pics – European metrology round-robin collaboration observing different aspects on high-quality X-Ray mirrors

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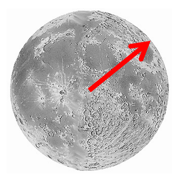
Project intention

The MooNpics project - Metrology On One-Nanometre-Precise Optics – was created as a collaboration between ten European light sources and two X-ray optic manufacturers aimed to improve the quality and availability of high-precision X-ray mirrors as it is required for the current needs in single nanometre level metrology and the production of high-precise X-Ray optics for diffraction limited light sources.

- ALBA
- DESY
- DIAMOND
- ELETTRA
- ESRF
- HZB
- MAX IV
- PSI
- SOLEIL
- WinlightX
- European XFEL
- ZEISS SMT GMbH

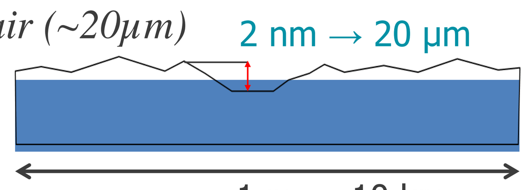

Light sources in Europe.

For appropriate beam focusing and alignment, the optics must have outstanding parameters regarding the surface shape. For X-ray mirrors, the required values are a single-nanometre figure error and 20 nrad rms slope error precision. For plane mirrors a radius of curvature > 1000 km is required. These requirements are challenging regarding the production techniques as well as the metrology methods used to measure the optics. Using deterministic polishing techniques mirrors with 1 nm accuracy can be manufactured. The needed accuracy of the metrology data provided for this iterative process is accordingly.



'Flat' like the surface of the Moon
$R_{Moon} = 1773$ km

'Smooth': less than a hair (~20µm) on a 10 km long street!



Within the MooNpics project, several work packages were created to focus on the metrology and analysis methods used in the European light sources' metrology labs as well as on software and methods for focal spot reconstruction and fast mirror alignment. Different aspects of X-ray mirror production and metrology were observed.

Main project objectives

- Bring European metrology on X-ray optics up to single-nanometer figure error precision
- Include mirror manufacturers in metrology process to improve surface finishing methods
- Establish standards
- Push the quality and market availability of high-precision X-Ray mirrors

➡ **Round-robin measurements** for cross-calibration of hardware and methods

➡ **Stitching software PyLOSt** for metrology (ESRF)

➡ **Wavefront sensing** techniques and software for sub-µm focal spot reconstruction and fast mirror alignment (DESY, ELETTRA, PSI)

Related articles:
Adapa BR, Thesis at Université Grenoble Alpes, 2020GRALY032 (2020)
Kharitonov K, et al., Opt. Express 29(14), 22345 (2021)
Krempaský J, et al., Adapt. X-Ray Optics V 10761, 55 (2018)
Nistea I-T, et al., Proc SPIE 11109,49 (2019)
Ruiz-Lopez M, et al., J. of Synchr. Radiation, 26(3), 899 (2019)
Ruiz-Lopez M, et al., Sensors., 20(22) (2019)
Schmidtchen S, et al ., Proc SPIE 11109, 25 (2019)
Seaberg M, et al., J. of Synchr. Radiation, 26(4), 1115 (2019)
Siewert F, et al ., Proc SPIE 11109, 155 (2019)
Svetina C, et al., Opt. Lett., Vol. 44(3), 574 (2019)
Wodzinski T, et al., J. of Physics Comm. 4(7), 075014 (2020)
Wodzinski T, et al., Appl. Opt., 59(5), 1363 (2020)
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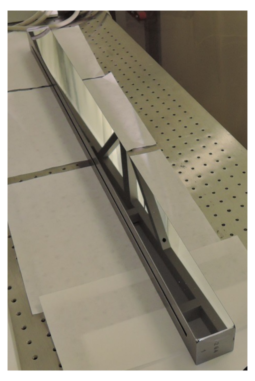
Round-robin

The round-robin experiment was used to observe different aspects of X-ray mirror production and metrology. **Three high-precision X-ray mirrors** have been sent to the participating facilities and industrial partners in a European-wide round-robin experiment over four years (2018 - 2022). To serve the large variety of different methods and instruments and to enable exploration of different aspects of height and slope error measurements, three mirrors with very different parameters were chosen.

