Table-top EUV/XUV source for metrology applications

NEXAFS spectroscopy

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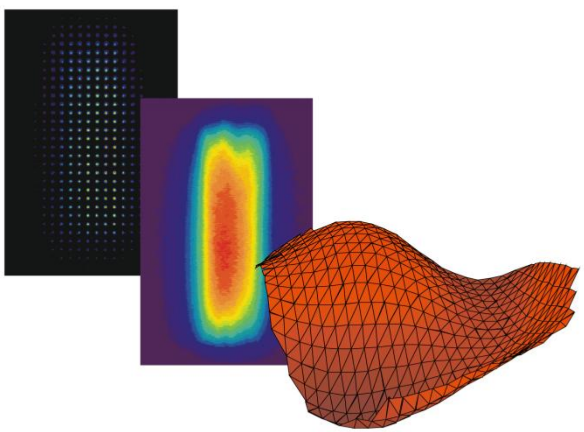
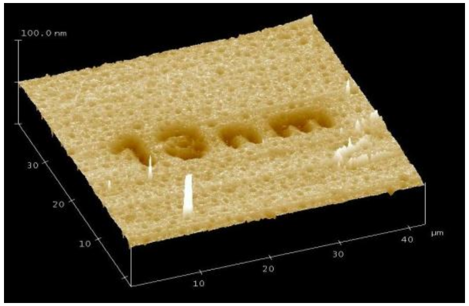
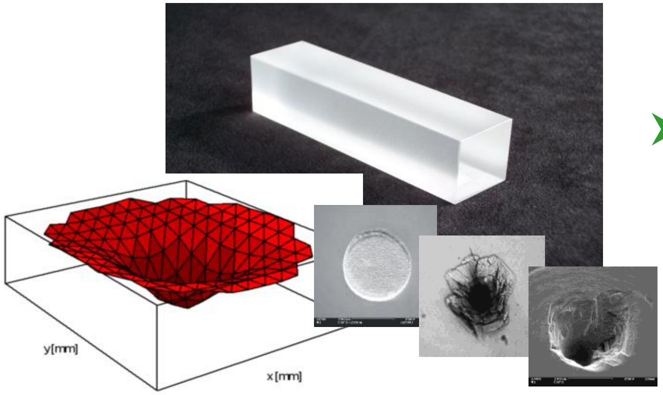
Dept.
"Optics / Short Wavelengths"

- Beam and Optics Characterization (**DUV**)

  - **Optics test** (351…**193 nm**)
    - *(Long term) degradation (10^9 pulses)*
    - *Non-linear processes*
    - *LIDT*
    - ***Absorption** / Scatter losses*
    - *Wavefront deformation*







- **Beam propagation**
  - *Wavefront*
  - *coherence*
  - *M²*

- **EUV/XUV technology**
  - *Source & Optics*
  - *Metrology*
  - *Material interaction*

Types of laser produced plasmas

Target material	Solid	Liquid	Gas
			
Advantages	+ conversion efficiency + Small plasma (~50µm)	+ conversion efficiency + mass limited, small target (~50µm)	+ „clean“ (no debris) + high flexibility + high stability + low effort
Disadvantages	– unflexible – „dirty“ (debris)	– high effort – debris: „snowballing“	– relatively low brilliance – size ~300µm

EUV/XUV radiation:

Lab source for metrology

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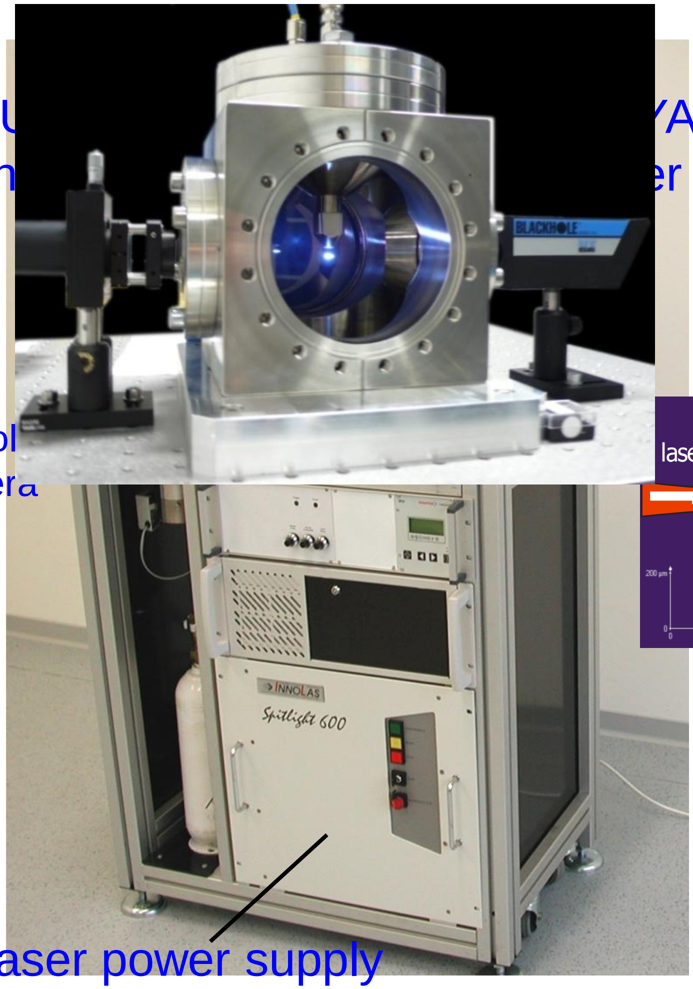
Spezifications:

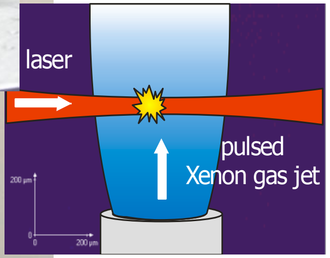
- Wavelength:	1 - 20nm
- Pulse energy (Xe):	4mJ (4πsr, 2%BW)
- Conversion eff.:	0.45% (Xe)
- Pulse length:	6ns
- Plasma size:	$\varnothing$ ~ 300µm

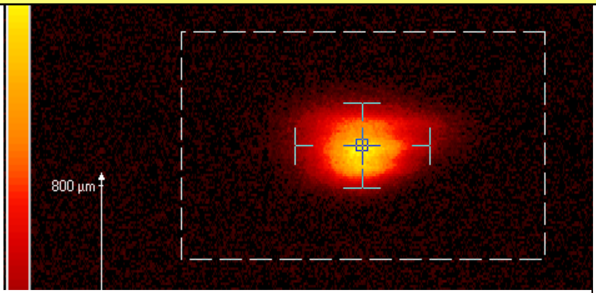
EU ... YAG
ch ... er

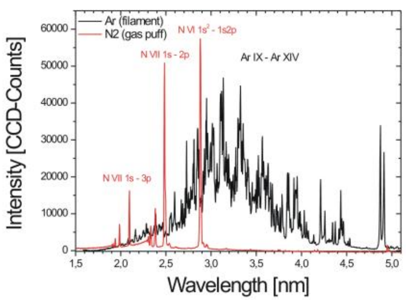


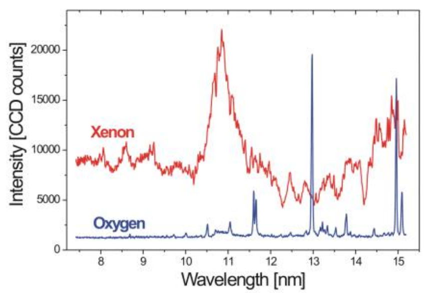
EUV
Pinhol
camera

Laser power supply









- Univ. Prag
- Univ. Göttingen
- Max-Planck Inst.

XUV: 1…10nm **EUV: 10…20nm**

LLG-Activities Based on EUV LPP Source

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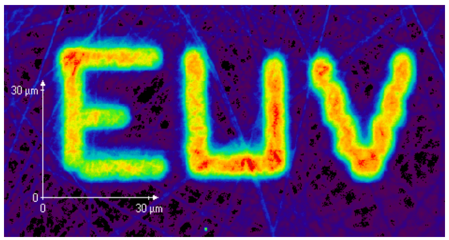
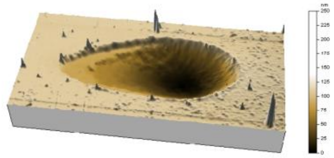
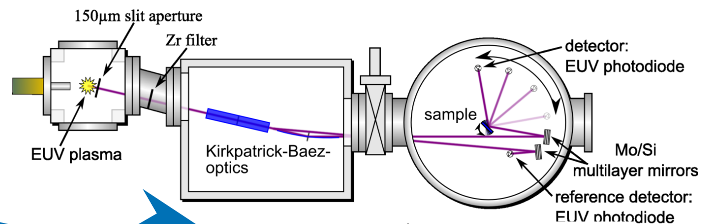
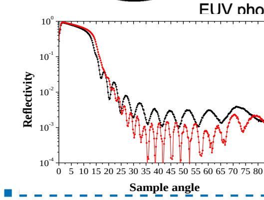
- Direct structuring

