

Operations Development on ESA's Plato and Ariel Exoplanet Missions

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Abstract

This paper details the combined and innovative operations development activities in preparing to launch ESA's two future Exoplanet missions, Plato and Ariel.

Both missions will be operated by ESA's space operations centre, ESOC in Darmstadt, Germany and will be launched on Ariane 6, with Plato due for launch in 2026 and Ariel in 2029. The management of the mission operations of the two missions is under the combined responsibility of a single unit in the Astronomy and Fundamental physics division at ESOC. Synergies between the missions exist and will be exploited in implementing the ground segment and flight operations teams to execute the operations. Mission differences also exist and must be managed, for example in the surveying operations concept. Plato carries the largest and most complex space based optical focal plane assembly, which it will aim at wide areas of sky for extended periods of time; whilst Ariel will be surveying a list of known single exoplanet targets, adjusting its pointing around 2-3 times per day.

Plato has adopted Model Based Systems Engineering practices for the ground segment design, the first mission at ESOC to do so and is the operational target mission for the ongoing studies managed by ESOC's ground segment development department. Plato will also be the first science mission to use ESA's new mission control system, EGOS-CC. The ground segment of Plato will be reused for Ariel and is also heavily based on that of Euclid. Euclid is the next mission due for launch in the division's operational mandate, and the first to develop functionality such as the CCSDS CFDP file transfer. Both Plato and Ariel are missions based on ECSS PUS-C and Ariel is the first Astronomy mission to be based on the Generic OIRD produced by ESOC. Such re-use, innovation and standardization are a core part of the ground segment and mission operations design of these Exoplanet missions.

Keywords: ESOC, Operations, Ariel, Plato, Exoplanets

Acronyms/Abbreviations

A-DCU	AIRS Detector Control Unit
AIRS	Ariel Infra-Red Spectrometer
AMC	Ariel Management Consortium
AOCS	Attitude and Orbit Control Subsystem
ARIEL	Atmospheric Remote-sensing Infrared Exoplanet Large-survey
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
DPU	Digital Processing Unit
ECSS	European Cooperation for Space Standardisation
EGOS-CC	European Ground Operations Systems – Common Core
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
FCU	FGS Control Unit
FDIR	Failure Detection Isolation and Recovery
FGS	Fine Guidance Sensor
GOIRD	Generic Operations Interface Requirements Document
GOP	Ground-based Observation Programme
GSEF	Ground Segment Engineering Framework
ICU	Instrument Control Unit
L2	Sun-Earth second Lagrange point
LEOP	Launch and Early Orbit Phase
LGA	Low Gain Antenna
MBSE	Model Based System Engineering

MCS	Mission Control System
MOC	Mission Operations Centre
OBC	On-Board Computer
OBCM	On-Board Computer and Mass memory
OHB	Otto Hydraulic Bremen
OIRD	Operations Interface Requirements Document
PCDU	Power Conditioning and Distribution Unit
PLATO	PLANetary Transits and Oscillations of stars
PMC	PLATO Management Consortium
PUS-C	Packet Utilisation Standard (ECSS 41C)
SAVOIR	Space AVionics Open Interface aRchitecture
SCOS-2000	Satellite Control and Operation System 2000
SGS	Science Ground Segment
SOC	Science Operations Centre
SSMM	Solid State Mass Memory
TCU	Telescope Control Unit
TAS-F	Thales Alenia Space, France

1. Introduction

The Plato^[1] and Ariel^[2] missions are part of ESA’s Cosmic Vision 2015-25 plan, implemented by the directorate of science as a framework for the scientific missions’ program. Plato is the third medium (M-class) mission (selected in 2014) and Ariel is the fourth (selected in 2018). For both missions the scientific objectives are focussed on the study of Exoplanets and the mission operations will be performed from ESOC in Darmstadt Germany. Traditionally the mission operations of such missions are managed in distinct units with a standard organisational structure, principally due to the ‘bespoke’ nature of science missions. After an analysis of the mission characteristics and operations concepts of Plato and Ariel, the missions were considered sufficiently similar that a different approach could be adopted, and it was decided to merge the management of both missions into a single flight operations unit. This is a first within ESOC for scientific missions in this stage of development and the intention is to keep the management merged for the full mission life-cycles in order to better exploit the synergies, whilst also being mindful of the differences.

2. Plato Mission Overview

2.1. Scientific Objectives

PLATO aims at finding and characterising a large number of extra solar planetary systems, with emphasis on the properties of the terrestrial planets in the habitable zone around bright solar-like stars. PLATO also aims at investigating seismic activity in stars, enabling the precise characterisation of the planets’ host star, including its age. PLATO will determine, with unprecedented accuracy, the planet radii, stellar irradiation, architecture of planetary systems and evolutionary ages/stages. In combination with ground-based observations, and thanks to the brightness of its targets, PLATO will provide accurate planetary masses and mean densities. Moreover, PLATO’s asteroseismology observations of a large number of different types of stars will significantly contribute to the advancement of stellar interior and evolution models. PLATO will also carry out an extensive complementary science programme that will address a broad range of astronomy topics.

