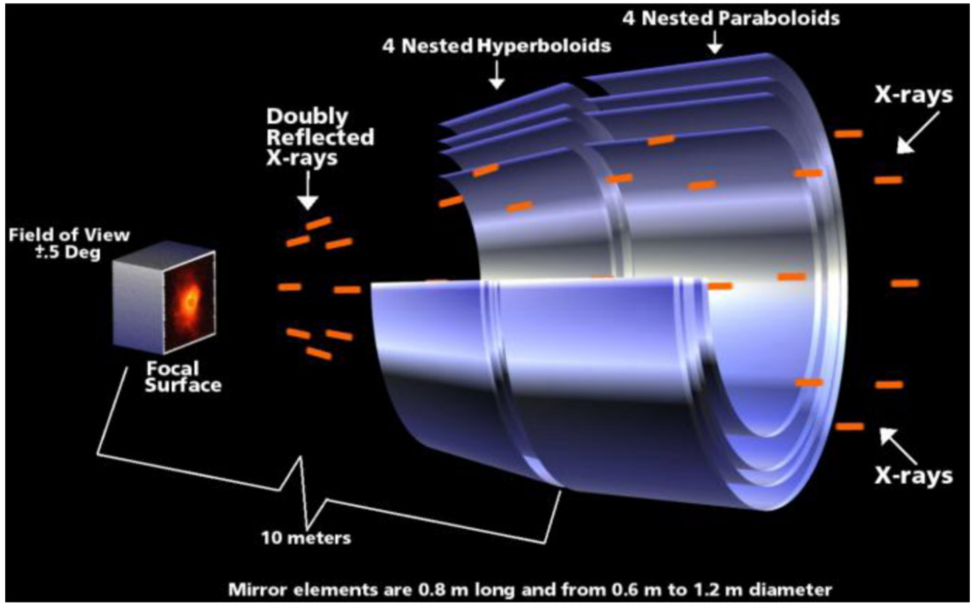
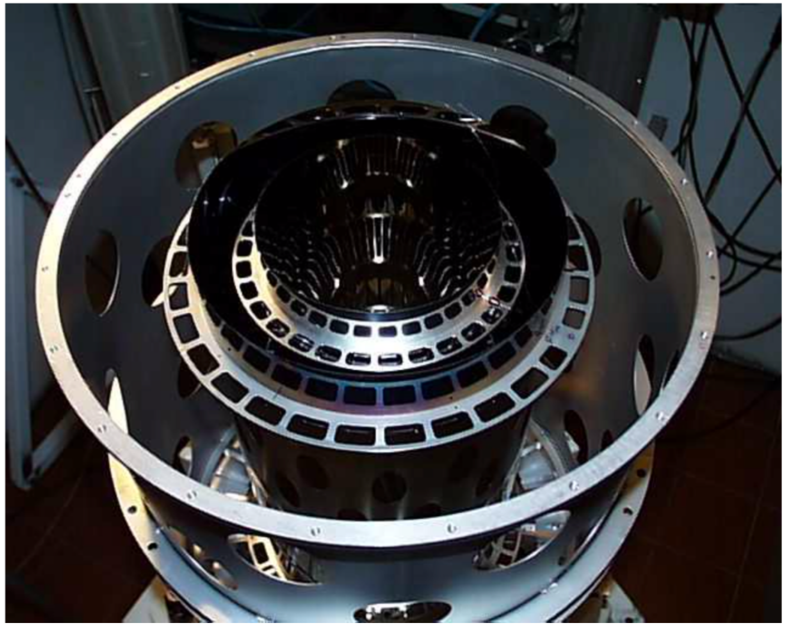
X-ray optics: People & Competencies & Funds

INAF-OAB Staff:

S. Basso, mechanical engineer
M. Civitani, optical designer
V. Cotroneo, test and design
M. Ghigo, ion beam figuring
R. Millul, scientific secretary
G. Pareschi, principal investigator
B. Salmaso, project manager
G. Sironi, data analysis
D. Spiga, optical design and modelling
G. Vecchi, mirror polishing





R&D Competencies:

- Optical design
- Ray-tracing
- Wave optic simulations
- New X-ray facilities design and realization
- Mirror grinding, polishing, and figuring
- Coating design and diagnostics
- Optic test and calibration
- Mirror metrology and data analysis

Current Funding:

- ESA SIMPOSIUM, Silicon Pore Optics Simulation and Modelling
- ESA BEaTriX (Beam Expander Testing X-ray facility)
- ASI TAO-X (Tecnologie Avanzate per Ottiche a Raggi X)

X-ray optics fabrication and test: facilities

The Ion Beam Figuring vacuum facility

The Zeeko polishing machine

The oven for hot forming of thin glass foils

The BEaTriX facility for segmented optics test

INAF-Brera is one of the worldwide leader institutes in the expertise and facilities for the fabrication, metrology, and X-ray tests of optics for X-ray telescopes.

The optics of Beppo-SAX, SWIFT/XRT, Newton-XMM have been manufactured at INAF-Brera (in collaboration with Medialario).

INAF-Brera is an active collaborator of ESA in the development of the optics of ATHENA (projects SIMPOSIUM, VERT-X, and BEaTriX).

Italian replica by electroforming technology

1993 — **Beppo SAX (ASI)**

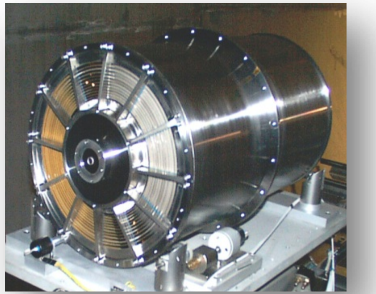
1995 — **JET-X → SWIFT (NASA-ASI)**

1999 — **XMM (ESA)**
The most powerful X-ray telescope ever built

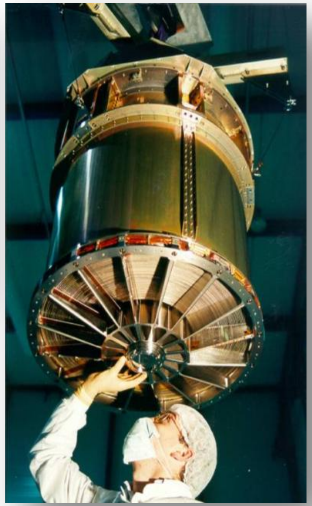
2010 — **ASI-sponsored technology development for NHXM**

