Laser plasma radiation source as a tool for testing X-ray and EUV astronomical optics

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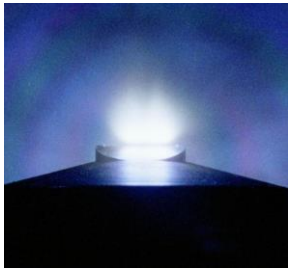
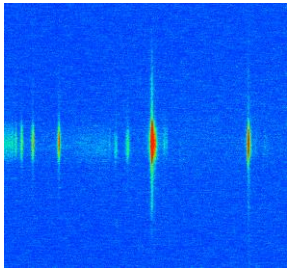
Outline

- **Introduction**
  - testing astronomical X-ray and EUV optics,
  - testing facilities and instruments.
- **Laser plasma source of soft X-rays and EUV**
  - principle of the source operation,
  - gas puff target approach,
  - application of the source.
- **Testing EUV and soft X-ray optics**
  - EUV multilayer mirrors,
  - EUV grazing incidence mirrors,
  - soft X-ray grazing incidence mirrors,
  - EUV filters
- **Summary and conclusions**

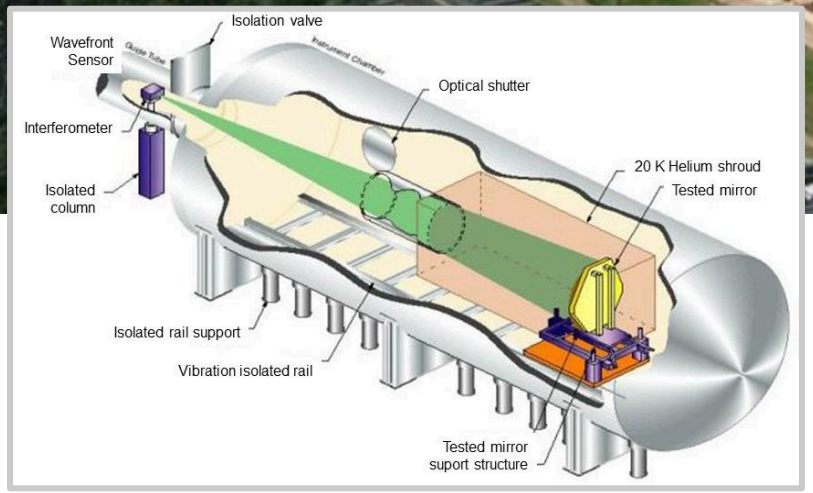


Marshall's X-ray and Cryogenic Facility (XRCF)

The **X-ray and Cryogenic Facility** at NASA's Marshall Space Flight Center in Huntsville, Ala., is a unique, world class optical, cryogenic and X-ray test facility.

The X-ray and Cryogenic Facility consists of a 1,700-foot-long (518 m) X-ray guide tube, a horizontal cylindrical vacuum chamber and two clean rooms.



7.3 × 22.8 m Polished Stainless Steel 10^{-7} Torr Vacuum Chamber

Astronomical X-ray optics testing facilities in Germany

Laboratories and X-ray Test Facilities | Max Planck Institute for extraterrestrial Physics (mpg.de)

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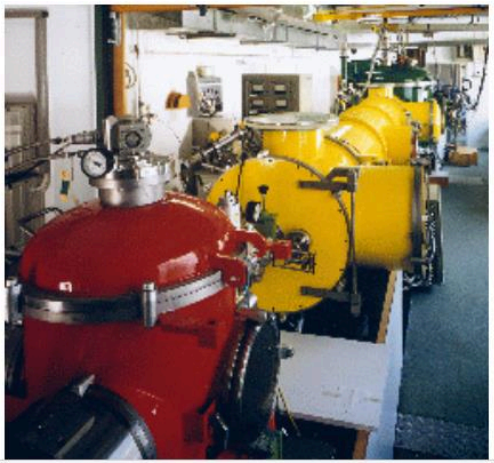
Laboratories and X-ray Test Facilities

Two X-ray test facilities (PANTER and PUMA) are operated by the High-Energy Astrophysics group and provide an unique service to test X-ray equipment from all over the world. Components for almost all major X-ray satellites have been tested there. MPE was substantially involved in the development, testing and calibration of the X-ray telescopes and the EPIC-pn camera for XMM-Newton and the Low Energy Transmission Grating (LETG) for Chandra.

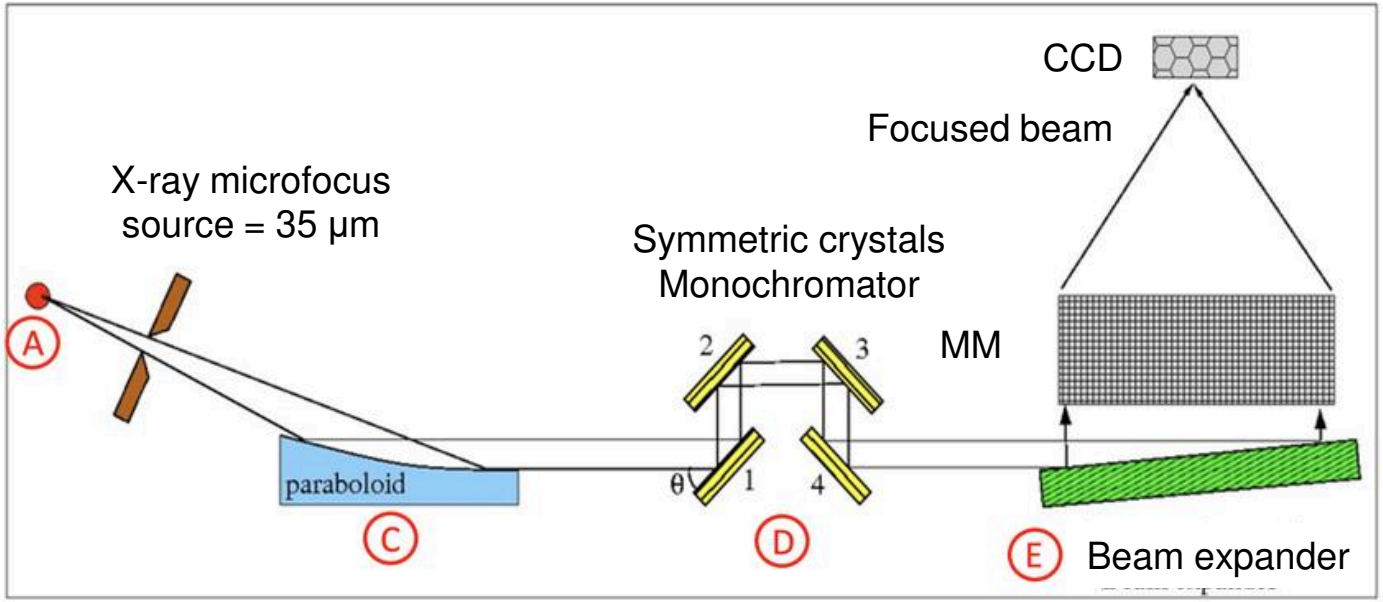


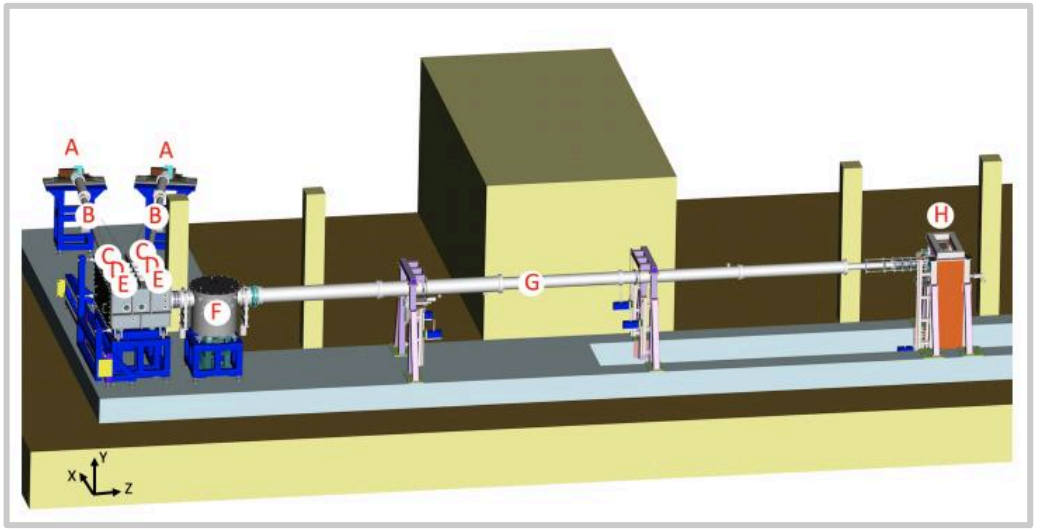
PANTER

PUMA

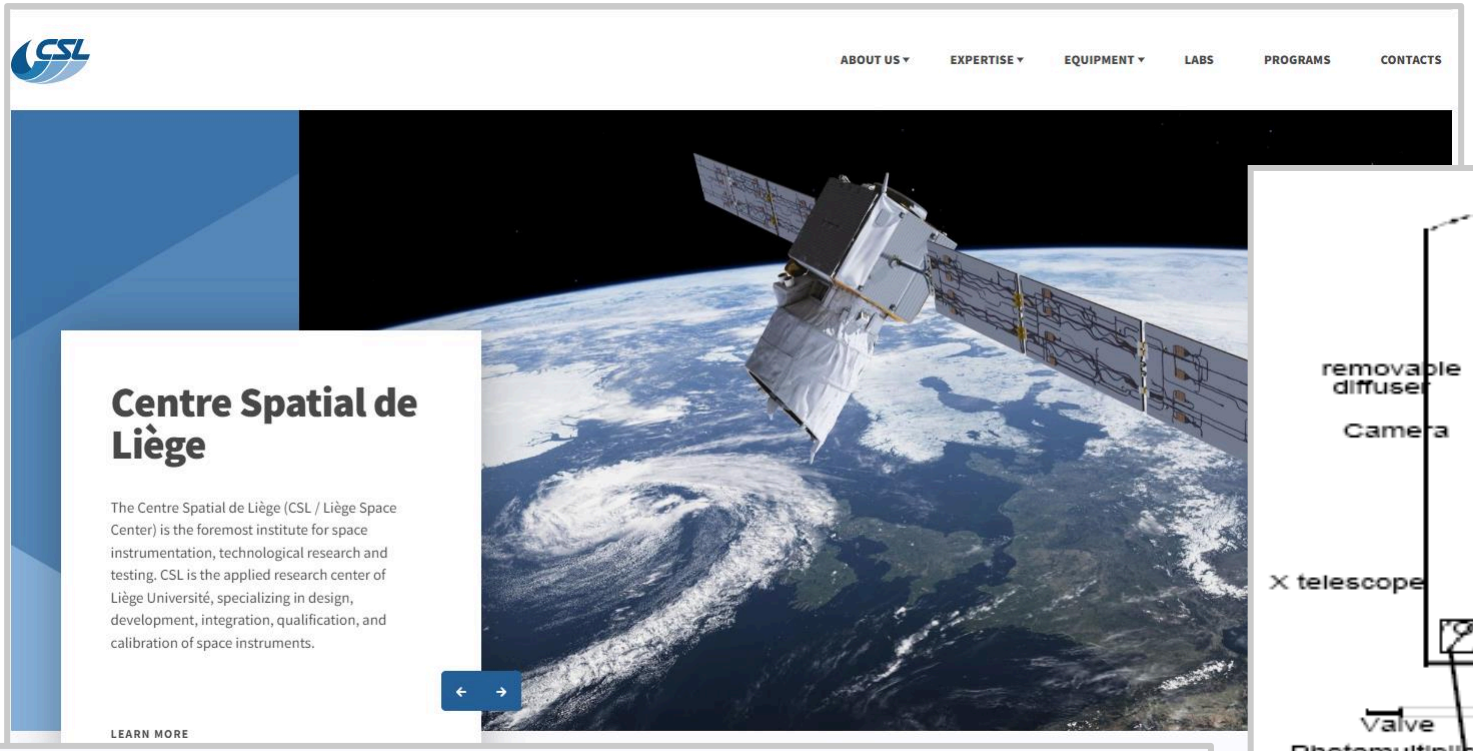
Facility for testing modular X-ray optics in Italy