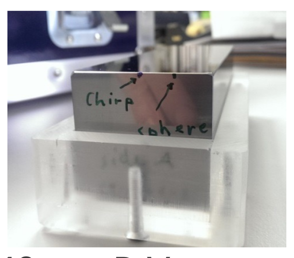
Plane mirror:

- 950 x 52 x 52 mm³, R > 1000 km
- Ion Beam Figuring (IBF)
- Fiducial marks for alignment

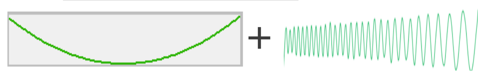


Sphere:

- 145 x 45 x 45 mm³
- Concave 9.3m (nominal)
- 2 different profiles

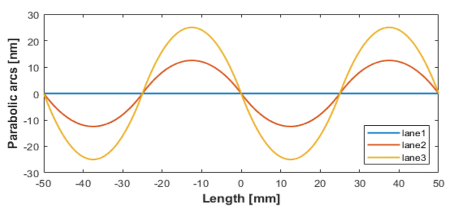


Spherical  ≈ 140 µm P-V

Chirp  ≈ 20nm P-V

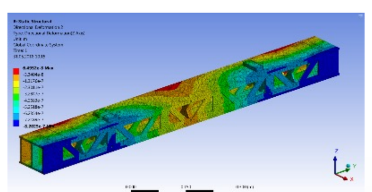
Tangential Ellipse[1]:

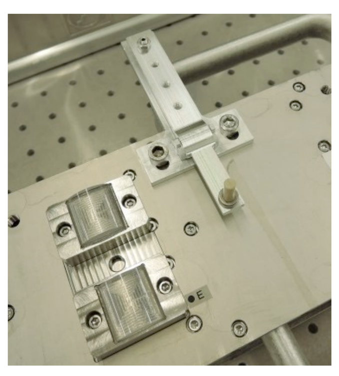
- 160 x 90 x 50 mm³
  - Rm 264 m (314 – 217 m)
  - 3 different profiles
  - IBF using results from RR
  - Fiducial marks for alignment

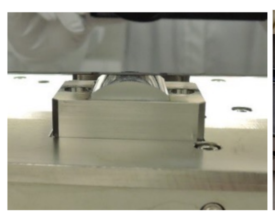


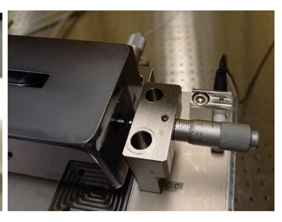
A special **mirror mounting** was designed for stable and reproducible measurements of the long plane mirror.

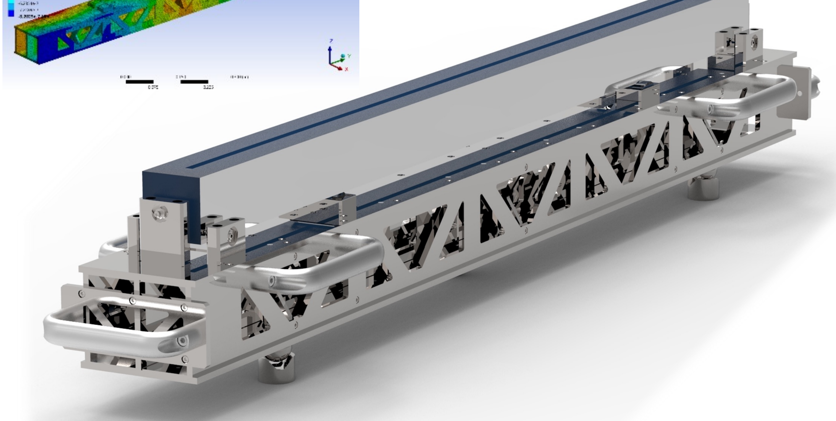
- FEA analysis
- Lifting mechanism to reduce interface stress[2]









