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Detecting Exoplanet Atmospheres Using High Altitude Balloon Telescopes

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Abstract

More than a thousand extrasolar planets have been detected, with many more awaiting confirmation. We can expect that several hundreds of thousands more will be detected in the next decade with discovery experiments from the ground and in space. To discover the physical conditions present on these distant worlds it is necessary to detect and characterize their atmospheres spectroscopically. Here we discuss how balloon-borne instrumentation can be used to access the near-IR and mid-IR parts of the electromagnetic spectrum with a spectral continuity and photometric stability that is not achievable with ground instrumentation. We review the Balloon-borne Exoplanet Transit Spectroscopy Experiment (BETSE) pathfinder whose goal is to demonstrate the stability of the upper stratosphere and characterize nearby hot Jupiters in the near-IR with a 50cm telescope. BETSE will open the path for more ambitious mission concepts like EchoBeach, which will be able to characterize a statistical sample of hot Jupiters from the near-IR to the mid-IR in a 100 day-long flight observing in the daytime during the Antarctic summer.

1. Introduction

Almost 2,000 exoplanets have been discovered in the past 20 years. Apart from mass, density and orbital period, little is known about these worlds. Spectroscopy in the near-IR and mid-IR holds the key to answering important questions about the existence and composition of their atmospheres. Transiting spectroscopy has emerged as an effective technique to detect and model exoplanet atmospheric compositions. Observations are notoriously challenging from the ground, because observational conditions are not stable and are limited to narrow atmospheric windows, as well as from space, since current facilities are not optimized for this type of observation. Balloon-Borne telescopes operating in the upper stratosphere have access to observational conditions which are similar to tose available to space instrumentation. Observations through the stable residual (0.5%) Earth atmosphere are not limited to just a few windows, and will allow multi-transit observations of hundreds of exoplanets. This class of experiments represents a unique opportunity to improve our limited knowledge of extrasolar systems especially as no dedicated exoplanet characterization missions have been scheduled in the next 10 to 15 years.

2. Stratospheric Balloon Environment

Earth's atmospheric transmission is estimated (Figure 1) for a site located in the Atacama Desert (5 km altitude), for the Sofia aircraft (10 km) and for the environment available from a stratospheric balloon-borne experiment (38 km). The MWIR and 1 to 5μm bands are only available in a stratospheric balloon flight, or from space. In a balloon flight with a 4mbar average ambient pressure, the Earth's atmospheric emission is greatly reduced compared to ground observations. The stratosphere is very stable, which means that any residual background is constant and can be efficiently removed in data analysis.

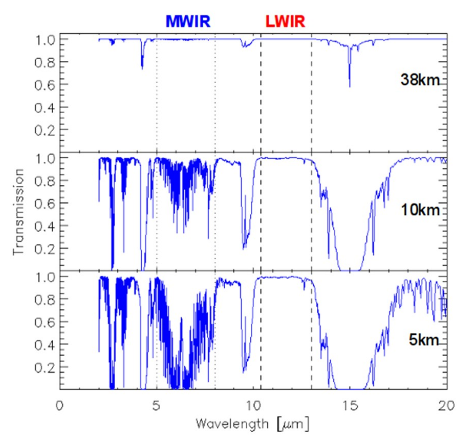

Figure 1: Earth's atmospheric transmission at different altitudes.

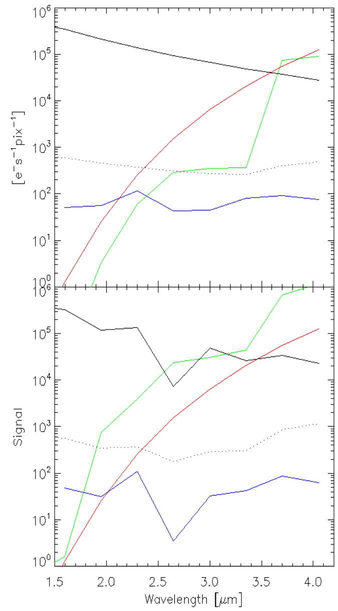

Figure 2: Signal breakdown for the hot Jupiter HD 189733b. The top plot is for a balloon instrument, while the bottom plot is for a similar instrument observing from Atacama. A 50cm telescope with a low spectral resolving power (R ~ 5), instrument is used in these simulations. Black solid line: signal from the combined star and planet; green solid line: Earth atmospheric emission; blue solid line: exoplanet emission; red solid line: emission from optical surfaces; black dotted line: expected noise in one second of integration.

