Exoplanet Transmission Spectroscopy in the Near Infrared with Keck/MOSFIRE

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Introduction

Goal: Use "twin planet" pair as natural laboratory – WASP-6 b and HAT-P-25 b

- Planets have similar masses and radii (see Fig. 1)
- Host stars have contrast in metallicity: 0.3 dex
- Perhaps the metallicity difference will dominate the differences in transmission spectra of planets

Instrument: Keck/MOSFIRE

- K band probes absorption by CH_4 and CO but not H_2O (possible culprit in featureless optical spectra)
- 6 arcminute field of view = typically one bright comparison star in field of view
- Our previous work shows our MOSFIRE reduction pipeline achieves differential spectrophotometric precision <2x photon noise

Methods

Observing Techniques

- Observe one transit per night for two full nights
- Observe target and one bright comparison star
- We find PSF wings extend ~15" from centroid (woah, that's wide!) which motivates use of:
  - Long slit mode with one 15" wide slit
  - AB dither pattern with 30" nod
- Challenge: choose slit width to capture most of the wings while minimizing sky background

Data Reduction

- Differential photometry in eight 0.052μm spectral bins (see Fig. 3)
- Flat field, nod subtraction, bad pixel correction
- Additional subtraction of left-over sky lines after nod subtraction

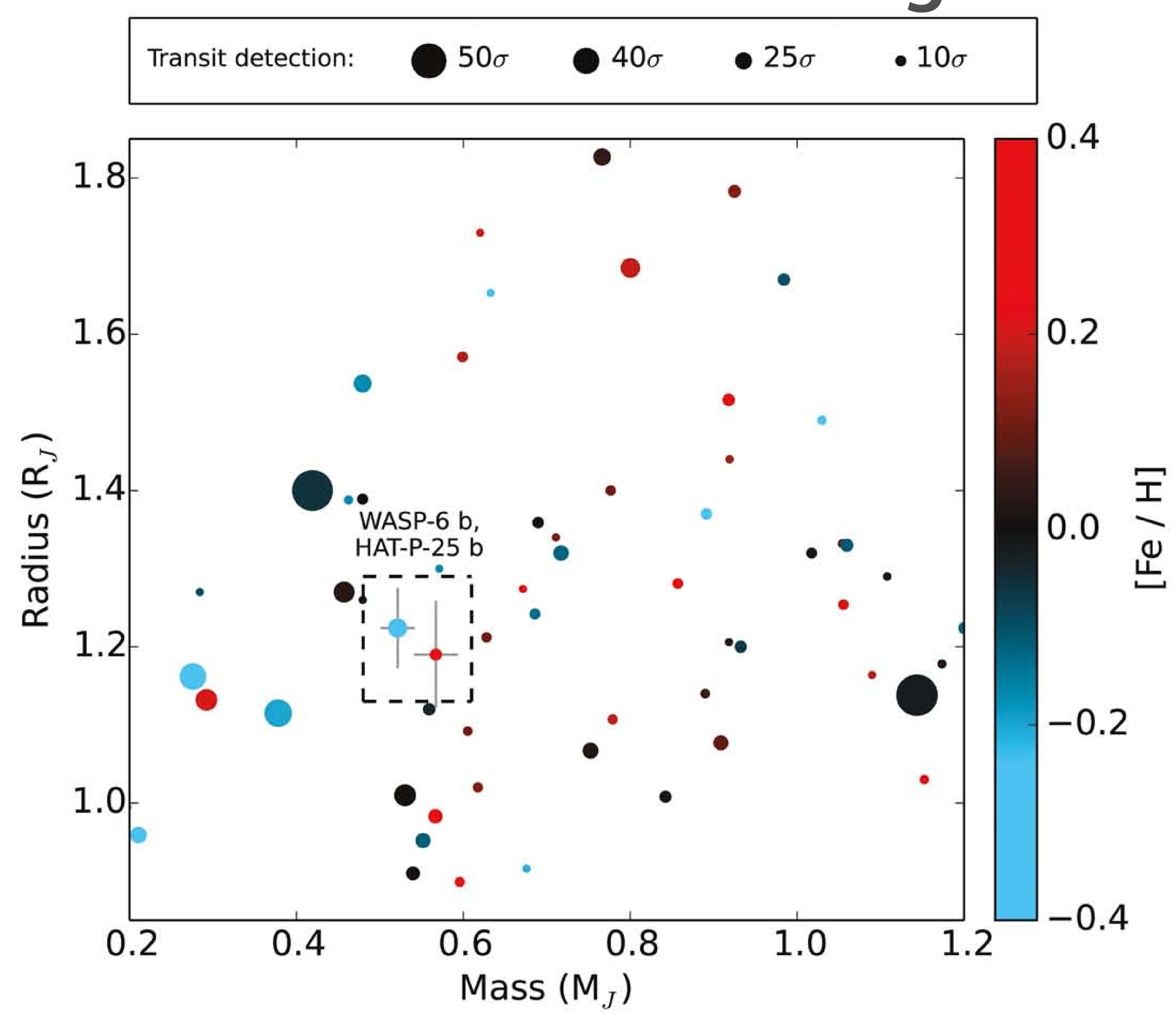
Light Curve Fitting

- Fit all light curves with ensemble sampling MCMC
- Link a/R_s, inclination, mid-transit time and limb-darkening parameters between all bins
- Fit R_p/R_s, out-of-transit flux, airmass trend for each spectral bin individually
- Functional form of light curve model:

$$F(t) = F_0\,\mathrm{occultquad}()\;(1 + c_X\,[X(t) - 1])$$

where F_0 is the out-of-transit flux, $X(t)$ is the airmass as a function of time, c_X is a scaling parameter and *occultquad()* is the Mandel & Agol (2002) transit model

Choosing "Twin Planets"



Properties	WASP-6	HAT-P-25
Spectral type	G8	G8
Stellar T_{eff} [K]	5375 ± 65	5500 ± 80
[Fe/H]	−0.2 ± 0.09	+0.31 ± 0.08
K mag	10.325	10.815
M_{planet} [M_J]	0.50 ± 0.038	0.567 ± 0.022
R_{planet} [R_J]	1.224 ± 0.052	1.190 ± 0.081
Period [d]	3.3610060	3.652836
a [AU]	0.0421	0.0466
Planet T_{eq} [K]	1194	1202

References: Guillon et al. (2009), Quinn et al. (2012), Nikolov et al. (2014)

Fig 1: We chose pairs of planets with similar masses and radii but significant differences in host star metallicity, while also optimizing for the highest transit transmission spectrum S/N in the K-band.