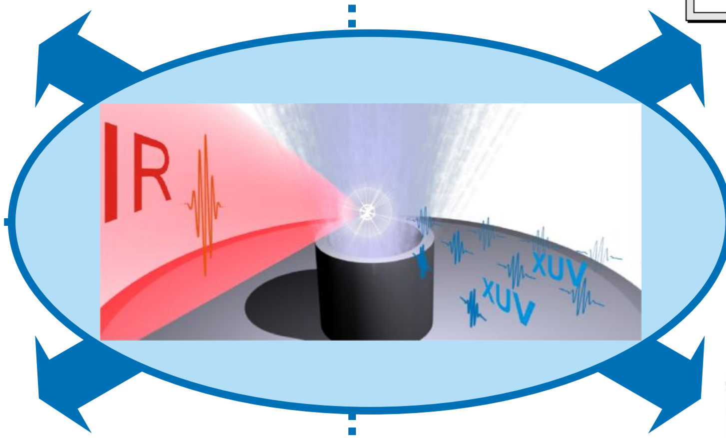


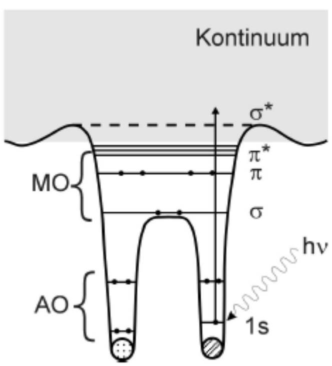


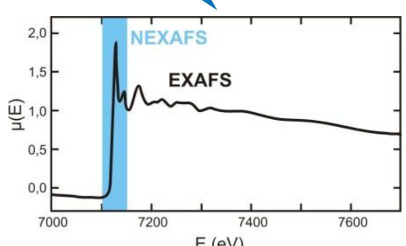
- Reflectometry



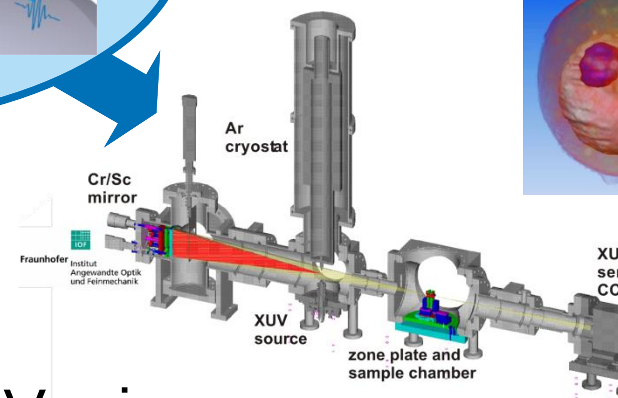


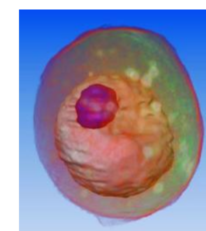






- NEXAFS spectroscopy

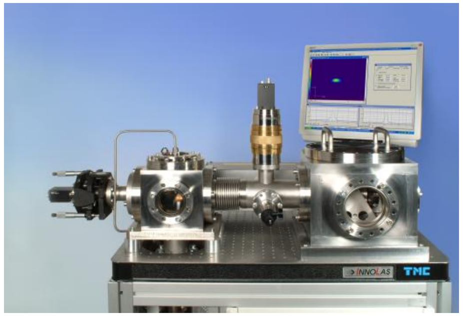




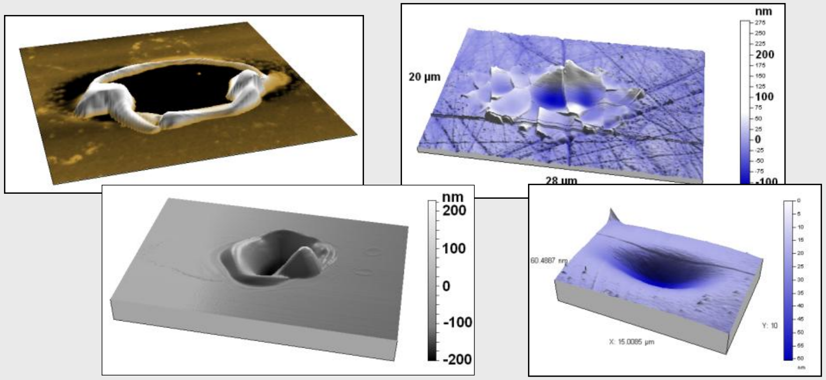
- XUV microscopy

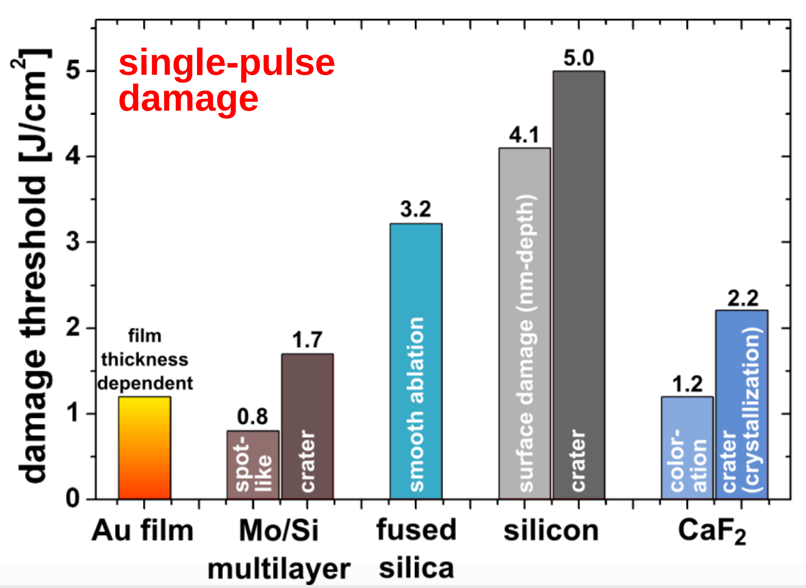
Ablation / damage thresholds @13.5nm

- Laser driven EUV/XUV plasma source setup
