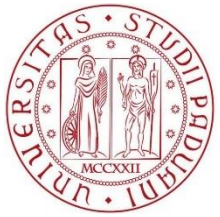


UNIVERSITÀ DEGLI STUDI DI PADOVA

CISAS G. COLOMBO

Optical and Opto-mechanical Analysis and Design of the Telescope for the Ariel Mission

Second Year Activities Report

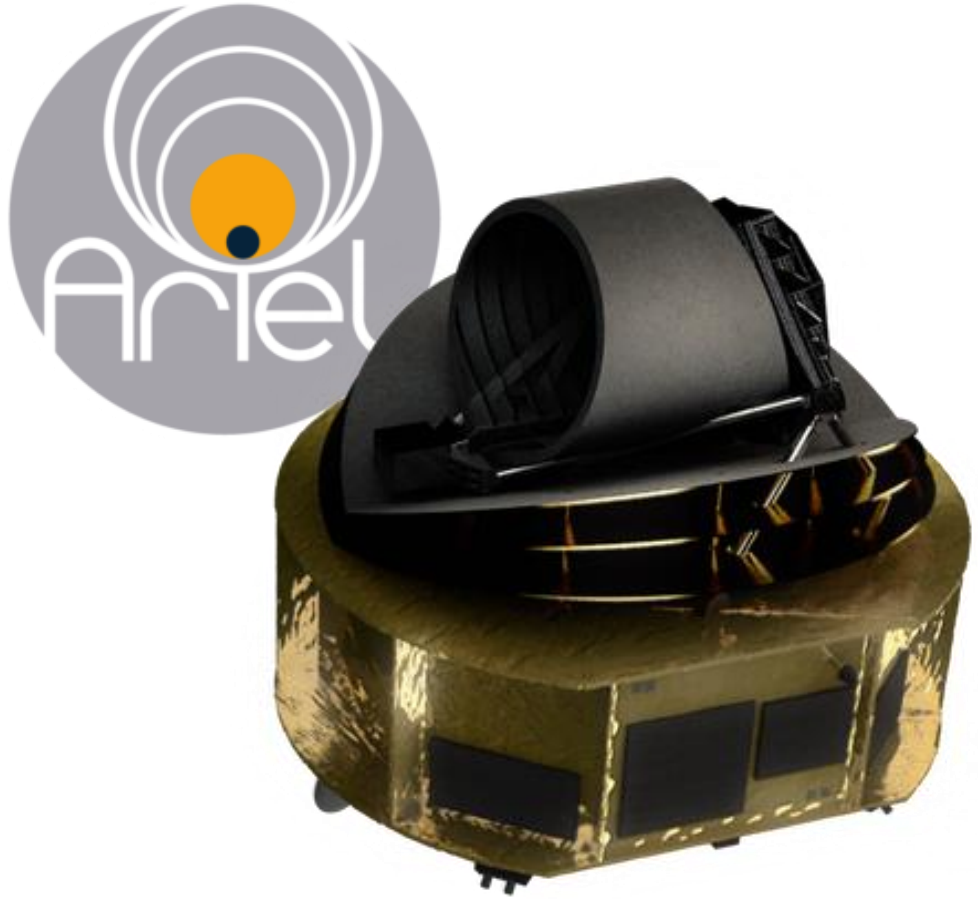
Padova, September 9th, 2021

PhD Candidate: Paolo Chioetto

Supervisor: Dr. Paola Zuppella Co-supervisor: Dr. Vania Da Deppo

Ariel – A Quick Review

- ARIEL is the **M4 mission** of ESA Cosmic Vision program to survey **exoplanet atmospheres** through infrared transit spectroscopy
- **All-aluminum telescope** design, operating at **cryogenic temperature** (< 50 K). Off-axis, unobscured optical design
- Two instrument modules: a **spectrometer** (1.95–7.8 μm), and a combined fine guidance system/visible photometer/NIR spectrometer
- **PI:** Prof. G. Tinetti, University College London, UK
- **Italian Co-PIs:** G. Micela, INAF-OAP, P. Malaguti, INAF-OASBO



Logo and Artist's rendering of the ARIEL spacecraft from Phase A (credit: ARIEL/Science Office)

Ariel Project Timeline

Assessment	Definition		Development			Operations	Disposal
Phase 0	Phase A	Phase B1	Phase B2	Phase C	Phase D	Phase E	Phase F
Mission analysis and identification	Feasibility	Preliminary Definition	Preliminary Definition	Detailed Definition	Qualification and Production	Utilization	Disposal

