High resolution day-side spectroscopy of the hot gas giant HD 102195b

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Recent observations of the transiting hot Jupiter HD189733b with the GIANO infrared (0.9-2.45) µm spectrograph at the Telescopio Nazionale Galileo have successfully proven that a 4-m class telescope with a performing high-resolution spectrograph can successfully study the atmospheres of exoplanets at high spectral resolution (R~50,000). Here we report on dayside spectroscopy observations with GIANO of the non-transiting hot giant planet HD102195b, aimed at detecting water vapour in its atmosphere. We employ a technique to disentangle the Doppler-shifted planet spectrum (whose individual lines are resolved at high spectral resolution) from the stationary telluric/stellar components. We then extract the planetary signal by cross-correlating the residual spectra with template models of the planet atmosphere computed through line-by-line radiative transfer calculations, and containing molecular absorption lines from water vapor. Based on this analysis, we present a detection of water in the atmosphere of HD102195b, and a first estimate of the planet's true mass and inclination angle of the orbital plane.

INTRODUCTION

The target: HD 102195b

HD 102195b is a non-transiting planet discovered in 2006 (Ge et al. 2006) with the radial velocity (RV) technique. It orbits around a mildly active G8 dwarf HD 102195, M= (0.926 ±0.016)$M_{\odot}$, R=(0.835 ± 0.016) $R_{\odot}$.

HD 102195b is a non-transiting planet with:

- *msin(i)*=(0.488 ± 0.015)M_{jup}
- P=(4.11390 ± 0.00072) d

The instrument: GIANO

Spectra have been obtained with the near-infrared (0.9-2.45) µm high-resolution (50.000) spectrograph GIANO mounted on TNG (a 4-m class telescope).

