CASE/ARIEL & FINESSE
Briefing

Presentation to NRC Committee for Exoplanet Science Strategy
including material from the ARIEL consortium
Mark Swain - JPL
19 April 2019

Background

• FINESSE is a proposed mission concept that was in step 2 competition in the 2016 Explorer program proposal cycle. Per HQ direction, the FINESSE step 2 study has been terminated as of 12 April 2018.

• ARIEL is the recently selected ESA M4 mission for a statistical survey of exoplanet atmospheres.

• CASE is a mission of opportunity concept in the 2016 Explorer program proposal cycle. CASE involves a hardware contribution to ARIEL (2 guider detectors and readout electronics) and a US science data center for handling science processing of photometric guide channels.
ARIEL: Key Questions and Science Objectives

- What are exoplanets made of?
- How do planets and planetary systems form?
- How do planets and their atmospheres evolve over time?

- Detect and determine the composition and structure of a large number of planetary atmospheres
- Constrain planetary interiors by removing degeneracies in the interpretation of mass-radius diagrams
- Constrain planetary formation and evolution models through measurements of the elemental composition (evidence for migration)
- Determine the energy budget of planetary atmospheres (albedo, vertical and horizontal temperature structure, weather/temporal variations)
- Identify and constrain chemical processes at work (thermochemistry, photochemistry, transport, quenching, etc.)
- Constrain the properties of clouds (cloud type, particle size, distribution, patchiness, etc.)
- Investigate the impact of stellar and planetary environment on exoplanet properties
- Identification of different populations of planets and atmospheres (for example, through color-color diagrams)
- Capacity to do a population study AND go into a detailed study of select planets
ARIEL – ESA M4 mission

- 1-m telescope, spectroscopy from VIS to IR
- Satellite in orbit around L2
- ~1000 exoplanets observed (rocky + gaseous)
- Simultaneous coverage 0.5-7.8 micron
- Payload consortium: 15 ESA countries + NASA under study
ARIEL – key Requirements

- > 0.6m² collecting area telescope, high throughput
- Diffraction limited performance beyond 3 microns; minimal FoV required
- Observing efficiency of > 85%
- Brightest Target: $K_{\text{mag}} = 3.25$ (HD219134);
- Faintest target: $K_{\text{mag}} = 8.8$ (GJ1214)
- Photon noise dominated
- Temporal resolution of 90 seconds (goal 1s for phot. channels)
- Average observation time = 7.7 hours, separated by 70° on sky from next target
- Continuous spectral coverage between spectral bands.

<table>
<thead>
<tr>
<th>Channel Name</th>
<th>Wavelength ($\mu$m)</th>
<th>Spectral Resolution Reqt / Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>VisPhot</td>
<td>0.5 – 0.55</td>
<td>Photometer</td>
</tr>
<tr>
<td>FGS-1</td>
<td>0.8 – 1.0</td>
<td>Photometer</td>
</tr>
<tr>
<td>FGS-2</td>
<td>1.05 – 1.2</td>
<td>Photometer</td>
</tr>
<tr>
<td>NIRSpec</td>
<td>1.25 – 1.95</td>
<td>$R = 20 – 25$</td>
</tr>
<tr>
<td>AIRS-Ch0</td>
<td>1.95 – 3.9</td>
<td>$R = 102 – 180$</td>
</tr>
<tr>
<td>AIRS-Ch1</td>
<td>3.9 – 7.8</td>
<td>$R = 30 – 64$</td>
</tr>
</tbody>
</table>
A chemical survey of a large population

SCIENCE REQUIREMENTS: EXOPLANET RADIATION, MOLECULAR & CLOUD SIGNATURES, STAR ACTIVITY

Simultaneous observations in the VIS and IR are needed.
Ariel 3-tier approach

**INDIVIDUAL PLANETS & POPULATION ANALYSIS**

- What fraction of planets have clouds?
- Have small planets still retained H/He?
- Colour-colour diagrams
- Refinement of orbital/planet parameters in IR

### SURVEY

- ~ 1000 PLANETS

### DEEP SURVEY

- ~ 500 PLANETS

### BENCHMARK

- ~ 50-100 PLANETS

- Main atmospheric component
- Trace gases
- Thermal structure
- Cloud characterization
- Elemental composition

- Atmospheric circulation
- Spatial & temporal variability

EWASS – April 2018
• ARIEL has similar performances to JWST for warm/hot planets around bright stars
• Multiple JWST instruments are combined here
• WFC3 limited wavelength range gives highly degenerate solutions
Join the ARIEL team!
CASE/ARIEL US Community Access

• ARIEL access model for consortium members does not use specific time allocations
• ARIEL PI welcomes US community input to the consortium discussion for target priorities
• US community makes recommendations to CASE Science Team
• CASE Science Team carries out simulations and studies
• CASE Science Team make recommendations to CASE PI
• CASE PI represents US science community in ARIEL consortium
# Capability Comparison

