The ARIEL Science Ground Segment and the Instrument Operations and Science Data Centre (IOSDC)

Chris Pearson: UKRI STFC RAL Space
Pino Malaguti: INAF
On behalf of the ARIEL Ground Segment

15th January 2020: ARIEL Science, Mission and Community Conference
The ARIEL Ground Segment

Satellite

Data

ARIEL GROUND SEGMENT
The ARIEL Ground Segment

Operations Ground Segment OGS

Science Ground Segment

Open Science Community
The ARIEL Ground Segment

Operations Ground Segment OGS

- Ground Station
- Mission Operations Centre MOC @ ESA

Science Ground Segment

- Science Operations Centre SOC @ ESA
- Instrument Operations and Science Centre IOSDC

Open Science Community
The ARIEL Ground Segment

Operations Ground Segment OGS
- Ground Station
- Mission Operations Centre MOC @ ESA

Science Ground Segment
- Science Operations Centre SOC @ ESA
  - Data Processing (Level 0-2)
  - Mission database
  - Science Archive
  - Helpdesk
- Instrument Operations and Science Centre IOSDC
  - Long term observing plan
  - Data processing pipeline
  - Instrument operations
  - Level 3 data products
  - Calibration support

Open Science Community
The ARIEL IOSDC

IOSDC Distributed Model
Under the smooth transition philosophy, the initial ground testing and calibration will closely resemble, and smoothly adapt/evolve, to the final operational environment.
Data Flow and Data Products

• The ARIEL Data Reduction Pipeline (ADaRP) will be developed by the IOSDC.

• The Pipeline will be delivered to and automatically run at ESA-SOC.

• In the science pipeline Data Levels define break points along the processing, at which specific science Data Products are generated.

• These products will be made available to the scientific community via the ESA ARIEL Science Archive.

• The Pipeline begins from the raw Level 0 data, processing through to the Level 2 data products (the target light curves).

• Level 3 data products (exoplanets spectra) will be delivered directly from the ARIEL Consortium to the ESA ARIEL science archive.
Data Flow and Data Products

Automatic processing pipeline @SOC

Level 0 > Level 1
Level 1 > Level 1.5
Level 1.5 > Level 2

Dedicated data processing @consortium/IOSDC

Level 2 > Level 3

Satellite telemetry flow

(0) Raw telemetry packets
(1) Uncalibrated photometric/spectral science frames
(1.5) Calibrated photometric / spectral images
(2) Wavelength binned Target light curves
(3) Exoplanet spectra

ARIEL Science Archive @ESA
Level 0 Data Product

![Diagram of a planet transiting a star with a light curve and signal changes over time.](image)

- Planet
- Star
- Transit

- Brightness
- Time
- Light curve

Observation

- Detector signal visualization
- Exposure
- NDR
- Ramp

- Signal (single detector array pixel)
Level 0 Data Product
Level 0 Data Product

- Raw compressed data files derived from spacecraft telemetry packets
- Delivered from MOC to SOC
Level 0 > Level 1 Processing

Level 0
- Decompression
- Unpacking
- Meta data extraction

Level 1
Level 1 Data Product

Unpacked, uncompressed, time-ordered, uncalibrated, meta enriched, data cubes of Target, containing Science Frames for each Exposure taken during an Observation

Spectroscopic Channels: raw data spectral image time stamped 3D cube of which each slice is a Science Frame:
- spatial pixel (pixel number)
- spectral pixel (pixel number)
- integrated signal value in ADU

Photometric Channels: raw data image time stamped 3D cube of which each slice is a Science Frame:
- spatial pixel (pixel number)
- spatial pixel (pixel number)
- Integrated signal value in ADU

Possible representations of one temporal slice (i.e.: one Science Frame) of an ARIEL Data Level 1 data product, for the spectroscopy channel AIRS CH0
Level 1 > Level 1.5 Processing

**Level 1**
- Flag saturated pixels
- ADU to e– unit conversion
- Non-linearity correction
- Pixel cross-talk correction
- Dark current subtraction
- Wavelength assignment
- Flat fielding
- Offset correction
- Persistence correction
- Background subtraction
- e– to e–/s unit conversion
- Bad pixel correction
- Pointing jitter correction

**Level 1.5**
Level 1.5 Data Product

Calibrated, background subtracted, instrument artefact corrected, fitted ramps of exposures of a Target observation

Spectroscopic Channels: time stamped spectral image 3D cube with each slice an array of fitted ramps (slopes):
- spectral pixel (microns)
- spatial pixel (pixel number)
- signal (slope) in e⁻/s

Photometric Channels: Time stamped image 3D cube of which each slice is an array of fitted ramps:
- spatial pixel (pixel number)
- spatial pixel (pixel number)
- signal (slope) in e⁻/s