  - 1.2 J/cm^2 (@ 13,5 nm, 2 % bandwidth)
  - 7.4 J/cm^2 (filtered by 2 Mo/Si mirrors)



- Damage thresholds of mirrors / substrates





F. Barkusky, K. Mann et al., Optics Express 18, 4347 (2010)

Integrated source and optics system:
→ EUV direct structuring

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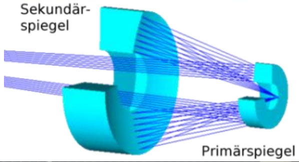
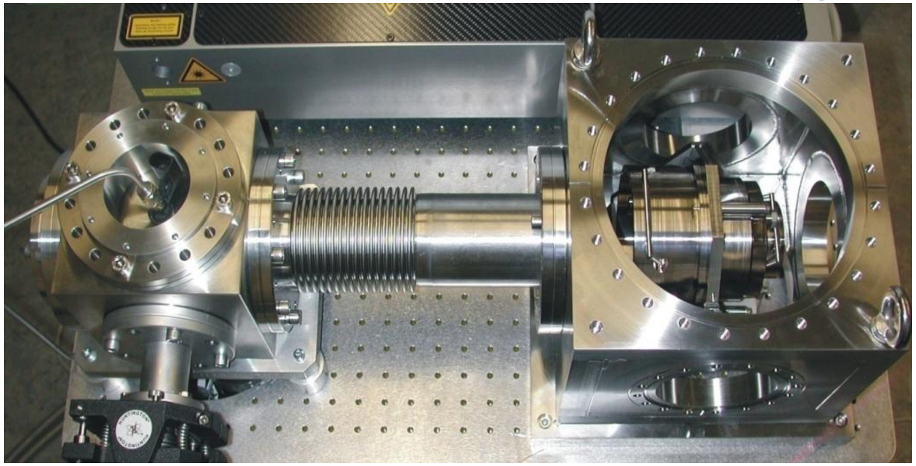
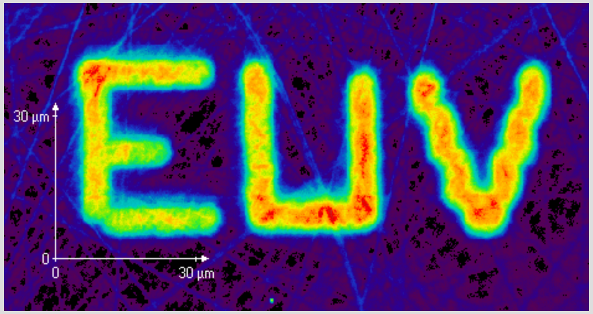
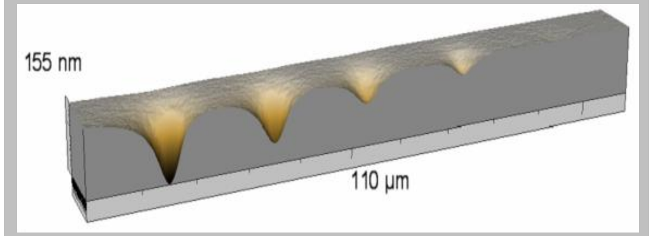
Schwarzschild objective
@13.5nm (Mo/Si):