2013 — **EROSITA (MPE)**

- 4 mirror modules
- 30 mirrors/module
- Thickness: 0.4-2 mm
- HEW@1,5keV: 60 “



- 1 mirror module
- 12 mirrors/module
- Thickness: 0.4-1.5 mm
- HEW@1,5keV: 15 “



- New mandrel manufacturing technology
- Aperiodic multilayer for hard-X ray reflection

- 7 mirror modules
- 54 mirrors/module
- Thickness: 0.2-0.5 mm
- HEW@1,5keV: 14”

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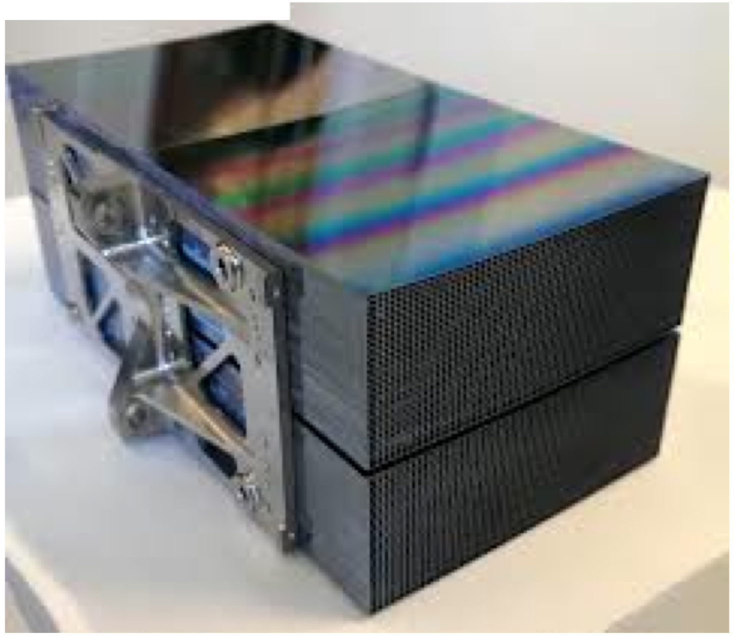
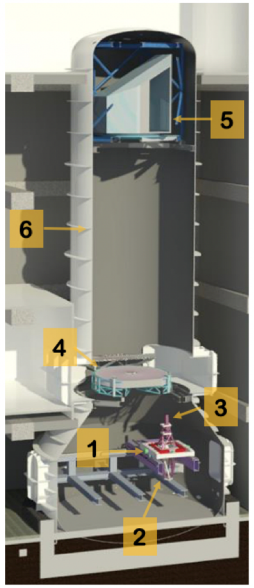
Silicon Pore Optics





1 Raster scan mechanism

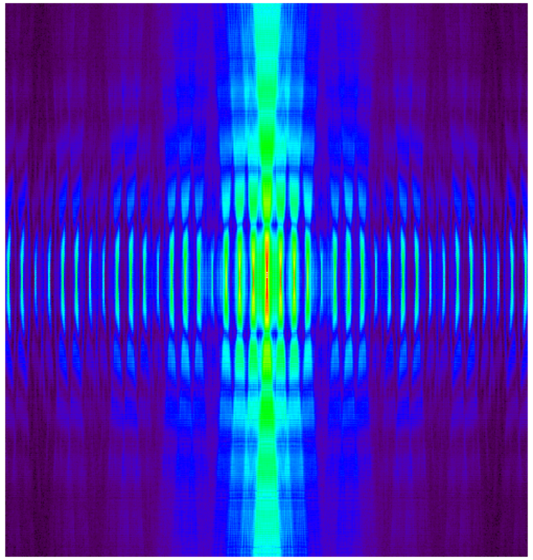
2 X-ray source

3 Collimator

4 ATHENA mirror

5 Detector

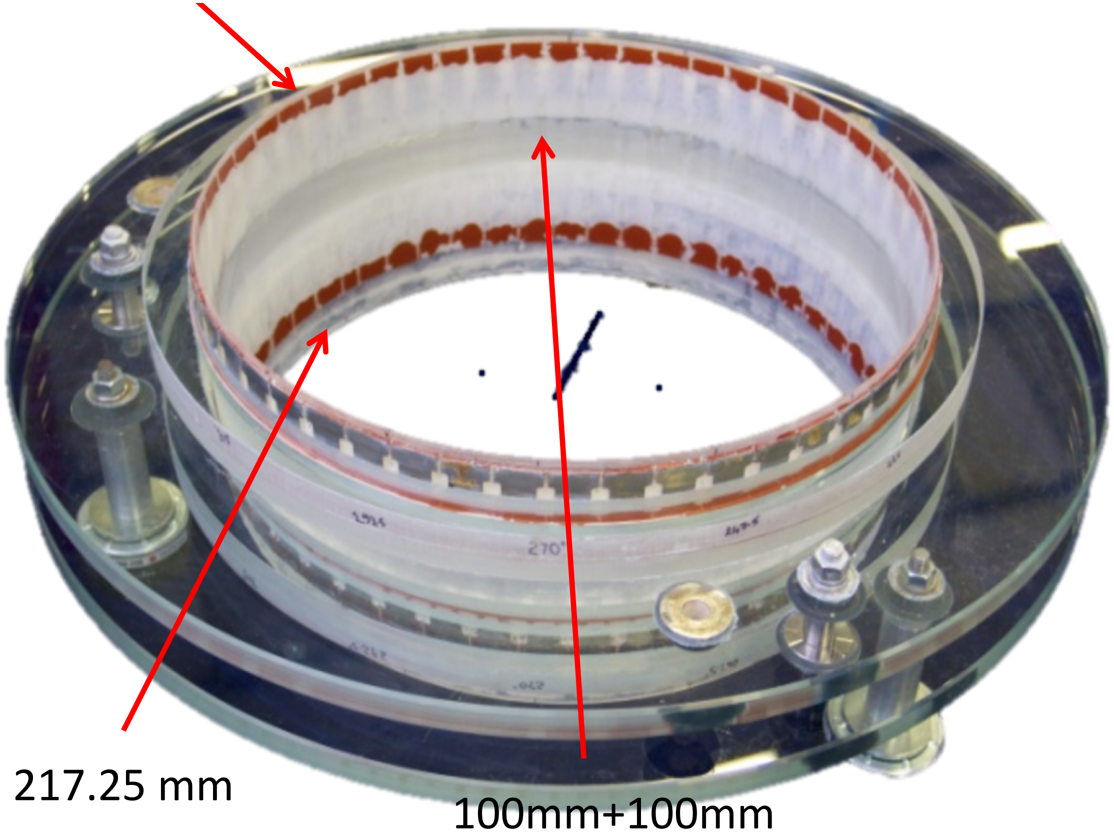
6 Vacuum chamber



Silicon Pore Optics are the technology selected for the optics of ATHENA, based on the assembly of modular elements obtained by stacking etched silicon wafers in order to form stiff arrays of pores.

