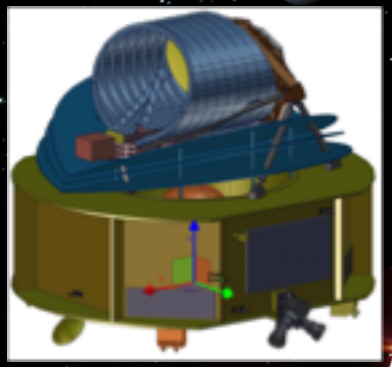
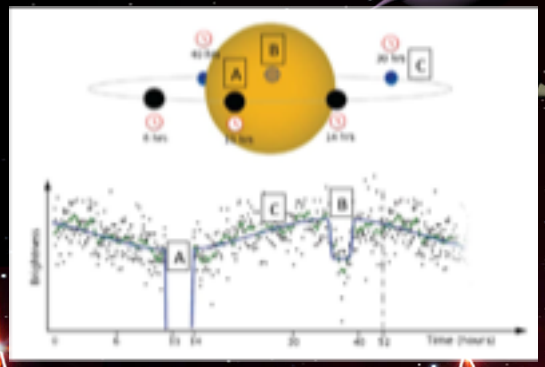
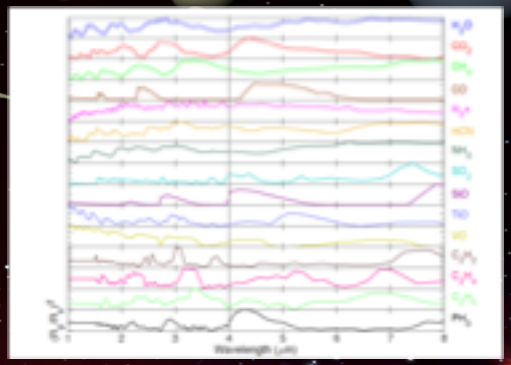

ARIEL –
Enabling Planetary Science Across Light-years
Mission and Community
Göran Pilbratt, ESA ARIEL Study Scientist
Spectroscopy of Exoplanets (ExoMol), Cumberland Lodge, 8-11 July 2018
European Space Agency

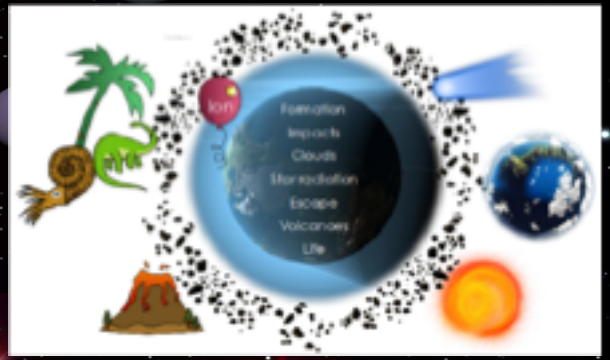
ARIEL – in a Nutshell

Atmospheric Remote-sensing Infrared Exoplanet Large-survey









ARIEL will enable transformative science

ARIEL selected as Cosmic Vision M4 mission

European Space Agency

Planetary science top down

‘Our knowledge of Earth and the Solar System planets will always exceed our knowledge of any individual exoplanet, but the diversity of exoplanets enables the statistical study of planets to crack difficult problems in planetary science.’

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, 127:311–327, 2015 March

Conference Highlights

Characterizing Transiting Planet Atmospheres through 2025

N. B. COWAN,[1] T. GREENE,[2] D. ANGERHAUSEN,[3] N. E. BATALHA,[4] M. CLAMPIN,[3] K. COLÓN,[5] I. J. M. CROSSFIELD,[6] J. J. FORTNEY,[7] B. S. GAUDI,[8] J. HARRINGTON,[9] N. IRO,[10] C. F. LILLIE,[11] J. L. LINSKY,[12] M. LOPEZ-MORALES,[13] A. M. MANDELL,[2] AND K. B. STEVENSON,[14] ON BEHALF OF EXOPAG SAG-10

Swap planets for stars:

‘Our knowledge of the Sun will always exceed our knowledge of any individual exosun, but the diversity of exosuns enables the statistical study of exosuns to crack difficult problems in stellar science.’

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‘Our knowledge of the Sun will always exceed our knowledge of any individual exosun, but the diversity of exosuns enables the statistical study of exosuns to crack difficult problems in stellar science.’

The characterisation of a large diverse sample of stars resulted in the HR diagram and an understanding of stellar evolution.

ARIEL will characterise a large well selected diverse representative sample of (exo-)planets orbiting a range of host stars with a variety of planetary system architectures – much more diverse than the Solar system can offer!

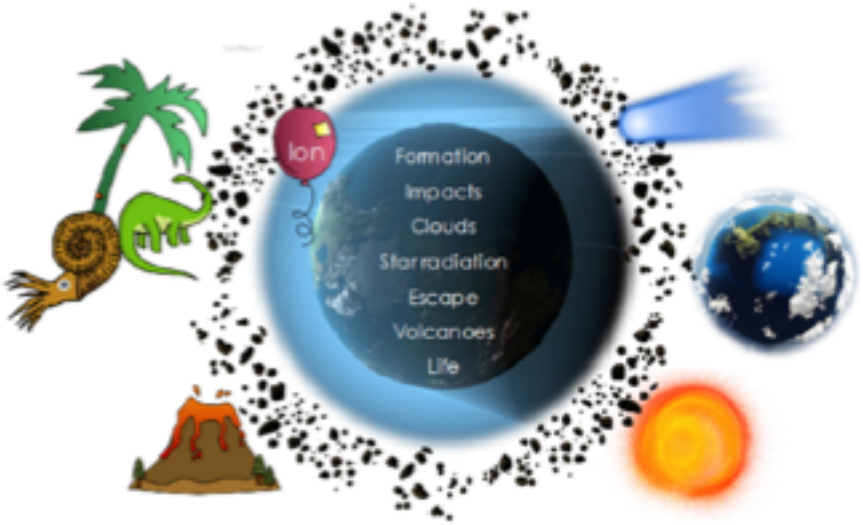
This is what makes ARIEL unique!

Exoplanets: next step

Chemical composition of a LARGE sample of KNOWN exoplanets

Key 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 (1.25-7.8 um)
- VNIR multiband photometry (0.5-1.2 um)

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 constrain bulk chemical composition