In order to achieve its science objectives, PLATO relies on high-precision photometry to produce a large sample of accurate stellar light curves, obtained over time intervals of months to several years, with a high duty cycle. The planet transit signal and the parent star oscillations are both derived from analysis of the light curve, enabling the detection of transiting planets, the determination of their radii and orbital parameters, and the characterisation of their hosting star.

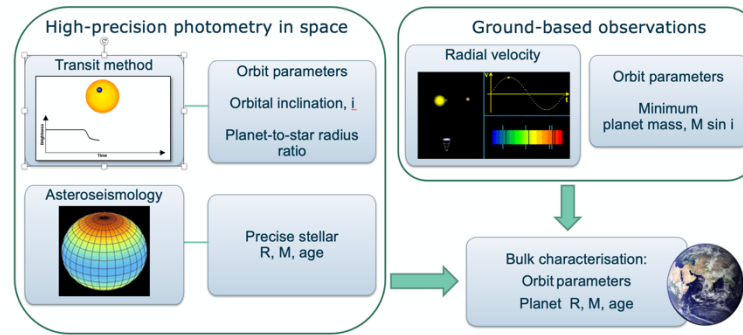


Figure 1 Plato Measurement Principle

To make its observations, Plato will use 26 cameras simultaneously, which will enable a combined higher ‘signal-to-noise’ ratio and larger field of view than has been possible with previous missions.

2.2. Plato Spacecraft

Plato will have a launch mass of about 2300 kg and a size of 3.5 x 3.1 x 3.7 metres when stowed during launch. Once its sun shield and solar panels are deployed, it will have a wingspan of around nine metres and the total surface area of its solar panels will be over 30 square metres. It will be launched on a dedicated Ariane 6 from ESA’s spaceport in Kourou, French Guiana.

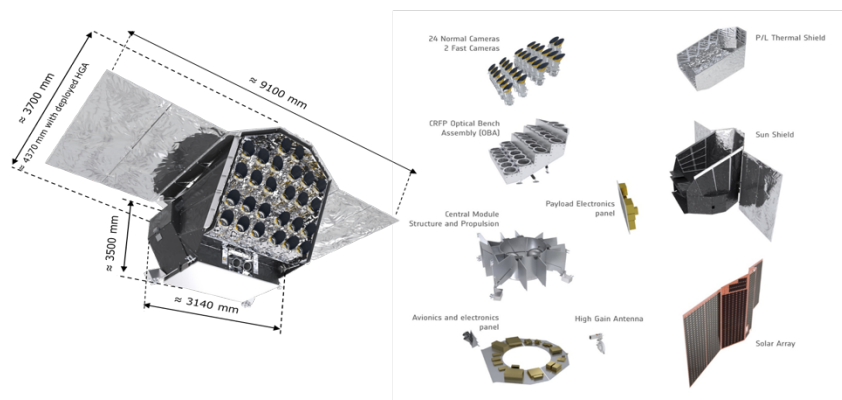


Figure 2 the Plato Spacecraft

The Plato Spacecraft comprises two main elements: the platform and the payload. These two modules are thermally isolated from one another with the Platform sitting at the 'bottom' of the spacecraft.

2.2.1. Platform

The platform contains all the subsystems necessary to operate the spacecraft, including a sunshield, the propulsion system, communication system, thermal control system, attitude control system, and control and data management system. The industrial Prime Contractor (OHB GmbH), together with the Core Team partners (Beyond Gravity and TAS-F), is in charge of developing the spacecraft platform, supporting the payload functions and performances, and of the delivery of the fully tested and integrated spacecraft (including payload) to ESA.

Communications are provided in two bands, x-band (for spacecraft operations) and k-band (for scientific data download). Two fixed Low Gain Antennas (LGAs) are used for commanding and engineering telemetry return. A steerable High Gain Antenna is used for scientific data return through k-band, with a co-located (and steered) x-band Medium Gain Antenna nominally used for commanding and engineering telemetry downlink. Uplink data rates of 2-16 kbps and downlink of 2-26 kbps are possible through the x-band subsystem with the k-band subsystem supporting 16-74 Mbps.