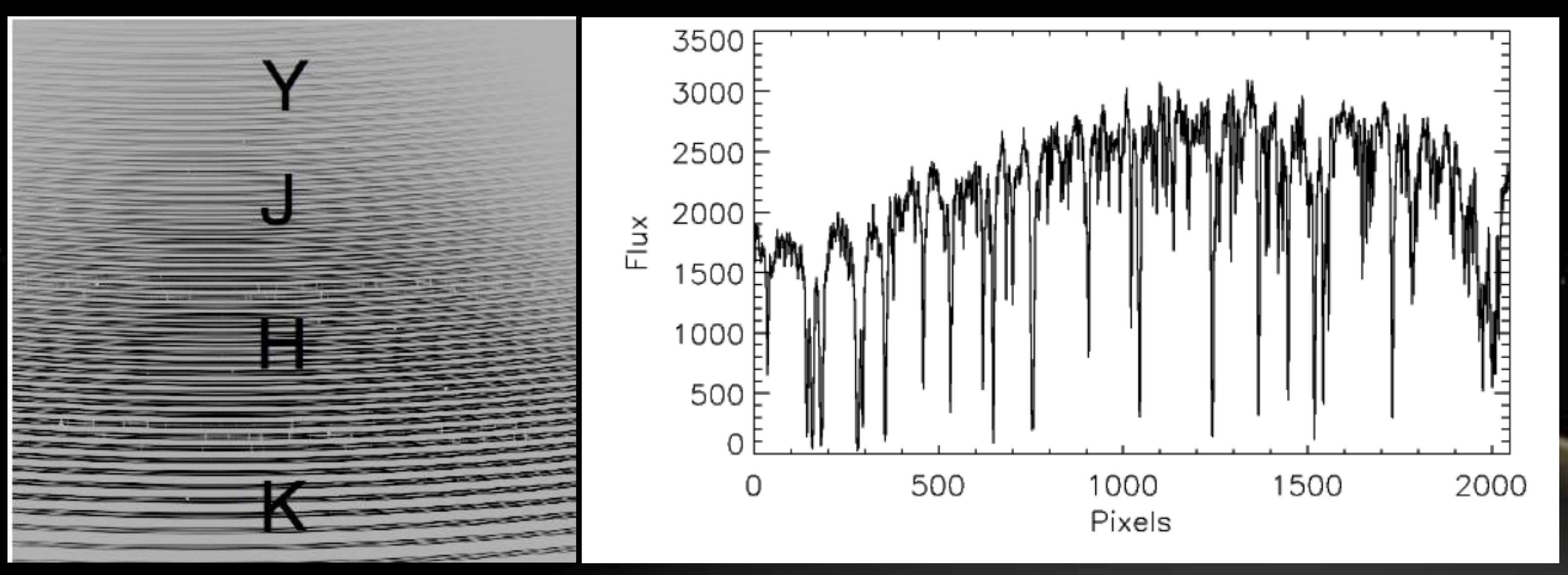


Figure 1. *Left panel: the whole GIANO echellogram. Right panel: an extracted GIANO spectrum.*

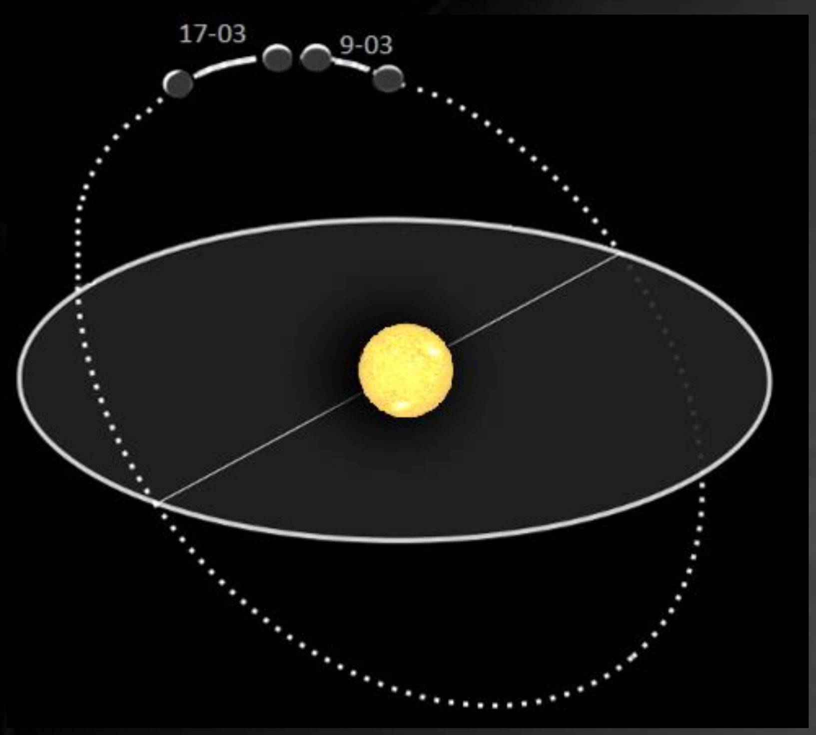


Figure 2. *Rapresentation of the system HD 102195. The system has been observed in 2016 on the nights of March 9 and 17, covering two ranges of planetary phases 0.40-0.44 and 0.46-0.50. During these phase intervals, the planet orbital motion changes by tens of km/s, while the telluric/stellar contamination are stationary signals in wavelength.*

OBSERVATION AND DATA ANALYSIS

Two nights of observations

We have observed HD 102195b during the nights of 9 and 17 March 2016, covering two ranges of planetary phases 0.40-0.44 and 0.46-0.50 (see *Figure 2*). During these phase intervals, the planet orbital motion changes by tens of km/s and greatly helps in disentangling the Doppler-shifted planet spectrum from the stationary signals in wavelength due to telluric contamination and to stellar spectrum.

Data extraction

This step involves the 48 orders identification covering the 4 spectral bands Y, J, H, K, straightening of the order traces (four for every order) and the extraction of the one-dimensional spectra performed by optimal extraction, (see *Figure 1)*.

Alignment of the observed spectra

To correct for misalignment of GIANO spectra, order by order we create a reference spectrum, we measure shifts through cross correlation and re-align the sequence by spline interpolation.