Targets: planetary classes

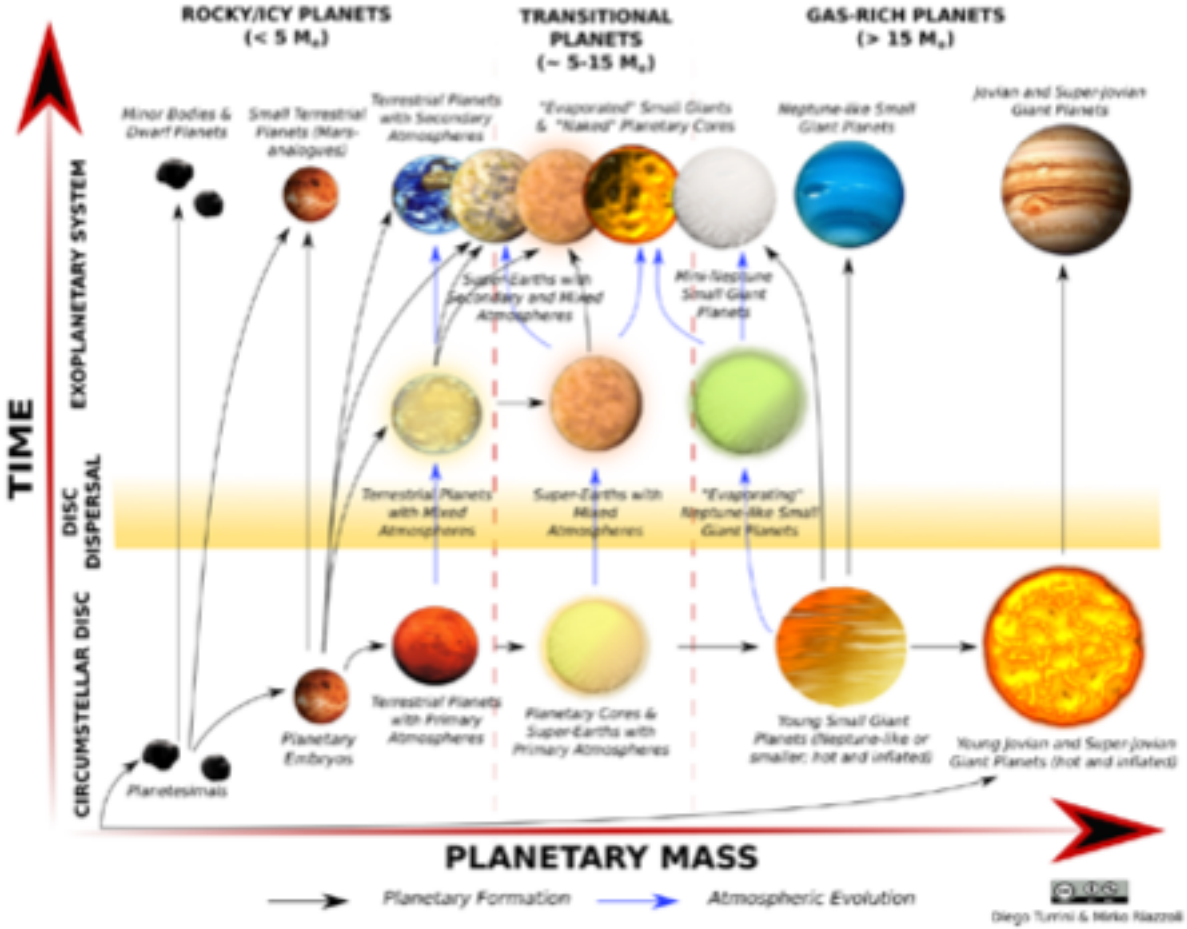
(Exo)Planetary systems

- 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
  - (Observational biases)

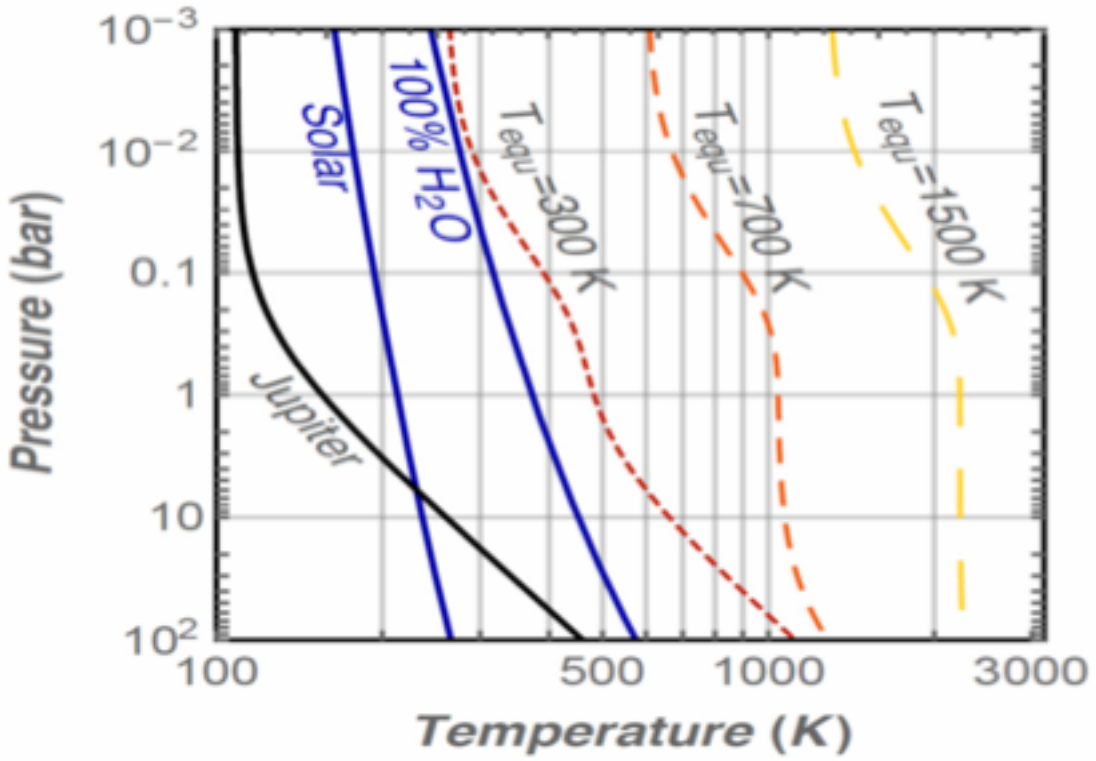
Observe large and statistically representative sample!



Targets: migration our ally

ARIEL will preferentially observe warm/hot planets

- Limited sequestration
- Linking atmospheric to bulk composition enabled



Other important species e.g. CO, CO_2, CH_4, and NH_3 condense at lower temperatures than H_2O

