From Hot Jupiters to Habitable Planets: Optimizing Atmospheric Characterization Methods

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Abstract

A big question in the search for life elsewhere in the universe asks *where* to look. Since the first exoplanet orbiting a main sequence star was discovered in 1995, a new era of astrobiological research begun. If life can exist on Earth, chances are that it can exist on another planet orbiting another star. With astronomers now estimating that every star in the galaxy has at least one bound planet, the possibilities are endless. How we can actually study these potentially habitable, if not inhabited, planets, however, is a distinct and challenging task that our research hopes to address. We are working to optimize an observational pipeline that is currently used to detect molecules in and characterize the atmospheres of hot Jupiters. In combination with the much higher resolution spectroscopy provided by the next generation of telescopes (Keck-NIRSPEC2.0, LUVOIR), our method will be able to characterize the much fainter Earth-like planets around other stars, many of which will be discovered by the TESS mission, scheduled to launch in 2018.

Hot Jupiters: First step to habitable planets

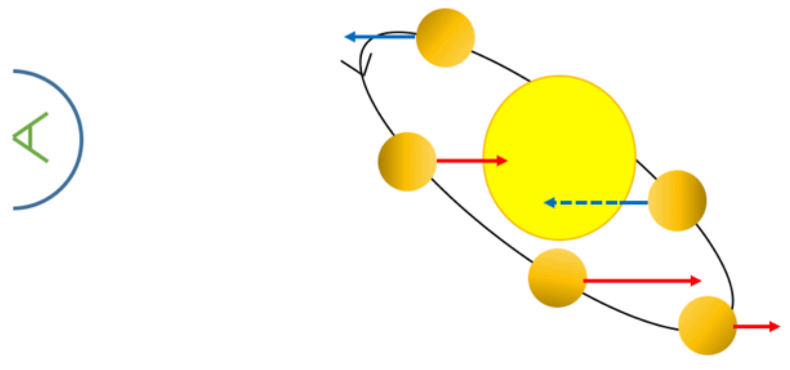
- Gas giant planets that orbit their host stars at extremely close orbital distances–within the orbit of Mercury in our solar system
- Planet-to-star contrast:
  - Hot Jupiters ~ 10^{-6}
  - Earth-like planets around Sun-like stars ~ 10^{-10}

We can therefore optimize techniques for characterizing hot Jupiter atmospheres to be able to characterize atmospheres of potentially habitable planets.

Characterization Technique: Direct Detection Method

Basic steps:

- Obtain spectra with the planet at multiple orbital locations
- Subtract out features from the Earth's atmosphere (telluric lines), so only signals from the planet and the star are left
- Use cross correlation to separate planet and star signal and detect molecules in the planet's atmosphere (e.g. Piskorz et al. 2016; Lockwood et al. 2014)!



Doppler shifting of nontransiting hot Jupiter spectrum at different orbital locations.

Benefits of the direct detection technique:

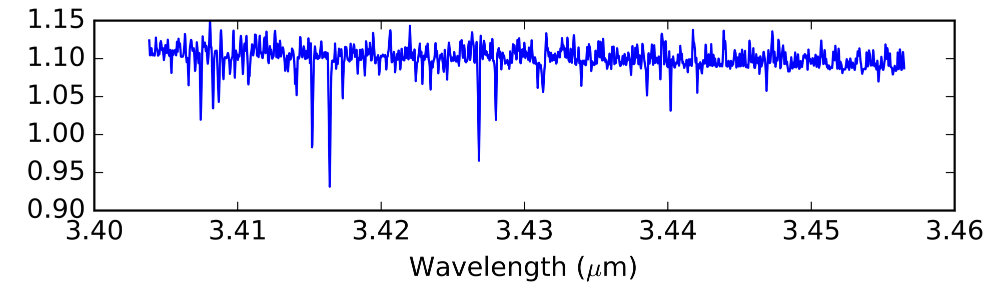
- Can detect spectra of *nontransiting* exoplanets. This will be critical for characterizing habitable zone planets because statistically, far more planets do not transit their host stars as viewed from Earth, than do.
- *Multi-epoch* data also allows us to look at planets further out from their stars. With multiple Doppler shifted spectra, it's easier to get full planet spectra without features obscured by either stellar or telluric lines.

Pushing the limits: Habitable Planets, Here we come!