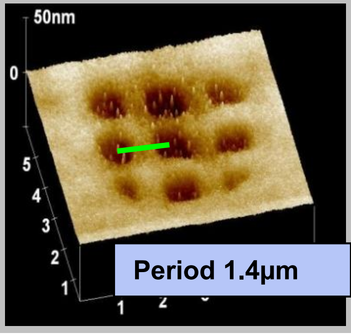
Color Centers in LiF





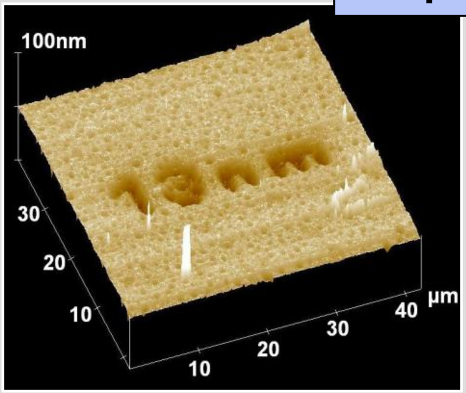
PMMA

Resolution 130nm



PMMA

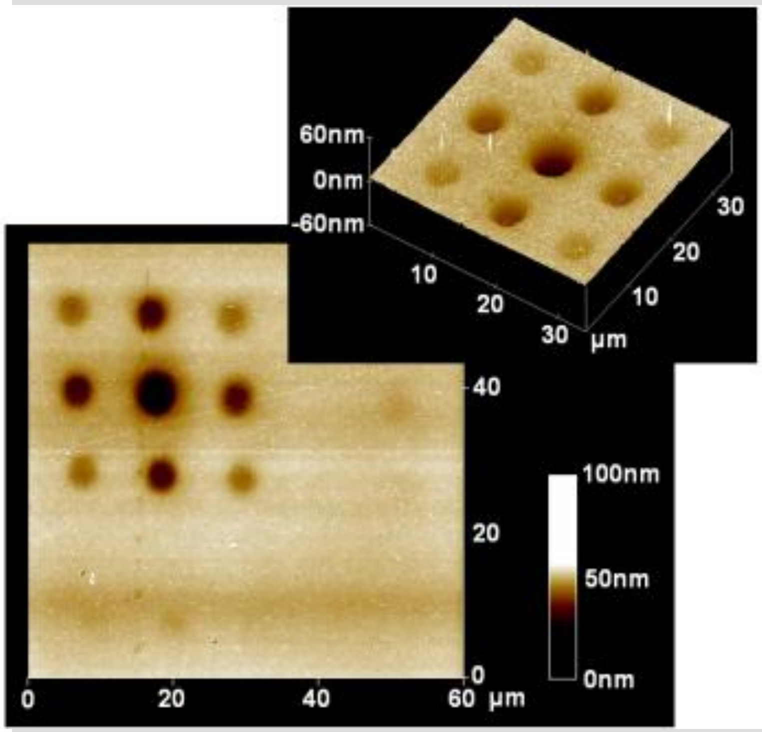
∅ 1µm

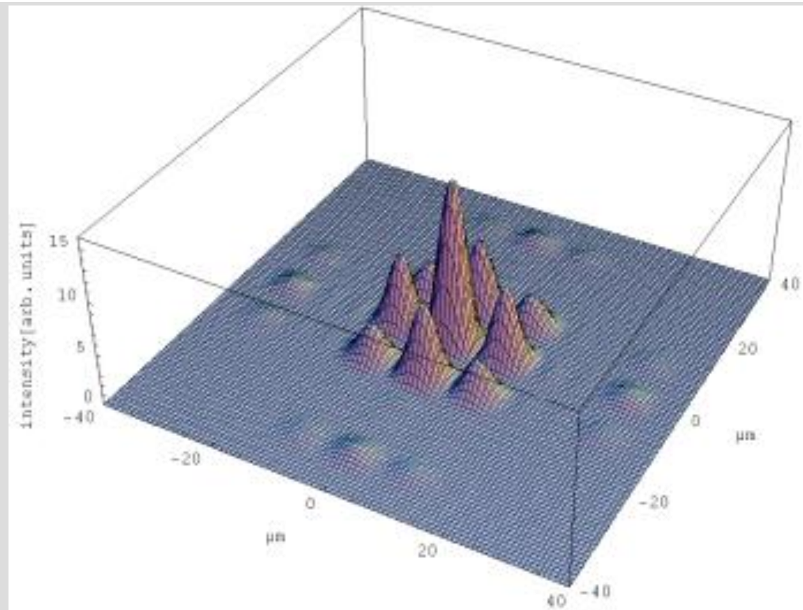


F. Barkusky, K.Mann et al., J. Appl. Phys. **101**, 124908 (2007)

EUV Diffraction experiment

- Pinhole (∅ 50µm) behind plasma
- mesh before objective
  → **diffraction pattern imprinted on PMMA**



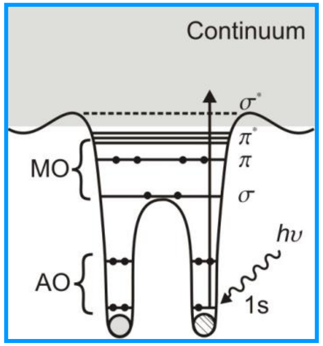


➢pure EUV radiation !

