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Ground-based characterization of transiting exoplanets using the GTC.

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Abstract

We observed the transits of six hot Jupiters with the Gran Telescopio de Canarias (GTC). The planets cover a large range of physical parameters such as planetary temperature, surface gravity, mass, radii and scale height (Table 1). This broad range of physical parameters allowed us to characterize different hot-Jupiter atmospheres. The transits were observed in the optical wavelength range, covering between 518 to 918 nm using the Optical System for Imaging and low Intermediate-Resolution Integrated Spectroscopy (OSIRIS) instrument. We present the different transmission spectra with different spectral absorption, depending on the atmospheric scale height.

1 Observations

The observations were carried out using long slit spectroscopy (to see Fig. 1), in which the target and one or more reference stars are placed inside one long slit. We used the R1000R grism to disperse the light over the total range from 500 to 1000 nm, with a pixel scale of 0.262 nm/pixel and a resolution of 1122. The time-series data were collected by two red-optimized 2048x4096 Marconi CCDs in the 200 or 500 kHz (according to the transit duration) and 2x2 binning readout mode. The full transits events along with one hour before the ingress and after egress were acquired. Depending on the seeing of the night, a slit of 12" or 40" was used.

2 Analysis

The transit light curves across the total range in wavelengths were fit simultaneously with instrument/weather systematics against the transit data to determine the physical planet parameters, which were then fixed for the analysis of the transmission spectra. For the

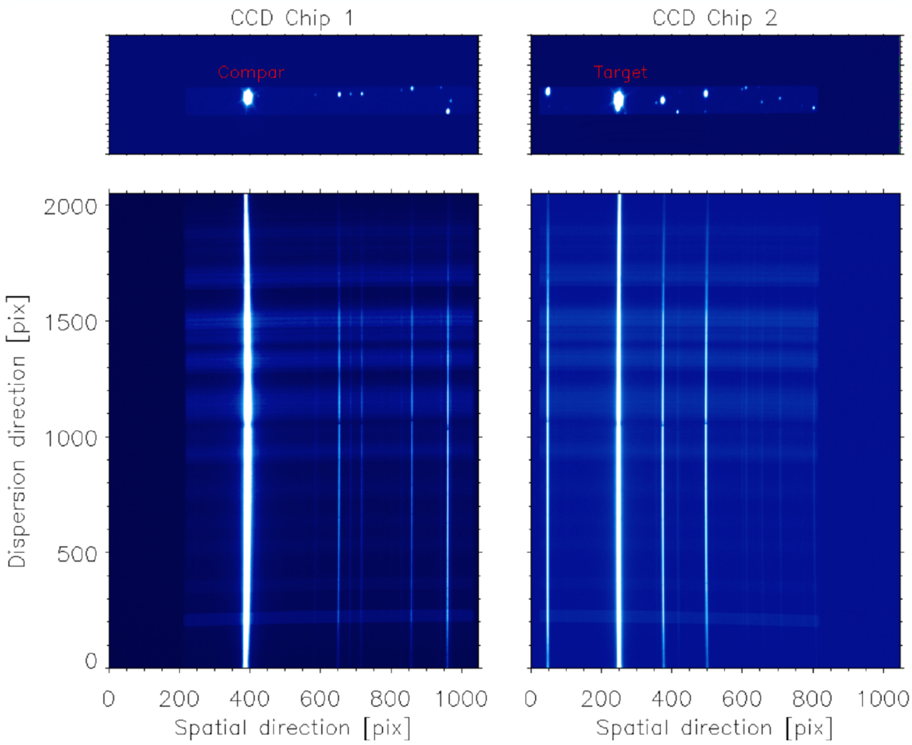

Figure 1: Example of long slit spectroscopy data. Through-slit images (top panels) and corresponding dispersed two-dimensional spectra images (bottom panels).

treatment of stellar limb darkening we employed the quadratic limb darkening law. We implement the same conditions as proposed by [4], using the parameters q1 and q2, which are related to the quadratic coefficients, u1 and u2. They were fixed using the Python package written by [2] given the effective temperature and surface gravity of the star. To create the transmission spectra, we extracted 10 nm bins in wavelength in the GTC/OSIRIS spectra and separately fit each bin for the planet-to-star radius ratio Rp/Rs and for instrument/ weather systematics. The analysis were carried out using MCMC methods, more specifically the MC3 code written by [1].

3 Results

The resulting transmission spectra are shown in Figure 2. They exhibit a variety of spectral absorption features as well as optical scattering slopes according to their scale height. We compared our transmission spectra to theoretical cloud-free models of [3]. Our results show several hot Jupiters that exhibit from clear to cloudy atmospheres. We found that only on planet with large scale height can their atmospheres be detected. But it not only depends on that feature, the hot Jupiters show strong pressure-temperature pro?iles due to the strong incident flux from their host star that hea3ng their upper atmospheric layers. Therefore

Table 1: Physical parameters of the planets studied in this work. H is the scale height.

