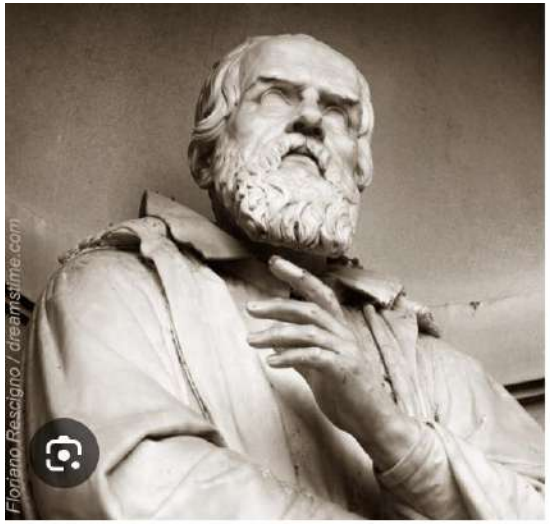
HWO and its optics system

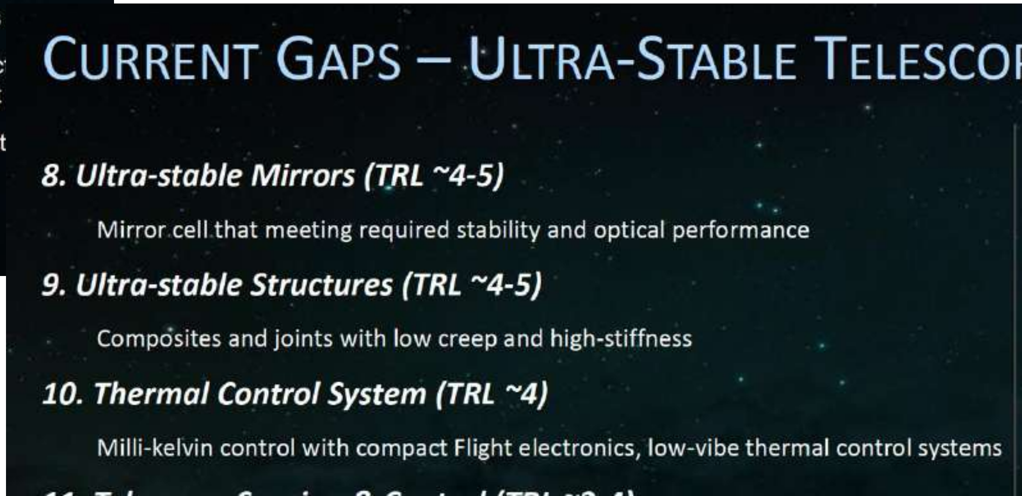
requirements, challenges and possible Italian/European contributions

Giovanni Pareschi

INAF – Osservatorio Astronomico di Brera



Shaping the Italian contribution to HWO workshop
Roma, 11 July 2025



Credits: Lee Feinberg

HWO optics cost model

(merely the reflecting surface)

EAC Primary Mirror ‘relative’ Size

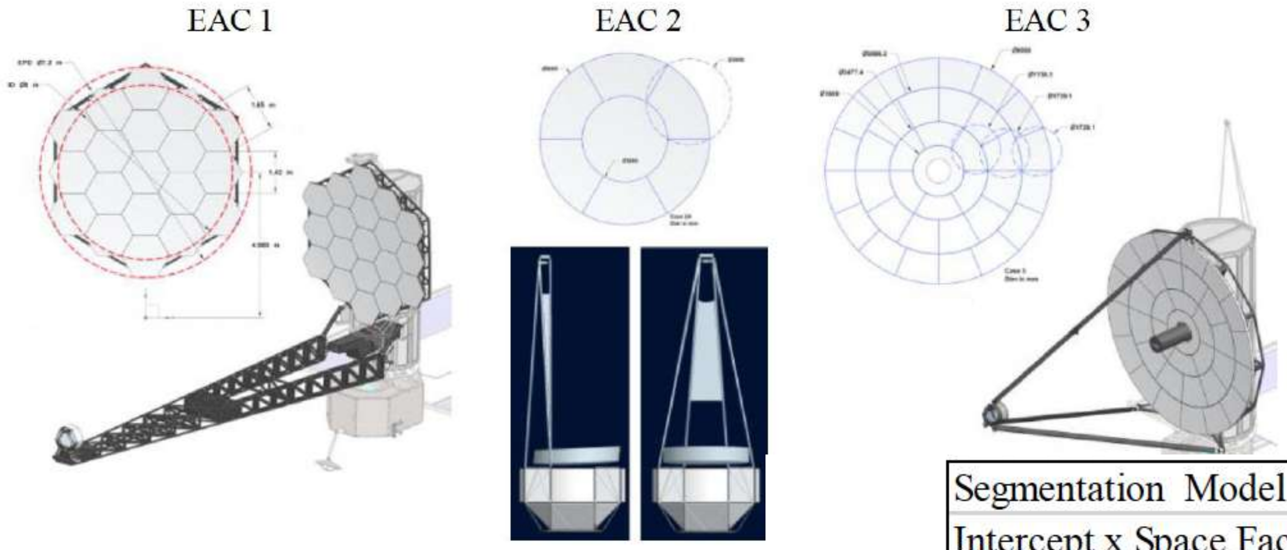


Figure 5: Current Habitable Worlds Observatory E:

Segmentation Model	Model	EAC-1	EAC-2	EAC-3
Intercept x Space Factor	750			
Nseg	0.8	19	7	35
Dseg [m]	1.7	1.8	3	1.8
WDLP [micrometer]	-0.5	0.4	0.4	0.4
Temperature [K]	-0.25	260	260	260
exp(YOD)	0.028	2030	2030	2030
50% Predicted Cost [CY$M]		$ 1,423	$ 1,525	$ 2,319
85% Predicted Cost [CY$M]	145%	$ 2,063	$ 2,211	$ 3,363

Figure 7: Segmented Primary Mirror Telescope Cost Model for HWO EAC-1, -2, & 3

H. Ph. Stahl, Variations of Parametric Cost Models for Ground and Space Telescopes, SPIE Proc, 2024 »NASA Marshall model»

Why Italy in the HOW optics stuff?