(@ 13.5 nm, 2% BW)

Soft x-rays with lab source: NEXAFS Spectroscopy

= Near-edge x-ray absorption fine-structure

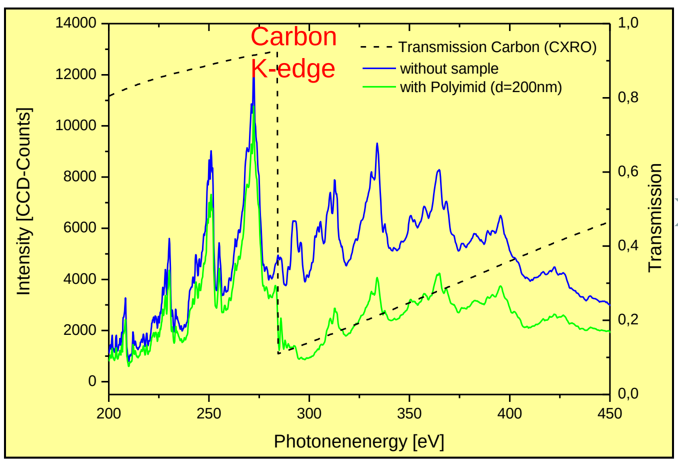


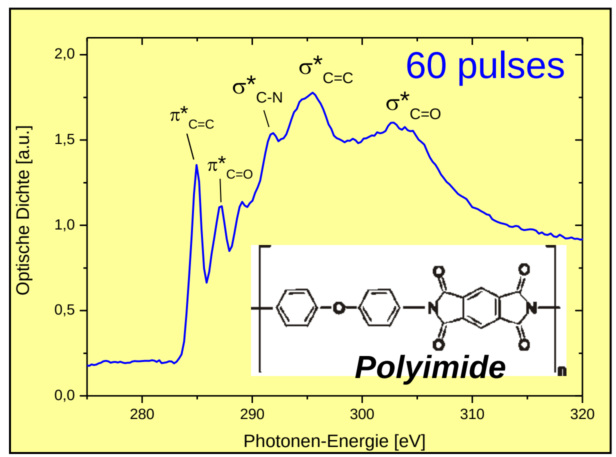
- Absorption in unoccupied molecular orbitals

  → „Fingerprint“ of molecules

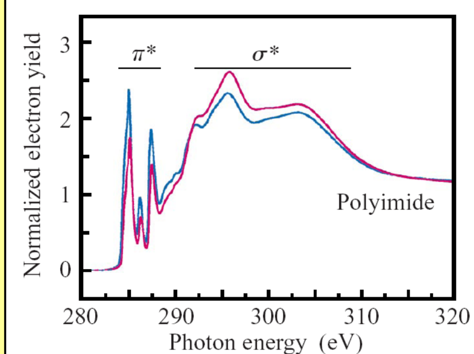
  - ***surface-sensitive chemical analytics***
  - ***polychromatic concept***

Plasma in Kr gas jet → „water window“ / Polyimide (d=200nm):





Synchrotron data (J. Stöhr):



C. Peth, K. Mann et al.,J. Phys. D **41** (2008) 105202

Setup of NEXAFS Spectrometer

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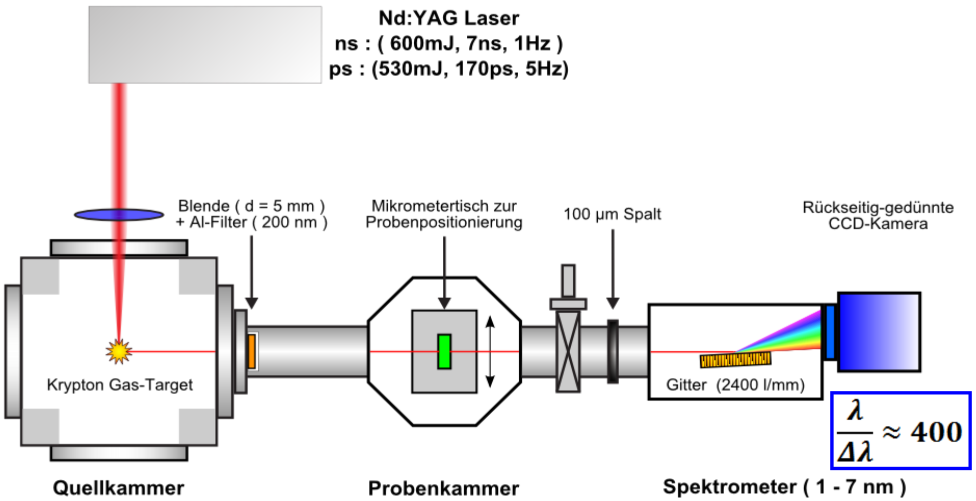
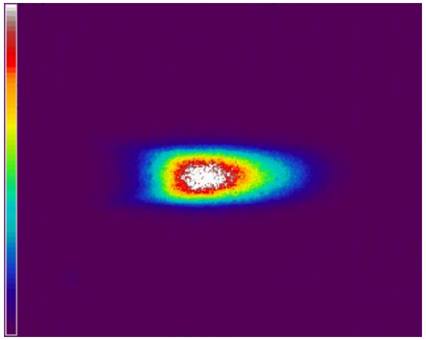
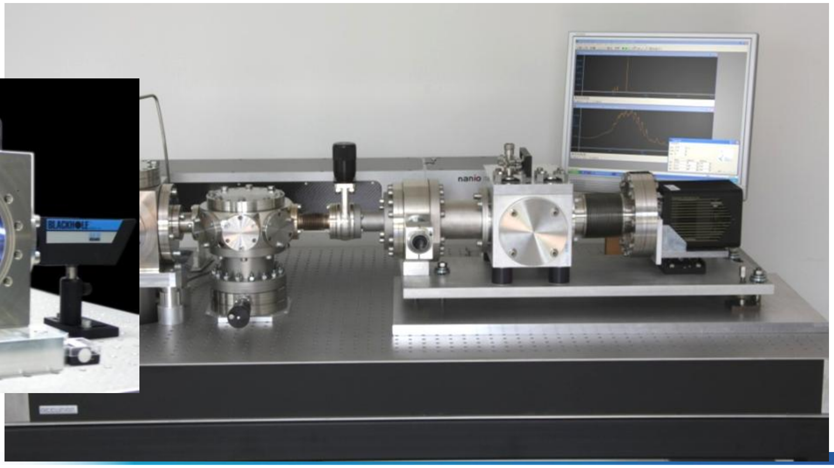
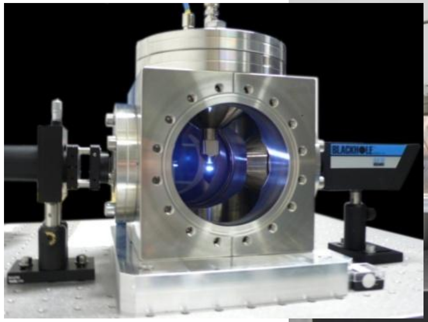


