The electrical design of the thermal control systems of the all-aluminum ARIEL telescope

Vladimiro Noce[a], Mauro Focardi[a], Pierpaolo Merola[a], Andrea Tozzi[a], Paolo Picchi[d], Paola Zuppella[m], Paolo Chioetto[m], Javier Perez Alvarez[b], Laura Garcia Moreno[b], Alejandro Fernandez Soler[b], Gianluca Morgante[l], Fausto Rosadi[c], Ottavio Nannucci[c], Umberto Barozzi[c], Andrea Paternoster[c], Emanuele Pace[d], Giampaolo Preti[d], Paul Eccleston[e], Salma Fahmy[j], Andrew Caldwell[e], Lucile Desjonqueres[e], Daniele Brienza[f], Delphine Jollet[j], Giuseppina Micela[k], Giuseppe Malaguti[l], Giovanna Tinetti[g], and the ARIEL team

[a]INAF - Osservatorio Astrofisico di Arcetri, L.go Enrico Fermi 5, Firenze, Italy
[b]UPM - Instituto Universitario de Microgravedad "Ignacio Da Riva", Madrid, Spain
[c]Leonardo SpA, Campi Bisenzio, Italy
[d]University of Florence - Department of Physics and Astronomy, L.go E. Fermi 2, Firenze, Italy
[e]UKRI - Rutherford Appleton Laboratory (RAL), Harwell Campus, Didcot, UK
[f]ASI - Italian Space Agency, via del Politecnico, Roma, Italy
[g]UCL - University College London, Astrophysics group, London, UK
[h]INAF - Institute of Space Astrophysics and Planetology (IAPS), Via del Fosso Cavaliere 100, Roma, Italy
[j]ESA-ESTEC, Keplerlaan 1, Noordwijk, Netherlands
[k]INAF - Palermo Astronomical Observatory, P.zza del Parlamento 1, Palermo, Italy
[l]INAF - Astrophysical and Space Science Observatory, Via Gobetti 93/3, Bologna, Italy
[m]CNR-IFN, via Trasea 7, Padova, Italy

ABSTRACT

The Atmospheric Remote-sensing InfraRed Large-survey (ARIEL) is a medium-class mission of the European Space Agency whose launch is planned by late 2029 whose aim is to study the composition of exoplanet atmospheres, their formation and evolution.

The ARIEL's target will be a sample of about 1000 planets observed with one or more of the following methods: transit, eclipse and phase-curve spectroscopy, at both visible and infrared wavelengths simultaneously. The scientific payload is composed by a reflective telescope having a 1m-class primary mirror, built in solid aluminum, and two focal-plane instruments:

1. FGS (Fine Guidance System), performing photometry in visible light and low resolution spectrometry over three bands (from 0.8 to 1.95 µm)
2. AIRS (ARIEL InfraRed Spectrometer) that will perform infrared spectrometry in two wavelength ranges between 1.95 and 7.8 µm.

This paper depicts the status of the TA (Telescope Assembly) electric section whose purpose is to deploy sensors, managed by the Telescope Control Unit, for the precise monitoring of the Telescope's temperatures and the decontamination system, used to avoid the contamination of the optical surfaces (mirrors in primis).

Keywords: Exoplanets atmospheres, NIR spectroscopy, Infrared radiation, Infrared telescopes, Remote sensing, Cryogenic

---

Further author information and correspondence:
V.N.: E-mail: vladimiro.noce@inaf.it, Telephone: +39 055 275 2240

Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave, edited by Laura E. Coyle, Shuji Matsuura, Marshall D. Perrin, Proc. of SPIE Vol. 13092, 130924Y · © 2024 SPIE · 0277-786X · doi: 10.1117/12.3018298