- Italy alone can’t afford a contribution to the HWO optics system & mirrors' final implementation
- Moreover, the R&D process in US has already started

HOWEVER

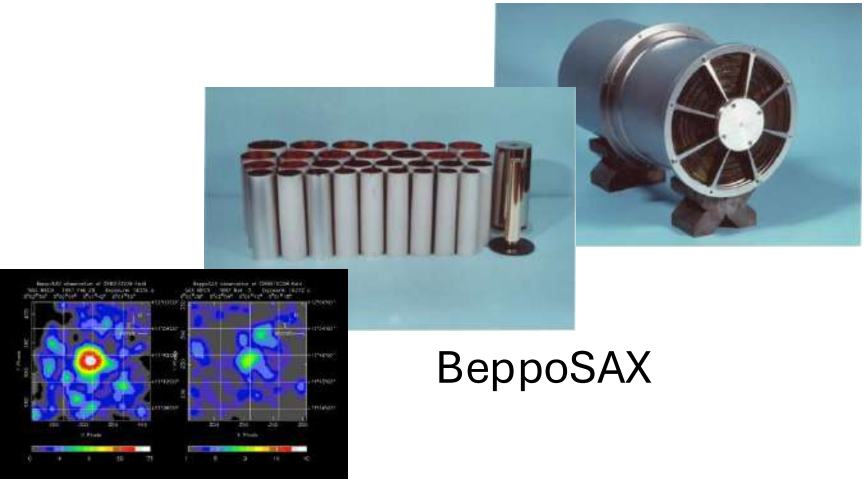
➔important heritage in space optics in Italy, including industrial partnerships (Media Lario, Leonardo, Officine Stellari, BCV...)

Fundamental Italian contribution also to the development of the optics systems of large missions like XMM-Newton

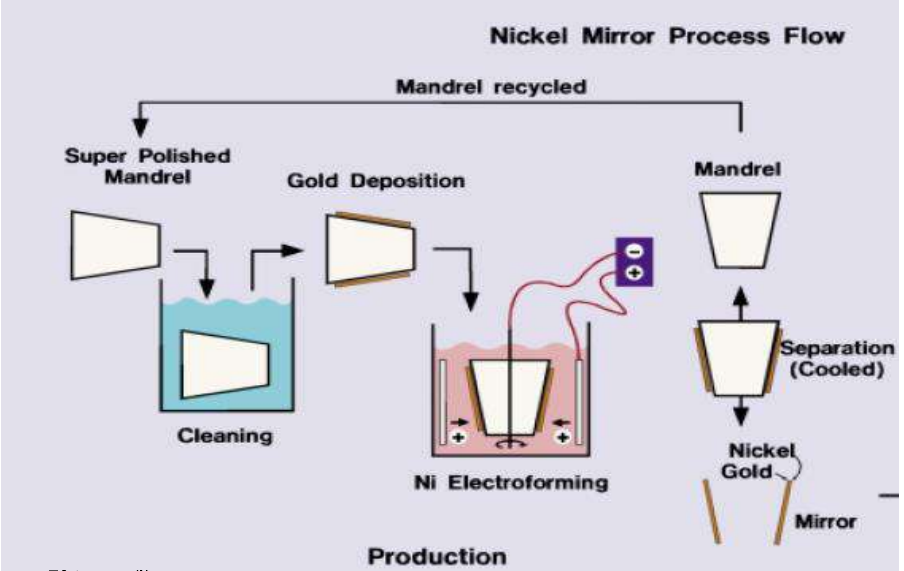
- ESA partnership!!!

- Excellent past collaboration of Italy (ASI+INAF) with NASA for optics (Swift XRT, MUSE UV telescopes), also for big missions (LYNX NASA/MSFC + ASI-INAF design and development)

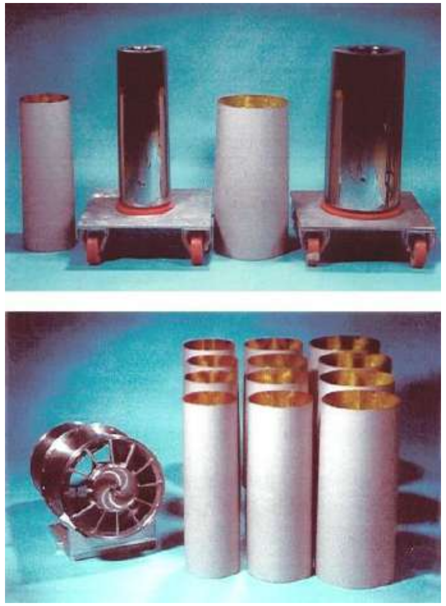
From BeppoSAX to XMM-Newton



BeppoSAX



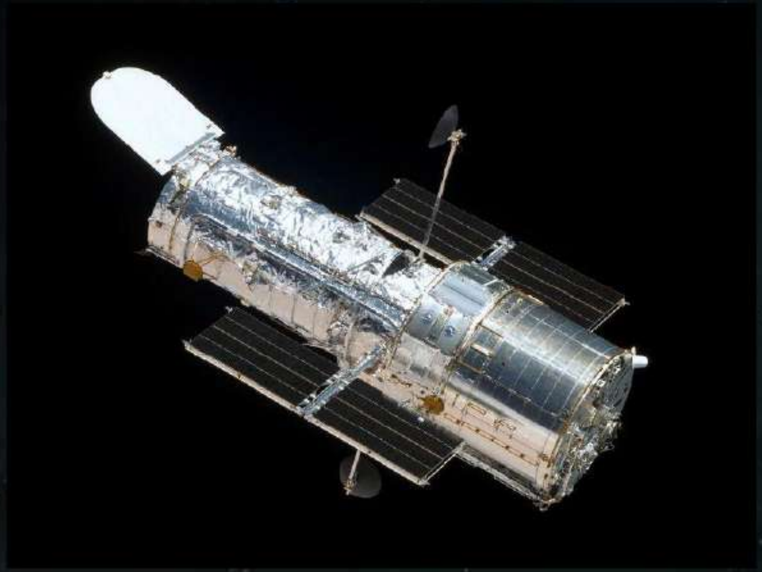
ESA credits



Jet-X/Swift

XMM-Newton

HISTORY OF LARGE (>1M) UVOIR SPACE TELESCOPES



Hubble Space Telescope

11,600 kg
Diffraction limited at 0.5 μm (post correction)
2.4 m Corning ULE Glass mirror
293K ± .1K
Space Shuttle

James Webb Space Telescope

6310 kg
Diffraction limited at 0.9 μm (reqt 2 μm)
6.5m semi-rigid Be segmented mirror
30-55K ± .15K (passive)
Ariane 5