Mission Selection

Mar 2018

Mission Adoption

Nov 2020

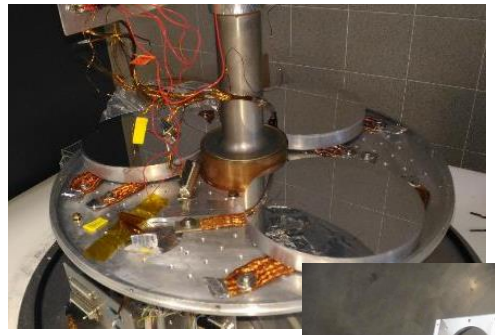
Launch

2029

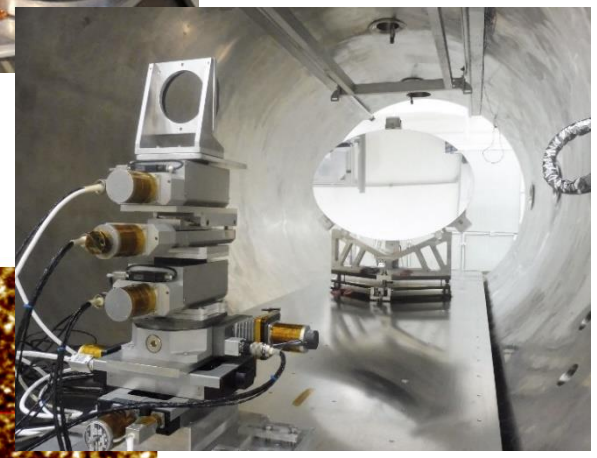
Year 1 Summary of Activites

Ariel Phase B1 (Preliminary definition), leading to Mission Adoption by ESA

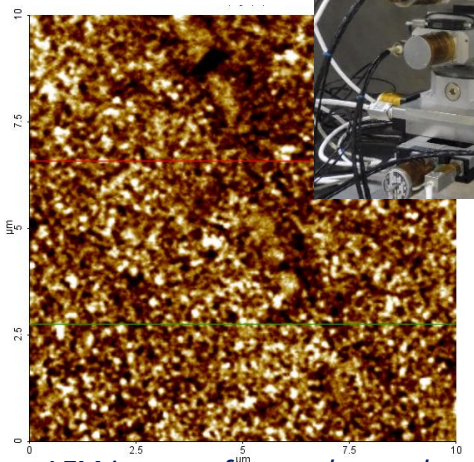
- Telescope performance requirements, mirrors reflectivity and throughput analysis
- Off-axis design refinement, discussions about moving to a free-form definition of the mirror surfaces
- Preliminary STOP analysis
- Primary Mirror Technology Development Activity (TDA), on aluminum samples and PTM (M1 technology demonstrator):
  - Mirrors substrate thermal stabilization
  - Machining and polishing
  - Optical coating qualification



150 mm samples being loaded in a cryochamber (credit: G. Morgante/INAF OASBO)



Loading of the PTM in a cryochamber for testing (credit: CSL)



AFM image of coated sample (Credit: CNR-IFN Padova)

Year 2 Summary of Activites – 1

Ariel Telescope and mirrors opto-mechanical analysis and design

Involvement in the following activities:

- Simulation of the effects of mirrors surface errors on the optical performance of the telescope, to set manufacturing tolerances
- Simulations of mechanical misalignments of the telescope mirrors to set ground alignment tolerances
- STOP analysis
- Preparation of the technical documentation for the Prime Contractor Tender for manufacturing of the Telescope (won by Leonardo S.p.A.)
- Planning and design of the tests to verify the thermal stabilization procedure on additional prototypes of the primary mirror

Year 2 Summary of Activites – 2

Mirrors optical coating qualification and performance assessment

- Validation tests of the coating of the telescope primary mirror prototype. The coating had already been qualified on samples during the previous phase of the mission
- Analysis of the measurements and tests on the samples coated alongside the prototype mirror
- Building of a setup and procedures for review of samples reflectivity, to assess lifetime durability of the coating
- Evaluation of the expected end-of-life throughput performance of the telescope

Telescope Opto-mechanical Analysis

Opto-mechanical design: integration of optics into mechanical structures to form an optical instrument, guaranteeing the shape and position of the surfaces of an optical system

STOP Analysis: analysis of Structural, Thermal and Optical Performance, the iterative analysis and design process to reach optical performance requirements from mechanical and optical design review

