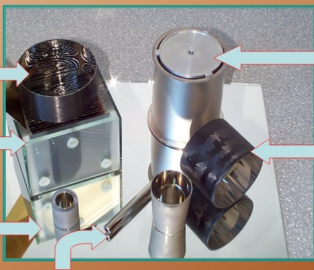
The Grazing Incidence Astronomical X-Ray Optics in the Czech Republic: 39 years of development



Various replicated X-ray optics

History of Grazing Incidence X-Ray Optics in the Czech Republic

- 1st X-ray mirror in 1969, for solar telescope in INTERKOSMOS program
- Number of mirrors flown in space: 8
- Spacecrafts with Czech X-ray optics: 4
- Number of space experiments with Czech X-ray optics onboard: 8

History of Grazing Incidence X-Ray Optics in the Czech Republic

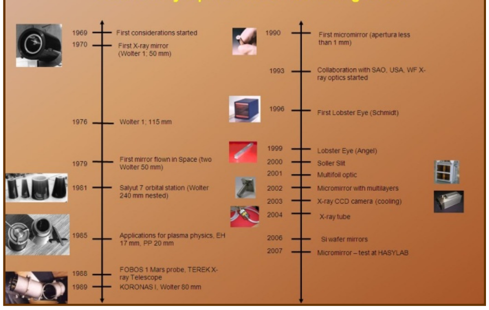
Early Stages

The early stages of the X-ray optics developments in the Czech Republic are closely related to the INTERKOSMOS Space Program (Soviet and East European equivalent of ESA operated until 1989). All of the X-ray imaging telescopes onboard Soviet spacecrafts were equipped with the Czech X-ray optics (exception: X-ray normal incidence mirrors in the special channel of the TEREK telescope). Later on, laboratory applications have started.

Total number of X-ray mirrors produced: more than 50
Total number of mirrors flown in space: 8
Total spacecrafts with Czech X-ray optics: 4
Total number of space experiments with Czech X-ray optics onboard: 8

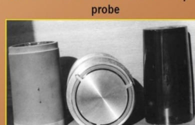
- 1969 first considerations started
- 1970 first X-ray mirror produced (Wolter 1, 50 mm)
- 1971 Wolter 1, 80 mm
- 1976 Wolter 1, 115 mm
- 1979 first mirrors flown in space (two Wolter 50 mm, Vertikal 9 rocket)
- 1980 Vertikal 11 rocket (two Wolter 50 mm)
- 1981 first large Wolter mirror (240 mm)
- 1981 Salyut 7 orbital station (Wolter 240 mm nested)
- 1985 applications for plasma physics, EH 17 mm, PP 20 mm
- 1987 first high quality X-ray foils for foil mirror X-ray telescope (SODART)
- 1988 Fobos 1 Mars probe, TEREK X-Ray Telescope
- 1989 KORONAS I X-ray mirror, Wolter 80 mm
- 1990 first micromirror (aperture less than 1 mm)
- 1993 collaboration with SAO, USA, WF X-ray optics started
- 1996 first Lobster Eye test module produced, Schmidt geometry
- 1997 double-sided X-ray reflecting flats
- 1997 Lobster Eye Angel geometry project started
- 1999 first Lobster Eye test module produced, Angel geometry
- 2001 thin segmented X-ray mirrors

Czech X-ray Optics: historical background

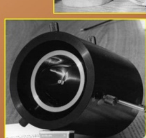


X - ray mirrors produced by replication in the Czech Republic (Hudec et al)

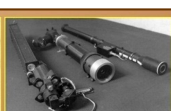
Left: EH and PP microscopes
Bottom: Wollter mirror for Phobos 1 space probe



X - ray images of the laser plasma by the 17 mm EH microscope (IPPLM Warsaw)



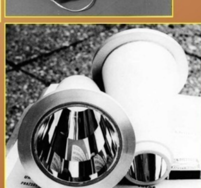
One of the first Czech X-ray Wolter mirrors, 1970, aperture 50 mm



TEREK Phobos 1 1988

The four mandrel used for the manufacture of X-ray mirror nested array for the RT-4M soft X-ray telescope (Glass ceramics Sital). Flown onboard the space station Salyut 7 in 1981.

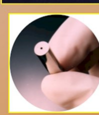
Replicated Wolter - 1 X-ray mirrors of the KORONAS satellite (aperture 80 mm), 1989

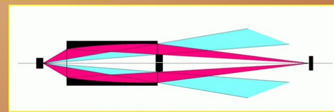


Two identical mirrors (large hyperbolas) of the RT-4M mirror array (Ni surfaces), 1981.