Roman Space Telescope

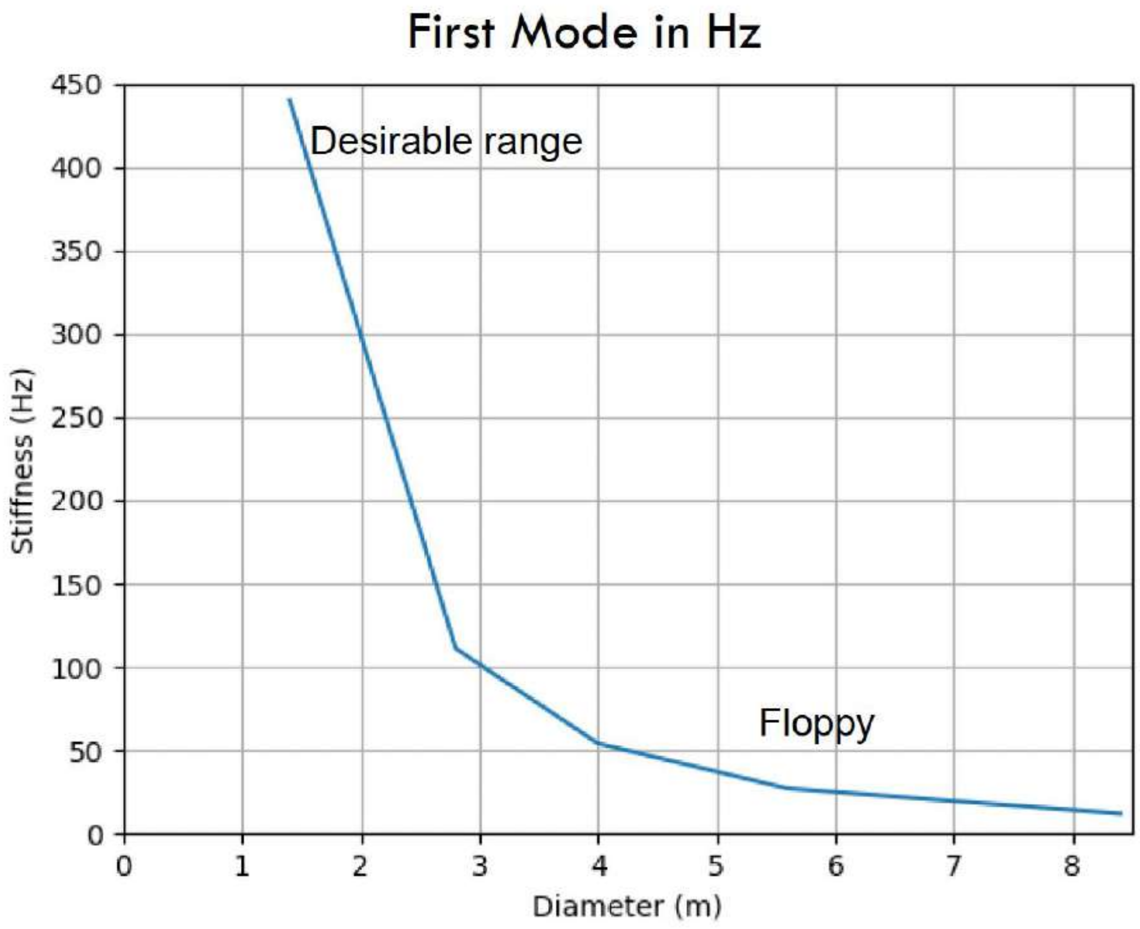
Mass Allowable: 10,000 kg
Diffraction limited at ~1.2 μm
2.4m Corning Ultra Low Expansion (ULE Glass) mirror
Mirror temp 265K ± 0.001K (active control)
Falcon 9H

Credits: Lee Feinberg

HABITABLE WORLDS OBSERVATORY (HWO)

- Aperture ~6 m diameter, 0.3 mas stability
- Diffraction-limited image quality at 0.5 μm
- Operating temperature of -30°C to 20°C
  - colder temperature shifts thermal emission farther into NIR. Cold mirrors require special consideration in mounting/flexures/strain/polymers
- Enhanced UV performance, goal of 100 nm cutoff (Lyman UV lines for H_2 and CO)
  - Enhanced FUV coatings needed to achieve 100nm cutoff
  - Low microroughness
- Thermal control ~ mK
- Compatibility with future launchers (Blue Origin New Glenn, NASA SLS, Space X Starship)

MIRROR STIFFNESS SCALES WITH DIAMETER



- A stiffer mirror is highly desirable to prevent deformation caused by dynamic inputs or strain from the back.
- An example based on a 15 kg/m2 areal density shows that this depends on the mirror's construction, making it a notional figure.
- You can produce a thicker, stiffer mirror; however, mirror manufacturing with ULE and Zerodur materials limits the thickness and, therefore, the stiffness.
- Borosilicate can be made thicker depending on the mass, but it would exceed what is feasible for New Glenn.

Credits: Lee Feinberg

Why segments?

- The mirror itself can be very stiff because of its smaller size (scales non-linearly), and the backplane can be stiffened through increased depth

- The mount architecture, coarse actuator, wavefront sensing and control, error budgeting, alignment, gravity approach, segment metrology, and system-level verification of the telescope leverage JWST experience

- The JWST AMSD mirror was made of ULE and reached TRL5, and a mount design was also developed. Zerodur and ULE are both options.

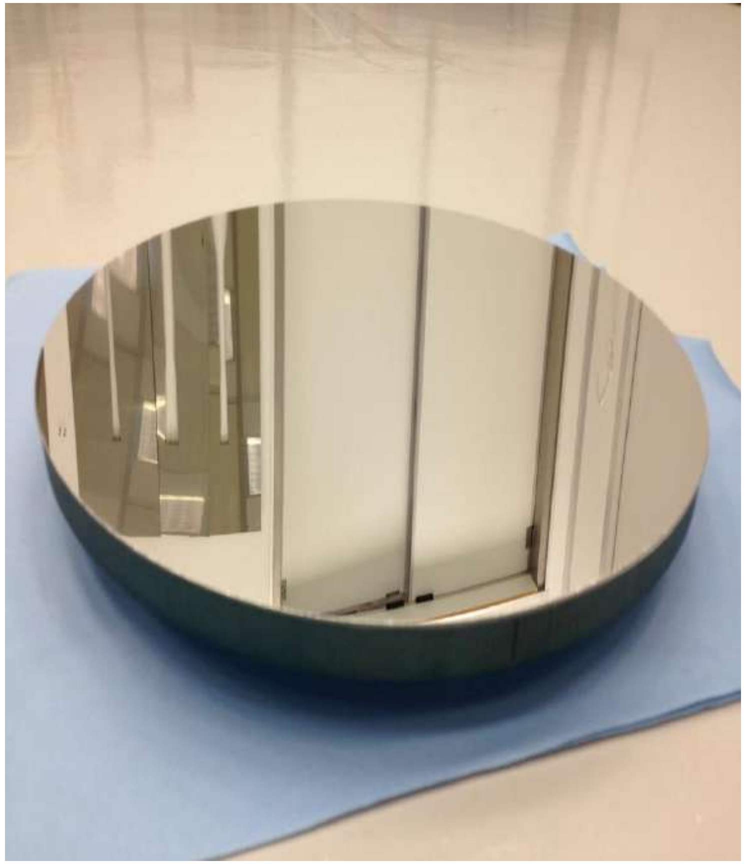
Key dicriminators for mirror fabrication approaches

