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The EXoplanet Infrared Climate TElescope (EXCITE)

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Abstract

The EXoplanet Infrared Climate TElescope (EXCITE) is a proposed low resolution 1-4 μm spectrograph that will measure emission spectra of hot Jupiters over their full orbits, providing phase resolved spectroscopy. These spectral measurements probe varying depths in exoplanets atmospheres thus contributing to our understanding into atmospheric physics, chemistry and circulation. Hot Jupiters provide an ideal laboratory for understanding atmospheric dynamics. EXCITE uses a commercially available 0.5 m diameter telescope pointed with high accuracy and stability using the successful Balloon Imaging Testbed (BIT) pointing platform. The telescope is coupled to a cooled spectrometer made from commercially available components. The combination of these elements results in a unique instrument for exoplanet atmospheric characterization. EXCITE's initial science will result from an antarctic long duration balloon flight.

1. Introduction

EXCITE will measure spectroscopic phase curves of bright, short-period extrasolar giant planets (hot Jupiters) over full orbital periods. The resulting phase-resolved spectroscopy maps the temperature profile and chemical composition of the planet as a function of planetary longitude. The wavelength range covers the peak in the planet's spectral energy distribution and H_2O, CO_2 , CO, CH_4 , TiO and VO spectral features. These data, combined with state-of-the-art 3D general circulation models (GCMs), will be used to study the atmospheric dynamics and chemistry in these strongly-irradiated planets. This will allow to to refine these models and improve their predictive power. Ultimately, the spectroscopic phase curves obtained from EXCITE can be used to study the links between the atmospheric properties of hot Jupiters and their formation, bulk properties, orbital dynamics and environment.

No existing instrumentation covers the whole EXCITE spectral range, essential to measure unambiguously the planet's global energy budget. Flying on a long duration balloon (LDB), EXCITE will fulfill a critical need as the first dedicated instrument for exoplanet atmospheric characterization.

2. Science Objectives

The primary goal of EXCITE is to obtain spectroscopic phase curve observations to constrain the global energy budget and circulation in hot Jupiters. Because each phase curve probes multiple wavelengths and pressures, these observations will map out the exoplanet's longitudinal heat distributions and vertical atmospheric structures.

Comparisons of phase curves measured at a range of wavelengths reveal how the relevant radiative, chemical, and dynamical timescales vary as a function of atmospheric pressure. EXCITE will naturally observe secondary eclipses and transits as well. Phase curve allows to constrain the global and spatially resolved energy budget of the planet, whereas transit/eclipse spectroscopy will provide the chemical bulk-compositions at the day side and the terminator, as well as a direct measurement of the vertical temperature profile of the atmosphere at the day side. By observing through the peak of the exoplanet's SED ($\sim 2\,\mu$m), EXCITE can directly constrain the global energy budget and circulation patterns. EXCITE will make further advances in our understanding of the diversity of hot Jupiter and the differences in the physics and chemistry of their atmospheres, particularly with respect to cloud formation and distribution.

Figure 1 demonstrates EXCITE's spectrocopic capabilities using retrieval simulations for the phase curve of hot-Jupiter WASP-18b, the TauREx retrieval framework, and a chemical equilibrium day & night-side

