MooNpics – Metrology On One-Nanometer-Precise Optics

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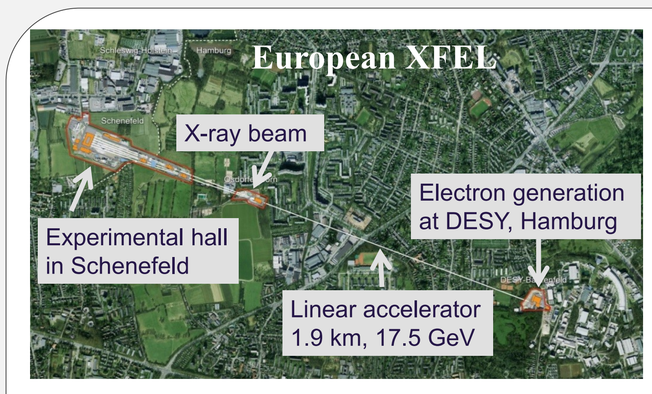
Background



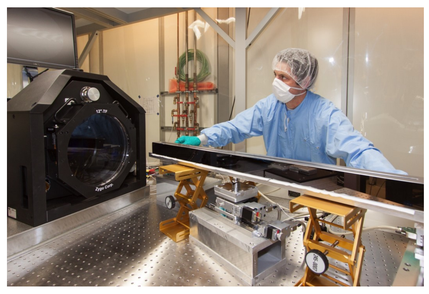
In high-energy light sources - like Free electron Lasers and Synchrotrons - high energetic X-ray beams are produced for scientific experiments.

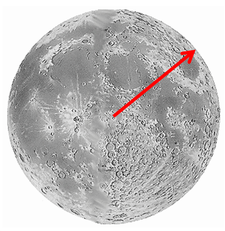
For the European Free Electron Laser (European XFEL) high energy electrons are generated at DESY (Deutsches Elektronen-Synchrotron).

Those electrons are accelerated and guided to European XFEL via a long tunnel. After ca. 2 km acceleration path, the electrons are passing undulators, are forced on zig-zag paths and produce the X-radiation. The X-rays are guided along the remaining tunnel (~1 km) to the experimental halls at European XFEL.

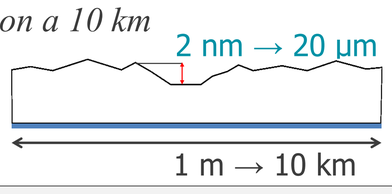
Extremely precise optics are used for the long distance transport and focusing of the X-ray beam. Such as very smooth and flat Silicon mirrors with lengths up to ~1m.

'Smooth' means a maximum deviation of surface height of about 2 nm over 1 m mirror length. 'Flat' corresponds to a radius of curvature > 1000 km. In the metrology labs of the facilities different methods are used to investigate the mirror surfaces.

