Probing the atmosphere of the 'hot Jupiter' TrES-1b with HST

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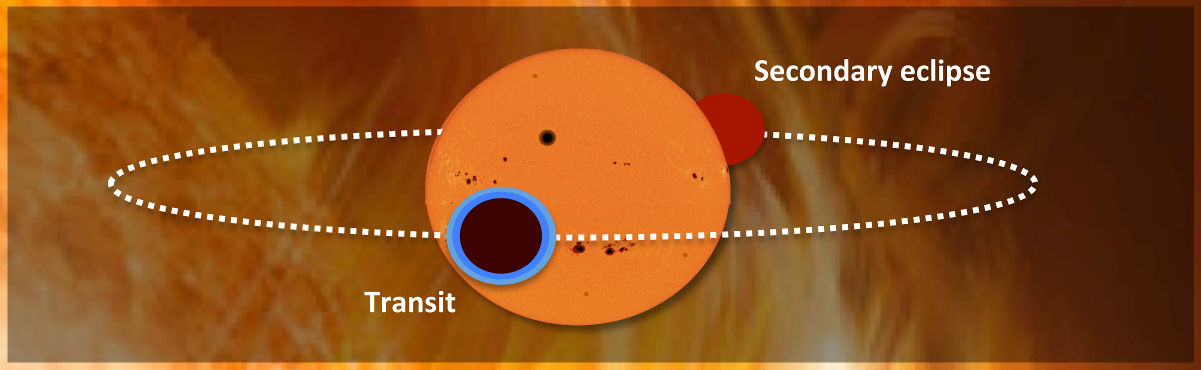
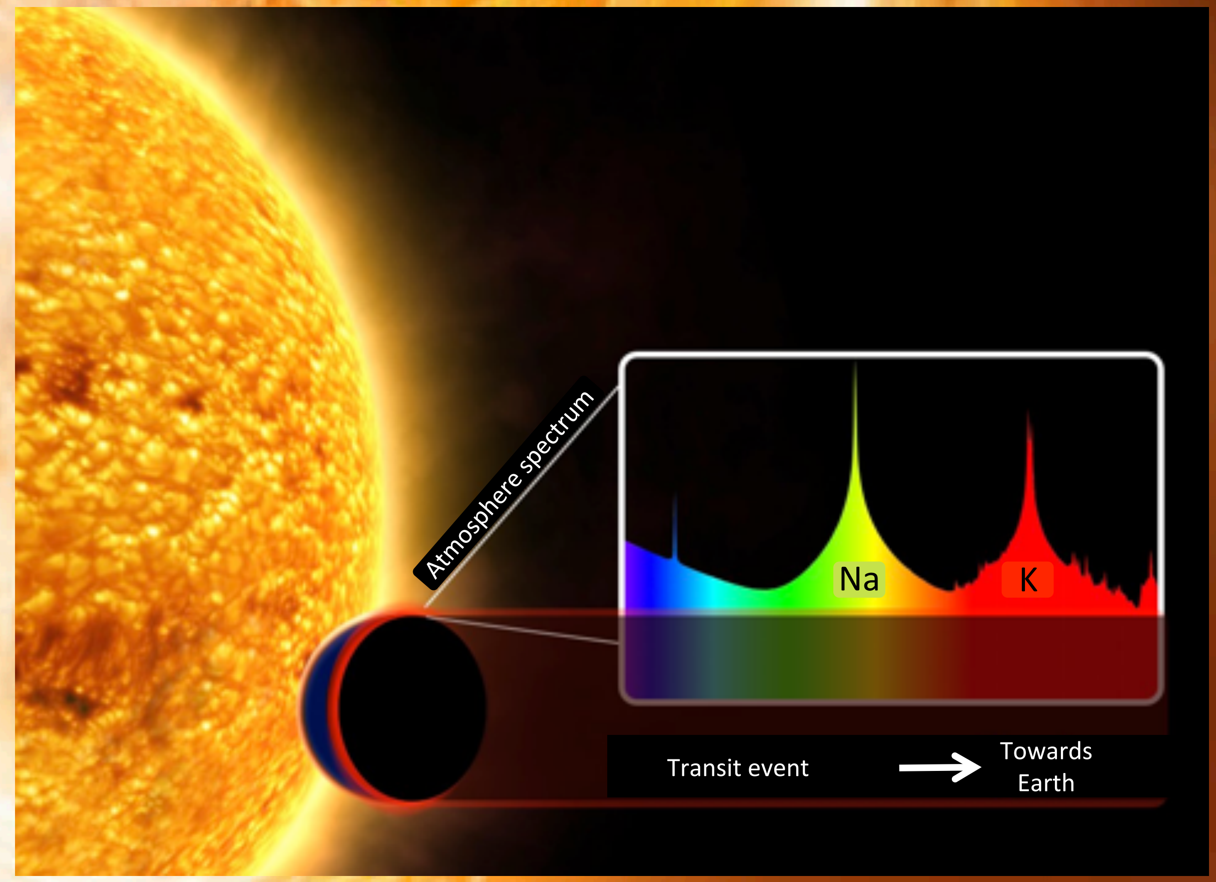
Abstract: The atmosphere of transiting exoplanets can be studied through **transmission spectroscopy**. A correlation has been observed between hot Jupiter emission spectra and stellar activity levels. We suggest a correlation between optical **haze** in the transmission spectra of planetary atmosphere and the level of **stellar activity**. We test this correlation on the HST optical transmission spectrum of **TrES-1b**, a hot gas giant planet orbiting an active star.





