ARIEL – Atmospheric Remote-sensing Infrared Exoplanet Large-survey

ARIEL: Mission Overview & Community Participation

Göran Pilbratt, ESA ARIEL Study Scientist
ARIEL: Science, Mission & Community 2020, ESTEC, Noordwijk, 14-16 January 2020

European Space Agency
ARIEL will enable transformative science:

*The first dedicated chemical census of a large diverse sample of exoplanets in diverse systems*

ARIEL selected as Cosmic Vision M4 mission
• Involve the exoplanet community at large in ARIEL
• Present ARIEL and its science as proposed for adoption
• Put ARIEL into context of other missions and observatories
• Discuss, plan, & promote long term community involvement
M4 – ARIEL

Issue of AO for new missions: 27 proposals

Selection by Advisory Structure: ARIEL THOR XIPE for study

CDF studies in ESTEC

ADS/TAS parallel industrial studies with support of payload consortium

Selection of one mission by Advisory Structure/SPC

Phases:
- Phase 0
- Phase A
- Phase B1

Goal: Prog & sci assmt Assessment

Reviews:
- MSR
- SPC
- pSRR
- MAR
- SPC


Definition Study leading to Mission Adoption by SPC
Spacecraft & mission

S/c under study by industry (x2) and ARIEL Consortium (PLM)

Instruments
- Spectrometers
  - NIRSpec: 1.1-1.95 µm R~15
  - AIRS0: 1.95-3.9 µm R~100
  - AIRS1: 3.9-7.8 µm R~30
- Photometer
  - VNIR channels: 0.5-0.6, 0.6-0.8, 0.8-1.1 µm

Telescope
- Off-axis Cassegrain (all aluminium)
- 1.1 x 0.7 m aperture (0.64 m² collecting area)

Spacecraft & mission
- Payload module (PLM) passively cooled
- Some detectors actively cooled
- Dual A62 launch, max launch mass 1335 kg
- Large halo-orbit around L2
- Nominal lifetime 4 years, extended 6 years
**Spacecraft & mission**

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**Spacecraft & mission**
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- Some detectors actively cooled
- Dual A62 launch, max launch mass 1.4 ton
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**ARIEL is realized by ESA and the ARIEL Mission Consortium (AMC)**
- ESA has overall responsibility for the mission
- ESA provides the SVM, launch services, mission operations (MOC), and part of the science operations (SOC)
- AMC provides the PLM, and part of the science operations (IOSDC)
Exoplanets: they abound
4104 confirmed exoplanets in 3047 systems (as of 12 Jan 2020)
Exoplanets: but limited knowledge

4104 confirmed exoplanets in 3047 systems (as of 12 Jan 2020)

Figures courtesy of Leconte
**ARIEL: the next step**

*Chemical census of a LARGE sample of DIVERSE exoplanets*

**Key top level questions**
- What are exoplanets made of?
- How do planets & planetary systems form?
- How do planets & their atmospheres evolve?

**Observations**
- Probe atmospheric chemistry & dynamics
- IR transit & eclipse spectroscopy (1.1-7.8 µm)
- VNIR multiband photometry (0.5-1.1 µm)

**Targets**
- ~1000 known exoplanets, transiting stars brighter than K=9.5
- Diverse sample from gas giants to super-earths (possibly reaching earth-sized)
- Focus on warm & hot planets, T >500 K, to limit sequestration
**ARIEL: the next step**

*Chemical census of a LARGE sample of DIVERSE exoplanets*

**Key top level questions**
- What are exoplanets made of?
- How do planets & planetary systems form?
- How do planets & their atmospheres evolve?

**Questions and priorities**
- Which targets are to be observed?
- What observations are to be carried out?
- Providing answers to what science objectives?

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Leconte et al. 2014
(Exo)planetary systems
- Solar system is one outcome of planetary system formation
- Many other possible outcomes

(Exo)planets
- Solar System has
  - Temperate rocky planets
  - Cold gas rich planets
- Exoplanetary systems have
  - Extreme diversity of planets
  - Types of planets missing in SS
  - More to come (and biases)

Observe large and statistically representative sample!

Turrini et al. 2018
ARIEL: beyond ‘bulk’ density

Planets with both size and mass

Atmospheric composition can clarify degeneracy

Same bulk density – different atmospheric signatures

López-Morales et al. 2016

See Valencia et al. 2013

ARIEL: Science, Mission & Community 2020 | ESA/ESTEC, Noordwijk | GLP | 14/01/2020 | Slide 12
ARIEL: ‘trends’ & populations?

Does chemical diversity correlate with other (stellar? disk?) parameters?