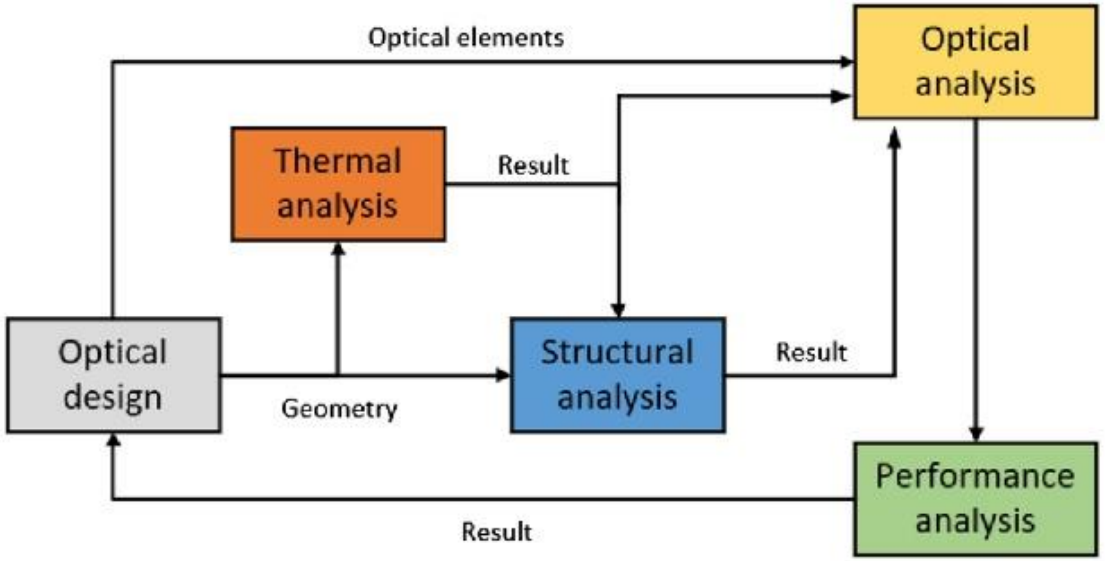


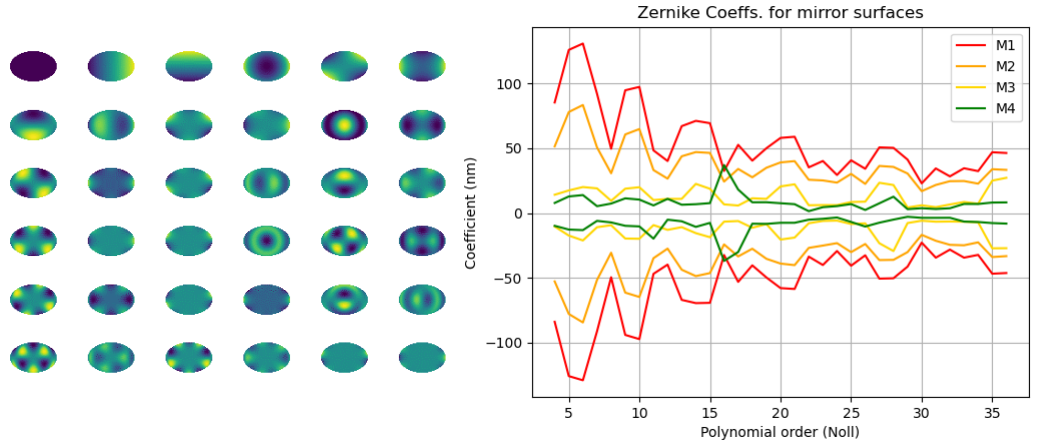
Diagram of STOP Analysis process flow

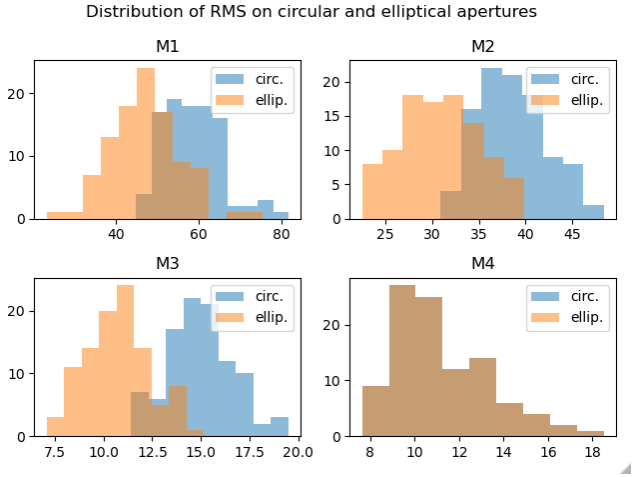
Telescope Opto-mechanical Analysis

Statistical analysis of the effects of mirrors surface errors on the Telescope optical performance

- Each mirror represented as sum of Zernike polynomials
- Inverse sensitivity analysis to find initial tolerances
- MonteCarlo analysis with Zernike coefficients sampled randomly from initial tolerances
- Telescope performance (PSF Encircled Energy) computed for each random realization
- Statistical analysis of results

Zernike polynomials on elliptical aperture (left) and coefficients from inverse sensitivy analysis (right)



