Transmission spectrum of HAT-P-1b as observed with the Hale telescope

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Abstract

Transmission spectrum has been proven to be a powerful probe in the atmospheric characterisation of exoplanets. When a planet transits its host star, the stellar light transmits through the atmosphere of planetary day-night terminator region, imprinted with atomic and molecular absorption features. On the other hand, the existence of clouds or hazes might mask out these potential spectroscopic signatures. Transmission spectroscopy with a large wavelength coverage provides opportunity to discriminate the atmospheric compositions.

HAT-P-1b is a hot Jupiter that closely orbits one member of a G0/G0 visual binary (Bakos et al. 2007). Previous atmospheric studies focused on its thermal emission from the dayside atmosphere, featuring a possible modest temperature inversion and inefficient heat redistribution between day and night (Todorov et al. 2010; de Mooij et al. 2011). As one of the most bloated transiting planets, it is also a favourable target for transmission spectroscopic observation. The 11″-apart companion of similar brightness makes the longslit observation feasible.

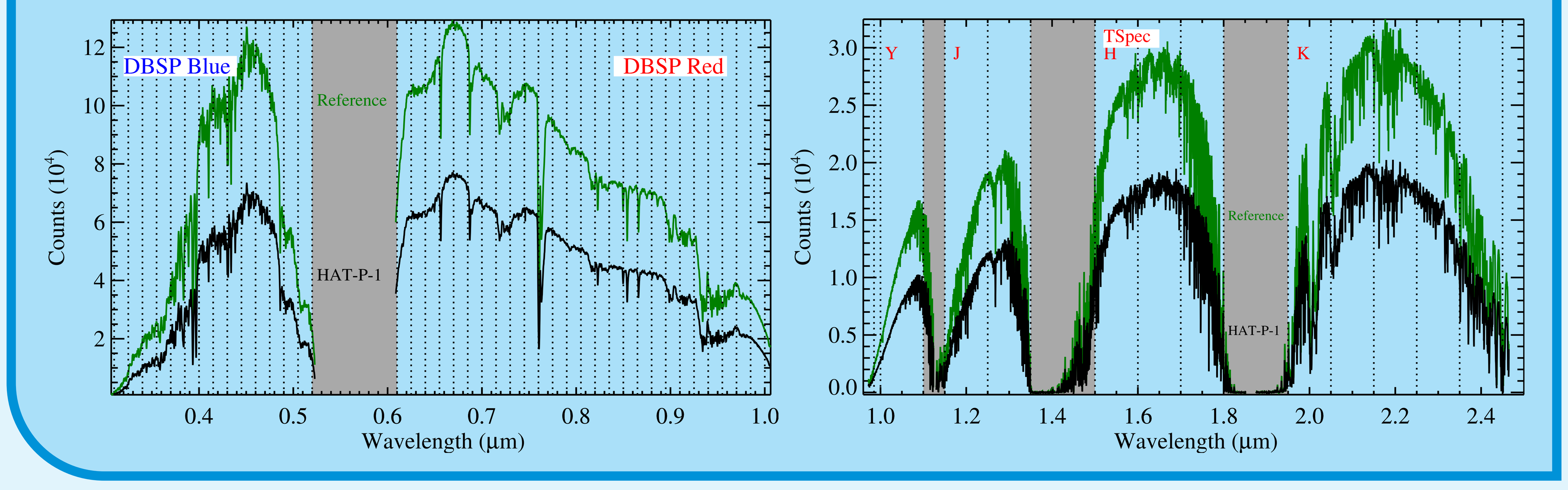
We observed two primary transits of HAT-P-1b, using the DBSP and TSpec on the Hale 200-inch telescope in September 2012, aiming at constructing its first optical-to-NIR transmission spectrum and thereby revealing its atmospheric properties. We have potentially detected the potassium absorption in HAT-P-1b's atmosphere, and greatly improved the transit ephemeris and system parameters. Detail atmosphere modelling is still in progress.