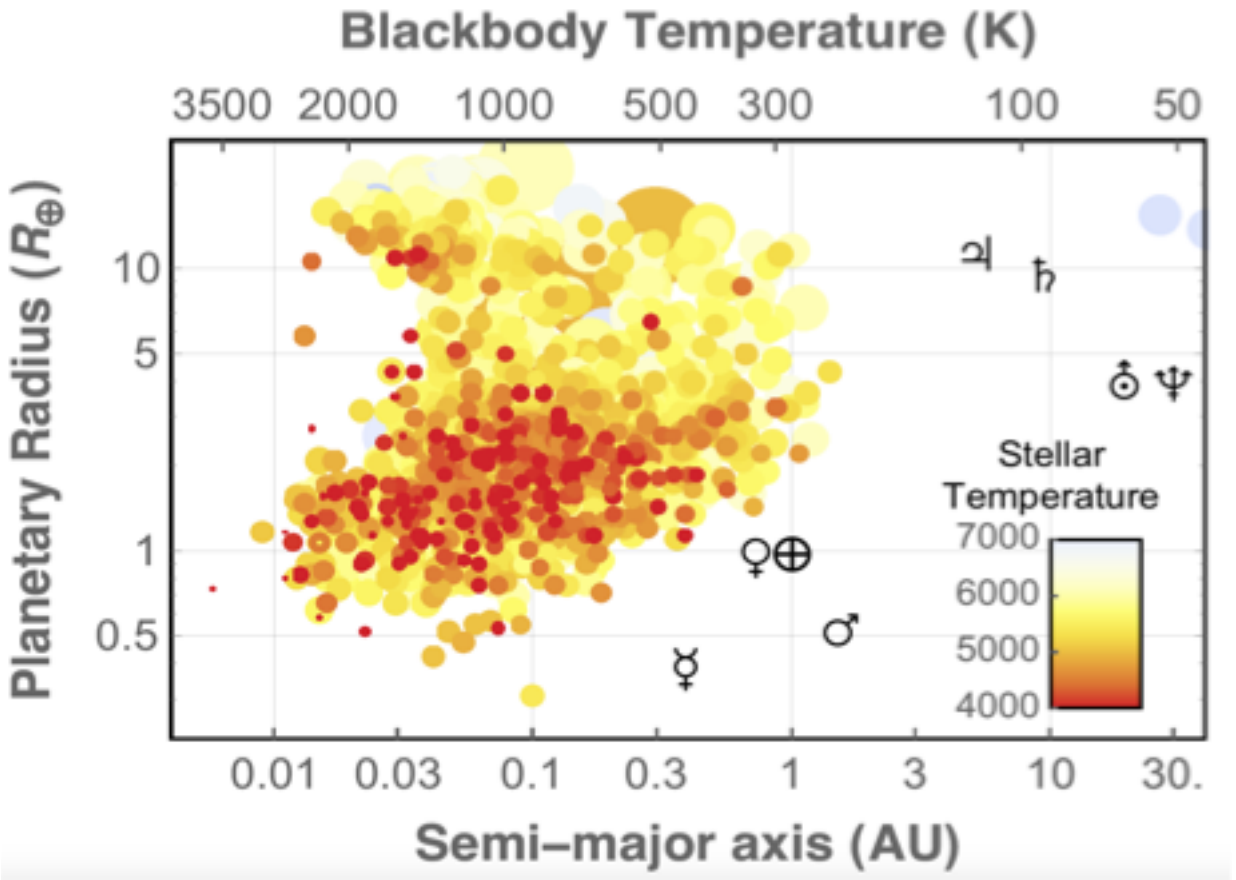
Targets: migration our ally

ARIEL will preferentially observe warm/hot planets

- Limited sequestration
- Linking atmospheric to bulk composition enabled

Planetary migration

- Common (beware of bias)
- ~½ of observed planets <0.1 AU



Targets: migration our ally

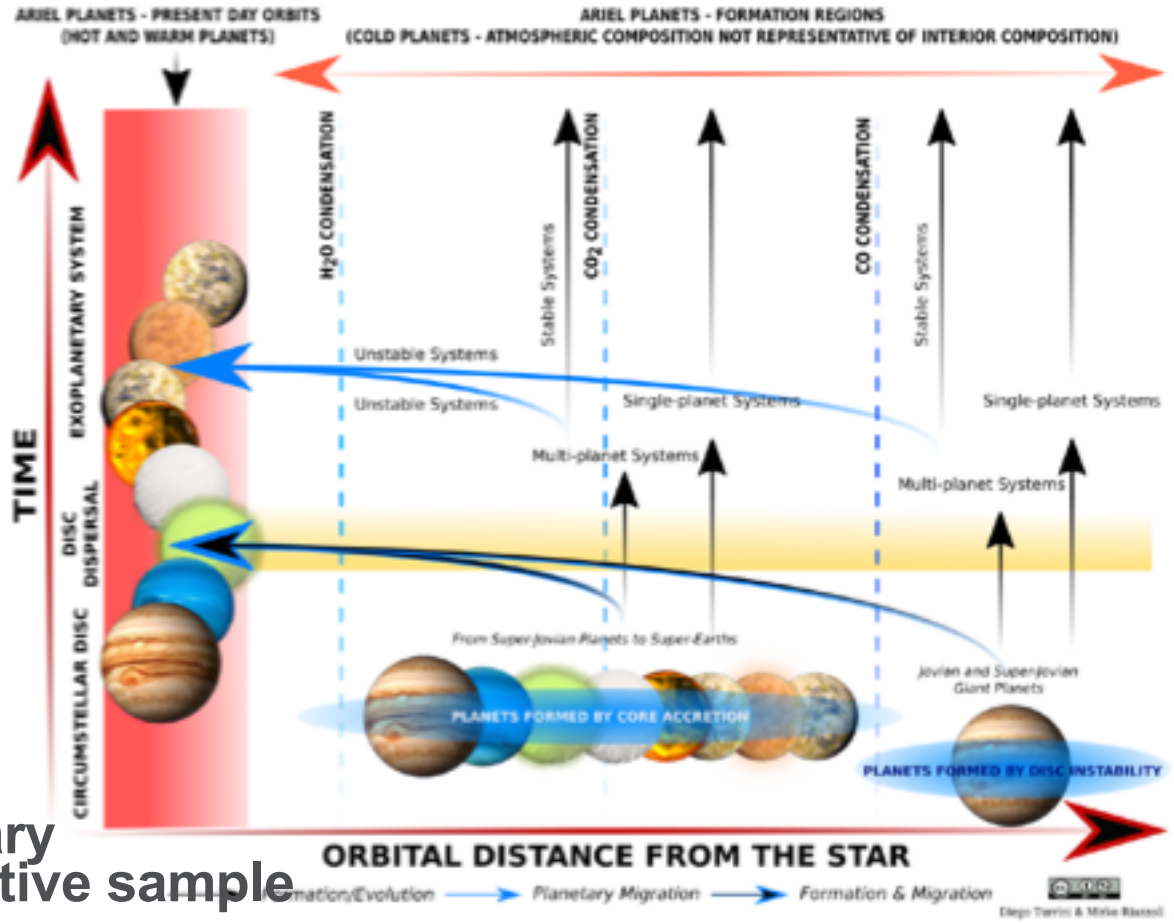
ARIEL will preferentially observe warm/hot planets

- Limited sequestration
- Linking atmospheric to bulk composition enabled

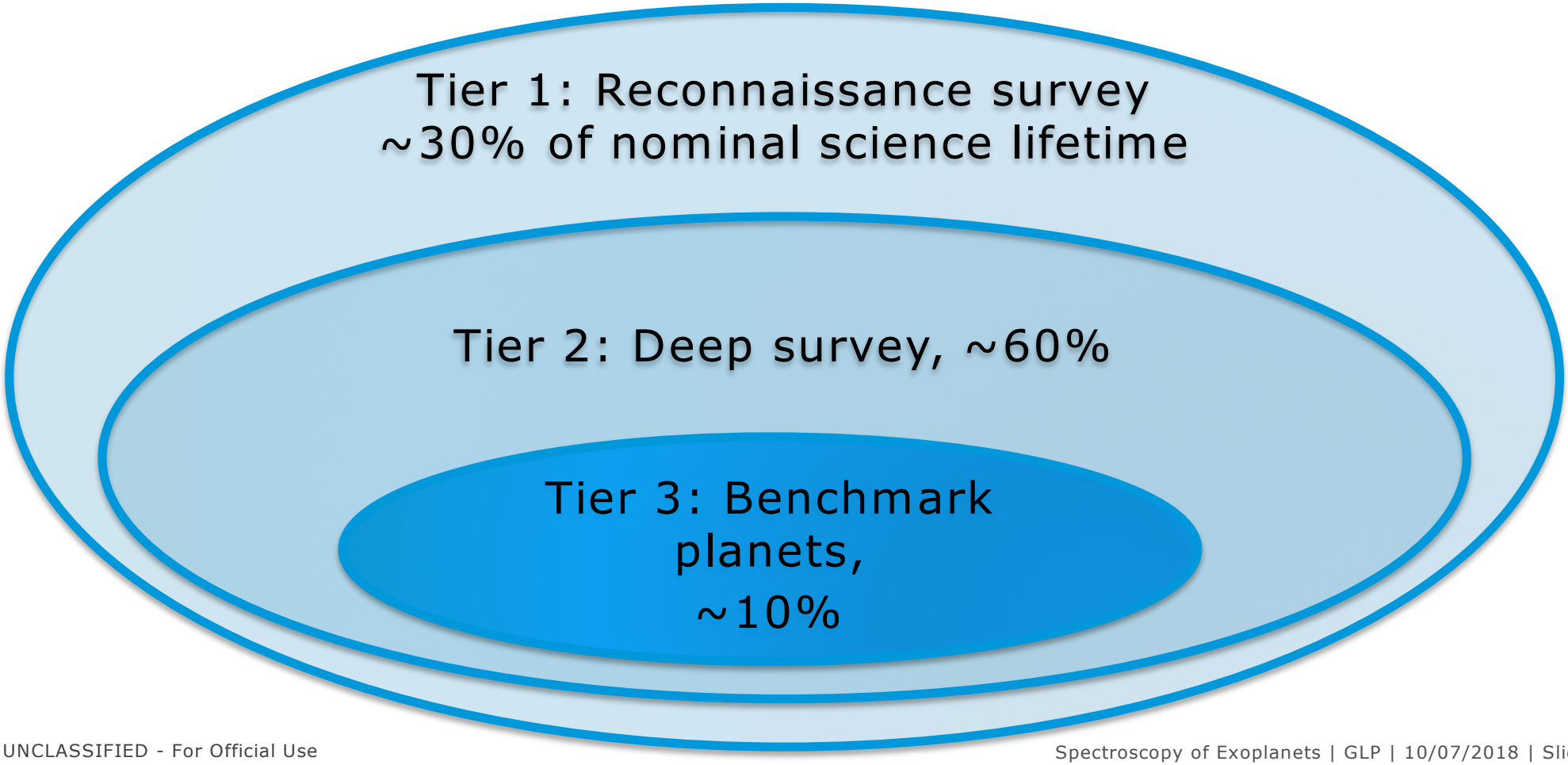
Planetary migration

- Common (beware of bias)
- ~½ of observed planets <0.1 AU
- Can take place at different times
  - In protoplanetary disk
  - After disk dispersal