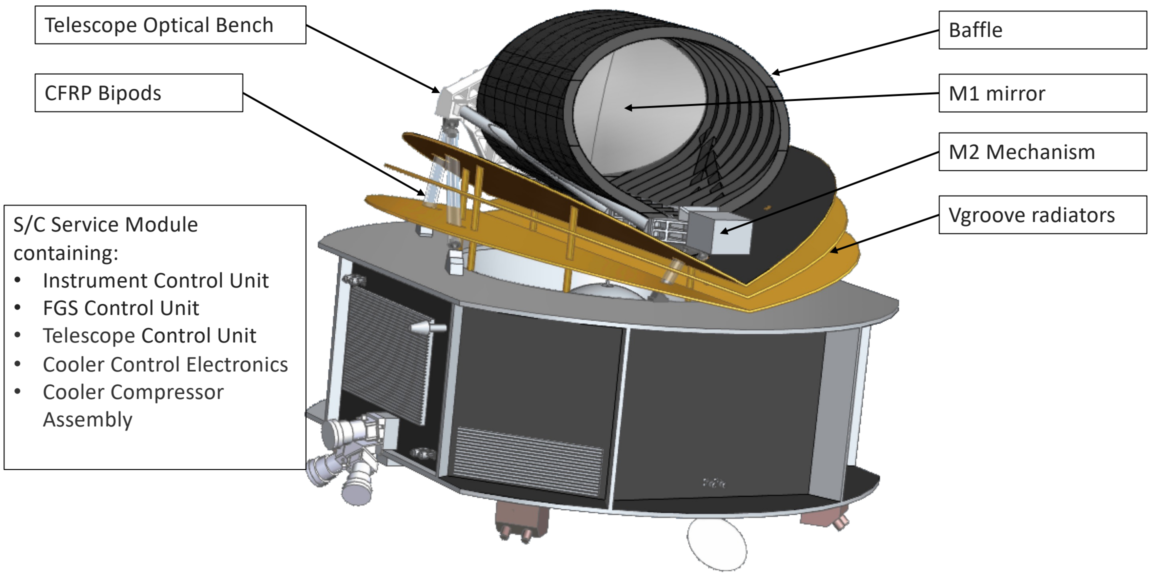

Figure 1: An image representing the ARIEL S/C with the main Payload components. The Service Module is in the warm part at the bottom.

1. INTRODUCTION

The Atmospheric Remote-sensing InfraRed Large-survey)[12] is the fourth medium-class mission of the European Space Agency (ESA), part of the Cosmic Vision 2015-2025 program. ARIEL aims to study the composition of exoplanet atmospheres, their formation and evolution and its launch is scheduled by late 2029, on an Ariane 6-2 vector, from the Kourou (Guiana) Space Centre with a mission duration of 4 years plus 2 years of extension.

ARIEL's scientific purpose is the study of the composition of exoplanet atmospheres,[3] their formation and evolution, by performing infrared spectroscopy of a large number of transiting exoplanets with temperatures from $\sim 500\,K$ to $\sim 3000\,K$. The target will be a sample of about one thousand planets observed with one or more of the following methods: transit, eclipse and phase-curve spectroscopy, at both visible and infrared wavelengths simultaneously.

The ARIEL[4] spacecraft is based on an off-axis Cassegrain telescope with an elliptic $1.1\,m \times 0.7\,m$ primary mirror built in solid aluminum 6061 and feeding, by means of an optic system (dichroics, mirrors and prisms), two instruments:

1. The Fine Guidance System (FGS) has the double purpose, as suggested by its name, of performing photometry (0.50-0.55 µm) and low resolution spectrometry over three bands (from 0.8 to 1.95 µm) and, simultaneously, to provide data to the spacecraft AOCS (Attitude and Orbit Control System) with a cadence of 10 Hz and contributing to reach a 0.02 arcsec pointing accuracy for bright targets.
2. The ARIEL InfraRed Spectrometer (AIRS) instrument will perform IR spectrometry in two wavelength ranges: between 1.95 and 3.9 μm (with a spectral resolution $R > 100$) and between 3.9 and 7.8 µm with a spectral resolution $R > 30$.

The Payload is passively kept at cryogenic temperatures ($\approx 55\,K$) and the instruments are further cooled by an Active Cooling System (ACS).

