# Probing Potassium in the Atmosphere of HD 80606b with Tunable Filter Transit Spectrophotometry

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***Abstract*** We report observations of HD 80606 using the 10.4-m Gran Telescopio Canarias (GTC) and the OSIRIS tunable filter (TF) imager. We acquired very-high-precision, narrow-band photometry in four bandpasses around the K I absorption feature during the January 2010 transit of HD 80606b and during out-of-transit observations conducted in April 2010. We find no significant difference between observations at 768.76 and 769.91 nm, which probe the K I line core. Yet, we observe significant differences ($3.08 \pm 0.53 \times 10^{-4}$ and $7.00 \pm 0.40 \times 10^{-4}$) between these observations and observations at two longer wavelengths that probe the K I wing (773.66 and 777.36 nm). The large change in the apparent planetary radius with wavelength (~3.6%) is much larger than the atmospheric scale height. This implies the observations probed the atmosphere at low pressures as well as a dramatic change in the pressure at which the slant optical depth reaches unity between ~770 and 777 nm. We hypothesize that the excess absorption may be due to K I in a high-speed wind being driven from the exoplanet's exosphere.

## *Background*

- Absorption of stellar photons by species in a transiting planet's atmosphere leads to a larger apparent size of the planet at the absorbing wavelengths (Brown 2001)
- Models predict the strongest absorption lines in the optical wavelength regime are from Na I (589.0 nm, 589.6 nm) and K I (769.9 nm) (Seager & Sasselov 2000; Brown 2001; Hubbard et al. 2001)
- Na I has been detected in the atmospheres of HD 209458b and HD 189733b (e.g., Charbonneau et al. 2002; Redfield et al. 2008), but K I has not been previously detected in any exoplanet atmosphere
- HD 80606 is one of the best systems for making very precise spectrophotometric measurements as it is very bright (V~9) with a comparably bright, very nearby (~20 arcsec) reference star (HD 80607)

## *Observations and Analysis*

- Used the OSIRIS TF imager on the 10.4-m GTC in La Palma, Spain
- Acquired exposures of HD 80606 and HD 80607 simultaneously, cycling through a set of four passbands centered around the K I feature, all with a FWHM of 1.2-nm
- Defocused the telescope to increase the exposure time and read out a single window of 300x600 pixels to reduce dead time, resulting in a cadence of 14-s for each in-transit observation
- Performed aperture photometry on the target and reference star
- Applied the external parameter decorrelation (EPD) technique (e.g., Bakos et al. 2007) to each light curve to remove some systematic effects before computing the weighted mean in-transit flux ratios for each wavelength