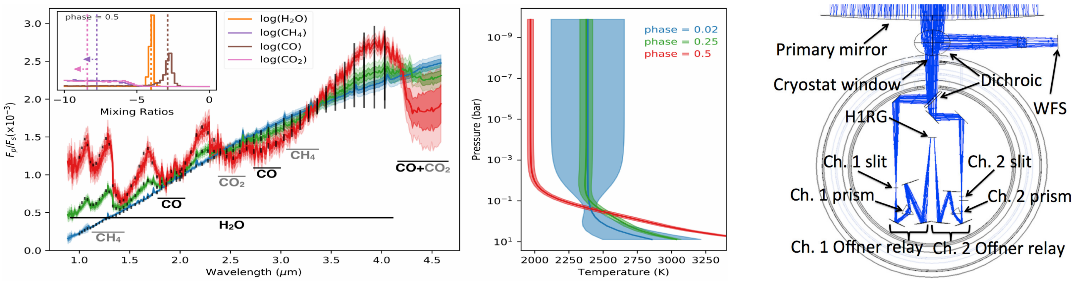

Figure 1: **Left**: The resulting emission spectra at phases 0.02 (blue), 0.25 (green) and 0.5 (red), predicted error-bars include a conservative 10 ppm noise floor. At C/O = 0.8 the main observables are water and carbon monoxide. These could be accurately retrieved with high degree of confidence, dotted lines show input values. At higher C/O ratios CH_4 , CO_2 and other species become increasingly abundant, we labeled their strongest absorption bands in gray. **Center**: Temperature profiles retrieved for varying phases. As more and more day-side emission becomes visible, the temperature profile departs strongly from the initial isothermal, as expected. **Left**: Optics ray tracing.

chemistry with C/O = 0.8 and solar metallicity.

3. Design and performance

EXCITE will use mostly off-the-shelf components. Optical ray-tracing is shown in Figure 1. The telescope from Officina Stellare has a diameter of 0.5 m. One ambient-temperature dichroic filter reflects wavelengths shorter than 1μm and transmits longer wavelengths. The reflected light is used to feed a fine pointing/wave-front sensor which provides the telescope attitude error. IR light propagates through cold optics (77 K) inside a long duration cryostat. Light is further split into two channels. Channel 1, covering the 1 μm to 2 μm, and Channel 2 from 2 μm to 4 μm with an extended sensitive tail to 5 μm. Cold slits are placed at the two prime foci, feeding two spectrometers with a spectral resolving power of $\lambda/\Delta\lambda \simeq 50$. The output of both spectrometers are imaged onto a single Teledyne H1RG detector ($\lambda_c = 5.3\,\mu$m). At a 77 K operating temperature the dark current is below 1e$^-$/s and read noise 15e$^-$–rms on correlated double samples. The BIT–type gondola and pointing system have demonstrated < 100 mas stabilization (Romualdez et al. ArXiv 2016).

Performance is studied through ExoSim's (Sarkar, SPIE 9904, 2016) time-domain end-to-end simulations. Simulations include photon noise from target, from the 4 mbar residual Earth atmosphere, and from instrument thermal emission. We have also implemented a balloon-specific model to account for the most challenging effects expected at stratospheric altitudes. Slit losses are made negligible by ensuring that input slit widths are at least one Airy diameter at the red-end of each spectroscopic channel. Photometric uncertainties arising from pointing jitter are made negligible by the combination of BIT's pointing stability and by Nyquist-sampling the spectral images in both spatial and spectral directions, reducing intra- and inter-pixel effects. Typical flight altitude fluctuations with ~ 1 km amplitude and 24 hr period, and ~ 50 m amplitude with ~ 5 min period induce atmospheric emission, transmission and instrument temperature variations. Simulations show that these effects are either negligible, or accountable in post-processing. Similarly, stellar variability over the time scale of the target orbital period are shown to be negligible post-processing. Simulation of all these effects and a post-processing pipeline are used to estimate the experimental uncertainties shown in Figure 1, and to compile the LDB target list.

4. Observations

The 1 to 4 μm region of the spectrum is not accessible by ground based or even airborne instrumentation due to atmospheric absorption. A Stratospheric balloon platform, reaching altitudes of $\sim$38 km, provides an alternative to space instrumentation. Flying from Antarctica during the Austral summer allows EXCITE to observe under stable conditions. The LDB target list includes 21 transiting hot jupiters that never set during the flight campaign (December–January). EXCITE will continuously observe a planet during one revolution, minimizing instrument-induced systematics. The target list includes, at the time of writing, WASP discovered planets in the Southern Hemisphere. It is expected that by the time EXITE will be flight-ready in 2020 the list will be enriched by new discoveries from ground based surveys, and space missions like TESS.