The spacecraft is 3-axis stabilised with an Attitude and Orbit Control Subsystem (AOCS) which uses Reaction Wheels and a monopropellant blow down propulsion system as actuators. It contains two thruster branches (for redundancy) with each branch consisting of 8 attitude control thrusters and 2 orbit control thrusters. Four Reaction Wheels are used in a configuration allowing a single reaction wheel loss. The AOCS uses high precision gyros and coarse rate sensors to deliver independent rate information into the AOCS. Attitude measurements are provided by two Star Trackers and six sun presence sensors, with an attitude anomaly detector also included for Failure Detection Isolation and Recovery (FDIR) purposes. When performing science measurements, the AOCS is additionally provided with attitude information from two of the payload cameras, that operate also as Fine Guidance Sensors (FGS).

Solar panels are mounted on the sunshield that provide around 3kW of electrical power through a maximum power point tracker and auxiliary power regulators. A battery is included for the ascent phase of the mission, with the power subsystem being managed by a Power Control and Distribution Unit (PCDU). Thermal control is provided by a mixture of passive and active methods, the latter being activation of heaters to maintain the units within their intended operational temperature ranges.

The Platform includes a combined Mass Memory Module and On-board Computer (OBCM). The OBC uses a LEON-2-FT SPARC v8 processor module with a local Mass Memory of 192 Gbits and an extended Mass Memory Module of 2.2 Tbit capacity, which is used for storing the science data. A Remote Terminal Unit is included to interface to several platform units and two data bus types are included for data exchange throughout the spacecraft, with a redundant 1553 bus used mainly within the platform and 6 redundant spacewire buses to provide data connection between the platform and payload and within the payload module.

2.2.2. Payload

The scientific payload of PLATO is developed and provided in collaboration between ESA and a European scientific consortium (the PLATO Mission Consortium - PMC). It consists of 26 Cameras, two of which operate at higher cadence (2.5s) and are used additionally as Fine Guidance Sensor (FGS), providing attitude information to the AOCS in the platform. The 24 Normal Cameras are used exclusively for science observations and operate at a cadence of 25s. All cameras have the same optical design and contain four CCDs each totalling 81.4 M pixels per camera (or 2 billion pixels across the payload, the highest of any scientific space mission). The cameras are grouped into four subsets consisting of 6 cameras each, with a combined field of view of 2250 deg² (see [Figure 3](#)). The FGS cameras (known as Fast Cameras) are also used for the observation of very bright stars and contain spectral filters (blue/red) to provide colour information for stellar analysis.

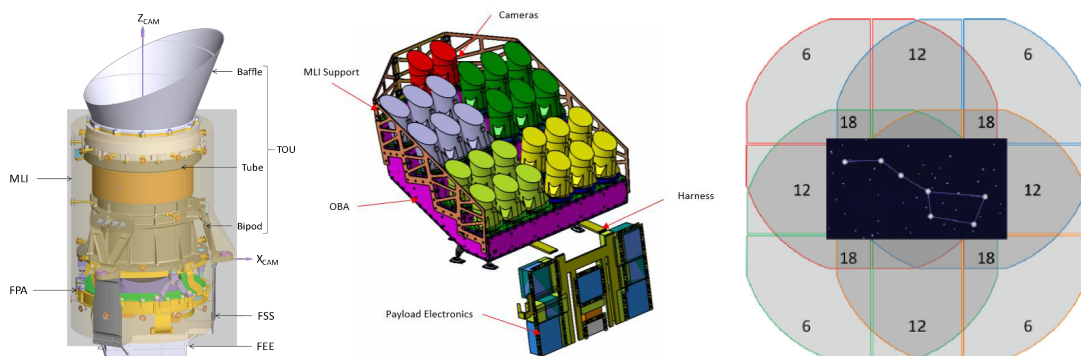


Figure 3 A Plato Camera, the Payload Configuration and Combined Field of View

The payload contains 14 Digital Processing Units (DPUs) that perform the basic photometric task and light intensity samples, centroid curves and imaggettes captured by the cameras. There is one DPU shared between two normal cameras with the fast cameras having a DPU each. In charge of managing the payload module at higher level is the redundant Instrument Control Unit, which also implements data compression and acts as the main data interface between the Payload and Platform modules. The ICUs and the DPUs use LEON-3FT¹ processor modules and transfer of data around the payload module is performed by spacewire data busses.

¹ The DPUs of the F-CAMs (that have a dedicated DPU per camera) use LEON-FT2s.

Figure 5 Plato Observation Strategy

3. Ariel Mission Overview

3.1. Scientific Objectives

Ariel will observe about 1000 exoplanets, ranging from rocky planets to gas giants. The mission will study the nature of these exoplanets, both as individuals and as populations. It will also monitor the activity of their host stars.

In studying this diverse sample of exoplanets, Ariel will provide direct independent measurements of the bulk chemical composition and thermal structures, covering a wide range of masses, densities, equilibrium temperatures, orbital properties and host-star characteristics. It will be able to detect signs of well-known ingredients in the planets' atmospheres, including water vapour, carbon dioxide and methane and it will also be able to detect exotic metallic compounds to decipher the overall chemical environment of the distant star system. For a few planets, Ariel will study their clouds and monitor variations in their atmospheres on both daily and seasonal timescales.

