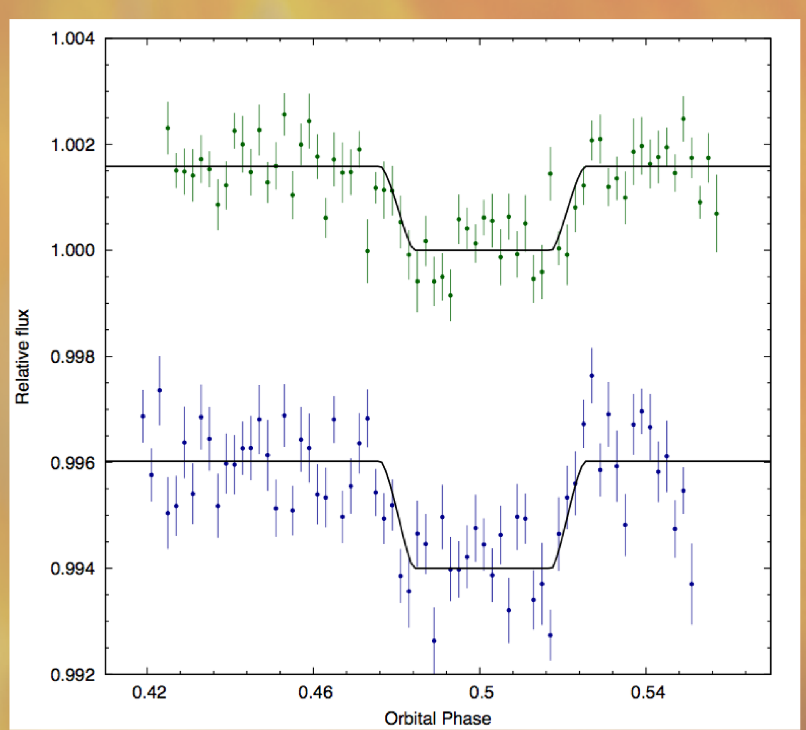
We observed two occultations with cold Spitzer/IRAC, one in channels 1 & 3 and one in channels 2 & 4. We analysed this data as part of a global MCMC analysis along with the ground-based occultation data, and the photometry and RVs from Hebb et al. (2010) and Hellier et al. (2011) *(left)*.

The data show that WASP-19b lacks a strong thermal inversion. Given that WASP-19 is an active star, this lends support to the activity-inversion theory of Knutson et al. (2010). The data are unable to distinguish between carbon-rich and oxygen-rich atmospheres *(right)*.



Red: carbon-rich; green: oxygen-rich

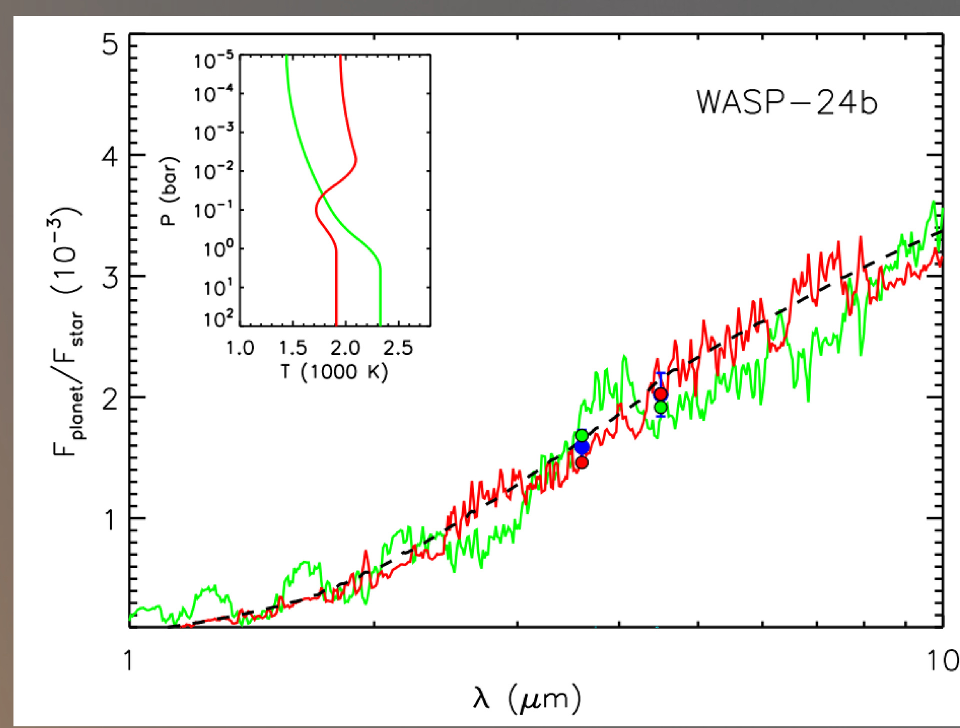
WASP-24b (Smith et al. 2012)



