Table-top EUV/XUV source

Generating 2-20 nm wavelength radiation

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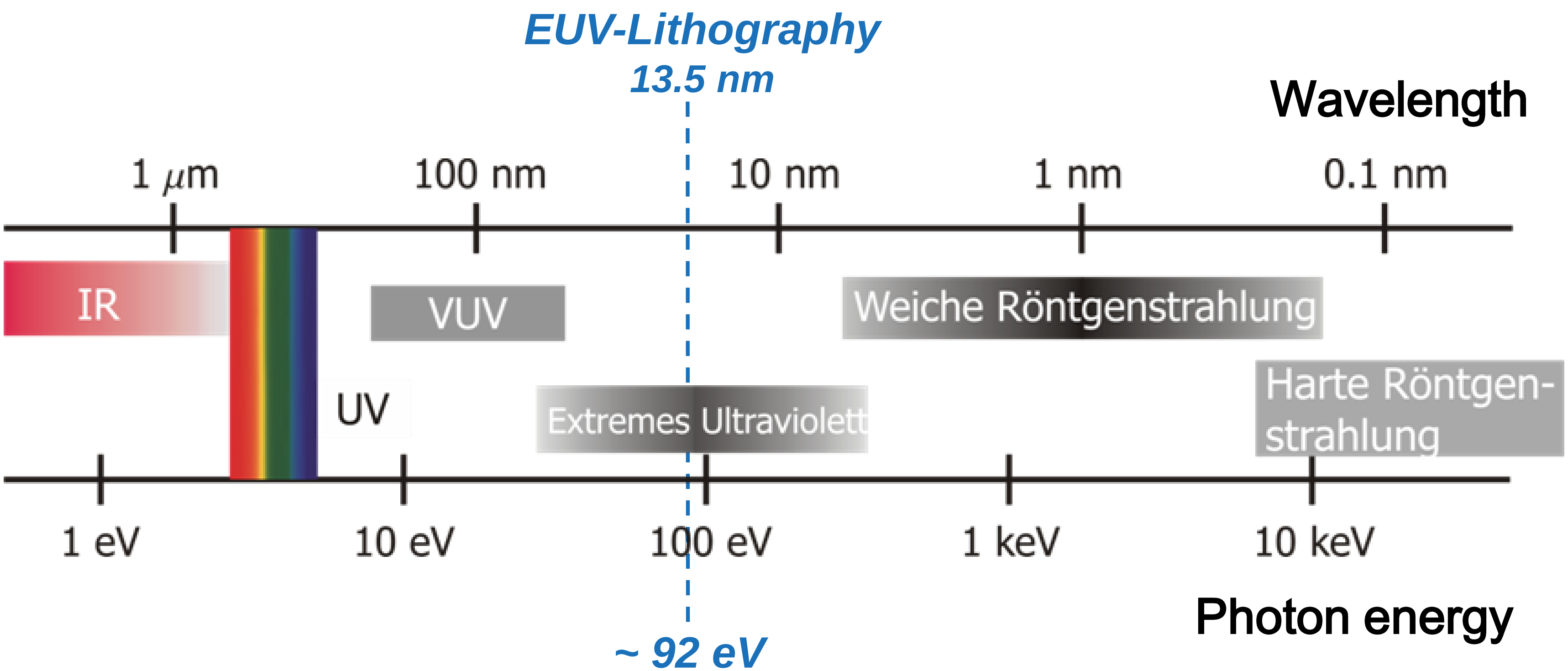
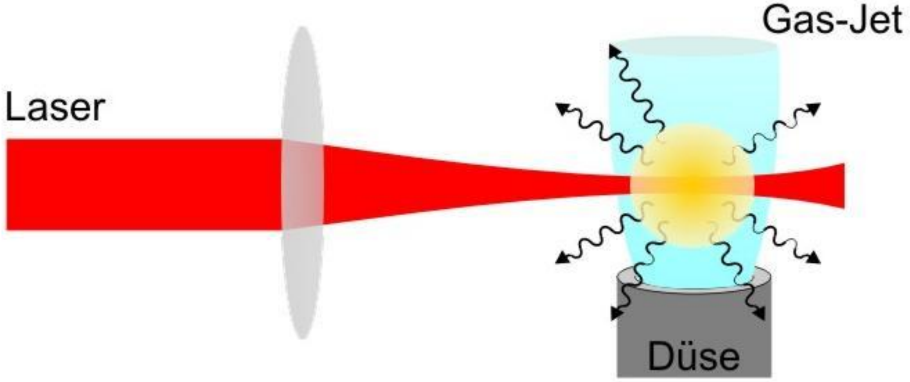
Hans-Adolf-Krebs Weg 1
D-37077 Göttingen

Laser-
Laboratorium
Göttingen e.V.

Spectrum of electromagnetic radiation

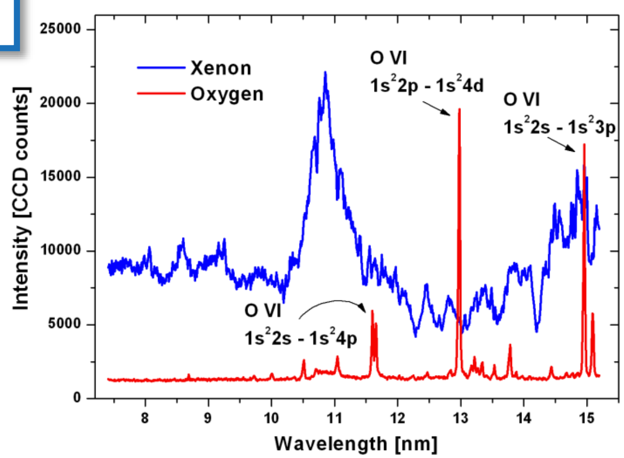


Principle of laser-produced plasma

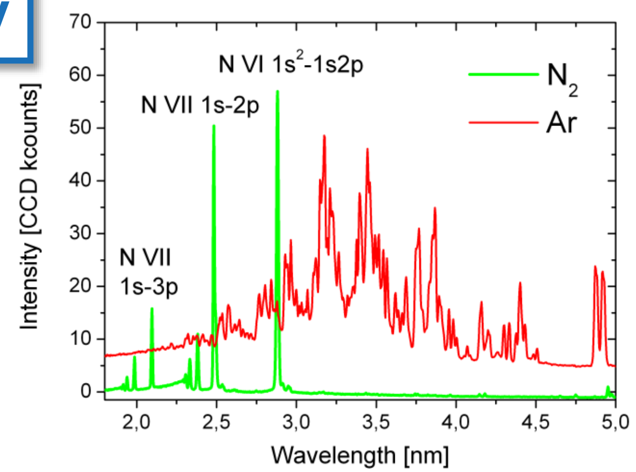


- High-energy laser focused on gaseous target
- Emission spectra depending on target gas

EUV



XUV



Laser-produced plasma

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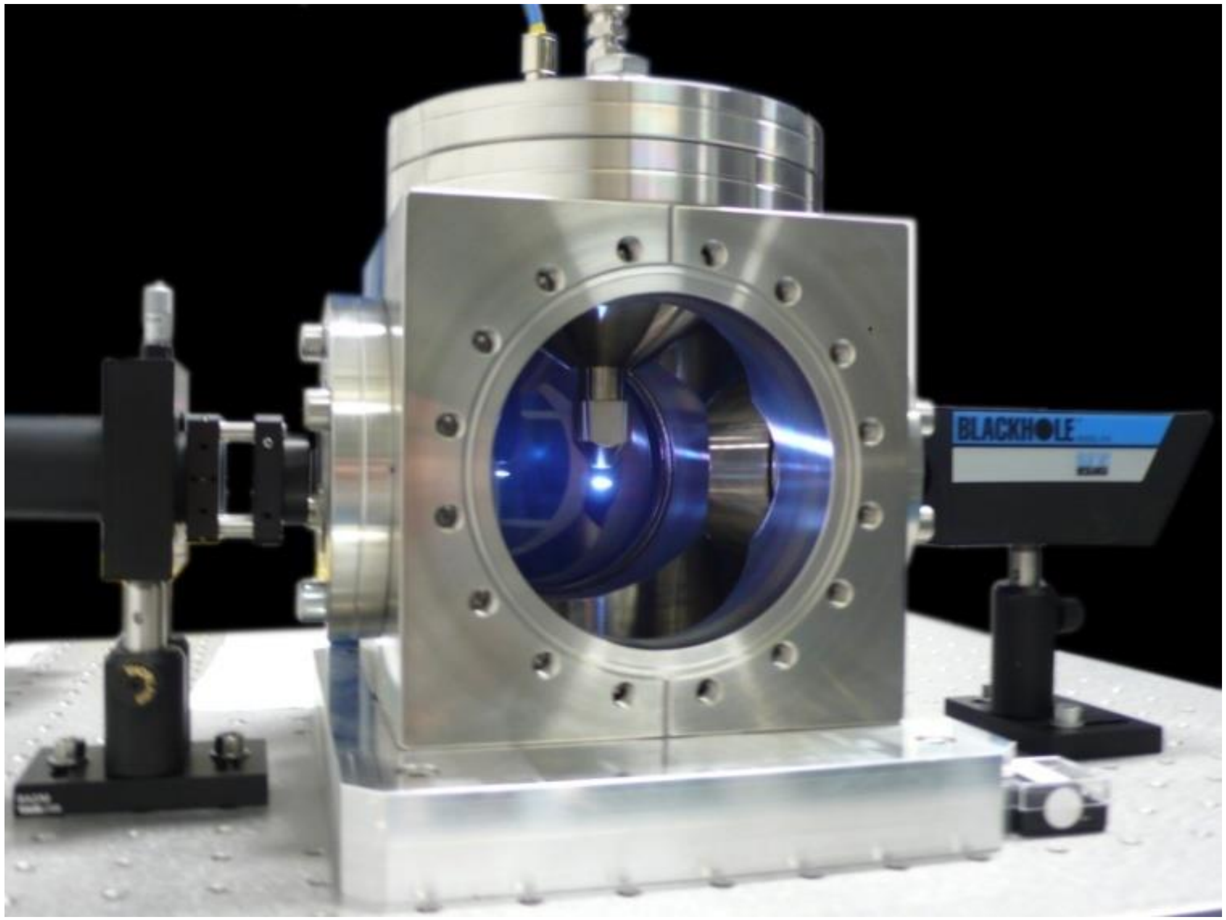
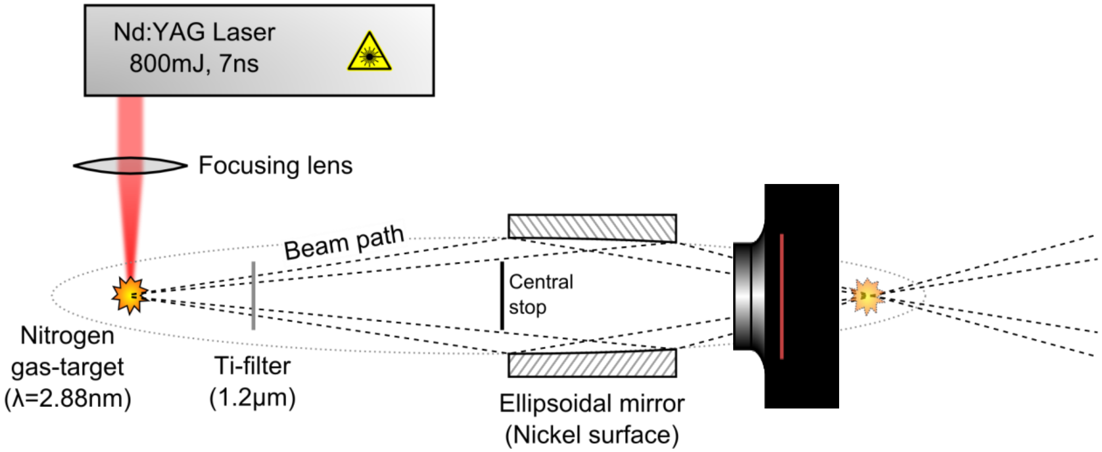
Göttingen e.V.