configurations and glasses

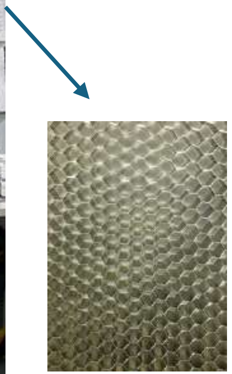
	ULE or Zerodur Monolith	Thick Borosilicate Monolith	Segmented ULE or Zerodur
Compatible with both large fairings in devpt (both New Glenn and Starship)	↓	↓	↑
Low CTE (ultra thermal stability)	↑	↓	↑
High stiffness (insensitive to dynamics, lurches from the back)	↓	↑	↑
Compatible with enhanced LiF FUV coating (to 100nm)	↓	↑	↑
Can work with 10^10 contrast, off axis	↑	↓	↑
Allows for flexibility on aperture size	↓	↓	↑
Stepping stone to future larger telescopes	↓	↓	↑

Credits: Lee Feinberg

INAF past experiences with lightweight optics



Space foamed Optics, 380 mm
Aereal Density 10 kg/m^2, rms figure 50 nm



Cherenkov LST/CTAO mirror
(core of Al hexacell)

Osservatorio Astronomico di Brera INAF

Media Lario

BCV progetti s.r.l

Proposed technology:

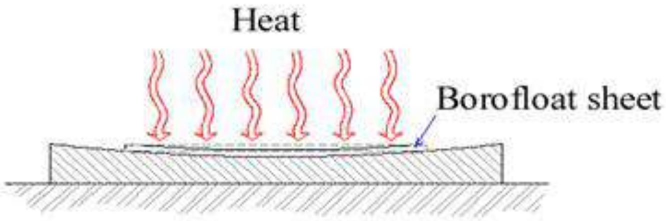
sandwiched glass mirrors made through a «hybrid» method

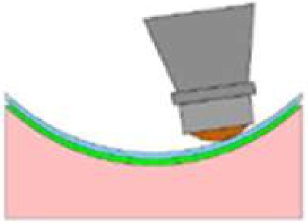
- Why Glass and not glass-ceramics (e.g. Zerodur):
  - Hot shaping possible (molding temp: borosilicate 700 ^{o}C, Fused Silica/ULE’: 1000 ^{o}C)
  - Amorphous: much easier superpolishing (UV grade!, < 2 nm rms roughness) and ion beam figuring correction.

- Why hybrid:
  - combination of pre-shaping via hot slumping + polishing + replication sandwiching and IBF correction processes

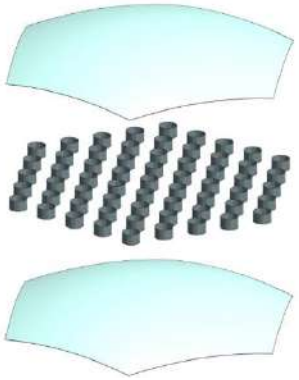
Process steps

- Shaping via hot Slumping

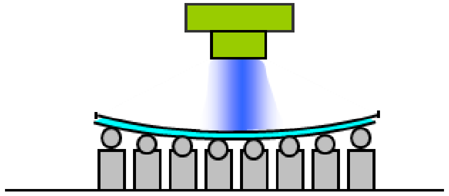




- Correction of the surface slabs via bonnet polishing using INAF's developed method for thin foils.

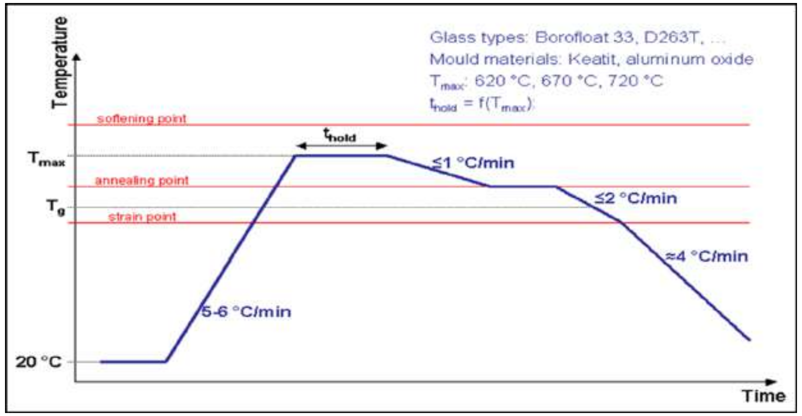


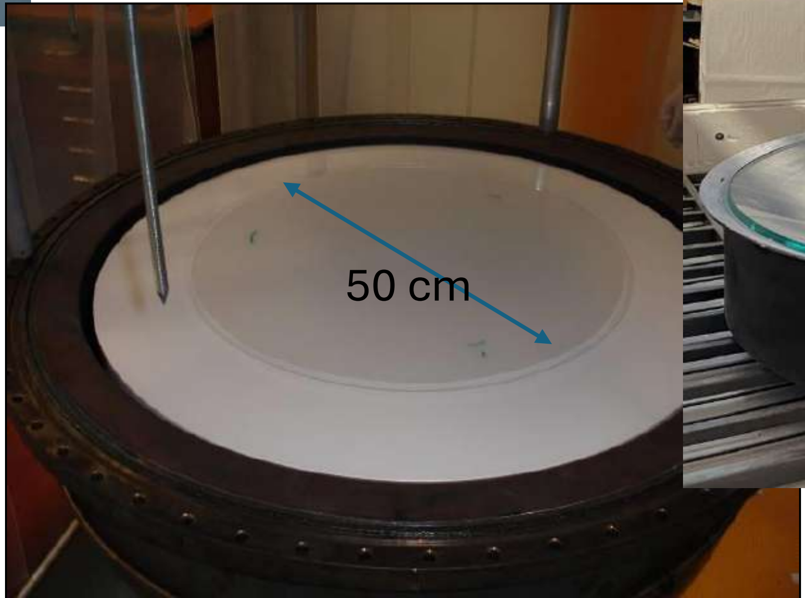
- Gluing of the spacers for making the sandwich

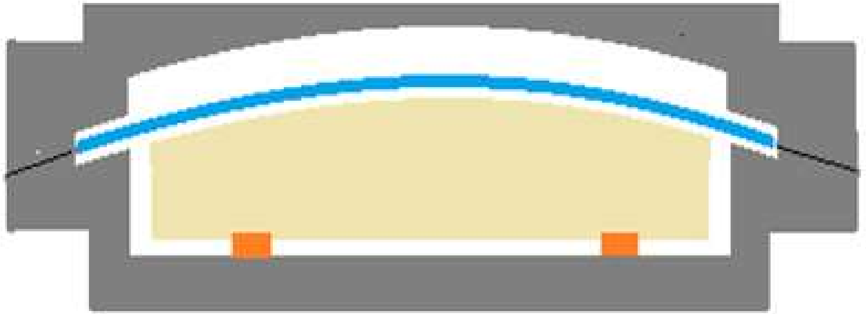


- Final correction with ion beam figuring, which also removes the spacers' print.