Observations and Data Reduction

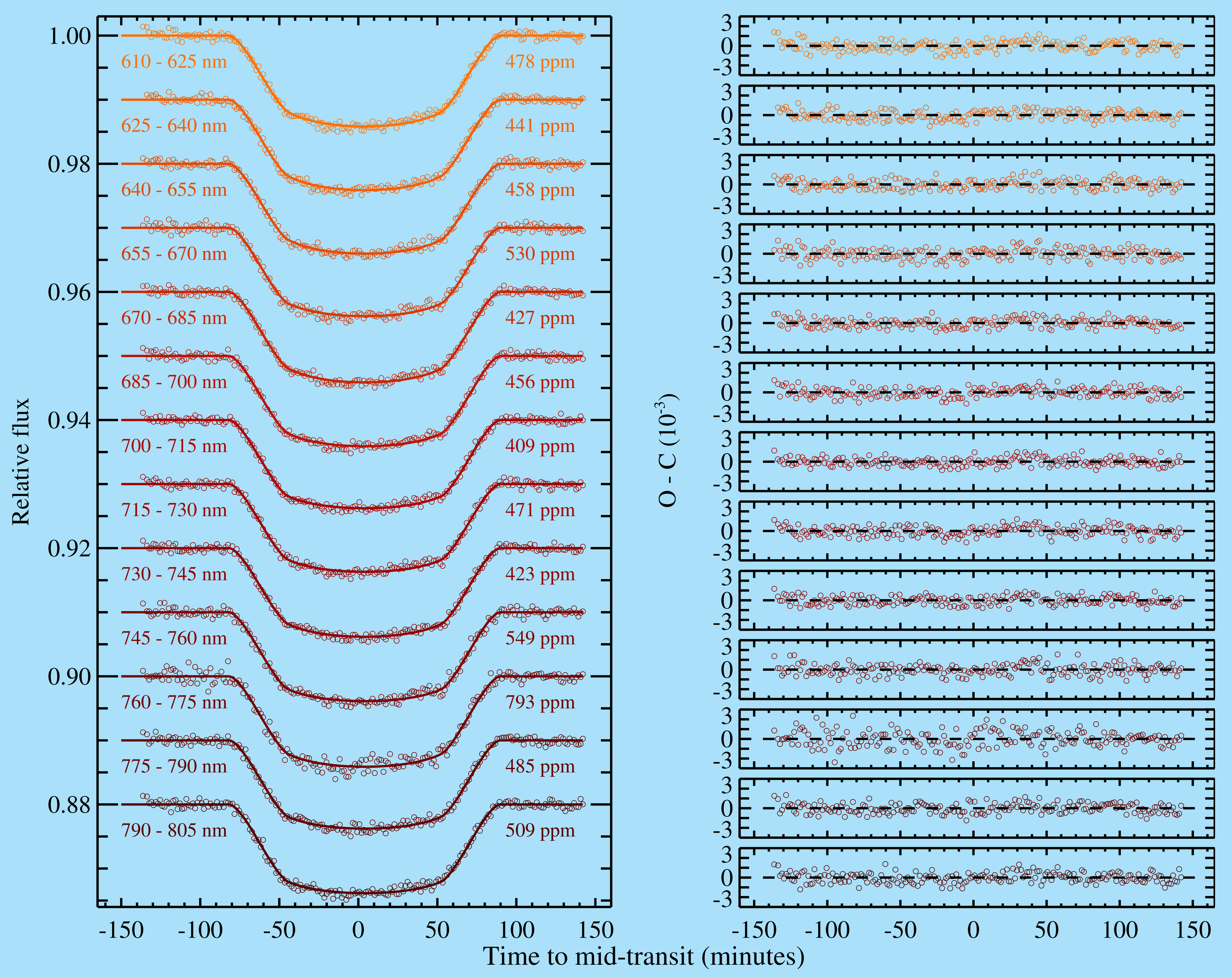
The Sep-06 transit was observed using TSpec, a low resolution NIR spectrograph that cross-disperses light into four spectral orders, covering wavelength from 1.0 μm to 2.4 μm. Only a 1″-wide 30″-long slit was available, which made us suffer from great slitlosses during the observation. We reduced the TSpec data with the IDL-based package Spextool (Cushing et al.2004). After flat correction, wavelength calibration, and spectral order rectification, the spectra were extracted using optimal extraction.

The Sep-15 transit was observed using DBSP, which employs a dichroic to split the optical light into the blue and red sides simultaneously. Both sides were in longslit mode, with a slit width of 10″ (128″ in length). The resultant dispersion were 0.11 nm pixel^{-1} for the blue and 0.15 nm pixel^{-1} for the red. We performed data reduction with IRAF, including bias subtraction, flat division, cosmic ray removal, spectra extraction, and wavelength calibration.

In the figure below, both panels display the extracted example spectra for HAT-P-1 and its reference star. The DBSP spectra were subdivided into 26 channels (15 nm in width), while the TSpec spectra were composed of 11 channels (0.1 μm in width).

