Do atmospheres exist? What are they made of? What kinds of climate do they have? Can biosignatures be detected?
More than 900 Exoplanets Detected

Radial velocity, Transit Surveys, Microlensing, Direct Detection

ESA-GAIA (2013) $\rightarrow$ $10^4$ new planets!

TESS (2017) $\rightarrow$ full sky survey

Ground-based surveys are growing larger and larger
More than 900 Exoplanets Detected
Radius, Mass, Orbital Parameters
We know the mechanics.

But, what these alien worlds really look like?
Exoplanet for which we have some kind of spectra: < 20

H$_2$O, CO, CH$_4$, CO$_2$, Na etc. identified, but data are sparse, degeneracy of interpretation

Swain et al., 2009
What is the Big Picture?
EChO
Exoplanet Characterisation Observatory

Candidate ESA M3 mission

Selection: 2014
Earliest Launch: 2022
Gaseous planets
formed elsewhere and migrated

- Planet formation
  - C/O ratio
- Planet-star interaction
  - Photochemistry
  - Day/night variation
- Planet evolution
  - Escape/$H_3^+$
- Energy budget
  - Albedo/thermal emission
- Weather
  - Temporal variability/T-P profile
Terrestrial planets
formed in situ? Or remnant of gaseous planets’ core?

Primary or secondary atmosphere?
H$_2$ retained or not

Energy budget
Albedo/thermal emission

Main atmospheric component
Primary transit observations

Planet-star interaction
Photochemistry

Does the planet have an atmosphere?
Spectral observations

Habitable conditions?
Temperature? H$_2$O?

Does the planet have an atmosphere?
Spectral observations

Habitable conditions?
Temperature? H$_2$O?
Planets considered by EChO

- **Jupiter**, **Neptune**, **Super Earth**
- **Radius**

- **‘Hot’** (850-1500K)
- **‘Warm’** (500-800K)
- **‘Temperate’** (250-350K)

- **F, G, K, M**
- **G, K, M**
- **M (G, K)**
Method: Transit

This is a zoom in!
Primary transit
Secondary Eclipse – Emission Spectra

\[ \sim \frac{F_p}{F_s} \left( \frac{R_p^2}{R_s^2} \right) \]
Spectral Signature of an Exoplanet

Individual lightcurves

Different transit depths

Flux

Time

Wavelength
Phase Lightcurves

HAT-P7b observed by Kepler (Borucki et al, 2010)
Phase Lightcurves

HAT-P7b observed by Kepler (Borucki et al, 2010)
From now to 2022 ...

EChO will provide the ultimate answer to some key questions about our understanding of the nearby Galaxy.

In the meanwhile, spectroscopy remains difficult to achieve using ground-based instrumentation

Mid-IR spectroscopy is virtually impossible
Mid-IR Key Unlocks
Seven Key Science Questions

1. **Bulk Characteristics**: What physical and chemical processes have shaped the appearance of planets around other stars?

2. **Climatology**: What processes govern the vertical structure of exoplanetary atmospheres?

3. **Dynamics and Circulation**: How do exoplanet atmospheres behave over time in response to their environmental conditions?

4. **Composition and Formation**: What is the bulk composition of an exoplanet atmosphere and what does this tell us about its formation and evolution?
5. Chemistry: How does thermochemistry and photochemistry determine the spatial distribution of trace gas species?

6. Cloud Physics: Can we detect the presence of clouds and hazes from mid-IR spectroscopy, and determine their composition?