Pre-shaping by Hot slumping

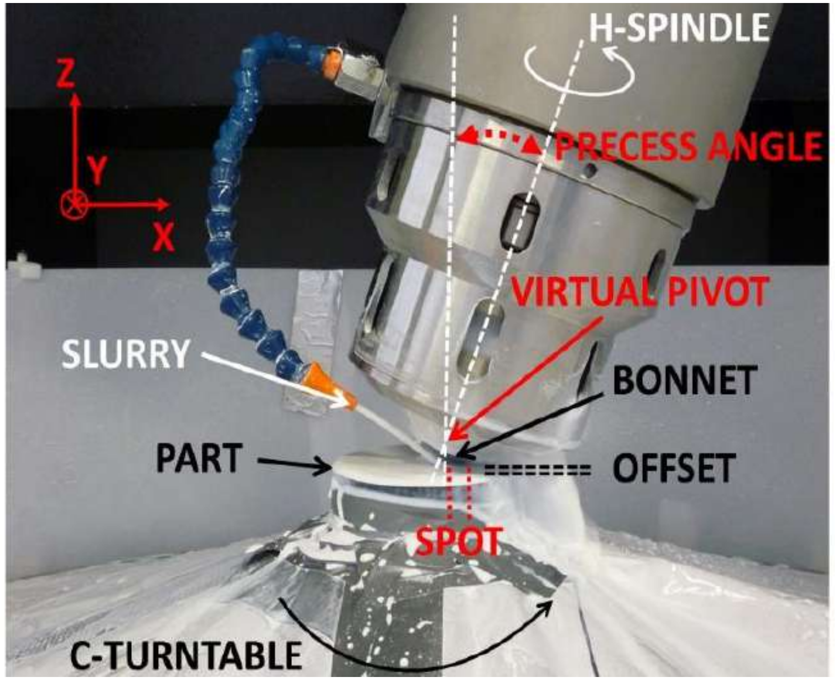






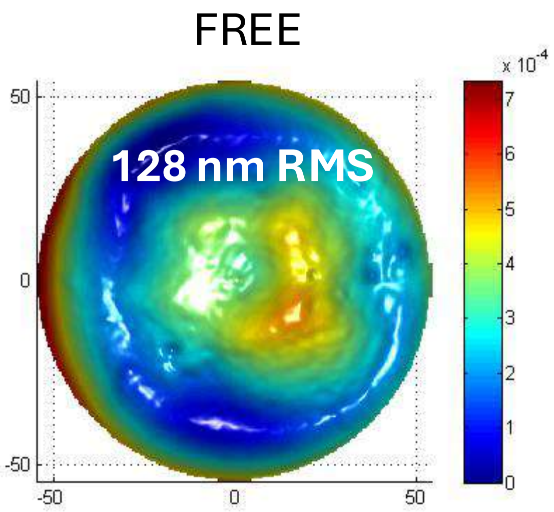
Bonnet Polishing/Figuring Technology

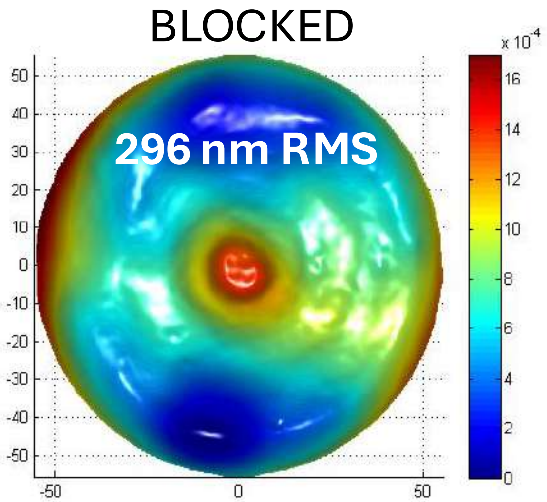
IRP1200 by Zeeko Ltd. is a 7 axis CNC machine @INAF/Brera

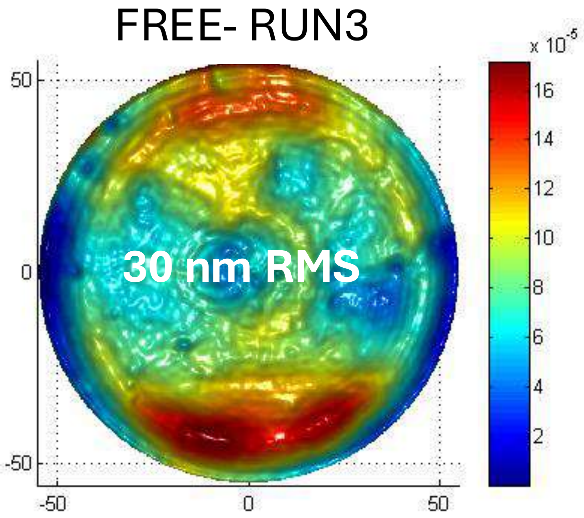


- The bonnet is an inflated spinning tool in contact with the optical surface and abrasives
- The bonnet is a compliant tool that conforms to the local aspheric shape of the surface
- Required accurate tool positioning and motion to guarantee the process consistency

Temporary stiffening of the thin shell and then release







Repeatability ~20 nm RMS

- Removal is deterministic (predictable) if the tool maintains a constant fit to [illegible] and all process parameters remain stable during polishing

- The blocking process does not deform as respect to the free standing error map. Otherwise, the applied offset (area of spot size) will be function of the deformation map

G. Vecchi, S. Basso, M. Civitani, M. Ghigo, G. Pareschi & B. Salmaso, CEAS Space Journal
https://doi.org/10.1007/s12567-019-00259-7, 2019