BEaTriX – testing facility for the modular X-ray optics of the ATHENA mission



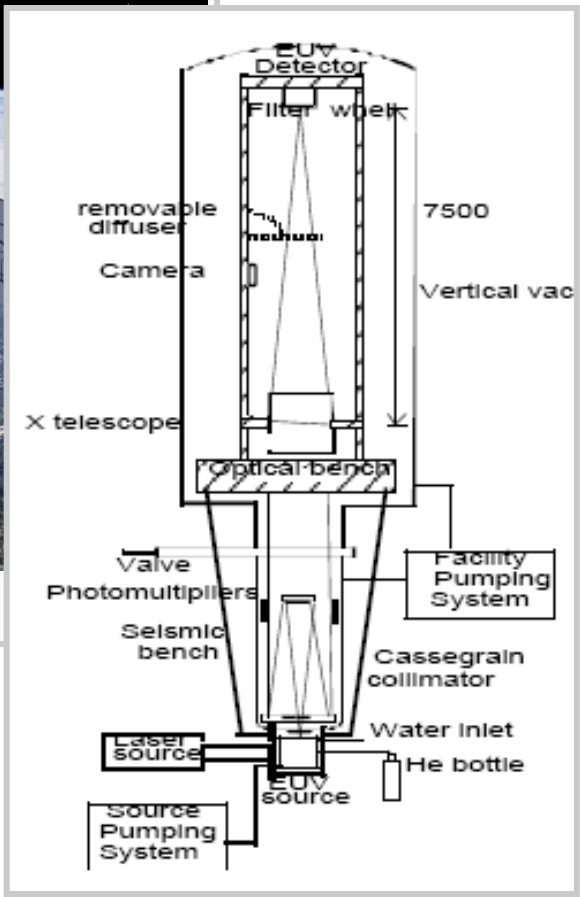


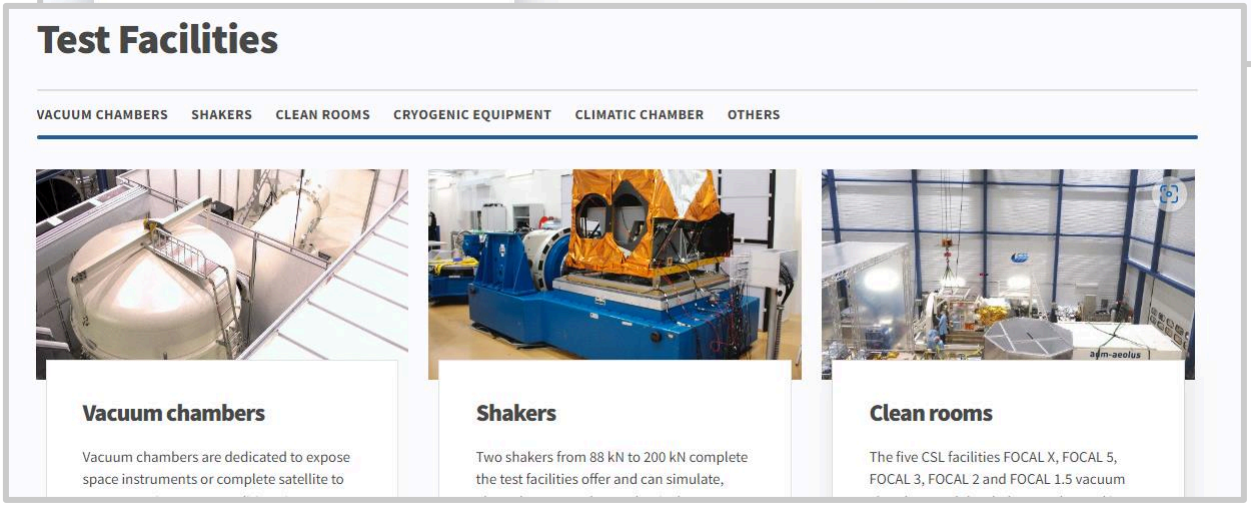
Testing facilities at CSL, Belgium



FOCAL X

EUV channel





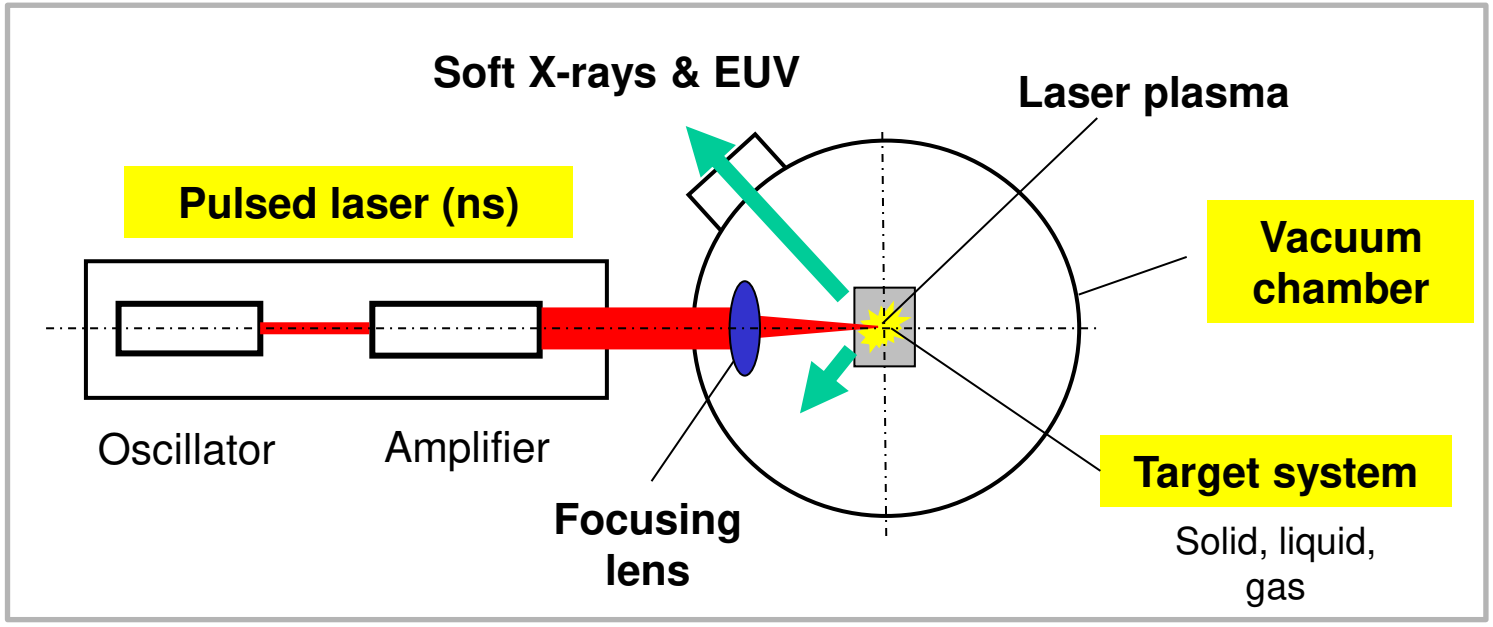
EUV source (ECR He source)

58.4 nm (8×10^{15} ph/sec∗sr)

30.4 nm (1×10^{15} ph/sec∗sr)

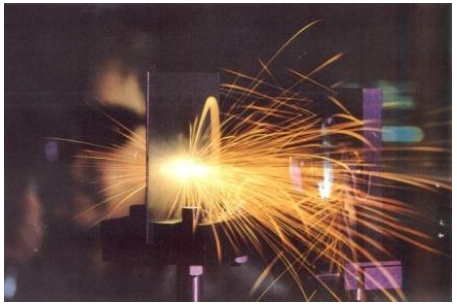
Laser plasma source of EUV and soft X-rays

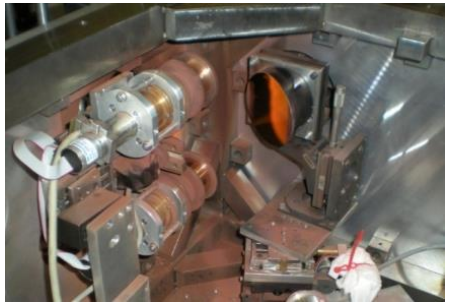
Schematic of a laser plasma source



Source characteristics:
- high single-pulse brightness
- short-pulse duration (ns)
- point-like shape
- easy tuning of wavelength
- low investment costs

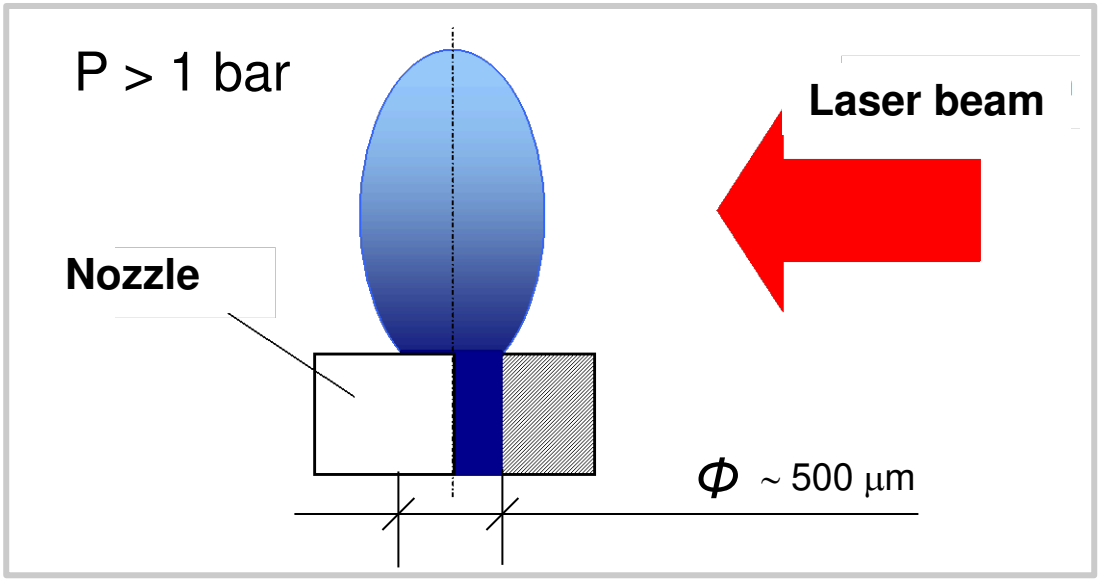
Main disadvantages:
- laser target operation
- **target debris production**



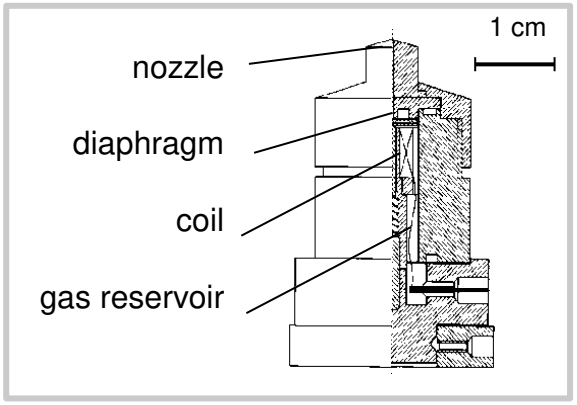


Gas puff target

Schematic of a gas puff target



Solenoid valve

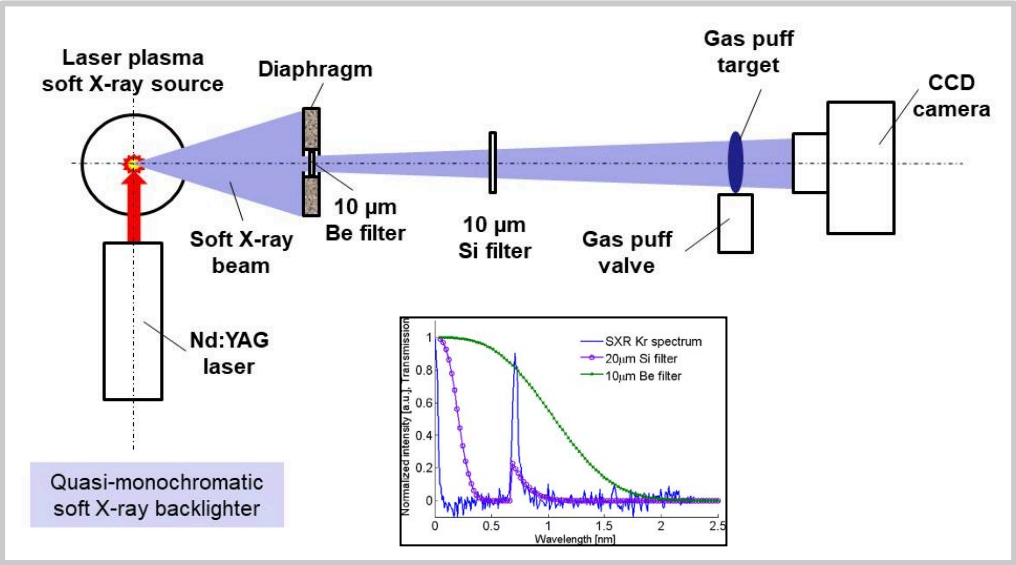


Power supply

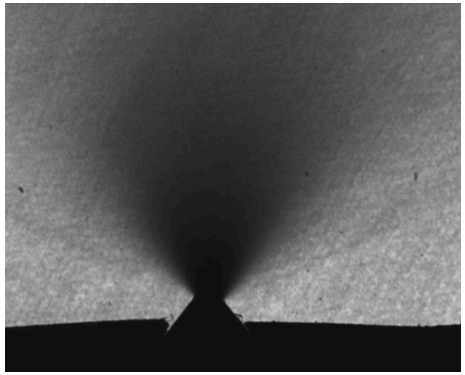
Appl. Phys. Lett. 62 (1993) 2778

Gas puff target characteristics

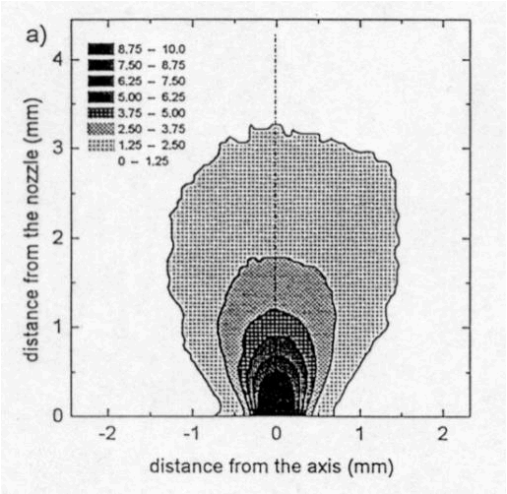
Soft x-ray shadowgraphy



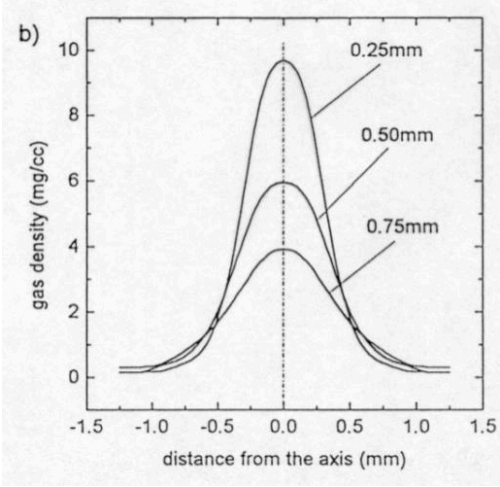
Typical soft x-ray shadowgram



Gas density contours

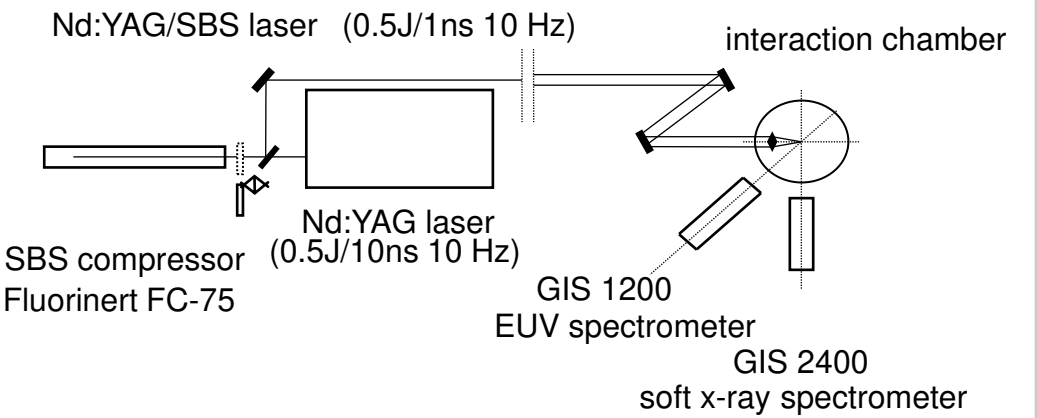


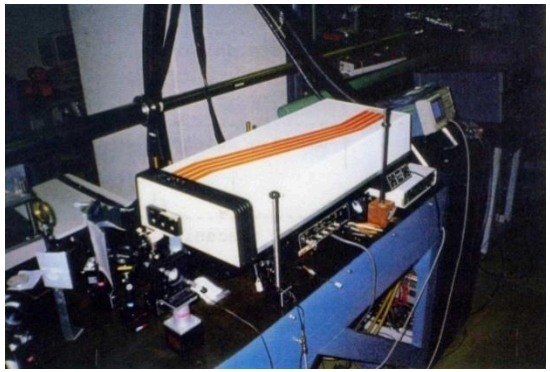
Gas density spatial profiles

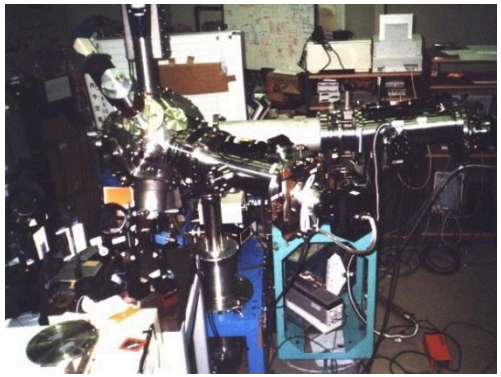


Soft X-ray/EUV emission studies

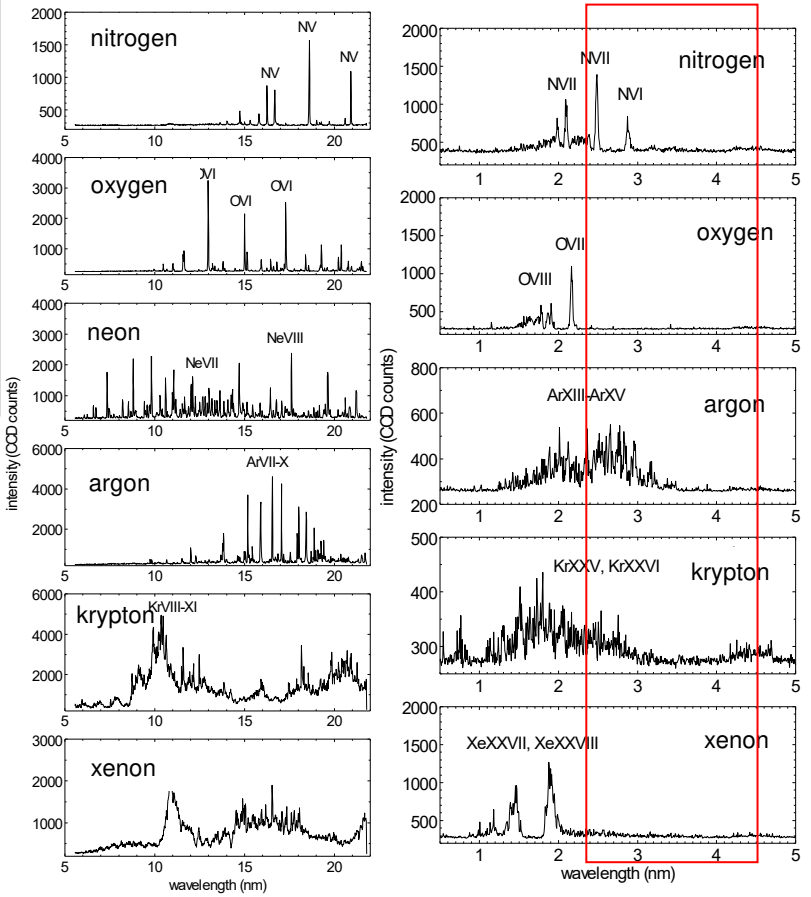
Institute of Laser Engineering, Osaka University, Japan