The mission will address the following fundamental questions:

- What are the physical processes shaping planetary atmospheres?
- What are exoplanets made of?
- How do planets and planetary systems form and evolve?

Ariel observations will simultaneously cover the entire 0.5-7.8 μm spectral range using a combination of photometry and spectroscopy. The simultaneous coverage of this wide spectral range is key to attaining Ariel's science goals, securing robust relative calibrations and enabling very small signals to be extracted from differences between measurements in different wavebands.

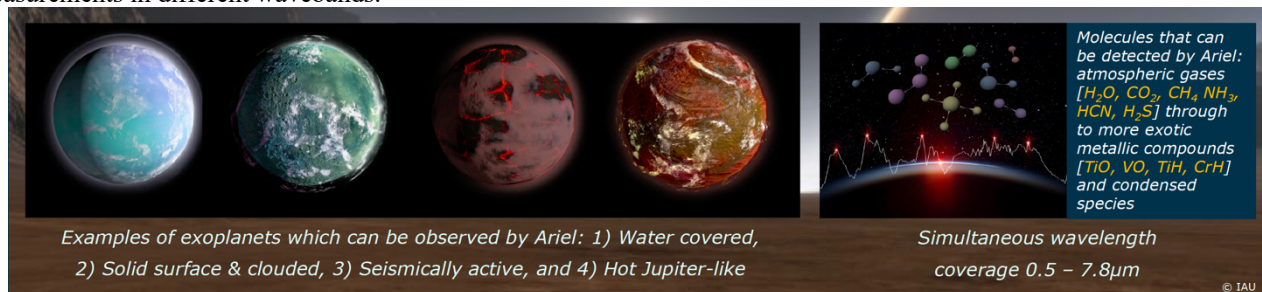


Figure 6 Examples of Exoplanets and atmospheric molecule detection

In studying the solar system characteristics of other stars, Ariel's observations will also contribute to our understanding of our own Solar System. The observations will lay the groundwork for future searches for life elsewhere in the Universe and planets similar to Earth.

3.2. Ariel Spacecraft

The Ariel spacecraft is comprised of two distinct modules: the Platform (or Service Module) and the Payload Module. These two modules are thermally isolated from one another with the Platform sitting at the 'bottom' of the spacecraft. Three V-Grooves, composed of an Aluminium-skin/Aluminium-honeycomb sandwich, and three pairs of low conductivity Glass Fibre Reinforced Plastic bipod struts sit on top of the Platform to support the Payload (including the optical bench, the telescope and the instruments). This thermal shield assembly allows the complete payload module to be passively cooled to ~55K (optical bench, telescope and instruments). In addition, a Neon Joule-Thomson cooler allows the AIRS instrument long wavelength channel to be cooled to ~42K.

Ariel will have a launch mass of about 1400 kg and a size of 3.3 x 2.7 x 2.8 metres, with no deployable appendages needing to be stowed for launch. It will be launched on an Ariane 6 from ESA's spaceport in Kourou, French Guiana, with Comet Interceptor as co-passenger.

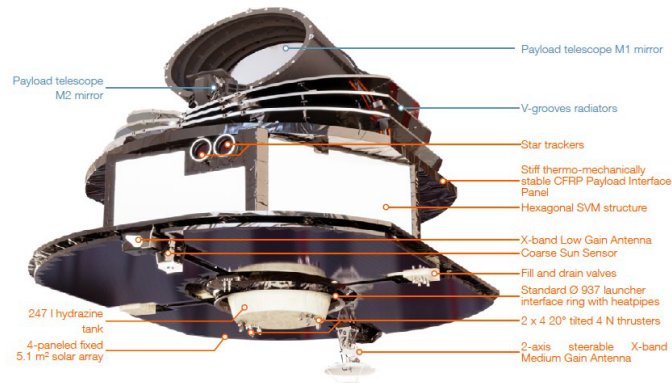


Figure 7 The Ariel Spacecraft

3.2.1. Platform

The platform contains all the subsystems necessary to operate the spacecraft, including a sunshield, propulsion system, communication system, thermal control system, attitude control system, and control and data management system. The industrial Prime Contractor (Airbus Defence and Space) is in charge of developing the spacecraft platform, supporting the payload functions and performances, and of the delivery of the fully tested and integrated spacecraft (including payload) to ESA. The scientific payload of Ariel is developed and provided in collaboration between ESA and a European scientific consortium (the Ariel Mission Consortium - AMC).