The Telescope Assembly (TA) is supported by six feet: two bipods at each Optical Bench side and two monopods at the front end. The ARIEL payload is composed of a cold part (PLM) and a warm side, hosting the electronic units: the ICU and the A-DCU (part of the AIRS instrument chain), the FGS (Fine Guidance System), the CCE (CryoCooler Electronics) and the TCU (Telescope Control Unit). The cold section is thermally

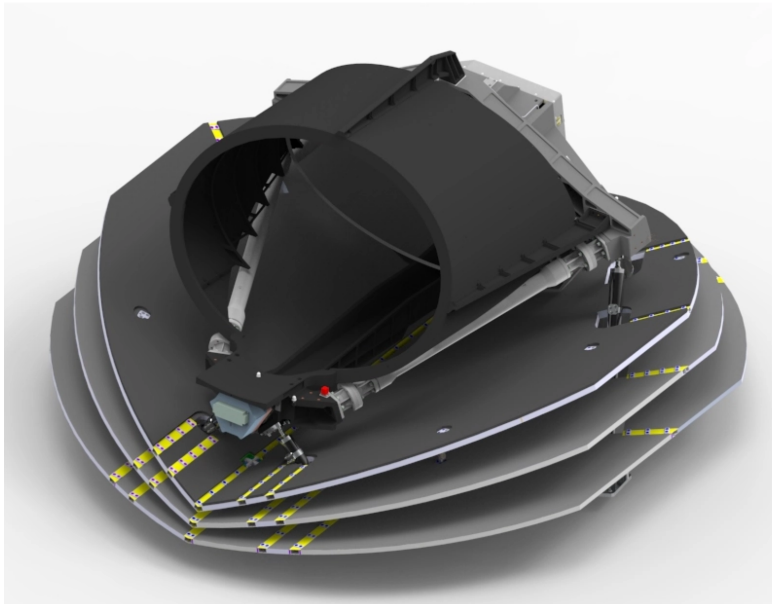

Figure 2: An image of the ARIEL Telescope and Vgrooves.

separated from the warm section of the Spacecraft and shielded from the Sun's light by a set of three Vgrooves (see Figure 2).

This paper reports the AIRS Telescope Assembly electrical system design status and gives an overview of its development stage just before the EM MRR (Manufacture Readiness Review). The first models foreseen by the model philosophy, illustrated in Section 4 (SM and EM) have been realized. In Section 2 we describe the TA electrical system, in Sections 3.1 and 3.2 we go in detail with its main components: the Thermal Monitoring and the Decontamination systems and in Section 4 we illustrate the development plan, including a description of the past, present and future activities.

2. THE ELECTRICAL SYSTEM

ARIEL Payload is serviced by several electrical circuits, all passing along the four rear bipods. Most of the connectors are connected to four PIPs (Payload Interface Panels) to facilitate the assembly and integration activities. Only the panels #1 and #4 carry signals that are in the scope of the present paper and the correspondent circuits are highlighted in bold in the following list:

1. Bipod Foot#1
    - **PL thermal monitoring** (partially: Vgrooves excluded)
2. Bipod Foot#2
    - AIRS Detector signals & thermal control
3. Bipod Foot#3
    - FGS Detector signals & thermal control
    - FGS FPE Survival heaters thermal control
4. Bipod Foot#4
    - M2M Drive & thermal control (INAF is in charge only of its routing on the TA)

- **Decontamination heaters thermal control**
- ACS Thermal control (routed along bipod #4 but connected directly to the CHX-CWF panel)

The INAF responsibility for these harnesses is limited to the path from the interface panels present on the TOB (including the panel structure) and the final component, in some cases, or up to the next connector (including or excluding the secondary panel structure) in other.

Other structures and institutes/industries with which the TA interfaces (substantial for this document) are:

- **B1** - Baffle: a cylinder that surrounds the M1 mirror, limiting the M1 field of view (Active Space Technologies, Portugal)
- **ACS** - Active Cooling System, Heat Exchanger (RAL, UK)
- **M2M** - M2 Mechanism: a refocusing mechanism with three degrees of freedom, whose aim is to correct the movements that can occur during the launch and the cooling and to compensate for any long-term drift in structural stability (IEEC/SENER Spain)
- **IR** - Instrument Radiator: the Instrument Bay cover (Admatis, Hungary)

The Telescope Assembly electrical system (see Figure 3) is mostly under INAF responsibility and is mainly composed of:

1. The TMS (Thermal Monitoring System), managed by the TCU (Telescope Control Unit) and consisting in a set of Cernox™ sensors in redundant configuration
2. The Decontamination System composed of pad heaters and Pt1000 sensors in triple voting configuration

3. THE TA ELECTRICAL SYSTEMS AND ITS DESIGN

The electrical scheme of the TA electrical system shown in Figure 3 drafts the harnesses under INAF responsibility in green. Despite the seeming simplicity, the routing and the placement of the components was complicated by the many constraints dictated by the systems already put in place and by other issues as space constraints for the heaters.