How to glue the glass cylindrical spacers to the glass slabs

DE GRUYTER
Adv. Opt. Techn. 2014; 3(3): 293–307

Review Article
Open Access

Anna-Maria A. van Veggel* and Christian J. Killow*

Hydroxide catalysis bonding for astronomical instruments

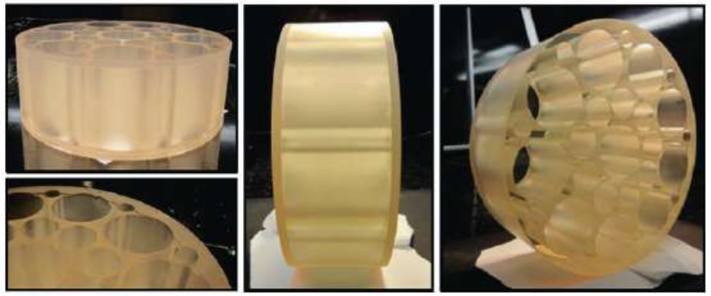
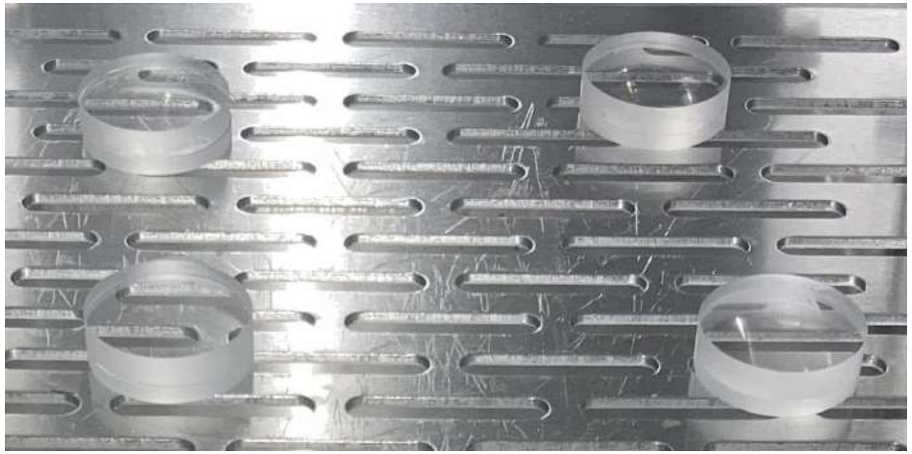


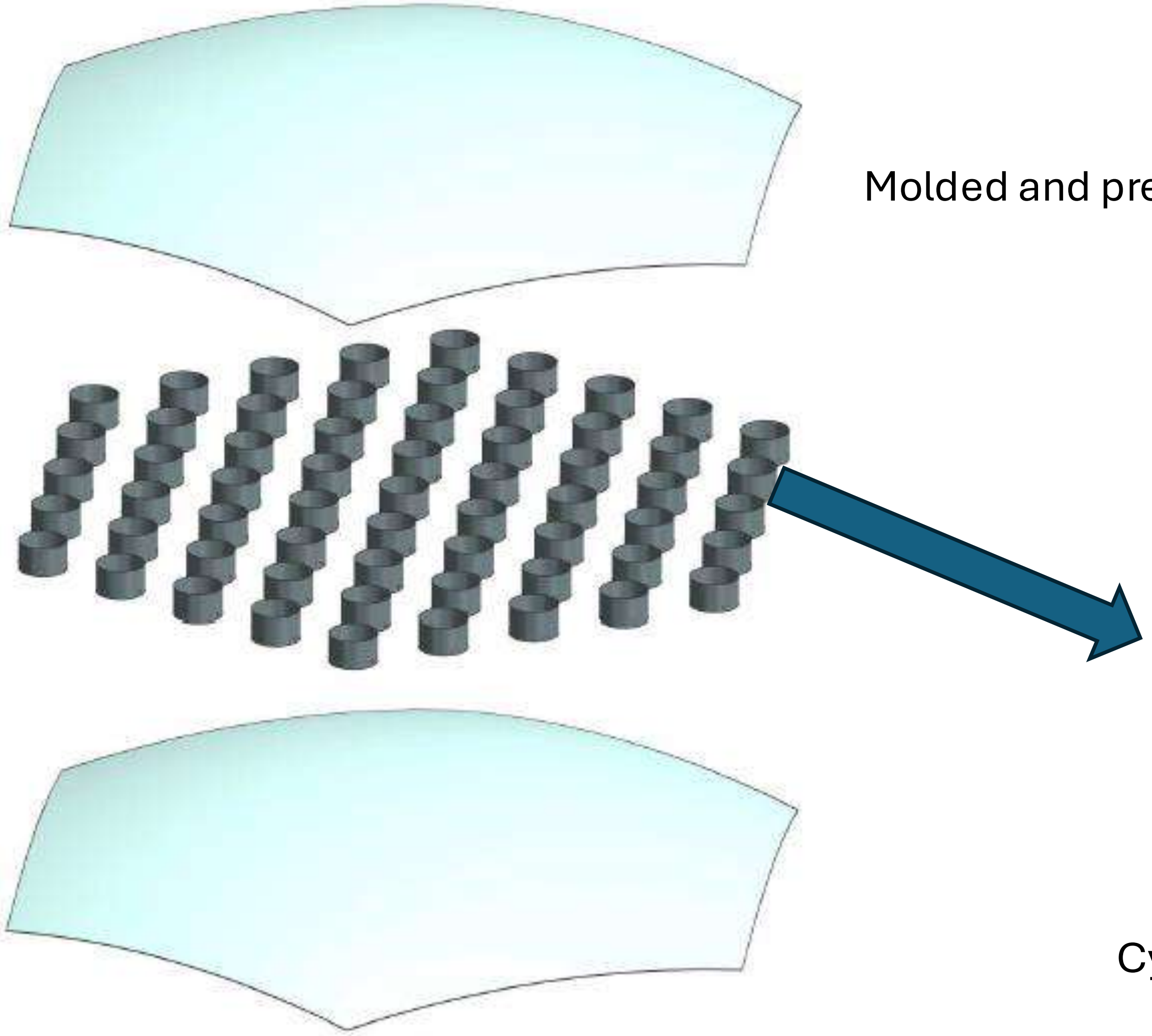
Figure 9 Photographs of a bonded 150 mm diameter lightweight mirror. Two thin slabs of low-expansion material are bonded to a heavily lightweighted middle section and then polished as required. This mirror is uncoated but coatings have been applied to similar mirrors. Pictures courtesy of Gooch and Housego (UK) Ltd.