Communications are provided in a single band (x-band) which is used both for scientific data download and engineering telemetry. Two fixed Low Gain Antennas (LGAs) are used for commanding and engineering telemetry return. A steerable Medium Gain Antenna is nominally used for scientific data return and engineering telemetry downlink. Uplink data rates of 2-16 kbps, and downlink of 2-26 kbps and 5.4 Mbps, are possible through the x-band subsystem.

The spacecraft is 3-axis stabilised by the Attitude and Orbit Control Subsystem (AOCS) that uses Reaction Wheels and a monopropellant blow down propulsion system as actuators. It contains two thruster branches (for redundancy) with each branch consisting of 5 thrusters used for both attitude and orbit control. Four Reaction Wheels are used in a configuration allowing a single reaction wheel loss. The AOCS uses 3-axis gyros to deliver rate information into the AOCS. Attitude measurements are provided by two Star Trackers and coarse sun sensors, with an accelerometer also included for orbit control purposes. When performing science measurements, the AOCS is additionally provided with attitude information from the payload, which also includes Fine Guidance Sensors (FGS).

Solar panels are mounted on the sunshield that provide around 1kW of electrical power through a sequential shunt regulator. A battery is included for the ascent phase of the mission, with the power subsystem being managed by a Power Control and Distribution Unit (PCDU). Thermal control is provided by a mixture of passive and active methods, the latter being activation of heaters to maintain the units within their intended operational temperature ranges, and in the payload module active cooling is used.

The Platform includes an On-board Computer (OBC), with integrated mass memory sized to also store the payload data. The OBC will use a LEON-2-FT SPARC v8 processor module with a local Mass Memory of 92 GB. A Remote Terminal Unit is included to interface to several platform units and two data bus types are included for data exchange throughout the spacecraft, with a redundant 1553 bus used mainly within the platform and redundant spacewire buses to provide data connection between the platform and payload and within the payload module.

3.2.2. Payload

The Ariel payload consists of an integrated suite comprising the telescope assembly, the Ariel infrared spectrometer (AIRS), and the Fine Guidance System (FGS)/photometer module, along with the necessary supporting hardware and services. The telescope assembly consists of an off-axis Cassegrain telescope (with a primary mirror of approximately 1.1 m × 0.7 m) with a third beam collimating mirror, passively cooled to a temperature of approximately 55K.

Fed by the telescope assembly, AIRS is a broad-band, medium-resolution near-infrared spectrometer operating between 1.95 μm and 7.8 μm . The spectrometer is a single module incorporating two dual Offner channels covering the 1.95–3.9 μm and 3.9–7.8 μm wavelength bands and provides a resolving power of R~30–200 across its spectral range. The operating temperature for the detectors is below 42 K, AIRS is mounted on the optical bench alongside the FGS and telescope interface.

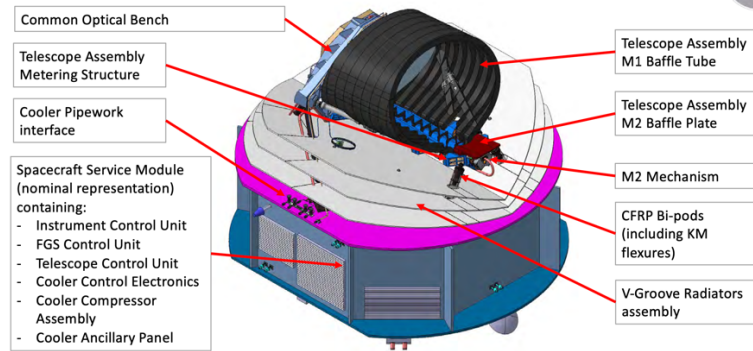


Figure 8 The Ariel Payload Module Architecture

The FGS module provides three narrow-band visible to near-infrared photometer channels (two used as guidance sensors as well as for science) and a low-resolution near-infrared spectrometer. This is the science instrument of the Ariel Payload providing photometry and spectrometry of the observed targets over visible to near IR wavebands in four bands:

- VisPhot: 0.5 – 0.6 μm (Photometer)
- FGS-1: 0.6 – 0.8 μm (Photometer)
- FGS-2: 0.8 – 1.1 μm (Photometer)
- NIRSpec: 1.1 – 1.95 μm (Spectrometer $R \geq 15$)

It also provides centroiding information on the target star, which is fed into the AOCS of the Platform.

Communication between the Platform and Payload units is via spacewire data busses to two intelligent units of the payload module, the Instrument Control Unit (ICU) and FGS Control Unit (FCU). The ICU then in turn communicates to the Telescope Control Unit (TCU) and AIRS Detector Control Unit (A-DCU) and is responsible for compressing and forwarding to the Platform the A-DCU science data. The TCU provides control and thermal sensing of the telescope.

