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Spectroscopic observations of Hot-Jupiters with the Hubble WFC3 camera

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Abstract

We report here the analysis of the near-infrared transit spectrum of the hot-Jupiter HAT-P-32 b which was recorded with the *Wide Field Camera 3* (WFC3) on-board the *Hubble Space Telescope* (HST). HAT-P-32 b is one of the most inflated exoplanets discovered, making it an excellent candidate for transit spectroscopic measurements. To obtain the transit spectrum, we have adopted different analysis methods, both parametric and non parametric (Independent Component Analysis, ICA), and compared the results. The final spectra are all consistent within 0.5σ. To interpret the spectrum of HAT-P-32 b we used $\mathcal{T}$-REx, our fully Bayesian spectral retrieval code. As for other hot-Jupiters, the results are consistent with the presence of water vapor ($\log H_2O = -3.45^{+1.83}_{-1.65}$), clouds (top pressure between 5.16 and 1.73 bar). Spectroscopic data over a broader wavelength range will be needed to de-correlate the mixing ratio of water vapor from clouds and identify other possible molecular species in the atmosphere of HAT-P-32 b.

1. Introduction

In the past decade the *Hubble Space Telescope* has been an invaluable observatory to study the properties of exoplanetary atmospheres. The majority of the planets observed to date are hot and gaseous as they are the easiest targets to probe. Transit observations in the UV, VIS and IR have started to provide important insights into the chemical composition and structure of the atmospheres of gas-giants orbiting very close to their star.

In this work we analyze the near-infrared transit spectrum of the hot-Jupiter HAT-P-32 b ($T_{eq} = 1786\,\mathrm{K}$) (Hartman et al., 2011) obtained with the WFC3 camera on-board the HST. HAT-P-32 b is one of the most inflated exoplanets discovered, being less massive than Jupiter ($M_\mathrm{p} = 0.79\,M_\mathrm{Jup}$) but having almost twice its radius ($R_\mathrm{p} = 1.789\,R_\mathrm{Jup}$). The atmosphere of HAT-P-32 b has been observed with ground-based instruments in the optical wavelengths, revealing a featureless transmission spectrum (Gibson et al., 2013; Zhao et al., 2014; Nortmann et al., 2016; Mallonn & Strassmeier, 2016). In addition, Zhao et al. (2014) suggested the presence of a thermal inversion in the atmosphere of HAT-P-32 b to interpret eclipse observations.

We used our dedicated WFC3 pipeline (Tsiaras et al., 2016a) to extract the transit light-curves per wavelength channel and obtain the planetary spectrum. We used in parallel Independent Component Analysis to correct for the instrumental systematics, and investigate the effect of different analysis techniques on the same data set. The final spectrum was analyzed using our fully Bayesian spectral retrieval code, $\mathcal{T}$-REx (Waldmann et al., 2015a,b).

2. Data Analisys

The spatially scanned spectroscopic images of HAT-P-32 b were obtained with the G141 grism and are available from the MAST archive[1]. Before extracting the light-curves (white and spectral), all frames were reduced using the routines described in Tsiaras et al. (2016a). HAT-P-32 A has an M1.5 stellar companion, HAT-P-32 B ($T_\mathrm{eff} = 3565 \pm 82\,K$, Zhao et al., 2014). The dispersed signals from HAT-P-32 A and B are blended when using the scanning mode. However, these two stars are separated enough ($2''.923 \pm 0''.004$, Zhao et al., 2014) to avoid blending when the differential reads (the difference between two consecutive non destructive reads are considered. Then was determined the photometric aperture and the signal was extracted. It is known that instrumental systematics (known as "ramps") affect the WFC3 infrared detector both in staring and scanning modes. We fitted the ramps on

[1] https://archive.stsci.edu/

the white light-curve using a similar approach to Kreidberg et al. (2014), i.e. we adopted an analytic function with two different types of ramps, short-term and long-term, to correct the data:

$$R(t) = (1 - r_a(t - t_v))(1 - r_{b1}e^{-r_{b2}(t-t_0)}) \quad (1)$$

where, t is the mid-time of each exposure, t_v is the time when the visit starts, t_0 is the time when each orbit starts, r_a is related to the long-term ramp and r_{b1}, r_{b2} are related to the short-term ramp.

Finally, for each wavelength bin we divided the spectral light-curve by the white light-curve (Kreidberg et al., 2014) and fitted a linear trend simultaneously with a relative transit model:

$$n_\lambda(1 + \chi_\lambda)(F_\lambda/F_W) \quad (2)$$

where n_λ is the normalization factor that needs to be calculated for each bin, χ_λ is the wavelength-dependent linear ramp (Tsiaras et al., 2016a,b), (F_λ/F_W) is the ratio between the spectral light-curve and the white light-curve.

3. ICA

Independent Component Analysis (ICA) is a blind signal-source separation (BSS) technique which is able to separate the source signals in a set of observations without any prior knowledge about the signals themselves or their mixing ratios. ICA has been used to remove instrument systematics and other astrophysical signals in exoplanetary light-curves. In this paper, we discuss a similar approach to the analysis of spectroscopic time series obtained with *HST*/WFC3 using the scanning-mode technique.
The main steps of the algorithm are:

1. ICA decomposition;
2. Fitting;
3. Finalizing the parameter error bars.

4. Atmosferic retrieval

To interpret the spectrum of HAT-P-32 b, we use $\mathcal{T}$-REx (Waldmann et al., 2015b,a), a Bayesian spectral retrieval code which uses line lists provided by ExoMol, HITEMP and HITRAN. With the exception of water vapor, the fitted values for all the other molecular mixing ratios are smaller than 10^{-7}. This result means that they are not detectable from this dataset. The water vapor mixing ratio oscillates, instead,

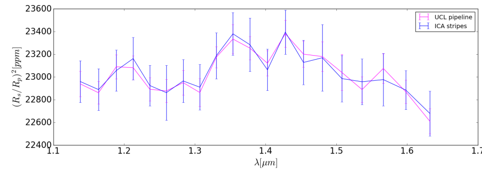

Figure 1: Spectra obtained with the UCL pipeline (magenta) and with stripe-ICA (blue).

between $\log H_2O = -3.45^{+1.83}_{-1.65}$ depending on the clouds' top pressure, which could occur between 5.16 and 1.73 bar.

5. Summary and Conclusions

We have reported here the analysis of the near-infrared transit spectrum of the hot-Jupiter HAT-P-32 b which was recorded with the *Wide Field Camera 3* on-board the *Hubble Space Telescope*. To interpret the spectrum of HAT-P-32 b, we used $\mathcal{T}$-REx, a fully Bayesian spectral retrieval code.

As for other hot-Jupiters, the results are consistent with the presence of water vapor ($\log H_2O = -4.66^{+1.66}_{-1.93}$) and probably clouds (top pressure between 5.16 and 1.73 bar). Spectroscopic data over a broader wavelength range will be needed to decorrelate water vapour's mixing ratio from clouds and identify other possible molecular species in HAT-P-32 b atmosphere.

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