Development process of the Ariel Space Telescope

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Background

The **Atmospheric Remote-Sensing Infrared Exoplanet Large Survey** (*Ariel*) will be an Optical/Infrared *ESA* mission. It will observe ~ 1000 exoplanets in primary and secondary transits around their parent stars. *Ariel* will study the chemical composition of their atmospheres and, for a smaller group, will also study the ephemerides.
The leading Italian contribution is the construction of the telescope. The primary mirror will be an off-axis paraboloid mirror measuring $1.2 \cdot 0.7m$.
The novelty of the telescope is that the mirrors and the telescope structure will be made entirely in aluminum Al6061T651, and the primary mirror surface will be bare aluminum without a thick hard coating.

Motivation

The choice of aluminum is mainly due to the **thermo-mechanical properties** of the material; using the same material for all the structures will allow better heat exchange between the mirror and the optical bench. The mirrors are **lighter** due to the material's low density and are easily machined to lighten them further, thanks to the high ductility. Finally, the **cost** of the material is much lower than the current materials used for infrared optics [2].

Problems

Using aluminum to make a mirror with the dimensions of *Ariel*'s primary mirror involves new problems to be addressed. Among these, the main ones are:
-Heat Treatment for materials as malleable as aluminum allows the stress accumulated by mechanical processing to be released and tempered to avoid future accumulations. The internal stress of aluminum can be released at the end of the processing of the mirrors, deforming their shape and roughness and taking them out of specification;
-Polishing must bring the surface to a roughness **$Sq \leq 10nm$ RMS and a Shape Error $SFE \leq 80nm$ RMS for the primary mirror.** A polishing recipe for a $1.2 \cdot 0.7m$ aluminum mirror had never been developed, and for the only possible alloy to use (A6061T651), where the normal presence of Si-Mg aggregates worsens the roughness (they are torn during polishing process).

Method

A thermal recipe has been developed based on that developed by Raymond G Ohl et al. by NASA/Goddard Space Flight Center [1].
The recipe includes a series of **high temperature** thermal cycling to dissolve the aggregates and harden the aluminum, and **low temperature** between the mechanical processes of mirror processing to release the accumulated stresses.

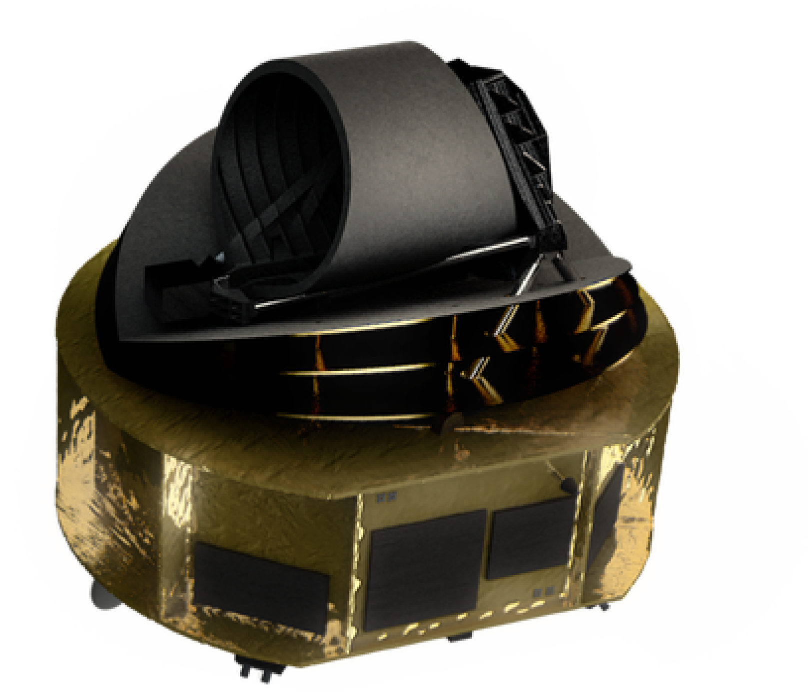

Fig. 1: Artistic picture of *Ariel*. Credit: *ESA*, *STFC*, *RAL Space*, *UCL*, Europlanet-Science Office.

The polishing process was developed **from scratch** and is currently being tested on a series of $50mm$ and $150mm$ samples and on two $0.7m$ mirrors called BreadBoards (BB1 and BB2). **The process must maintain the mirror with a roughness of less than $10nm$ RMS (which the Single Point Diamond Turning process can achieve) while machining the shape to bring it to specification.**
Solubilizing Si-Mg aggregates through heat treatment can help to be more aggressive to improve shape without worsening the roughness of the mirror surface.

References

[1] Ohl IV, Raymond G and al. "Comparison of Stress Relief Procedures for Cryogenic Aluminum Mirrors". In: *Cryogenic Optical Systems and Instruments IX SPIE.* Vol. 4822. 2002.

[2] Webside. *ARIEL ASSESSMENT STUDY REPORT (YELLOW BOOK).* `https://sci.esa.int/documents/34375/36249/1567260310680-ESA_SCI-2017-2_ARIEL.pdf`.

[3] Webside. *ARIEL DEFINITION STUDY REPORT (RED BOOK).* `https://sci.esa.int/documents/34022/36216/Ariel_Definition_Study_Report_2020.pdf`.