3.2.3. Mission Phases

Ariel will be launched from the Guiana Space Centre, Kourou, with Ariane 6.2 into a direct transfer to a large orbit around the second Lagrangian Point (L2) of the Sun-Earth system, together with Comet Interceptor as a co-passenger. After a transfer phase and the commissioning activities lasting overall 3 months, performance verification will commence lasting up to launch plus 6 months. Thereafter, nominal scientific operations will commence that will last 3.5 years, with the possibility of an extension for an 2 additional years. The initial Launch and Early Orbit Phase (LEOP) is sized at 48 hours. It includes the initial critical operations from launch vehicle separation and ends with a trajectory correction manoeuvre to ensure the optimal transfer trajectory to L2 (with no L2 insertion manoeuvre required).

3.2.4. Ground Segment and Operations Concept

The mission and science operations will be carried out by ESA at a Mission Operations Centre located at ESOC and a Science Operations Centre located at ESAC. The AMC will contribute to the science ground segment in the areas of instrument calibration and operations, data processing, and scientific expertise.

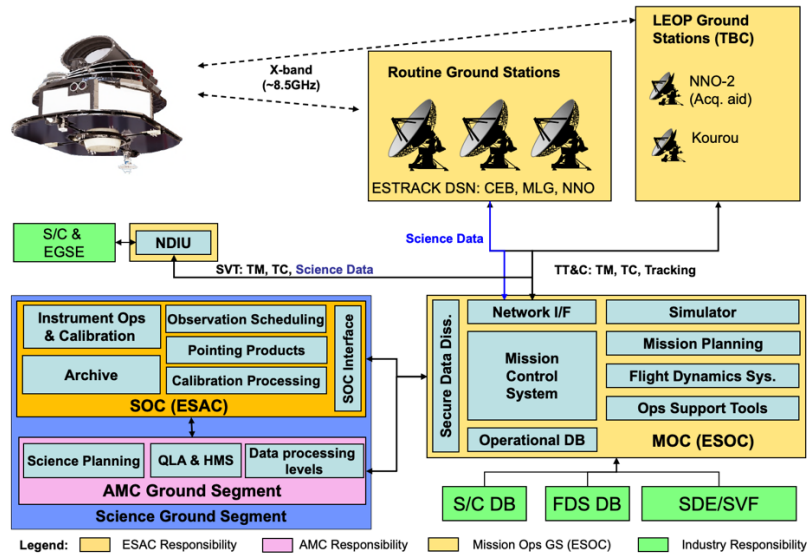


Figure 9 The Ariel Ground Segment

The duration of the ground station passes is driven primarily by the volume of data to be downlinked, which is dimensioned at 236 Gbits per week. This data is planned to be downlinked in three ground station passes spread through the week totalling 15 hours duration. Routine operations during nominal passes will be automated.

Ariel will observe known exoplanets and will therefore be planned to point at specific targets during the expected time of the planetary transit. These will have various durations depending upon the planetary system being observed, but average observing time is expected to be 7.7 hours.

4. Ground Segment and Mission Operations Harmonisation

The previous sections describe the Plato and Ariel missions, from which it is apparent that there are significant similarities but also a number of differences. In this section these will be further explored with an emphasis upon their impact on the ground segment and mission operations.

4.1. Importance of standardisation and automation

Within ESOC the Flight Control Teams are tasked with developing the ground segment and performing the in-flight spacecraft operations throughout the full mission life cycle. In most previous cases these teams have been dedicated to a particular mission. This has been the optimum solution based on the nature of the missions entrusted to ESOC to fly, which are often complex and bespoke in nature.

Over recent years a general trend to increase harmonisation and standardisation has continued to be applied to ESA mission design. Applying this principle where possible allows greater re-use and efficiencies in the space segment and ground segments of the missions and has assisted in a parallel trend, which is an increase in the number of space missions being developed and operated. Together with increased autonomy and automation^{[3][4]} in both the space and ground segments, this increased standardisation has allowed other organisational structures in mission operations to be applied. When appropriate, Flight Control Teams responsible for more than one mission may be better placed to exploit synergies and increase overall efficiencies. This model has been successfully applied in other space mission family types, such as Earth Observation, where the mission volume and similarity have allowed the most synergies in the space and ground segments within ESOC.

Scientific spacecraft and mission design is driven at the top level by the scientific objectives of the missions. These are usually (and often by definition) novel, which means they are generally pushing the boundaries of what is technologically possible in some areas. This typically results in highly bespoke payload modules, which in turn can also place some demanding requirements on the Platforms that must provide a suitable environment for the payload to operate in. This more bespoke and complex nature of scientific missions means that dedicated teams are usually the most suitable approach, but with increased autonomy and standardisation some science missions may also be suitable for a combined team approach. To decide on the best approach an early analysis of the mission characteristics is appropriate.