'Delivers' warm/hot planets from different formation and evolutionary tracks helps forming a representative sample



Observing: 3-tier strategy



Science: 3-tier strategy

Tier name	Observational strategy	Science case
Reconnaissance survey (~30%)	Low Spectral Resolution observations of ~1000 planets in the VIS & IR, with SNR ~ 7	• *What fraction of planets are covered by clouds?* • *What fraction of small planets have still retained H/He?* • *Classification through colour-colour diagrams?* • *Constraining/removing degeneracies in the interpretation of mass-radius diagrams* • *Albedo, bulk temperature & energy balance for a subsample.*
Deep survey (~60%)	Higher Spectral Resolution observations of a sub-sample in the VIS-IR	• *Main atmospheric component for small planets* • *Chemical abundances of trace gases* • *Atmospheric thermal structure (vertical/horizontal)* • *Cloud characterization* • *Elemental composition*
Benchmark planets (~10%)	Very best planets, re-observed multiple time with all techniques	• *Very detailed knowledge of the planetary chemistry and dynamics* • *Weather, spatial & temporal variability*

Exoplanet population analysis

Single planet and population analysis

Very detailed study of select planets

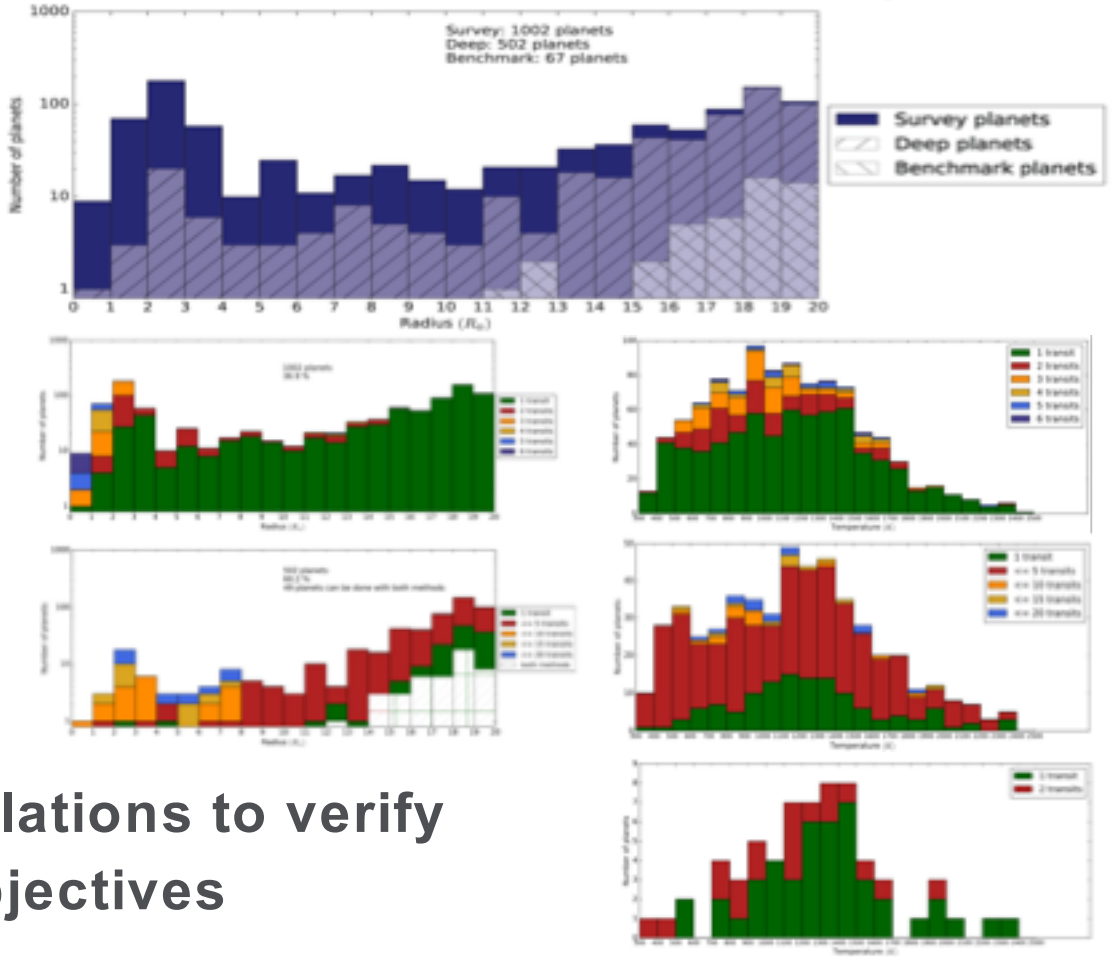
Targets: sample

Potential ARIEL targets

- Hundreds available now
- 8000+ expected by 2028
  - Most from TESS (CHEOPS, PLATO)
  - Groundbased also contributing

Mission Reference Sample

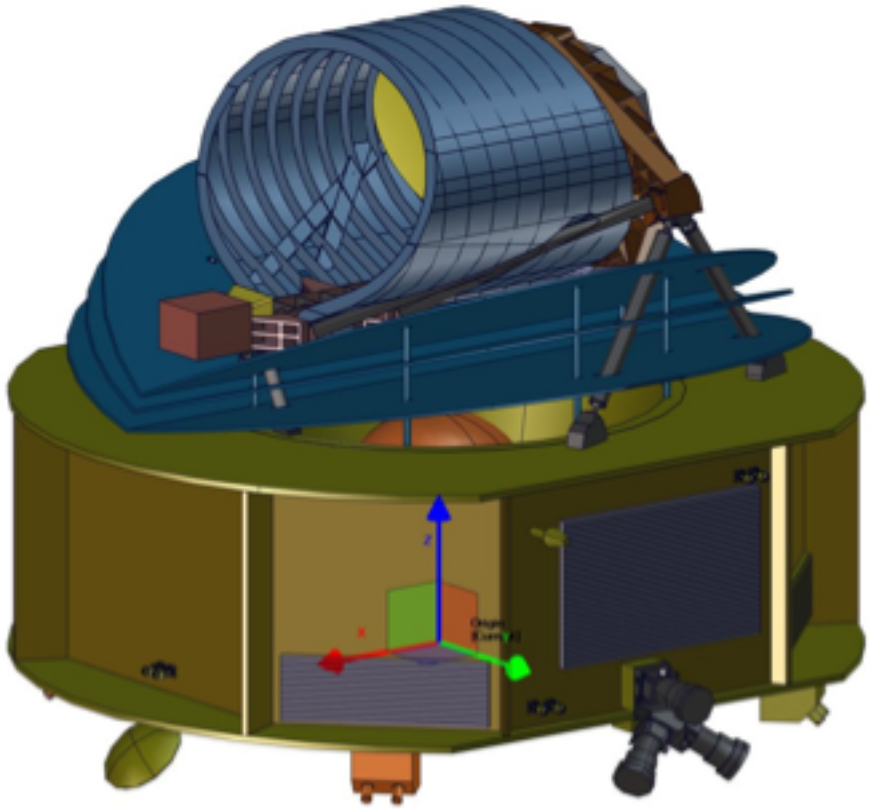
- Will continuously evolve
- New targets
- New observations
- New questions
- Yellow Book example illustrated



YB MRS used for successful simulations to verify the feasibility of ARIEL science objectives

Implementation: spacecraft

Under study by industry (x2) and ARIEL Consortium (PLM)