INAF-Brera currently cooperates with ESA for:
- Optical Simulations (SIMPOSIUM)
- Mirror module integration in UV (Medialario)
- SPO mirror module screening (BEaTriX)
- Vertical facility for the calibration of the ATHENA optical assembly (VERT-X).

Thin Fused silica shells



Techonolgy development for Lynx mission

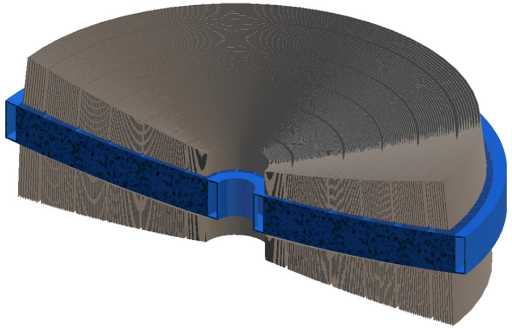


Fig. 1 Mirror assembly configuration: a single spoke is placed between the primary and the secondary shell sections.

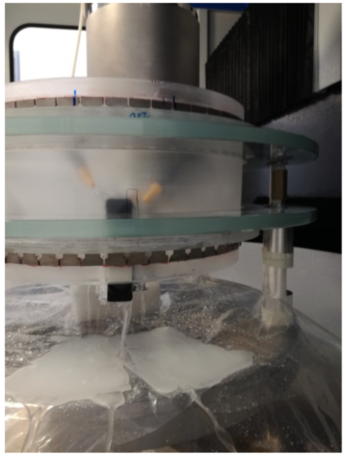


Fig. 13 The pitch tool equipped with TRizact 3M™ is fixed on the robotic arm of the Zeeko machine and the vertical carriage movement has been used to move the tool up and down.

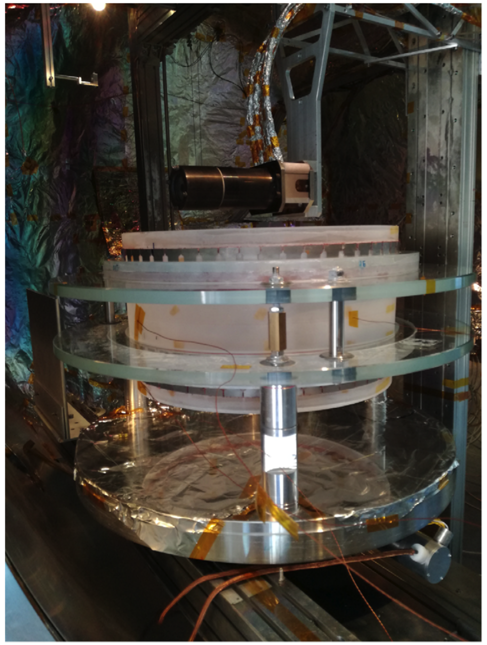
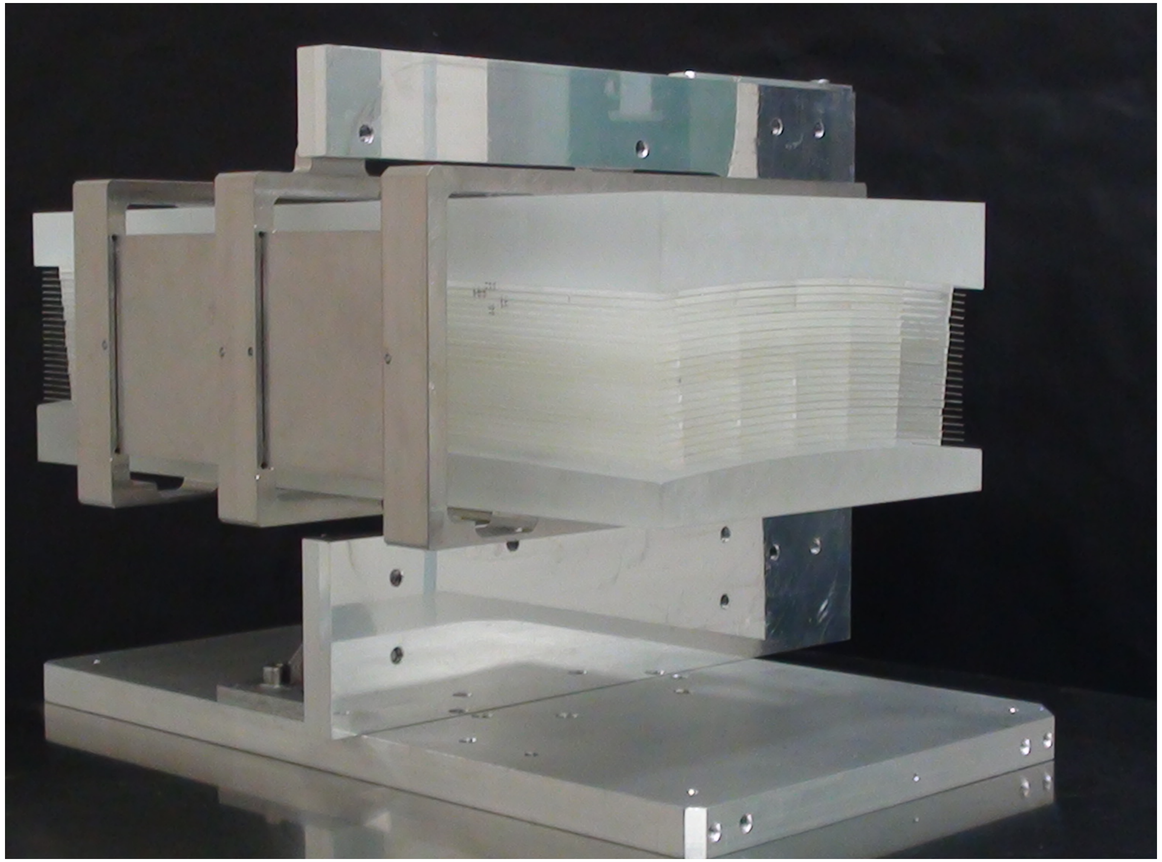
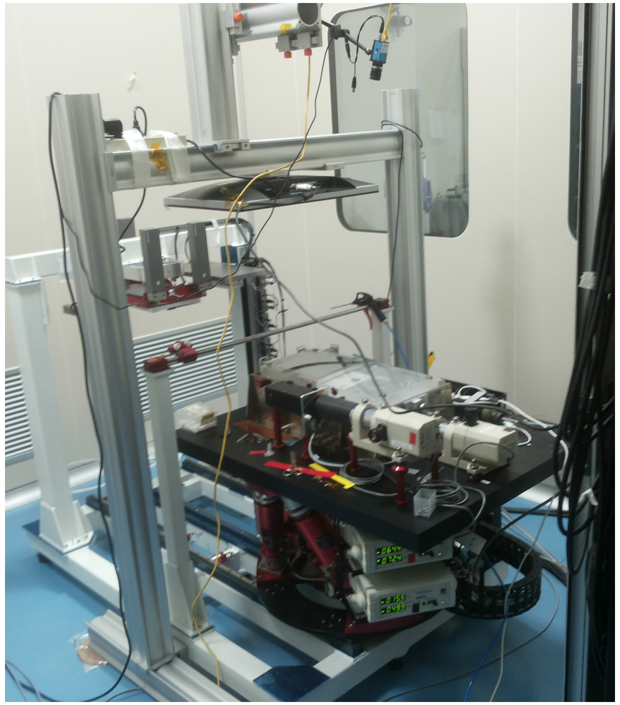
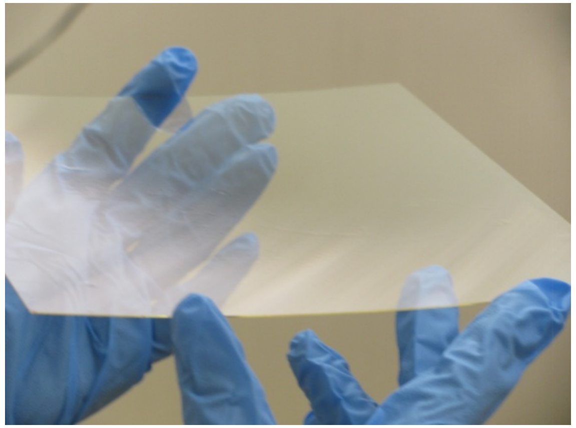