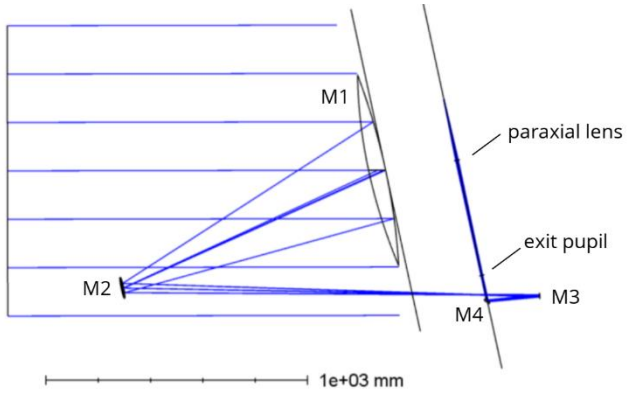


Histograms of RMS distributions of MC realizations for each mirror

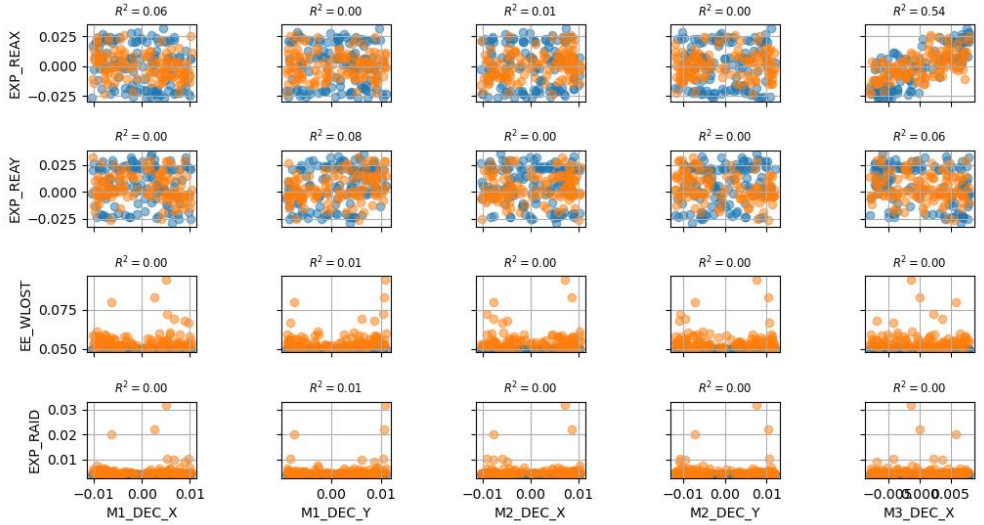
Telescope Opto-mechanical Analysis

Statistical simulation of the effects of mirrors displacements on Telescope optical performance

- Flight case: analysis of the effects of mirrors displacements during flight from MonteCarlo simulation
- Each case is optimized using compensators (M2 adjustment mechanism and line-of-sight tilt)
- Targets: Telescope performance (Encircled Energy), exit pupil displacement



Ariel Telescope optical layout

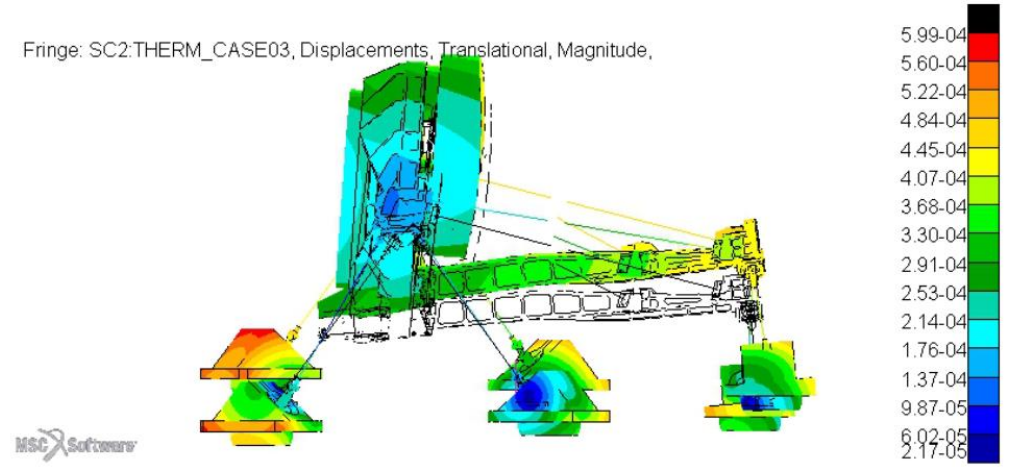


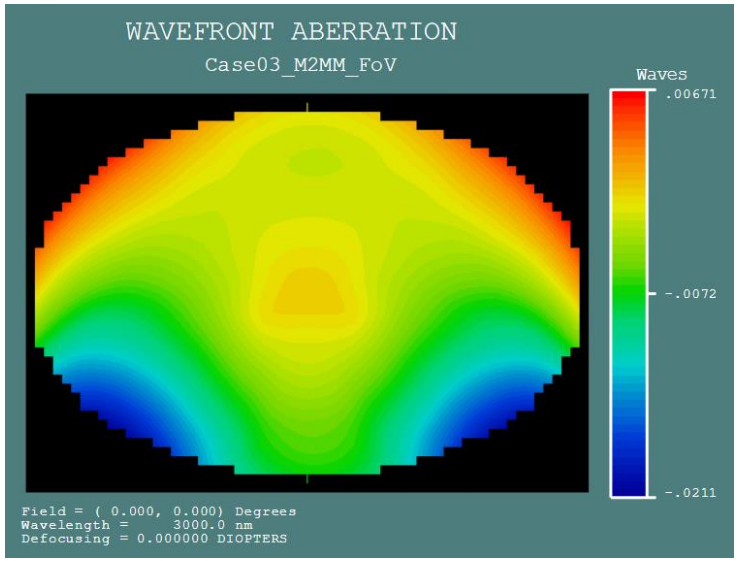
Correlation matrix of tolerance parameters and performance targets