Now-CB, INAF PRIN Grant, S. Basso/Brera PI

INAF Brera + University/INFN of Ferrara (A. Mazzolari, M. Tamisari

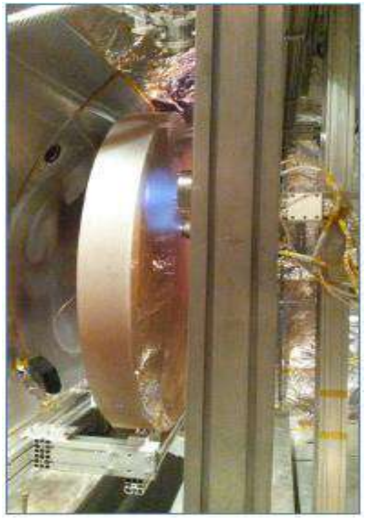
Making the open-structure panel

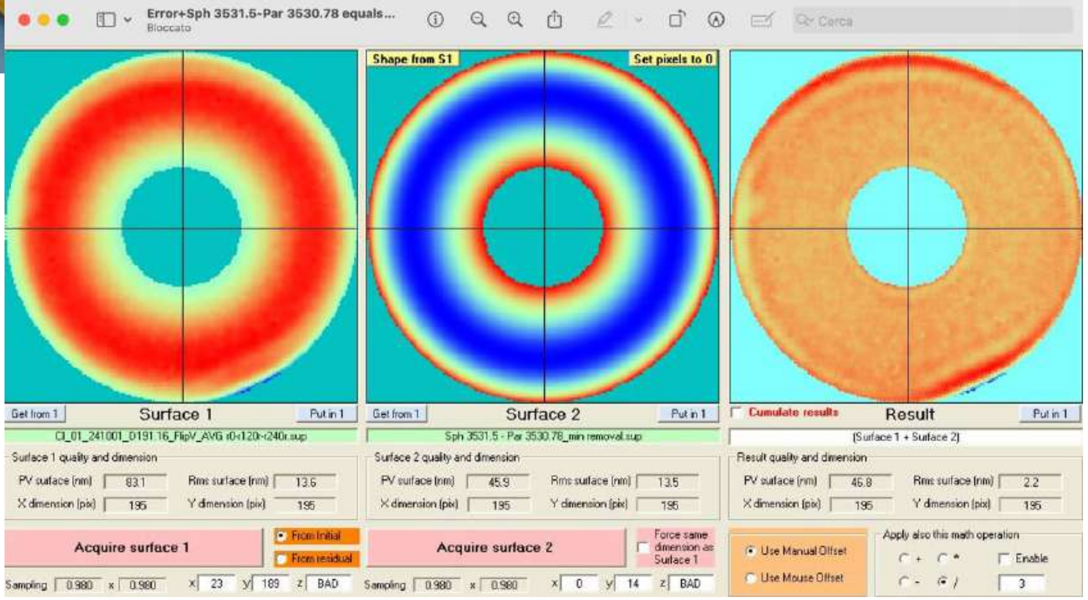


Molded and prepolished glass slab

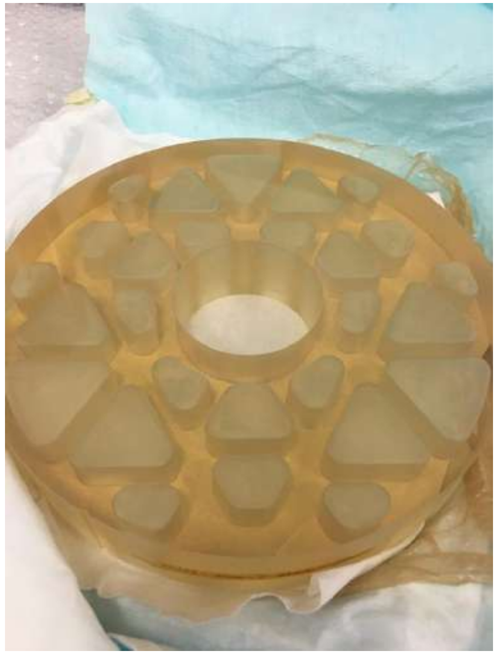
Cylindrical glass spacers

Final correction via Ion-Figuring @INAF/Brera





M. Ghigo, V. Cotroneo, D. Spiga, G. Vecchi

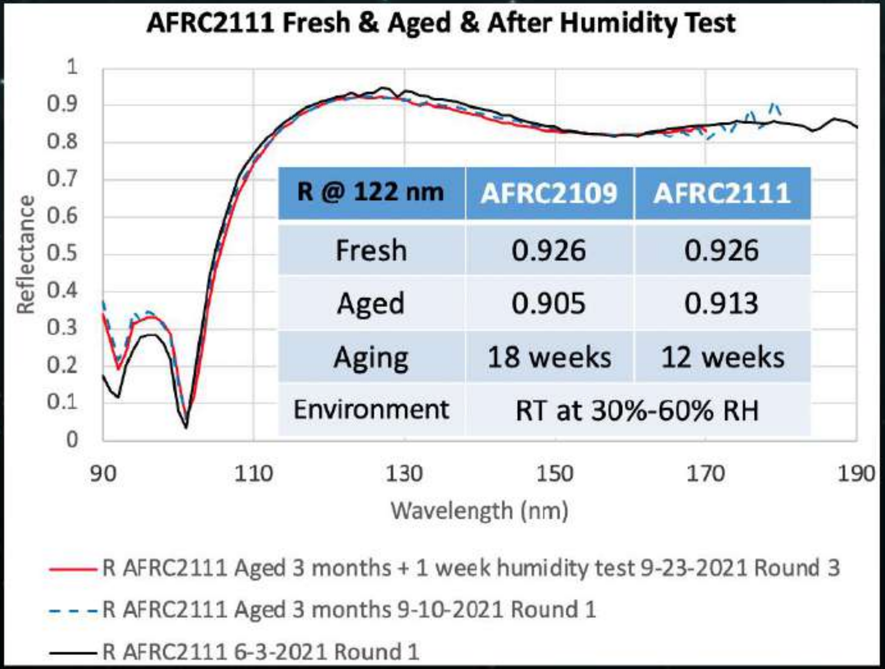


ASI/INAF Contribution to the MUSE UV Solar mission

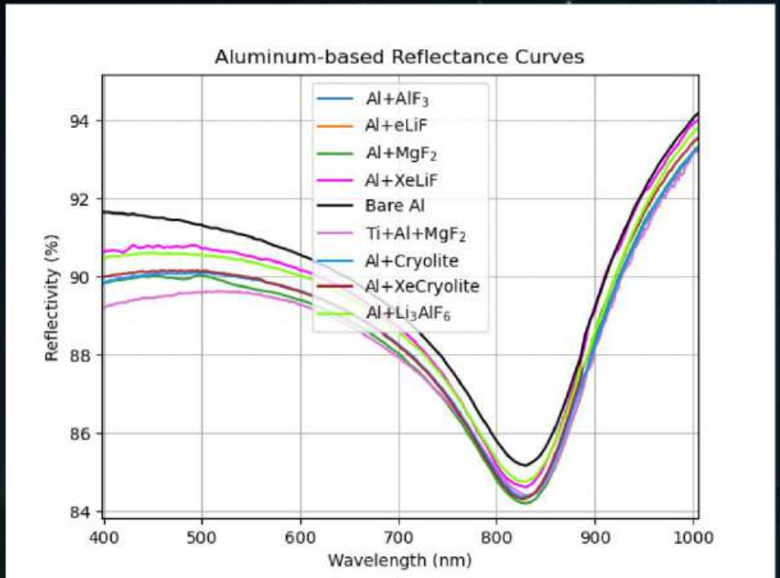
2025: 2 nm rms figure accuracy achieved!!!!

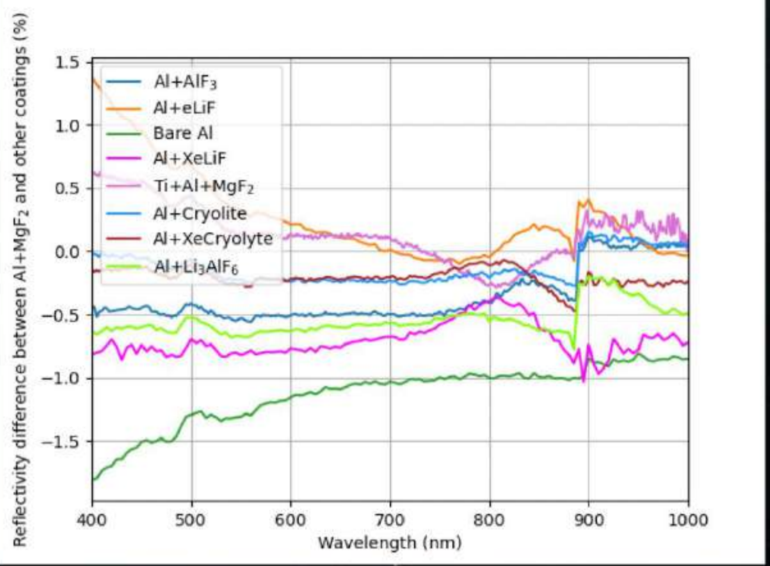
FAR-UV BROADBAND COATINGS

- Aluminum-based coatings can provide high reflectance in the UV (i.e., Al+XeLiF) with excellent aging statistics
- Key Challenges:
  - Scaling up while maintaining high uniformity (2-3%) between segments
  - Need to test surface roughness and coating-induced stresses