EUV spectra **Soft X-ray spectra**



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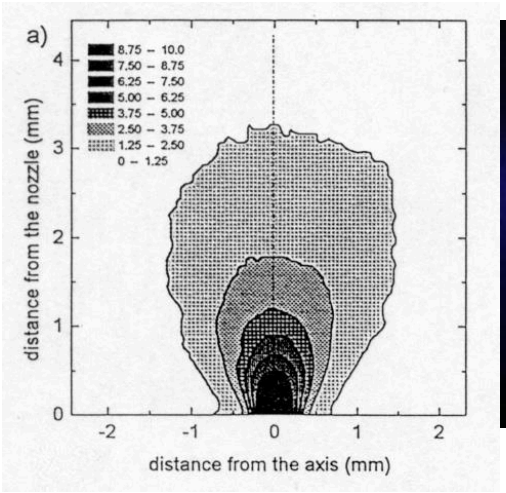
Gas puff target limitations

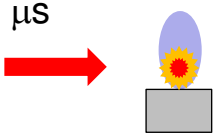
❑ nozzle degradation

Laser beam

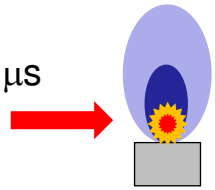


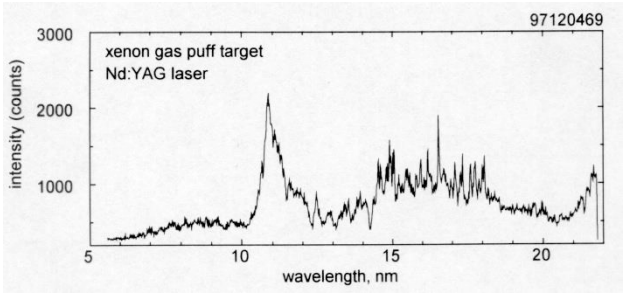
❑ self-absorption of EUV radiation in cold gas

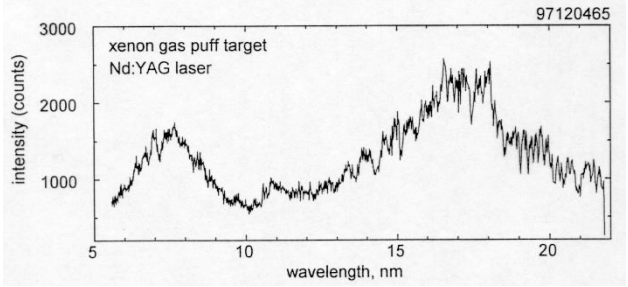
Δt = 200 μs



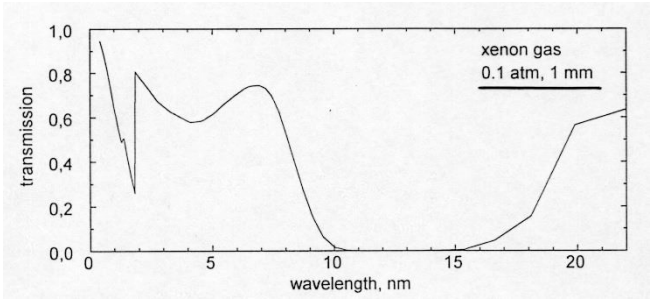
Δt = 350 μs







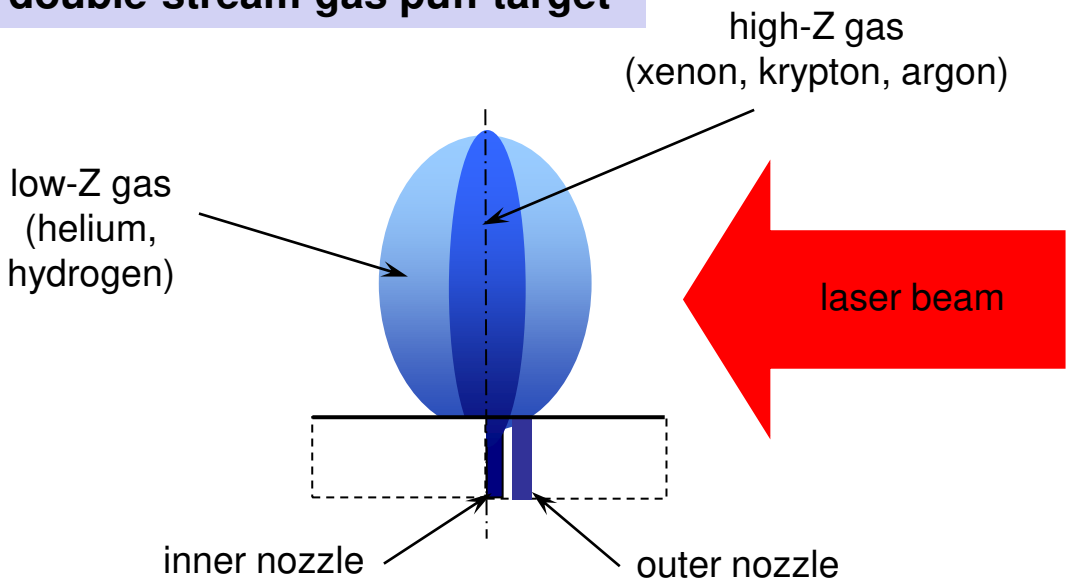
EUV transmission in xenon



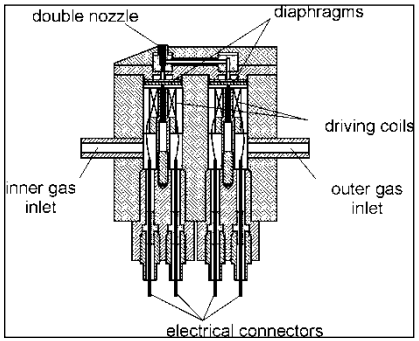
10 - 15 nm

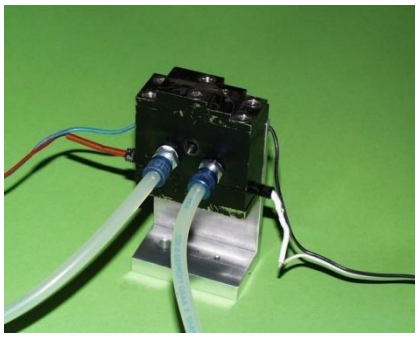
Double-stream gas puff target

- **schematic of a double-stream gas puff target**

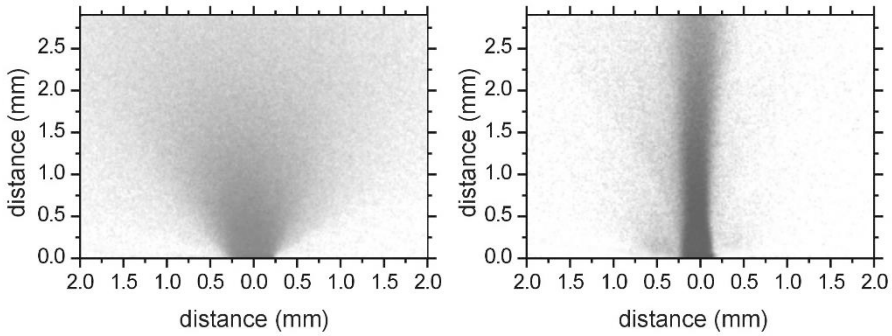


- **electromagnetic valve system**





- **X-ray backlighting images**



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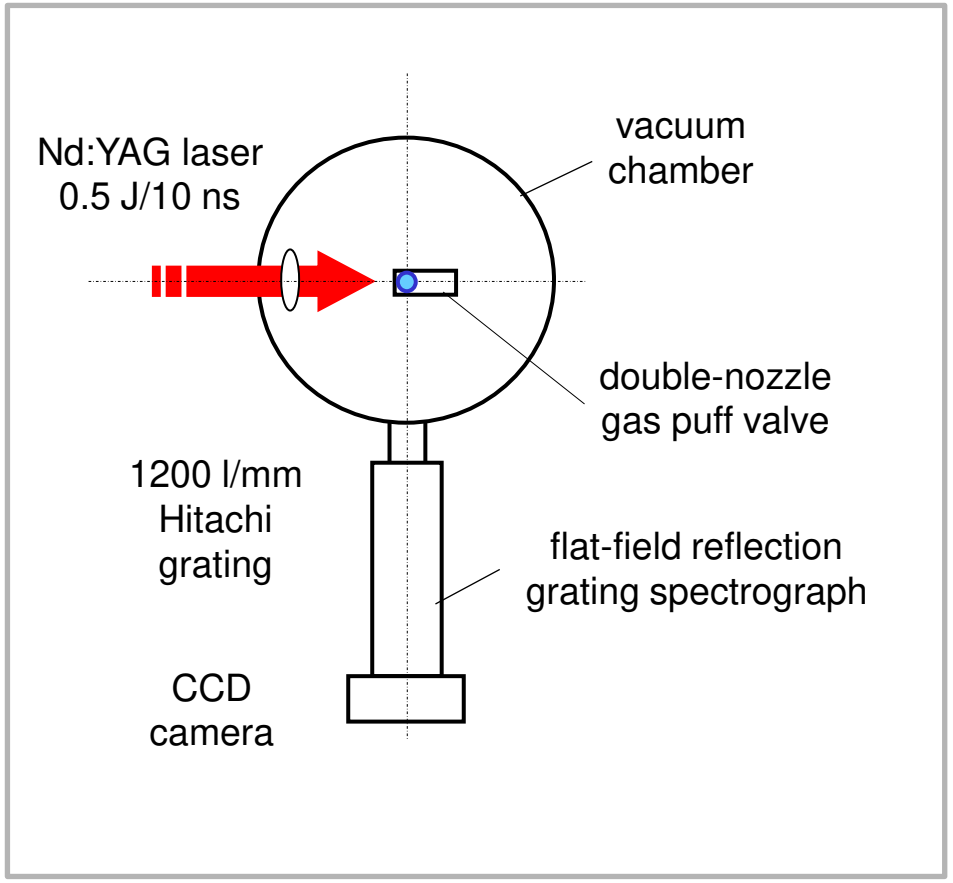
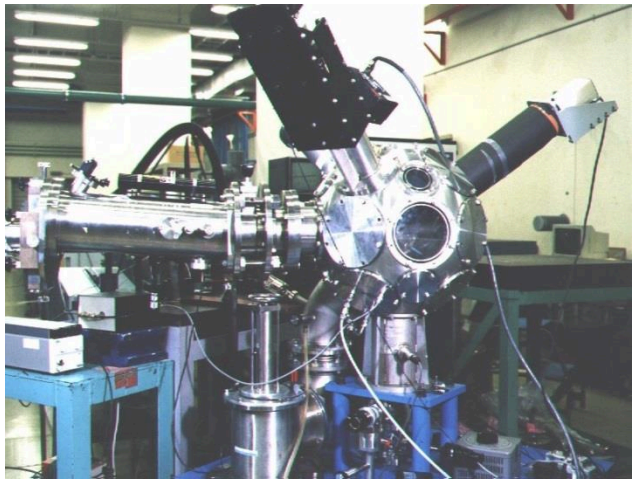
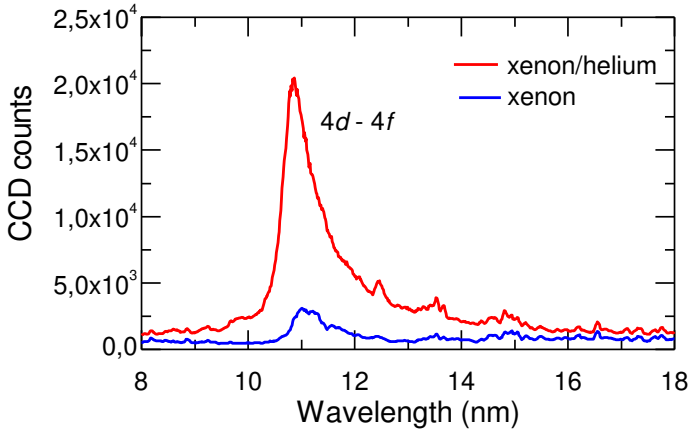
EUV emission studies

- **Nd:YAG laser (Institute of Laser Engineering, Osaka, Japan)**







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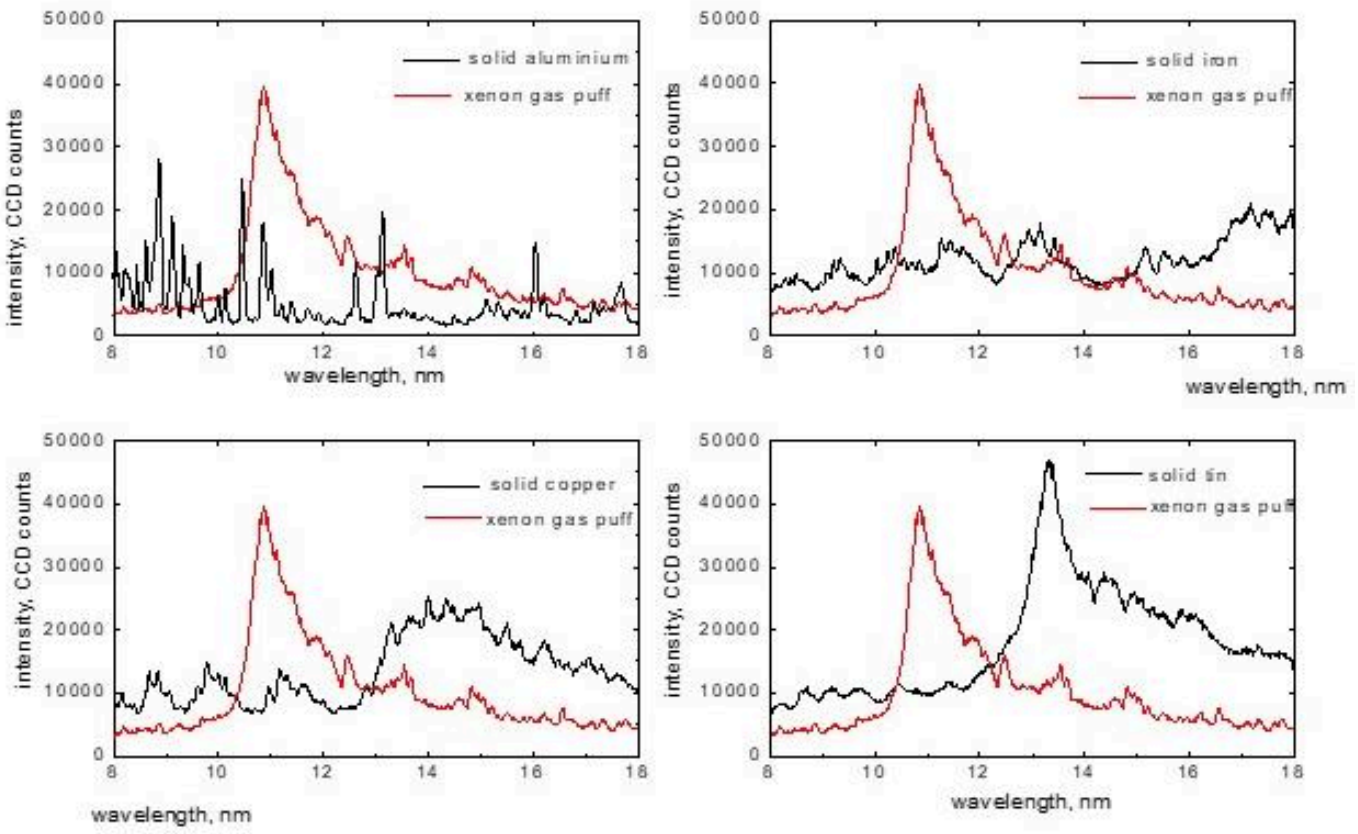
EUV emission studies

- **EUV emission from various targets irradiated with a Nd:YAG laser (0.5J/10ns)**