Results

The roughness measurement at the interferometer has a value of $Sq \leq 10nm$ RMS already after the Diamond Turning, before the Polishing process. The goal will be to maintain these roughness values while machining the mirror shape.

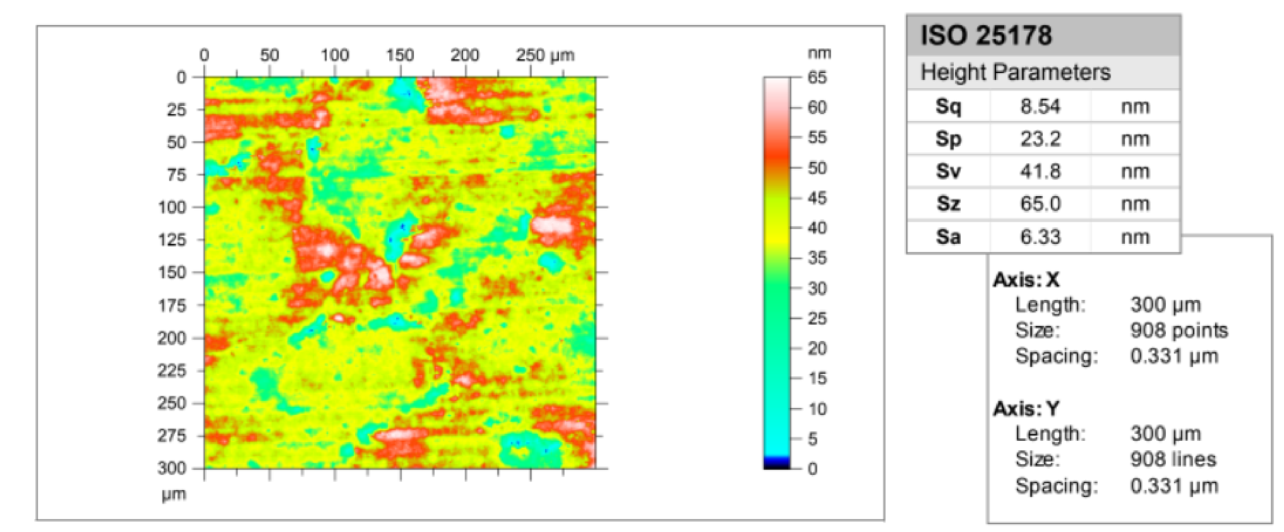

Fig. 2: Example of roughness measure.

The *SFE* measurement is, on average, $838nm$ RMS, and $4223nm$ PtV after Diamond Turning. The best polishing recipe is being sought to keep the roughness low while working this shape.

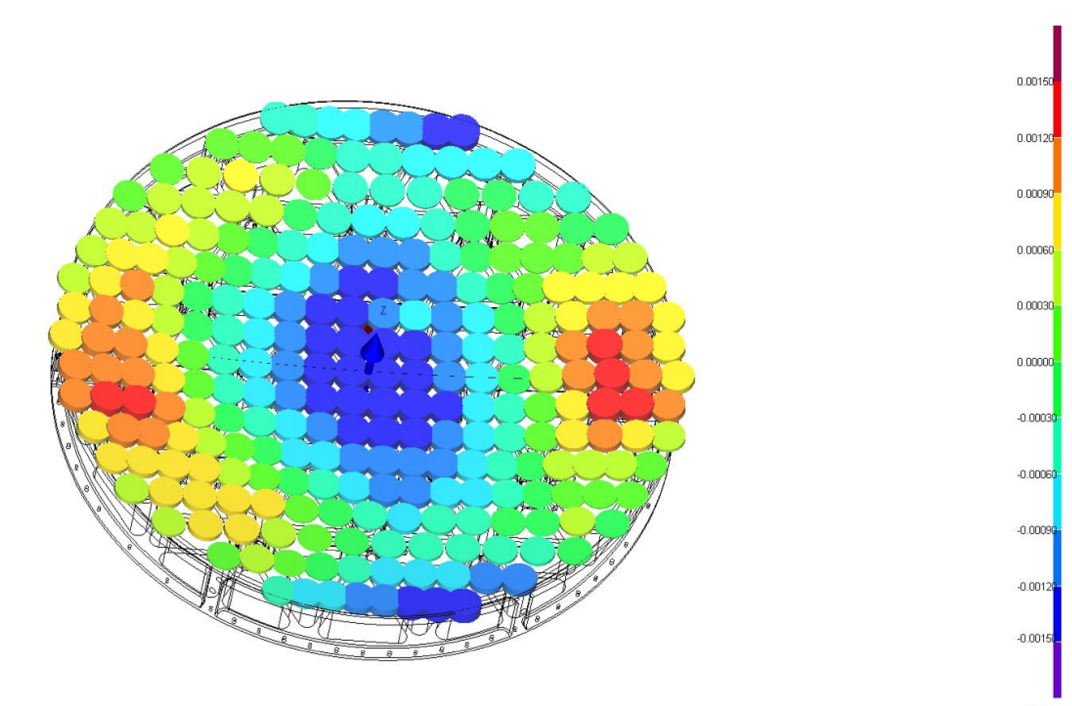

Fig. 3: SFE preliminary measurement.

Conclusion

The Heat Treatment and Polishing processes continue to be tested on the Samples. The goal is to apply them effectively on the BBs mirrors, reaching the optical specifications, before moving on to the realization of the System Model in Phase C [3].