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The ARIEL Mission – Atmospheric Remote-sensing Infrared Exoplanet Large survey

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Abstract

The Atmospheric Remote-Sensing Infrared Exoplanet Large-survey (ARIEL) is one of the three candidate missions selected by the European Space Agency (ESA) for its next medium-class science mission (M4) due for launch in 2026. It is just coming to the conclusion of the assessment phase (phase A) study and beginning the process that will lead to mission selection. The goal of the ARIEL mission is to address the fundamental questions on how planetary systems form and evolve by means of investigating the atmospheres of many hundreds of planets orbiting other stars.

During its four-year baseline mission ARIEL will observe approximately 1000 exoplanets in the visible and the infrared with its meter-class telescope in L2 orbit. ARIEL targets will include Jupiter- and Neptune-size down to super- Earth and Earth-size exoplanets around different types of stars. The main focus of the mission will be on hot and warm planets orbiting very close to their star, as they represent a natural laboratory in which to study the chemistry, formation and evolution of exoplanets. The analysis of ARIEL spectra and photometric data will allow extraction of the chemical fingerprints of gases and condensates in the planets' atmospheres for the whole observational sample, as well as to define the elemental composition of hundreds of these planets. It will also enable the study of thermal and scattering properties of the atmosphere and its variability as the planet orbits around the star.

The ARIEL mission concept and payload design has been developed by a consortium of more than 50 institutes from 12 European countries, along with the European Space Agency and two industry primes who have conducted phase A studies of the mission and spacecraft. This paper gives an overview of the mission science case, the baseline spacecraft and payload design that has been developed to deliver these exciting discoveries and talk about the future plans for mission implementation if the mission is selected.

Keywords: Exoplanet, Spectroscopy, Transit, Atmospheres

1. Introduction

The ARIEL mission will address the fundamental questions on **what exoplanets are made of** and **how planetary systems form and evolve** by investigating the atmospheres of many **hundreds of diverse planets** orbiting different types of stars. This unbiased survey will contribute to the progress in answering the first of the four ambitious topics listed in the ESA's Cosmic Vision: "*What are the conditions for planet formation and the emergence of life?*"

This paper is a concise summary of the full assessment phase report produced following the phase A study of the mission [1]. Section 2 of this paper presents a summary of the science case for the mission, with section 3 then presenting the measurement and observational techniques that are planned to be used to make the measurements. Section 4 provides a summary of the spacecraft and mission design, with section 5 giving a summary of the payload design. Section 6 provides some details on the planned ground segment, science data processing plans and the data policy foreseen for the data generated by the mission, while section 7 provides a summary of the planned schedule.

1.1. Background

Thousands of exoplanets have now been discovered with a huge range of masses, sizes and orbits: from rocky Earth-like 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.

ARIEL will observe a large number (~1000) of transiting planets for statistical understanding, including gas giants, Neptunes, super-Earths and Earth-size planets around a range of host star types using transit spectroscopy in the 1.25-7.8 µm spectral range and multiple narrow-band photometry in the optical. We will focus on 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). 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.

For this ambitious scientific programme, **ARIEL is designed as a dedicated survey mission for transit and eclipse spectroscopy**, capable of observing a large and well-defined planet sample within its 4-year mission lifetime. Transit, eclipse and phase-curve 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 part per million (ppm) relative to the star and, given the bright nature of targets, also allows more sophisticated techniques, such as eclipse mapping, to give a deeper insight into the nature of the atmosphere. The wavelength range proposed covers all the expected major atmospheric gases from e.g. H_2O, CO_2, CH_4 NH_3, HCN, H_2S through to the more exotic metallic compounds, such as TiO, VO, and condensed species.

Progress with these science questions demands a large, unbiased spectroscopic survey of exoplanets.

The ARIEL candidate 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. Science Case

2.1. Background and Limits of Current Knowledge of Planets

Since their discovery in the first half of the 1990's, planets have been found around every type of star, including pulsars and binaries. As they form in the late stage of the stellar formation process, planets appear to be rather ubiquitous. Current statistical estimates indicate that, on average, every star in our Galaxy hosts at least one planetary companion [2,3] and therefore ~10^{12} planets are predicted to exist just in our Milky Way.