Forget & Leconte 2014
Leconte et al. 2014

Turrini et al. 2015

Öberg et al. 2011
Potential ARIEL targets
• Hundreds available then, more now
• Thousands expected by 2028
  • Most from TESS (CHEOPS, PLATO)
  • Groundbased also contributing

Mission Reference Sample
• Will continuously evolve
• New targets
• New science questions/priorities
• New observations
• Yellow Book example illustrated

Yellow Book (2017) MRS used for successful simulations to verify the feasibility of ARIEL science objectives

Zingales et al. 2018
Targets: constructing MRS

Introduce 4D space: $T_{\text{eff}}$, [Fe/H], $R_{\text{pl}}$, $T_{\text{pl}}$

<table>
<thead>
<tr>
<th>Stellar Temp.: $T_{\text{eff}}$</th>
<th>3000 &lt; $T_{\text{eff}}$ &lt; 4100</th>
<th>4100 &lt; $T_{\text{eff}}$ &lt; 5800</th>
<th>$T_{\text{eff}}$ &gt; 5800K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labels</td>
<td>M-Late K</td>
<td>Early K-G</td>
<td>F-G</td>
</tr>
<tr>
<td>Metallicity: [Fe/H]</td>
<td>[Fe/H] &lt; -0.15</td>
<td>-0.15 &lt; [Fe/H] &lt; 0.15</td>
<td>[Fe/H] &gt; 0.15</td>
</tr>
<tr>
<td>Labels</td>
<td>Low [Fe/H]</td>
<td>Solar</td>
<td>High [Fe/H]</td>
</tr>
<tr>
<td>Planet Radius: $R_{\text{pl}}$</td>
<td>$R_{\text{pl}}$ &lt; 3$R_{\oplus}$</td>
<td>3 &lt; $R_{\text{pl}}$ &lt; 8</td>
<td>$R_{\text{pl}}$ &gt; 8$R_{\oplus}$</td>
</tr>
<tr>
<td>Labels</td>
<td>Earths/ Super Earths</td>
<td>Neptunes</td>
<td>Jupiters</td>
</tr>
<tr>
<td>Planet Temp.: $T_{\text{pl}}$</td>
<td>contiguous bins: [250, 500, 800, 1200, 1600, 2600] K</td>
<td></td>
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</tbody>
</table>

‘Optimal’ sample definition
- (Down-)Selection of potential targets to ‘optimal’ MRS currently discussed
- Here the YB sample (1002 targets)
- What is a/the ‘optimal’ sample?
- Depends on scientific priorities!
- Expect changes from now => launch!

Micela 2018 priv comm
Targets: constructing MRS

‘Optimal’ sample definition

- Maximise to 10 planets per bin – slightly lower number of targets
  1002 => 908 (left)
- Ongoing work – will continue!

Micela 2018 priv comm
### Science: 4-tier strategy

#### TIER 1: RECONNAISSANCE SURVEY

<table>
<thead>
<tr>
<th>Observational strategy</th>
<th>Science outcome</th>
<th>Expected No. of planets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low resolution spectroscopy (5-10(^*) spectral resolution elements covering the 1.10 – 7.80 (\mu)m range) measurements with average SNR ≥ 7</td>
<td>What fraction of planets are covered by clouds?</td>
<td>800+</td>
</tr>
<tr>
<td>All planets in the sample</td>
<td>What fraction of small planets have still retained H(_2)?</td>
<td></td>
</tr>
<tr>
<td>Transit or eclipse</td>
<td>Colour-colour diagrams</td>
<td></td>
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<tr>
<td></td>
<td>Constraining/removing degeneracies in the interpretation of mass-radius diagrams</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Albedo, bulk temperature &amp; energy balance for a subsample</td>
<td></td>
</tr>
</tbody>
</table>

#### TIER 2: DEEP SURVEY

| Spectroscopic measurements for a subsample (e.g., 50% of sample) | Main atmospheric components for small planets                                | 400+                     |
| R~10 for 1.10 < \(\lambda\) < 1.90 \(\mu\)m; R~50 for 1.95 < \(\lambda\) < 3.90 \(\mu\)m; R~15 for 3.90 < \(\lambda\) < 7.80 \(\mu\)m, with average SNR ≥ 7 | Chemical abundances of trace gases                                         |
| Transit and/or eclipse            | Atmospheric thermal structure (vertical/horizontal)                           |                           |
|                                    | Cloud characterisation                                                        |                           |
|                                    | Elemental composition                                                         |                           |