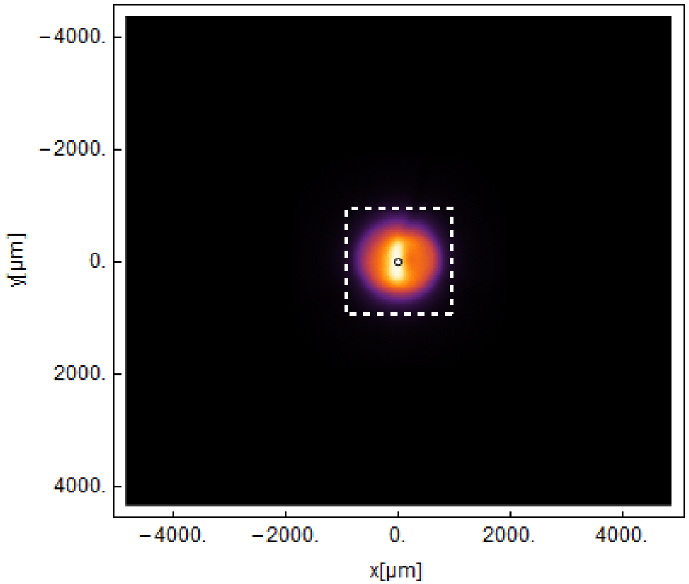
Focusing of laser plasma:

Laser-
Laboratorium
Göttingen e.V.



▲ Focusing of soft X-rays by ellipsoidal mirror

▼ Intensity profiles captured by phosphor coated CCD



X-ray microscopy

Table-top microscope
operating at λ = 2.88 nm

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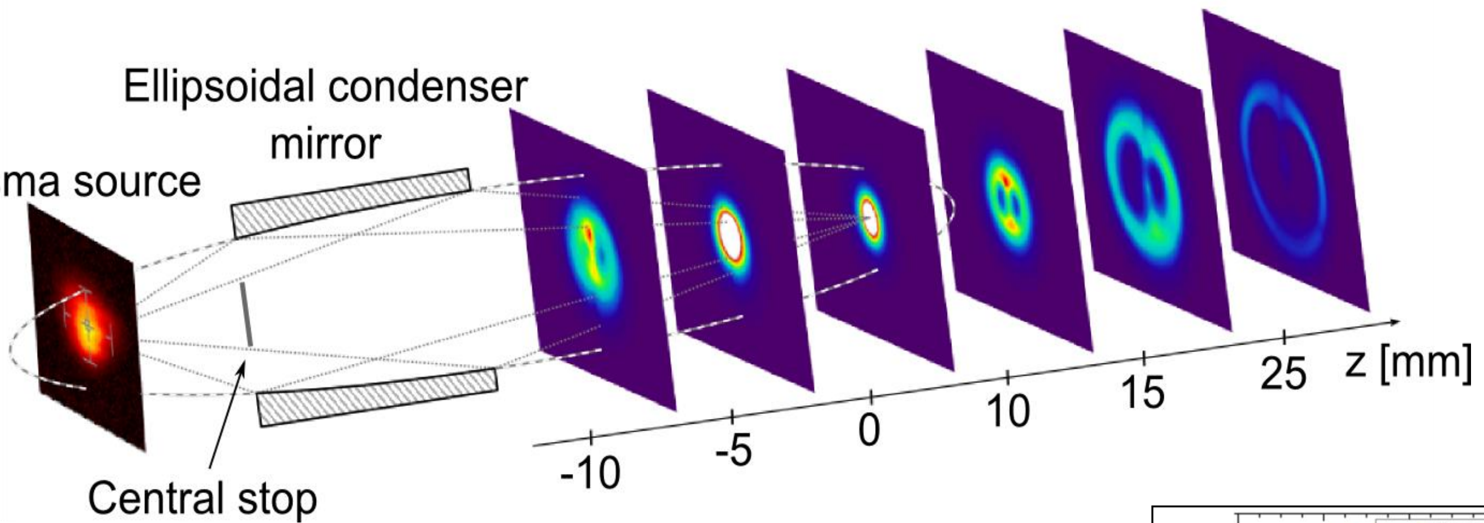
Monochromatic radiation @λ = 2.88 nm

→ Table-top x-ray microscope



Spectrum of
N_2 plasma + Ti-Filter:

@λ = 2.88 nm

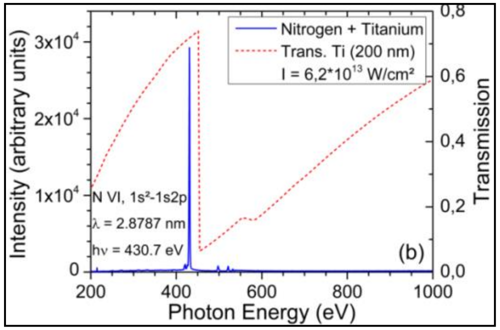
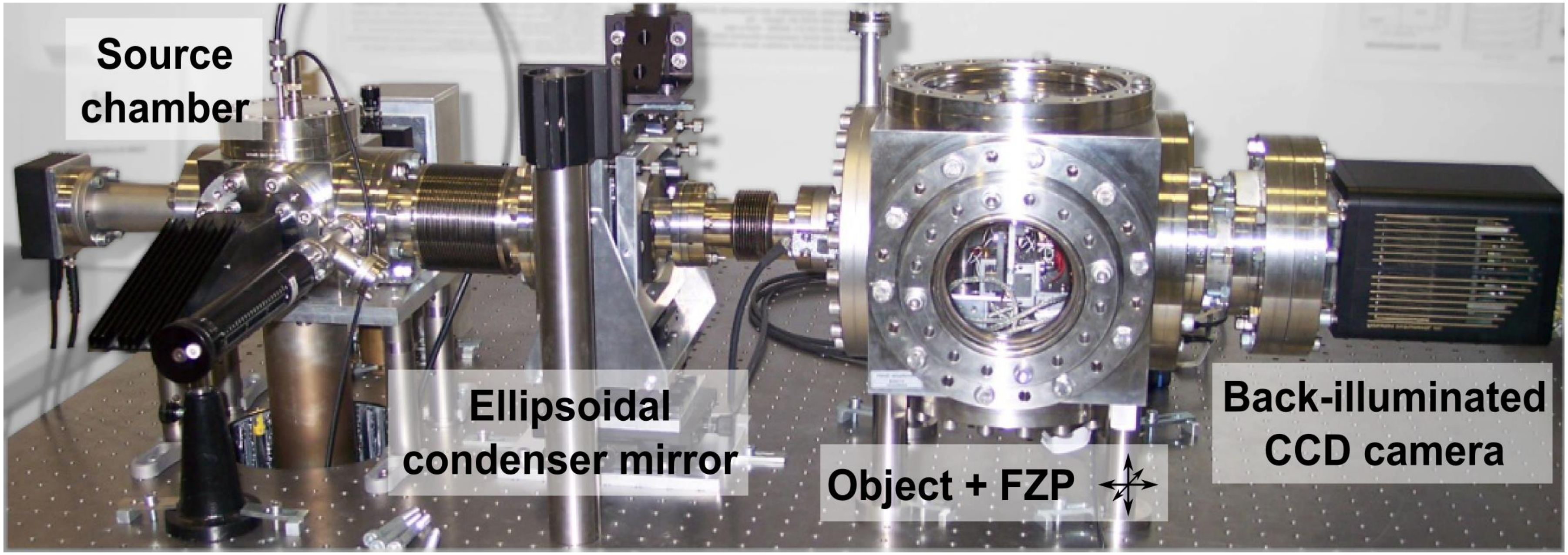


Table-top x-ray microscope

λ = 2.88 nm



1 m

Micrographs @λ = 2.88 nm

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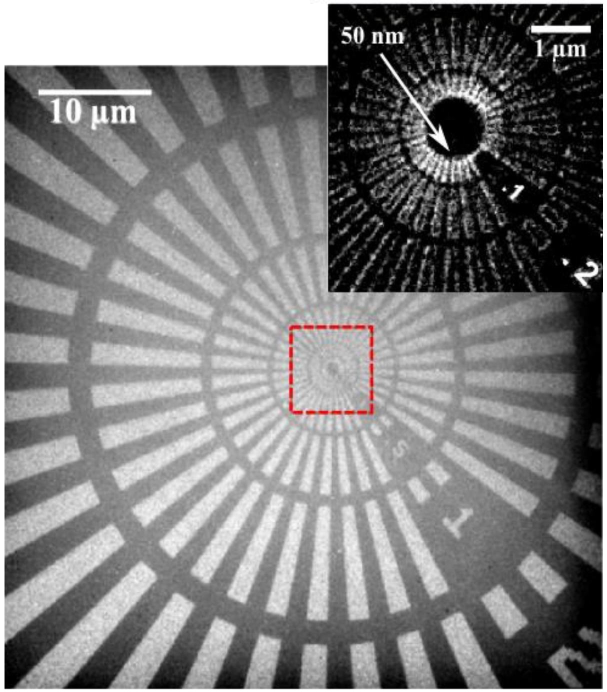
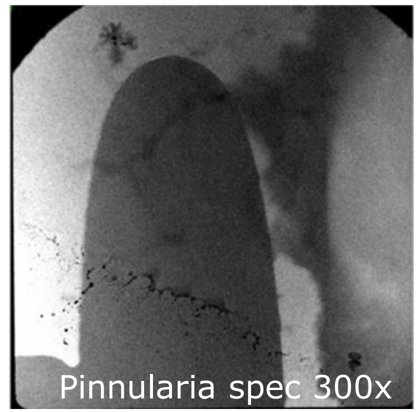
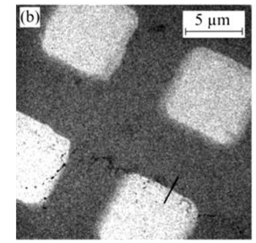
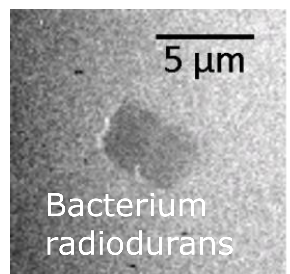
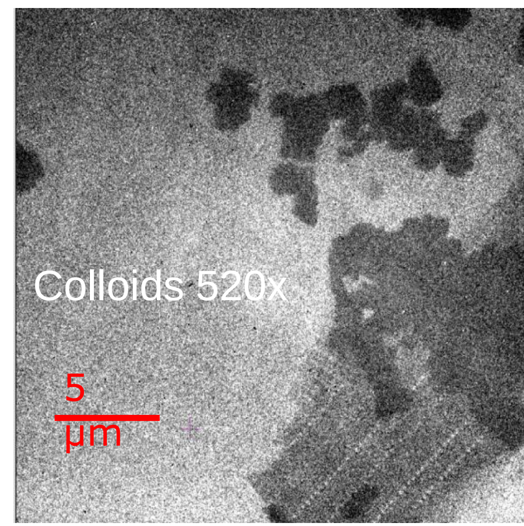