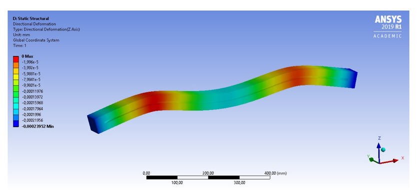


1 *Development of a multi-lane X-ray mirror providing variable beam sizes", D. Laundy et al., Rev. Sci. Instr. 87, 051802 (2016)*
2 *Schmidtchen et al., Proc. Volume 11109, Adv. in Metr. for X-Ray and EUV Optics VIII; (2019)*

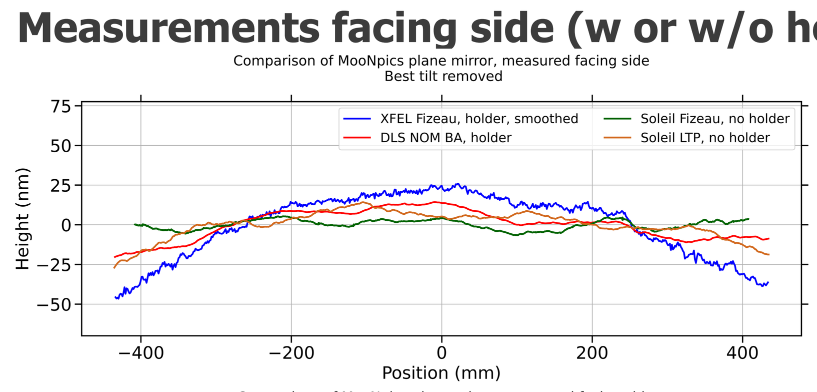
Plane mirror comparison

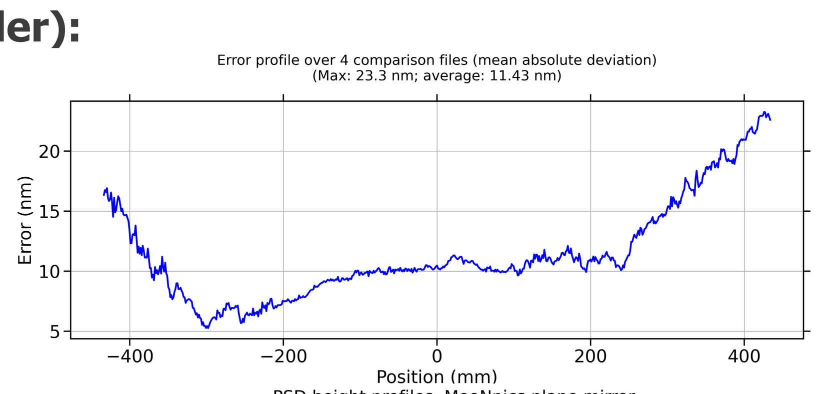
The plane mirror was measured at the participating metrology labs with instruments such as **Fizeau interferometers**, **Long Trace Profilers (LTP)** and **Nanometer Optical Component measuring Machines (NOM)**. The mirror was measured in different configurations, with and without the mirror mount, facing sideward and upwards, depending on the metrology instrument used.