Instrument

- Spectrometers:
  - NIRSpec 1.25-1.95 μm R~10
  - AIRS0 1.95-3.9 μm R~100
  - AIRS1 3.9-7.8 μm R~30
- Photometer:
  - 3 VNIR channels 0.5-1.2 μm

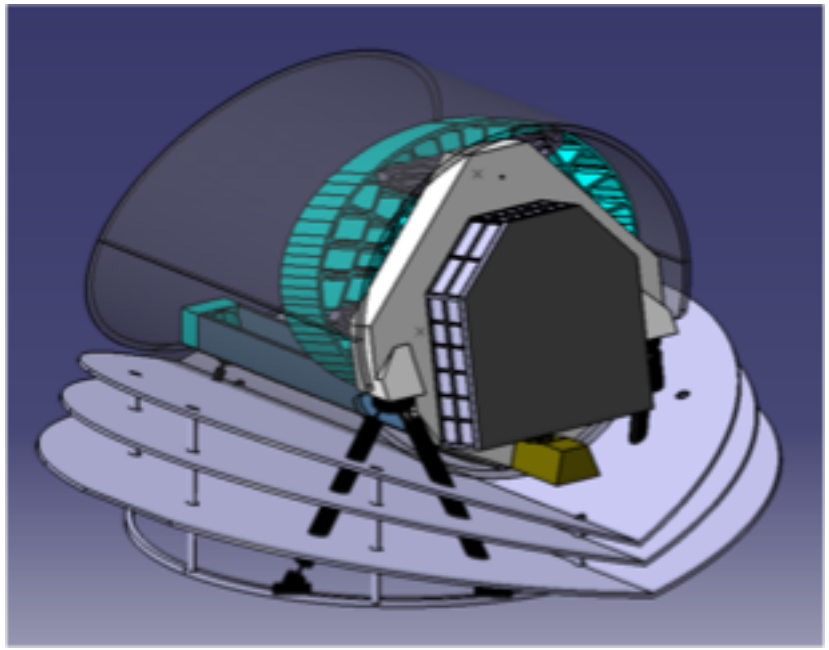
Telescope

- 3-mirror off-axis Cassegrain (all aluminium)
- 1.1 x 0.7 m aperture

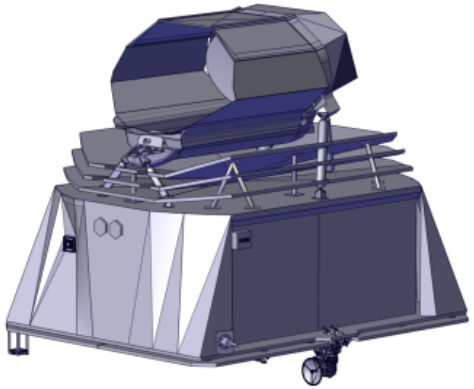
Spacecraft & mission

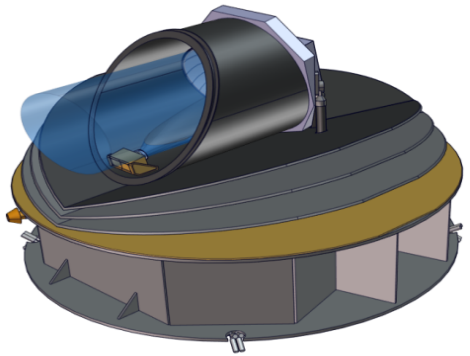
- Payload module (PLM) passively cooled
- Some detectors actively cooled
- Dual A62 launch, max launch mass 1.4 ton
- Large halo-orbit around L2
- Nominal lifetime 4 years, extended 6 years