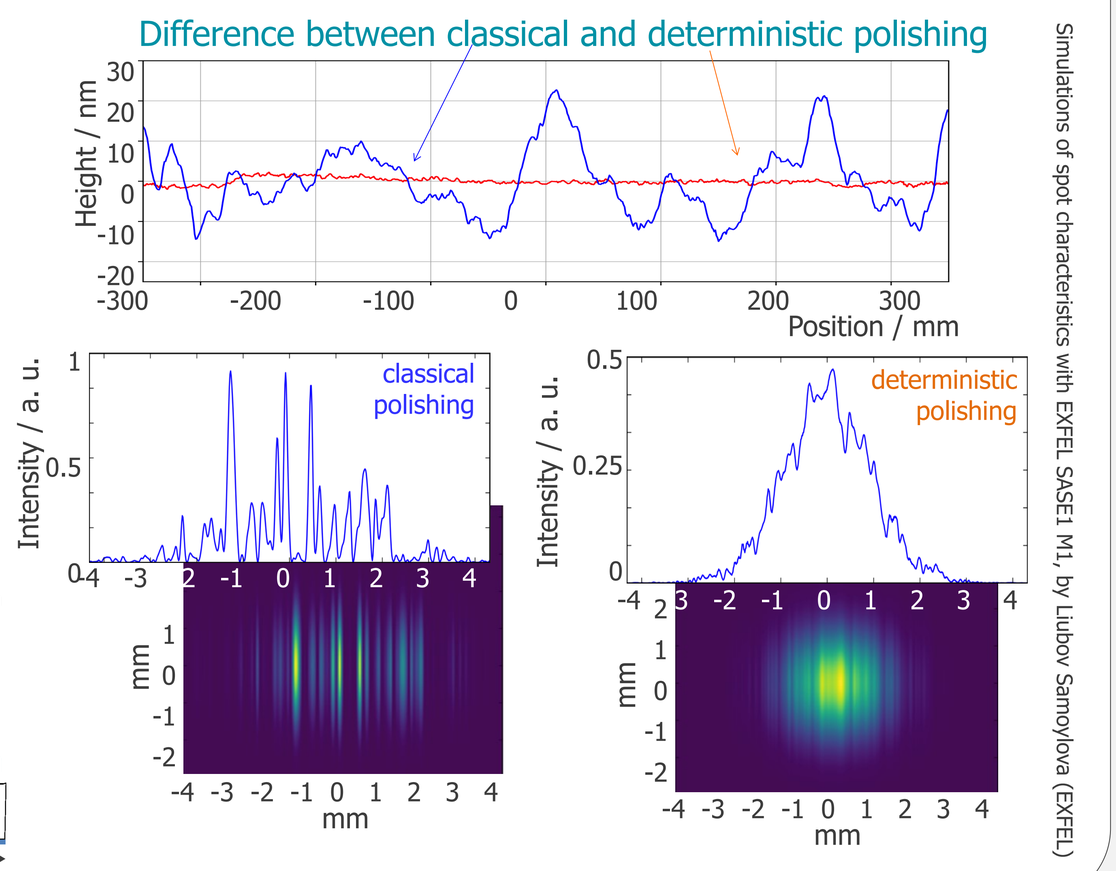

M. Vannoni at European XFEL metrology lab. 950mm X-ray mirror (Si) in front of a Fizeau interferometer.


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

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

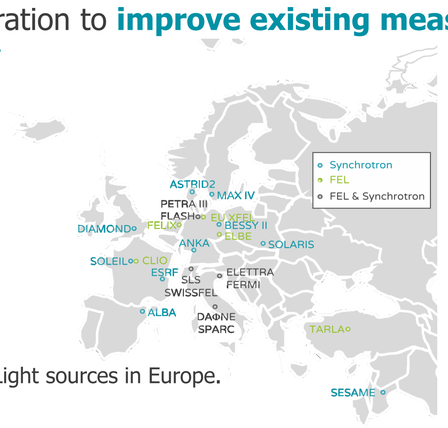


The quality of the beam is limited by the mirror's imperfections and misalignment. Using deterministic polishing techniques mirrors with 1 nm accuracy can be manufactured. But to achieve these accuracies the metrology of long X-ray mirrors also needs nm-precision.



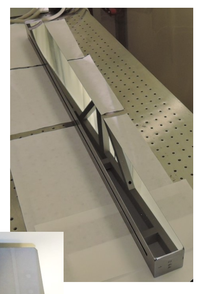
Project

- 10 European light sources, 2 manufacturers of high precision mirrors
- Collaboration to **improve existing measurement techniques and mirror quality**

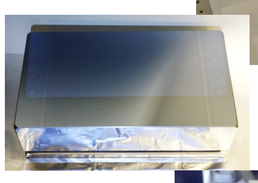


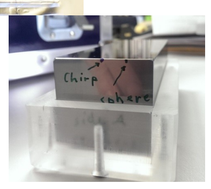
Light sources in Europe.