Transmission spectroscopy

The atmosphere of an exoplanet can be studied from its emission spectrum (e.g. using direct imaging, secondary eclipse) or from its transmission spectrum (transit spectrophotometry).

A planet transiting in front of its star decreases the stellar brightness by a quantity which depends on the planet's apparent size (e.g. Charbonneau et al. 2000). Absorption of stellar photons by atoms and molecules in a transiting planet's atmosphere leads to a larger apparent size of the planet at the absorbing wavelengths. The wavelength dependence of the planet's apparent radius returns a transmission spectrum of the planet's upper atmosphere (Seager & Sasselov 2000).

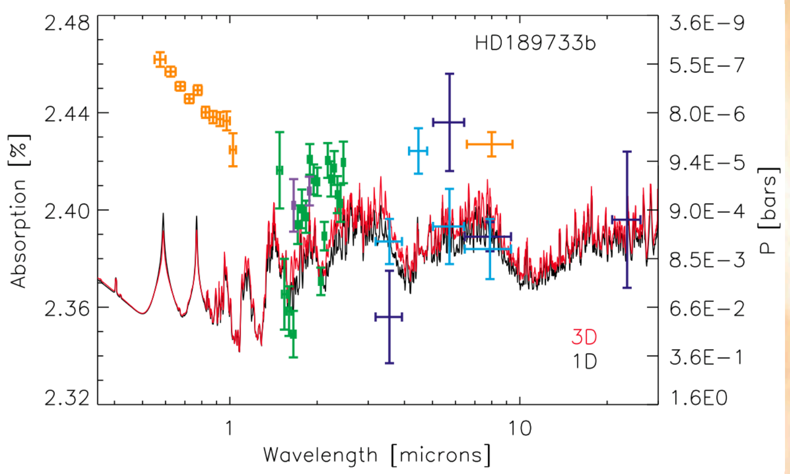


Figure 1: The transmission spectrum of HD189733b (figure taken from Fortney et al. 2010). Data from different teams are in different colours. Fortney et al. 2010 atmosphere models are in black and red. HD189733b orbits an active star and exhibits optical haze and no atmospheric thermal inversion.

Stellar activity and thermal inversion

The emission spectra of several hot Jupiters (short-orbit Jupiter-size planets) have been observed with multi-wavelength secondary eclipse observations. Some of these planets exhibit no atmospheric thermal inversion. Knutson et al. 2010 present a correlation between no-inversion and stellar activity. Planets around active stars exhibit no thermal atmospheric inversion (Fig. 2) as the increased UV flux from the active host star destroys the high-altitude absorber responsible for the formation of the temperature inversion.

