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The primary mirror of the ARIEL mission: study and development of a prototype

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Abstract

ARIEL (Atmospheric Remote-sensing Infrared Exoplanet Large-survey) has been selected by ESA as the fourth medium-class (M4) mission in the framework of the Cosmic Vision Programme. ARIEL is expected to be launched in 2028 [1].

ARIEL aims to study the atmospheres of a selected sample of warm and hot exoplanets mainly by means of primary and secondary transit spectroscopy [2].

The payload is based on a 1-m class telescope ahead of a suite of instruments: two spectrometric channels covering the band 1.95 to 7.80 µm without gaps, three photometric channels working in the range 0.5 to 1.2 µm, and a low resolution spectrometer in the range 1.25-1.95 µm.

The ARIEL telescope is based on an eccentric pupil two-mirror classic Cassegrain configuration coupled to a tertiary off-axis paraboloidal mirror.

The 1-m diameter primary mirror (M1) is one of the main technical challenges of the mission. A trade-off on the material to be used for its manufacturing was carried out, together with optical analyses and the realization of a mirror prototype.

1. Introduction

Following the detailed material trade-off analysis conducted in the assessment phase of the mission, the material adopted for the whole telescope, i.e. mirrors and structure, is aluminium [3].

For the fabrication of space telescopes observing in the infrared wavelength range, nowadays metals, like aluminium alloys, are frequently considered. In fact, aluminium alloys have proved to be an excellent choice both for IR small size mirrors and structural components, but the manufacturing and thermo-mechanical stability of large metallic optics still have to be demonstrated, especially at cryogenic temperatures.

So, a dedicated pathfinder mirror telescope program has been adopted to study, realize and test an ARIEL primary mirror prototype.

2. Telescope optical design

ARIEL is based on a 1-m class telescope ahead of two IR spectrometer channels covering the band 1.95 to 7.8 µm. In addition, photometric channels are used for fine guidance and photometry, three for visible and NIR light photometry (FGS1&2 and Vis-Phot) and one (NIRSpec) used as a low-resolution spectrophotometer [4].

The ARIEL system has a fore-module common afocal telescope that will feed the whole spectrometer and the photometric channels. The optical design of the telescope has been conceived to satisfy the scientific and optical requirements [5].

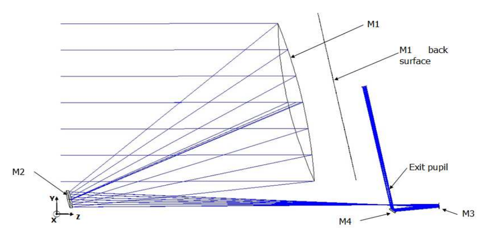

Figure 1: ARIEL telescope optical layout.

The telescope configuration is based on a classic Cassegrain layout (M1 and M2 mirrors) used with an eccentric pupil and coupled to a tertiary off-axis paraboloidal mirror, M3, (see Figure 1). A flat folding mirror (M4) redirects the beam towards the spectrometer and the photometric channels. The combination of M1 and M2 gives a 14 m focal length telescope. The optical design has been conceived to be diffraction limited, with a residual RMS wavefront error of about 20 nm.

3. The primary mirror

The ARIEL telescope will be realized on-ground, at 1 g and room temperature environmental conditions, but it shall operate in space at about 50 K. For this reason, a detailed tolerance analysis was performed to assess the telescope expected performance [6].

M1 is an off-axis section of a paraboloidal mirror and will be machined from a single blank as a stand-alone part. To prove the feasibility of such a large aluminium mirror, a pathfinder mirror program (PTM) has been started. The prototype, with the same size of the M1 flight model but a simpler surface profile, has been realized and tested, so far at room temperature, by Media Lario S.r.l.. Cryogenic testing of the prototype will be performed during Phase B1.

3.1 Pathfinder mirror program

Considering the time constraints and available funding, the planned baseline scope for the PTM was to manufacture, and test at ambient temperature, a full-size simplified spherical mirror, with surface and roughness quality less demanding w.r.t. the FM.

Figure 2: The PTM mirror prototype.

The curvature radius assumed for the PTM corresponds to the calculated best fit sphere of the considered off-axis paraboloidal part of the primary mirror.

The procured aluminium blank has been rough machined and lightweighted, then diamond turned. Finally, an ad-hoc set-up to avoid the effect of gravity has been first analyzed and then used to measure the actual mirror surface properties.

As for the obtained results, concerning the radius of curvature it is within 0.1% of its nominal value, while the residual surface shape accuracy is about 2 μm.

Further activities are in progress to test the figuring and polishing process.

4. Summary and Conclusions

The design and realization of a 1-m prototype aluminium mirror developed in the framework of the ARIEL ESA mission have been described.

The characteristics of the telescope optical design have been briefly described and the steps and aims for the development of a primary mirror prototype have been given.

Future activities are foreseen to be undertaken in Phase B to improve the manufacturing process and to assess the prototype behavior in cryogenic environment.

Acknowledgements

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