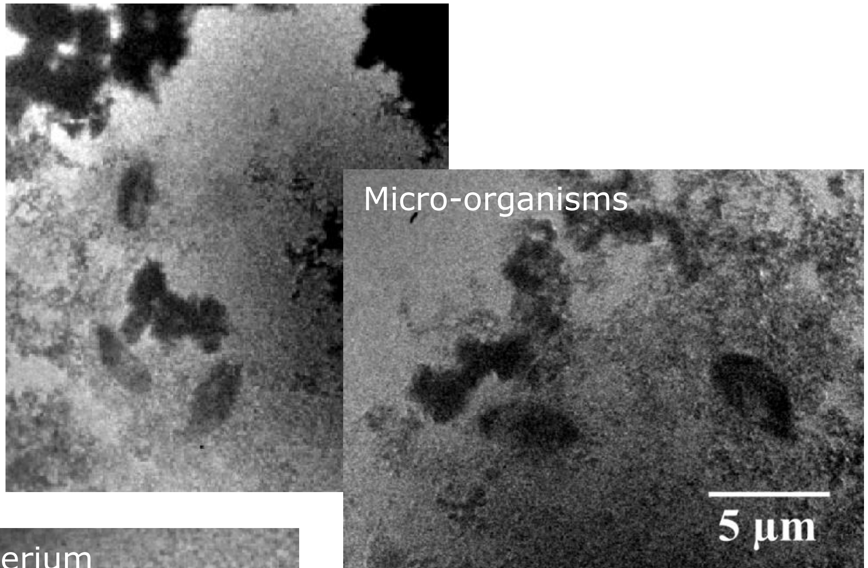


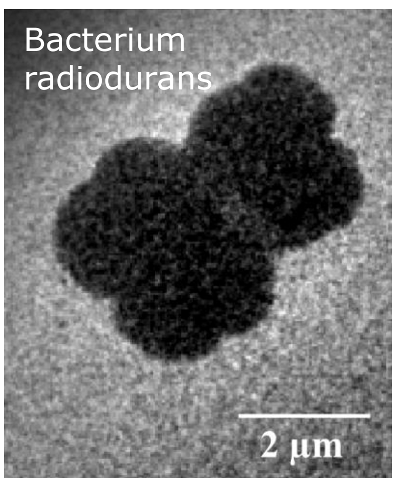


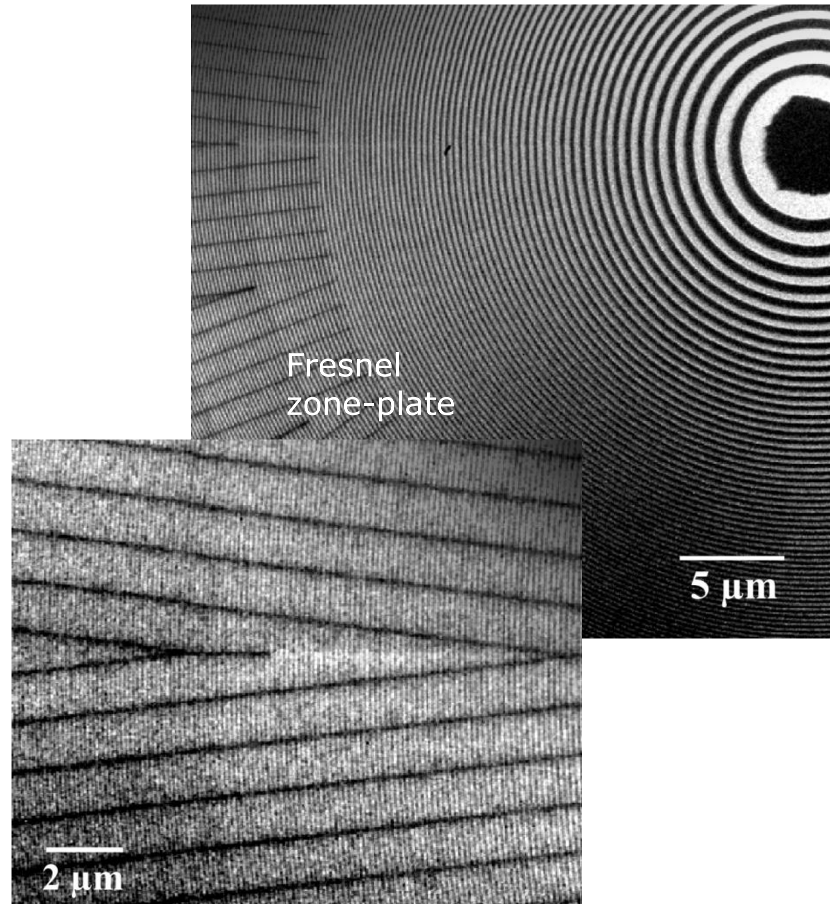
- Compact, stable soft x-ray microscope
- Spatial resolution ≈ **50 nm** (up to now)
- Next step: biological samples

M. Müller, K. Mann, Optics Express 2014

Micrographs @λ = 2.88 nm







NEXAFS spectroscopy

Near-edge x-ray absorption fine-structure spectroscopy

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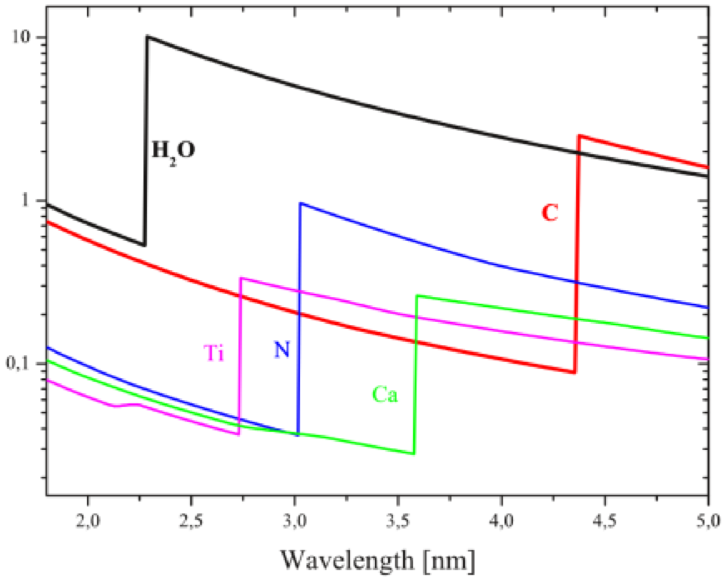
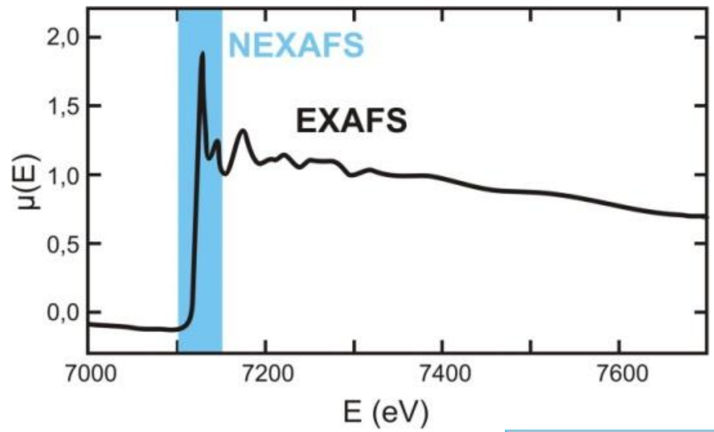
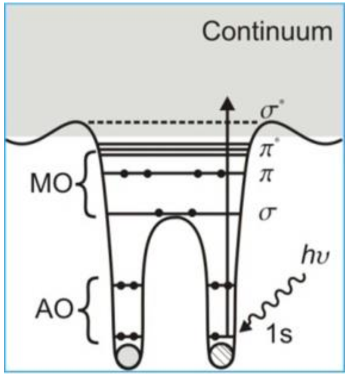
Laser-Laboratorium Göttingen e.V.

NEXAFS - Principle



- **Absorption-edges in the XUV wavelength range (selected elements)**





Fine-structure at absorption edge

- molecular orbitals
- oxidation states
- coordination of an absorbing element

NEXAFS - Setup

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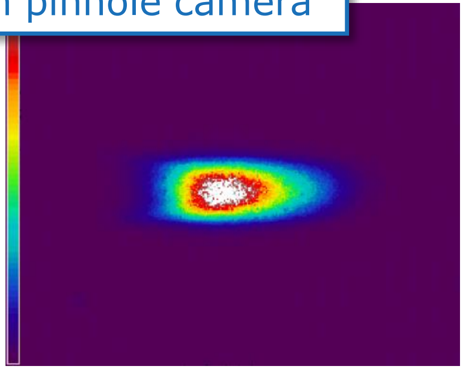
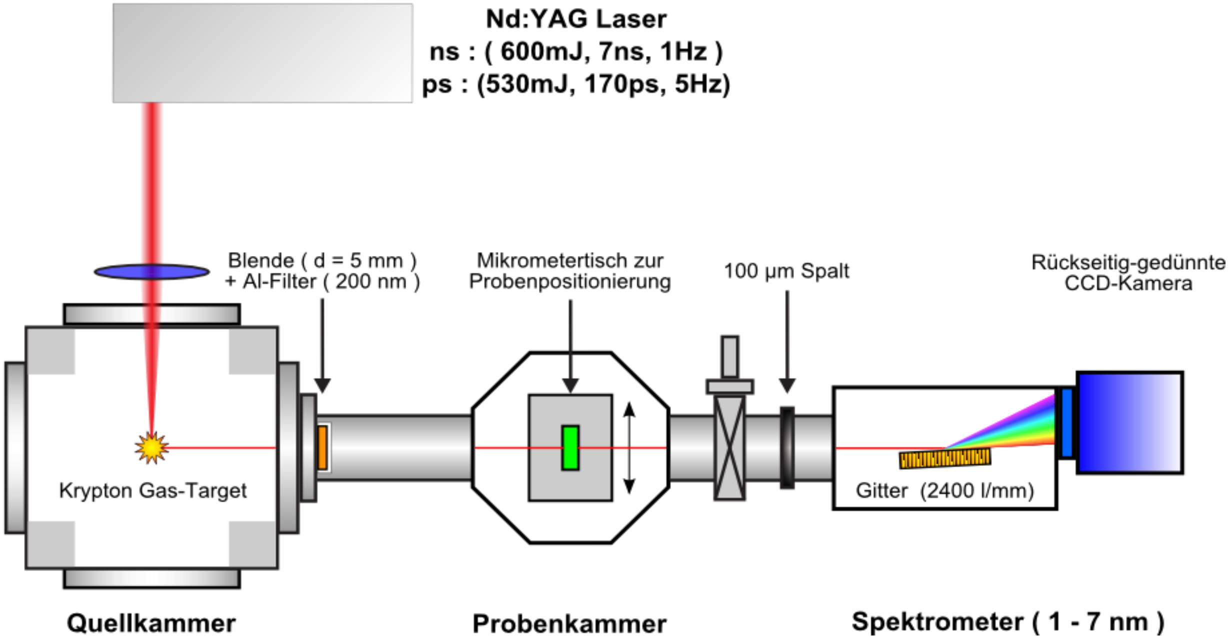
- Table-top system
- „Single-shot“
- Pump-probe exp.