Fig. 15 The prototypal shell#4 in the ion beam chamber of the INAF/OAB during the first figuring test. Protection layers have been inserted on the ISW and uncoated witness glass samples distributed on the shell inner surface to monitor the sputtering process.

Slumped glass optics (Hot/Cold)

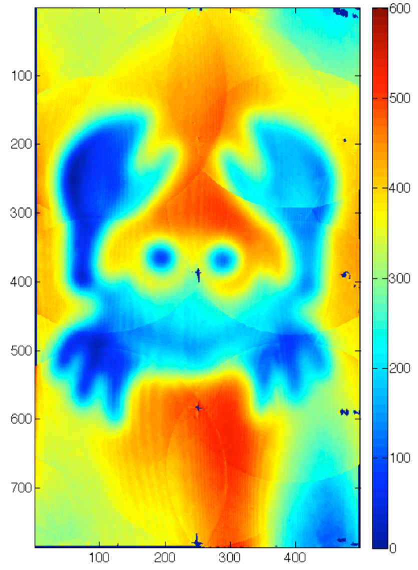






R&D activities

Adjustable X-ray optics



Final correction with IBF for 400 micron thick glass

M. Civitani, et. Al. , "Ion beam figuring of thin glass plates: achievements and perspectives," Proc. SPIE 9905, 2016

Low cost replica of aluminium shell substrates realization
INAF Patent, 2020

M. M. Civitani, et al., "A novel approach for fast and effective realization of high-resolution x-ray optics in metal," Proc. SPIE 11822, 2021

Metrology equipment at INAF-Brera

~~«If you can measure it, you can do it»~~, Lord Kelvin never said that

«… *when you can not measure it, when you can not express it in numbers, your knowledge is of a meagre and unsatisfactory kind*.» (W. Thomson, Lord Kelvin, in «The practical applications of electricity,» 1883)

Metrology

i.e. measuring whether things being made are ~~good or bad~~ within the specs (and so provide feedback to the fabrication tool)

Shape of optical components and mechanical parts:

- Coordinate Measuring Machine
- Long Trace Profilometer
- Optical interferometers
- Optical probe scanning systems
- Optical deflectometer

Surface finishing of mirrors, lenses, gratings

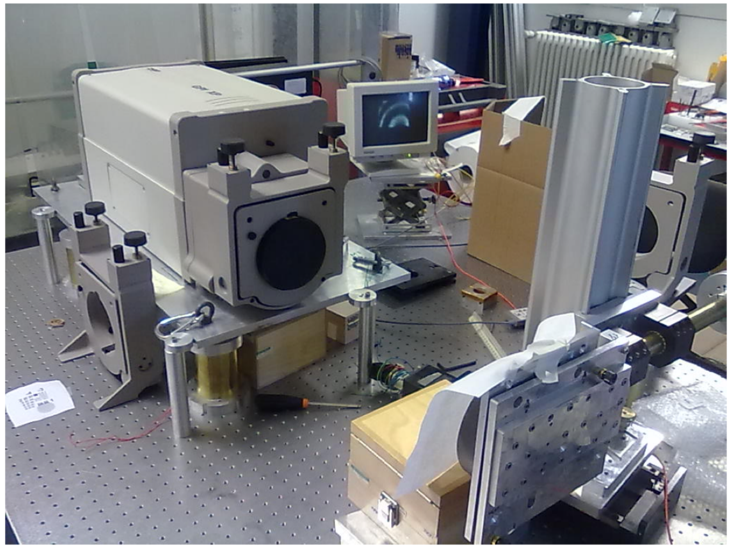
- Micro-interferometer
- Light scattering device
- Atomic Force Microscope
- X-ray diffractometer