Wavelength solution

A wavelength solution is obtained matching the position (in pixels space) of chosen sets of telluric lines in the observed spectra with those (in λ space) in a model spectrum.

EXTRACTING THE PLANETARY SIGNAL

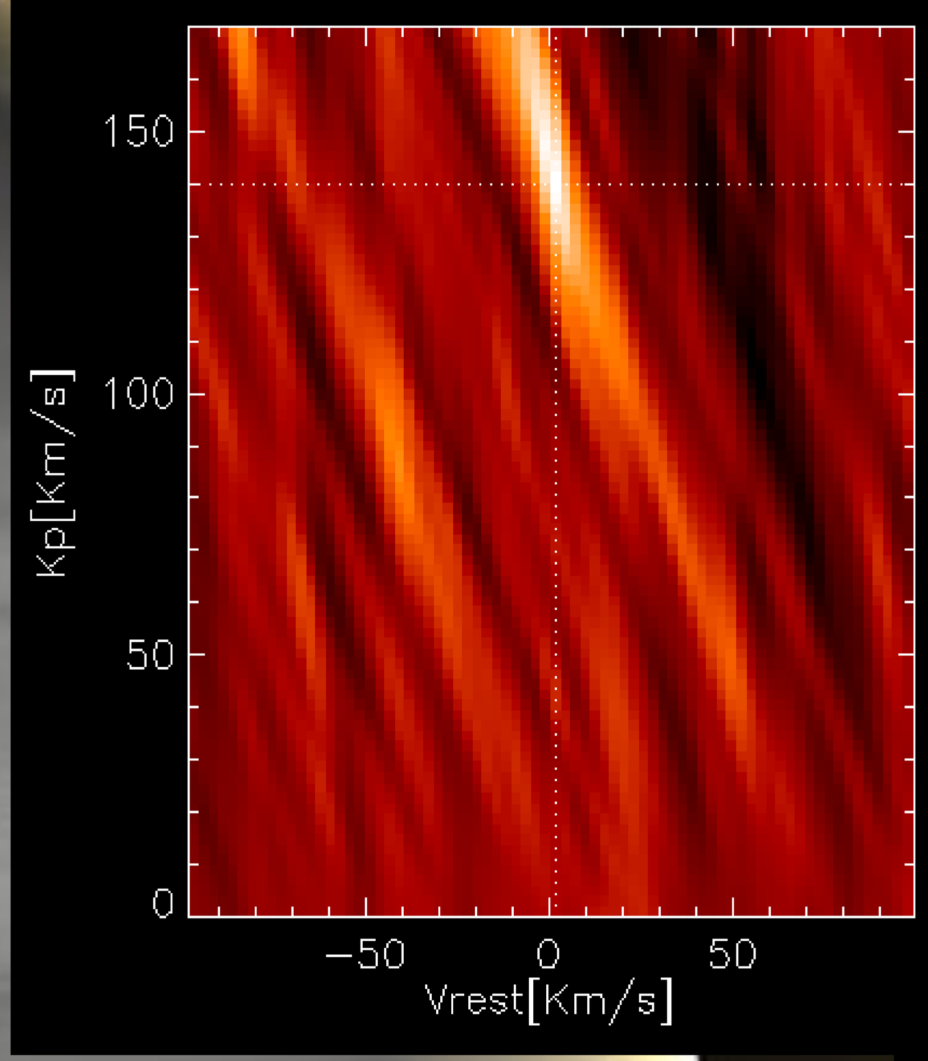
Time dependent effects

In order to extract the planet signal we have to remove variations in instrumental throughput (due to pointing, seeing, and sky transparency) and atmospheric absorption (due to changes in air-mass and amount of water vapor). (See Brogi et al. 2018 for details)

Enhancing the planet signal via cross-correlation

We cross-correlate the data with a high resolution template spectrum for the planet atmosphere, convolved with the instrument profile of GIANO (a Gaussian with FWHM ~6.0 km/s) and Doppler-shifted over a fixed grid of RVs (-225,+225) km/s, in steps of 2.7 km /s. The CC is performed for every image and for every order separately, the CCFs are then coadded over time. Since the planetary RV amplitude Kp is unknown, we assumed a range of (0,170) Km/s. To maximise the planetary signal the matrix of CCFs is co-added in the rest-frame of the planet: for each value of Kp we shift every CCF via interpolation so that it is centered around

$V_p = K_p \sin(2\pi\varphi(t)) + rv_{oss}(t) + V_{sys}$, where V_{sys} =1.93 Km/s.