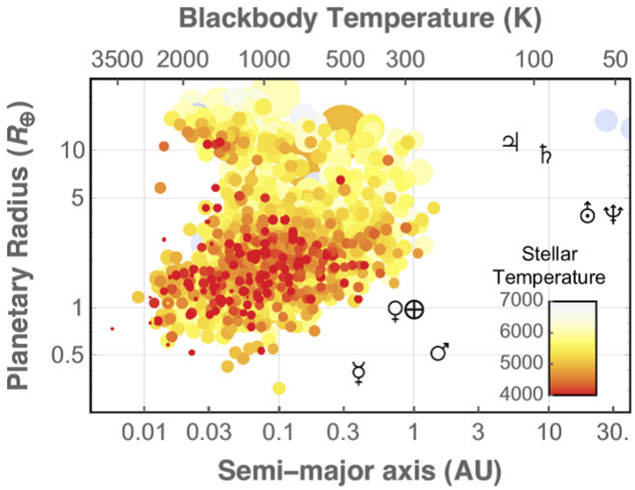

Figure 1: Currently known exoplanets, plotted as a function of distance to the star (up to 30 AU) and planetary radii. The graph suggests a continuous distribution of planetary sizes – from sub-Earths to super-Jupiters – and planetary temperatures that span two orders of magnitude.

On the same plot we show the conversion of the orbital period into planetary equilibrium temperature, i.e. the temperature that a black body would have at the given distance of a Sun-like star. Notice that in general a planet is not a black body: the albedo and atmospheric greenhouse effect, which are currently unknown for most exoplanets, have a great impact on its real temperature.

While the number of planets discovered is still far from the thousands of billions mentioned above, the ESA GAIA mission is expected to discover tens of thousands new planets [4]. In addition to the ongoing release of results from Kepler [3], ground-based surveys and the continuing K2 mission [5] will add to the current ground and space based efforts. In the future, we can look forward to many more discoveries from the TESS (NASA) [6], Cheops (ESA) [7] and PLATO (ESA) [8] missions. The targets that can be expected from these various missions and surveys are summarised in Table 2.6 of [1].

In all scientific disciplines, taxonomy is often the first step toward understanding, yet to date we do not have even a simple taxonomy of planets and planetary systems in our galaxy. In comparison, astrophysics faced a similar situation with the classification of stars in the late 19th and early 20th century. Here it was the systematic observations of stellar luminosity and colours of large numbers of stars that led to the breakthrough in our understanding and the definition of the classification schemes that we are so familiar with today. The striking observational phenomenon that the brightness of a star correlates with its perceived colours, as first noted by Hertzsprung & Russell [9,10], led to a link between observation and theoretical understanding of interior structure of a star its and their nuclear power sources (e.g. work by Eddington [11] & Bethe [12]). Thus, observation of a few basic observables in a large sample allowed scientists to predict both the physical and chemical parameters and subsequent evolution of virtually all stars. This has proved to be an immensely powerful tool, not only in studying "local" stellar evolution, but also in tracing the chemical history of the universe and even large scale cosmology.

We seek now a similar approach (i.e. the study of a large sample of objects to seek the underlying physical properties) to understand the formation and evolution of planets. Interestingly, planets do not appear to be as well behaved as stars in terms of parameter-space occupancy: what is certain, though, is that without observing a large number of planets, we will never be able to identify any trend allowing us to pinpoint the general principles underlying their formation.