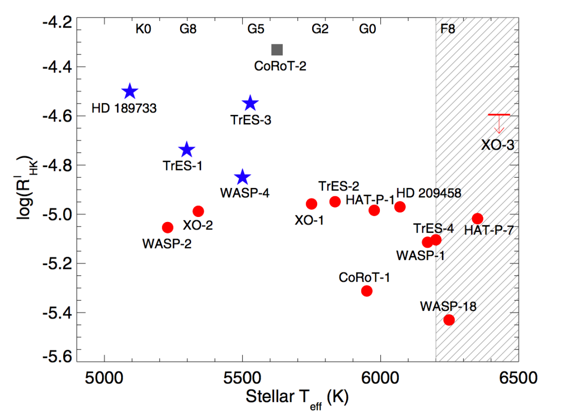


Figure 2: Correlation between stellar activity level (R_{HK} index) and atmospheric temperature inversion (figure taken from Knutson et al. 2010). Non-inverted atmosphere planets (blue) are associated with chromospherically active stars.

Stellar activity and atmospheric haze

We propose a correlation between stellar activity level and haze in the optical transmission spectra. We suggest that the strong UV radiation from the active host star creates a photochemical haze in the planet's atmosphere which scatter lights in the visible.

We test this hypothesis on the optical transmission spectrum of the hot Jupiter TrES-1b. TrES-1b orbits an active star with activity level between HD189733 and HD209458. Under the suggested correlation, the transmission spectrum of TrES-1b should exhibit haze, similar to HD189733b but maybe optically thinner (Fig. 3).

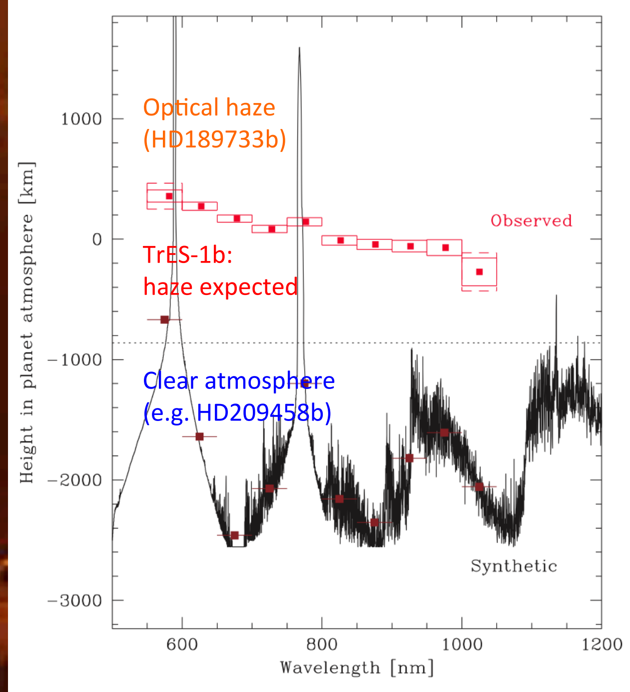


Figure 3: The atmospheric transmission spectrum of HD189733b in the optical is a flat slope which is explained by atmospheric haze scattering the visible light (Pont et al. 2008). To the contrary, HD209458b which orbits a quite star, exhibits a clear atmosphere with sodium absorption (Sing et al. 2008). Under the suggested haze-activity correlation, TrES-1b should be an intermediate case and its transmission spectrum should exhibit haze scattering in the optical.