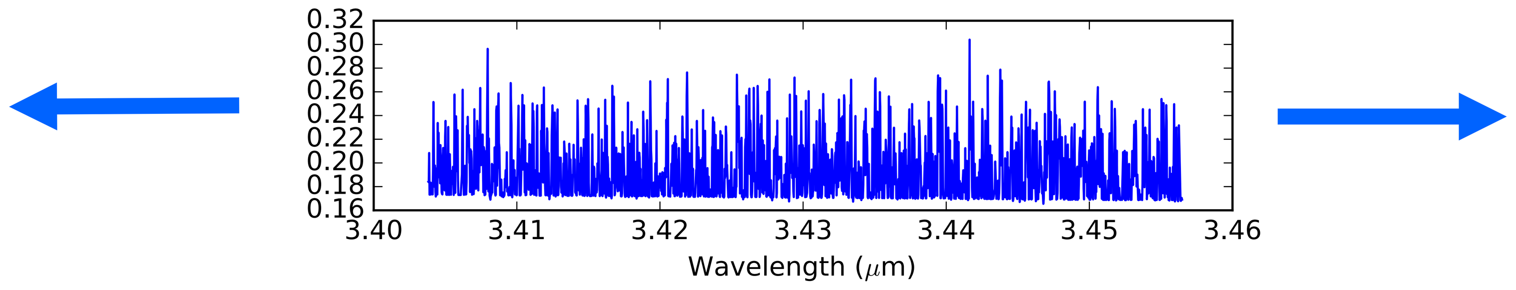
What to optimize…

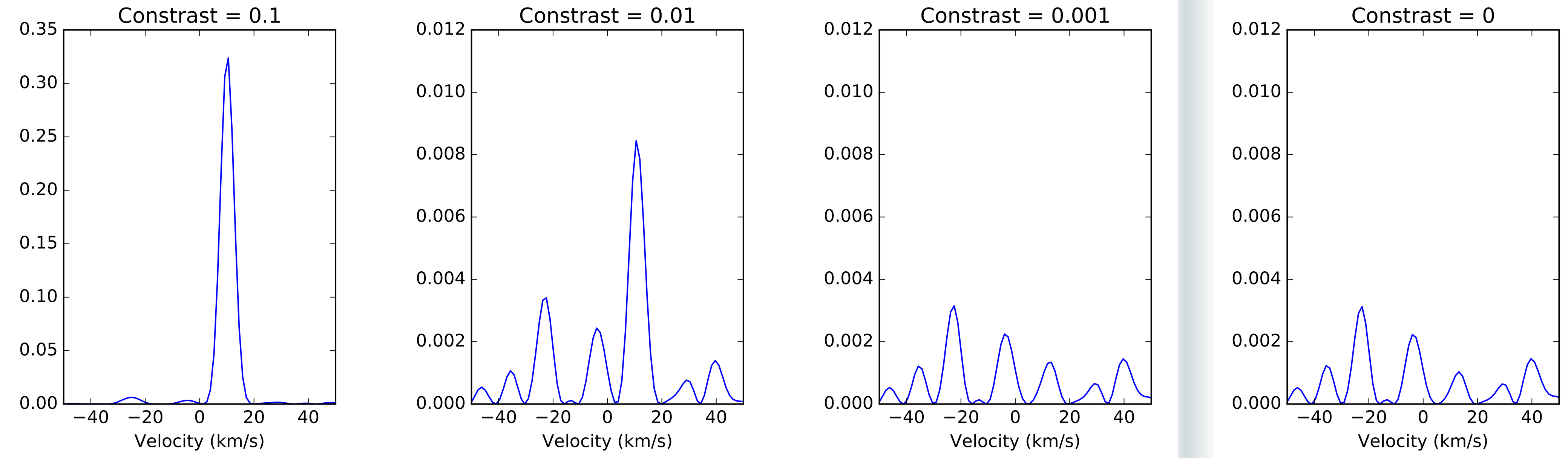
Our spectra are from the Near-Infrared Spectrometer (NIRSPEC) on Keck. In order to perfectly isolate planet spectra, we need to find wavelength regions with **small unintended star/planet cross correlation.** We start by testing the cross correlation of model spectra to see when unintended correlation between spectrum of the star and the planet will be larger than intended correlation.

Model of "real" spectrum: Stellar spectrum + Planet spectrum at 10 km/s Doppler shift and contrast of 0.01



Model of planet spectrum: Shift and cross correlate with "real" spectrum





At high enough contrast, cross correlation can easily find the planet signal in the "real" spectrum.

10^{-6} Contrast: Typical Hot Jupiter Contrast

0 Contrast: All correlation is unintended

10^{-10} Contrast: Typical Earth-size planet

Future work

- Find wavelength regions where unintended star/planet correlation is minimized. Moving to longer wavelengths (obtainable by TMT/ELT or a large aperature space telescope such as LUVOIR or the OST) will also optimize planet/star contrast for habitable planets.
- Investigate methods to remove stellar signal from data, so planet signal is retrievable down to lower contrasts