4.2. Ground Segment and Operations Similarities and Differences in the Plato and Ariel Missions

Before expanding on the specifics of the Plato and Ariel missions it is useful to elaborate on some of the general concepts introduced in the previous section.

The interfaces between the space and ground segment are key drivers in the ground segment design. CCSDS^[5] and ECSS^[6] standards are used extensively in ESA missions, limiting mission specific changes to ground segment elements that are re-used or shared between missions. In some areas these standards are ‘tight’ and in others they can be ‘looser’ thereby allowing various options to be used. The extent of interface standardisation has increased in recent years for ESOC missions in the generation and application of the Generic Operations Interface Document (GOIRD)^[7]. The GOIRD is a tailoring mainly of the ECSS 11C^[9] (Operability) and 41C^[8] (Packet Utilisation Standard)² and contains requirements applied to the space segment in the area of mission operations. Of the many requirements contained in this document a very high fraction (circa 97%) are standard to all ESOC missions, with a small percentage reserved for mission family types (Earth Observation, Interplanetary and Astronomy mission families). The Telecommand and Telemetry Service harmonisation has strong benefits in the ease of ground systems re-use, particularly of the Mission Control System. This, together with the functional operability requirements, means that operator staff training and sharing is also greatly facilitated. On top of developing the ground segment systems, and performing the in-flight operations, members of the Flight Control Teams must obtain a deep understanding of the spacecraft modes, functions and subsystems. This is necessary to be able to maintain and develop flight control procedures of all types (e.g. manually executed, automated in ground systems or on-board in OBCPs). In addition the team has to be able to perform planned critical operations, to understand and respond to anomalies and to perform contingency recoveries. The closer alignment of functional requirements in the GOIRD and ECSS 11C help in this regard, as does the related ESA avionics standardisation activities such as SAVOIR.

The nature of the missions flown by ESA means that significant differences will always exist and it is important to understand the nature of the differences and how they impact the ground segment and mission operations. It is useful to look at some broad categories:

Mission Objectives

Plato and Ariel are both exoplanet science missions. Whilst the scientific objectives of a mission are not a direct part of the core tasks of the mission operations teams, it is nevertheless very useful to understand the mission rationale, as this leads to a more intuitive understanding of the design choices and operational priorities. Both Plato and Ariel are driven by exoplanet transit detection and analysis, making many their top-level drivers very similar. This in turn flows down into the spacecraft architecture and subsystems and further into the ground segment and operations concept.

A key difference between the missions, is that Plato is *detecting* exoplanets, and Ariel is analysing *known* exoplanets. This means Plato deploys a very large field of view to simultaneously observe a large number of targets, whilst inertially pointed at the same part of the sky for long periods of time. In the first years of the mission Plato will be rotated around the payload line of sight at quarterly intervals, to maintain the sun aspect angle within allowed ranges. In looking at a large volume of sky and objects without knowing when the interesting events will take place, also contributes to a *higher data volume* and relatively *high availability rates*.

Ariel’s operations concept has the fundamental difference of *frequent ‘point and shoot’ type operations* that must be planned at known targets in specific time windows. This means the spacecraft is frequently re-pointed (average transit observation time of 7.7 hrs), which involves planning in advance the targets through the ground segment mission planning system and further commanding to the spacecraft. This contributes to the significantly *lower data volume* to be downlinked, which means the *communications and data storage subsystems of the two missions differ*. Plato has a dual x/k band communications subsystem and a large dedicated SSMM whereas Ariel uses a single x-band communications subsystem with a smaller, local integrated mass memory.

Orbital Location

The second Sun-Earth Lagrange point has been for some years the preferred location of many optical or near optical Astronomy missions, such as Gaia, Herschel, Planck and James Webb. This location is chosen since it offers a thermally stable environment, with the main objects that optical Astronomy missions want to avoid (the Sun, Moon and Earth) all in the same area of the sky. Plato and Ariel are no different and therefore will also be operated at L2. This *similar orbital location* means the launcher injection, initial critical operations phase (LEOP), transfer operations (including correction manoeuvres) and routine orbit maintenance activities, are all very similar. Also, the link budget, on-board communications (except for the data volume driven dual band on Plato) and ground antenna infrastructure

² In fact, the experience of the ESA missions harmonized GOIRD is now being fed back into the applicable ECSS standards.

are similar or the same. This *means large scale re-use of the flight dynamics and ground station subsystems and infrastructure is possible*. Operating from the same location also allows the same team to optimise and de-conflict ground station passes, since both missions will be in similar sky locations as seen from the ground stations.