Alignment of optical components

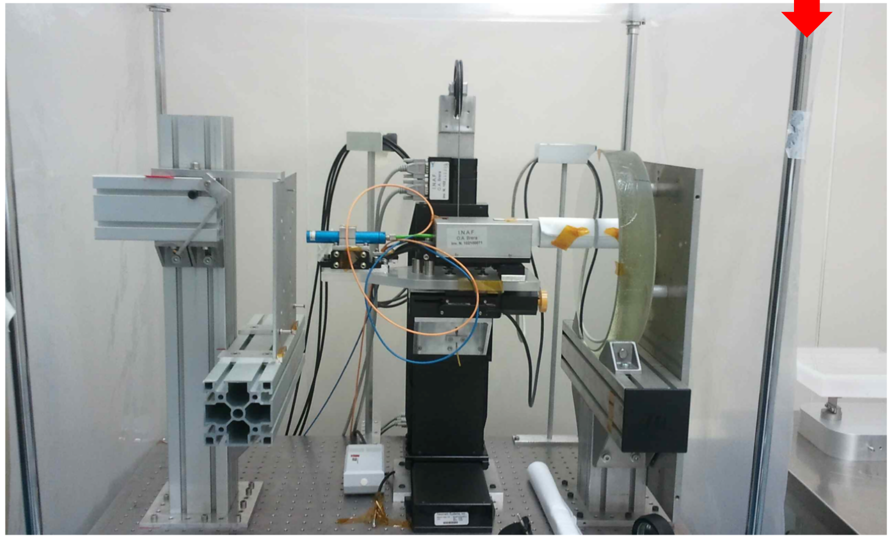
- FARO laser tracker
- Hartmann test
- Coordinate Measuring Machine

Shape errors (meters - millimeters)

ZYGO GPI-XP optical interferometer: max diam. 300 mm, planar or near-spherical 3D mapping non-contact measurement

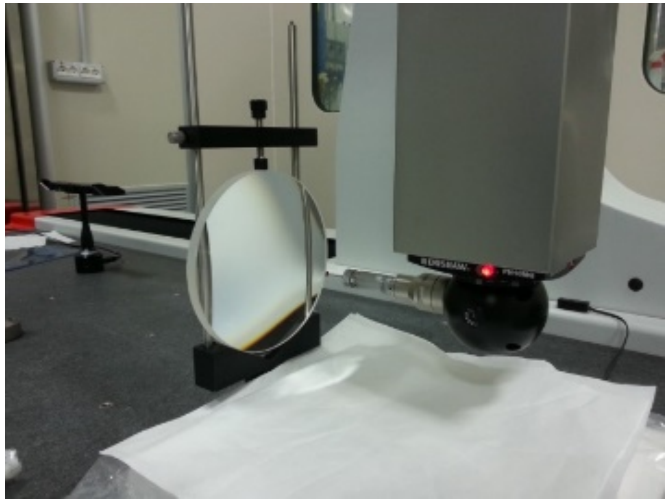


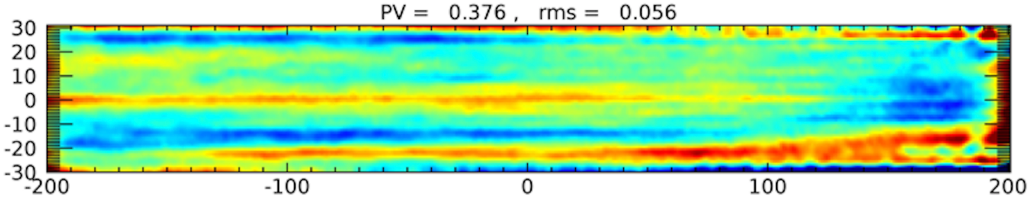
Characterization universal profilometer (CUP): free-form mirror, non-contact measurements up to 300 mm diameters, clean room ISO 6



Mandrel Profiler-Roundmeter (MPR, at Medialario) 3D mapping free-form, max diameter 500 mm, non-contact measurement with optical distance sensor

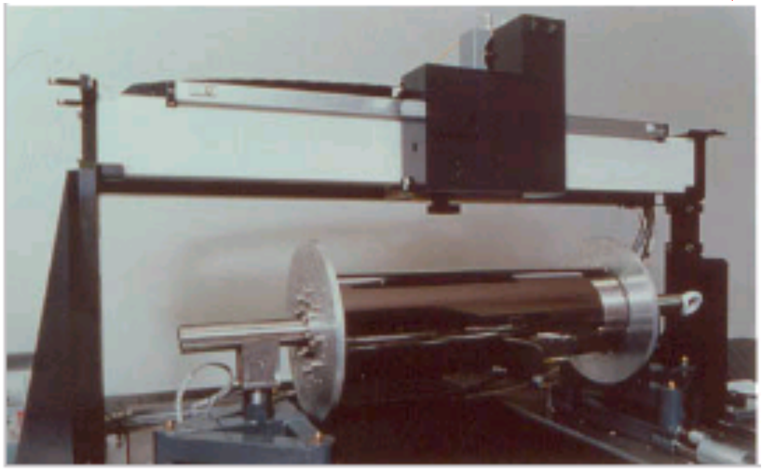
Coordinate Measuring Machine (CMM): cartesian metrology system, max accuracy 1.8 µm, 2600 x 1050 x 900mm in an ISO7 clean room.