Telescope Opto-mechanical Analysis

STOP Analysis

- Analysis of thermo-mechanical deformations of the Telescope assembly under various conditions
- The deformations are then applied to the optical model to assess the impact on performance
- STOP Analysis results are then fed back to mechanical teams for design refinement



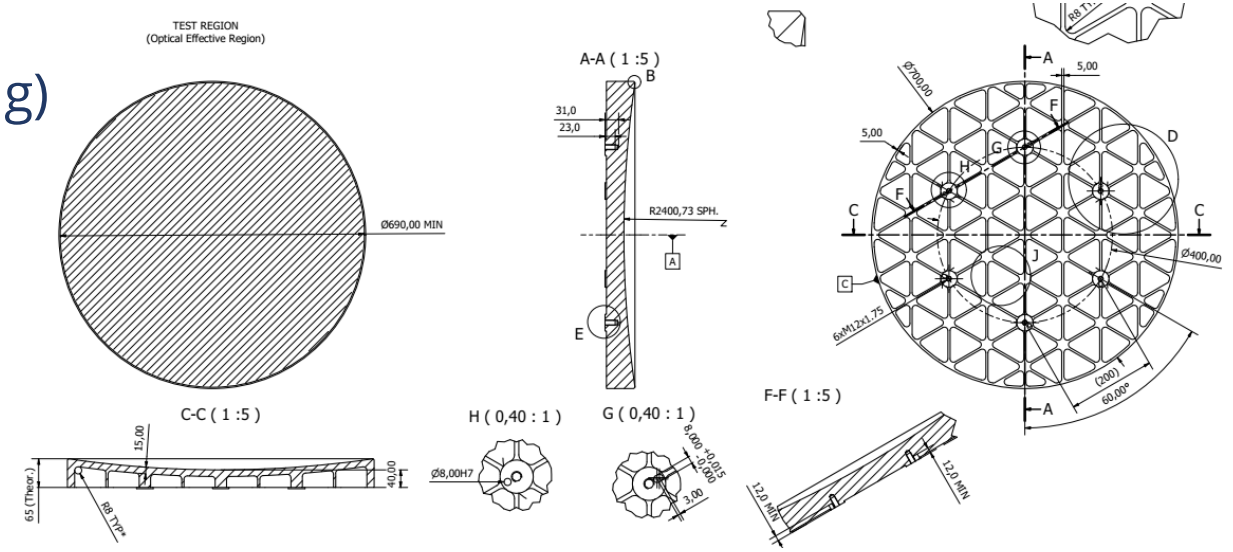


Analysis of thermo-elastic deformation through FEM (top) and optical performance (bottom). Credit: Universidad Politecnica de Madrid, Centre Spatial de Liege

Telescope Opto-mechanical Analysis

Verification of the thermal stabilization procedure on the new prototypes of the primary mirror for phase B2 of the mission

- Continuation of the Technology Development Assessment program started during phase B1
- Two additional demonstrators of primary mirror manufacturing technologies
  - Machining (Single Point Diamond Turning)
  - Polishing
  - Substrate thermal stabilization

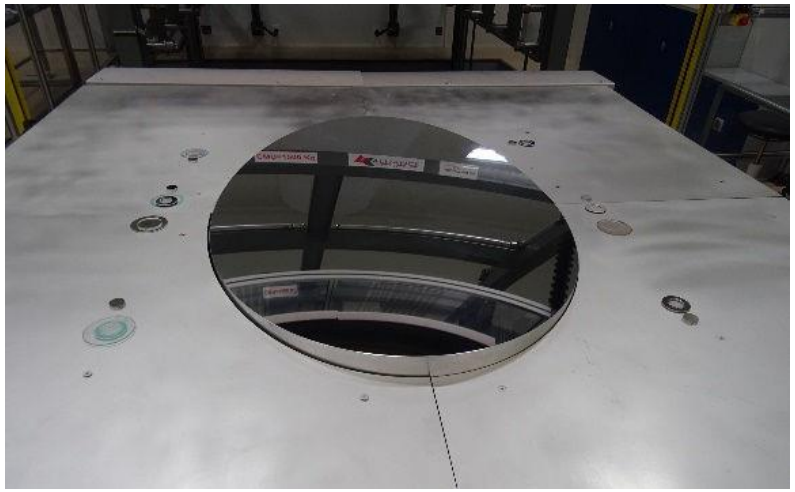


M1 Phase B2 Breadboard draft drawing (Credit: L. Carbonaro, INAF)

