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Direct Spectroscopic Characterization of Hot Exoplanet Atmospheres

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Abstract

We will present current results from our program using high-contrast, high-resolution spectroscopy to directly detect and characterize the atmospheres of short period, hot exoplanets. Our observations target the thermal emission of these planets, and are sensitive to molecules in their atmospheres. We treat these planet+star systems as spectroscopic binaries, and measure the radial velocity of the planet with orbital phase and the planet/star flux ratio at specific bandpasses. These quantities yield a planet's true mass and probe the physics and chemistry of its atmosphere. This technique can directly characterize the large population of non-transiting planets that other surveys are insensitive to.

1. Introduction

Over the past fifteen years, ground-based surveys using indirect techniques have discovered more than 500 exoplanets orbiting nearby stars, including an unexpected population of gas-giant, Jupiter mass planets that orbit very close-in to their stars, with periods of only a few days. These close-in planets are strongly irradiated by their parent stars, which results in atmospheric temperatures of $\gtrsim 1000 - \lesssim 2500$ K, and chemistry that is very different from the giant planets in our solar system. To more fully characterize the origins and evolution of these planets, it is necessary to measure their atmospheric physical conditions, such as temperature, pressure, and winds, and chemistry. Such measurements require directly detecting photons from a planet, which are, under nearly all circumstances, overwhelmed by the flux from the parent star and require extremely precise observations to distinguish.

Planet characterization has been successfully carried out using photometry and low-resolution spectroscopy to directly detect atomic and molecular signatures in a small group of planets that transit their stars. These primary and secondary transit results have improved our knowledge of a few hot Jupiter exoplanet atmospheres. However, the sample of planets that has been directly measured remains at fewer than ten, despite more than a decade of successful efforts. Understanding these objects as populations, instead of just individuals, requires direct measurements of a much larger planet sample.

The high signal-to-noise (S/N) required to achieve the contrast needed for a planet direct detection necessarily implies that candidates for these investigations orbit stars in close proximity to the Sun. Of the more than 100 confirmed transiting planets, only six orbit stars closer than 50 pc, and most active transiting planet surveys (including Kepler and CoRoT) are targeting stars that are much more distant. Consequently, meaningfully expanding the sample of planets with direct detection measurements requires targeting non-transiting planets.

2. SB2 Planet Direct Detection

We are carrying out a large observational survey to directly detect and characterize hot exoplanets orbiting nearby stars by observing the systems as double-lined spectroscopic binaries (SB2s). In high-resolution spectroscopy, the blended signal of two objects can be disentangled using the two dimensional cross-correlation technique (TODCOR, [1]). This algorithm simultaneously cross-correlates two "template" spectra against a blended science spectrum, while optimizing the radial velocity of each template and their relative flux ratio. Molecular absorption in planet atmospheres produces combs of lines that are excellent cross-correlation targets. Because this approach uses spectral dispersion and radial velocity motion, and not transits, to disentangle the stellar and planet signals, it can be used to directly detect and characterize non-transiting systems that have been avoided by most direct detection campaigns. Such observations characterize a target planet in three distinct ways: 1) they measure the planet's orbital semi-major axis, which yields its true mass and inclination; 2) they detect molecules in the planet's atmosphere; and 3) by measuring the flux ratio over all orbital phases, they probe phase dependent quantities that are linked to global circulation.

We are obtaining very high S/N, high-resolution spectroscopy of nearby stars with hot, short period planets. We target absorption bands in the near-infrared using the NIRSPEC spectrograph on the 10m Keck II telescope, and in the visible using the High-Resolution spectrograph on the 9.2 m Hobby-Eberly telescope. Both facilities can produce spectra with S/N of several thousand. We process these spectra using custom pipelines that are designed for high S/N observations. Telluric correction is carried out with TERRASPEC, a forward modeling line-by-line synthesis algorithm that corrects telluric absorption to the observational noise level [2]. TERRASPEC combines the HITRAN linelist [3] with a parametrized atmospheric model, and uses the line-by-line radiative transfer code LBLRTM [4] to customize a synthetic telluric absorption function for each observed science spectrum.

A stellar template is generated synthetically for each target, using the measured stellar parameters (e.g. metallicity, rotation, temperature, and gravity) and our observed spectrum. A suite of planet templates that covers the range of plausible planet parameters is also generated. Using these templates with the cross-correlation analysis, we measure radial-velocities and flux ratios for each of our planet targets. To distinguish a true correlation-peak, representing a planet detection, from noise in the correlation curve, we rely on the multi-epoch SB2 solution, finding the set of correlation peaks that are self consistent with a Keplerian orbit, and which produces consistent flux ratios and correlation amplitudes.

3. Summary

Our program is targeting numerous hot exoplanets orbiting nearby stars. Even when restricted to observing only the brightest and nearest planet + star systems, we have the potential to more than double the number of planets with direct detections. We will describe the current status of the program and present recent results from it.

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