Analysis of TrES-1b

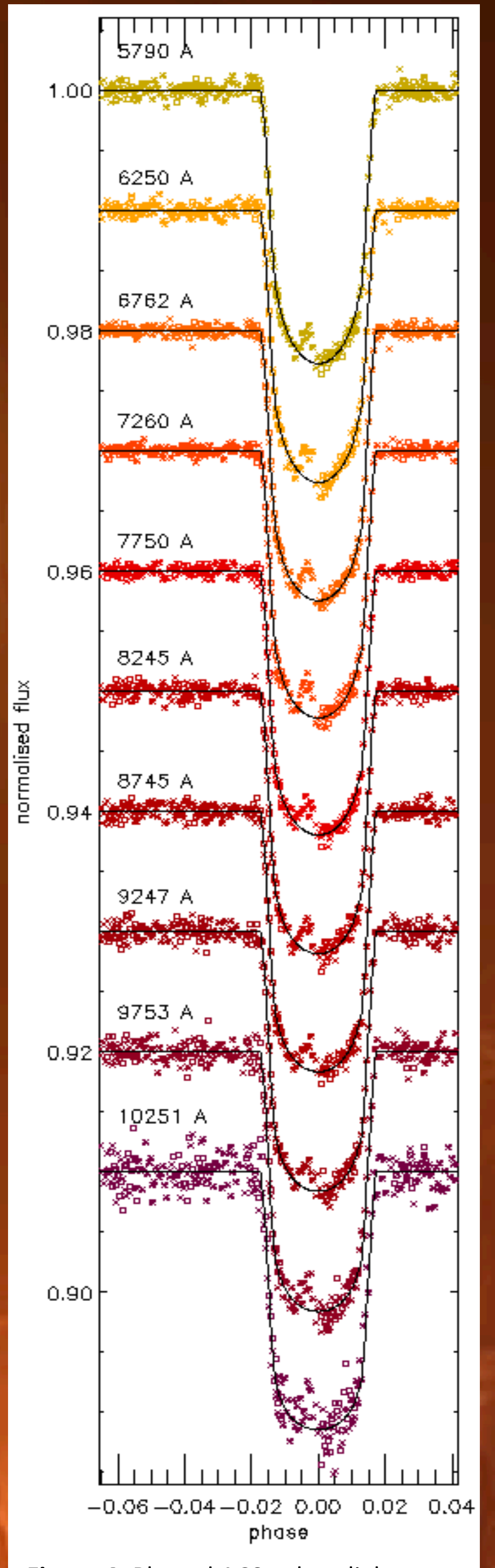


Figure 4: Phased ACS colour light curves in the ten 500A-wide wavelength bands, shifted vertically for visibility. The three HST visits are marked with different symbols. The fits are performed on the light curves corrected from the effect of occulted and unocculted spots. The stellar limb darkening is modeled with a quadratic law with the coefficients fixed to optimized values (Fig. 5).

The data used are multi-wavelength optical light curves of three HST/ACS archived visits over TrES-1b's transit (Rabus et al. 2009). For each colour light curve, the planet apparent radius is least-square fitted to Mandel & Agol 2002 analytical transit models (Fig. 4). The other transit fitting parameters are fixed to the values derived from the fit to the white light curve. The quadratic limb darkening coefficients are fixed to the optimized values derived from a linear interpolation over the model coefficients (Fig. 5). The uncertainties on the fitted values are derived from the fit.

Challenges: The photometric signatures of occulted and unocculted stellar spots distort the transmission spectrum, so they are corrected from. The transit depth is degenerate between the planet's radius and the stellar limb darkening, so the latest is carefully estimated (Fig. 5).

The different choices of limb darkening coefficients and the study of the individual visits lead to different planet radii and hence to slight differences in the transmission spectrum of TrES-1b.

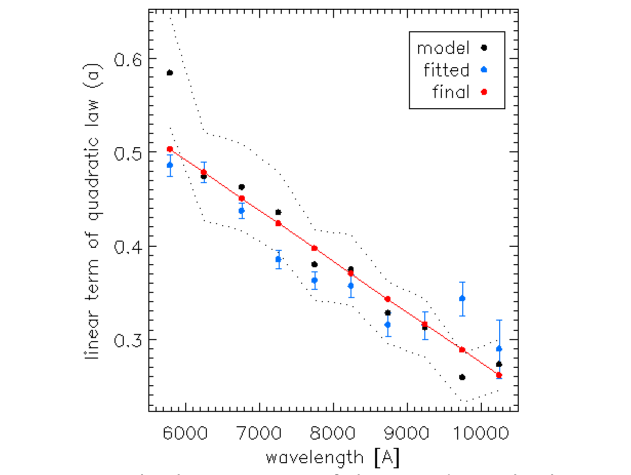


Figure 5: The linear term of the quadratic limb darkening law is fixed to a linear interpolation (red) over the model values (black) derived from Kurucz stellar atmosphere models. The blue values are derived from the transit fits with free linear term of the quadratic limb darkening law. The quadratic term is fixed to the model values.

Conclusions:

The final analysis of the transmission spectrum of TrES-1b is a work in progress. The transmission spectrum is sensitive to the stellar limb darkening modeling and to the individual transit visits. The final results will be published in Alapini, Pont & Sing 2011 (in prep.).

References

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Questions? Please ask