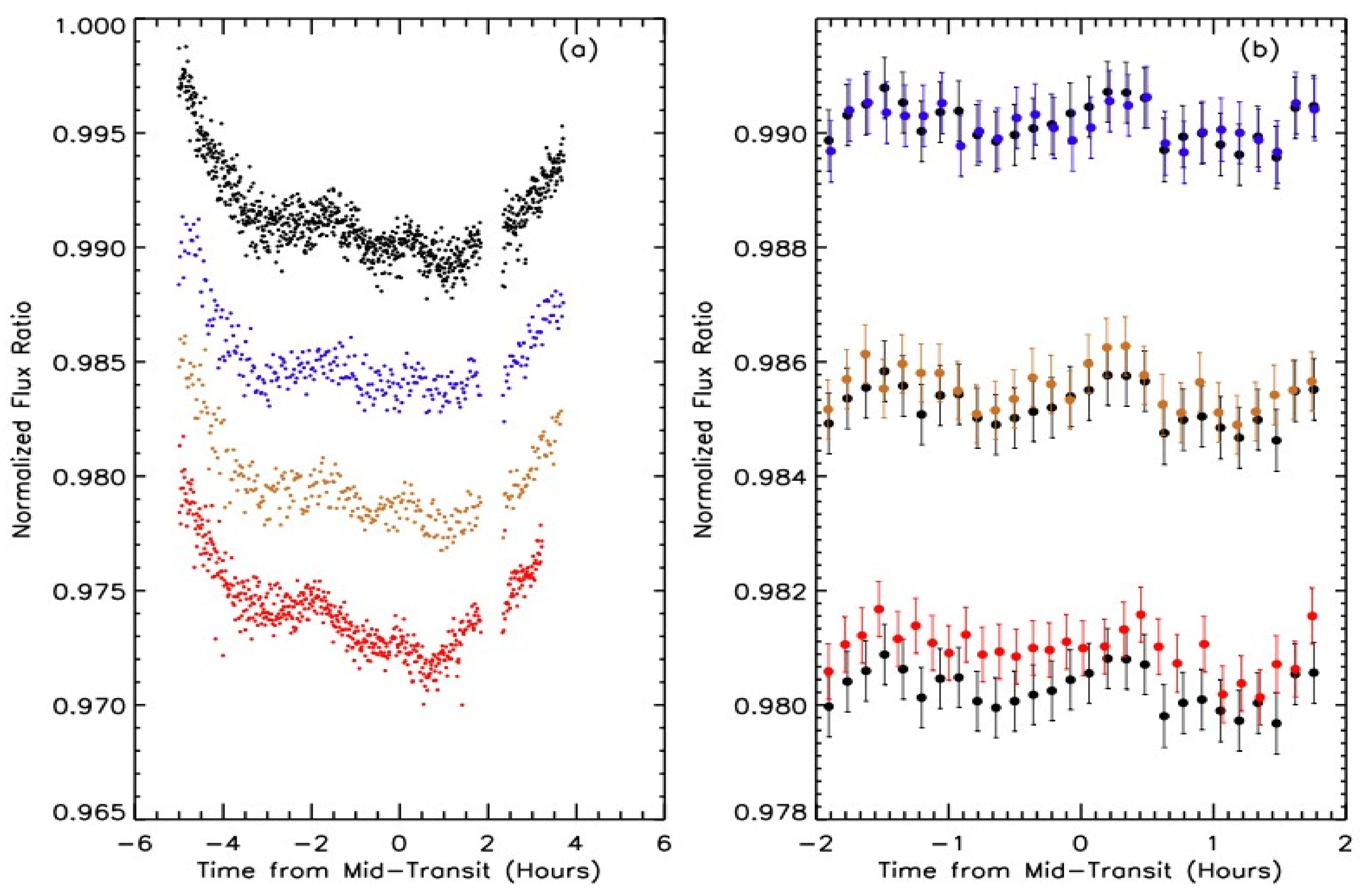


*Figure 1. Normalized light curves for observations of the full transit (a) and bottom of the transit (b) as observed nearly simultaneously in different colours on 2010 January 13-14. The "on-line" light curve (769.91-nm) is shown in black, and the "off-line" light curves (768.76, 773.66 and 777.36 nm) are shown in blue, brown and red. In panel (a), the "off-line" light curves have been arbitrarily offset and error bars are not shown for clarity. In panel (b), EPD has been applied to each set of light curves, which have also been offset and binned for clarity.*

## *Results*

- We obtained differential photometric precisions as small as $\sim 2.9 \times 10^{-5}$
- We find no significant difference between observations at 768.76 and 769.91 nm, which probe the K I line core
- We observed large differences ($3.08 \pm 0.53 \times 10^{-4}$ and $7.00 \pm 0.40 \times 10^{-4}$) between observations at 769.91 nm and observations at 773.66 and 777.36 nm, which probe the K I wing, indicating a change in the apparent planetary radius of up to ~3.6%
- Our measured in-transit flux ratios differ from those from Hebrard et al. (2010) by ~0.09%, possibly indicating a systematic uncertainty in our normalization of the transit depths, but this would not affect the spectrum shape