2.2. The way forward: the chemical composition of a large sample of planets

The lesson taught us by the study of the planets in the Solar System is that to explore the formation and evolution of a planetary body we need to characterise its composition. The lesson taught us by exoplanets is that to grasp the extreme diversity existing in our galaxy we need large and statistically representative samples. A breakthrough in our understanding of the planet formation and evolution mechanisms – and therefore of the origin of their diversity – will only happen through the direct observation of the chemical composition of a statistically large sample of planets. This is achievable through the remote sensing observation of their gaseous envelop, their atmospheres. Knowing what exoplanets are made of is essential to clarify not only their individual histories (e.g. whether a planet was born in the orbit it is observed in or whether it has migrated over a large distance), but also those of the planetary systems they belong to. Knowledge of the chemical makeup of a large sample of planets will also allow us to determine the key mechanisms that govern planetary evolution at different time scales (see Figure 2).

Figure 2: Key physical processes influencing the composition and structure of a planetary atmosphere. While the analysis of a single planet cannot establish the relative impact of all these processes on the atmosphere, by expanding observations to a large number of very diverse exoplanets, we can use the information obtained to disentangle the various effects.

A statistically significant number of planets need to be observed in order to fully test models and understand which physical parameters are most relevant. This aim requires observations of a large sample of objects (hundreds), generally repeatedly or on long timescales, which can only be done with a dedicated instrument from space, rather than with multi-purpose telescopes, such as JWST and E-ELT.

2.3. The way forward: ARIEL

In order to fulfil the ambitious scientific program outlined in the previous section, ARIEL has been conceived as a dedicated survey mission for transit, eclipse & phase-curve spectroscopy capable of observing a large, diverse and well-defined planet sample. The transit and eclipse spectroscopy method, whereby the signal from the star and planet are differentiated using knowledge of the planetary ephemerides, allows us to measure atmospheric signals from the planet at levels of 10-50 ppm relative to the star. It is necessary to provide broad instantaneous wavelength coverage to detect as many molecular species as possible, to probe the thermal structure and cloud distribution and to correct for potential contaminating effects of the stellar photosphere due to variability and sun-spots. This can only be achieved with a stable payload and satellite platform specifically designed for this purpose.

3. Measurement and Observational Strategy and Planning

3.1. Measurement techniques

For transiting planets, we have five complementary methods to probe their atmospheric composition and thermal structure, which are described briefly in the following paragraphs. ARIEL will use them all.

1. When a planet passes in front of its host star (**transit**), the star flux is reduced by a few percent, corresponding to the planet/star projected area ratio (transit depth, Figure 3). The planetary radius can be inferred from this measurement. If atomic or molecular species are present in the exoplanet's atmosphere, the inferred radius is larger at some specific (absorption) wavelengths corresponding to the spectral signatures of these species (see [13,14,15] for details).

   The transit depth $\Delta F(\lambda)$ as a function of wavelength (λ) is given by:

   $$\Delta F(\lambda) = \frac{2\int_0^{z_{max}}(R_p + z)(1 - e^{-\tau(z,\lambda)})dz}{R_*^2} \tag{1}$$

   where z is the altitude above R_p and τ the optical depth. Eq. (1) has a unique solution provided we know R_p accurately. R_p is the radius at which the planet becomes opaque at all λ. For a terrestrial planet, R_p usually coincides with the radius at the surface. For a gaseous planet, R_p may correspond to a pressure $p_0 \sim$ 1-10 bar.

2. A direct measurement of the planet's emission/reflection can be obtained through the observation of the **planetary eclipse**, by recording the difference between the combined star+planet signal, measured just before and after the eclipse, and the stellar flux alone, measured during the eclipse, Figure 3. Observations provide measurements of the flux emitted/reflected by the planet in units of the stellar flux (see [16,17] for more details). The planet/star flux ratio is defined as:

   $$\phi(\lambda) = (R_p/R_*)^2\ F_p(\lambda)/F_*(\lambda) \tag{2}$$

3. In addition to transit and eclipse observations, monitoring the flux of the star+planet system over the orbital period (**phase curve**) allows the retrieval of information on the planet emission at different phase angles (Figure 3). Such observations can only be performed from space, as they typically span a time interval of more than a day (e.g. [18,19,20]).

The combination of these three prime observational techniques utilized by ARIEL will provide us with information from different parts of the planet atmosphere; from the terminator region via transit spectroscopy, from the day-side hemisphere via eclipse spectroscopy, and from the unilluminated night-side hemisphere using phase variations.