ILE, Osaka

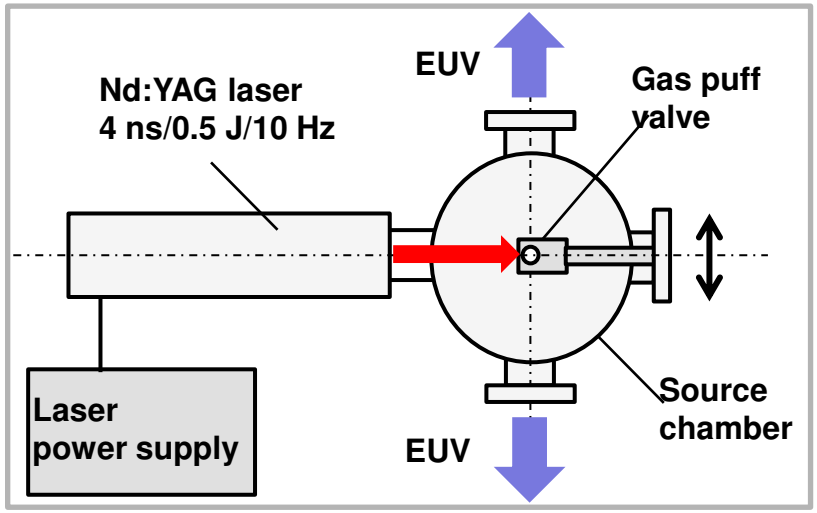
IOE, Warsaw

Gas puff target

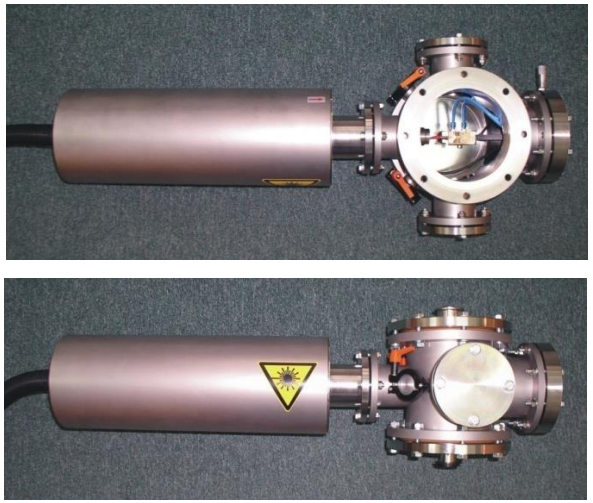
- **Elimination of debris**
- **Operation with repetition**
- **Conversion efficiency improvement**

Compact laser plasma EUV source

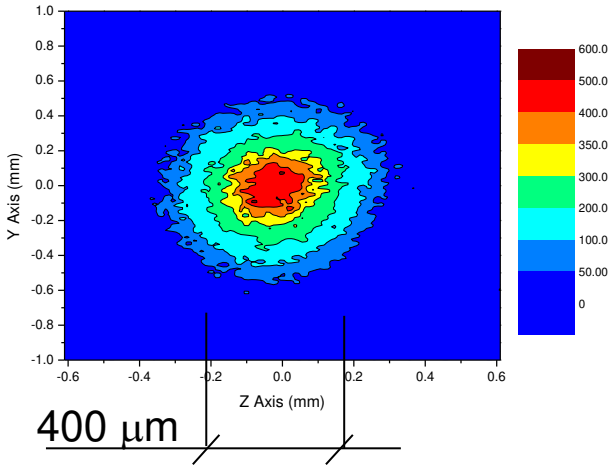
Schematic of the source



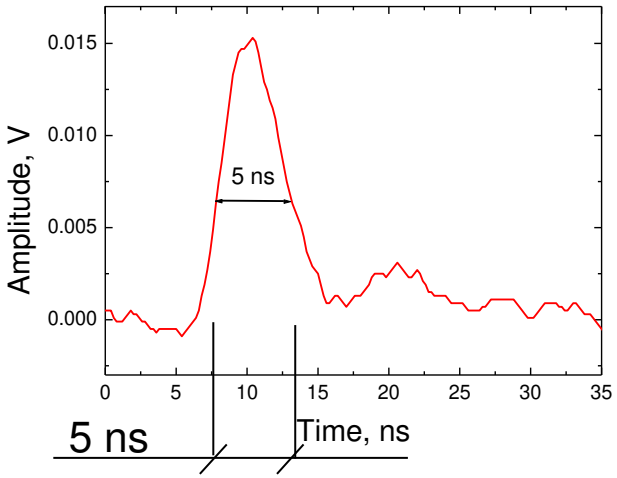
EUV lamp



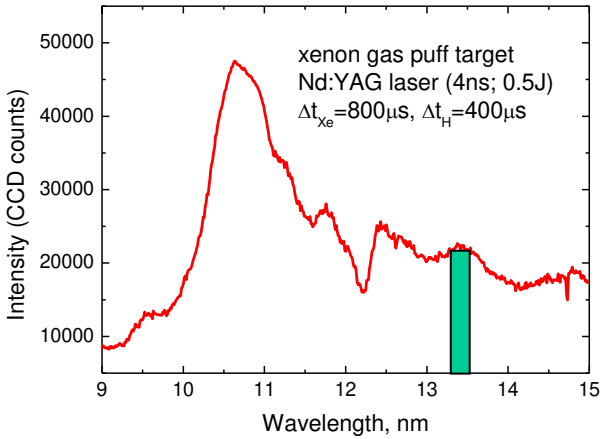
Spectral image at 13.5 nm



Time profile



EUV spectrum

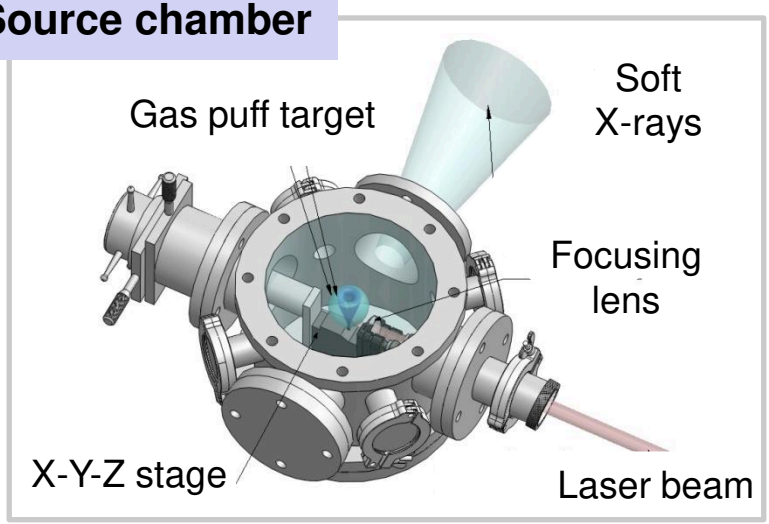


~ 1.5 % CE at 13.5 nm

J. Alloys&Compounds **401** (2005) 99

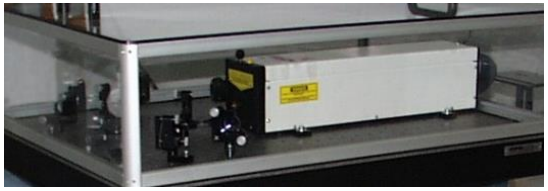
Laser plasma soft X-ray source

Source chamber



We use commercial Nd:YAG lasers

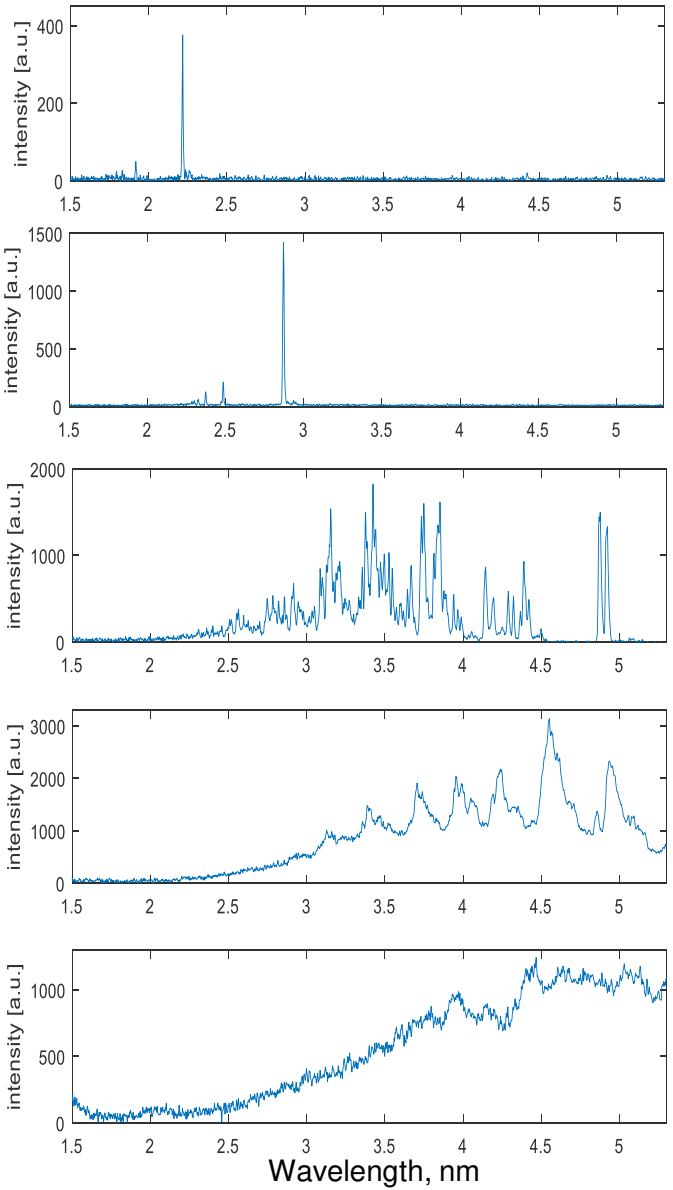
4 ns
0.5-0.8 J
10 Hz



10 ns
2.5 J
10 Hz

1-10 ns
10 J
10 Hz

Soft X-ray spectra



oxygen

nitrogen

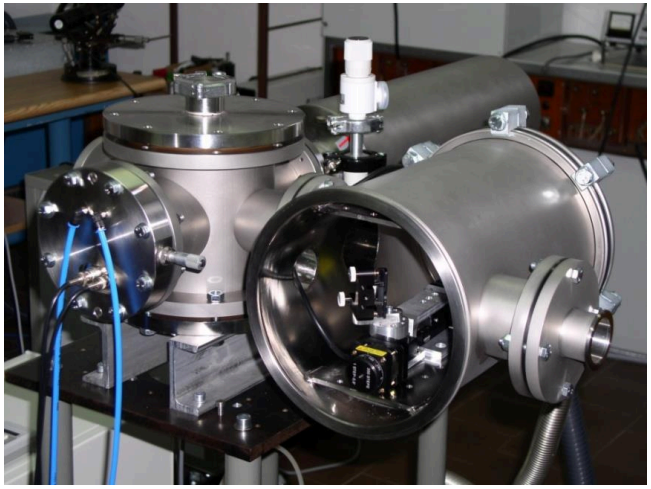
argon

krypton

xenon

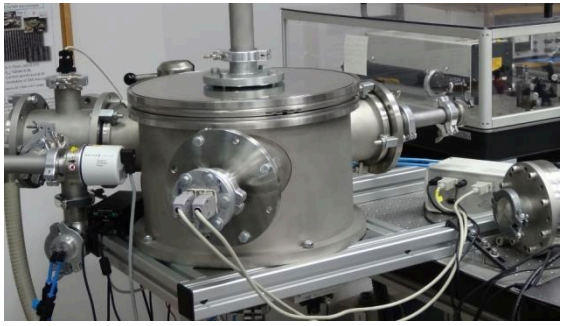
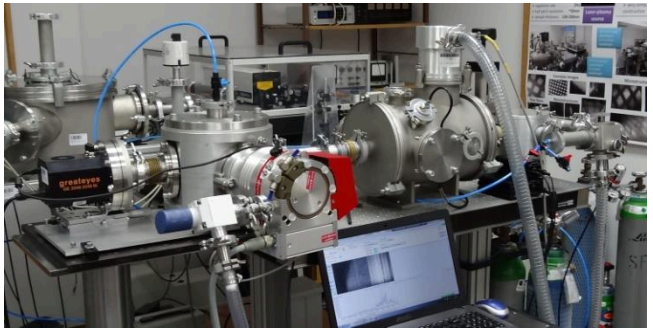
Laser plasma EUV/soft X-ray sources based on a gas puff target







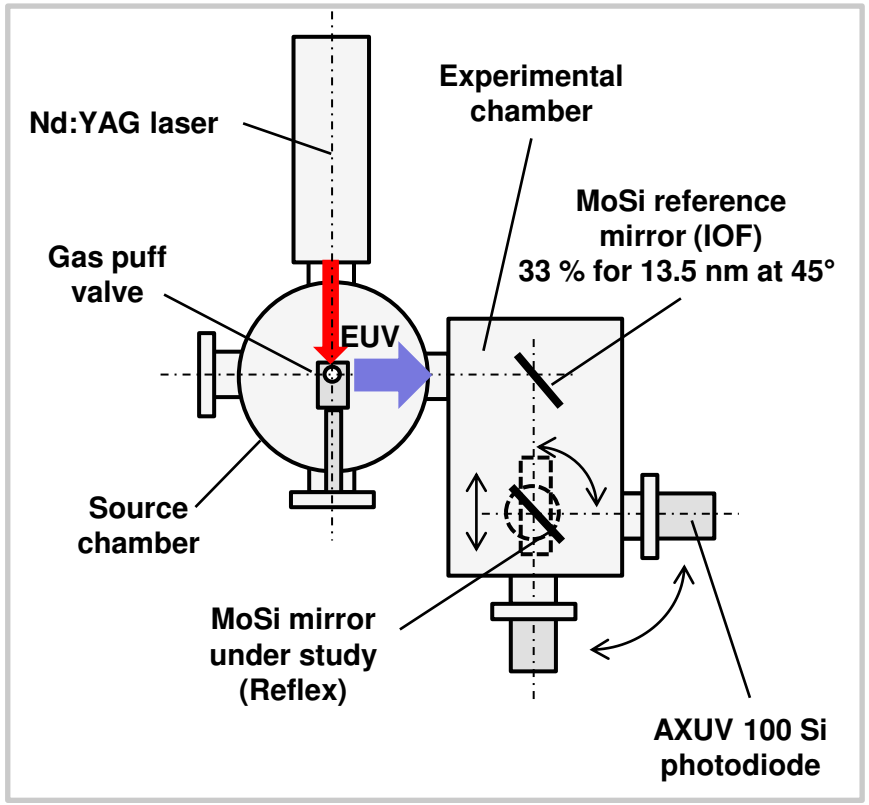


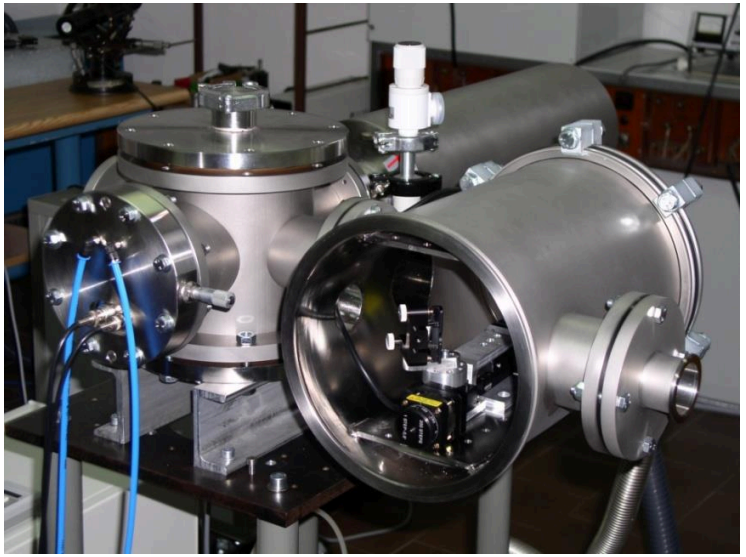



Testing EUV mirrors

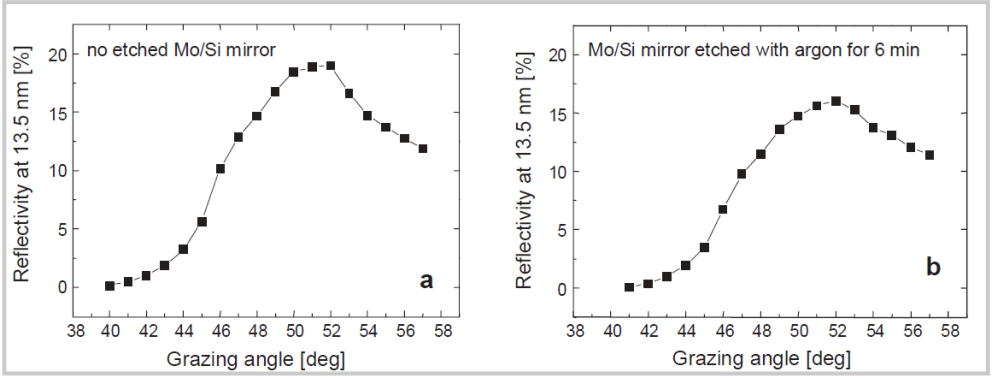
Characterization Mo/Si multilayer mirrors