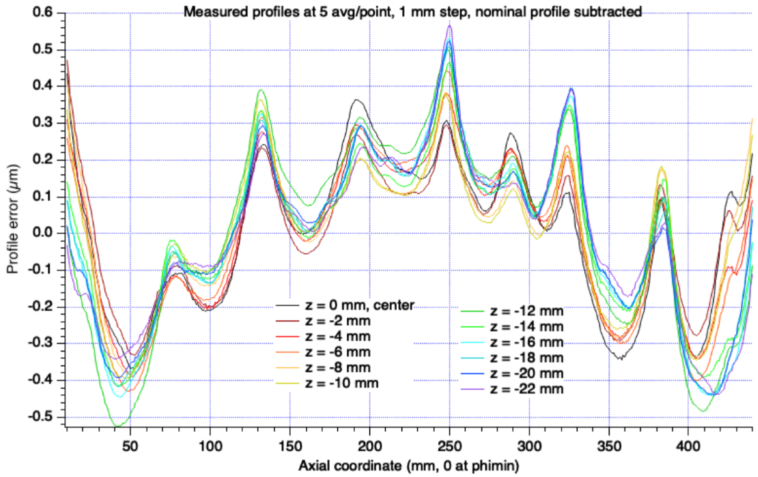




Shape errors (meters - millimeters)

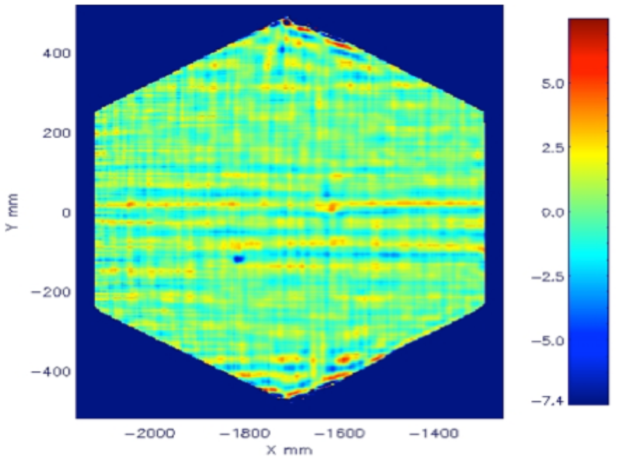
Long Trace Profilometer (LTP): optical laser device for slope detection of mandrels and mirrors, 1 m – 1 mm sensitivity, up to $\pm$ 5 mrad slopes.

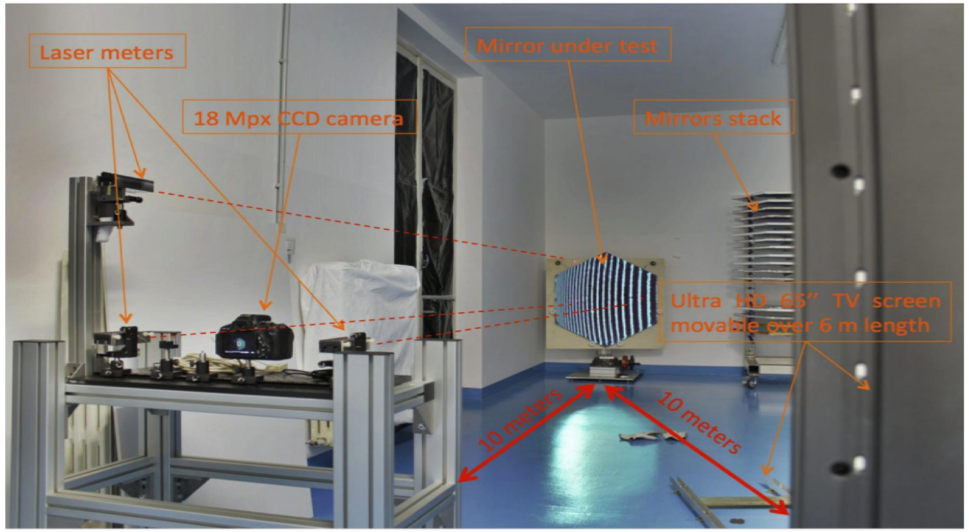




Dimetior Vbe ESDI: Fizeau interferometer with vibration compensation and high-rate acquisition. Resolution < $\lambda/8000$, accuracy < $\lambda/100$.

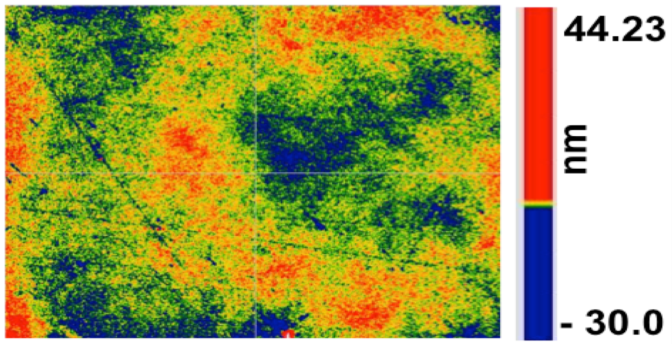
Deflectometric system: optical contactless measurement based on Ronchi test for accurate slope error detection of mirror panels.

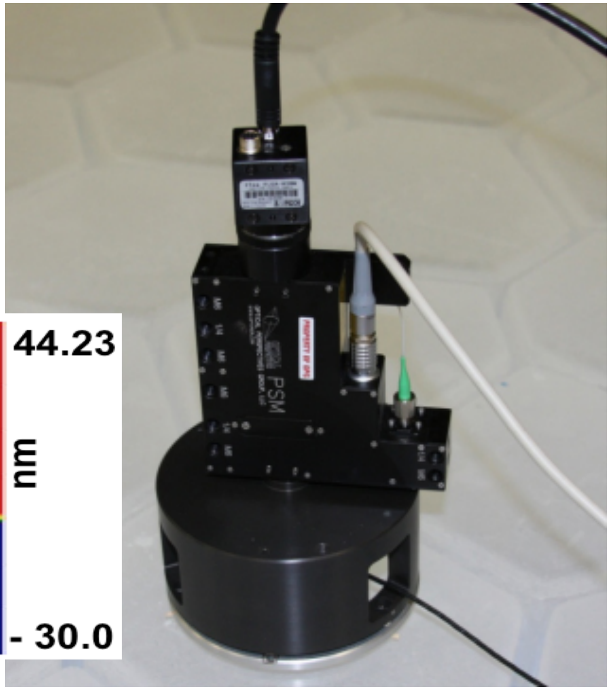




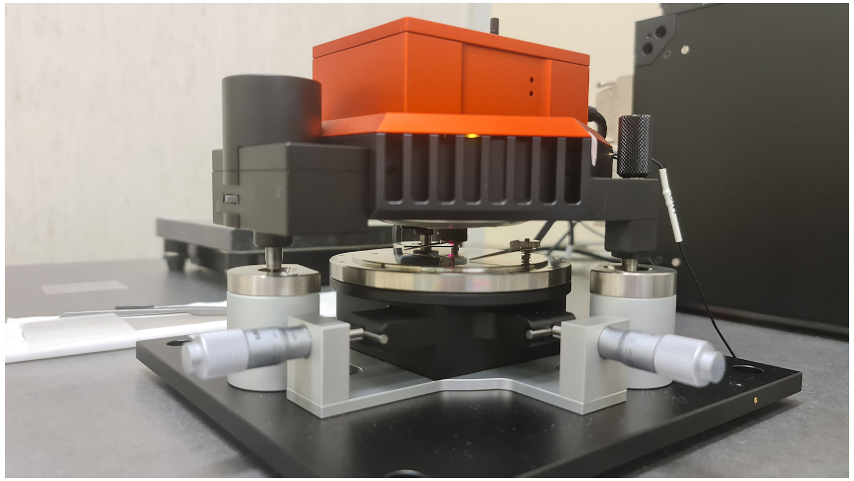
Surface/roughness errors (millimeters - microns)