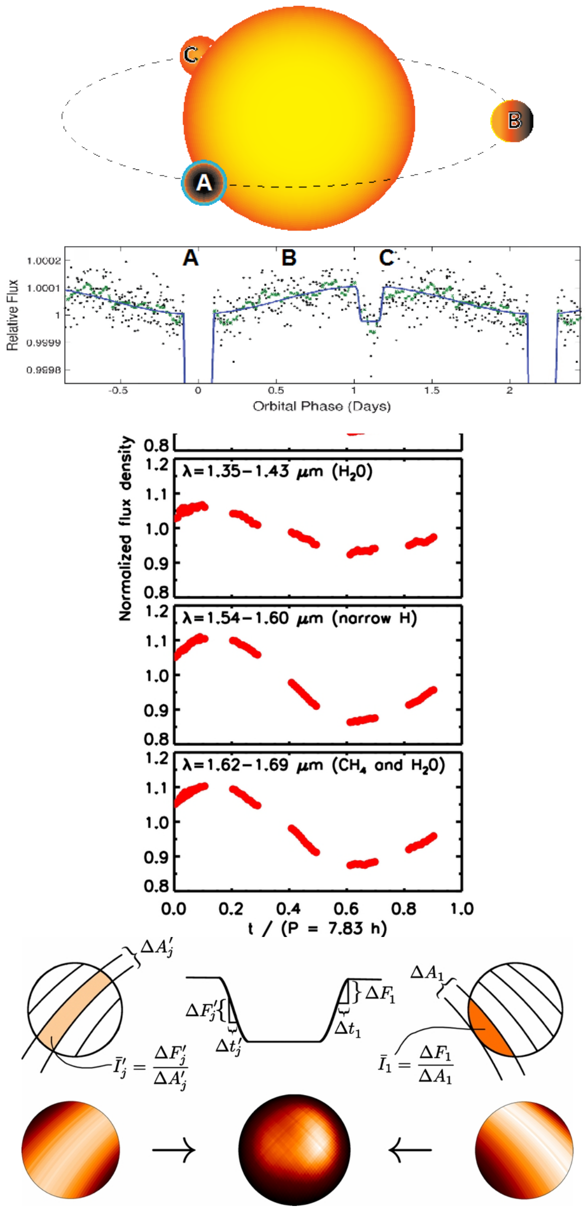

Figure 3: Methods adopted by ARIEL to probe the exoplanet composition and structure. Top: orbital lightcurve of the transiting exoplanet HAT-P-7b as observed by Kepler [19]. The transit and eclipse are visible. Centre: time series of brown-dwarf narrowband light curves observed with HST-WFC3 [21]. The spectral bands have been selected to probe specific atmospheric depths and inhomogeneities in the cloud decks. Bottom: slice mapping with ingress and egress maps as well as a combined map of HD189733b at 8 μm. These were achieved with Spitzer [22,23].

4. In addition, eclipses can be used to spatially resolve the day-side hemisphere (**eclipse mapping**). During ingress and egress, the partial occultation effectively maps the photospheric emission region

of the planet [24]. Figure 3 illustrates eclipse mapping observations (from [22,23]).

5. Finally, an important aspect of ARIEL is the repeated observations of a number of key planets in both transit and eclipse mode (time series of narrow spectral bands). This will allow the monitoring of global meteorological variations in the planetary atmospheres, and to probe cloud distribution and patchiness (see e.g. [20] for similar work on brown dwarfs, Figure 3).

3.2. Observation Strategy

The primary science objectives summarised section 2 above call for atmospheric spectra or photometric light-curves of a large and diverse sample of known exoplanets covering a wide range of masses, densities, equilibrium temperatures, orbital properties and host-stars. Other science objectives require, by contrast, the very deep knowledge of a select sub-sample of objects. 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 Table 1.

Table 1: Summary of the survey tiers and the detailed science objectives they will address.

