Results from the First Ground-Based Exoplanet Atmosphere Survey with Gemini/GMOS

University of Colorado Boulder

Catherine M. Huitson[1], J-. M. Désert[2],
J. Bean[3], J. Fortney[4], K. Stevenson[3], M. Bergmann[5]

1. Email: catherine.huitson@colorado.edu, CASA, University of Colorado, 389 UCB, Boulder, Colorado, 80309, USA
2. University of Amsterdam, The Netherlands, 3. University of Chicago, USA, 4. University of California, USA, 5. NOAO/Gemini, USA

Abstract

We report from the first multi-semester survey program dedicated to exoplanet transmission spectroscopy using a ground-based multi-object spectrometer (MOS) in the visible. Our 4-year survey focused on 9 hot Jupiters for which the wavelength dependent transit depths were measured with the Gemini Multi-Object Spectrometers (GMOS). Each planet was observed ~4 times to test repeatability and our large sample allows us to determine sources of noise. Our typical precision is about 100 ppm / 10 nm bin. We present here a survey overview, characterization of GMOS noise sources and first results.

1. Overview of the Survey

Survey designed for optical low-resolution coverage (R=600-1700). The aim is to detect dominant atmospheric absorbers in the optical:

- Uses Gemini Multi-Object Spectrometers (GMOS) on the north and south Gemini telescopes (Hook et al. 2004, Allington-Smith et al. 2002), with R150 and B600 gratings
- Homogeneous survey of 9 hot Jupiters designed to enable:
  1) comparative exoplanetology and 2) testing of systematics and robustness of MOS for exoplanet atmosphere studies

2. Observations

- Observations executed in Queue mode, which allows scheduling of time-critical observations
- Secured 36 transits over 230 hours of telescope time with each planet observed on average for 4 transits

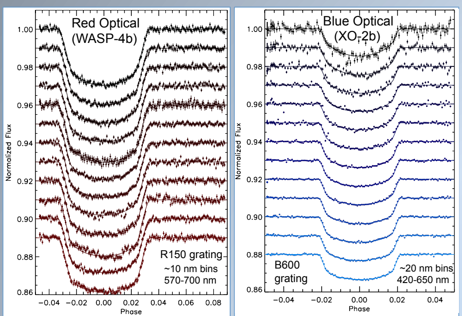

Fig. 1. Sample transit lightcurves in the red optical (left) and in the blue optical (right) in 10-20 nm bins blueward of 700 nm. Precisions are comparable to space-based platforms. Lightcurves have been de-trended and the best fitting transit models from Mandel & Agol (2002) are overplotted.

3. GMOS Performance for Exoplanet Atmospheres

- Precisions: ~100 ppm / 10 nm. Comparable to space-based platforms (Figure 1)
- Single comparison star of the same magnitude and spectral type improves S/N over multiple different-type comparison stars
- Main instrumental systematic: wavelength-dependent shift of spectra over time causing a "stretching" effect, which can mimic cloud signatures if not accounted for (Figure 2)
- Other important limitations:
  1. Fringing in GMOS-S: now removed due to installation of new detectors
  2. Electronic discretization of flux values, which are most noticeable in narrow bands
  3. Time-variable grating throughput for the red grating blueward of 550 nm over 4-5 hour timescales

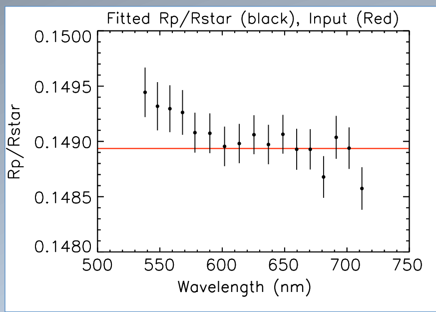

Fig. 2. Effect of spectral dispersion direction stretches on measured exoplanet transmission spectrum. Red = input spectrum, black = measured spectrum in the presence of stretch. The instrumental effect is an increase in Rp/Rstar from red to blue wavelengths of ~2 scaleheights, which could be interpreted as due to Rayleigh scattering if not properly corrected.

4. First Transmission Spectra

- Two hot Jupiters fully analyzed (Figure 3)
  - WASP-4b: a planet with T_{eq}= 1700 K orbiting a moderately active star
  - XO-2b: a planet with T_{eq}= 1400 K orbiting an inactive binary star
- Results
  - WASP-4b: cloud-dominated. Consistent with large-grain cloud scattering
  - XO-2b: cloud-free, with the Na I feature wings clearly visible

Transmission spectra removed due to upcoming paper

Fig. 3. Transmission spectrum of the hot Jupiter WASP-4b from 1 blue and 3 red observations (upper) and of XO-2b from 3 red and 3 blue observations (lower). Due to fringing only 1 transit was used > 700 nm for WASP-4b. Also shown in both plots are cloud-free models based on Fortney et al. (2010) (green), scattering from small 0.1-µm grains (purple) and scattering from large 1.0-µm grains (pink). The atmosphere of WASP-4b is cloud-dominated while the atmosphere of XO-2b is cloud-free, despite being approximately 300 K cooler.

5. Conclusions

- First cloud-free hot Jupiter with broad Na wings detected by MOS
- Two planets, similar bulk properties, yet diversity in atmospheres is seen
- Ground-based MOS is competitive with space-based observations
- Instrumental systematics must be carefully treated as they can mimic cloud signatures such as Rayleigh scattering (see Figure 2)

References: Allington-Smith, J., et al., 2002, PASP, 114, 892; Désert et al., 2016, in prep; Fortney, J.J., 2010, ApJ, 709, 1396; Hook. I.M., et al., 2004, PASP, 98, 609; Huitson et al. 2016, in prep; Mandel, A. and Agol, E., 2002, ApJ, 580, L171