Experimental setup





EUV mirror reflectivity angular dependence at 13.5nm



Collaboration with REFLEX s.r.o. Prague, Czech Republic

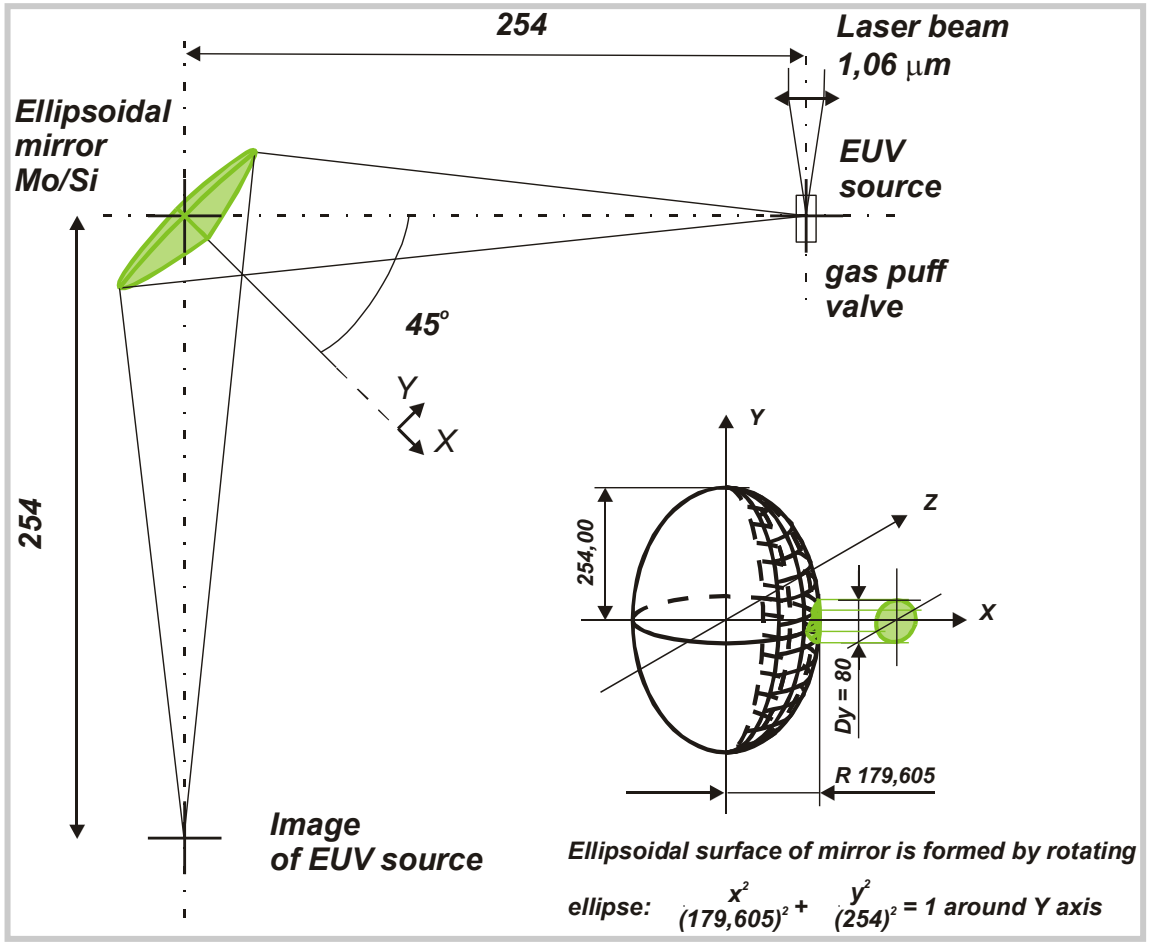
R. Rakowski *et al., Optica Applicata* ***36*** *(2006) 593*

Testing EUV mirrors

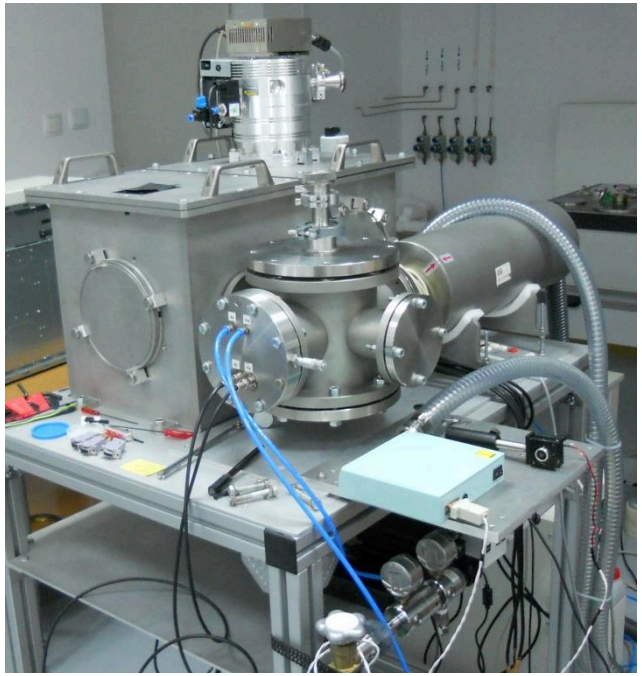
EUV ellipsoidal mirror with Mo/Si coating

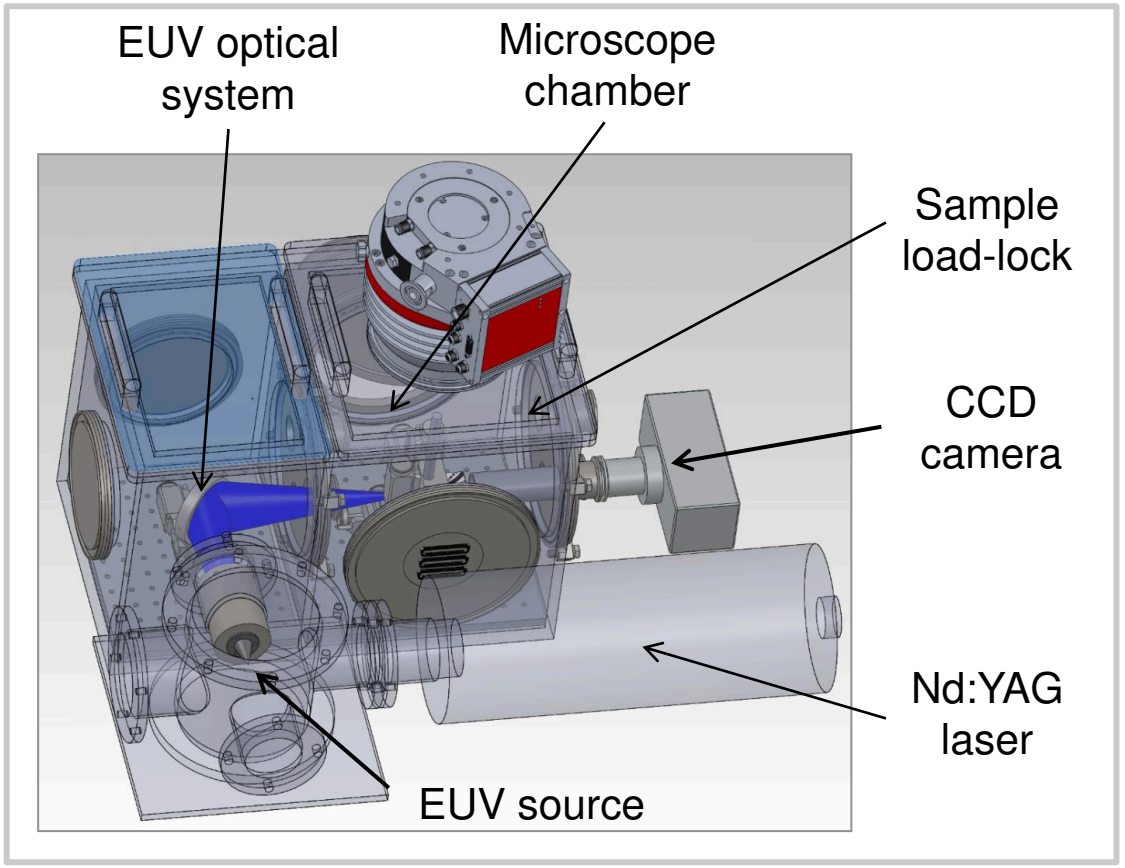
Collaboration with REFLEX s.r.o. Prague, Czech Rep.(substrate) and IOF, Jena, Germany (multilayers)

Optical diagram of the mirror

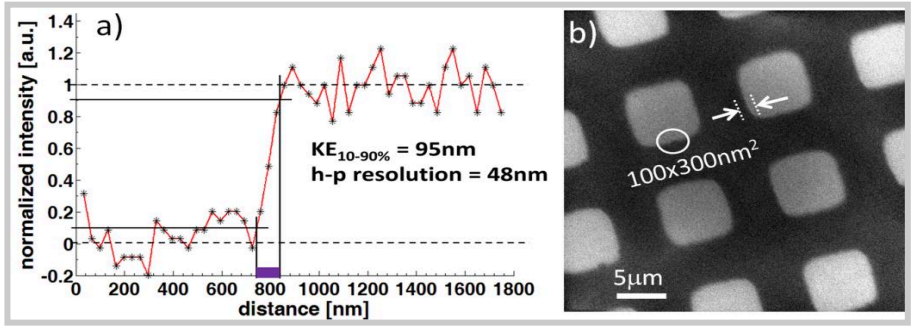


Compact EUV microscope





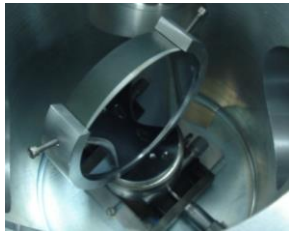
48 nm
spatial resolution



P. Wachulak et al. *Meas. Sci. Techn. (2016)*

EUV microscopy based on a Fresnel optic

Condenser
ellipsoidal Mo/Si multilayer mirror



Sample holder

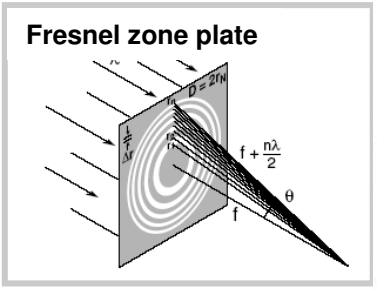
CCD camera

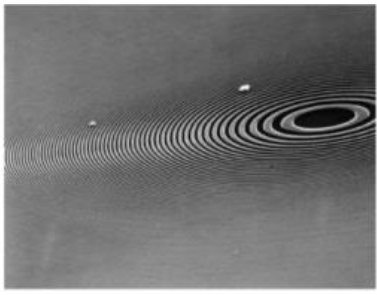
100 nm Ti filter

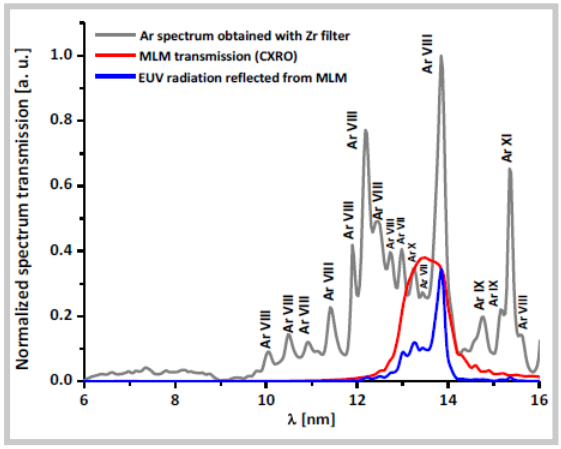
Objective
Fresnel zone plate

Nd:YAG laser

Quasi-monochromatic laser plasma source
λ = 13.8 nm







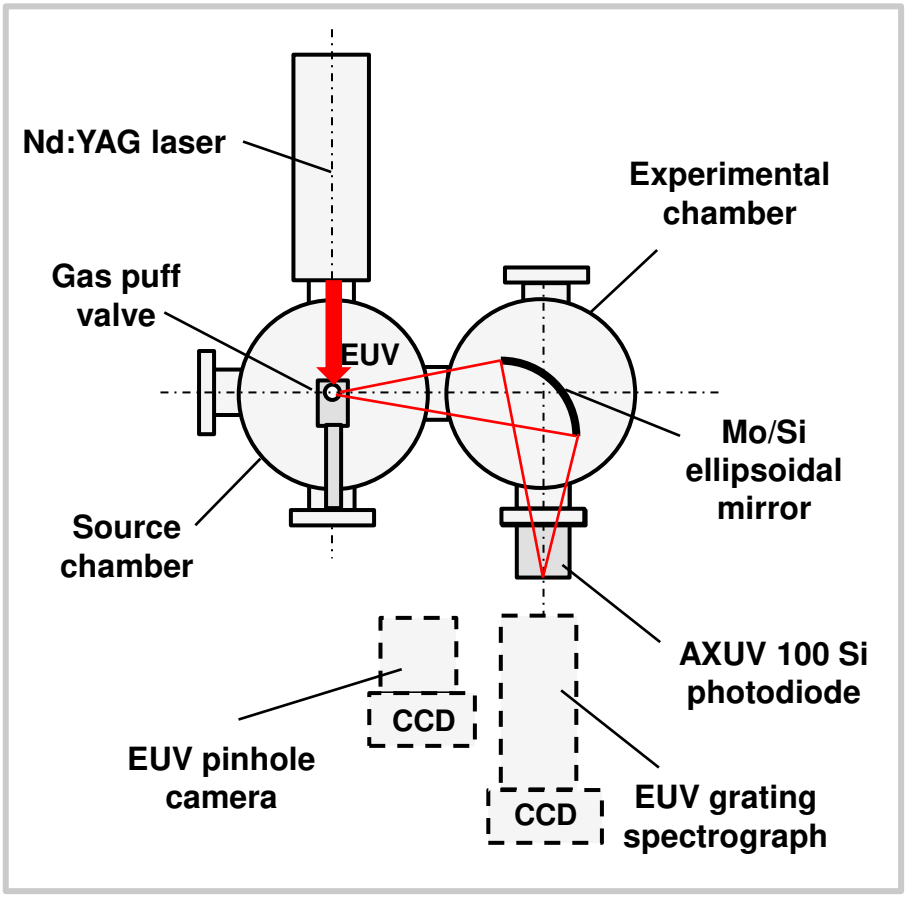
Ar plasma
EUV spectrum

Zone plate parameters:

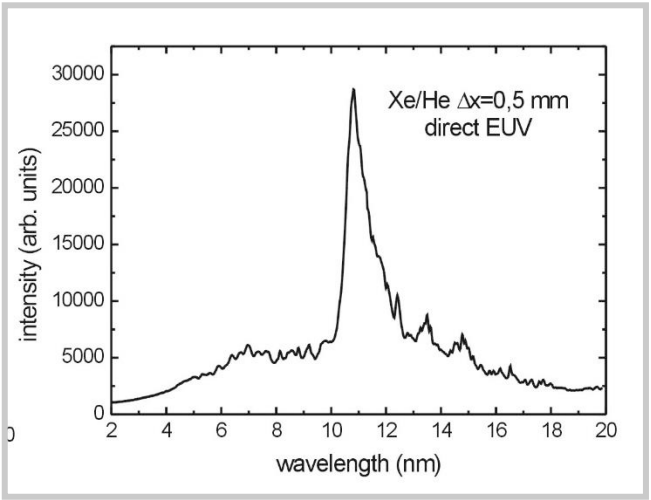
Diameter:	200 μm
Outer zone width:	50 nm
Focal length:	0.723 mm
Number of zones:	1000
Numerical aperture:	0.137
Theoretical resolution (Rayleigh criterion):	61 nm
Depth of focus:	+/- 369 nm

Testing EUV ellipsoidal Mo/Si mirror

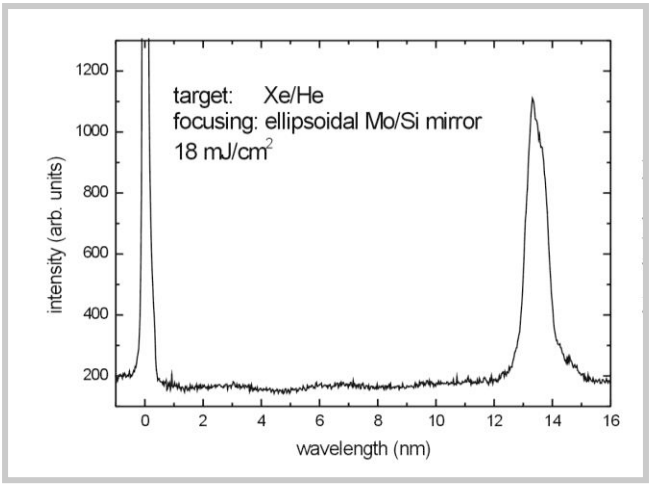
Experimental setup



EUV beam characteristics

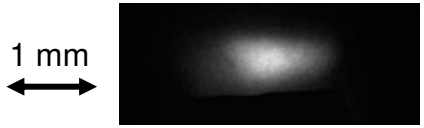


Direct Xe spectrum



Reflected Xe spectrum

EUV fluence 3 mJ/cm^2

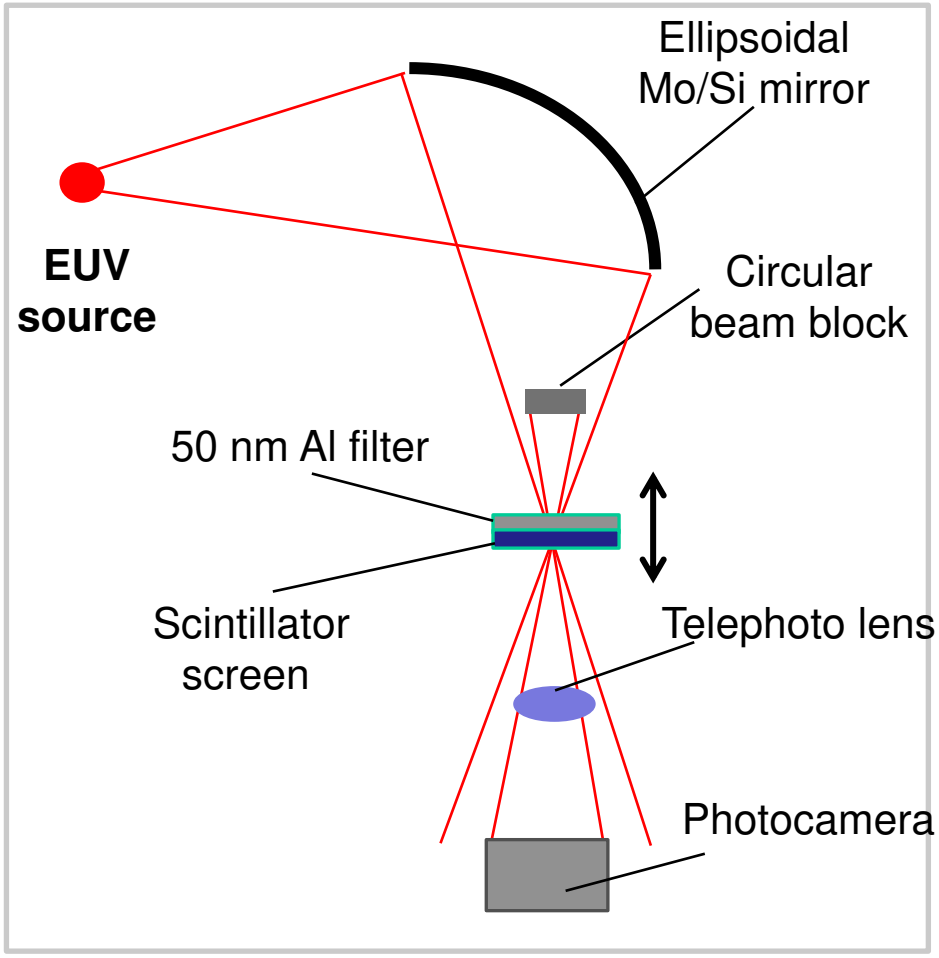


EUV source image at 13.5 nm

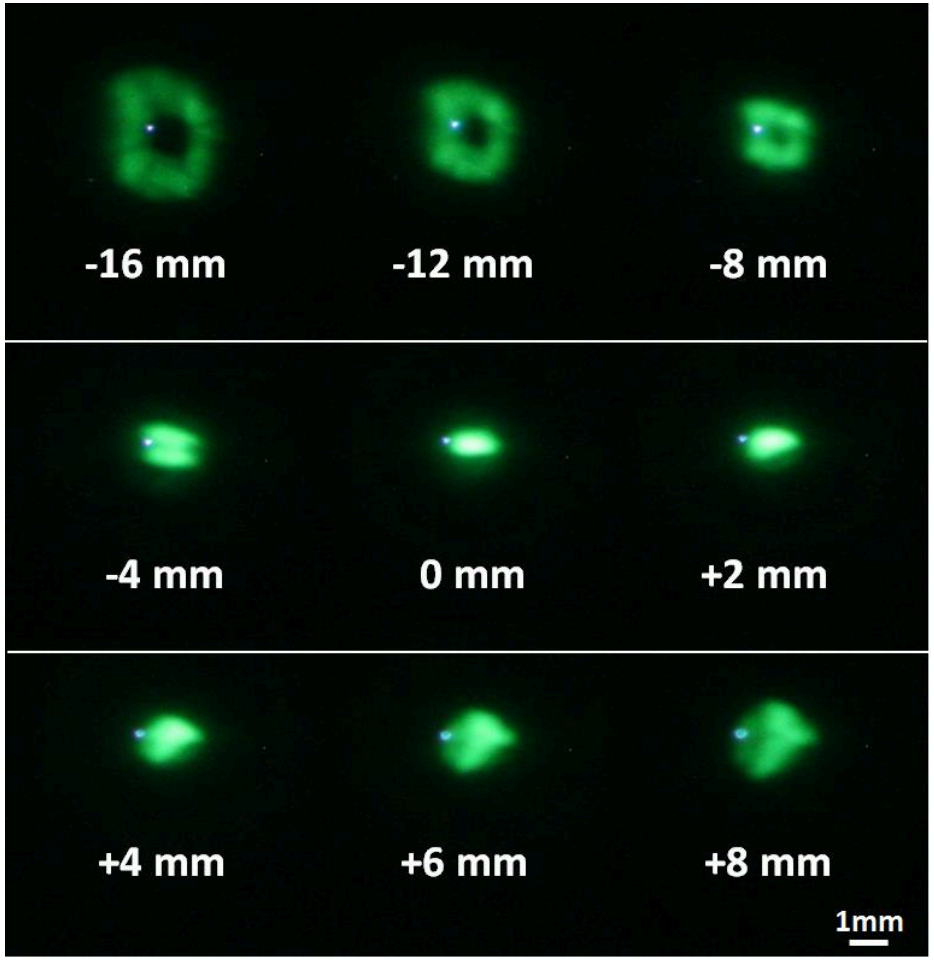
A. Bartnik et al. *Acta Phys. Pol.* 116 (2009) 108