Tier name	Observational strategy	Science case
Reconnaissance survey (~30%)	Low Spectral Resolution (R = 10 – 30) 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 (R= 30 – 300) observations of a sub-sample in the VIS-IR with SNR ~ 7	• *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*

3.3. Performance Simulation and Results

In order to simulate the performance of the ARIEL system, the ExoSim tool [25] has been used. ExoSim is a generic, numerical end-to-end simulator of transit spectroscopy intended as open-access software. It permits the simulation of a time-resolved spectroscopic observation in either primary transit or secondary eclipse. The observational parameters can be adjusted, and the telescope and instrument parameters changed in a simple manner to simulate a variety of existing or proposed instruments. ExoSim is a tool to explore a variety of signal and noise issues that occur in transit spectroscopy observations, including the effects of the instrument systematics, correlated noise sources, and stellar variability. The simulations are fast, which allows ExoSim to be used for Monte Carlo simulations of such observations. A specific instance "ARIEL-Sim" has been created with the baseline instrument parameters of the payload and spacecraft performance detailed in other parts of this paper [26].

The simulator has been validated against both existing published transit data [27,28], and the combination of simulator and ARIEL specific instrument parameters has been validated against the independent (static) Radiometric Model prepared by ESA [29]. The simulations include a representative pointing jitter timeline (supplied by the ESA industrial study teams) and all other noise sources identified in [1]. A basic data reduction pipeline (not using optimal data extraction and noise decorrelation techniques at this stage) is used to post-process the output data in the same way as the real science data will be handled.

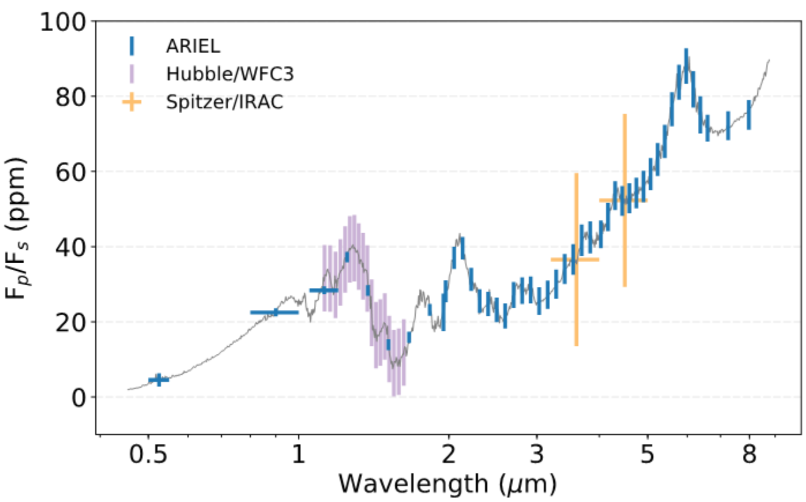

Figure 4: Expected output (with error bars) from the ARIEL processed data product compared with the input model assumption for a hot super-Earth similar to 55-Cnc-e around a G-type star with Kmag of 4. ARIEL performances using 8 eclipses (~32 hours of observation) are compared to currently available data for 55 Cnc e from Spitzer-IRAC (8 eclipses, [20]) and performances of Hubble-WFC3 extrapolated from transit observations of 55 Cnc e [30].