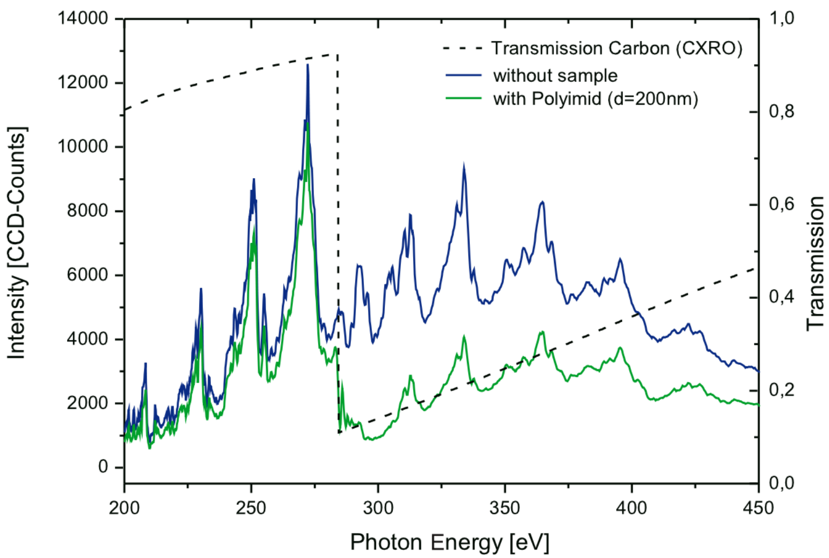
XUV plasma (Kr)
with pinhole camera



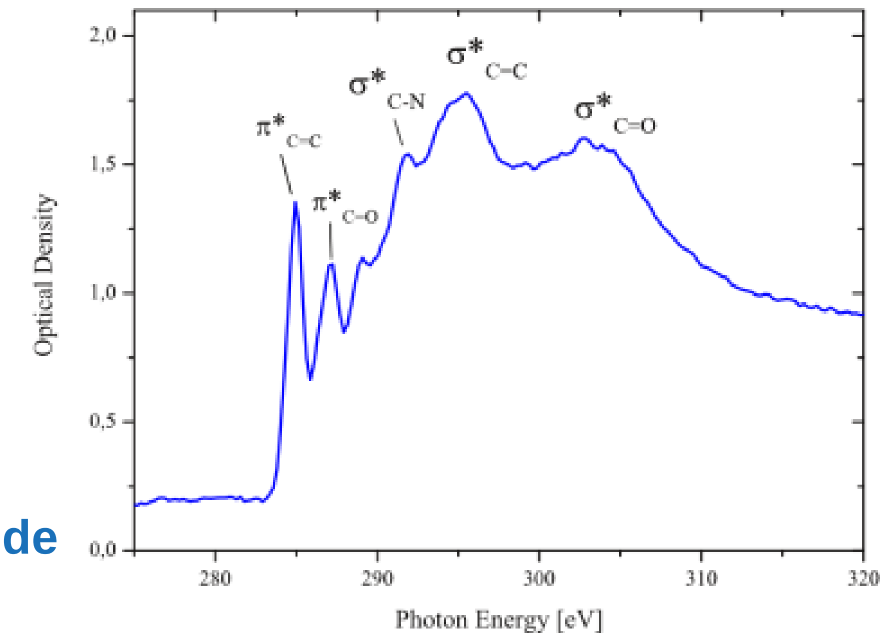


$$\frac{\lambda}{\Delta\lambda} \approx 400$$

NEXAFS - Measurement



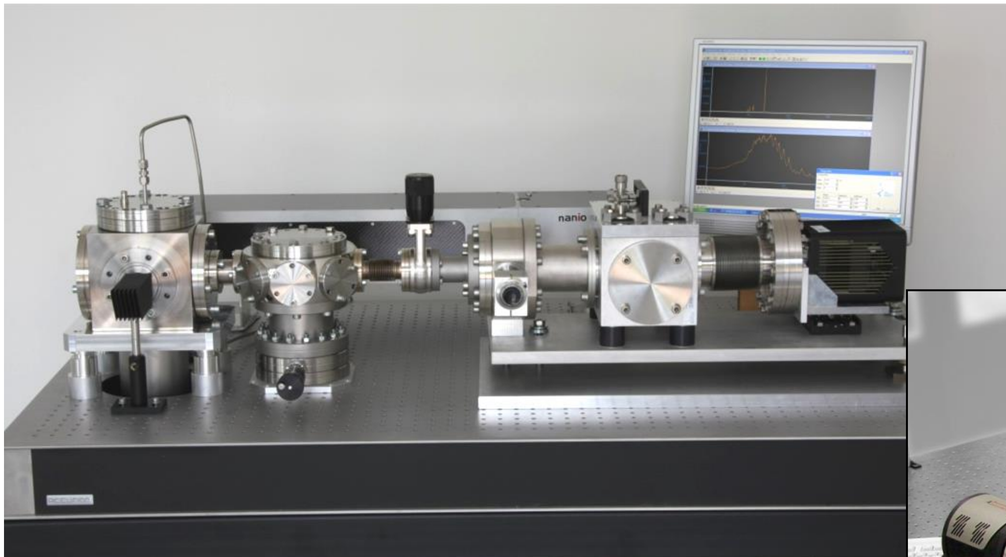
◄ **Emission spectra of Krypton with and without sample**



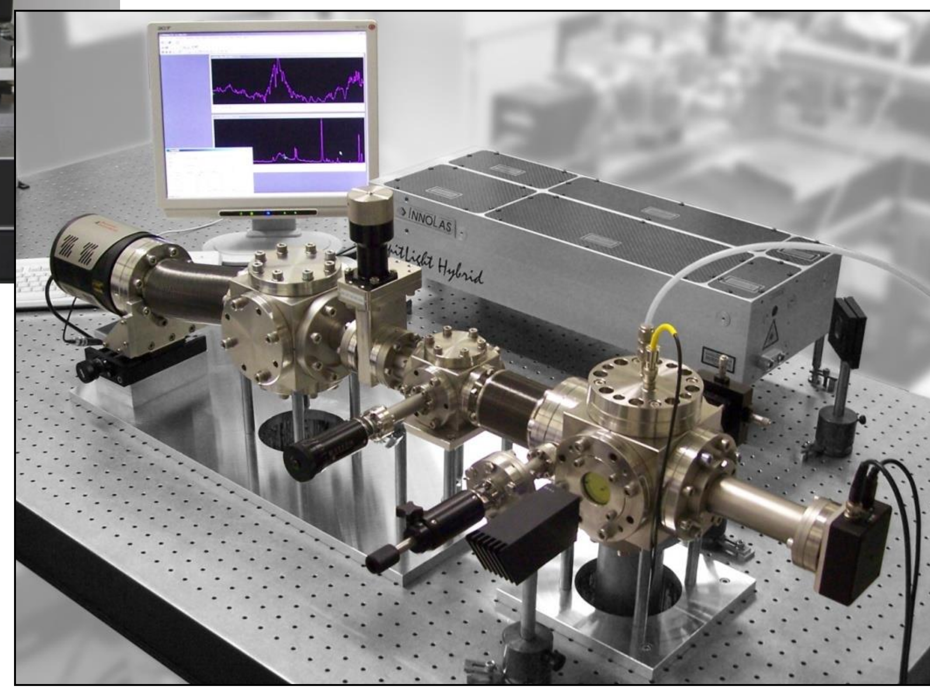
► **NEXAFS spectrum of Polyimide**

Setup of NEXAFS Spectrometer

Laser-Laboratorium Göttingen e.V.



◄ **XUV – NEXAFS (2-5 nm)**

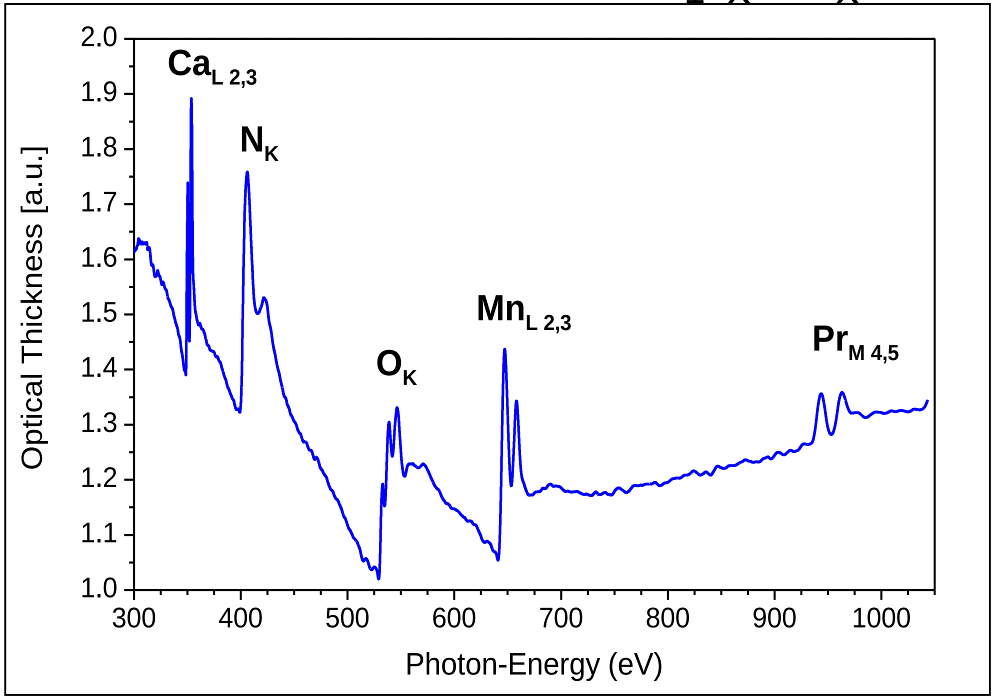


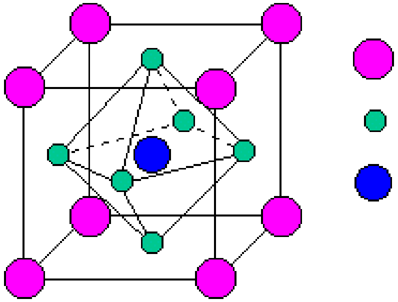
► **EUV – NEXAFS (7-16 nm)**

NEXAFS – Results II

PCMO (Perovskite-type manganate)

$Pr_{1-x}Ca_xMnO_3$



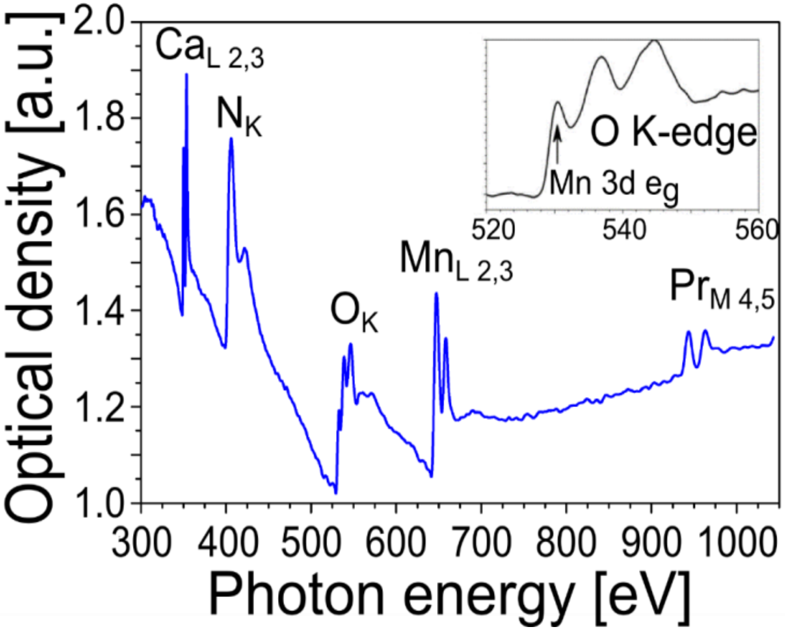


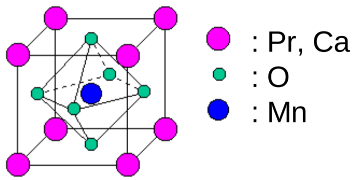
- Every element visible (single shots)
- Pump-probe experiments

E. Novakova, C. Peth, K. Mann, T. Salditt et al.: Biointerphases, **3** (2008) FB44

NEXAFS spectra

$Pr_{1-x}Ca_xMnO_3$:

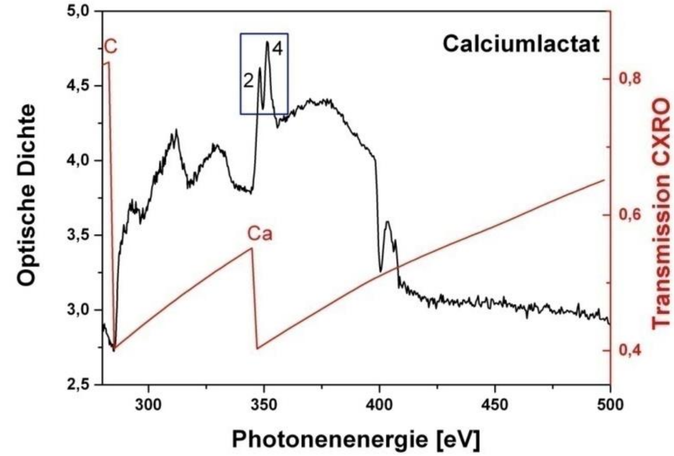


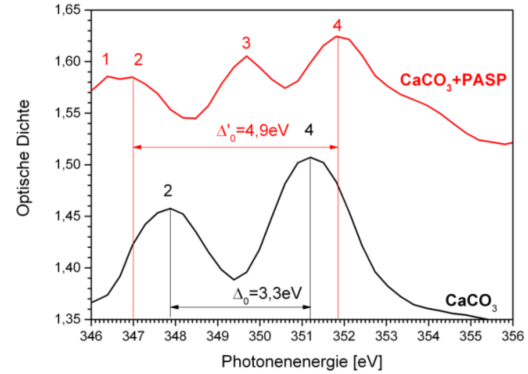


Pump-probe

→ Optically induced phase transition

Ca L-edge:

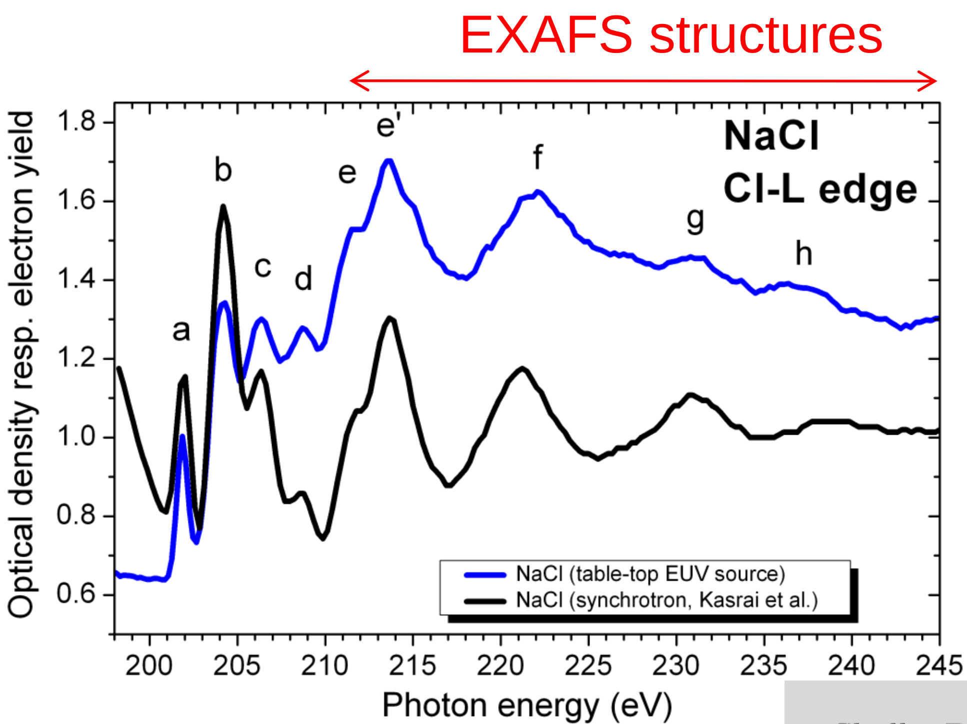


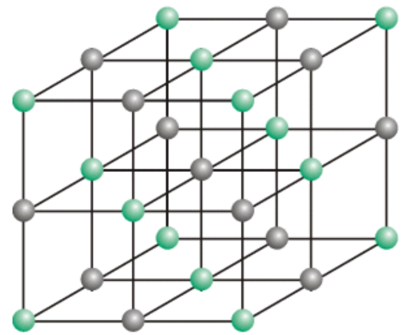


P. Großmann, K. Mann et al., Rev. Sci. Instr. 83 (2012)

F.-C. Kühl, Bachelorarbeit (2013)

EXAFS: Cl L-edge of NaCl





- 200nm NaCl film
- L-edge of Cl (EUV range)
- **Bond lengths:** Excellent agreement with Synchrotron data

$$R_i = \sqrt{\frac{C}{E_i - E_{Streu}}}$$

Shell	Peak	R[Å] Fit.	R[Å] gemessen	R[Å] Kasrai
R1	h	2,82	2,86	2,85
d_{111}	g	3,26	3,18	3,18
R2	f	3,99	3,88	3,85
R3	e	4,88	5,13	5,02

MnCl2 and Fe2O3

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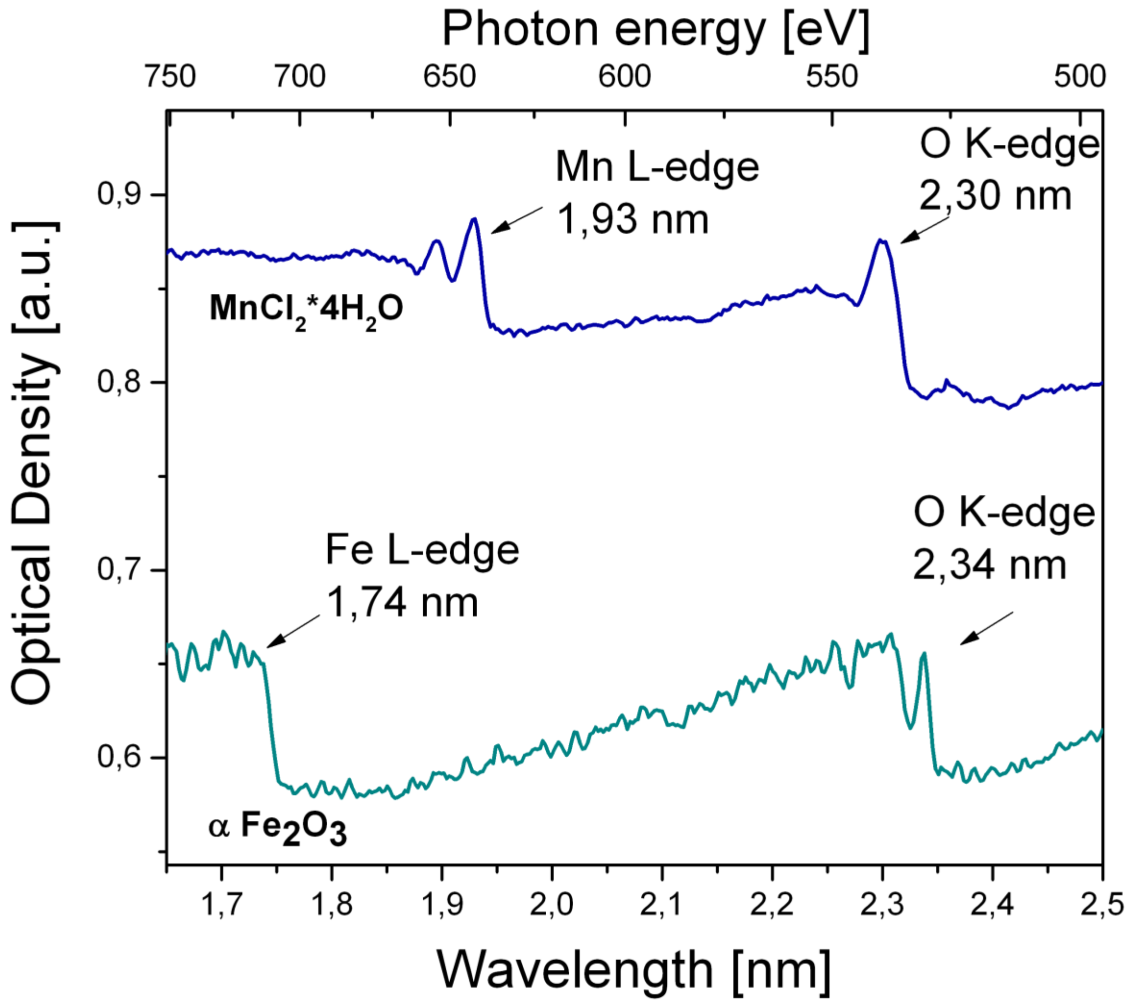

Brilliance improvement by density enhancement

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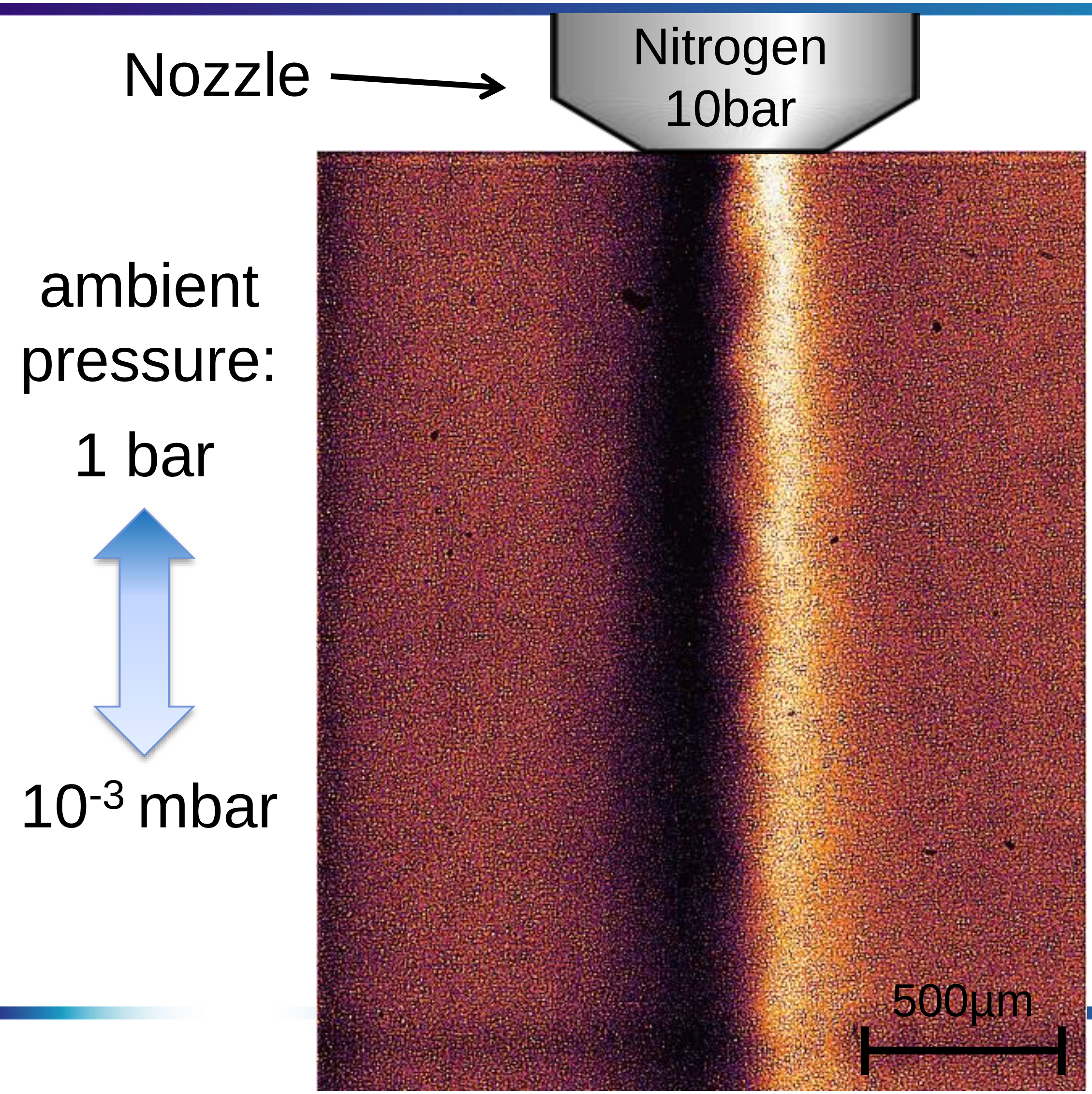
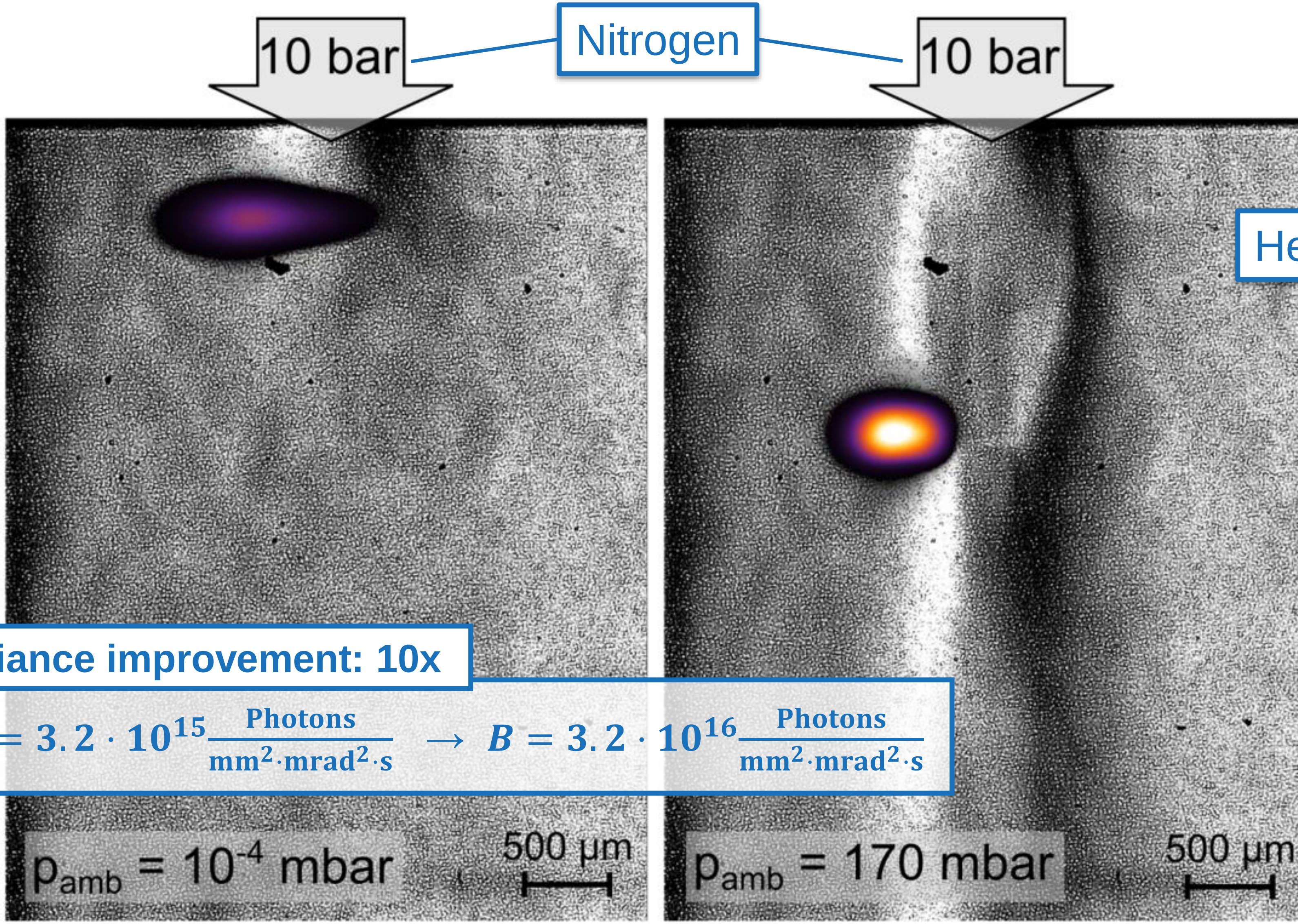