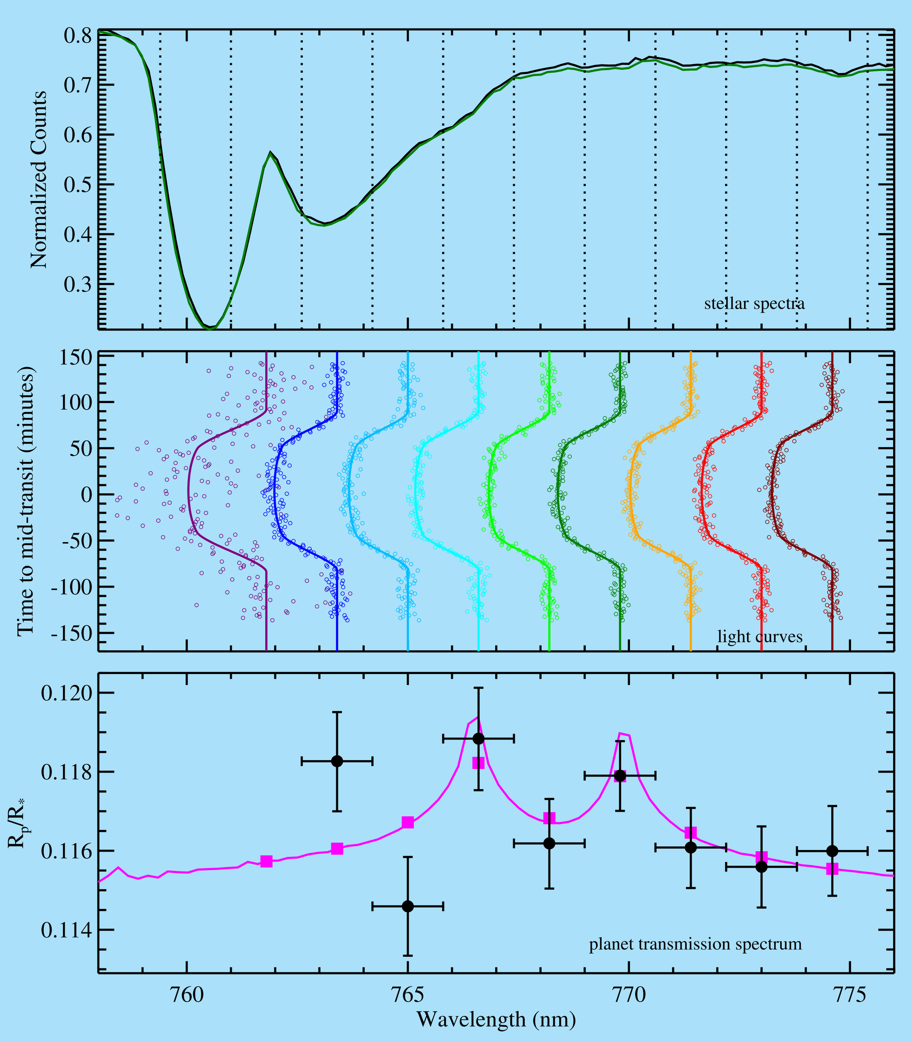


Spectroscopic Light Curves



We created both broadband and spectroscopic light curves. The former (only DBSP; TSpec were of poor quality) were jointly modelled to derive the transit and physical parameters (see the table at the bottom), while the latter were used to derive the wavelength-dependent $R_{\rm p}/R_{\star}$. We modelled the light curves with the Mandel & Agol (2002) model multiplied with a detrending function that corrects the effect of spectra's position drifts and seeing variations. An example of the fitted spectroscopic DBSP red light curves and their O–C residuals are shown above. The precision for the DBSP blue and red spectroscopic light curves achieves ~1.25–1.57 and ~1.57–2.87 times of the photon noise limit, respectively.