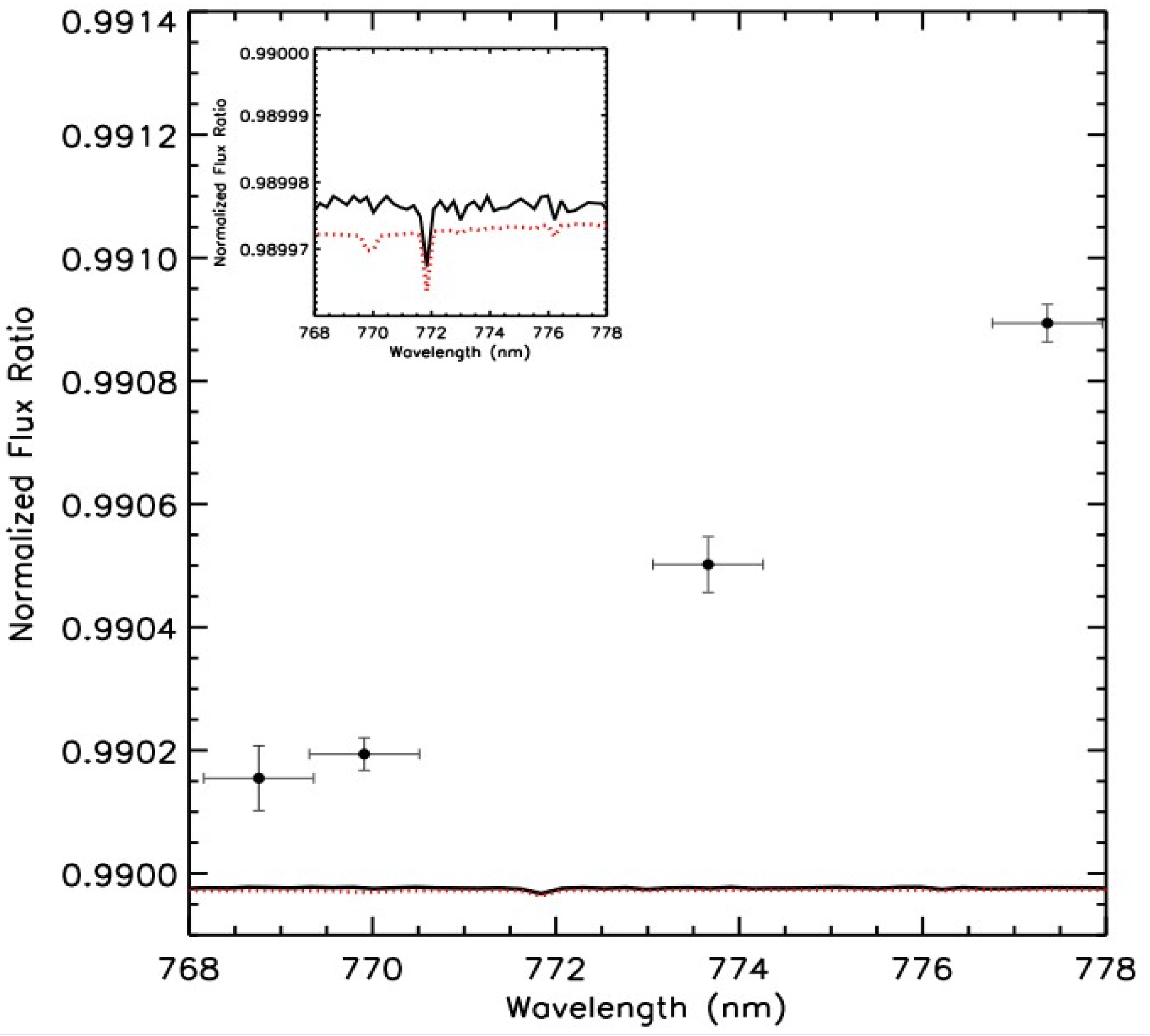


*Figure 2. Normalized in-transit flux ratio vs. observed wavelength (in the frame of the planet). The flux ratios shown are the weighted mean ratios [$\delta F/F \sim (R_p/R_{star})^2$] as computed for each bandpass. The vertical error bars include a scaling factor to account for the effects of red noise. The "error bars" in the horizontal direction indicate the FWHM of each bandpass. The lines show the predictions of "cold" (solid line) and "hot" (dotted line) planetary atmosphere models. The inset figure shows the predicted variation with wavelength with a small vertical scale. While limb darkening or night-to-night variability (of the Earth's atmosphere or either star) could affect the overall normalization, the change in the flux ratio with wavelength is insensitive to such systematics.*

## *Discussion and Conclusions*

- Observations do not match conventional 1-D "cold" or "hot" atmosphere models (Fortney et al. 2010)
- No line core was detected, indicating a lack of K I at altitudes probed by our observations, possibly due to (a) K I being condensed into clouds before the time of transit and/or (b) a high-speed wind (≳ 200 km) causing the line core to be blue shifted out of our "on-line" bandpass
- A high-speed wind could result from large and rapid changes in incident stellar flux and atmospheric temperatures as well as stellar wind flux following each pericenter passage (a result of the highly eccentric orbit; $e = 0.93$)
- We observed a very large change in the planet's apparent radius of ~3.6% or ~2500 km between observations on the K I line core and at 777.36 nm
- Assuming a 500 K (2000 K) upper atmosphere temperature and a scale height of ~20 km (~81 km), the change in the apparent radius suggests we probed ~125 (~31) scale heights or to a pressure of $\sim 10^{-55}$ ($\sim 10^{-14}$) bars
- Whether HD 80606b's atmosphere is "cold" or "hot", our estimates imply that we probed pressures that would exist in an exosphere
- We investigated potential systematics and determined our results are largely insensitive to those effects (see Colón et al. 2010 for further discussion)
- We consider K I the most viable absorber in this wavelength regime and hypothesize that we have observed absorption by K I that is part of a high speed wind coming off the exosphere
- Similar observations of other planets (e.g., XO-2b; Sing et al. 2010) will enable comparisons of the atmospheric composition and structure

### References

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