Preliminary WASP-6 b Spectrum

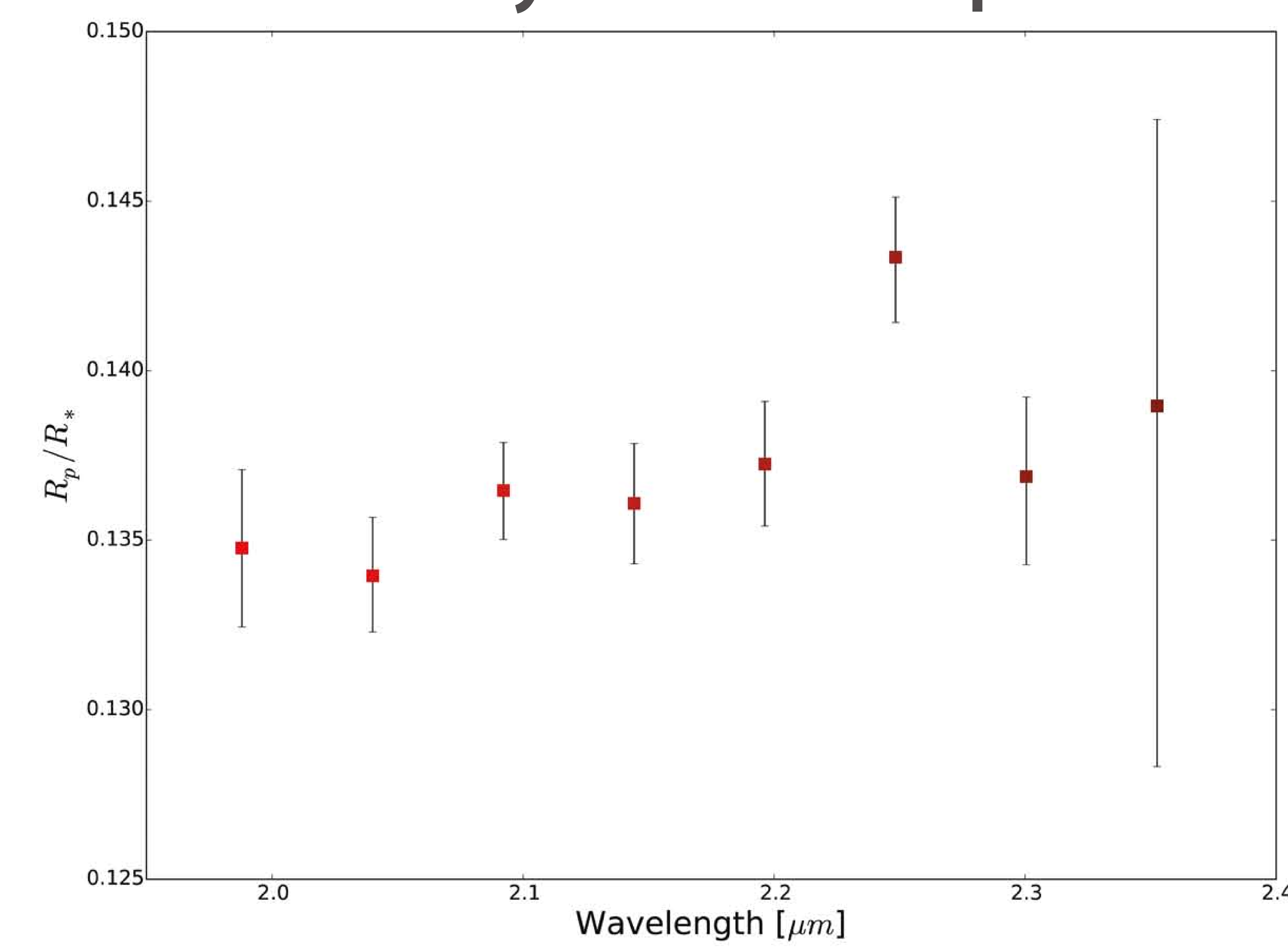


Fig 2: The transit transmission spectrum of WASP-6 b shows a slightly positive slope, 3σ consistent with zero slope; or 1.2σ consistent with zero slope if the light curve at 2.248 μm is thrown out. The uncertainties grow towards longer wavelengths primarily due to higher sky brightness.

Results

Towards The Photon-Noise Floor

- Remaining photometric noise dominated by bright sky lines incompletely removed, and contamination in the nod subtraction by a nearby galaxy
- We're presently nearing the photon-noise floor in some spectral bins

Perhaps Not a "Flat" Spectrum?

- Within the uncertainties, the preliminary WASP-6 b spectrum is flat or has a positive slope (see Fig. 2)
- Rayleigh scattering produces a negative slope, which appears inconsistent with data
- CH_4 and CO absorb near 2.3μm

Next Steps

- Reduce December 2014 observations of "twin" HAT-P-25 b, compare with WASP-6 b
- We will compare the WASP-6 b spectra with optical (HST) and IR (Spitzer) observations of WASP-6 b from Nikolov et al. (2014) and ground-based observations (IMACS/ Las Campanas) by Jordán et al. (2013)
  - Are starspots changing apparent R_p/R_s between observations?
- Observe a larger ensemble of planets, begin comparative exoplanetology