Spacecraft – end phase A

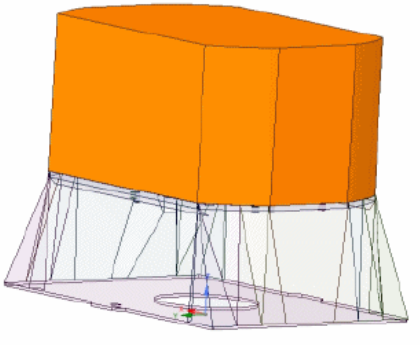


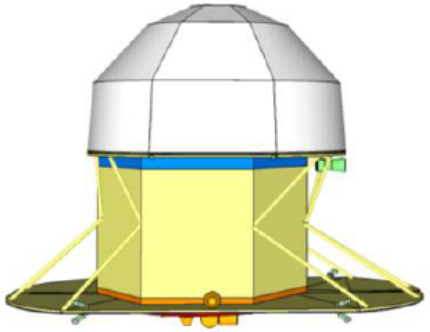
Consortium PLM at end of Phase A





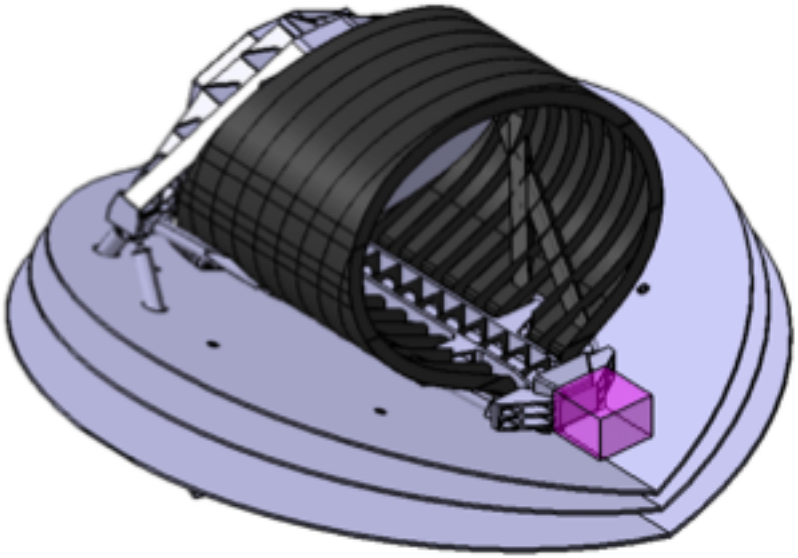
ADS & TAS S/C at end of Phase A

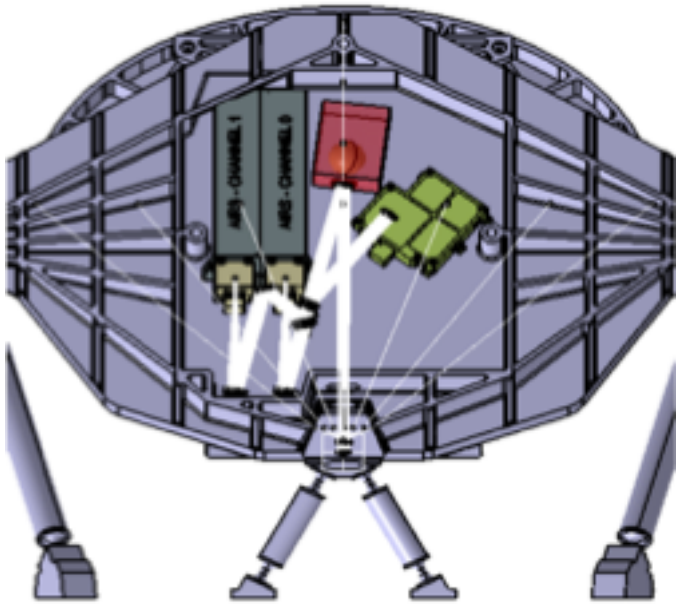




ADS & TAS S/C after Phase A extension with PLM ejectable cover concept

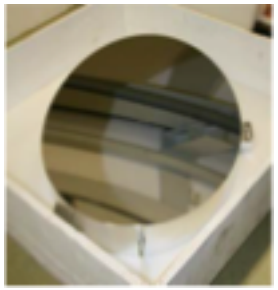
Payload module – end phase A

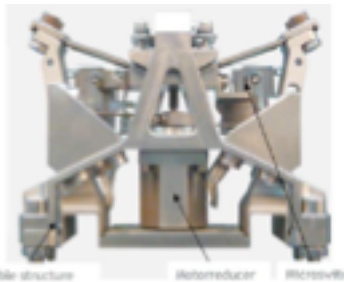




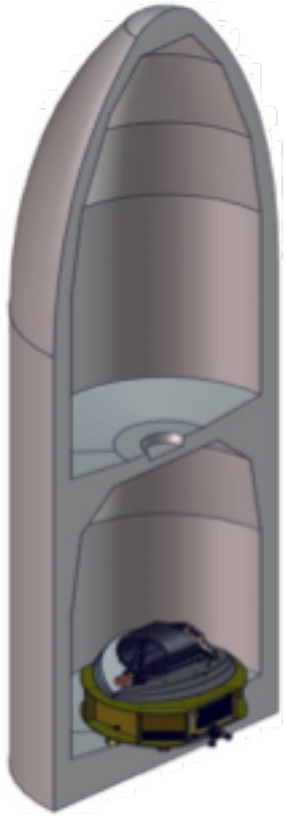
Recent updates

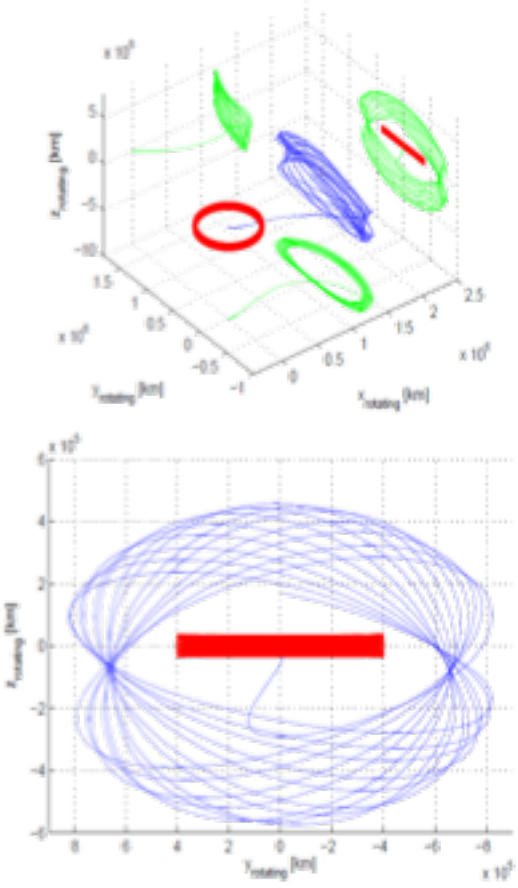
- All Teledyne detectors
- Finalising active cooling needs – AIRS0?
- Silver coating – M1?
- Optimising FGS/VNIR channel bands
- Various technical development activities:
  – M1 PTM, cooler, M2M, dichroics (D1!)

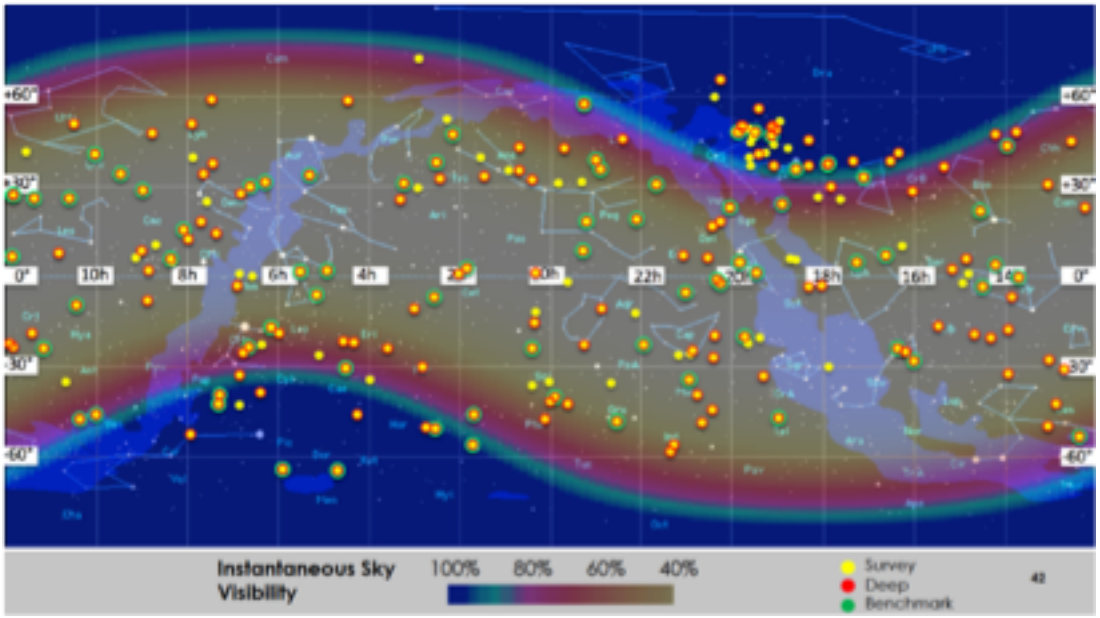




Launch, orbit & sky visibility





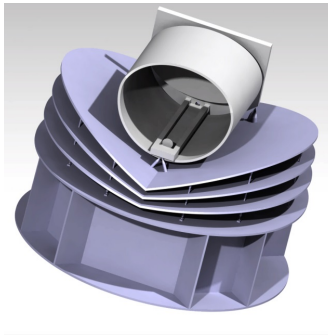


Recent updates

- All Teledyne detectors
- Dual launch => max wet launch mass 1.4 ton

Continuous update: available targets

Operations (routine science phase)



Uplink

Downlink

Mission operations (ESA)

- Mission Operations Centre (MOC)
- Ground station(s)

Instrument Operations Science Data Centre (DOC@ Consortium)

- Long term observing plan
- Instrument operations
- Data processing pipeline modules
- High level (level 3) data products

Science operations (ESA)

- Science Operations Centre (SOC)
- Observing requests
- Data processing pipeline (levels 0, 1, 2)
- Mission database & science archive

Exoplanet Community

Synthetic data

ExoSim (ARIELsim)

Synthetic data

- Observation & instrumental input
- Synthetic data output

Data processing

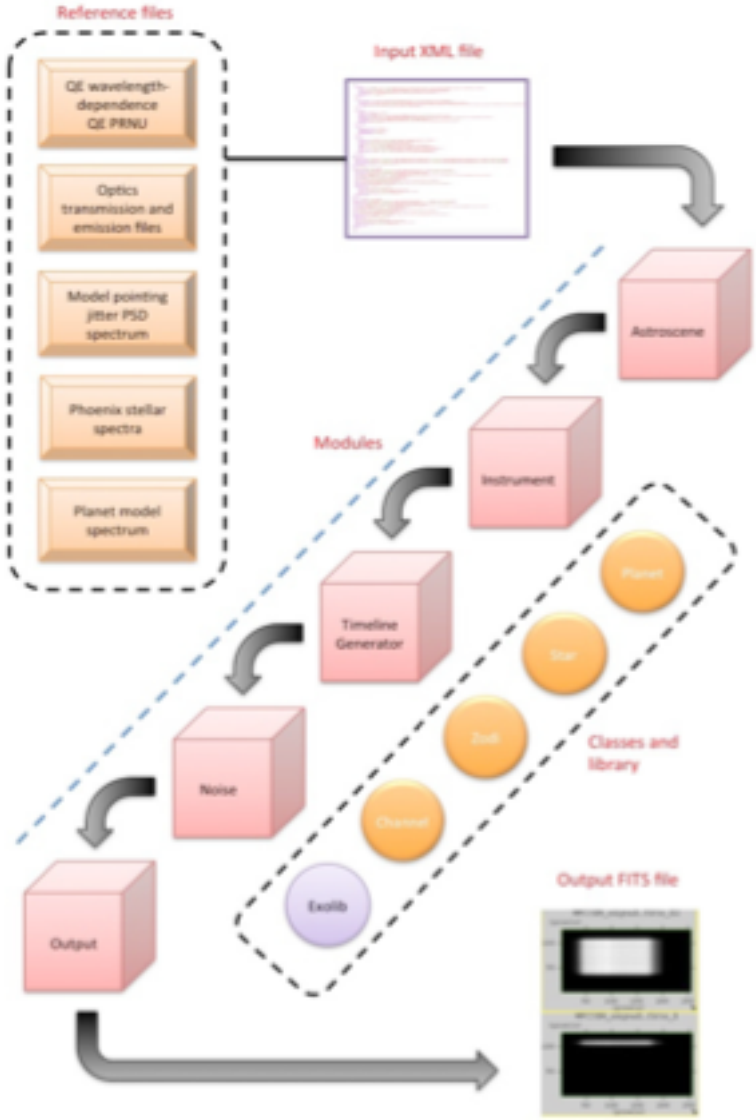
- Generates data products
- Different levels