- local density enhancement by the *„barrel shock“*
- improved conversion efficency
- variable distance to nozzle minimizes degradation effects

The barrel shock



Brilliance improvement: 10x

$$B = 3.2 \cdot 10^{15} \frac{\text{Photons}}{\text{mm}^2 \cdot \text{mrad}^2 \cdot \text{s}} \rightarrow B = 3.2 \cdot 10^{16} \frac{\text{Photons}}{\text{mm}^2 \cdot \text{mrad}^2 \cdot \text{s}}$$

EUV damage

Material interaction studies with
13.5 nm radiation

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EUV Schwarzschild Objective

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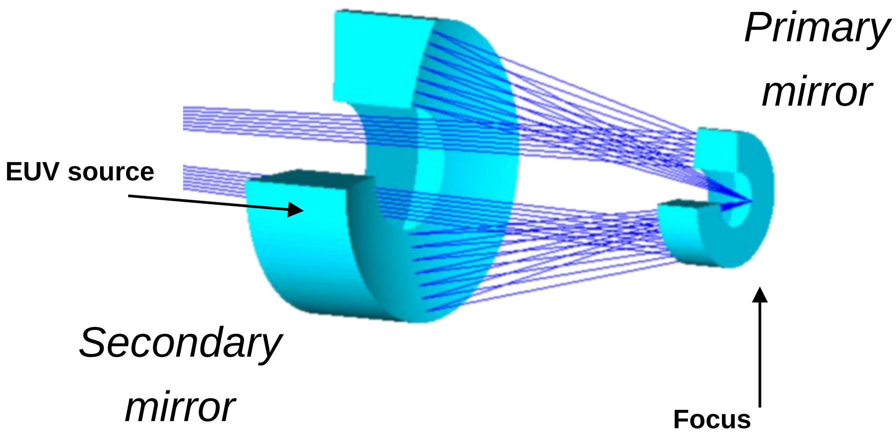
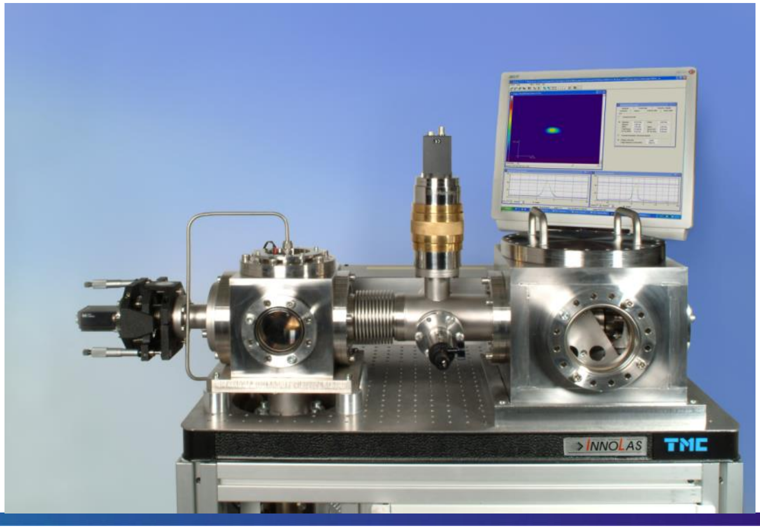




Schwarzschild Objective

- Magnification 10:1
- High numerical apterture (0.4)
- Generation of high energy densities

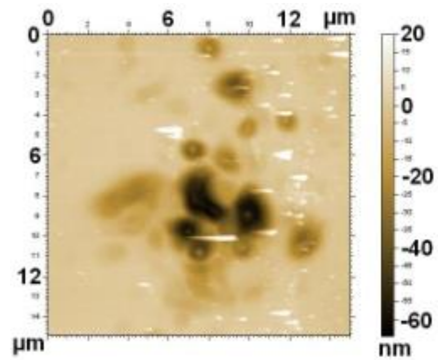
EUV Damage: Optics

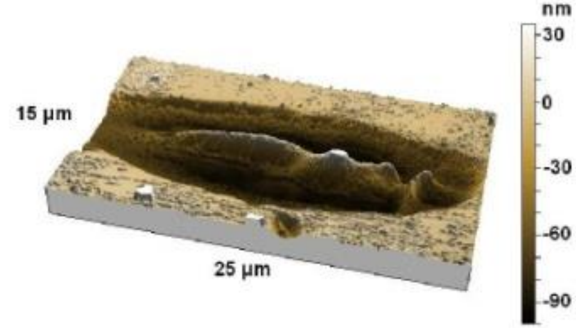
Laser-Laboratorium Göttingen e.V.

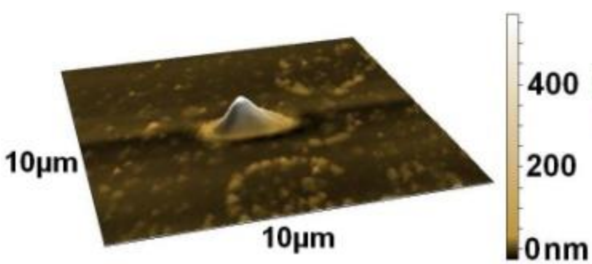
TEM-Micrograph of Mo/Si mirror

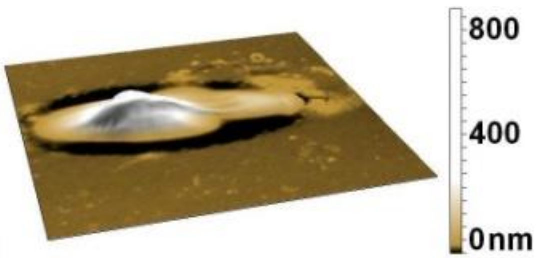
Fraunhofer IOF Institut Angewandte Optik und Feinmechanik

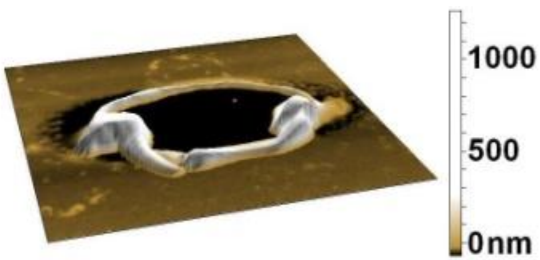
- Damage of Mo/Si multilayer EUV mirrors







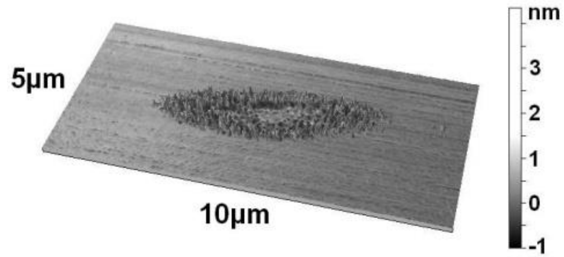


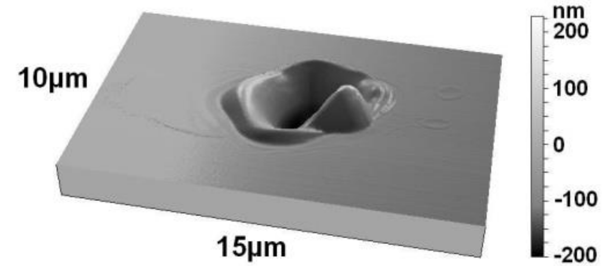


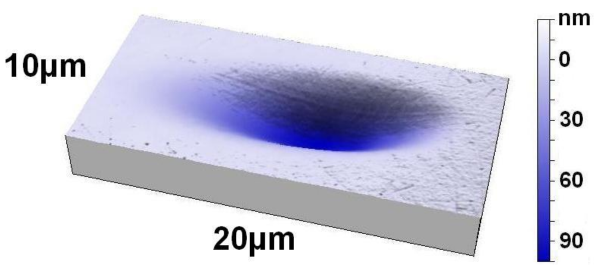
▲ Damage of thin gold films (grazing-incidence EUV mirrors)

EUV Damage: Substrates

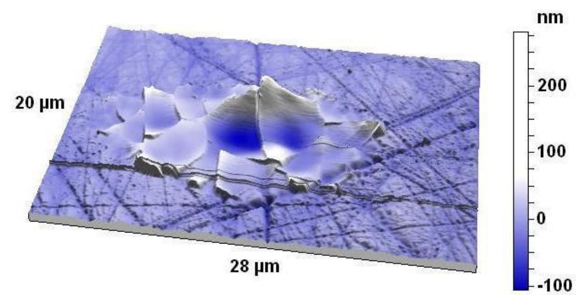
- Damage of Silicon wafers at different EUV energy densities

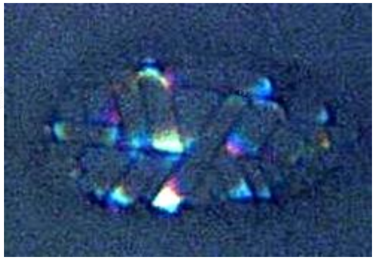






- Damage of fused silica





- Damage of calcium fluoride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tik / Kurze Wellenlängen
EUV
Kompakte
EUV -
Laborstrahlquelle
Abteilung
Optik / Kurze Wellenlängen
Messtechnik
Kompakte EUV-Quelle
dpa

EUV reflectometry

Reflectometry @ 13.0 nm wavelength

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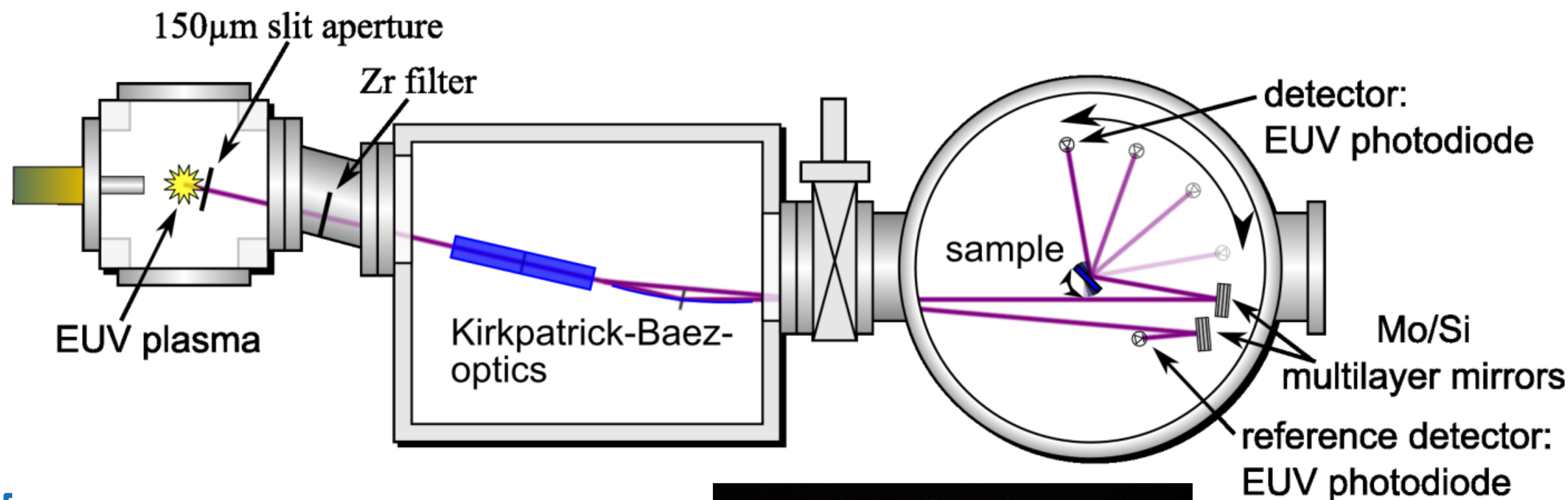
D-37077 Göttingen

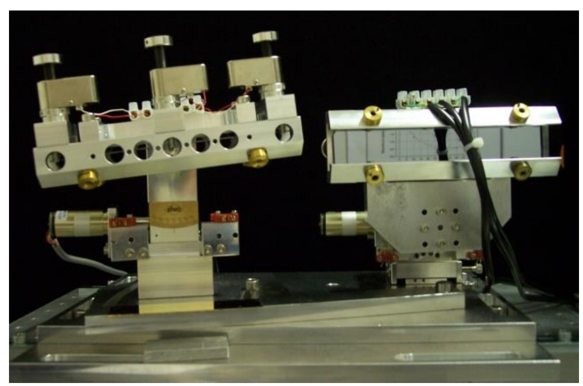
Laser-Laboratorium Göttingen e.V.