#### TIER 3: BENCHMARK/REFERENCE PLANETS

| Spectroscopic measurements | Detailed knowledge of the planetary chemistry and dynamics                  | 50+                      |
| R~15 for 1.10 < \(\lambda\) < 1.90 \(\mu\)m; R~100 for 1.95 < \(\lambda\) < 3.90 \(\mu\)m; R~30 for 3.90 < \(\lambda\) < 7.80 \(\mu\)m, with average SNR ≥ 7 achievable in 1-2 observations | Weather, temporal variability                                               |
| Transit and/or eclipse, repeated in time | Elemental composition                                                        |                           |

#### TIER 4: BESPOKE OBSERVATIONS & PHASE-CURVES

| Phase-curves, eclipse mapping, bespoke observations | Detailed knowledge of the planetary chemistry and dynamics | 10+                      |
| Multiple-band photometry/spectroscopy with SNR ≥ 7 | Spatial variability                                               |                           |
Data products

- **Level 0**: Compressed and time ordered Telemetry packets.
- **Level 1**: Unpacked, uncompressed Level 0 Data, organized in raw, uncalibrated data cubes: Raw photometric or spectral images of Science Frames.
- **Level 1.5**: Calibrated, background subtracted, bad pixel masked, ramp fitted, units converted Level 1 Data: Calibrated photometric or spectral images of Exposures.
- **Level 2**: Spectrally resolved Light-curves of Target.
- **Level 3**: Broad-band Exoplanets spectra.

**ARIEL Public Archive @SOC**
ARIEL and the Community

ARIEL wants to embrace and have a dialogue with the Community

Attend ARIEL conferences
• Like this one – there will be more at a TBD frequency

Join the ARIEL Mission Consortium (AMC)
• Talk to the AMC

Use public ARIEL data
• ARIEL survey data and complementary science data – rules under discussion/definition
Data releases

*Timely deliveries of high quality data products (core science) currently under discussion/definition*

Data products Level ≤ 2

- **SDP**: data public *immediately* after quality control is completed
- **Tier 1**: data public *immediately* after quality control is completed
- **Tiers 2 & 3**: data public *6 months* after quality control is completed
- **Tier 4**: data public *12 months* after quality control is completed

Data products Level 3

- Will be made public *after publication* in journal

For complementary science products and rules are different
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‘Formal’ Community participation – under discussion/definition
• Community Scientist in the ARIEL Science Team (AST)
• Participation in the definition of the target lists
• Complementary science programme
Community participation

Currently under discussion/definition

Community Scientist in the ARIEL Science Team (AST)

- (Selected) AST responsibilities:
  - Maximising the **scientific return** of ARIEL within programmatic constraints, … while ensuring that the development and operations of the mission remain compatible with its main scientific objectives
  - Optimising the **scientific performance** of the payload and spacecraft, calibration, data products, scientific exploitation, …
  - Supervising and being closely involved in the preparation and periodic update of the **Mission Candidate Sample** (MCS) list and being responsible for defining the scientific priorities for the generation of the **Mission Reference Sample** (MRS) list(s)
  - **Promoting** the mission

- A **TBC number of Community Scientists** will be recruited through an Announcement of Opportunity (AO) issued by ESA, and **appointed by ESA** (as all AST members are)
- **Timescale**: (shortly) after mission adoption
Community participation

Currently under discussion/definition

Participation in the definition of target lists

- Mission Candidate Sample (MCS) and Mission Reference Sample (MRS) lists
  - **MCS**: ‘all potential’ ARIEL targets
    - Today most are ‘virtual’ sources, but in the future need to become real targets
  - **MRS**: a list of targets that could be observed in the nominal ARIEL mission
    - Multiple MRSs can/will be produced from the MCS with different scientific priorities, provided by the AST, as part of science optimization before and during the mission
- These lists will be made **publicly available** online through a dedicated website
- **Complementary processes** for participation are currently being considered:
  - ‘Continuous’ processes consisting of input provision through a dedicated website, and public regular workshops
  - Other ‘dedicated’ processes are also being considered
Community participation

Currently under discussion/definition

Complementary science programme

- Due to the **nature of the ARIEL exoplanetary observations** there will be a fraction (~10% TBC) of the total available observing time which cannot be used for these
- The bulk of these **non-schedulable slots will be short**, ~75% ≤2 hours, a few x1000 ≤4 hours, some longer
- This time can be used for complementary science observing
  - Must be **schedulable as ‘fillers’** – not time critical
  - **Cannot drive** the mission/payload in any way
- An **ESA-led AO is foreseen** for such observation proposals
  - Data products up to level 1.5 (for some 2) are foreseen
  - Proprietary time of 6 months after receiving the data.
We are the first generation to know that the ancient hypothesis about planets around other stars is true.
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We are also the first generation who are capable of studying these other worlds.
Thank you!