The TA harness electrical design started separating the lines crossing the thermal gradient (the so-called *cryoharness*) from the cold part and segmenting the harnesses on self-standing panels (brackets) placed on the TOB. A separation is also naturally present at the interfaces where there is a responsibility handover (e.g. Baffle, Instrument Radiator and ACS). Another bracket has been provided just before the M2/M2M (Mirror#2 Mechanism) assembly, on the very front of the telescope, to facilitate the mounting/dismounting of the assembly itself.

The choice of the number of separated lines was a compromise between the number of connectors and the needs of the integration activities. At the end, the 22 TMS sensors were grouped onto 4x MDM37 connectors (hosting, respectively, 6-5-6-5 sensors), doubled for redundancy.

There are seven separated decontamination circuits (see Table 2) that are very different with respect to the delivered power and that can be divided into 3 groups:

1. **TOB** - Telescope Optical Bench: split into 2x4 lines in order to optimize the huge amount of power delivered ($\approx 200\,W$)
2. **M1** - Mirror#1: allocated on separate connectors to facilitate the routing
3. **M2, M3, M4 and ACS**: delivering small power

The decontamination system was, in the end, allocated on 9 different connectors (1 for sensors and 2 for redundant heaters for each group described above) and, finally, the optimization process led to a total of 17 connectors, considering the redundancy of TMS sensors and of DEC heaters.