Possible representations of a single temporal slice (corresponding to a single exposure) of an ARIEL Level 1.5 data Product, for the spectroscopy channel AIRS CH0
Level 1.5 > Level 2 Processing

- Aperture masking (spectroscopic channels)
- Extract 1-D Spectrum
- Aperture masking (photometric channels)
- Spectral light-curve binning
- e-/s to Flux Conversion
Level 2 Data Product

Spectrally resolved light-curves of the Target (star + planet(s))

Spectroscopic Channels: wavelength binned 2D set of light curves of the Target:
- Time axis (s)
- Wavelength axis (microns)
- Flux (W/m²)

Photometric Channels: One broad-band light curve per channel of the Target:
- Time axis (s)
- Photometric band (FGS1/2, VisPhot)
- Flux (W/m²)

Possible representations of ARIEL Data Level 2 for the spectroscopy channel AIRS CH0. The overall Level 2 data array and slices through wavelength to show the measured light curve for selected spectral bins.
Level 2 > Level 3 Processing

Level 2

- Instrumental systematics correction (detrending)
- Stellar activity correction 1 (lightcurves)
- Lightcurves transit models fitting
- Stellar activity correction 2 (spectra)

Level 3
Level 3 Data Product

Exoplanet broad-band spectra

All Channels (AIRS and VNIR):
- Individual planet(s) spectrum (e.g.: ppm vs wavelength) for each observation with time (s)
- Legacy Co-added planet(s) spectrum (e.g.: ppm vs wavelength) for all observations
- stellar properties

Possible representations of ARIEL Data Level 3 showing exoplanet spectrum with wavelength.
# ARIEL Mission Phases

ARIEL nominal mission lifetime 4 years
All observations reprocessed in 6 month intervals by automatic pipeline

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<thead>
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<th>month</th>
<th>launch-6</th>
<th>&gt;6</th>
<th>&gt;12</th>
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<tr>
<td>Early</td>
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<td>cycle2</td>
<td>cycle3</td>
<td>cycle4</td>
<td>cycle5</td>
<td>cycle6</td>
<td>cycle7</td>
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<table>
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<th>month</th>
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<th>5</th>
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<tbody>
<tr>
<td>launch</td>
<td>Commissioning</td>
<td>Performance Verification (PV)</td>
<td>Science Demonstration</td>
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</table>
ARIEL Survey and Data Products

TIER 1

TIER 2

TIER 3

TIER 4
Tier 1 Reconnaissance Survey

- ~1000+ targets
- Low resolution spectroscopy (5+ spectral elements)
- S/N >7
- All Planets in sample
- Transit or eclipse
Tier 2 Deep Survey

- ~500 + targets
- R~10 for 1.10< λ<1.90 μm
- R~50 for 1.95<λ<3.90 μm
- R~15 for 3.90<λ<7.80 μm
- S/N >7
- Transit and/or eclipse
Tier 3 Benchmark Survey

- 50 + targets
- 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
- S/N >7 achievable in 1-2 obs
- Transit or eclipse repeated in time
Tier 4 Bespoke obs / Phase Curves

- 10 + targets
- Phase-curves
- eclipse mapping
- bespoke observations
- photometry/spectroscopy
- SNR ≥ 7
Estimated data volumes for Data Level Products and HK Data over mission lifetime. After 4 years of mission, plus final reprocessing 6 months after the end of nominal life. Expected data volume budgets is ≈74 TBytes

<table>
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<th>Data Level</th>
<th>Overall Data Archive Volume (TB) along ARIEL Mission lifetime</th>
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<tr>
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<td>after 0.5 years</td>
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<tr>
<td>Level 0</td>
<td>0.77</td>
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<td>Level 1</td>
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<td>Level 1.5</td>
<td>1.15</td>
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<td>Level 2</td>
<td>0.02</td>
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<td>Level 3</td>
<td>2×10⁻⁵</td>
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<tr>
<td>HK</td>
<td>5×10⁻³</td>
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<tr>
<td>Total</td>
<td>3.49</td>
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• Data processing up to Level 2 and archive ingestion done continuously throughout the mission.

• All data will be released after processing, consolidation and quality control are completed, approximately 1-2 months after the last required observation is taken.

• All data products will be accessed from the ARIEL Science Archive @SOC (ESA) via web interface.

• A fraction of Tier 2 or 3 data, will be observed and Level 2 products released as part of the Science Demonstration Phase.

• The data release up to Level 2 products during the routine mission phase is envisioned as:
  o Tier 1 data public immediately after quality control is completed;
  o Tier 2 data public 6 months after quality control is completed;
  o Tier 3 data public 6 months after quality control is completed;
  o Tier 4 data public 1 year after quality control is completed.

• Level 3 science products will be made public after their publication in peer review journals.
ARIEL 2028

Enabling planetary science across light-years