XUV plasma (Kr)
with pinhole camera







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

Single pulse NEXAFS spectra

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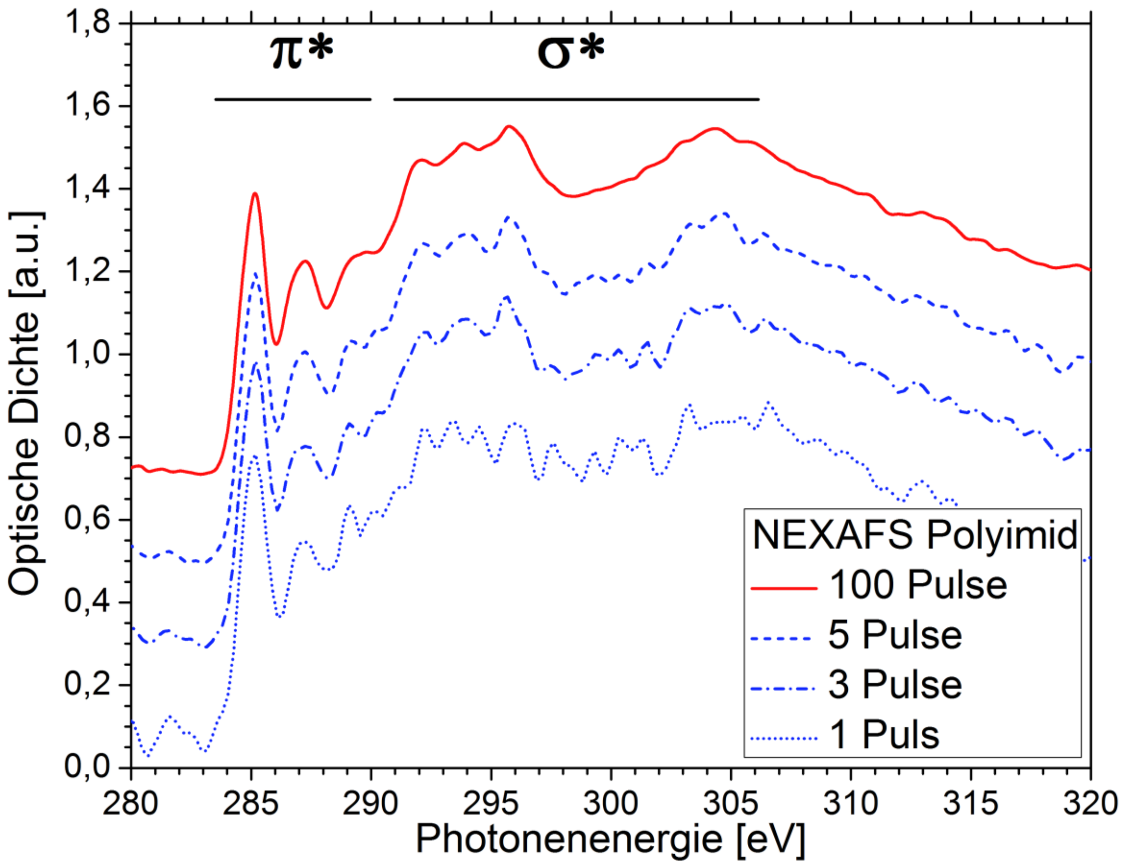


