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MEASURING POTASSIUM IN EXOPLANET ATMOSPHERES WITH THE OSIRIS TUNABLE FILTER

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RESUMEN

Se presentan observaciones de la estrella con exoplaneta HD 80606, con los filtros sintonizables del OSIRIS. La fotometría en cuatro pasos de banda alrededor de la línea de absorción del ion K I fue adquirido durante un tránsito del HD80606b en enero 2010, con adicionales observaciones fuera de tránsitos tomados en enero y abril 2010. Obtuvimos precisiones de fotometría diferencial de $\sim 2.08 \times 10^{-4}$ para la relación de los flujos en la línea del K I (769.91 nm) durante el tránsito. El cambio de profundidad del tránsito a través de los bandas observados corresponde a un cambio de unos 4.2% en el radio aparente del planeta, lo cual es mucho mayor que la escala de la altura de su atmósfera. Eso implica que las observaciones exploraron la atmósfera en zonas de muy baja presión además de una dependencia drástica de la presión correspondiente a la profundidad óptica única. Discutimos la viabilidad de varias hipótesis, entre ellos la de un exceso de absorción debido al K I en vientos de alta velocidad, generados por la exosfera del planeta. También presentamos recientes observaciones similares del exoplaneta XO-2b, todavía bajo análisis. Al fin, delineamos futuras perspectivas para la caracterización de exoplanetas con la espectrografía de filtros sintonizables.

ABSTRACT

We report observations of the exoplanet host-star HD 80606 using the OSIRIS tunable filter imager. Very-high-precision, narrow-band photometry in four bandpasses around the K I absorption feature was acquired during the January 2010 transit of HD 80606b, with further off-transit observations taken January and April of 2010. We obtained differential photometric precisions of $\sim 2.08 \times 10^{-4}$ for the in-transit flux ratio measured at 769.91 nm, which probes the K I line core. The observed changes in the depth of the transit across several wavelengths is equivalent to a $\sim$4.2% change in the apparent planetary radius with wavelength, which is much larger than the atmospheric scale height. This implies the observations probed the atmosphere at very low pressures as well as a dramatic change in the pressure at which the optical depth reaches unity across the bands observed. We hypothesize that the excess absorption may be due to K I in a high-speed wind being driven from the exoplanet's exosphere and discuss the viability of this and alternative interpretations. We also present similar observations of the exoplanet XO-2b that were acquired recently and which are currently being analysed. Finally, we discuss future prospects for exoplanet characterization using tunable filter spectrophotometry.

Key Words: planets and satellites: atmospheres — stars: individual (HD 80606, XO-2) — techniques: photometric

1. INTRODUCTION

Seager & Sasselov (2000), Brown (2001) and Hubbard et al. (2001) developed models for hot-Jupiter atmospheres that predicted strong absorption in the optical due to Na I and K I. In photometric transit observations, one can measure deeper transits that are due to the larger apparent size of the planet at the relevant absorbing wavelengths (Brown 2001). Such measurements can also be used to constrain the atmospheric metallicity, rainout of condensates, distribution of absorbed stellar flux, and photoionization of atmospheric constituents. Here, we discuss observations that probed K I absorption in the atmospheres of two different exoplanets and that are based on a new technique that utilizes fast, narrow-band, spectrophotometry with the Op-

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tical System for Imaging and low Resolution Integrated Spectroscopy (OSIRIS) installed on the Gran Telescopio Canarias (GTC). Fast line spectrophotometry can be more efficient (e.g., ∼34% with GTC/OSIRIS) than typical high resolution spectrographs (∼1–2%) thanks to the use of a tunable filter (TF) rather than diffraction gratings. Further, this technique has the potential to be less sensitive to some systematic noise sources, such as seeing variations that cause line variations in wide spectrograph slits (specifically in non-fiber fed spectrographs), atmospheric variations (since target and reference stars can be observed simultaneously), and/or flat-fielding errors (since on- and off-line data are obtained at the same detector location).

2. OBSERVATIONS AND DATA ANALYSIS

We present extremely precise measurements of the variation in the apparent radius of the Jupiter-size exoplanets HD 80606b and XO-2b with wavelength near the K I feature based on transit observations made with the GTC/OSIRIS TF imaging mode. In the TF mode, the effective wavelength decreases radially outward from the optical center; because of this effect, we positioned the target and a nearby nearly-identical reference star at the same distance from the optical center and on the same CCD chip. We measured the flux of each target and its reference simultaneously, and we cycled through a set of several wavelengths throughout the observations, with one on the predicted core of the K I line (769.91 nm). Our results are based on the ratio of in-transit flux ratio (target over reference) to out-of-transit flux ratio (target over reference), after correcting for various systematic trends in the data.

3. RESULTS AND DISCUSSION

As illustrated in Figure 1, our observations of HD 80606b do not match existing models. We find a large change in the apparent planet radius with wavelength, but do not observe a significant difference where the K I line core would be expected. Thus, our observations place a strong limit on the strength of the line core (unless it has been Doppler shifted by $\gtrsim$100 km s^{-1}). In the absence of other viable absorbers and the lack of any obvious systematic source causing the observed spectrum, absorption by K I remains the most viable explanation. One possible model is absorption by K I that is part of a high speed wind coming off the exosphere. While high speed winds have been observed for other exoplanets, the mechanism for powering such winds is unclear. We encourage investigations to improve models for

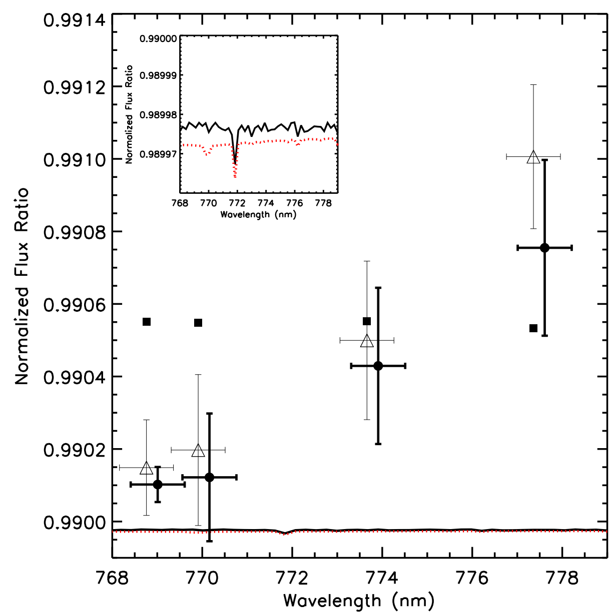

Fig. 1. For HD 80606, normalized weighted mean in-transit flux ratio versus observed wavelength (in the frame of the planet). The open triangles and solid circles represent the flux ratios as computed for each light curve but are based on slightly different analyses. The solid circles have been offset by 0.25 nm for clarity. The vertical error bars include a factor to account for the effects of red noise in both the in- and out-of-transit data. The "error bars" in the horizontal direction indicate the FWHM of each bandpass. The solid squares represent the mean in-transit flux ratios estimated from limb-darkened transit light curve models. The lines show the predictions of planetary atmosphere models. The inset figure shows the atmosphere models on a small vertical scale. Refer to Colón et al. (2012) for further details.

transmission spectroscopy of exoplanet exospheres in general and the specific challenge of HD 80606b.

While not shown here, our preliminary results for XO-2b indicate that we have measured absorption due to K I and that the absorption occurs where we expect the line core to be. Our detection tentatively confirms the measurements made by Sing et al. (2011) for XO-2b and further demonstrates the effectiveness of using the GTC/OSIRIS TF for transmission spectrophotometry.

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