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Mini grant: Mid-Spatial frequency study for the Ariel Space Mirror

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Abstract

The objective of this proposal is the modeling, analyze, and test the contribution of Medium Spatial Frequency to the Wave Front Error for the low-density and large-dimension mirrors. After an accurate modeling phase, through the Power Spectral Frequency study, tests will be performed on aluminum samples purposely built and treaded.
The result will have an impact on optics for space with similar properties.

Introduction

The **Atmospheric Remote-Sensing Infrared Exoplanet Large Survey** (**Ariel**) is the M4 mission adopted by ESA's "Cosmic Vision" program.
Its launch is scheduled for 2029. The mission aims to study exoplanetary atmospheres on a target of ~1000 exoplanets.
Ariel's scientific payload consists of an off-axis, unobscured Cassegrain telescope. The light is directed toward a set of photometers and spectrometers with wavebands between 0.5 and 7.8 µm and operating at cryogenic temperatures.
The Ariel Space Telescope consists of a primary parabolic mirror with an elliptical aperture of **1.1 x 0.7 m**, followed by a hyperbolic secondary, a parabolic collimating tertiary, and a flat-folding mirror directing the output beam parallel to the optical bench; **all in bare aluminum**.
To date, an aluminum mirror the M1 size of Ariel's primary has never been made for the space. An Ad Hoc process has therefore been studied to achieve the tolerances required by the project for the surface of the primary mirror: **Roughness ≤ 10nm RMS** and **Surface Error (SFE) ≤ 60nm RMS**.
Specifications for optical surfaces are traditionally given in terms of low-frequency and high-frequency components, often with a separate classification for surface slope. Low spatial frequency components are commonly referred to as figure errors (SFE) and can be described by the standard 37-term Zernike polynomial set. High spatial frequency errors are frequently referred to as finish and are quantified using RMS roughness.
However, a critical component to keep under control is missing for a large mirror like Ariel's M1 and which is usually treated as residuals of little weight of the Zernike polynomials: the Mid-spatial frequency (MDF). In the case of Ariel's M1, however, it is relevant due to the mirror's large size and to the polishing technique, which impresses ripples on the surface. At this spatial scale, a ripple in the mirror's surface causes light to diffract, worsening the measurement quality.
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Objective and Plans

The modeling analysis and test of this surface error contribute are the objectives.

At the moment, it is not yet known how to quantify the contribution described above uniquely. Today we are able to model the long scale/low frequency (Zernike polynomials) and small scale/ high frequency (RMS roughness). The missing medium scales (MSF) are buried in the residuals of both approaches, and for this, it is impossible to model all the frequencies in a consistent way.
Approaching the available literature, the **Power Spectral Density (PDS)** was identified as a helpful analysis model. This is an alternative method for specifying optical surfaces and quantifying **each spatial regime's contribution to the total surface error**. This approach naturally **includes the mid-range spatial frequency errors of our interest**. This method has not yet received general acceptance within the community.
What I want to do, therefore, is to face the question through different points/steps:
a) Building a model based on the Power Spectral Density PSD.
b) Apply the model to several optical systems simulated with Zemax. The aim is to create optical systems with known defects in the medium frequencies, circular or orthogonal to the optical surface, which are possible for the Diamond Turning and Polishing processes, and to study the error contribution to the optical surface by comparing it with PSD template.
c) Make aluminum samples of small plane mirrors (about 100-150 mm) of the Ariel M1 material and diamond turning (if possible) and polishing, and measure them for roughness and shape. The results will be compared with the realized model.
d) Improvement of the model in case of apparent discrepancies.
In addition to being applied during the phase C of Ariel for constructing the following M1 mirrors, the results obtained from this project can also be used for other projects with similar characteristics (large mirrors and low-density materials).
This model can allow for an effective approach to the analysis of MSF and to obtain tolerances as good as the high and low spatial frequencies.

Planned Schedula

0 - 1 month Acquisition of hardware and Zemax software to carry out the mini-grant activity.
2 - 6 months Acquisition of the minimum necessary skills of the Zemax software.
7 - 10 months First simulations of optics to which the method of Power Spectral Density for medium frequencies, Zernike polynomials for low frequencies, and roughness for high frequencies can be applied
At the end of this phase, I am confident to have enough material for a first publication and/or meeting presentation.
11 - 15 months Acquisition of Aluminum material and polishing material for producing the samples mirrors.
16 -18 months Interferometric measurements of the mirrors and comparison between the results and the simulations.
19 - 24 months Improvement of the Power Spectral Density model.

Real Schedula

0 - 6 month Acquisition of hardware and Zemax software to carry out the mini-grant activity.
6 - 18 months Acquisition of the minimum necessary skills of the Zemax software.
18 - 21 months First simulations of optics to which the method of Power Spectral Density for medium frequencies, Zernike polynomials for low frequencies, and roughness for high frequencies can be applied
At the end of this phase, I am confident to have enough material for a first publication and/or meeting presentation.
15- 21 months Acquisition of Aluminum material and polishing material for producing the samples mirrors.
21 - 24 months Interferometric measurements of the mirrors and comparison between the results and the simulations.
Over times Improvement of the Power Spectral Density model.

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