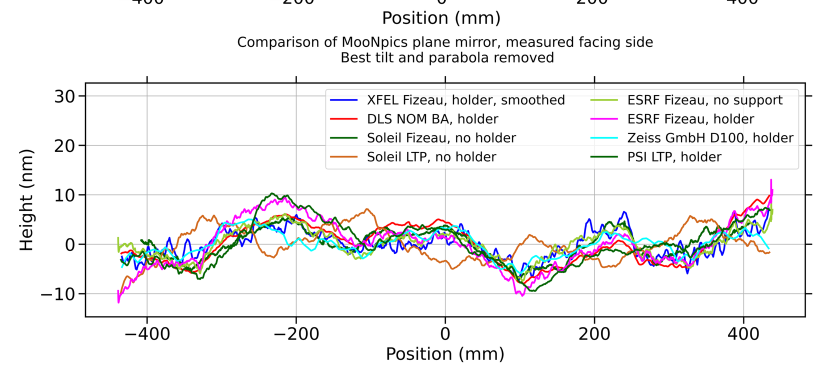
- **Fiducial marks** to align the mirror for measurement and data
- **Gravity compensation** for face up measurements

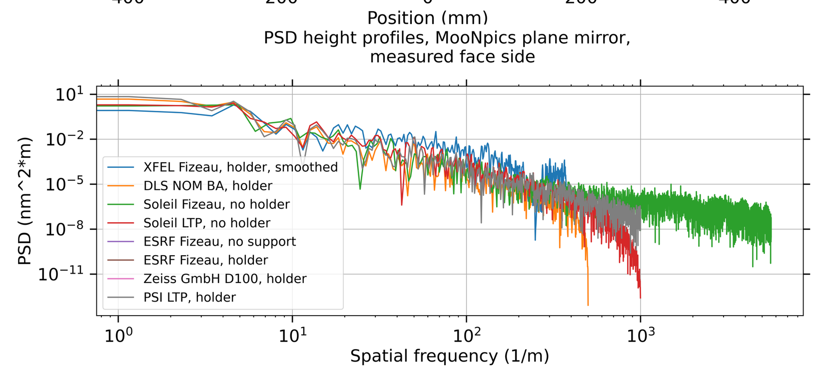


Measurements facing side (w or w/o holder):