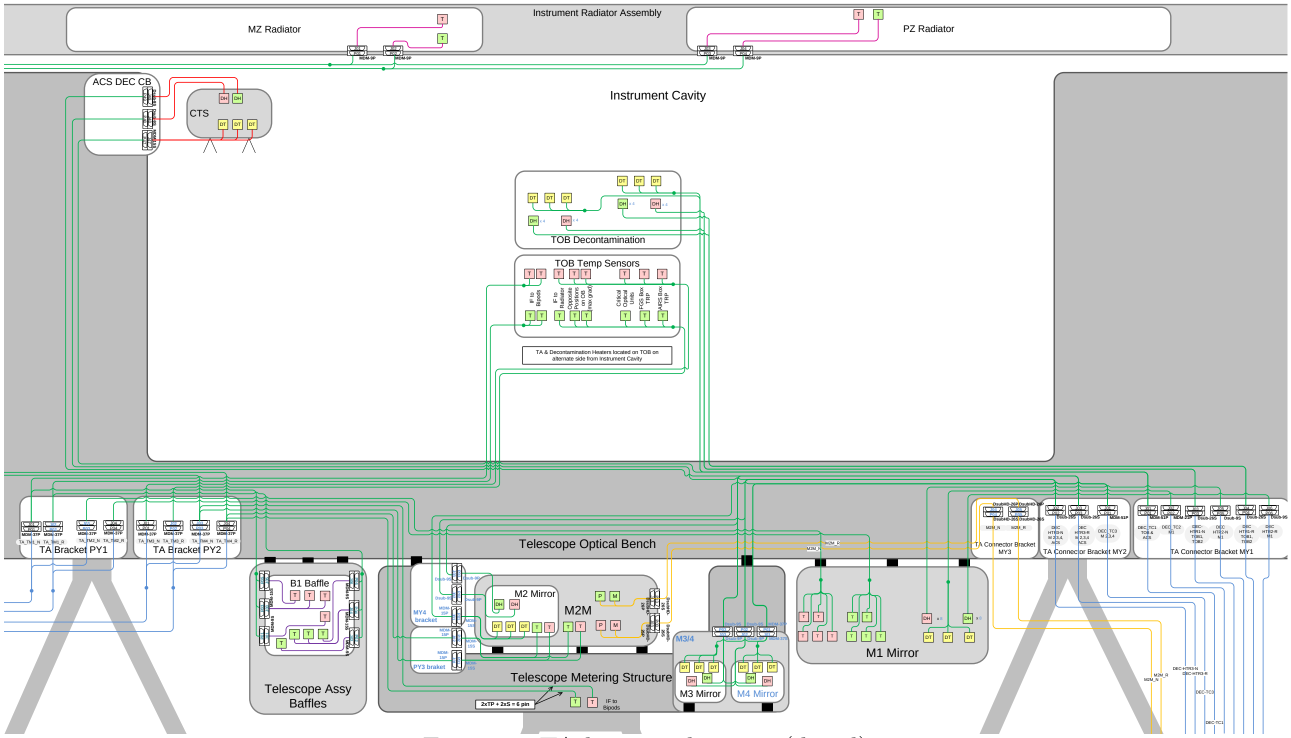

Figure 3: TA harness diagram (detail)

3.1 Thermal Monitoring System

The TMS is managed by the Telescope Control Unit (TCU), an electronic box placed in the warm side of the Spacecraft. The TCU is cold redundant and the Cernox™ (CX-1080) sensors that it reads (22 placed on the Telescope Assembly and 15 on the Vgrooves) are duplicated for the same reason. The thermistors are connected in a four-wire configuration.

Unit	Number	Notes
TOB	8N+8R	
TMS	1N+1R	front side
M1	5N+5R	
M2+M2M	2N+2R	disconnected in the front bracket
IR	2N+2R	not provided by INAF
Baffle	4N+4R	not provided by INAF

Table 1: TA TMS lines

3.2 Decontamination system

The Decontamination system is piloted directly by the Spacecraft's Service Module (RIU - Remote Interface Unit) and it is based on a number of heaters delivering very variable amounts of power (from few W to hundreds), supplied by the PCDU (Power Conditioning and Distribution Unit). The target temperature is monitored by Pt1000 sensors in a triple voting configuration. The +28V regulated voltages are protected against over-current by LCL (Latching Current Limiters), switching off the power in case the currents exceed the limit.

The purpose of the decontamination system is to actively heat the various surfaces in order to control the thermal transitions from cold to warm (and vice-versa), avoiding molecular contamination (mainly humidity). In fact, contamination can reduce the optical throughput and create spurious stray-light, causing a performance degradation of the telescope.