Testing EUV ellipsoidal Mo/Si mirror

EUV beam control - mirror alignment

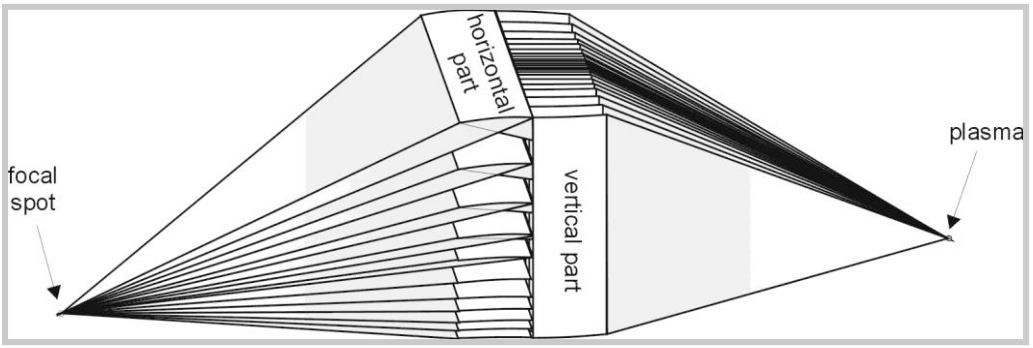


Intensity distributions in and out of the focal plane of the mirror

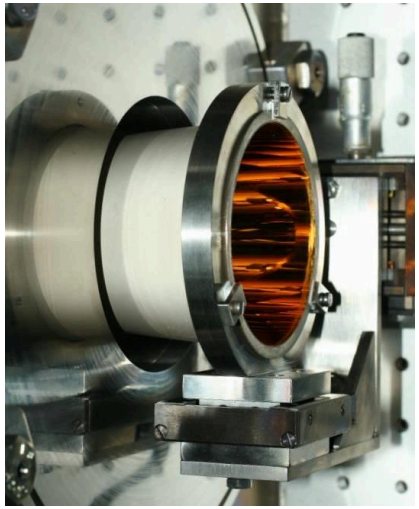


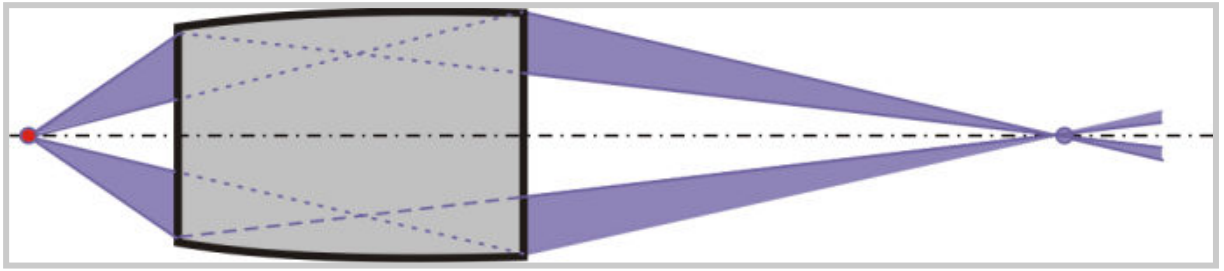
Testing EUV grazing incidence mirrors

Multi-foil grazing incidence EUV optic



Axisymmetrical ellipsoidal grazing incidence EUV mirror

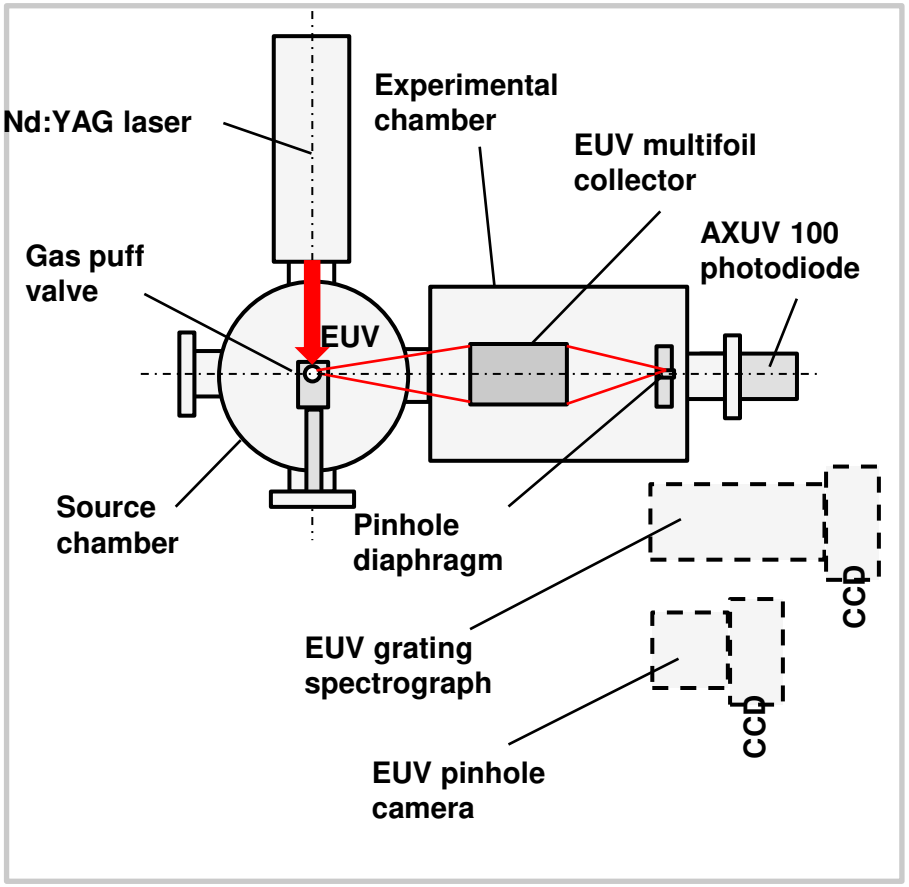


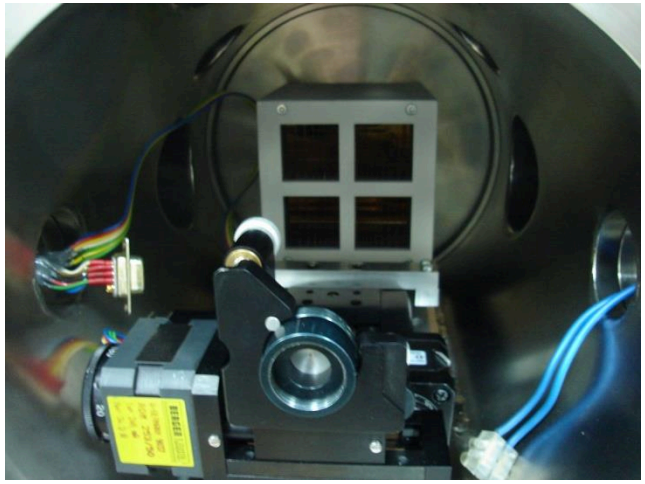


Rigaku

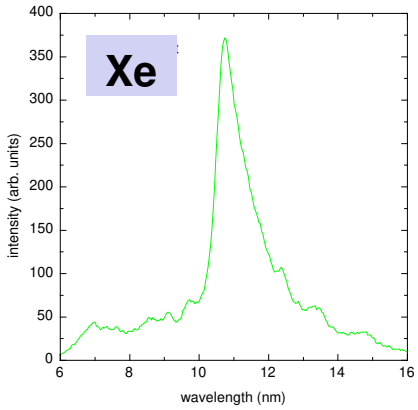
Testing EUV multifoil optic

Experimental setup

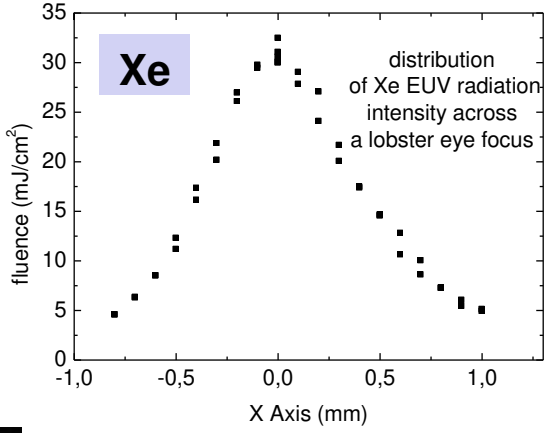




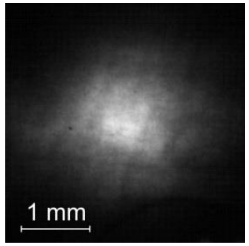
EUV spectrum



EUV fluence distribution



EUV focal spot

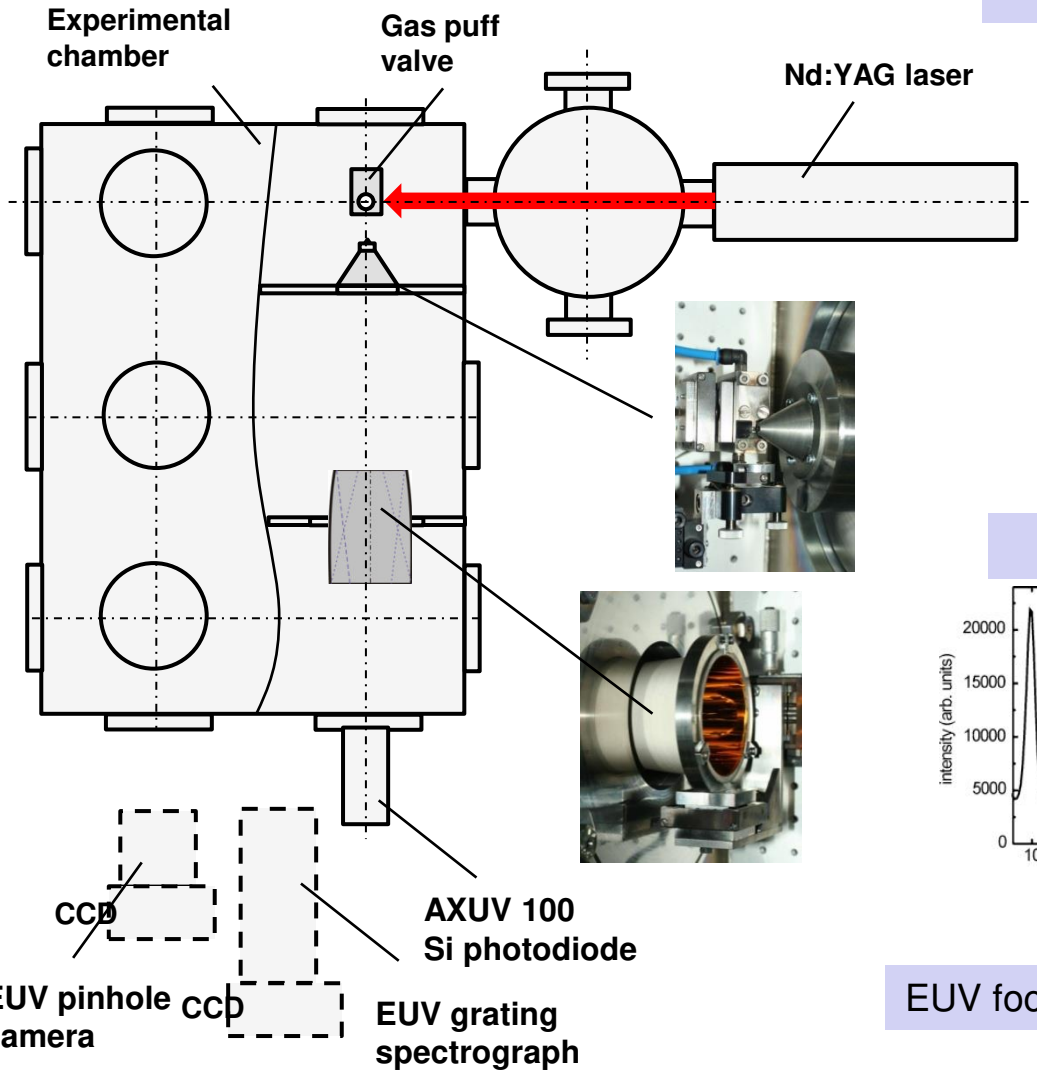


Maximum EUV fluence

~30 mJ/cm²

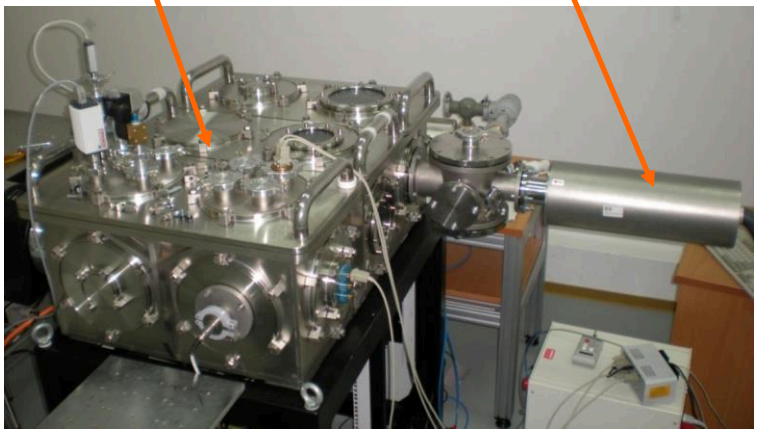
Testing EUV ellipsoidal grazing incidence mirror

Experimental setup

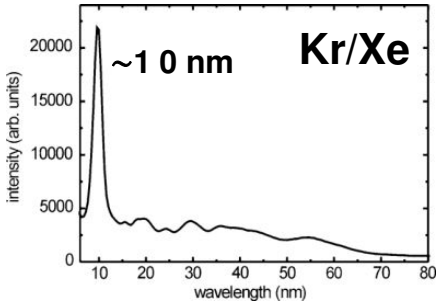


Experimental vacuum chamber

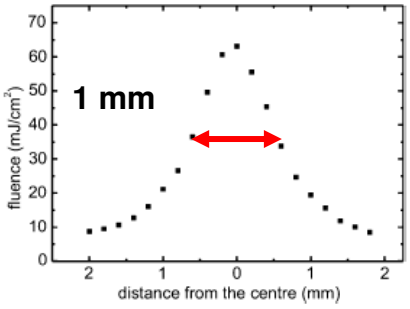
Nd:YAG laser



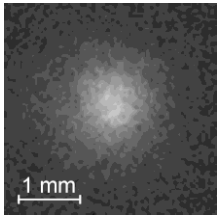
EUV spectrum



EUV fluence



EUV focal spot

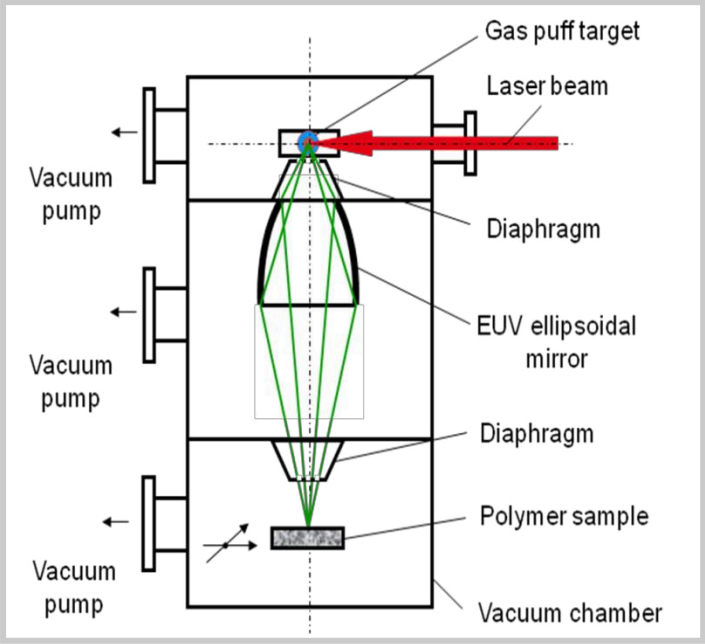


70 mJ/cm²

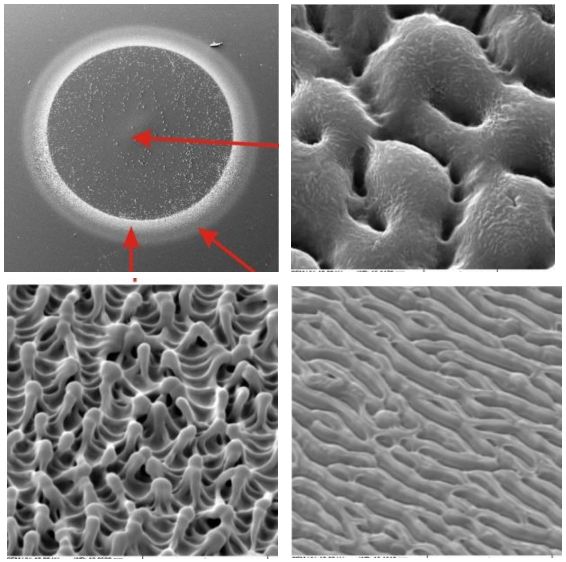
A. Bartnik *et al.* Appl.Phys. B (2012)

