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# ESA M4 ARIEL: Phase B

**Giovanna Tinetti** (1); Paul Eccleston, STFC – RAL Space, UK; Anna Aret, Tartu Observatory, Estonia; Jean-Philippe Beaulieu, Institut d'Astrophysique de Paris, France; Matt Griffin, Cardiff University UK; Pierre-Olivier Lagage, CEA, France; Giuseppe Malaguti, INAF-OAS Bologna, Italy; Giusi Micela, INAF – Osservatorio Astronomico di Palermo, Italy; Mirek Rataj, Space Research Centre, Polish Academy of Science, Poland; Ignasi Ribas, IEEC, Spain, Enric Palle, IAC, Spain; Bart Vandenbussche, University of Leuven, Belgium; Manuel Guedel, University of Vienna, Austria; Paul Hartogh, Max Planck Sonnnensystem, Germany; Pedro Machado, IA - Institute of Astrophysics and Space Sciences, Portugal; Michiel Min, SRON Netherlands Institute for Space Research, the Netherlands; Lars Buchhave, DTU, Denmark; Tom Ray, Dublin Institute for Advanced Studies, Ireland; Mark Swain, JPL, US; Stephanie Werner, University of Oslo, Norway; Martin Ferus, Heyrovsky Institute of Physical Chemistry, Czech Republic; Robert Szabo, Konkoly Observatory, Hungary; Kay Justtanont, Onsala Space Observatory, Sweden; Kevin Middleton, RAL Space, UK; Gustavo Alonso, UPM, Spain; Jerome Amiaux, CEA, France; Georgia Bishop, RAL Space, UK. Neil Bowles, University of Oxford, UK; Deirdre Coffey, DIAS, Ireland; Martin Crook, RAL TD, UK; Vania Da Deppo, CNR-IFN Padova, Italy; Jose J. Diaz, IAC, Spain; Mauro Focardi, INAF-OAA; Jose M. Gomez, IEEC, Spain; Giuseppe Malaguti, INAF - OAS Bologna, Italy; Andrea Moneti, IAP, France; Gianluca Morgante, INAF - OAS Bologna, Italy; Marc Ollivier, IAS Paris, France; Roland Ottensamer, University of Vienna, Austria; Emanuele Pace, Università di Firenze, Italy; Enzo Pascale, La Sapienza Universita di Roma / Cardiff University, UK; Chris Pearson, RAL Space, UK; Mirek Rataj, Space Research Centre, Polish Academy of Science, Poland; Richard Stamper, RAL Space, UK; Francesc Vilardell, IEEC, Spain;.Berend Winter, MSSL, UK; Michel Berthé, CEA, France; Emanuele Pace, Uni di Firenze, Italy; Josep Colomé, IEEC – CSIC, Spain; Deirdre Coffey, DIAS, Ireland; Søren Møller Pedersen, DTU, Denmark; Manfred Steller, IWF Graz, Austria; Manuel Abreu, IA, Portugal; Joanna Barstow, UCL, UK; Luca Borsato, University of Padova, Italy; Matt Burleigh, University of Leicester; Sarah Casewell, University of Leicester, UK; Benjamin Charnay, Observatoire de Paris, France; James Cho, QMUL, UK; Svatopluk Civiš, Heyrovsky Institute, Czech Republic; Vincent Coudé du Foresto, LESIA, France; Athena Coustenis, LESIA, France; Nicholas Cowan, McGill University, Canada; Camilla Danielski, CEA, France; Olivier Demangeon IA- Portugal; Pierre Drossart, LESIA, France; Luca Fossati, IWF Graz, Austria; Gabriella Gilli IA- Portugal; Csaba Kiss, Konkoly Observatory, Hungary, Anastasia Konkori, Royal Museums Greenwich, UK; Carole Haswell, OU; Jérémy Leconte, Laboratoire d'Astrophysique de Bordeaux; Juan Carlos Morales, IEEC, Spain; Pierre- João Mendonça, DTU, Denmark; Antonio García Muñoz, Technische Universität Berlin, Germany; Ravit Helled, University of Zurich, Switzerland; Mihkel Kama, Cambridge, UK; Theresa Lueftinger, University of Vienna, Austria; Pedro Machado, Obs. Lisboa, Portugal; Yamila Miguel, University of Leiden, the Netherlands; Nikos Nikolaou, UCL, UK, Isabella Pagano, INAF, Italy; Enric Palle, IAC, Spain; Olja Panic, Leeds, UK, Giampaolo Piotto, University of Padova, Italy; Marco Rocchetto, Konica Minolta; Subhajit Sarkar, Cardiff University, UK; Franck Selsis, Université de Bordeaux, France; Clara Sousa-Silva, MIT, US, Jonathan Tennyson, UCL, UK; Diego Turrini, INAF-IAPS, Italy; Angelos Tsiaras, UCL, UK; Olivia Venot, LISA, France; Krisztián Vida, Konkoly Observatory, Hungary, Ingo Waldmann, UCL, UK; David Waltham, RHUL, UK; Gyula Szabo, University of Eötvös Loránd, Hungary; Maria-Rosa Zapatero Osorio, CSIC-INTA, Spain.