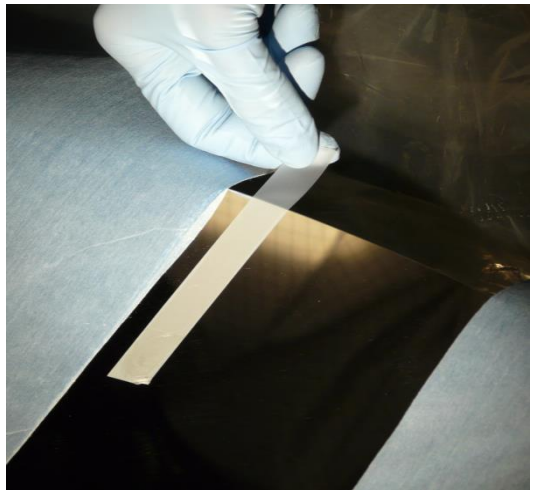
Optical Coating Qualification

Coating of the Primary Mirror demonstrator

- Verification of coating process consistency on samples
- Coating durability tests on the demonstrator



M1 Demonstrator and samples on the coating tray (Credit: CILAS Arianespace)



Adhesion test on the M1 Demonstrator (Credit: MediaLario)

Samples with * are kept as aging references	Cleanability	Abrasion	Temperature	Humidity	Adhesion
Sample 14*					
Sample 15*					
Sample 16	✓	✓			
Sample 18			✓	✓	✓
Sample 19			✓	✓	✓
Sample 20			✓	✓	✓
PTM					✓