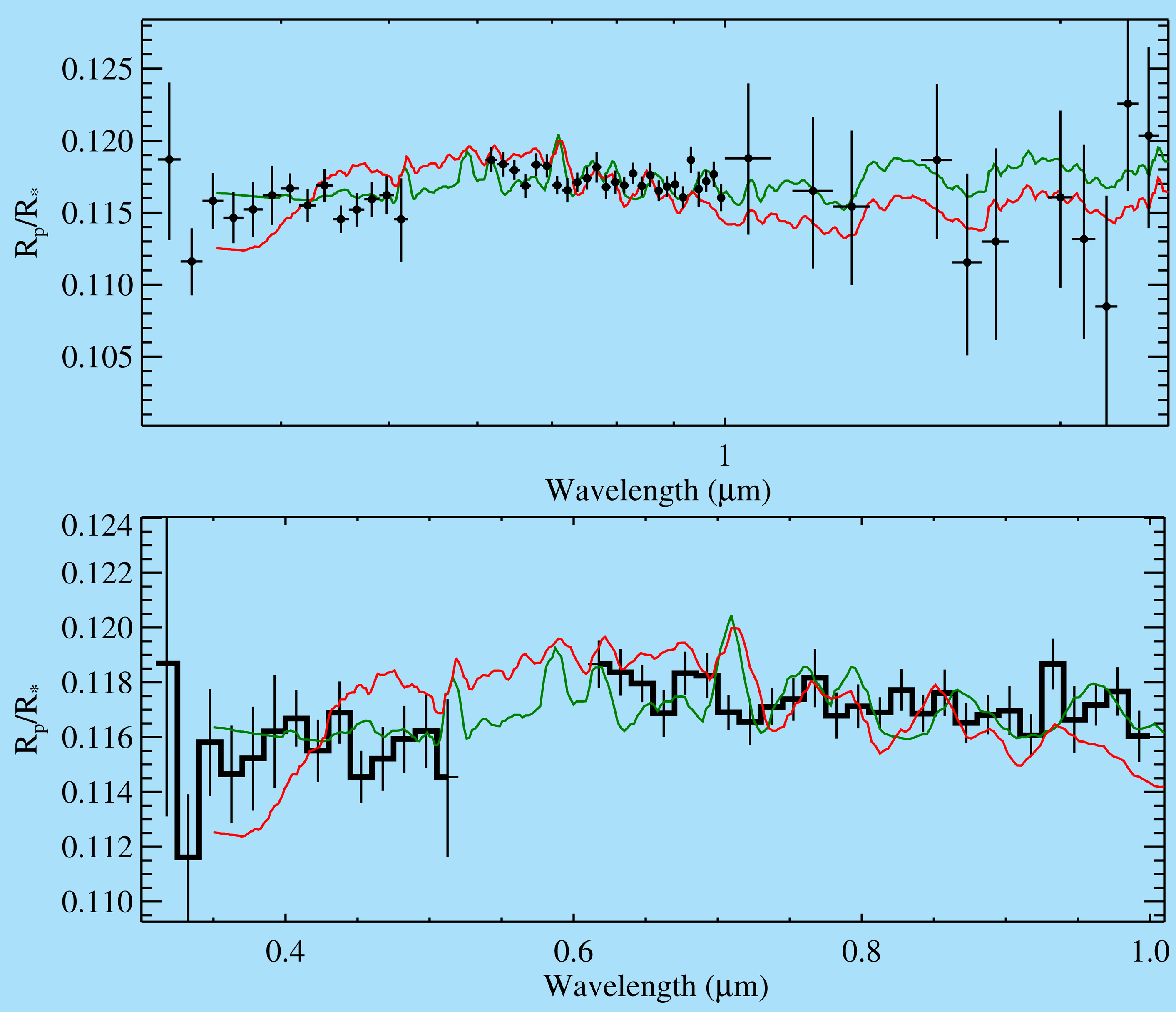
Detection of Potassium Absorption?



The absorption feature of potassium resonance doublet locates in the spectral channel 760–775 nm, which is contaminated by the telluric O_2 absorption between ~760 nm and ~765 nm. We further studied this wavelength range in a higher resolution with a bin size of 16 Å.

As shown in the figure, the bluest channels are heavily contaminated. For the wavelength longer than 765 nm, a doublet profile is already visible. A toy atmosphere model is shown in pink just for comparison (Fortney et al. 2008,2010).

Transmission Spectrum for HAT-P-1b



The final transmission spectrum for HAT-P-1b created from the DBSP and TSpec data. Also overlaid are two toy atmosphere models from Fortney et al. (2010), with a temperature of 1500 K (green) and 2000 K (red), just for a quick look. Atmospheric spectral retrieval modelling is undergoing.

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Derived Parameters

Parameter	Value
$M_{\rm p}$ $[M_{\rm Jup}]$	0.517 ± 0.007
$R_{\rm p}$ $[R_{\rm Jup}]$	1.346 ± 0.018
$\rho_{\rm p}$ $[\rho_{\rm Jup}]$	0.212 ± 0.007
$g_{\rm p}$ [m s^{-2}]	7.40 ± 0.28
P [days]	4.46529970(56)
a [AU]	0.05498 ± 0.00098
$T_{\rm eq}$ (A=0, f=1/4) [K]	1335 ± 14