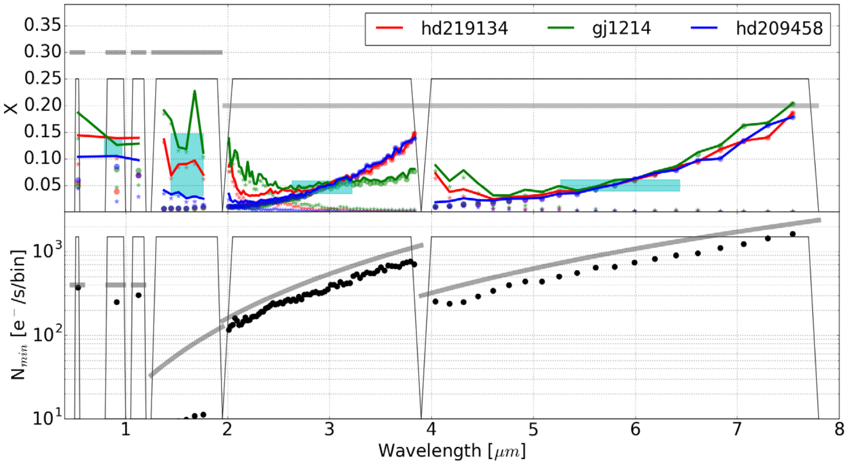

Figure 5: Noise Performance of ARIEL for the brightest, bright and faintest targets compared to noise requirements from the Mission Requirements Document. The requirements are shown by the bold grey lines, the thin grey lines denote the channels and the red, green and blue are the different targets. The noise requirements are expressed as the achieved Varience on the signal (Var(s)) must be less a factor of (1+X) above the target star signal (N0) with an absolute varience floor of Nmin. Hence the noise requirement is that $Var(s) = (1+X)N0 + Nmin$ where X and Nmin are given in the plots above for each channel. These noise requirements are shown to be equivilent to a photometric stability requirement of 10 – 100ppm for the range of target brightnesses covered by ARIEL.

4. Mission and Spacecraft Design

If selected by ESA for the Cosmic Vision M4 mission ARIEL will be launched from Kourou (FR) on board an Ariane 62 in 2026. Its nominal operations orbit is a large amplitude orbit around the Sun-Earth L2 point. This orbit provides a stable environment, along with a large instantaneous field of regard, both of which are key to allowing ARIEL to meet its science objectives. The spacecraft is designed in a modular way, with a service module (SVM) and a payload module (PLM) that can be procured and tested in parallel. A payload consortium funded by national agencies will provide the full ARIEL payload (telescope and instrument) and ESA will provide the spacecraft. An illustration of the baseline payload module and a representative SVM is shown in Figure 6.

The SVM contains all the units required to operate the spacecraft and maintain the payload in its nominal operating conditions. The spacecraft has a wet mass of ~1.2 t and a power generation capability of ~1 kW. 180 Gbit of science data will be generated every week, and are down-linked in 3 ground contacts totalling 14 hrs/week using an X-band system and the 35 m ESTRACK ground stations. The fine pointing requirements achieved by the AOCS system are (3 sigma): APE ≤ 1"; RPE ≤ 200 mas up to 90 s; PDE ≤ 100 mas up to 10 hrs for integrations of 90 s. This is achieved with a Fine Guidance Sensor (FGS, part of the payload instrument suite) and reaction wheels only as the sole actuators (accommodated on dampers, and operated within a narrow angular speed range to minimise any micro-vibrations and avoid exciting structural modes of the S/C).

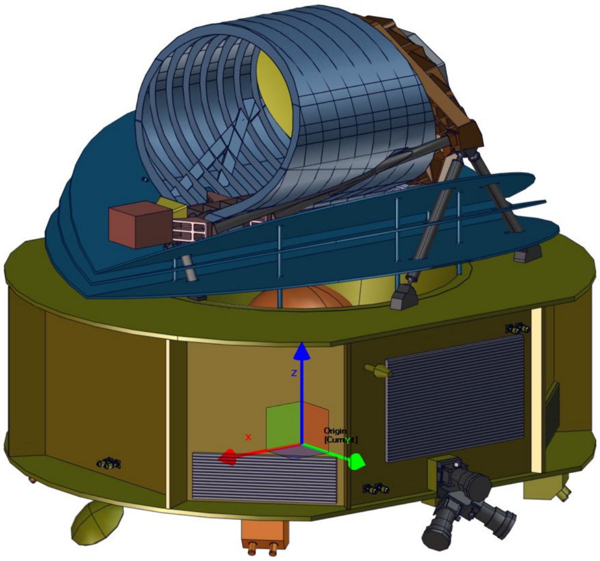

Figure 6: Illustration of ARIEL S/C concept design

5. Payload Design

The payload for ARIEL consists of a 1m-class telescope feeding three low and medium resolution spectrometer channels covering the wavelengths from 1.25 to 7.8 microns, and three photometric channels (two of which also acts as a Fine Guidance Sensor) with bands between 0.5 and 1.2 microns. The entire payload is provided by a consortium of European countries as an integrated and verified unit in order to maximise the stability and optimise the performance of the system.