  - Full characterization of polarization-induced aberrations



R @ 122 nm	AFRC2109	AFRC2111
Fresh	0.926	0.926
Aged	0.905	0.913
Aging	18 weeks	12 weeks
Environment	RT at 30%-60% RH	





Credits: Lee Feinberg

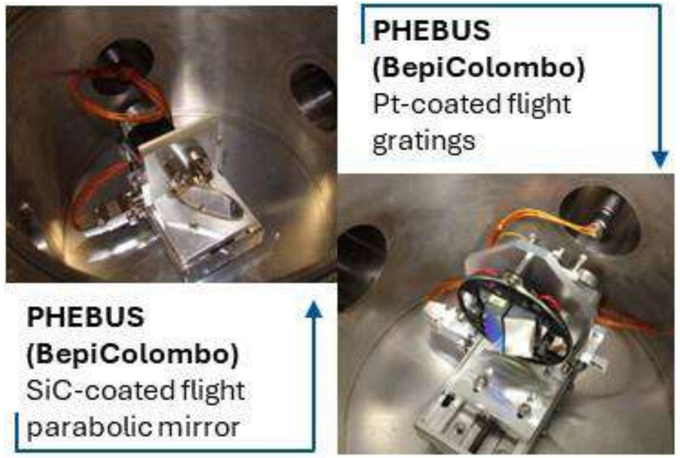
Development, characterization and testing of ultraviolet coatings in relevant space environment

Maria Pelizzo, UNIPD/CNR-PD

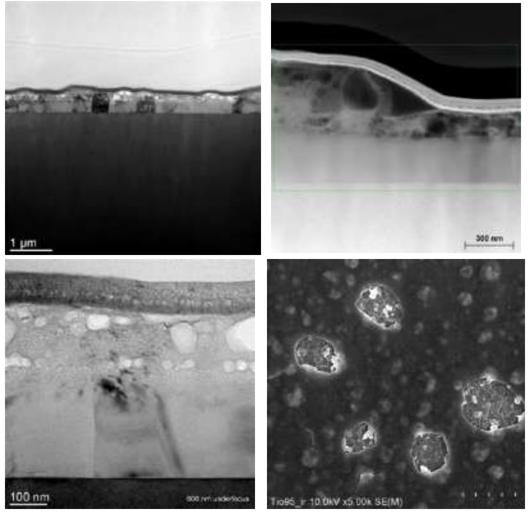
Consiglio Nazionale delle Ricerche

Contribution to the following space projects:

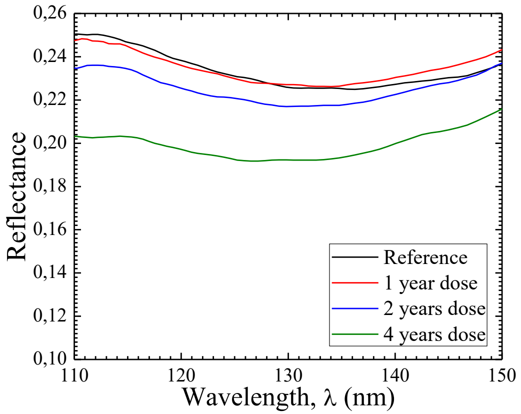
- ESA Solar Orbiter, METIS
- NASA, MUSE
- ESA Bepi-Colombo, PHEBUS



SEM/TEM of a Al/TiO_2 irradiated sample with 16 keV He+ ions, fluence of of $4 \cdot 10^{17}$ cm^{-2}



R of Ir samples irradiated with He+ at different doses, final dose $1.04 \cdot 10^{16}$ cm^{-2}



R and TEM of an EUV ML prior and after irradiation with 1 keV H+ ions, final fluence of of $5 \cdot 10^{16}$ cm^{-2}