EUV processing materials

Laser-plasma EUV source for processing materials

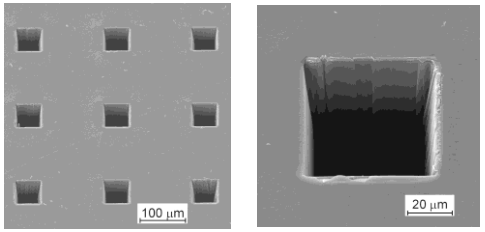


Modification polimer surface for biocompatibility control



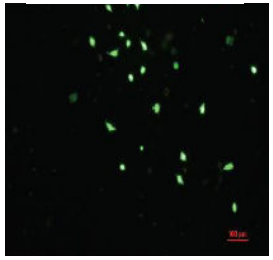
EUV beam

Micromachining polymers

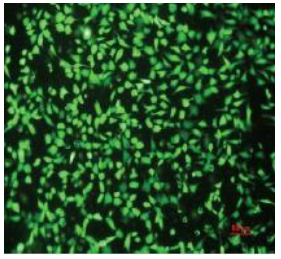


PVF sample

Pristine

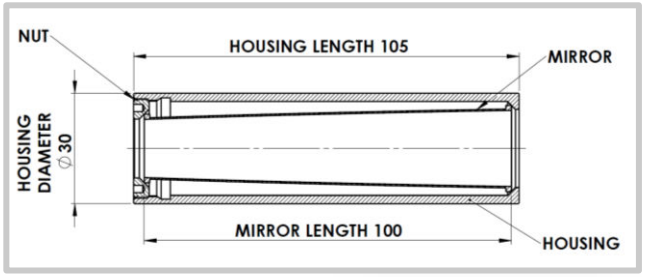


EUV modified

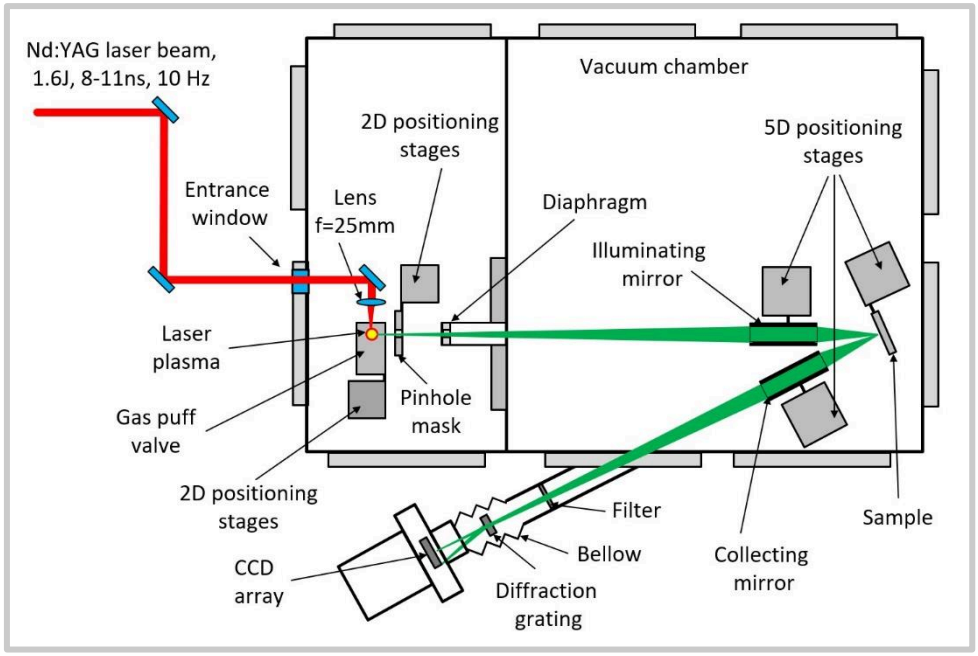


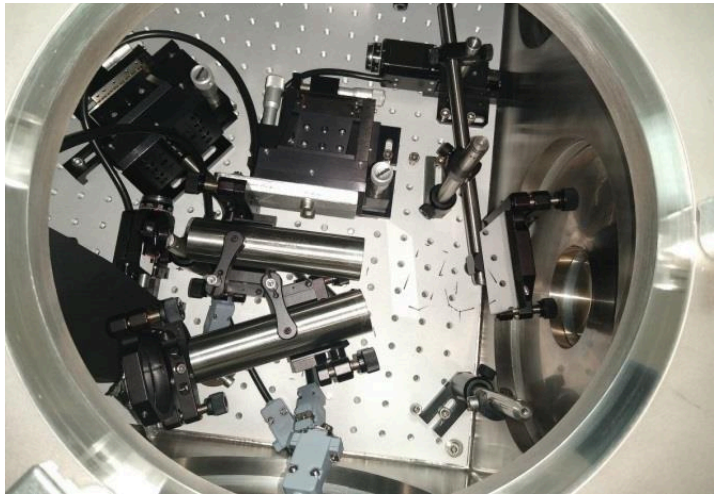
Soft X-ray grazing incidence optics

Ellipsoidal mirrors for focusing soft X-ray and EUV beams

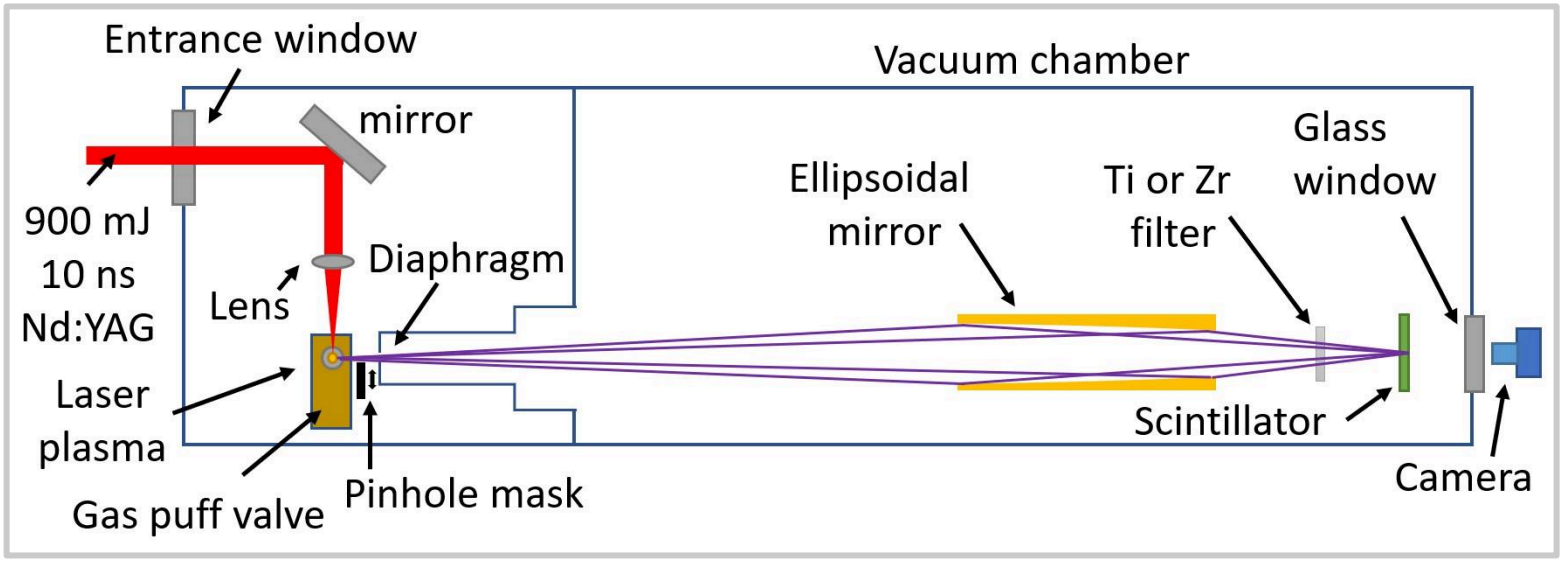


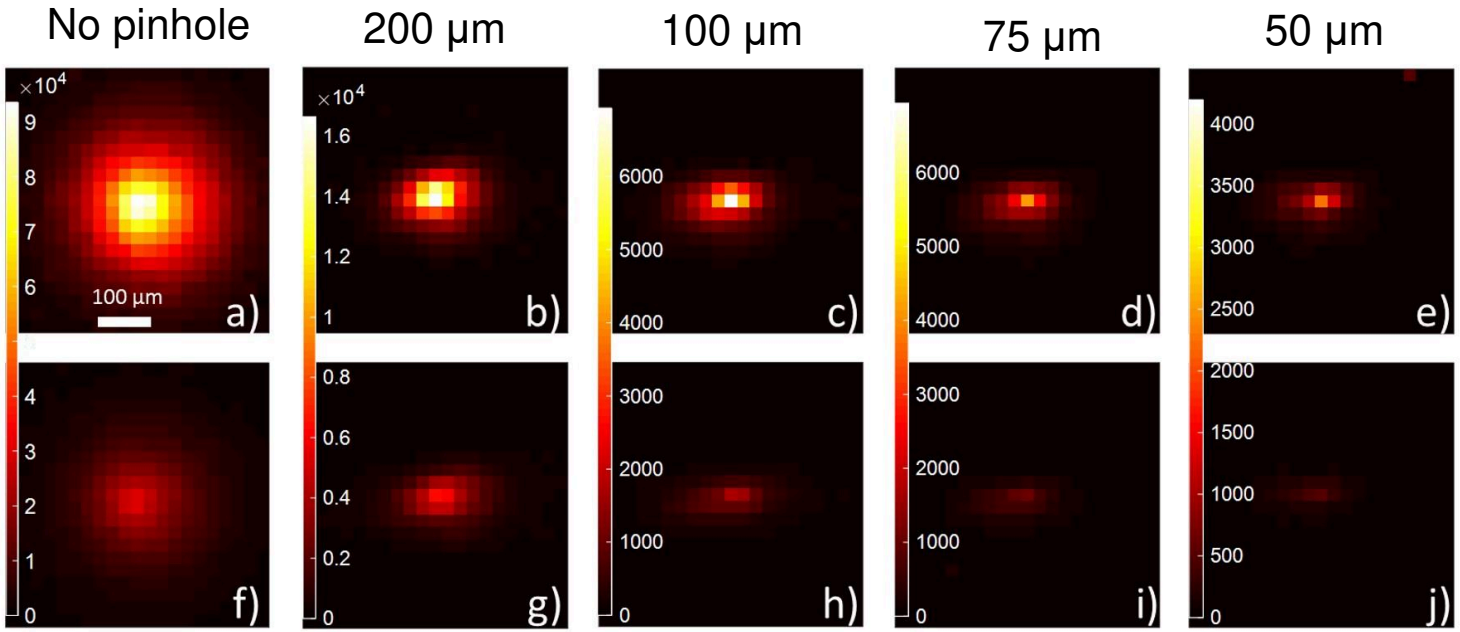
Rigaku





Testing focusing soft X-ray optics

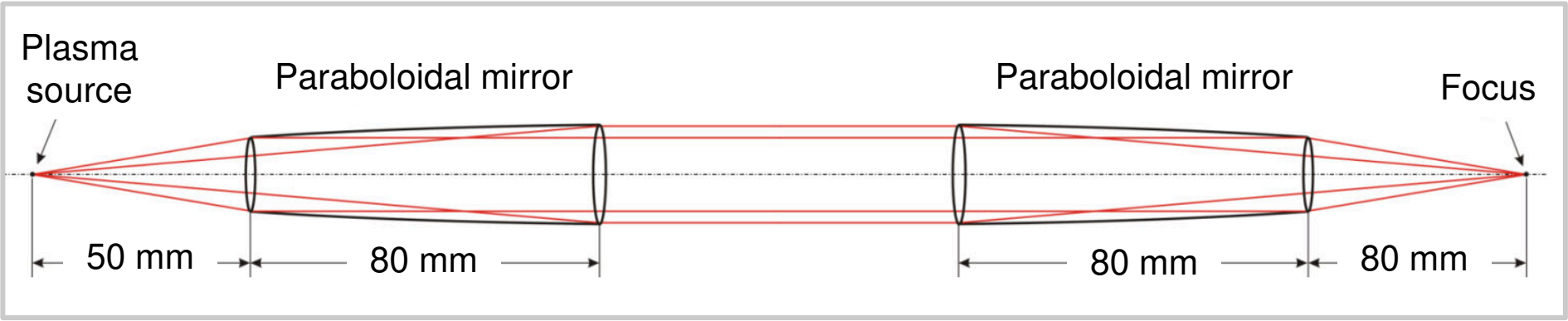


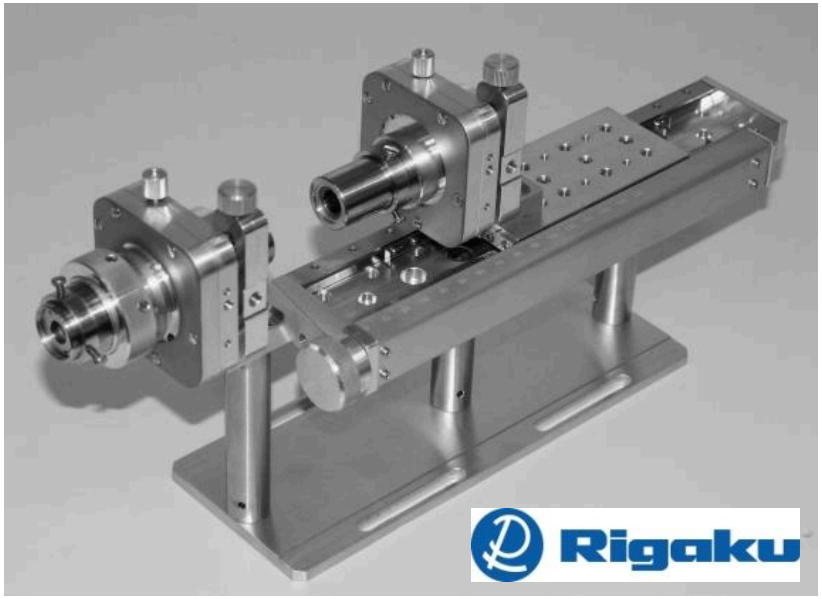


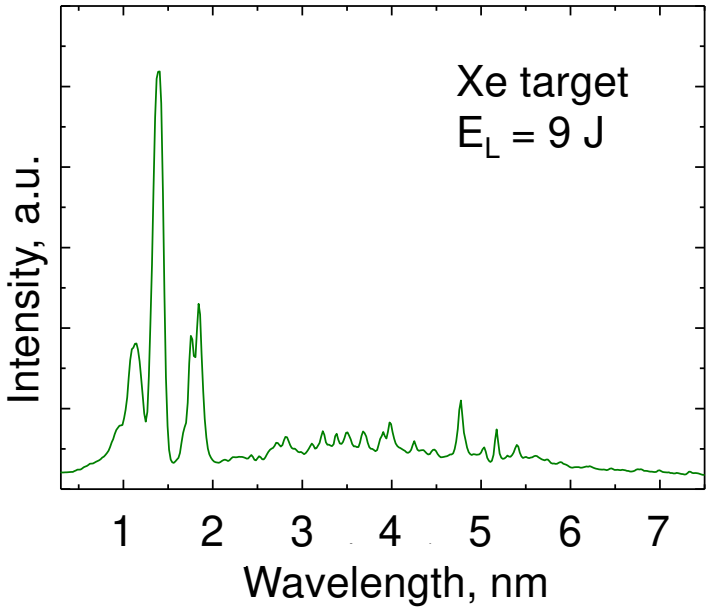
Arikkatt et al.Optics Express **30** (2022) 13940

Soft X-ray grazing incidence optics

Tandem of axisymmetrical paraboloidal grazing incidence soft X-ray mirrors



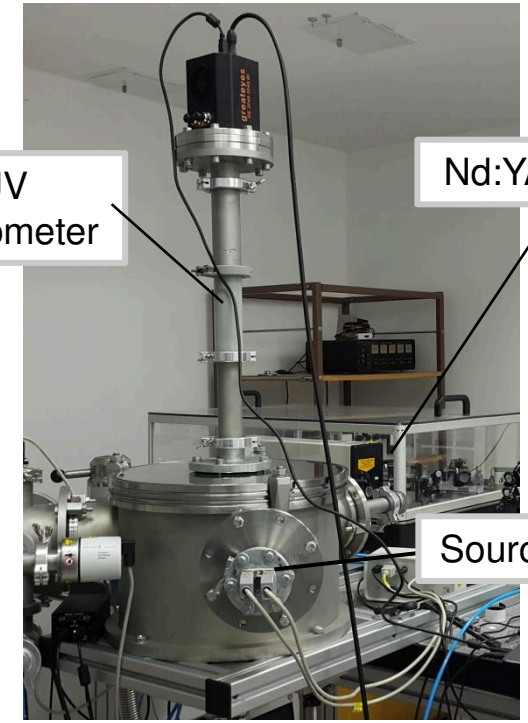


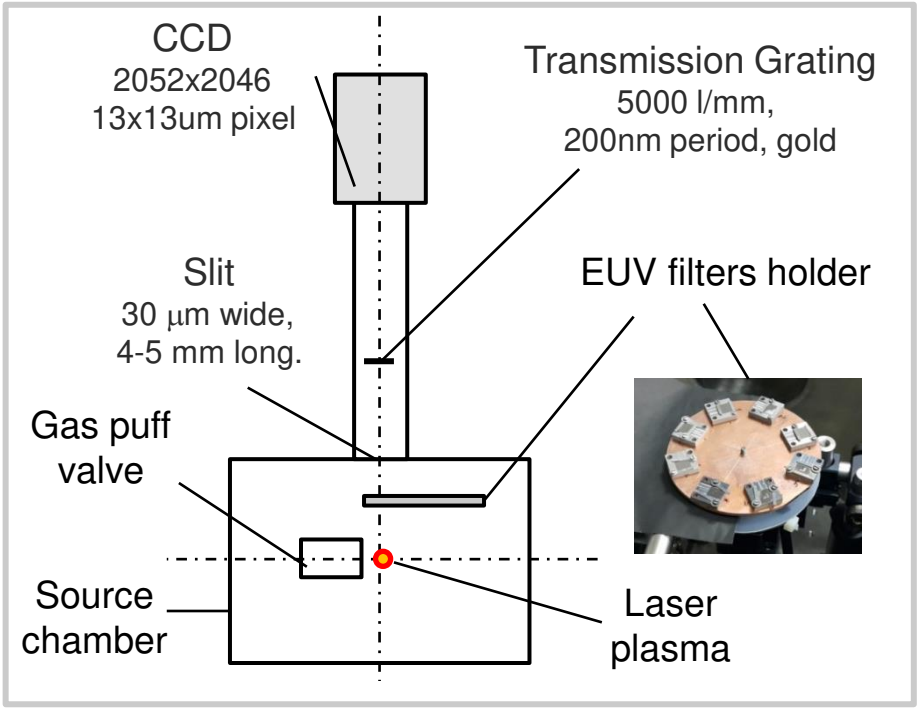


Testing EUV filters

EUV filters (Nb/Zr on Si_3N_4) transmitance measurements

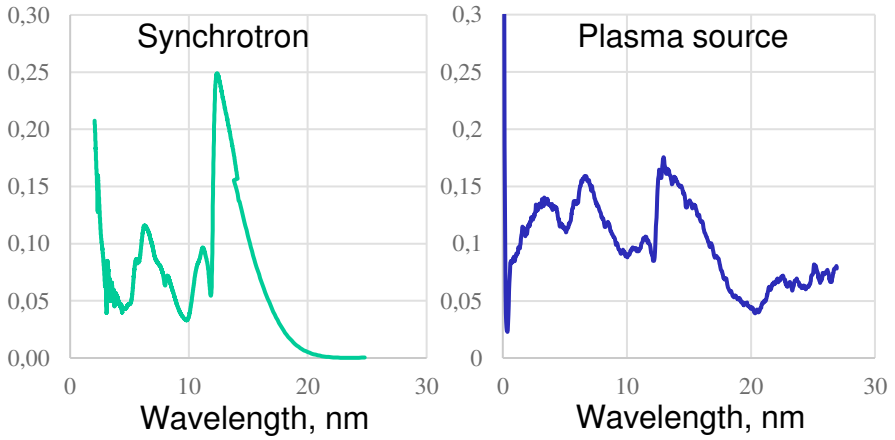
Experimental setup





Collaboration with University of Padova (K. Jimenez, P. Nicolosi & P. Zupella)

Erasmus Mundus Joint Doctorate (EMJD) Programme **EXTATIC**



K. Jimenez et al. Thin Solid Films **695** (2019) 137739

Testing EUV filters for space mission

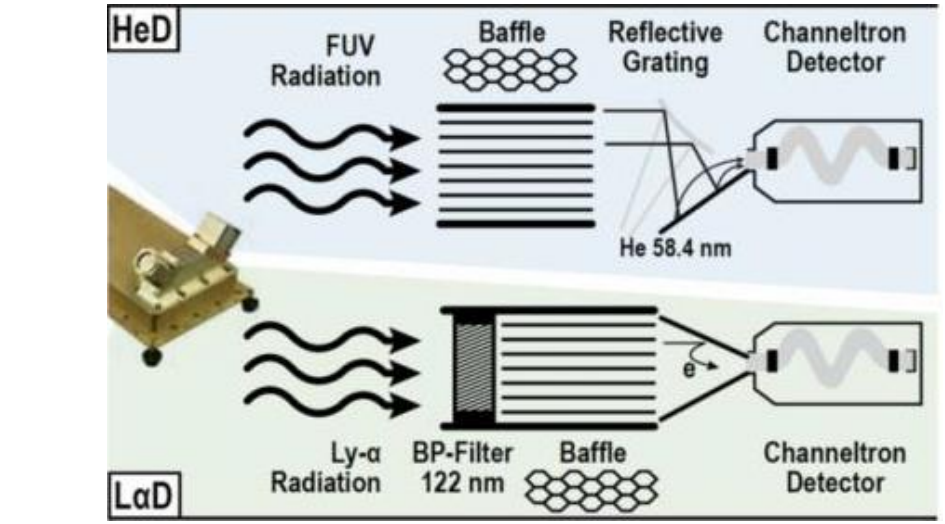
NASA IMAP Mission (2025)
(The Interstellar Mapping and Acceleration Probe)

Center for Space Research
Polish Academy of Sciences

GLOWS (Global Solar Wind Structure)

Testing BP-Filter (MgF_2)

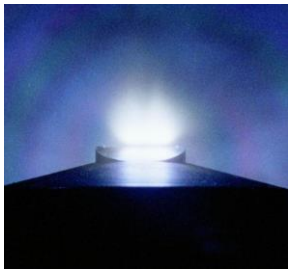
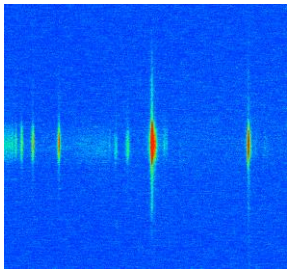
- synchrotron (PTB)
- RF source (SwRI)
- laser plasma (MUT)



Summary and conclusions

- laser plasma EUV and soft X-ray sources based on a **gas puff target** have been introduced,
- **characterization measurements** of EUV and soft X-ray mirrors and EUV filers were performed,
- presented laser plasma sources may be also useful for **testing astronomical optics** (we believe).



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[Opto-Electronics Review - PAS Journals (pan.pl)]

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- Space optics

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