7. Habitability: In addition to the parameters describing the characteristics of an exoplanet, can we detect astronomical biosignatures (spectral features that are indicative of life, such as O2, O3, N2O, etc.), or environmental conditions which might be suitable to permit habitable conditions?
Status of the field

No much luck attempting to answer these questions until EChO flies, as we are stuck with having “high quality IR/MIR spectra” of just two exoplanets!!!
ERC Synergy Grant 2013
Research proposal (Part B2)

The Balloon Borne Exoplanet Characterization Experiment
| EchoBeach

Cardiff, Rome, Oxford, Toronto, UCL
Convergence of Expertises

EChoBeach
High Performance
mid-IR
stratospheric
telescope

Giant Planet
Atmospheres,
spectroscopy thermal
structure and dynamics

Solar System Airless
bodies
Moon/Asteroids/Comets
Surface composition and
thermophysical
properties

Astronomy
Instrumentation

Exoplanet Transit
Spectroscopy

Polar Stratospheric
Dynamics

Enzo Pascale
SCAR AAA, Siena July 2013
EchoBeach: a balloon borne pathfinder for EChO

The MWIR window is not accessible from the ground or aircraft.

It becomes accessible at top of stratosphere from a stratospheric platform.

LWIR atmospheric emission is so large at 10Km that swamps the exoplanet signal. But it is low enough at 40Km enabling the possibility of observing in this window.
EchoBeach Mission Concept

Telescope aperture: 1.6m
Telescope temperature: 100K
Wavelength coverage: 4μm – 20μm
Spectral resolution: ~100 (4μm – 14μm)
(plus 4 photometric bands 14 – 20μm)
Pointing accuracy:
2” coarse
80mas fine through FGS

Detectors: Teledyne MCT or Raytheon SiAs
Cooling: Mechanical coolers

Flight duration: Antartica 2 weeks
Possible ULDB option
Mid-IR spectroscopy with EchoBeach

Figure 4 EChOSim simulations of EchoBeach. Panel a: achievable signal to noise ratio for R = 30 (red) and 100 (green) in 7 hrs for a planet similar to HD189733b. The spectrometer has two detectors per spectral resolving element, and the detector SNR is shown in black. The detected contrast spectra for the same observation are shown for R = 100 and R = 30 in the panels b and c, respectively. For regions above 14μm, where the atmosphere dominates making spectroscopy impossible, we will provide broad band photometric channels and we show the spectral points in green here. The underlying model spectrum is shown on the R=30 plot in gray.
Dream Flight allows many targets being observed over many transits
Instrument Overview
Cassegrain Telescope Feeds Offner Grating

Pupil image
M5
M3
TFP
M4
Slit
Offner grating
Spectrometer Configuration

Figure 8: *EchoBeach* Offner Spectrometer concept (middle and left panels), instrument module dimensions are approximately 300x150x110mm. The Right panel shows the spatial/spectral division at the detector focal plane.

Other solutions investigated includes
- Mach-Zehnder FTS (modulation, background subtraction, fewer detector pixels required, but loading is too high)

- Prism spectrometer (simple, enough resolution for science, but too low for loading)
**Schedule**

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<thead>
<tr>
<th>Year</th>
<th>Quarter</th>
<th>Milestone</th>
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<tbody>
<tr>
<td>Yr1</td>
<td>Q2</td>
<td>Program Start</td>
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<tr>
<td></td>
<td>Q3</td>
<td>Mission Requirements Review (MRR) Development Plan Review</td>
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<tr>
<td>Y2</td>
<td>Q1-Q2</td>
<td>System and sub-system Preliminary Design Review (PDR) Breadboarding of critical subsystems Purchase of long lead items</td>
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<td></td>
<td>Q4</td>
<td>System and Sub-system Critical Design Review (CDR)</td>
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<td>Y3</td>
<td>Q2</td>
<td>Pointed Platform Integration Begins</td>
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<td></td>
<td>Q4</td>
<td>Telescope Integration Begins</td>
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<td>Focal Plane Instrument Commissioning</td>
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<tr>
<td>Y4</td>
<td>Q1</td>
<td>Focal Plane Integration</td>
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<td>End-to-end tests begin</td>
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<td>Q2-Q4</td>
<td>First LDB Flight</td>
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<td>System Refurbishment Begins</td>
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<tr>
<td>Y5</td>
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<td>Y6</td>
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