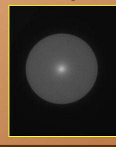
Focussing X-ray micromirrors

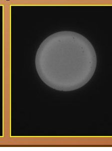
Hasylab proposal accepted, 3 years, 2007-2009, tests at synchrotron





Beam convergence angles as low as 1 miliradian full angle.

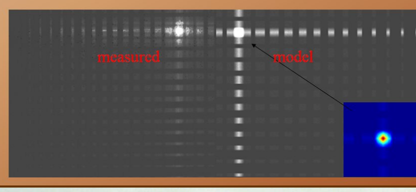


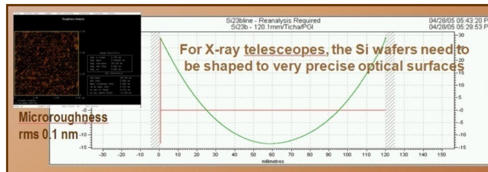


X-ray micromirror, aperture 0.7 mm, with replicated MLs inside (left) and with only Au (right), focal images at 8 keV. The influence of the ML deposition is clearly demonstrated.

Lobster Eye X-Ray Optics: X-ray experiment vs. simulation

- Point-to-point focusing system, LE Schmidt mini
- source-detector distance 1.2 m, 8 keV photons
- image width: 2x512 pixels, 24 mm pixel
- Gain: ~570 (measured) vs. ~584 (model)



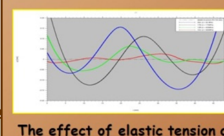


Si wafers represent a very promising substrate for large space X-ray mirrors, as they are very light (volume density 2.3 gcm-3), very smooth, and have a very good thickness homogeneity

Optically formed Si wafer

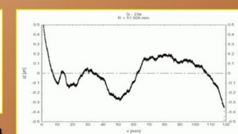
Thermally formed Si wafers

Thermally (at T > 1000 deg C) formed Si wafer to test cylinder (R = 150 mm, 72 x 23 x 0.325 mm)



The effect of elastic tension on deviation from ideal surface (thermal forming of Si wafers)

Applications at synchrotrons



Taylor-Hobson profilometer - deviation from ideal shape D = 150 mm, t = 0.625 mm, parabolic shape

Astronomical X-ray Optics in the Czech Republic

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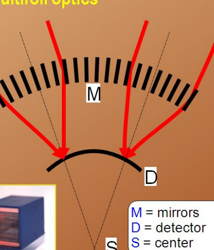
Lobster eye & multifoil optics

- Wide FOV
- Foil thickness from 30 µm to 1 mm
- Foils 3x3 mm to 300x300 mm
- Planar & ellipsoidal mirrors
- for soft X-rays
- Glass and/or silicon substrate



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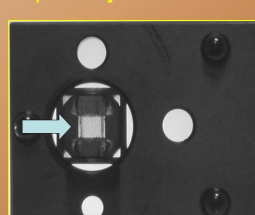
Micro LE: 3 x 3 x 14 mm module

glass foils 30 microns thick

separated by 70 microns

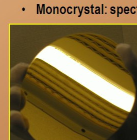


Lobster Eye X-ray Optics

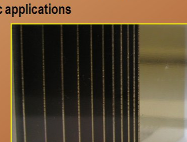
Focal image, 8 keV

X-ray Optics – novel technologies

Si wafers: novel promising substrate for X-ray optics:
- Light (2.3 g*cm^{-3}, essential for space applications – ESA XEUS)
- rms ~0.1 nm need for precise optical shaping
- 1D bent (cylinder, aspheric, ...), 2D bent (parabolic)
- 4 different technologies for precise optical shaping tested
- Monocrystal: spectroscopic applications



bent Si wafer



stacked Si wafer test module

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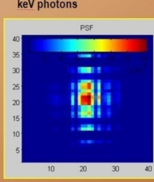
Lobster Eye & multifoil optics tests

The developed LE optics has performance identical to calculated

- Point-to-point focusing system, LE Schmidt micro (3x3x0.03 mm mirrors)
- source-detector distance 160 mm, 8 keV photons



X-ray experiment vs. simulation

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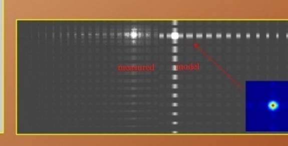

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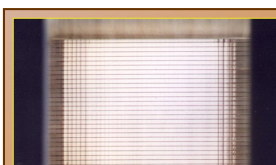

The front wiew of the mini - lobster module, Schmidt arrangement, based on 100 micron thick plates spaced by 300 microns, 23 x 23 mm each