This is shown in Figure 2, which provides a signal breakdown for hot Jupiter HD 189733b . Top plot is for a balloon instrument, while the bottom plot is for a similar instrument observing from Atacama. A 50cm telescope with a low spectral resolving power, R ~ 5, instrument are used in these simulations.

3. The BETSE and EchOBeach Mission Concepts

BETSE (Balloon Exoplanet Transit Spectroscopy Experiment) is a pathfinder using a 50cm Cassegrain telescope and prism spectrometer (R~200) illuminating Teledyne MCT detectors. This is a low-cost, fast-track experiment using the BIT (U of Toronto) sub-arcsecond pointed platform and off-the-shelf components. BETSE's goals are to demonstrate the suitability of stratospheric flights for exoplanet transit spectroscopy in the 1 to 5μm band. Its main targets are the nearest transiting hot Jupiters.

EchOBeach is a 2m telescope with a grating spectrograph illuminating a focal plane operating over the 1 to 20μm band using Teledyne (MCT) or Raytheon (MCT+Si:As) detectors. With a 100 day-long flight in a Ultra-Long Duration Balloon mission from Antarctica, EchOBeach has enough sensitivity to survey a statistical sample of several tens of hot Jupiters.

Both instrument concepts operate during both day- and night-time. Simulations predicting the performances are shown in Figures 3 and 4.

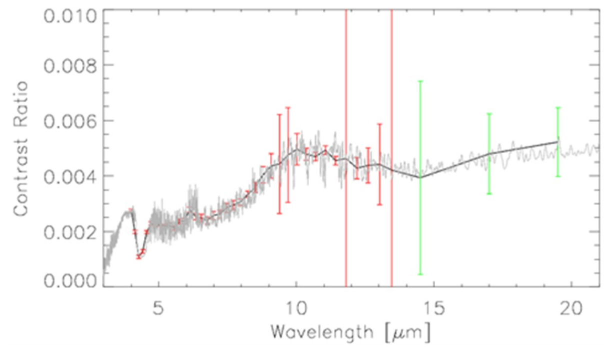

Figure 3: EChOSim simulations of a MIR balloon mission concept similar to EchOBeach based on a 100 K cold instrument with a 1.6 m aperture. The reconstructed dayside spectrum binned to R = 30 at wavelengths shorter than 14 μm is shown for a planet similar to HD 189733b, observed during two secondary transits. The spectrometer has two detector pixels per spectral resolving element. For regions above 14μm, where the atmosphere dominates making spectroscopy impossible, a broad-band photometer (points shown in green) would be useful to constrain the continuum. The underlying model spectrum is shown in grey.

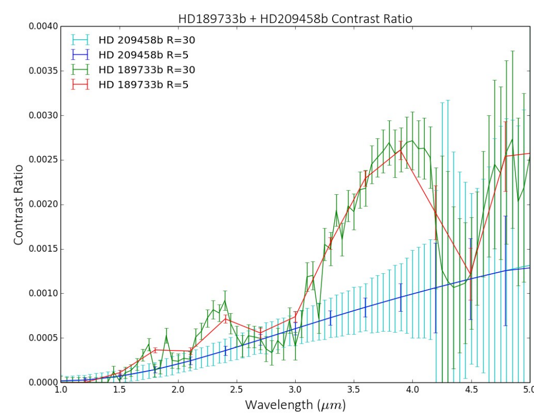

Figure 4: EChOSim simulations for one single secondary transit of HD 189733b and HD 209458b observed by BETSE are shown in the left panel, binned to two different spectral resolving powers. HD 189733b simulations use an input contrast ratio from a radiative transfer code. A blackbody spectrum is used for HD 209458b.