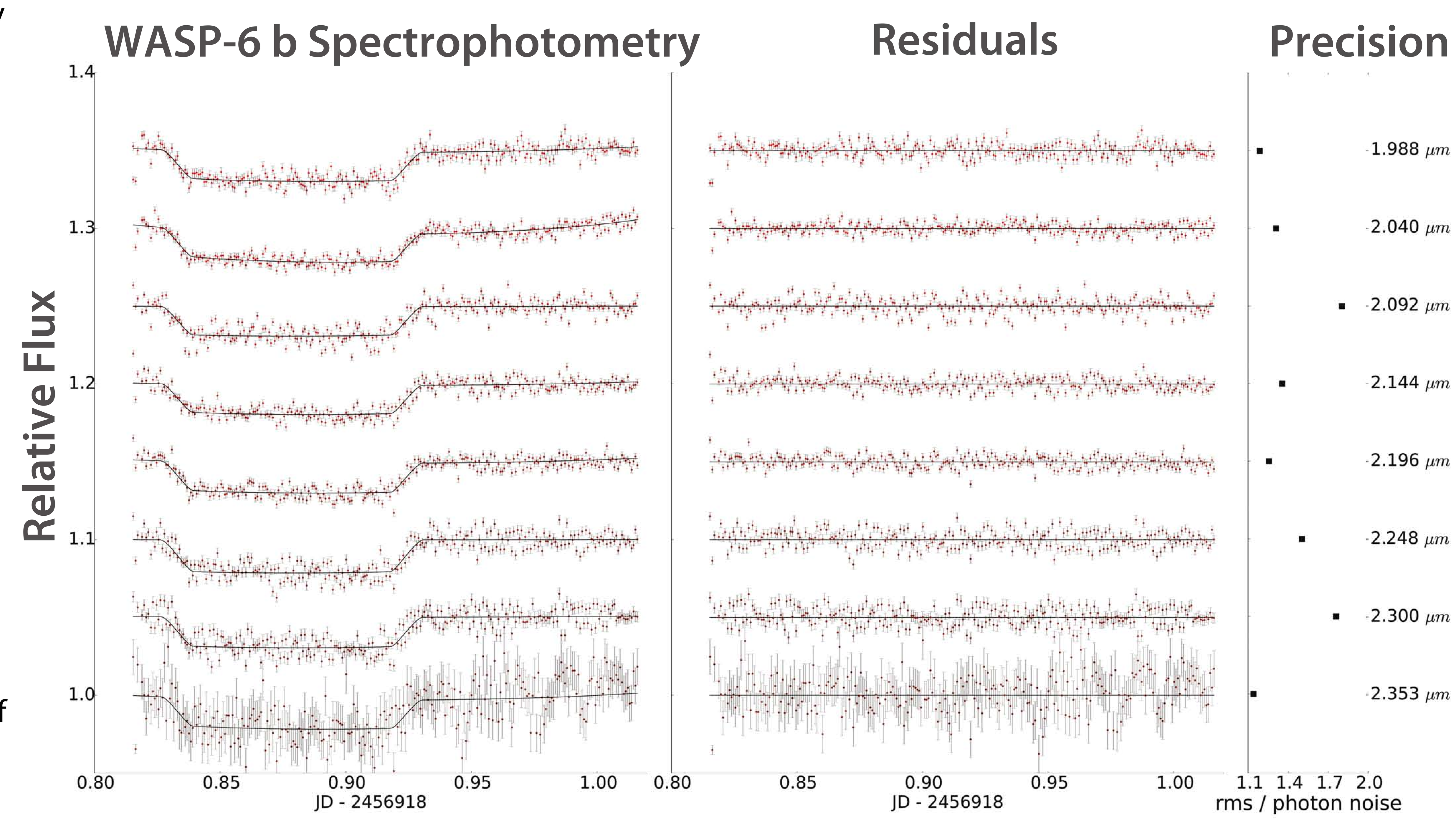


Fig 3: (*Left*) We split the spectrum of WASP-6 b into eight spectral bins across the K band and did photometry in each bin, shown in the leftmost plot. Error bars show the expected Poisson noise contribution to the uncertainty. The photometric noise increases at longer wavelengths primarily due to increased sky brightness. We fit each light curve independently for R_p/R_s, out-of-transit flux, and an airmass trend. (*Middle*) Best-fit residuals for each bin. (*Right*) The ratio of the light curve residual rms to the expected photon noise in each bin is a factor of 1-2x the photon noise.