Interfaces

As mentioned in the more general introduction to this section there has been increased standardisation the Telemetry and Telecommand interface with the introduction of the GOIRD, though this activity was completed after Plato development start. Nevertheless, *both missions are applying the PUS-C (ECSS 41C) standard*. Since the tailoring of this PUS-C is further standardised by the GOIRD and this is applied to all future ESOC missions the spacecraft primes across Europe are already taking this into account such that Plato and Ariel are very close in PUS and are also applying similar file-based operations concepts.

Detailed Spacecraft Interfaces

The detailed spacecraft design still differs in areas driven by the mission objectives (most prominently in the payload modules, but also in the platforms) and also in areas where different spacecraft primes take different approaches to similar problems (either for technological or programmatic reasons). Different approaches may also be taken in the interest of progress and innovation. Since an important part of the mission operations task is acquiring and maintaining an expert knowledge in the spacecraft design, this is an area that implies a higher-level mission dedicated support (for example, payload operations subsystem engineers would require more dedicated mission expertise).

Ground Segment

A cursory look at [Figure 4](#) and [Figure 9](#) of the ground segment architecture show that the MOC part is very similar between Plato and Ariel (and with previous Astronomy missions such as Euclid and Gaia). The Plato MOC follows closely the Euclid MOC (which is the first to implement the CCSDS CFDP file transfer protocol) with the important difference of the Mission Control System, which is planned to be based on EGOS-CC, rather than SCOS-2000.

4.3. Use of EGOS-CC

Plato is planned to be the first science mission to launch using the new mission control system infrastructure being applied for ESOC missions, called EGOS-CC. This is an example of where change is applied in the interest of progress and innovation (within the ground segment). EGOS-CC use for mission operations is designed to be significantly easier to tailor between missions than SCOS-2000 is, which will benefit future missions. The first missions to use it in-flight or through the development and launch, will however require some additional dedicated work to allow a smooth implementation. The general approach in ESOC is that some flying missions will first demonstrate use of EGOS-CC in parallel to their existing SCOS-2000 systems³. This de-risks future missions planning to launch directly on EGOS-CC.

Both Plato and Ariel are based on direct use EGOS-CC based systems, with Plato implementing a testing checkpoint in mid 2023 to confirm that EGOS-CC is on track for the Plato launch⁴. This avoids later having to migrate Plato to EGOS-CC in-flight and keeps the two missions baseline control system the same, also facilitating team harmonisation. Euclid will also benefit from this approach in that a largely common system will be available for the Euclid mission to migrate to during the routine mission phase after launch.

4.4. Use of MBSE and standardised development processes

In the development phase the MOC ground segment must be procured and implemented, with the design including a large element of subsystem re-use and tailoring. Requirements flow down from upper to lower level is being managed through a newly developed MBSE-based prototype system. The so-called Ground Segment Engineering Framework (GSEF) is an in-house MBSE tool that essentially delivers a model-centric implementation of the ECSS-E-ST-70C (“Ground Systems and Operations”) processes. This system allows linking and tracing from top level customer requirements through to system and subsystem requirement specifications. The tool also manages test campaigns, with requirements linked to specific test steps, and the ability to perform test step reporting directly in the tool, with semi-automated test reporting possible. The MBSE tool also provides the capability to manage specific mission operational constraints, allocating them to particular ground segment subsystems as appropriate. MBSE based systems are already used by the Plato Project team in ESTEC and data can be easily exchanged between the systems.

³ Swarm in Q1 2023 will start taking EGOS-CC passes in parallel to their existing SCOS-2000 MCS

⁴ The back-up option would be to launch using a Euclid based SCOS-2K system and migrate to EGOS-CC later after launch. The Euclid simulator will be used in testing the Plato EGOS-CC MCS for this early checkpoint.

As in other areas with ESOC, the various levels of ground segment requirement specifications themselves are now more standardised (e.g. the Operational Ground Segment System Requirements for Plato are already 95% similar⁵ to Euclid). These two approaches of more standardised ground segment systems and better development management tools also facilitate sharing and re-use of staff between the missions.

5. Conclusions

This paper presents the designs of the space and ground segments of the two new ESA Exoplanet missions, Plato and Ariel. The two designs are reviewed in some detail, focussing on the similarities and differences, and using some broad categories to explain their origin, often traced back to the high-level scientific objectives of the missions. The missions are considered sufficiently similar such that the management responsibility of these two missions has been recently merged into a single organisational unit at ESOC, in a first for missions of this type.

This organisation is thought to be better suited to more naturally exploit synergies and also highlight where differences remain, which become a focus of attention in the development of the ground segment and mission operations concepts of the missions.

The methodology applied here is considered quite generic and suitable for assessing the suitability of combined operations responsibilities across a range of mission types. The wider context of standardisation in ESA space and ground segments is also presented, along with new tools and systems, and how these are foundational elements in allowing such synergies in mission operations.

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⁵ Entirely unchanged or containing small edits that do not drive significant changes.