The baseline architecture for the ARIEL payload is illustrated in Figure 4-1 below. This diagram also shows the nationalities of the members of the payload consortium who are currently taking responsibility for each element.

The baseline architecture splits the payload into two major sections, the cold payload module (PLM) and the items of the payload that mount within the spacecraft service module (SVM). The major items are:

- Cold PLM:
  - Telescope system, incorporating M1, M2 & M3 mirrors, a re-focusing mechanism on the M2 mirror (M2M), the telescope structure and baffles.
  - An optical bench / metering structure onto which the telescope and instruments are mounted.
  - A set of common optics including fold mirrors, dichroics, formatting optics, and a common calibration source.
  - The ARIEL IR Spectrometer (AIRS) instrument.
  - The Fine Guidance Sensor / Visible Photometer / Near-IR Spectrometer (FGS / VISPhot / NIRSpec) instrument.
  - Thermal hardware including: active cooler coldhead, passive radiator for cooling of FGS detectors and all cFEE & the V-grooves and support structure to isolate the PLM from the warmer SVM.
- Warm SVM mounted units:
  - Instrument Control Unit (ICU) housing the AIRS detector control unit (DCU), the central data processing unit (DPU), a power supply unit (PSU) and the telescope control unit (TCU).
  - FGS Control Unit (FCU) electronics incorporating the FGS / VISPhot / NIRSpec wFEE and the processing electronics and SW for determining the pointing from the FGS data.
  - Active cooler system consisting of the Cooler Drive Electronics (CDE), the Cooler Compressors and the Cooler gas handling panel.
- The cryoharnesses that connect the warm SVM units to the PLM with good electrical properties and low thermal conductance.

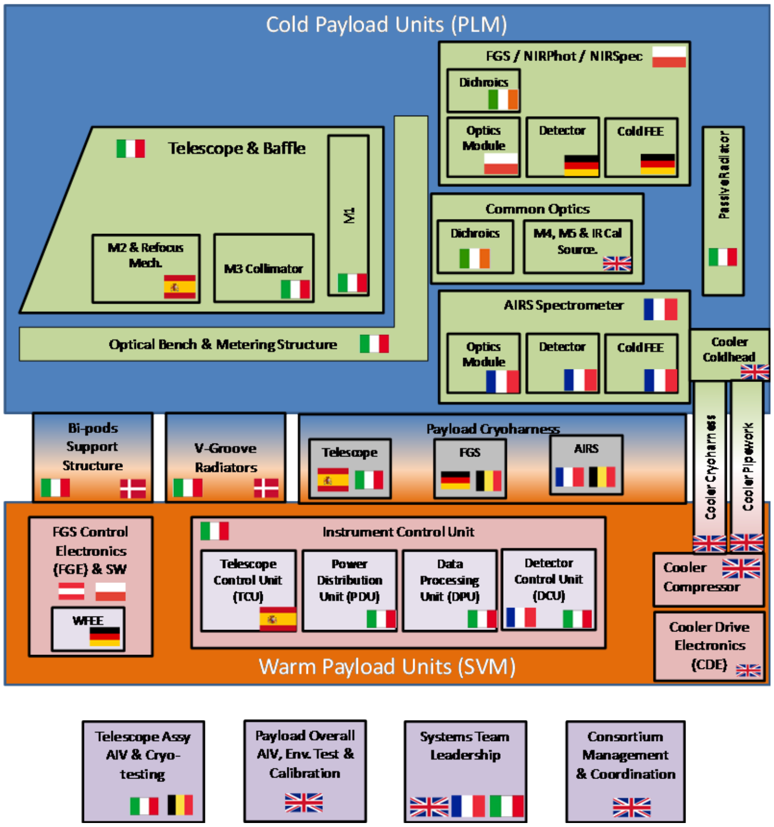

Figure 7: ARIEL Payload architecture and responsibilities

Extensive details of the design of the ARIEL payload are contained in [1] and [31]. Participation and contributions from other interested parties may be incorporated into the payload module by the consortium if the mission is selected. We also note that NASA has recently selected a contribution to ARIEL as a Mission of Opportunity [32] so that if selected then the consortium will integrate this contribution into the management plan in phase B1.