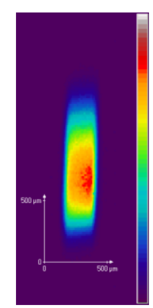
EUV reflectometry: Setup



Reflectivity @ 12.98 nm

- Oxygen emission line
- Angular resolution 0.3°
- Angular range 1°- 85°

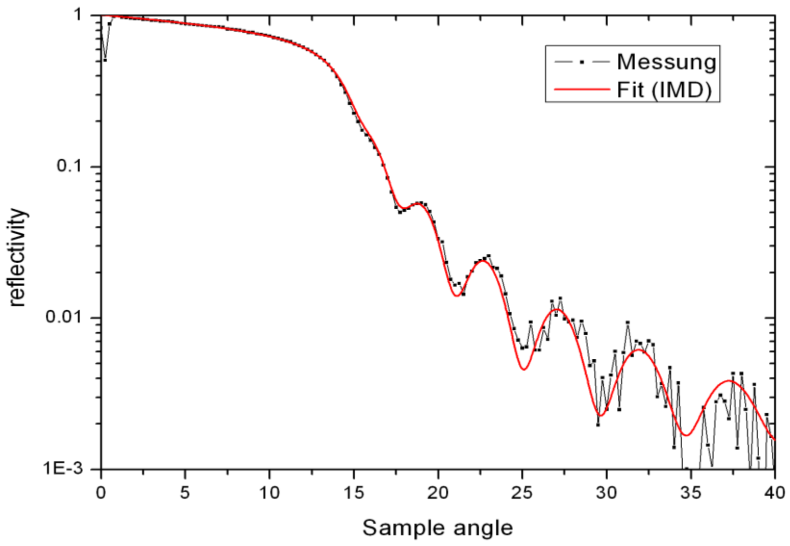


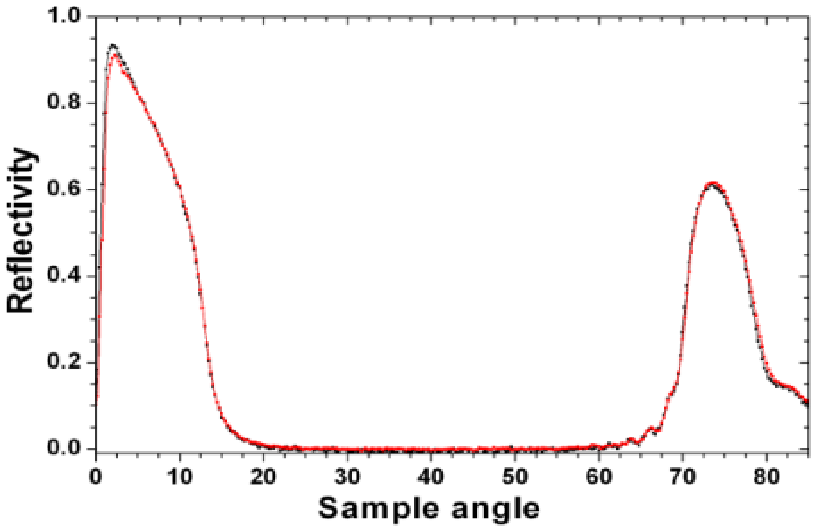


EUV spot on sample

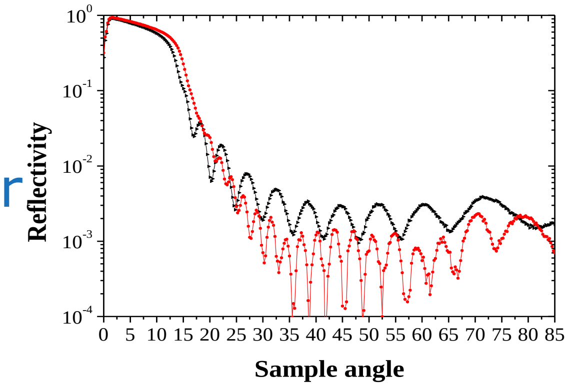
EUV reflectometry: examples

- Carbon layer, thickness 75nm





- Mo/Si multilayer mirrors



EUV Beam characterization

Wavefront sensor and coherence measurements

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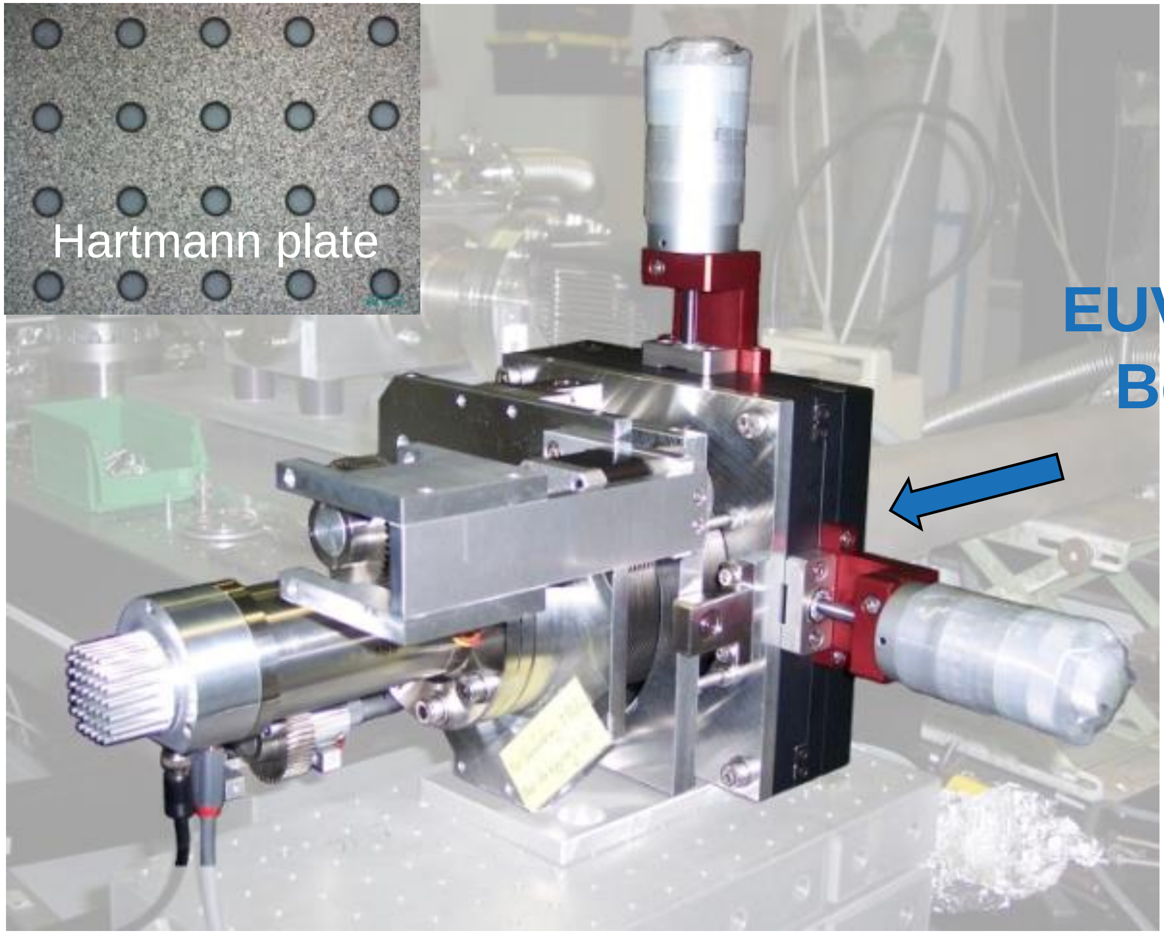
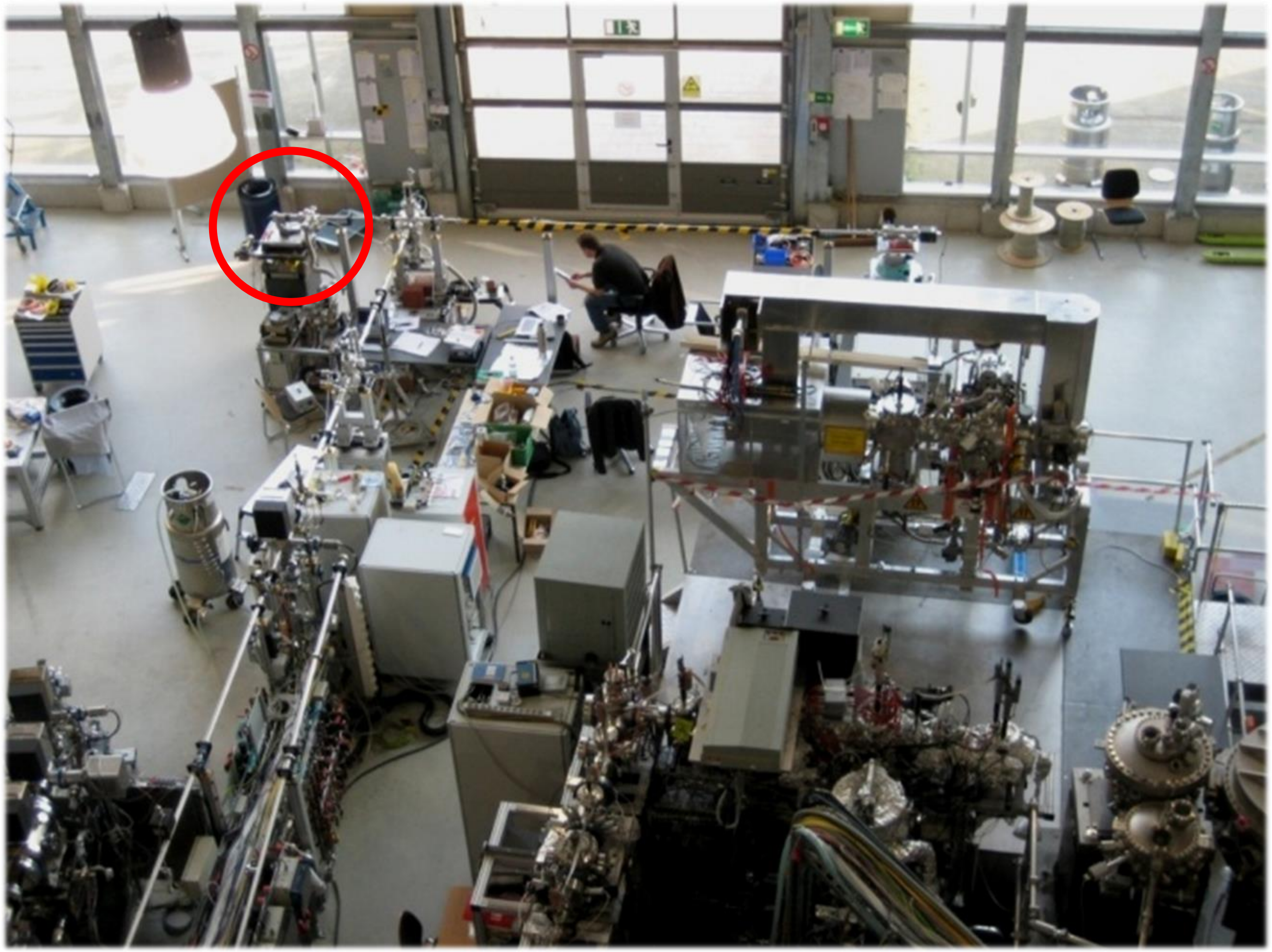
D-37077 Göttingen

Laser-Laboratorium Göttingen e.V.