WASP-24b orbits a F8-9 star with a period of 2.34 days (Street et al. 2010). We observed two occultations with warm Spitzer/IRAC, one in each of channels 1 and 2 *(left)*; these are the first occultation observations of this system. We analysed this data as part of a global MCMC analysis along with the photometry and RVs from Street et al. (2010) and Simpson et al. (2011) and two new transit light curves from the CAHA-2.2m/BUSCA.

Models atmospheres with and without a thermal inversion fit equally well *(right)*; we are unable to distinguish between them without near-IR data.

Top: 3.6 µm
Bottom: 4.5 µm



Red: with inversion
green: without inversion

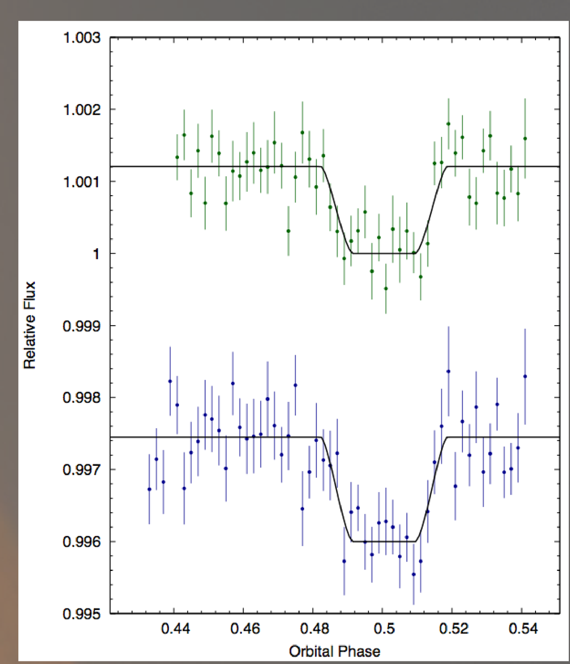
λ / µm	WASP-19b	WASP-24b	WASP-26b
3.6	$\Delta F = 0.483 \pm 0.025$ % $T_B = 2346 \pm 57$ K	$\Delta F = 0.159 \pm 0.013$ % $T_B = 1974 \pm 71$ K	$\Delta F = 0.121 \pm 0.014$ % $T_B = 1773 \pm 80$ K
4.5	$\Delta F = 0.572 \pm 0.030$ % $T_B = 2273 \pm 64$ K	$\Delta F = 0.202 \pm 0.018$ % $T_B = 1944 \pm 85$ K	$\Delta F = 0.145 \pm 0.016$ % $T_B = 1681 \pm 83$ K
5.8	$\Delta F = 0.65 \pm 0.11$ % $T_B = 2260 \pm 2307$ K	-	-
8.0	$\Delta F = 0.73 \pm 0.12$ % $T_B = 2260 \pm 250$ K	-	-

Table: Fitted occultation depths and corresponding brightness temperatures for the three planets

WASP-26b (Mahtani et al. in prep.)

WASP-26b orbits a G0 star with a period of 2.76 days (Smalley et al. 2010). We observed two occultations with warm Spitzer/IRAC, one in each of channels 1 and 2; these are the first occultation observations of this system. We analysed this data as part of a global MCMC analysis along with the photometry and RVs from Smalley et al. (2010) and Anderson et al. (2011).

Interpretation of our occultation depths is currently in progress, but WASP-26b appears to fall among the planets with an inversion, according to the empirical index of Knutson et al. (2010).



Top: 3.6 µm
Bottom: 4.5 µm

Conclusions

WASP-19b, a planet orbiting an active star, does not exhibit a strong thermal inversion, and thus it supports the activity-inversion correlation of Knutson et al. (2010). Further NIR data is required to determine whether, like that of WASP-12b (Madhusudhan et al. 2011) the atmosphere is carbon-dominated. Day-night heat redistribution is relatively inefficient.

Near-IR data from the ground is also required to determine whether WASP-24b, a planet orbiting a relatively inactive star, has an inversion. Day-night heat redistribution is very efficient.

We find no evidence for non-zero orbital eccentricities in WASP-19b, WASP-24b or WASP-26b.

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