(1) Centre for Space Exoplanet Data (CSED), University College London, UK (g.tinetti@ucl.ac.uk)

## Abstract

ARIEL, the Atmospheric Remote-sensing Infrared Exoplanet Large-survey, was selected as the fourth medium-class mission in ESA's Cosmic Vision programme. This paper provides an overall summary of the science and baseline design derived during the phase A study and further progressed during phase B1.

During its 4-year mission, ARIEL will study what exoplanets are made of, how they formed and how they evolve, by surveying a diverse sample of about 1000 extrasolar planets, simultaneously in visible and infrared wavelengths. It is the first mission dedicated to measuring the chemical composition and thermal structures of hundreds of transiting exoplanets, enabling planetary science far beyond the boundaries of the Solar System.

Transit spectroscopy means that no angular resolution is required and detailed performance studies show that a 1-metre class telescope is sufficient to achieve the necessary observations on all the ARIEL targets within the mission lifetime. The satellite is best placed into an L2 orbit to maximise the thermal stability and the field of regard.

The baseline integrated payload consists of an all-aluminium, off-axis Cassegrain telescope, feeding a collimated beam into two separate instrument modules. A combined Fine Guidance System / VIS-Photometer / NIR-Spectrometer contains 3 channels of photometry between 0.50 µm and 1.1 µm, of which two will also be used as a redundant system for provided guidance and closed-loop control to the AOCS. One further low resolution (R = ~15 spectrometer in the 1.1 µm – 1.95 µm waveband is also accommodated here. The other instrument module, the ARIEL IR Spectrometer (AIRS), provides spectral resolutions of between 30 – 100 for a waveband between 1.95 µm and 7.8 µm. The payload module is passively cooled to ~55 K by isolation from the spacecraft bus via a series of V-Groove radiators; the detectors for the AIRS are the only items that require active cooling to <42 K via an active Ne JT cooler. The payload mechanical design and an example hot case of the thermal model results are shown below.

The ARIEL mission payload is developed by a consortium of more than 50 institutes from 18 ESA countries, which include the UK, France, Italy, Germany, the Netherlands, Poland, Spain, Belgium, Austria, Denmark, Ireland, Norway, Sweden, Czech Republic, Hungary, Portugal, Estonia and Switzerland. A NASA contribution is under study.

# 1. Introduction

Thousands of exoplanets have now been discovered with a huge range of masses, sizes and orbits: from rocky Earth-size planets to large gas giants grazing the surface of their host star. However, the essential nature of these exoplanets remains largely mysterious: there is no known, discernible pattern linking the presence, size, or orbital parameters of a planet to the nature of its parent star. We have little idea whether the chemistry of a planet is linked to its formation environment, or whether the type of host star drives the physics and chemistry of the planet's birth, and evolution. Progress with these science questions demands a large, unbiased spectroscopic survey of exoplanets. The ARIEL mission has been conceived to conduct such a survey and to explore the nature of exoplanet atmospheres and interiors and, through this, the key factors affecting the formation and evolution of planetary systems.

# 2. ARIEL Science Goals

ARIEL will address the fundamental questions:

– *What are exoplanets made of?*

– *How do planets form and evolve?*

through the direct measurement of the atmospheric and bulk chemical composition. ARIEL will focus on warm and hot planets, for which the atmospheric composition is more representative of the bulk one.

ARIEL will observe a large number, i.e. ~ 1000, of warm and hot transiting gas giants, Neptunes and super-Earths around a range of host star types using transit spectroscopy in the ~1.1-8 µm spectral range and multiple-band photometry in the optical (see Table below). We target in particular warm and hot planets to take advantage of their well-mixed atmospheres which should show minimal condensation and sequestration of high-Z materials and thus reveal their bulk and elemental composition (especially C, O, N, S, Si). Observations of these hot exoplanets will allow the understanding of the early stages of planetary and atmospheric formation during the nebular phase and the following few millions years. ARIEL will thus provide a truly representative picture of the chemical nature of the exoplanets and relate this directly to the type and chemical environment of the host star.