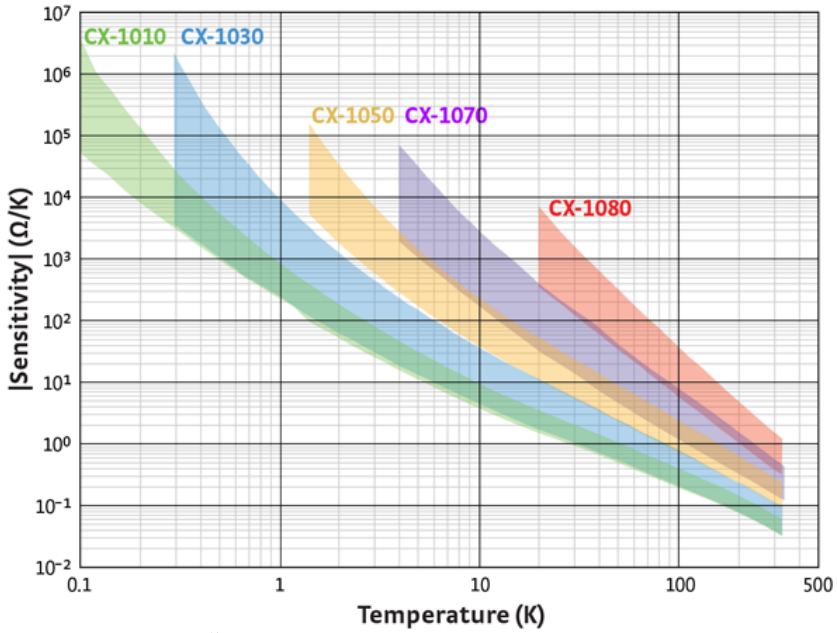

Figure 4: Cernox™ sensors: working range of temperatures for CX-1080 model

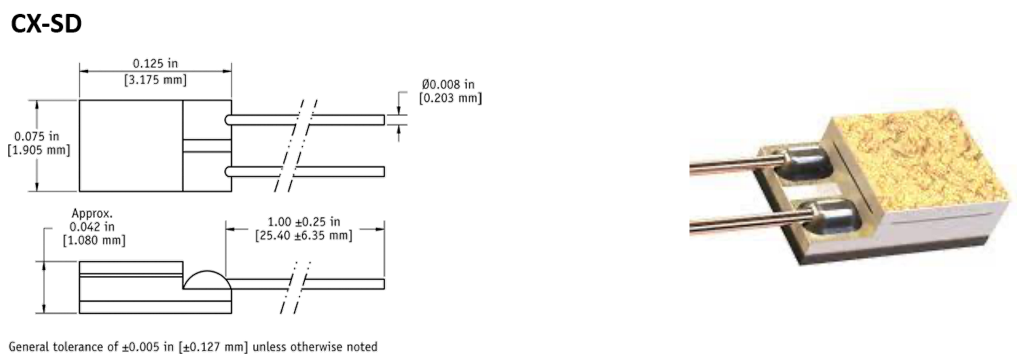

Figure 5: SD package of Cernox™ sensors

3.2.1 Pt1000

The decontamination function is monitored by Pt1000 sensors in a triple voting configuration. Also these sensors are wired in a four-wires configuration.

Unit	Number	Resistance	Dimensions $mm \times mm$	Total Power
TOB-1	8N+8R	$33\,\Omega$	50×100	98 W
TOB-2	8N+8R	$33\,\Omega$	50×100	98 W
M1	8N+8R	$298\,\Omega$	25×60	20 W
M2	2N+2R	$496\,\Omega$	14×52	3 W
M3	1N+1R	$372\,\Omega$	12.5×46.5	2 W
M4	1N+1R	$372\,\Omega$	17×36	2 W
ACS	1N+1R			2 W*

*not provided by INAF

Table 2: Decontamination circuits with their characteristics.

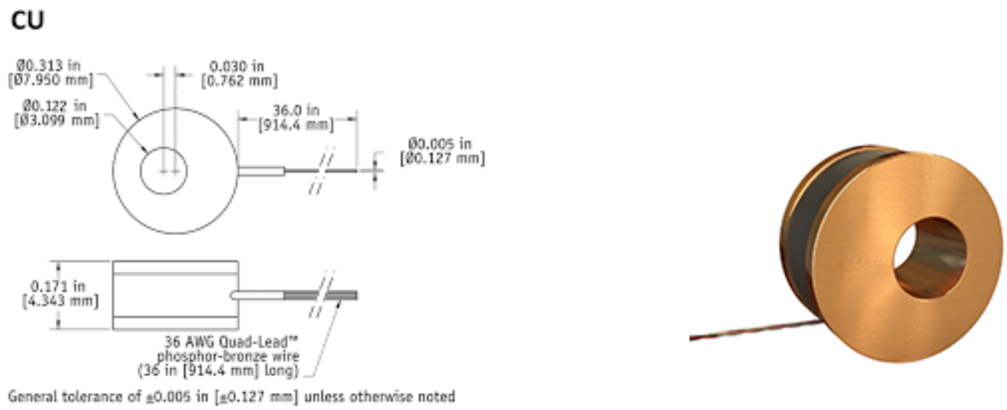

Figure 6: CU package of Cernox™ sensors

Figure 7: The Pt1000 package

3.2.2 Pad heaters

Several different heater models have been investigated for the purpose of delivering power: from discrete cartridge resistors to SMD mounted on flex PCBs. The discrete resistors, to be screwed to the structure, were excluded because the optical surfaces (e.g. mirrors) would be deformed due to the screw tightening (this is also the reason why we adopt two types of Cernox™ sensors). The SMD resistors on flex PCB is a solution flexible and scalable but was excluded because of concerns about the effectiveness in transmitting power to the substrate. Despite the huge difficulty to satisfy different and competing constraints on:

- Maximum rated power density;
- Maximum resistance per cm^2;
- Space available

in the end, the FHK (Flexible Heater Kapton) custom size heaters (see Table 2, supplied by RICA/Zoppas and compliant to ESCC 4009/002, have been adopted as the general solution. This component is made of two layers of Polymide insulating Inconel heating wire.