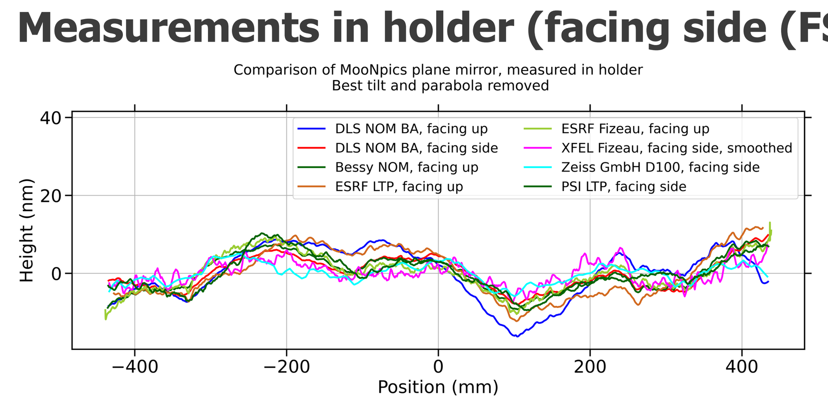


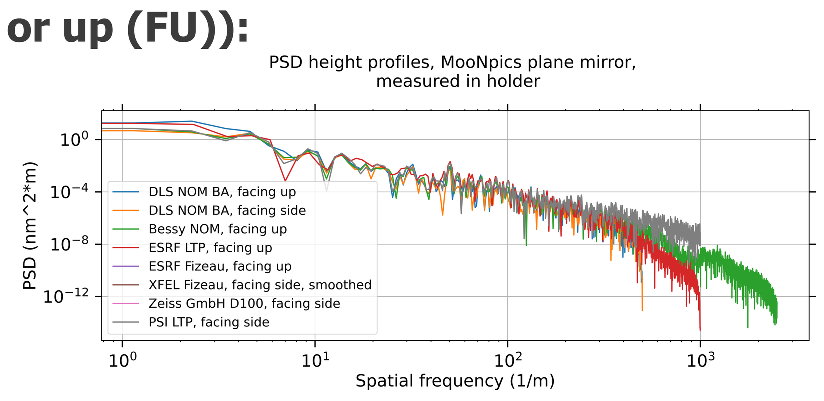




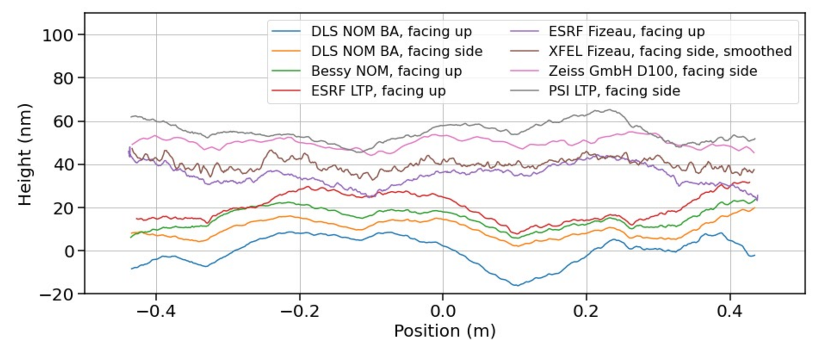


Measurements in holder (facing side (FS) or up (FU)):





Data shifted vertically:



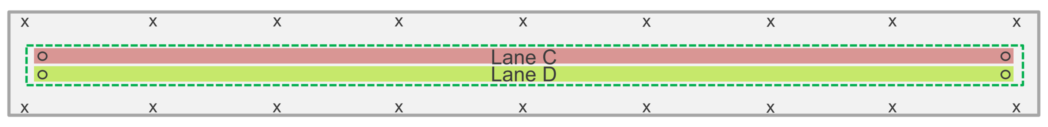
- Mirror shape is very sensitive to support conditions: change in curvature
- Good agreement,considering mirror dimensions (950 x 52 x 52 mm³)
- Overall surface shape within a range of ~20nm
- Mid frequency errors show similar structures for several instruments and mounting setups

Due to the high surface quality and flatness of the plane mirror, the labs were able to calibrate and upgrade their instruments, to reveal uncertainties and improve measurement and analysis.

Customized calibration mirrors

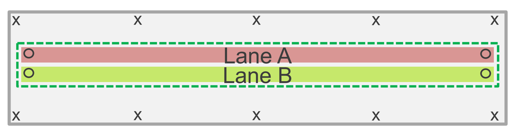
With the experience gained, the specifications for samples for calibration could be optimized and customized to the metrology needs. This was finalized in two standardized calibration mirrors with specific shapes and structures for precise testing of the instrument's accuracies.

- Better fiducial marks for precise alignment
  - IBF dots: ≈100 nm deep holes
  - Cross-hairs: for the longer mirror spacing < 120 mm (4 fiducials always visible in field of view of Fizeau (assuming 150 mm diameter)
- 4 surface profiles



Mirror 1 (484 mm)
Lane C: Sinusoid, ~5 mm period, decreasing amplitude
Lane D: Sinusoid, ~5 mm period, increasing amplitude

Mirror 2 (215 mm)
Lane A: Chirped profile, constant amplitude in slope
Lane B: Chirped profile, constant amplitude in height



Achievements

The MooNpics project was an outstanding collaboration of European metrology labs and X-Ray mirror manufacturers. The perennial open round-robin experiment, successfully performed with 3 mirrors, enabled a cross-calibration of metrology instruments, improvement of analysis, upgrade of hardware and methods based on the comparison data at several metrology labs. The plane mirror reinforced the importance of finding improved support methods to minimise unwanted distortion.

The experiences gained were transferred to 2 customized calibration mirrors => up to 5 very well characterized calibration standards are available for cross-calibration.

The round-robin provided valuable findings about mirror alignment, fiducial preparation and mirror mounting. In addition, the close cooperation with mirror manufacturers facilitated the improvement of their metrology and production technologies in close accordance to the requirements of the light sources.

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