# 3. Observational Strategy

For this ambitious scientific programme, ARIEL is designed as a dedicated survey mission for transit, eclipse and phase-curves spectroscopy, capable of observing a large and well-defined planet sample within its 4-year mission lifetime. Transit, eclipse and phase-curves spectroscopy methods, whereby the signal from the star and planet are differentiated using knowledge of the planetary ephemerides, allow us to measure atmospheric signals from the planet at levels of ~10-100 ppm relative to the star (post-processing) and, given the bright nature of targets, also allows more sophisticated techniques, such as phase curve analysis and eclipse mapping, to give a deeper insight into the nature of the atmosphere. Transit spectroscopy means that no angular resolution is required and detailed performance studies show that a 1-metre class telescope is sufficient to achieve the necessary observations on all the ARIEL targets within the mission lifetime. The satellite is best placed into an L2 orbit to maximise the thermal stability and the field of regard.

To maximize the science return of ARIEL and take full advantage of its unique characteristics, a three-tiered approach has been considered, where three different samples are observed at optimised spectral resolutions, wavelength intervals and signal-to-noise ratios. A summary of the survey tiers is given in [1] and possible implementations are described in [2].

# 4. ARIEL Data Policy

The ARIEL data policy has been designed to embrace the astronomy community in general and the exoplanet community in particular. It is recognised that ARIEL data and data products will be of huge interest to the entire exoplanet community, not only to those directly involved in the mission. The intention is to provide high quality data in a timely manner and to have a continuous dialogue with the wider community, maximising the science that can be achieved by the mission.

Inputs to the target list – to be observed will be solicited from the wider community (e.g. through whitepapers, meetings, and a dedicated website), the community will be kept informed about the status of the target list, as will the ESA Advisory Bodies whose feedback will be solicited.

A Science Demonstration Phase (SDP) will be conducted as the final step before routine science phase operations commence. The SDP is foreseen to provide approximately one month worth of data observed in the same manner that the core survey will be conducted. These data will be made public on a timescale of about a month, in conjunction with organisation of a major public workshop.

Beyond the science community, ARIEL's mission to characterise distant worlds offers an immense opportunity to capture the public imagination and inspire the next generation of scientists and engineers. Through the provision of enquiry-based educational programmes and citizen science platforms (e.g. ARIEL Data Challenges https://ariel-datachallenge.azurewebsites.net ), school students and members of the public will have the opportunity to participate directly in the analysis of ARIEL data.

| **Wavelength range** | **Resolving power** | **Scientific motivation** |
|---|---|---|
| Blue filter 0.50 – 0.60 μm | Integrated band | - *Correction stellar activity (optimised early stars)*<br>- *Measurement of planetary albedo*<br>- *Detection of Rayleigh scattering/clouds* |
| Red filter 0.60 – 0.80 μm | Integrated band | - *Correction stellar activity (optimised late stars)*<br>- *Measurement of planetary albedo*<br>- *Detection of clouds* |
| NIR1 filter 0.80 – 1.10 μm | Integrated band | - *Correction stellar activity (optimised late stars)*<br>- *Detection of clouds* |
| Low Resolution NIR Spectrometer (NIRSpec) 1.10 – 1.95 μm | R≥15 | - *Correction stellar activity (optimised late stars)*<br>- *Detection of clouds*<br>- *Detection of molecules (especially TiO, VO, metal hydrides)*<br>- *Measurement of planet temperature (optimised hot)*<br>- *Retrieval of molecular abundances*<br>- *Retrieval of vertical and horizontal thermal structure*<br>- *Detection temporal variability (weather/cloud distribution)* |
| IR spectrograph (AIRS) – 1.95 – 7.8 μm | R≥100 below 3.9μm<br>R≥30 above 3.9μm | - *Detection of atmospheric chemical components*<br>- *Measurement of planet temperature (optimised warm-hot)*<br>- *Retrieval of molecular abundances*<br>- *Retrieval of vertical and horizontal thermal structure*<br>- *Detection temporal variability (weather/cloud distribution)* |

**Table 1**: Summary of the ARIEL spectral coverage (left column) and resolving power (central column). The key scientific motivations are listed in the right column

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