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



- Measurement of three mirrors in three **round-robin** cycles
  - Flat mirror: 950 x 52 x 52 x mm³, R > 1000km
  - Tangential Ellipse: 160 x 90 x 50 mm³, Rm 264 m (314 – 217 m)
  - Sphere: 150 x 45 x 40 mm³, R ~9.8 m
- Development of a **mirror mounting**
- Development of fast in-situ optimisation procedures for active optics systems – portable **wavefront sensors**
- Development **of stitching software for metrology**



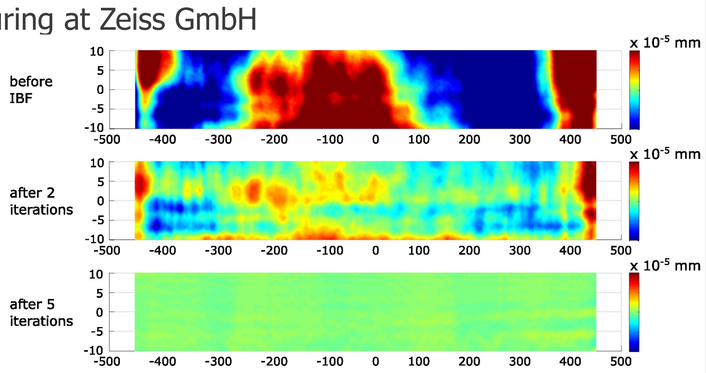


Mirror preparation

- Flat mirror (950 x 52 x 52 x mm³)
- Repolished with ion-beam-figuring at Zeiss GmbH
- 5 iterations

Results:

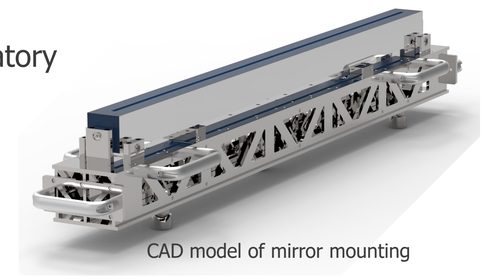
- Radius of curvature: 160 km ⟶ > 1000km
- Rms tangential slope error: 1.1µrad ⟶ 0.1µrad

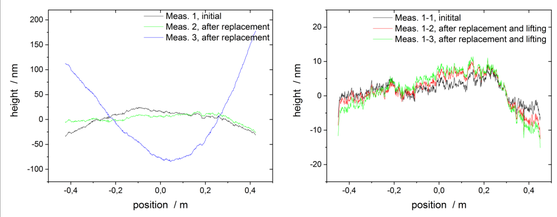


Measurements from Carl Zeiss SMT GmbH, ZEISS Group, Oberkochen

Mounting with lifting mechanism

- Similar measurement conditions in each laboratory
- > 10x transport through Europe
- 10x different labs and setups
- Improve repeatability of measurements in each metrology lab for sufficient comparability
- Titanium for low temperature dependency
- Lifter mechanism for minimization of stress induced to the mirror


CAD model of mirror mounting



a) Not using the lifter

b) using the lifter

- Surface center profile of 3 measurements of 950mm long flat mirror
- 12" Fizeau interferometer, in grazing incidence, facing side
- Mirror removed and replaced between measurements

Round-robin

- Each mirror sent to all facilities and measured with the present metrology hardware and methods
- Started: October 2018, duration 3 years
- Cross-calibration of hardware and methods
- Improvement of analysis methods
- Improvement of manufacturing processes
- Joint development of standard methods, mounting methods and calibrated test mirrors
- Dissemination of developed technologies and software

Mid-term achievements

- First comparison of round-robin data. Good agreement in many cases. Used to improve setups in several labs.
- Successful development of a stitching tool for metrology, applicable to various measurement methods
- Successful development of wavefront sensing techniques and software, applied at several beamlines in different facilities.

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