Retrieval

- Get desired parameters
- Different packages

Validation

- Aids capture of mission & software requirements
- Demonstration of mission feasibility



Data reduction

Pipeline processing data flow

Level 0: Raw telemetry

- Delivered by the MOC to the SOC

Level 1: Raw spectral frame cubes

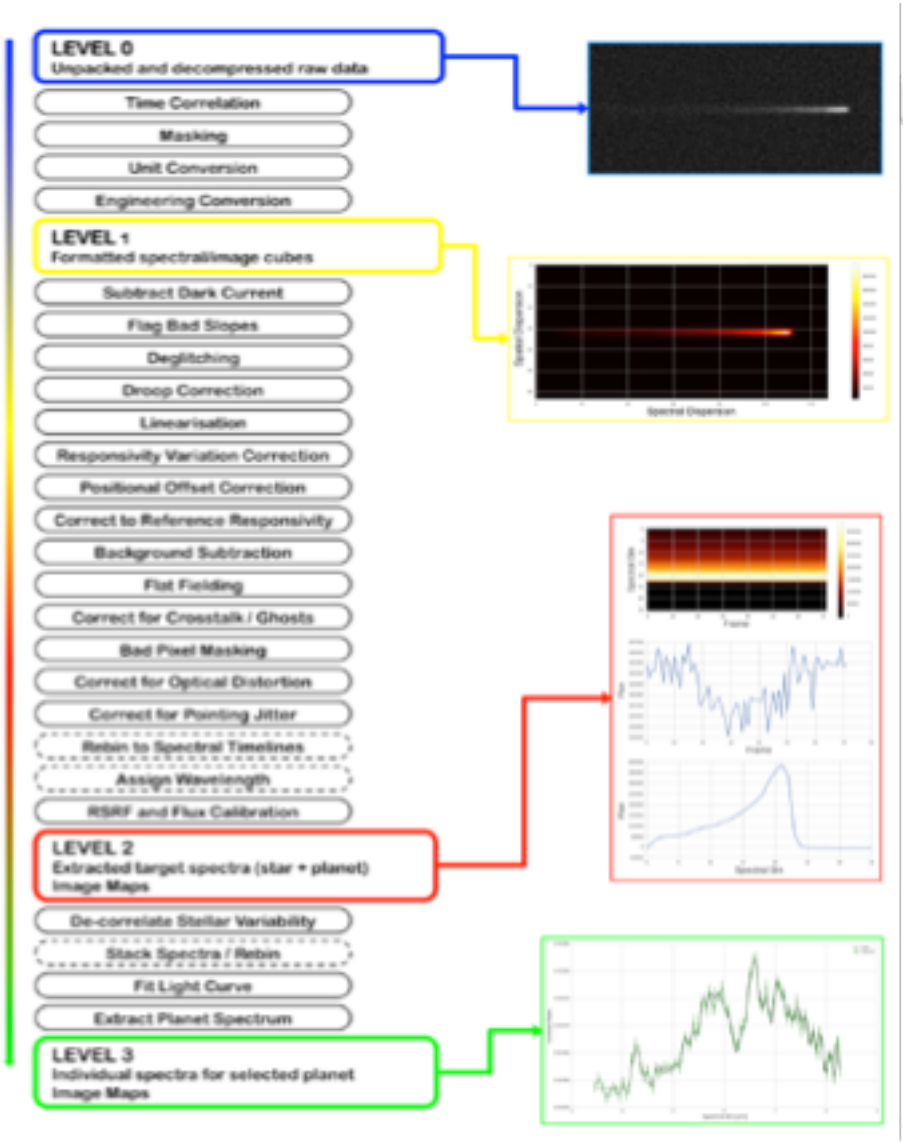
- Systematic processing at the SOC
- Pipeline delivered by the Consortium

Level 2: Target spectra (star + planet)

- Systematic processing at the SOC
- Pipeline delivered by the Consortium

Level 3: Individual planet spectra

- Processed by the Consortium
- Expected to require manual intervention
- Delivered to the SOC



Science data product levels

Level 0: Raw telemetry

- Delivered by the MOC

Level 1: Raw spectral frame cubes

- Re-ordered uncompressed data & metadata
- Cubes of raw spectra w metadata for all frames

Level 2: Target spectra (star + planet)

- Science data w instrument signatures removed
- Level 1 data converted to target spectra in physical units vs time; calibrated etc

Level 3: Individual planet spectra

- Final core science product
- Level 2 products stacked & planet spectra extracted

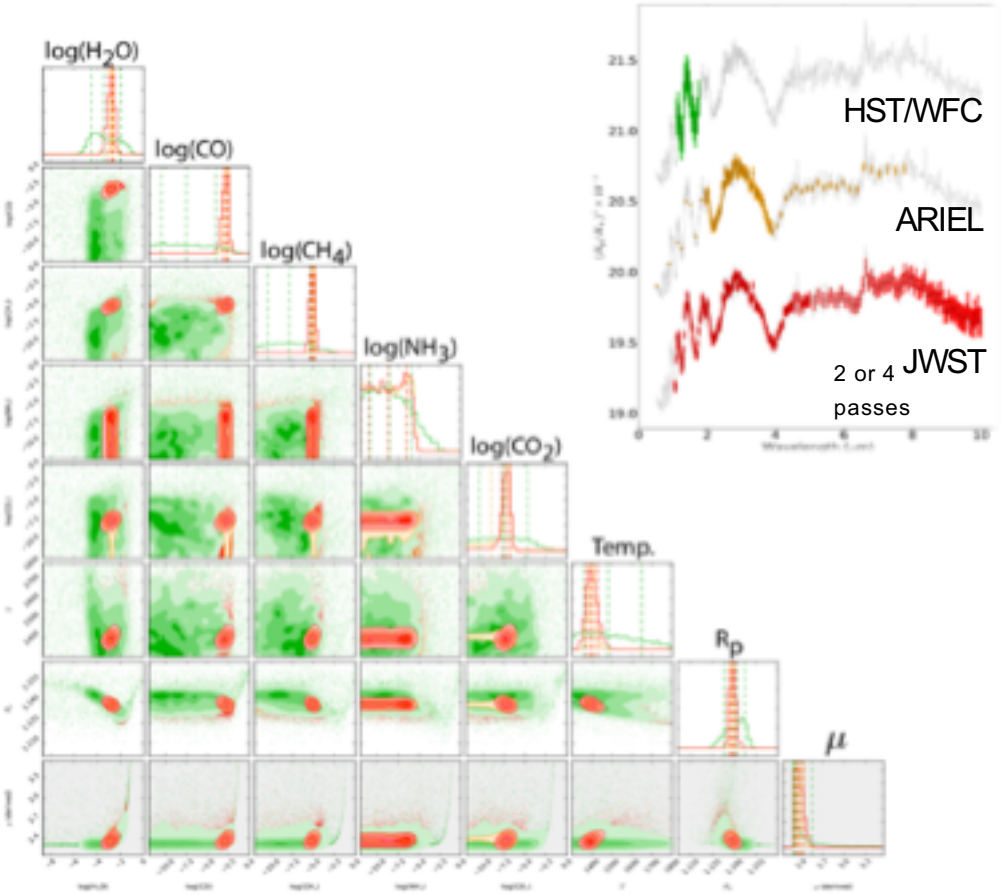
All data provided by the SOC to the Community