Planet	T_{eq}(K)	g (ms^{-2})	$R_p(R_J)$	$M_p(M_J)$	P (days)	H (Km)
WASP-36b	1724	32.13	1.28	2.30	1.53	193
QATAR-1b	1500	26.65	1.18	1.33	1.42	210
TrES-3b	1620	27.54	1.29	1.92	1.30	211
HAT-P-33b	1782	6.91	1.68	0.72	3.47	926
HAT-P-41b	1941	6.91	1.68	0.80	2.69	1008
KEPLER-12b	1447	3.71	1.69	0.43	4.43	1426

a small shi9 on its temperature could move the cloud base and to change from clear to cloudy atmosphere or viceverse. Furthermore hot Jupiters have a wide variety of values of gravi3es and metallici3es , which affect the atmospheric temperatures. More ground-based observa3ons are needed to able to dis3nguish between clear and cloudy exoplanetary atmospheres.

References

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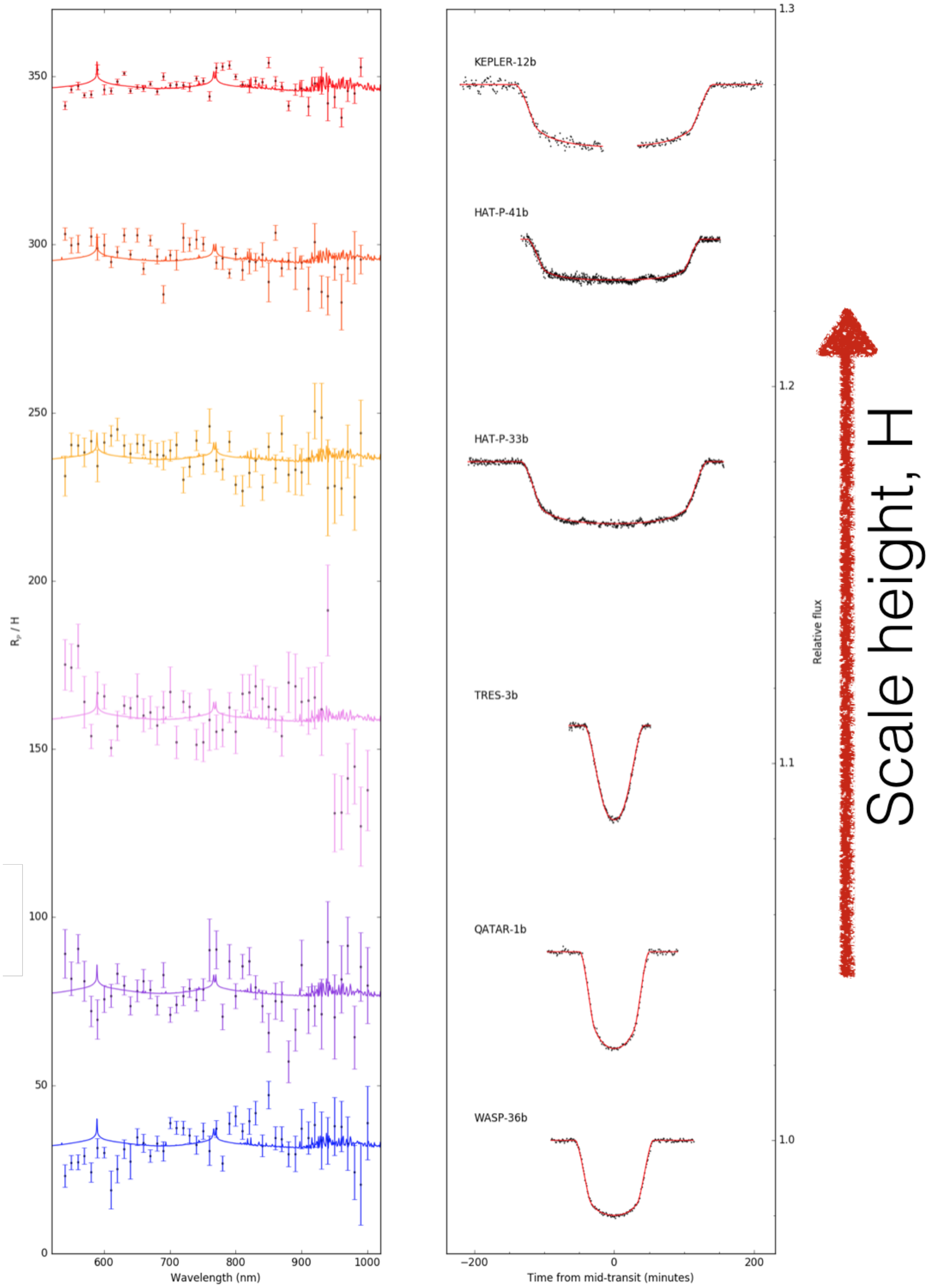

Figure 2: Left panel: GTC/OSIRIS transmission spectra, which are the difference between on-transit and offtransit spectra. Solid coloured lines show fitted atmospheric models corresponding to cloud-free models. The spectra have been offset and are ordered by values Rp/H. Right panel: Transit white light curves after removing the systematics, overlaid with the best fitting transit model.