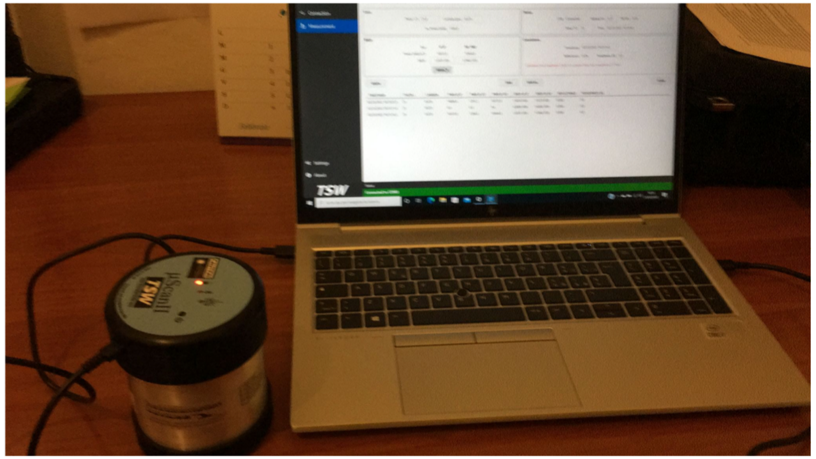
Microfinishing Topographer (MFT): optical stand-alone micro-interferometer for surface microroughness measurement over spatial scales < 1 mm.



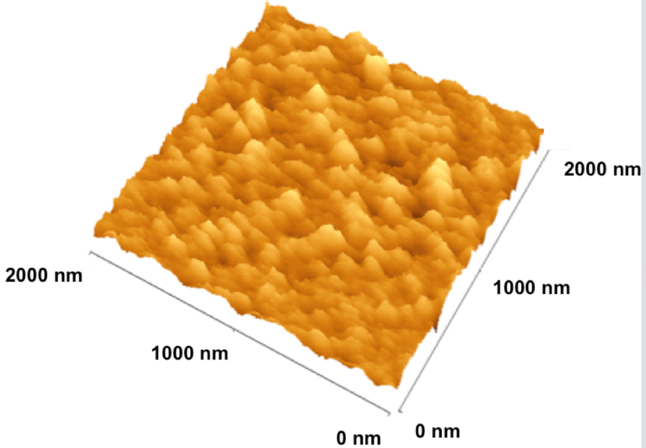


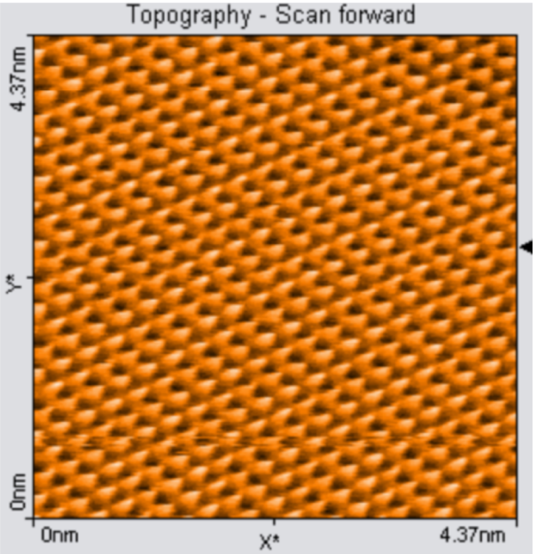
Atomic Force Microscope (AFM): Stand-alone Nanosurf, 3D measurement over lateral scales < 11 µm, vertical sensitivity < 1 Å in non-contact mode. Also working as Scanning Tunneling Microscope (STM).





Laser scattering meas. system TSW Microscan2: for measurement of surface roughness down to lateral scales of 100 µm.





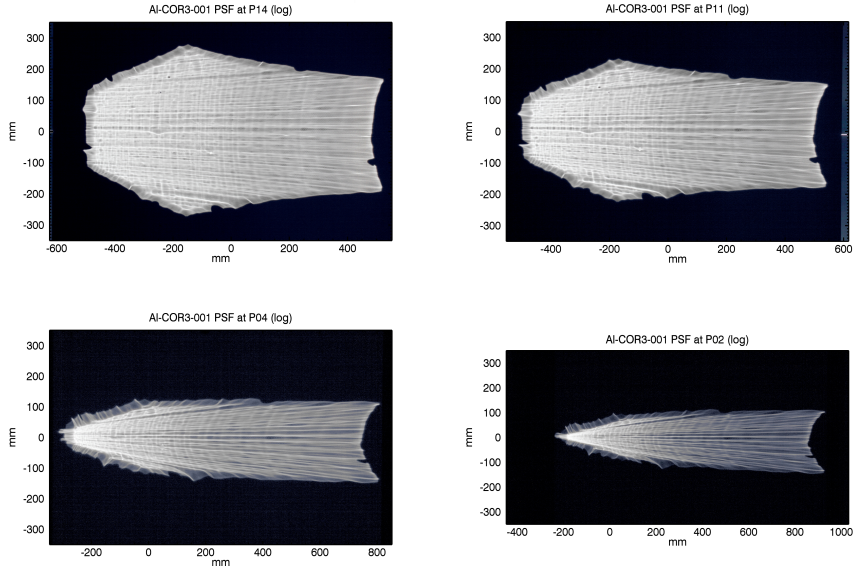
X-ray diffractometer scattering and reflectivity