Using a unique solution has the advantage of requiring a single qualification process for all these components. This type of heater can deliver a maximum of $0.54\,W/cm^2$ (according to ESCC 4009). An acceptance process is necessary for its use at cryogenic temperatures (way below the minimum at which it is qualified, i.e. -65°C) and will require a dedicated test campaign, also involving the adhesive used to glue the heaters.

4. STATUS AND FUTURE ACTIVITIES

The TA Model Philosophy comprises the following models:

1. **Structural Model (SM)**, a model representative of mass and external interfaces, used to populate the S/C Structural Model

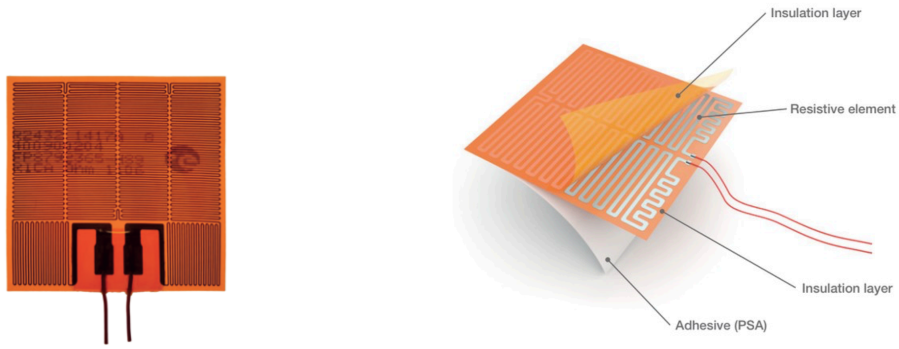

Figure 8: The FHK type heaters: appearance and composition (courtesy Zoppas)

2. **Engineering Model (EM)**, optically, functionally and electrically representative of the flight standard
3. **Flight Model (FM)**, final model for integration in ARIEL PL and launch

The Telescope Assembly EM is facing the MRR (Manufacturing Readiness Review). Now that the routing is definitive, the EM can be integrated and subject to: vibration, thermal and vacuum tests.

ACKNOWLEDGMENTS

This study has been supported by the Italian Space Agency (within the ASI-INAF agreement n. 2021-5-HH.2-2024 "Scientific activity for the ARIEL Mission – B2/C/D1 Phases").

REFERENCES

[1] Puig, L., Pilbratt, G., Ratti, F., Scharmberg, C., Boudin, N., Crouzet, P.-E., Halain, J.-P., Haag, M., Escudero, I., Bielawska, K., Kohley, R., Symonds, K., Renk, F., Findlay, R., Ertel, H., and Biesbroek, R., "The ESA Ariel mission is ready for implementation," in [*Space Telescopes and Instrumentation 2020: Optical, Infrared, and Millimeter Wave*], Lystrup, M., Perrin, M. D., Batalha, N., Siegler, N., and Tong, E. C., eds., **11443**, 189 – 199, International Society for Optics and Photonics, SPIE (2020).

[2] Pascale, E. et al., "The ARIEL space mission," in [*Space Telescopes and Instrumentation 2018: Optical, Infrared, and Millimeter Wave*], Lystrup, M., MacEwen, H. A., Fazio, G. G., Batalha, N., Siegler, N., and Tong, E. C., eds., **10698**, 169 – 178, International Society for Optics and Photonics, SPIE (2018).

[3] Tinetti, G. et al., "Ariel: Enabling planetary science across light-years," *arXiv e-prints* , arXiv:2104.04824 (Apr. 2021).

[4] Eccleston, P. et al., "The ARIEL payload: A technical overview," in [*Space Telescopes and Instrumentation 2020: Optical, Infrared, and Millimeter Wave*], Lystrup, M., Perrin, M. D., Batalha, N., Siegler, N., and Tong, E. C., eds., **11443**, International Society for Optics and Photonics, SPIE (2020).