<table>
<thead>
<tr>
<th></th>
<th>FINESSE</th>
<th>ARIEL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Launch date</strong></td>
<td>2023</td>
<td>2028</td>
</tr>
<tr>
<td><strong>Orbit/cooling</strong></td>
<td>L2/passive + heaters</td>
<td>L2/passive + active cooler</td>
</tr>
<tr>
<td><strong>Mission duration</strong></td>
<td>2 y + (2 y extd.)</td>
<td>4 y + (2 y extd.)</td>
</tr>
<tr>
<td><strong>Mirror Size</strong></td>
<td>0.75 m</td>
<td>1.1 x 0.7 m</td>
</tr>
</tbody>
</table>
| **Spectral Resolution**| R= 150 @ 0.7 μm  
R= 70 @ 1.2 μm  
R= 200 @ 3 μm | R~0.5 0.5-1.2 μm  
R=20 1.2-1.95 μm  
R=150 1.95-5.0 μm  
R=30 5.0-7.8 μm |
| **Instrument**         | Prism, 1 detector                            | 3 filters, prism, 2 gratings, 4 detectors  |
| **Observing strategy** | 500 transits (5 mo.)  
100 phase curves (9 mo.)  
New targets/revisit (8 mo.) | 1000 targets Tier 1 (1 yr.)  
~500 <10 visits each Tier 2  
~50-100 Tier 3 targets |
| **Data products**      | Light curves, spectra, retrievals public <90 days | Periodic public releases (no specific timeline) |
FINESSE: Key Questions and Science Objectives

- Is our solar system formation scenario typical or exceptional?
- How does the planet formation process influence planetary composition?
- What are the atmospheric factors that influence planetary climate?

### Science Goals vs Science Objectives

<table>
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<tr>
<th>Science Goals</th>
<th>Science Objectives</th>
<th>Science Measurement Requirements</th>
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<tbody>
<tr>
<td>Formation 1: Determine if our solar system formation scenario is exceptional or typical by comparing the relationship between planet mass and metallicity slope, $m_m$, for the solar system and for a statistically representative sample of exoplanets from 5 M$<em>\oplus$ Super Earths to 8 M$</em>\oplus$ sub-Neptunes and 1000 M$_\oplus$ Gas Giants (hereafter termed F1 sample).</td>
<td>Transmission spectrum 250 planets • Measured when planet transits the star Captures features of key molecules H$_2$O, CH$_4$, CO$_2$, CO (mass from RV measurements)</td>
<td>$m_m \pm 0.25$</td>
</tr>
<tr>
<td>Formation 2: Determine the characteristic properties of atmospheric metal enrichment and the carbon to oxygen ratio (diagnostics of the accretion process and location) by measuring the dispersion, $c_{\alpha_m}$, and intercept, $b_{\alpha_m}$, of the mass-metallicity relation and by determining the average carbon to oxygen ratio, $&lt;C/O&gt;$, for the F1 sample.</td>
<td>Transmission spectrum 250 planets • Measured when planet transits the star Captures features of key molecules H$_2$O, CH$_4$, CO$_2$, CO (mass from RV measurements)</td>
<td>$c_{\alpha_m} \pm 0.07$ dex $b_{\alpha_m} \pm 0.15$ dex $&lt;C/O&gt; \pm 0.1$ dex</td>
</tr>
<tr>
<td>Formation 3: Test a key prediction of the core accretion model for planet formation, that lower mass planets have a different mass-metallicity relation, by determining if there is characteristic mass, $M_c$, of the &quot;break point&quot; in the mass-metallicity relation in the sub-Neptune mass regime. This science objective is descoped in the threshold mission.</td>
<td>Transmission spectrum 500 planets • Currently known + TESS/K2 discoveries</td>
<td>$M_c \pm 5 M_\oplus$</td>
</tr>
<tr>
<td>Climate 1: Determine the global energy budget encompassing how heat is absorbed and transported in planetary atmospheres by measuring Bond Albedo, $A_b$, day-night redistribution efficiency, $\zeta$, longitude of maximum temperature, $\Phi_{max}$, and vertical temperature contrast, $\Delta T_v$, for planetary equilibrium temperatures of 750-2500 K (specified as median precision for subset of F1 sample).</td>
<td>Emission Measurement 100 planets • Dayside spectrum • Phase curve (nightside emission from transit measurements)</td>
<td>$A_b \pm 0.2$ $\zeta \pm 0.12$ $\Phi_{max} \pm 15^\circ$ $\Delta T_v \pm 250$</td>
</tr>
<tr>
<td>Climate 2: Determine the occurrence rate of aerosols (clouds and haze), by providing the capability of measuring the median aerosol amplitude, $a_\alpha$, for the F1 sample.</td>
<td>Transmission spectrum 250 planets</td>
<td>$a_\alpha \pm 1.25$</td>
</tr>
</tbody>
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### Requirements and survey method

- Requirements and survey method optimized to answer these questions and validated with a complete design reference mission simulation.
FINESSE and ARIEL have similar performance

- Same target set and observing model used for both cases.
- Simulation of mass-metallicity relation parameters.
JWST benefits from ARIEL

• ARIEL allows extrapolation of detailed JWST knowledge to the broader planet population

• Potential opportunity if ARIEL schedule were accelerated
  • TESS target ephemerides maintenance
  • TESS target secondary eclipse timing
  • Identify best TESS targets for detailed JWST study by detecting spectral modulation
  • Large amounts of phase curve science
  • Allows JWST to concentrate the most important exoplanet targets