6. Ground Segment and Data Policy

Responsibility for, and provision of, the ARIEL ground segment is split between ESA and a payload consortium provided, nationally-funded, Instrument Operations and Science Data Centre (IOSDC). The ground segment and operations infrastructure for the Mission Operations Centre (MOC) will be set up at the European Space Operations Centre (ESOC) in Darmstadt, and the ARIEL Science Operations Centre (SOC) set up at the European Space Astronomy Centre (ESAC) near Madrid, which will also host the ARIEL archive comprising mission data base and science data archive. Lower-level data products will be produced at the SOC using processing pipelines based on algorithms and software models that will be developed by the IOSDC, and delivered to the SOC. Final exoplanet spectra will be produced using state-of-the-art tools developed at the IOSDC, and delivered to the SOC for ingestion into the ARIEL science data archive. The pipeline, as well as scripts with critical parameters used to generate the final exoplanet spectra, will be clearly and thoroughly documented and available to users to enable reprocessing of data taken with ARIEL. Long-term mission planning, which will include scheduling of the time-critical observations of ARIEL target transits, will be a joint MOC-SOC-IOSDC activity with scientific guidance provided by the ARIEL Science Team.

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 other mechanisms), 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 months worth of data observed in the same manner that the core survey will be conducted. These data sets will verify readiness to conduct routine science operation and will be made public on a timescale of about a month, in conjunction with organisation of a major public workshop.

Regular timely public releases of high quality data products at various processing levels will be provided throughout the mission. The data will be pipeline processed to different levels of data products labelled ‘raw telemetry’ (level 0), ‘raw spectral frame cubes’ (level 1), ‘target (star + planet) spectra’ (level 2), and ‘individual planet spectra’ (level 3), respectively. The lower levels can generally be released quicker than higher levels, but the objective is to release all levels timely in order to maximise the science return and impact of ARIEL.

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, school students and members of the public will have the opportunity to participate directly in the analysis of ARIEL data.

7. Project Schedule

The key dates for the ARIEL project top level schedule are shown in Table 2 below. The required launch date for the ESA M4 launch slot is in 2026. With the kick-off of the Implementation Phase in 2019, this leaves ~7 years for the complete development, manufacturing, assembly, integration, testing and launch campaign.

Table 2: Current key schedule dates for ARIEL M4 Mission

Milestone	**Schedule**
Mission Adoption Review	Q2 2019
Phase B2/C/D Kick-off	Q3 2019
System Reqts Review	Q4 2019
Preliminary Design Review	Q3 2020
Critical Design Review	Q2 2022
Flight Acceptance Review	Q3 2025
Launch (L)	2026
LEOP	L + few hours
Start of S/C & PLM Commissioning	L + few days
Start of nominal operation phase	L + < 6 months
End of nominal operation phase	L + 4 years

The critical path contains the manufacturing, testing and assembly of the telescope, followed by the pFM AIV for the PLM, the FM AIV of the complete spacecraft, and finally the launch campaign. The payload FM will be delivered to the spacecraft in Q3 2024.

8. Conclusions

Planetary science stands at the threshold of a revolution in our understanding of our place in the Universe: just how special are the Earth and our Solar System, and why? It is only by undertaking a comprehensive spectral survey of exoplanets, in a wide variety of environments, that we will answer these fundamental questions. ARIEL represents a once in a generation opportunity to make a major impact on the knowledge of our place in the Cosmos – we intend to seize it.

Acknowledgements

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