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The EXoplanet Climate Infrared TElescope (EXCITE)

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Abstract

EXCITE is a balloon-borne near-infrared spectrometer designed to observe from 1 to 4 μm and to perform phase-resolved spectroscopy of hot Jupiters. 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[1]. 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 us 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. Flying on a long duration balloon (LDB), EXCITE will fulfill a critical need as the first dedicated instrument for exoplanet atmospheric characterization in the coming decade.

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 measurements constrain the global and spatially resolved energy budget of the planet, whereas transit/eclipse spectroscopy 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.

3. Design and performance

EXCITE will use mostly off-the-shelf components. An optical ray-trace is shown in Figure 1. The telescope from Officina Stellare has a diameter of 0.5 m.

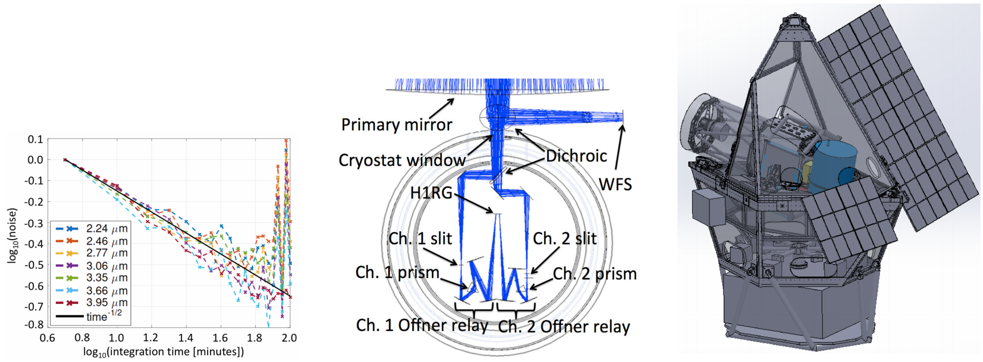

Figure 1: **Left**: Results of the EXCITE end-to-end simulation for an observation of the phase curve of WASP-18b. We show measurement noise across channel 2 as a function of integration time. Correlated effects do not contribute to the noise for measurements shorter than $\sim$ 90 minutes. **Middle**: Optics ray trace. **Right**: EXCITE integrated with the BIT gondola and pointing system.

One ambient-temperature dichroic filter reflects wavelengths shorter than 1 μm and transmits longer wavelengths. The reflected light is used to feed a fine pointing that provides the telescope attitude error. IR light propagates through cold optics (<62 K, solid nitrogen) 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 sensitivity tail to 5 μm. Cold field-stops 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), read through the ASIC for Control And Digitization of Imagers for Astronomy (ACADIA) detector controller that was developed for the Wide Field Infrared Survey Telescope (WFIRST).

The BIT–type gondola (Figure 1) and pointing system have demonstrated < 100 mas stabilization [2].

Performance is studied through ExoSim's [3] 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. 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 $\sim$ 1 km amplitude and 24 hr period, and $\sim$ 50 m amplitude with $\sim$ 5 min period induce atmospheric emission, transmission and instrument temperature variations. Simulations show that these effects are either negligible, or accountable in 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. Further details in Nagler et al. (2018)[1].

4. Conclusions

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 like EXCITE, reaching altitudes of $\sim$38 km, is best suited for resource-intensive phase curve measurements. For a typical LDB flight duration of $\sim$ 20 days, and for an average orbital period of $\sim$ 2 days, EXCITE can measure phase curves of up to ten planets in a single flight. Space missions like HST and JWST are multi-purpose. JWST will measure some phase curves, but given time allocation priorities it is unlikely to carry out as comprehensive a program as EXCITE. Not until a decade from now will ARIEL carry out such observations. With sensitivity comparable to that obtained by space-based observatories and sufficient bandwidth to measure key molecular features in the NIR, EXCITE will fill a key near-term need as a dedicated platform for studying exoplanet atmospheric physics.

References

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[2] Romualdez, L. J., et al., SPIE 10702, 2018.
[3] Sarkar, S., et al., SPIE 9904, 2016.