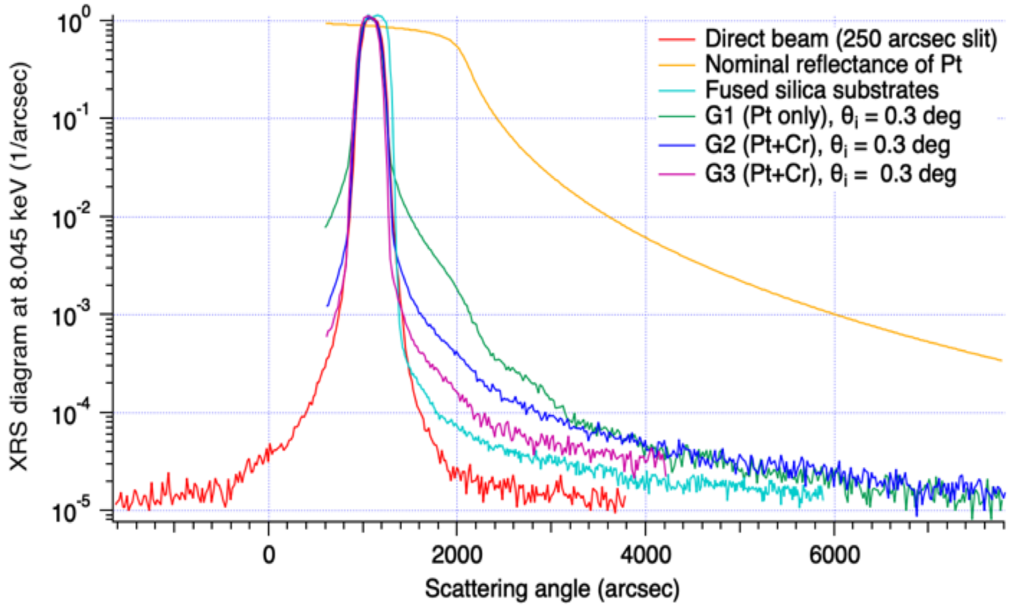
BEDE-D1 X-ray diffractometer, at 8.05 and 17.4 keV + W anode tube for continuum, scattering measurements for surface roughness detection.

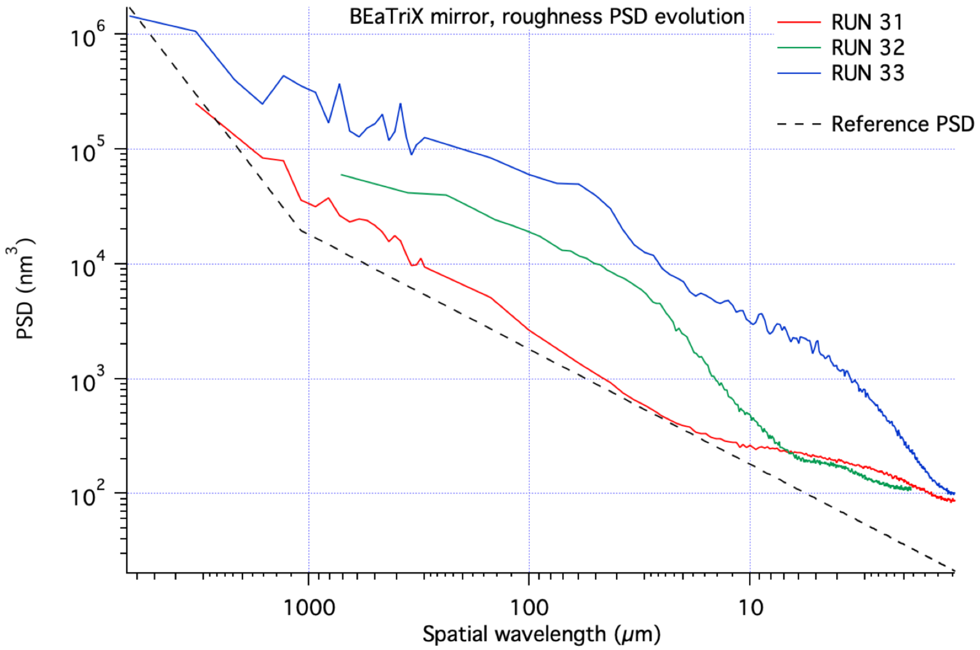
Position errors

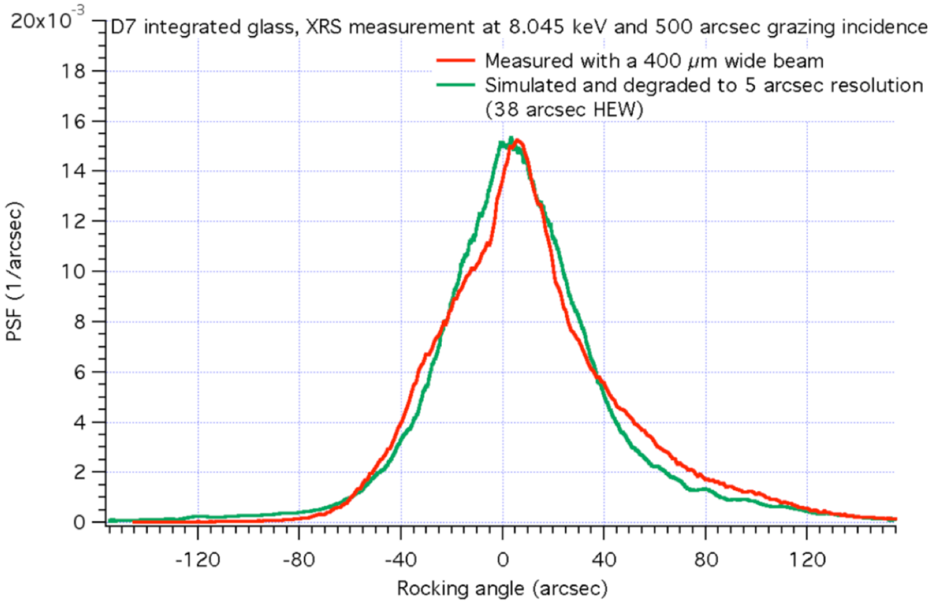
Laser tracker FARO: laser scanner / reflector / contact sensor in 3D out to 80 m with 20 µm + 5 µm/m in a full lab or mechanical parts, complementary to the CMM.

Self-consistent data analysis









Different kind of data analysis, mostly based on wave optics, is possible to account for the effect of roughness and shape errors.