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Ground-based Near-infrared Spectroscopy of HD 209458b

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Abstract

Repeated measurements of the exoplanet HD 189733b indicate enhanced K- and L-band emission which has been explained by non-LTE CH_4 ν_3 emission. We observed one of the brightest exoplanets, HD 209458b, with IRTF/SpeX to search for similar emission features. We use a reduction method that removes common wavelength- and time-correlated errors and bins wavelength channels in Fourier space to decrease the flux variance by 1.4 orders of magnitude to detect HD 209458b's K-band eclipse signal with a precision of 219 parts-per-million. Our absolute K-band emission spectrum is consistent with *Hubble*/NICMOS observations and does not exhibit enhanced K- and L-band emission features like HD 189733b.

1. Introduction

To date, the ∼300 eclipsing exoplanets span a wide range of masses ($\sim$1M$_{Earth}$–$\sim$20M$_{Jupiter}$), radii ($\sim$0.5R$_{Earth}$–$\sim$2R$_{Jupiter}$), and effective temperatures (∼500–∼3000 K). Spectroscopic eclipse observations yield the exoplanet's optically thick radius, thermal profile, and chemical abundances. During secondary eclipse, the planet's dayside thermal emission is measured when it passes behind the star. Measurements of this eclipse are sensitive to the planet's dayside composition and thermal profile.

We used NASA's 3.0 meter Infrared Telescope Facility (IRTF) and SpeX spectrometer to measure the absolute spectrum of one of the brightest (V-mag = 7.65, K-mag = 6.30) exoplanets, HD 209458b, in the K- and L-bands. We are inspired by the observations by Swain et al. (2010) [7] and Waldmann et al. (2012) [10] of one of the other brightest exoplanets, HD 189733b (V-mag = 7.68, K-mag = 5.54). They repeatedly measured a bright emission source at 3.3 microns and enhanced K-band emission which they attributed to non-local thermodynamic equilibrium (non-LTE) CH_4 ν_3 fluorescence [1]. By comparison, HD 209458b is predicted by thermochemical models to have lower CH_4 abundances due to its hotter temperatures [3, 4, 2], which suggests the lack of both a large 3.3 micron feature and enhanced K-band emission. Our IRTF/SpeX data and analysis indicates a non-zero eclipse depth in some of the final reduced light curves and all of our K-band spectral points agree to 1σ with the *Hubble*/NICMOS emission spectrum [8], suggesting the validity of our observation and reduction techniques. We do not find any enhanced K-band emission.

2 Observations

We observed HD 209458b's 2011 September 9 (UT) secondary eclipse with the 3.0 meter NASA Infrared Telescope Facility (IRTF) at Mauna Kea Observatory and SpeX, a near-IR spectrometer with a wavelength coverage of 2.0–4.2 micron (K- and L-bands), a resolution of R = 2500, and a 1.6"×15" slit [5]. *Hubble*/NICMOS observations [8] also partially covered the near-IR K- and L-bands and therefore provide a necessary verification for these difficult ground-based observations.

3 Data Reduction

Typical sources of error for ground-based observations include the changing airmass as the target rises and sets, telescope jitter, seeing, and mirror flexure. Such errors can cause data scatter on the order of ∼10–20 % which dwarf HD 209458b's expected secondary eclipse depth of $\leq$ 0.2 %. To correct for these error sources, we constructed a reduction method based upon the "self-coherence" (SC) methods of Swain et al. (2010) [7] and Waldmann et al. (2012) [10] which: [1] separates the nods, [2] normalizes the data to reduce the variance due to systematic errors, [3] fits the time-varying flux to an exponential curve to correct for airmass, [4] removes outliers, [5] enhances the eclipse signal and reduce the signal due to noise by binning data in Fourier space, [6] flattens residual curvature, and [7] re-combines the nods.

4 Results and Conclusions

The validity and success of the reduction method is indicated by 1σ agreement with a *Hubble*/NICMOS spectrum [8]. HD 209458b's K-band spectrum differs significantly from HD 189733b's IRTF/SpeX K-band spectrum [7] between ~2.2–2.4 microns (Fig. 1). According to Drossart et al. (2011) [1], non-LTE emission could manifest itself not only in the L-band, where it has been repeatedly measured by Waldmann et al. (2012) [10], but also in the other CH_4 bands, such as the K-band.

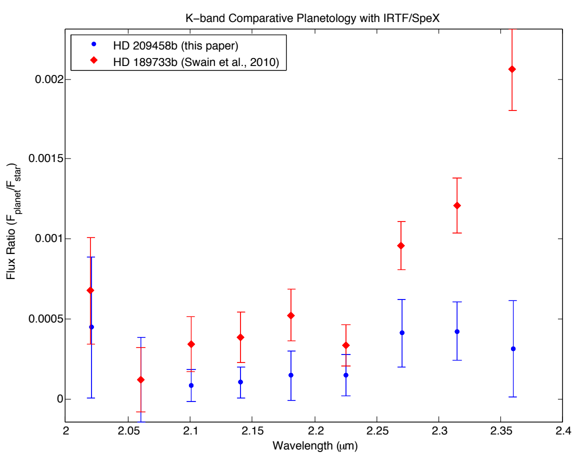

Figure 1: IRTF/SpeX K-band spectra of HD 209458b (blue circles) and HD 189733b [7] (red diamonds). Both observations were taken with IRTF/SpeX. The discrepancy at longer wavelengths could be non-LTE CH_4 emission on HD 189733b. [11]

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