- Through the ARIEL Science Archive

Retrieval

TauREx on simulated spectra

- Posterior distributions of trace gases, temperature, top cloud pressure, and derived mean molecular weight
- Considerable degeneracy for WFC
- Very constraining for ARIEL & JWST
- For the brighter sources information content of ARIEL & JWST is similar
- For fainter sources JWST (& E-ELT) – but limited time available*
- ARIEL dedicated for 3.5 (5.5) years of routine science observing



*e.g. Cowan et al. 2015, PASP 127, 311
assumes 300 days in 5 years, this is 25% of all available time

ARIEL: for the community

ARIEL is a survey mission – and wants to embrace the Community

Target list

- Under the responsibility of the Science Team – 'continuously' updated
- Has been used to demonstrate feasibility – mix of real and 'predicted' targets
- Until flight will be used to assess options – new targets to be introduced
- **Mechanism(s) to involve the community to be put in place**

Data policy

- Designed to embrace the Community – maximising the science return from ARIEL
- **Regular timely public provision of high quality data products**

Dialogue with the Community

- Maintain dialogue – website, helpdesk, workshops & symposia
- Enable follow-up and ancillary data taking – planning and schedules to be made public
- Intention to dedicate some Consortium resources to coordinate community support
- **Current preliminary thoughts – will be firmed up in Science Management Plan (SMP)**

ARIEL: data policy

ARIEL data – regular timely provision of high quality products

- Early **'science demonstration phase' data release**
  - 1 month (TBC) of data, released as soon as practical after observing
  - Benchmark / JWST planets
  - **Public meeting** to present & assess ARIEL performance

ARIEL: data policy

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- Early **'science demonstration phase' data release**
  - 1 month (TBC) of data, released as soon as practical after observing
  - Benchmark / JWST planets
  - **Public meeting** to present & assess ARIEL performance
- **Regular timely high quality data releases** foreseen (details => SMP)
  - **Tier 1 up to 'Level 2' data: Star + planet lightcurves** in physical units with instrumental signatures removed – **quarterly** releases
  - **Tier 2+3 up to 'Level 2' data:** releases – **after semester when required SNR & spectral resolution** has been achieved
  - Associated **ancillary data** in connection with above releases
  - **'Level 3' products** will be produced and **publicly released** – these require manual processing and good understanding of instrumental signatures

Schedule

Current plan for M4 mission implementation

• Selection of M4 mission by the SPC	Mar 2018
• Phase B1 Consortium & industrial KO	Q2 2018
• Intermediate Review	Q1 2019
• Payload SRR (pSSR)	Q1 2020
• Mission Adoption Review (MAR) & SMP	Q2 2020
• Mission adoption & impl preps	Q3 2020
• **Adoption by the SPC**	**Nov 2020**
• Industrial ITT for phases B2/C/D/E1	Q2 2021
• Industrial Prime KO	Q4 2021
• System PDR	Q1 2023
• System CDR	Q1 2025
• Launch	2028

Schedule

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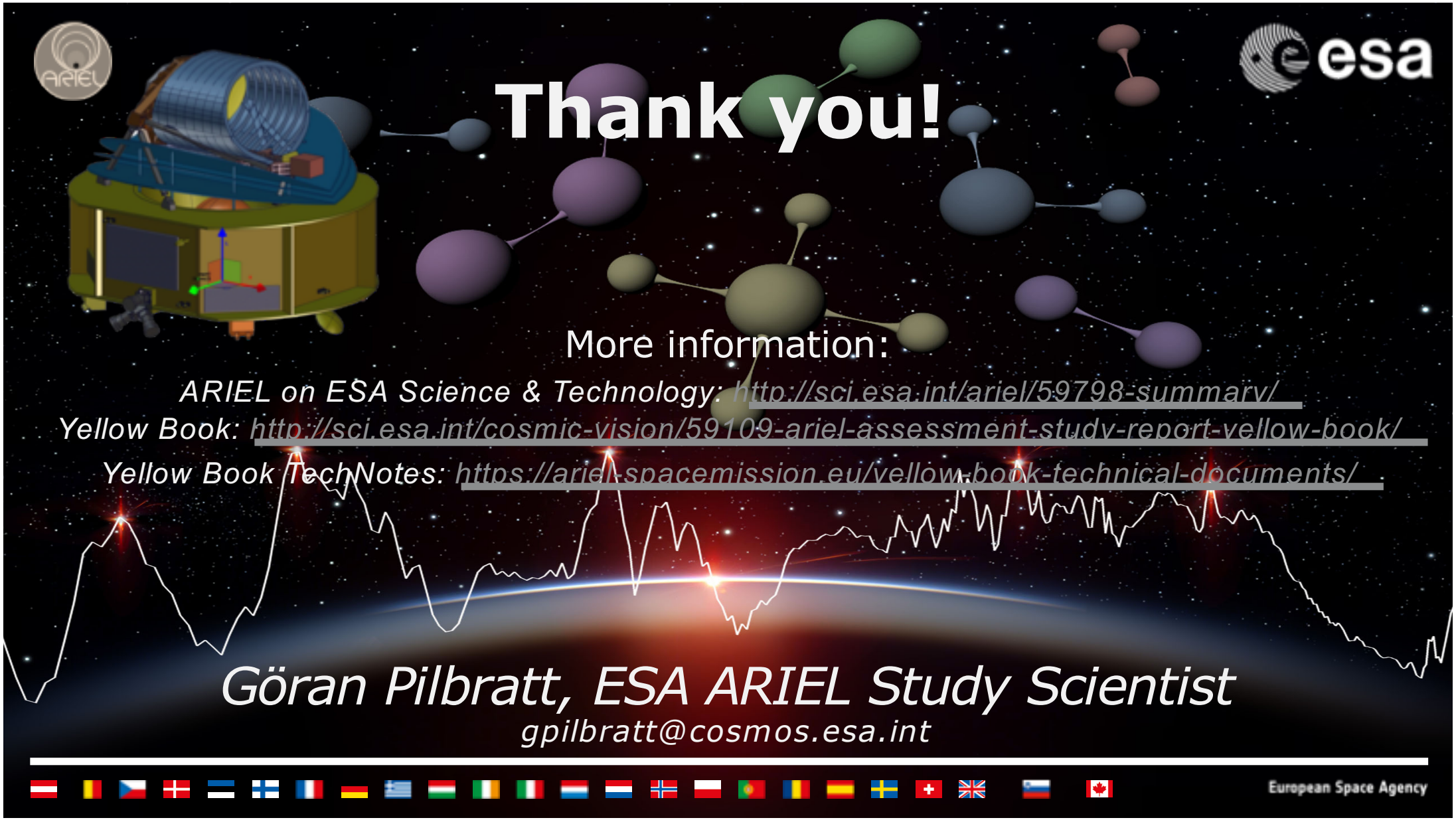
• Selection of M4 mission by the SPC	Mar 2018
• Phase B1 Consortium & industrial KO	Q2 2018
• **Launch**	Q1 2019
• LEOP	Q1 2020
• Commissioning Phase	Q2 2020
• Performance Verification Phase	Q3 2020
• Science Demonstration Phase	Nov 2020
• **Start of Routine Science Phase** **6 months**	Q2 2021
• **End of nominal mission** **4 years**	Q4 2021
• (Potential extended mission 6 years)	Q1 2023
• System CDR	Q1 2025
• Launch	2028


Thank you!
More information:
ARIEL on ESA Science & Technology: http://sci.esa.int/ariel/59798-summary/
Yellow Book: http://sci.esa.int/cosmic-vision/59109-ariel-assessment-study-report-yellow-book/
Yellow Book TechNotes: https://ariel-spacemission.eu/yellow-book-technical-documents/
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