EPSC Abstracts
Vol. 8, EPSC2013-1036, 2013
European Planetary Science Congress 2013

The Balloon-Borne Exoplanet Experiment (EchoBeach)

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Abstract

The Balloon-Borne Exoplanet Experiment (EchoBeach) is a proposed sub-orbital spectroscopic instrument. Its primary scientific goal is to detect and characterize the atmospheres of transiting exoplanets in the Mid-IR part of the electromagnetic spectrum from 4 to 20μm using a 1.6m diameter telescope. It is in this wavelength range where the contrast between the star and planet emission grows exponentially, and this spectral region is key to answering important questions about the existence and composition of exp-atmospheres. Due to the Earth atmospheric absorption and emission, observations at these wavelength are impossible from the ground or even at aircraft altitudes, but become available to balloon-born instrumentation flying in the upper stratosphere. At present we have high fidelity Mid-IR spectra of just two exoplanets of any type. EchoBeach can greatly improve on this by observing a multitude of transiting exoplanets, well in advance of any planned space-mission.

1. Introduction

The discovery and characterisation of extra-solar planets is one of the most rapidly changing and exciting areas of astrophysics. A combination of ground-based surveys and dedicated space missions have resulted in ~850 planets being detected up to the end of 2012, and over two thousand candidates that await confirmation. Since 1995, the number of planets known has increased by over two orders of magnitude. NASA's Kepler mission is discovering many hundreds of new planets around some of the 100,000 stars it is surveying during its 3 to 4-year lifetime and the ESA-Gaia mission is expected to discover thousands more. The detection techniques employed allow us to determine basic parameters of these planets: i.e. their orbit, mass, size and basic nature (rocky or gaseous). However, to push our understanding of these worlds beyond these first steps, we must use spectroscopic techniques to probe for the presence of an atmosphere and, where one is present, to determine its physical nature and chemical constituents. The observation of planetary atmospheres is at the cutting edge of exoplanet science, and we propose that a high-altitude balloon observatory can reveal regions of the spectrum previously inaccessible for exoplanet studies.

Pioneering work using space and ground based telescopes has shown that it is possible to detect the spectra of a handful of exoplanets using transit spectroscopy techniques.

With the majority of the molecular transitions of interest lying in the Mid-IR part of the electromagnetic spectrum (2-20μm), no major progress can be expected in the immediate as this band is largely unavailable from the ground. It is only really from space that the mid-IR range is accessible, but no current space facility accesses this spectral range and we must wait until JWST and the proposed EChO mission are launched in ~2018 and 2022 respectively before any significant new facility becomes available.

We suggest that a high altitude balloon facility operating in the 4-20μm band can be built and operated within five years; breaking new and exciting scientific ground, and developing the instrumentation, data reduction, and modelling techniques required for EChO and JWST.

2. Mission scenario

Conducting spectroscopy of confirmed transiting exoplanets over the spectral range from 4 to 20μm is impossible or very challenging from the ground. The 10.5-13μm band is contaminated by atmospheric emission even at aircraft altitudes, while the 5 to 8μm band is still too opaque at altitudes of 10km. Both bands become transparent enough (>0.98) at altitudes of 38km, and so are accessible from a stratospheric balloon platform. At these altitudes the residual atmospheric emission is greatly reduced to ~2% of the ground level emission, and spectroscopy becomes possible. With resolving powers up to 100, it would be possible to distinguish key features of CO_2, CH_4

and H_2O with much superior resolution compared to previous observations of this type of objects. Above 13µm, spectroscopy is challenging even at balloon-altitudes, but the continuum can be effectively constrained with a multi-band photometer.

Enough sensitivity is required to disentangle the small modulation imposed by the exoplanet's signal over the large parent star component, where planet-star contrast ratios can be as low as 10^{-4}. This sets stringent requirements on the level of systematic contamination and instrument stability over time scales comparable with the planet's transit time.

The required sensitivity is achieved through a combination of both photon-noise limited detectors and a large collecting aperture. Angular resolution is not a major driver, but a cold diffraction-limited instrument is needed to reduce the foregrounds arising from the instrumental emission and the residual atmospheric emission which, although greatly reduced, is still important at these wavelengths. The balloon-environment in the upper stratosphere is sufficiently stable that the atmosphere's emission and transmission properties do not vary appreciably over the mission time, which can be weeks. The only atmospheric modulation arises from the motion of the platform, but this is a measurable systematic quantity, varying on a typical time scale of ~10 minutes and can be monitored and subtracted using established photometric and decorrelation techniques. A 1.6m diameter diffraction-limited telescope meets the scientific requirements and can be manufactured at a contained cost, but a larger diameter mirror (>2.5m) can be easily flown on a stratospheric platform. The telescope needs to be equipped with a focus adjustment capability to compensate for thermal variations, which, during the flight mission, change the geometrical parameters of the main optical elements.

High spectral and photometric stability mandates low 1/f detector noise, and frequent monitoring of calibration drifts. The latter can be achieved through a combination of frequent in-flight observations of stable reference stars and by using an internal calibration system to monitor any gain drift between calibration events. Limited imaging capabilities are also required for the simultaneous measurement of the source signal and the sky foreground. Pointing stability needs to be maintained at an ~80mas level, and can be achieved in a number of ways. A high-accuracy pointed platform, providing 2" pointing stability, and a Fine Guidance System (FGS), controlled by a fast optical sensor in the primary optics is a possible, mature and well known technique to achieve this pointing requirement. The FGS also provides the error signal for the telescope control system.

The high sensitivity and high dynamic range required are achieved using a grating spectrometer. The baseline for *EchoBeach* incorporates a diffraction grating in an Offner configuration to cover the first part of the band from 4 to 14µm. The grating allows for optimal detection of spectral features in the presence of the backgrounds of the residual Earth atmosphere and of the parent star. Provision for photometric channels at the longer wavelength is also given. A square detector array can be used to sample the spectral-spatial signal and the instrument needs to be cooled in a cryostat mounted to the pointed platform (gondola) along with the telescope optics. This instrument configuration has the advantage of minimizing the loading on each detector pixel that arises from the residual atmospheric background. Simulations indicate that instrument emission will be kept to a negligible level by operating all optical elements at a temperature <100K.

3. Conclusions

A balloon-borne spectrometric instrument operating in the Mid-IR is an effective to obtain high-fidelity spectra of transiting exoplanets. The instrument can be built using proven technology, tested in several balloon-flights in recent years. A dedicated space-mission such EChO would give the ultimate answers the field is craving for, while a balloon-borne instrument can be built and operated in a much shorter time scale (about 5 years), breaking new and exciting scientific ground, and developing the instrumentation, data reduction, and modelling techniques required for EChO and JWST.