Wavefront sensor

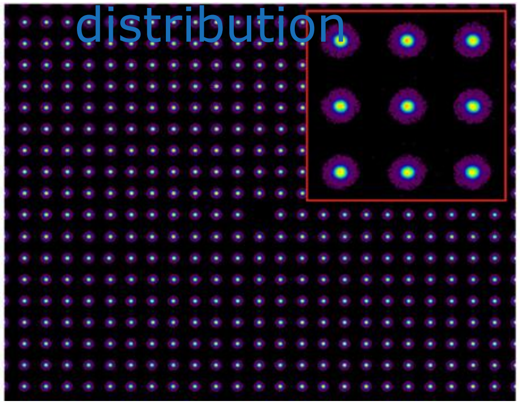


Test of EUV wavefront sensor at Free-electron laser (FLASH)

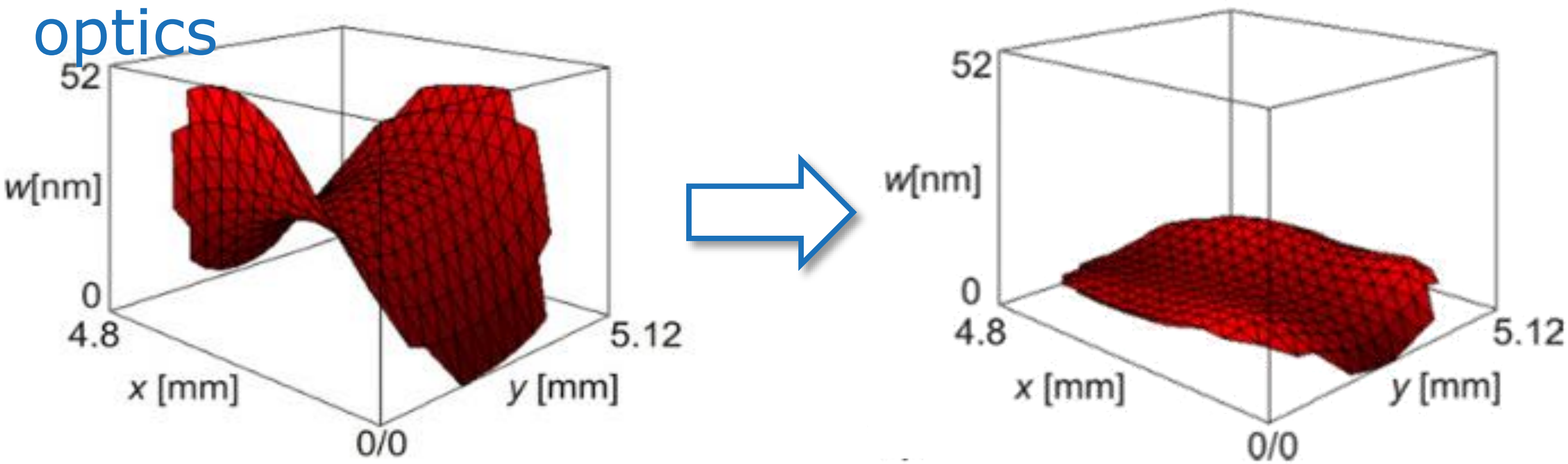


EUV wavefront sensor: Beam adjustment at FLASH

- Spot distribution

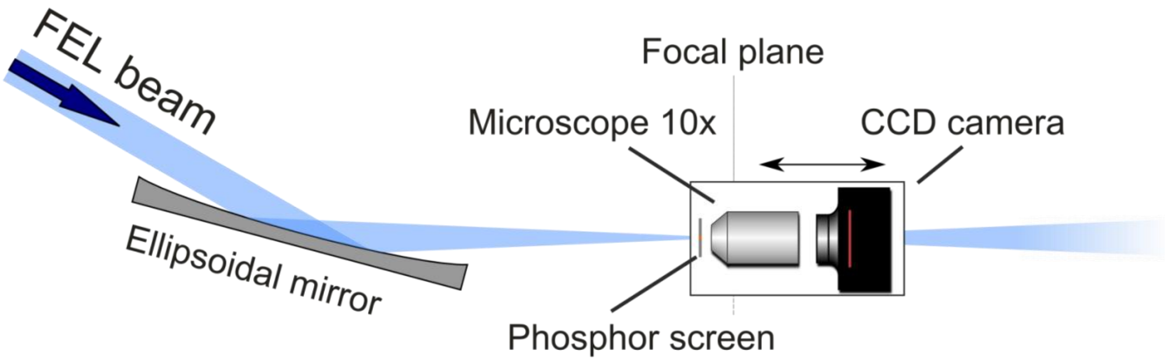


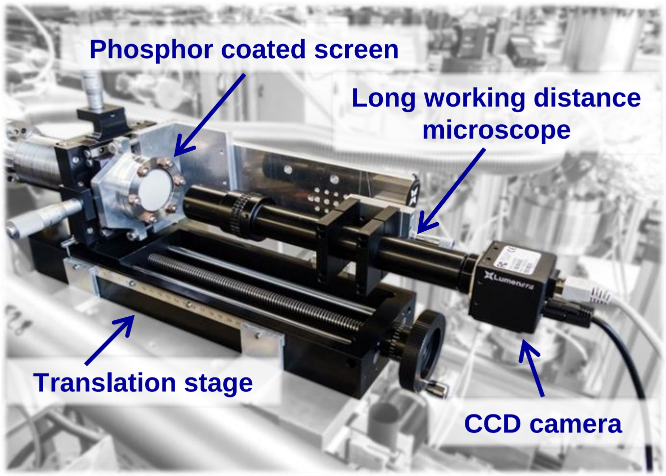
- Adjustment of beam line optics



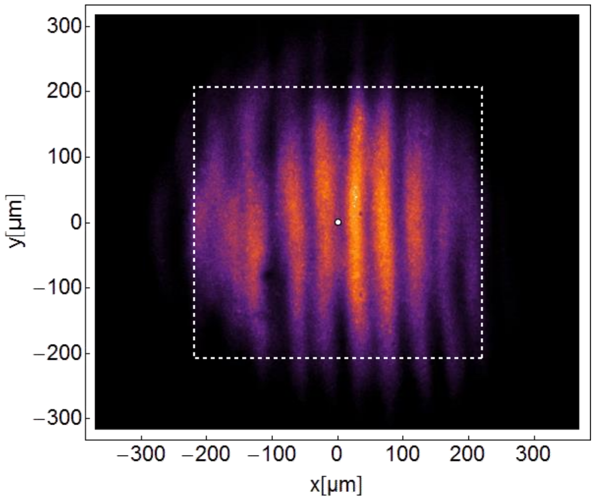
B. Flöter, K. Mann, K. Tiedtke et al. NIM **A 635**, S108–S112 (2011)

Caustic measurement at FLASH

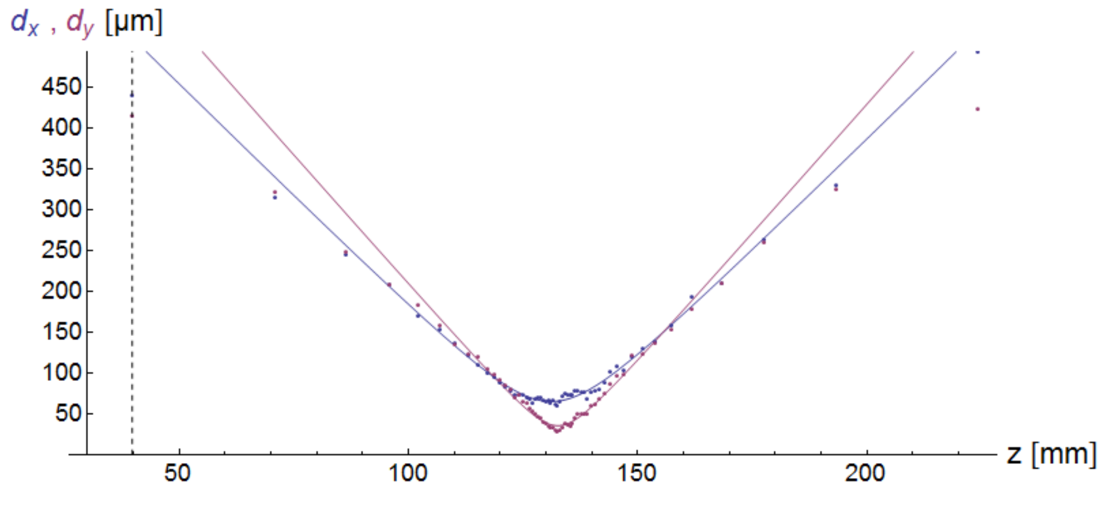




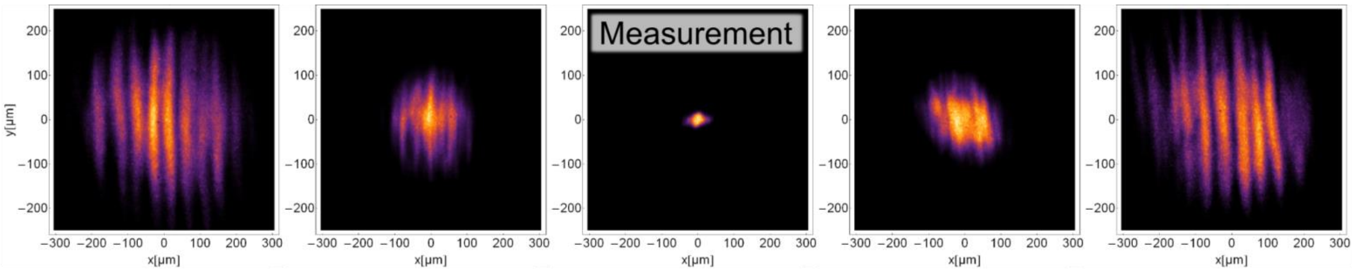
Intensity distribution



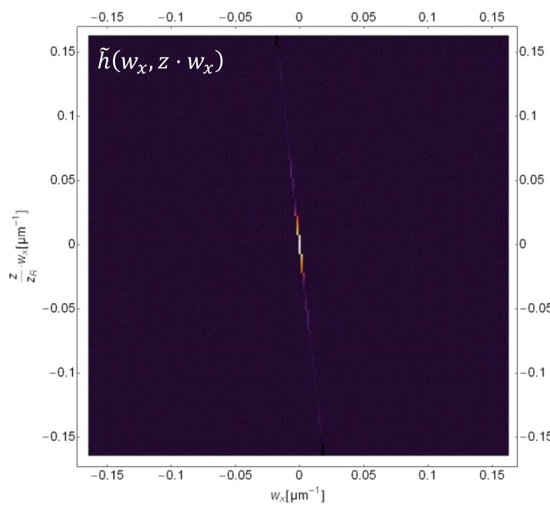
Beam diameter



Coherence calculation by the Wigner distribution function

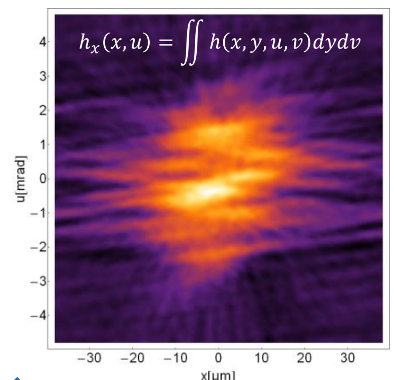


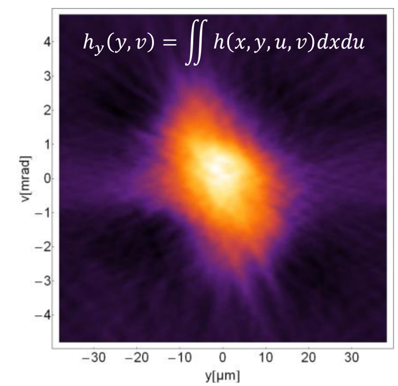
mapping measured data into 4D Wigner Fourier space (here: 2D representation)



FFT

▼ Wigner distribution function





reconstruction of intensity profiles from Wigner distribution

Global degree of coherence

$$K = \frac{\iint h(\vec{x},\vec{u})^2 dx^2 du^2}{\iint h(\vec{x},\vec{u}) dx^2 du^2} = 1.6\%$$