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# Ground-based Near-infrared Spectroscopy of HD 209458b with Palomar/TripleSpec

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## Abstract

We present J, H, and K-band infrared spectroscopy of the exoplanet HD 209458b using Palomar/TripleSpec. Preliminary reductions of secondary transit emission data indicate an upper limit on the planet-to-star emission ratio of $5{\times}10^{-3}{\pm}1.7{\times}10^{-3}$. This initial result is consistent with previous *Hubble*/NICMOS observations by Swain et al. (2009) [5] and illustrates Palomar/TripleSpec's potential for exoplanet spectroscopy.

## 1. Introduction

### 1.1. Transits

Spectroscopic observations of transits reveal an exoplanet's atmospheric composition. During primary eclipse, when the planet passes in front of the host star, the transmission of sunlight through the planet's atmosphere at the terminator produces absorption features. During secondary eclipse, the planet's dayside thermal emission can be measured when it passes behind the star. These two techniques complement each other. The former is sensitive to the planet's composition and radius, which ultimately depend on its internal structure and vertical opacity profile. The latter is sensitive to the composition and the thermal profile. Thus, spectral measurements during both primary and secondary transits are necessary to fully characterize an exoplanet's atmosphere.

Until recently, only the *Hubble Space Telescope* and *Spitzer Space Telescope* have been sufficiently stable for near-infrared observations. Swain et al. (2010) [6] demonstrated the infrared capability of ground-based telescopes by successfully observing the near-IR emission spectrum of the exoplanet HD189733b using NASA's 3.0-m Infrared Telescope Facility (IRTF) with SpeX at Mauna Kea, Hawaii, USA. Swain et al. (2010) [6] overcame the IRTF's instability with a novel reduction technique, opening the doors of exoplanet near-IR spectroscopy to ground-based observatories.

Here we present near-IR (J, H, and K-band) spectroscopic observations of the exoplanet HD 209458b with the 200-inch (5.08-m) Hale Telescope and TripleSpec instrument, using the reduction method outlined in Swain et al. (2010) [6]. We demonstrate Palomar's capability for near-IR exoplanet transit spectroscopy.

### 1.2. HD 209458b

HD 209458b is one of the brightest (V-mag = 7.65, K-mag = 6.308), most extensively measured, and best understood transiting exoplanets. This hot Jupiter (M = $0.69M_{Jupiter}$) has been investigated with UV to IR transmission and emission spectroscopy. However, its composition remains poorly constrained due to large degeneracies in its temperature profile, chemical abundances, and optically thick radius. The solutions that fit current data do not match predicted values; for example, spectra indicate more methane than predicted by models that include photochemistry, thermochemistry, and general circulation [2]. However, HD 209458b's near-IR spectrum has only been partially sampled with limited spectral and photometric measurements [5, 3, 1].

We plan to constrain the $CH_4$, $H_2O$, and $CO_2$ abundances with our near-IR transmission spectrum observations of the terminator. The emission spectrum, which samples the planet's dayside, does not necessarily have the same composition. However, the $H_2O$ emission and transmission abundances will match, as the water abundance is constant across the planet. We will connect the two spectra with the $H_2O$ abundance and constrain the temperature profile using the emission spectrum.

## 2. Data, Reduction, and Preliminary Results

Observations were conducted on the 200-inch (5.08-m) Hale Telescope at the Palomar Observatory in California, USA. Our dataset includes observations of both the primary and secondary transits on 2010 August 19 and 2010 September, respectively.

We used TripleSpec, a spectrometer with a wavelength coverage of 1.0–2.4 $\mu$m and a resolution of R=2500–2700. This instrument is particularly useful as it can simultaneously cover the near-infrared J, H, and K-bands. This spectral region is also covered by *Hubble*/NICMOS, allowing for the verification of our own measurements and confirmation of Palomar/TripleSpec's capability for exoplanet spectroscopy.

TripleSpec's resolution is lower than other platforms. For example, Snellen et al. (2010) [4] used high-resolution (R=100,000) spectroscopy on the Very Large Telescope in Cerro Paranal, Chile, to detect CO lines during HD 209458b's primary transit. While TripleSpec's resolution is comparatively lower, it is capable of observing the broad spectral behavior of HD 209458b, allowing it to nicely complement its high-resolution counterparts.

Our observations will help open the doors of exoplanet near-IR spectroscopy to other lower-resolution ground-based observatories—a crucial feat considering the delay of the *James Webb Space Telescope* and the limitation of orbital near-IR observations to only *Hubble* and *Spitzer*. Palomar/TripleSpec greatly expands our observing capability.

We are reducing our data with the method outlined in Swain et al. (2010) [6], which has successfully and repeatedly recovered HD 189733b's emission spectrum from observations by the ground-based IRTF [6, 7]. This method eliminates systematic errors correlated in wavelength or time (e.g., airmass) by assuming that they are large with respect to the signal. We first select spectral channels that are negligibly affected by telluric (Earth) emission features. We then eliminate wavelength-correlated errors by normalizing each wavelength channel by its neighbors. Next, we correct for the airmass by dividing each channel's lightcurve by an exponential function of the airmass. In order to maximize the channel's signal-to-noise (S/N) ratio, we convert each wavelength channel from time-space to frequency-space using the Fourier transform. The S/N ratio is further increased by binning multiple channels together with the geometric mean. The resulting binned signal is then converted back into time-space with the inverse Fourier transform. Any curvature left over from the Fourier transform is then flattened by dividing by a second degree polynomial. The transit depth of each bin indicates the planet-to-star flux ratio. A large transit depth indicates a strong planetary spectral feature while a small transit depth indicates a weak feature. We calculate each bin's transit depth to calculate the flux ratio and plot it versus the bin's wavelength to construct the exoplanet's overall spectrum.

We will discuss the implications of these data on the temperature-pressure profile, chemical abundances, and optically thick radius with a plane-parallel radiative transfer model.

Preliminary reductions of the secondary transit emission observations indicate an upper limit on the planet-to-star emission ratio of $5\times10^{-3}\pm1.7\times10^{-3}$. This initial result is consistent with the previous *Hubble*/NICMOS observations by Swain et al. (2009) [5] and illustrates the potential of TripleSpec for exoplanet spectroscopy.

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## References

[1] Beaulieu, J.-P., et al.: Water in the atmosphere of HD 209458b from 3.6-8 $\mu$m IRAC photometric observations in primary transit, MNRAS, Vol. 409, pp. 963–974, 2010.

[2] Moses, J., et al.: Disequilibrium Carbon, Oxygen, and Nitrogen Chemistry in the Atmospheres of HD 189733b and HD 209458b, arXiv, 1102.0063, 2011.

[3] Snellen, I. A. G.: High-precision K-band photometry of the secondary eclipse of HD 209458, MNRAS, Vol. 363, pp. 211–215, 2005.

[4] Snellen, I. A. G., et al.: The orbital motion, absolute mass and high-altitude windows of exoplanet HD 209458b, Nature Letters, Vol. 465, pp. 1049, 2010.

[5] Swain, M., et al.: Water, methane, and carbon dioxide present in the dayside spectrum of the exoplanet HD 209458b, ApJ, Vol. 704, pp. 1616–1621, 2009.

[6] Swain, M., et al.: A ground-based near-infrared emission spectrum of the exoplanet HD 189733b, Nature Letters, Vol. 463, pp. 637–639, 2010.

[7] Waldmann, I. P., et al.: Ground-based NIR emission spectrscopy of HD 189733b, arXiv, 1104.0570, 2011.