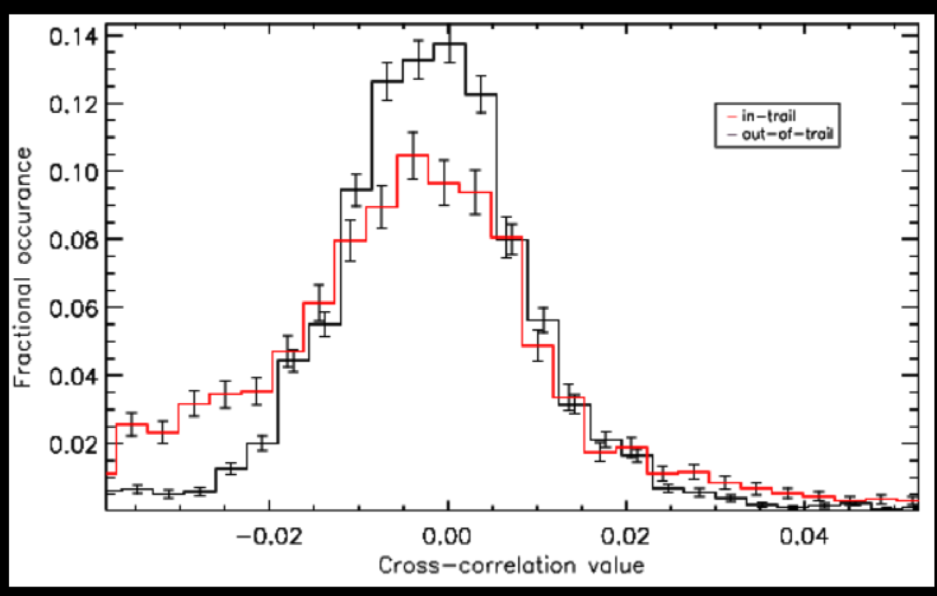


Figure 3. *Left panel: Total CC signal obtained by combining the two nights. A signal at the 6.92 SN is visible at the planet radial velocity of Kp= 142^{+12}_{-8} Km/s. This corrisponds to a planetary mass of $M_p=0.44^{+0.04}_{-0.03} M_{jup}$ and to 2σ, 3σ lower limits on orbital inclination of 73.09°,63.47°.*

Right panel: normalized distribution of the CC values out of trail (black line) and in trail (red line). The in trail distribution is centered to lesser values than the out-of-trail one with a 5,83σ confident level.

RESULTS

Figure 3. shows the CC signal for the two nights combined. A peak in the map is found at a value of Kp= 142^{+12}_{-8} Km/s. Its SNR is 6.92, computed by dividing the peak CC value by the standard deviation of the noise. The statistical significance of the signal is derived evaluating how much the distribution of the CCF(V,t) inside the RV curve is different from that outside, *Figure 3*. This is tested using a Welch t-test that returns a significance of 5.63σ. The combination of the stellar RV semi amplitude, known to be Ks=(63.4±2.0)m/s (Ge et al. 2006), with our measured Kp, gives a star/planet ratio of Ms/Mp= Kp/Ks=2208^{+202}_{-144}, which translates into a planet mass of $M_p=0.44^{+0.04}_{-0.03}M_{jup}$. The orbital velocity of the planet, computed through Kepler's Third Law, is equal to Vp=(129.5±0.7)Km/s. From the ratio *Vp/Kp=sini* we estimate 2σ, 3σ lower limits on orbital inclination of 73.09°,63.47°. By the non-detection of the planet in previous photometric monitoring, (Ge et al. 2006), we set an upper limit on the system inclination imax= (84.79±0.09)°.