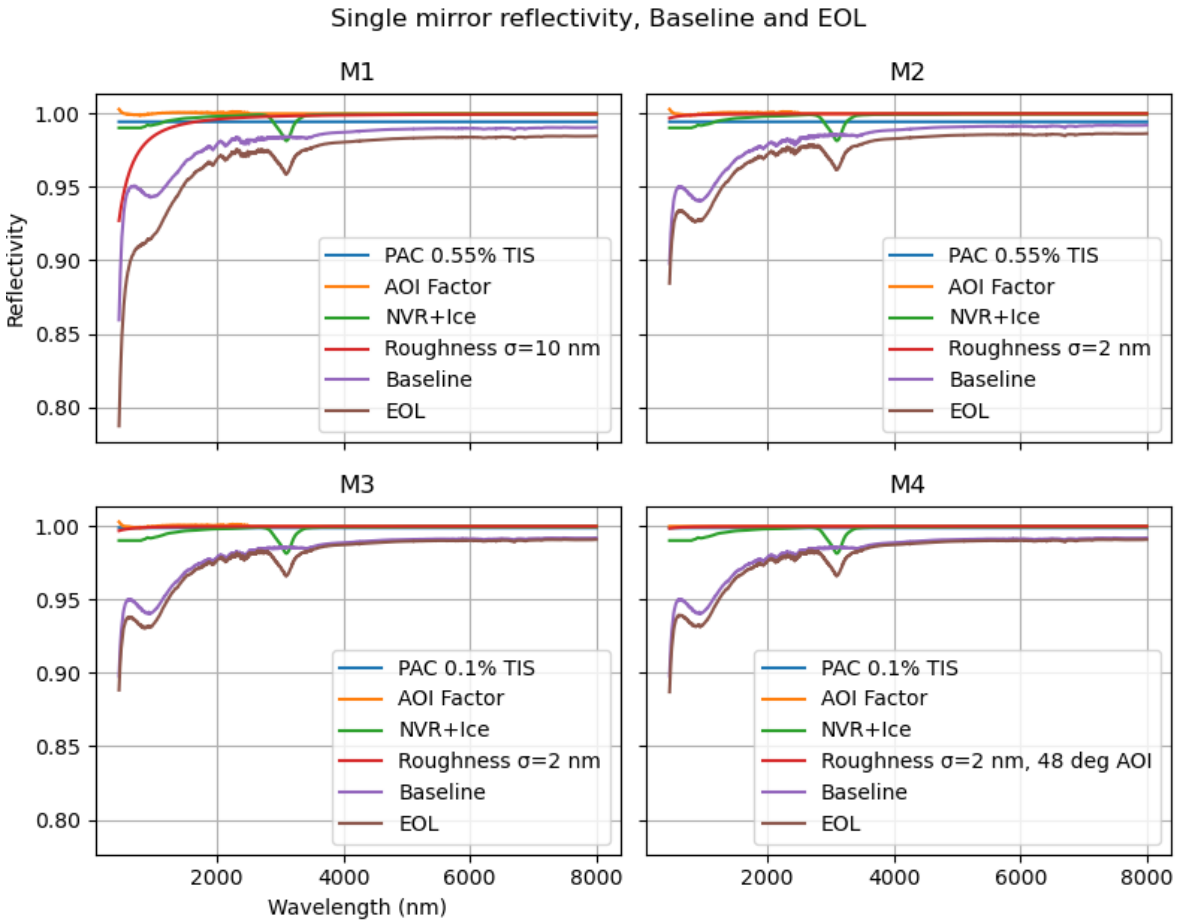
Coating test matrix

Telescope Throughput Model

Update of the Telescope throughput model

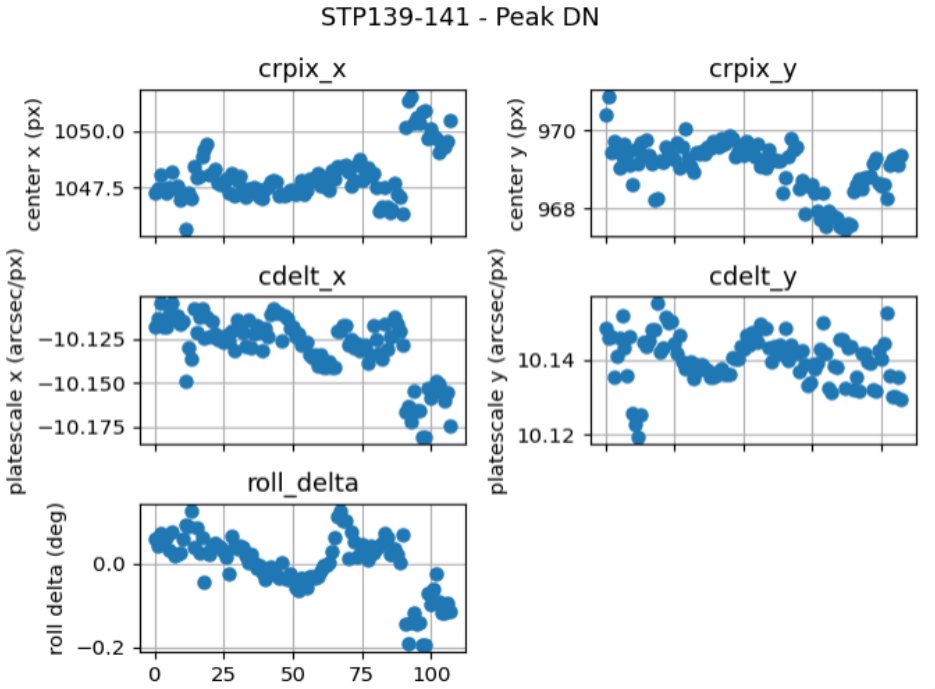
Evaluation of the expected end-of-life throughput performance of the telescope

- using measured reflectivity data from coating qualification
- scattering losses from surface roughness and particulate contamination
- absorption losses from molecular contamination



Work on Other Missions

- Review of the opto-mechanical design and analysis of the Visible Channel of Metis[1], and the Optical Head of EnVisS[2].
- Design and development of a tool to automatically identify visible stars on Metis images from the commissioning phase. Estimation of WCS transformation sets to map image pixels to celestial coordinates from large collection of images.