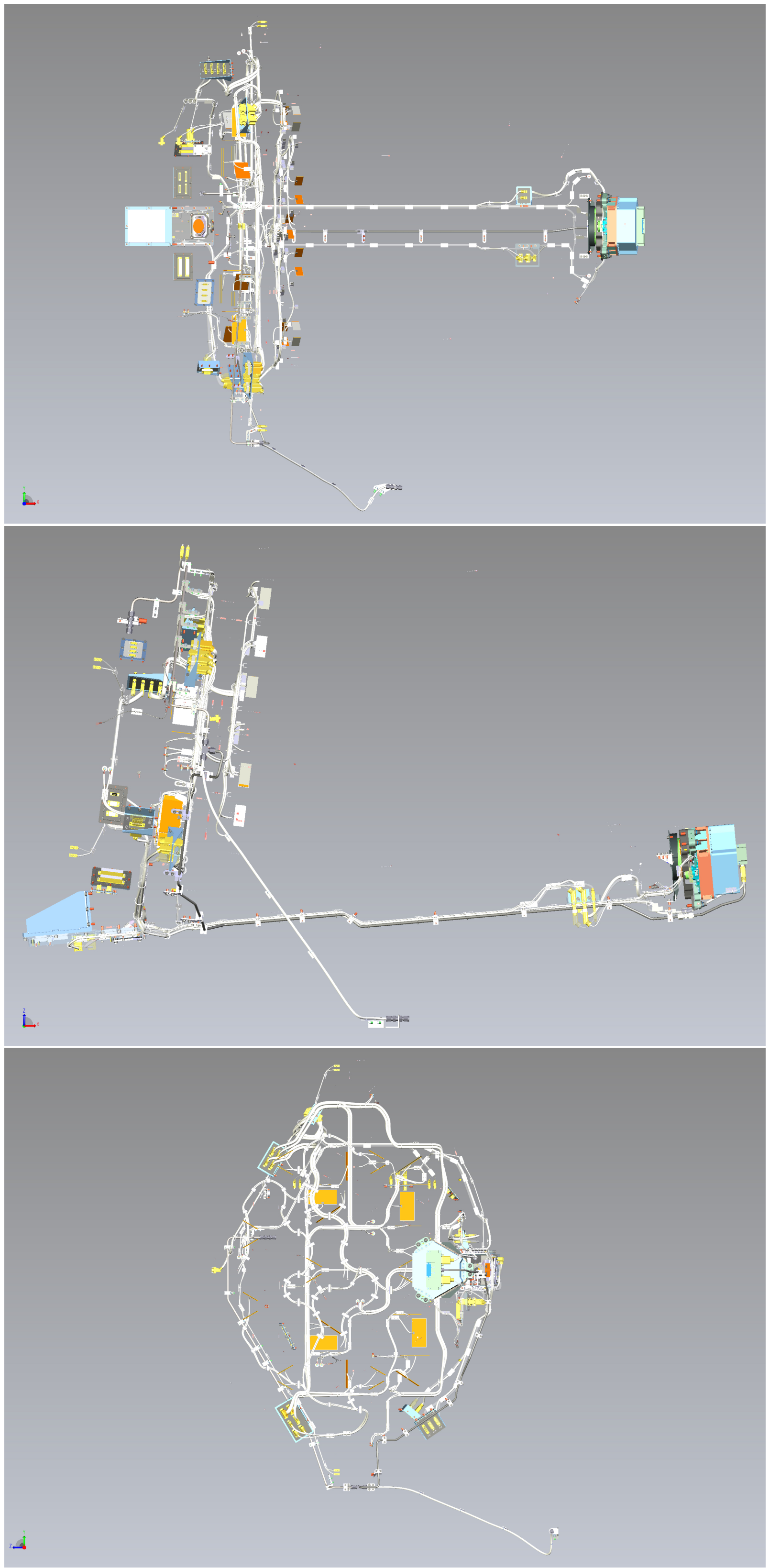

Figure 9: Three views of the harness routing (Courtesy UPM).