Geometric calibration parameters for a series of Metis Images

[1] PI: Prof. Marco Romoli, Università degli Studi di Firenze, Italy

[2] PI: Dr. Vania Da Deppo, CNR-IFN Padova, Italy

Publications

Technical Reports

1. Chioetto, P., Zuppella, P., Coating Qualification Review, INAF-CSL-COA-RP-005, Ariel Payload Consortium Phase B2 Study Report (2020)
2. Chioetto, P., A semi-automated stars discovery and catalog system for Metis images, CNR-IFN-PD-METIS-IR-01, CNR-IFN Technical Report, Prot. 1038_070421 (2021)
3. Chioetto, P., Ariel Telescope Throughput Budget Calculations, ARIEL-CNR-PL-ML-001, Ariel Payload Consortium Phase B2 Study Report (2021)
4. Zuppella, P., Brienza, D., Chioetto, P., ARIEL - TA Critical Item / Long Lead Item List, ARIEL-CNR-PA-LI-001, Ariel Payload Consortium Phase B2 Study Report (2021)
5. Zuppella, P., Brienza, D., Chioetto, P., ARIEL - TA Qualification Status List (QSL), ARIEL-CNR-PL-LI-002, Ariel Payload Consortium Phase B2 Study Report (2021)
6. Zuppella, P., Chioetto, P., Brienza, D., ARIEL - TA Dependability and Safety Analysis Report, ARIEL-CNR-PA-AN-001, Ariel Payload Consortium Phase B2 Study Report (2021)
7. Tozzi, A., ARIEL Telescope Assembly Budgets Report, ARIEL-INAF-PL-RP-001, Ariel Payload Consortium Phase B2 Study Report (2021)
8. Brienza, D., PA requirements from PTM lessons learnt, ARIEL-INAF-PL-RS-005, Ariel Payload Consortium Phase B2 Study Report (2021)
9. Tozzi, A., TA Aluminium Procurement and De-Risking process, ARIEL-INAF-PL-TN-014, Ariel Payload Consortium Phase B2 Study Report (2021)
10. Diolaiti, E., Cortecchia, F., Lombini, M., Brienza, D., Chioetto, P., et al, Telescope Assembly AIT Plan, ARIEL-INAF-PL-PL-013, Ariel Payload Consortium Phase B2 Study Report (2021)
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2. Da Deppo, V., Pernechele, C., Jones, G. H., Brydon, G., Zuppella, P., **Chioetto, P.**, Nordera, S., Slemer, A., Crescenzio, G., Piersanti, E., Spanò, P., Bucciol, G., Consolaro, L., Lara, L. and Slavinskis, A., "The optical head of the EnVisS camera for the Comet Interceptor ESA mission: phase 0 study", Proc. SPIE 11443, Space Telescopes and Instrumentation 2020: Optical, Infrared, and Millimeter Wave, 1144379 (13 December 2020); https://doi.org/10.1117/12.2562907
3. Grimani, C., Andretta, V., **Chioetto, P.**, Da Deppo, V., Fabi, M., Gissot, S., Naletto, G., Plainaki, C., Romoli, M., Spadaro, D., Stangalini, M., Telloni, D. and Uslenghi, M., "A Radiation Environmental Study for the Metis Coronagraph on board Solar Orbiter", presented at AGU Fall Meeting 2020 (14 December 2020).
4. Casini, C., Da Deppo, V., Zuppella, **P., Chioetto**, P., Slemer, A., Frassetto, F., Romoli, M., Landini, F., Pancrazzi, M., Andretta, V., De Leo, Y., Bemporad, A., Fabi, M., Fineschi, S., Frassati, F., Grimani, C., Jerse, G., Heerlein, K., Liberatore, A., et al., "On-ground flat-field calibration of the Metis coronagraph onboard the Solar Orbiter ESA mission", Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020, 118525B (11 June 2021); https://doi.org/10.1117/12.2599945
5. **Chioetto, P.**, Zuppella, P., Da Deppo, V., Nordera, S., Pace, E., Tozzi, A., Morgante, G., Terenzi, L., Brienza, D., Missaglia, N., Bianucci, G., Spinelli, S., Guerriero, E., Rossi, M., Grisoni, G., Bondet, C., Chauveau, G., Porta, C., Grezes-Besset, C., et al., "Test of protected silver coating on aluminum samples of ARIEL main telescope mirror substrate material", International Conference on Space Optics — ICSO 2020, 165, SPIE, Online Only, France (2021); https://doi.org/10.1117/12.2599794
6. Da Deppo, V., **Chioetto, P.**, Andretta, V., Casini, C., Frassetto, F., Slemer, A., Zuppella, P., Romoli, M., Fineschi, S., Heinzel, P., Naletto, G., Nicolini, G., Spadaro, D., Stangalini, M., Teriaca, L., Bemporad, A., Casti, M., Fabi, M., Grimani, C., et al., "In-flight optical performance assessment for the Metis solar coronagraph", Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020, 1185210 (11 June 2021); https://doi.org/10.1117/12.2599220
7. Nordera, S., **Chioetto, P.**, Zuppella, P., Pace, E., Morgante, G., Tozzi, A., del Vecchio, C., Scippa, A., Micela, G. and Da Deppo, V., "Methodology for the analysis of a thermo-mechanically deformed optical system", Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020, 1185250 (11 June 2021); https://doi.org/10.1117/12.2599824
8. Pernechele, C., Da Deppo, V., Consolaro, L., Jones, G. H., Brydon, G., Zuppella, P., **Chioetto, P.**, Nordera, S., Lara, L. M. and Slavinskis, A., "The fisheye of the comet interceptor's EnVisS camera", Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020, 118524V (11 June 2021); https://doi.org/10.1117/12.2599817
9. Da Deppo, V., Jones, G., Brydon, G., Pernechele, C., Zuppella, P., Nordera, S., Tubiana, C., Della Corte, V., Fulle, M., Bertini, I., **Chioetto, P.**, Castro, J. M., Lara, L. M., Slavinskis, A., Praks, J., Rotundi, A., "The EnVisS camera for the Comet Interceptor ESA mission", European Planetary Science Congress 2021, online, 13–24 Sep 2021, EPSC2021-101, (2021); https://doi.org/10.5194/epsc2021-101
10. Da Deppo, V., Nisticò, G., Giordano, S., Battams, K., Gallagher, B., and **Chioetto, P.** and the Metis "Comets and other Solar System Bodies" Topical Team, "Observing comets with the Metis coronagraph on-board the Solar Orbiter mission", European Planetary Science Congress 2021, online, 13–24 Sep 2021, EPSC2021-394 (2021); https://doi.org/10.5194/epsc2021-394
11. Tinetti, G. et al., "Ariel: Enabling planetary science across light-years", Ariel Definition Study Report-Ariel Redbook (2020); https://arxiv.org/abs/2104.04824
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13. Grimani, C., Andretta, V., **Chioetto, P.**, et al., "Cosmic-ray flux predictions and observations for and with Metis on board Solar Orbiter", submitted to Astronomy & Astrophysics, accepted for publication.

Conclusions

Next Steps

- Ongoing work on Telescope design, tolerance analysis and STOP analysis
- Phase B2 M1 prototypes manufacturing and testing
- Study of ageing in storage of coated samples for environmental stability
- Thesis writing