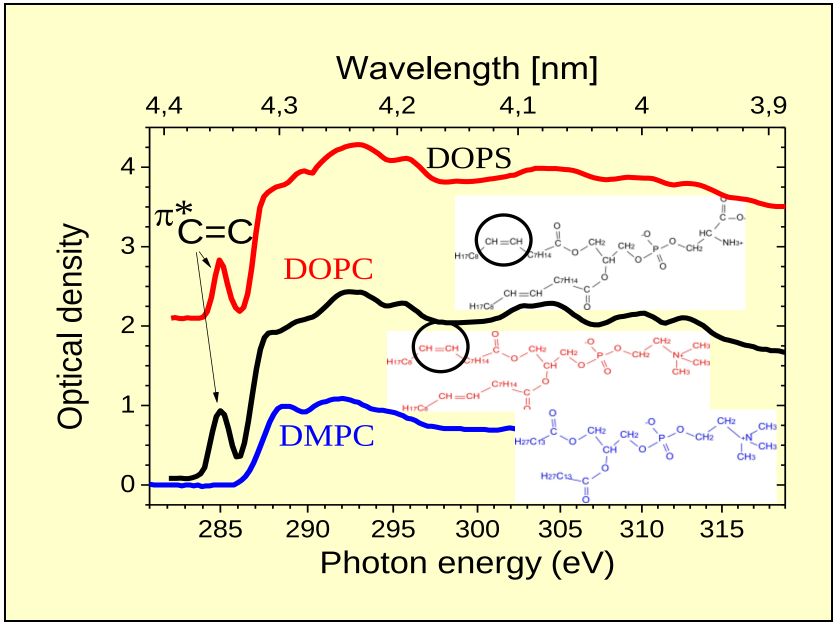
NEXAFS spectroscopy on thin films

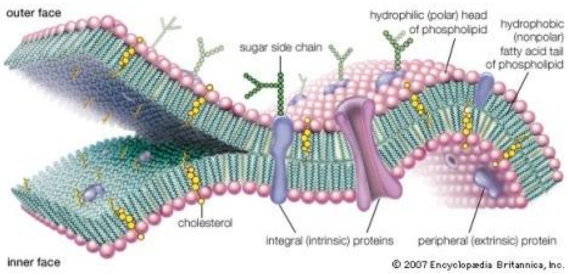
Laser-Laboratorium Göttingen e.V.

Courant Research Centre
Nano-Spectroscopy and X-Ray Imaging

- Lipid membranes (carbon K-edge)

  (T. Salditt)



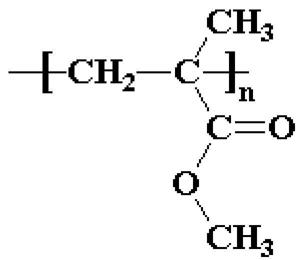


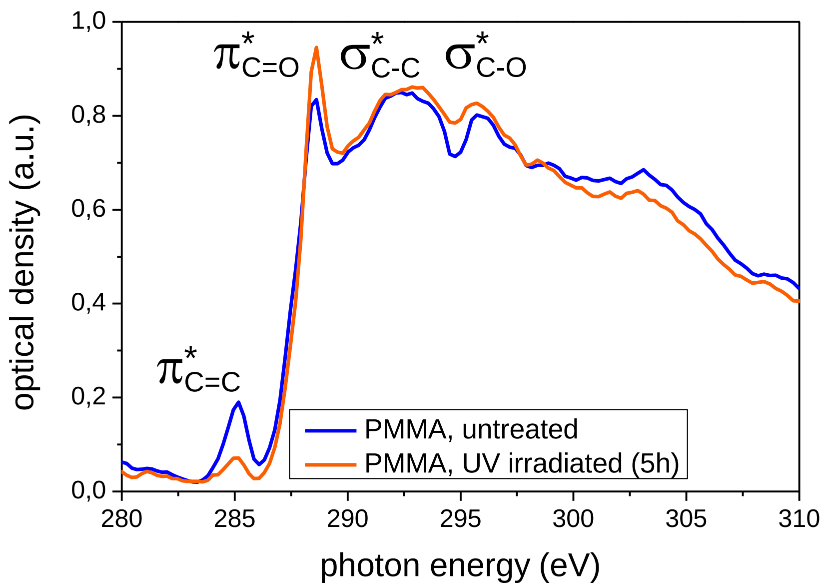
E. Novakova, C. Peth, K. Mann, T. Salditt et al.: Biointerphases, **3** (2008) FB44

NEXAFS spectra of PMMA

Laser-Laboratorium Göttingen e.V.

- PLD: PMMA films (200nm)
  - Softer as bulk material ⇔ shorter polymer chains
  - C=C bonds visible





- UV irradiation
  - Chemical changes :
    - Loss of C=C bonds
    - Increase of C=O bonds
  - repolymerization

    → bulk material

B. Fuchs, P. Großmann, K. Mann, H.U. Krebs et al., Appl. Phys. A**98**, 711-715 (2010)

NEXAFS spectrum PCMO

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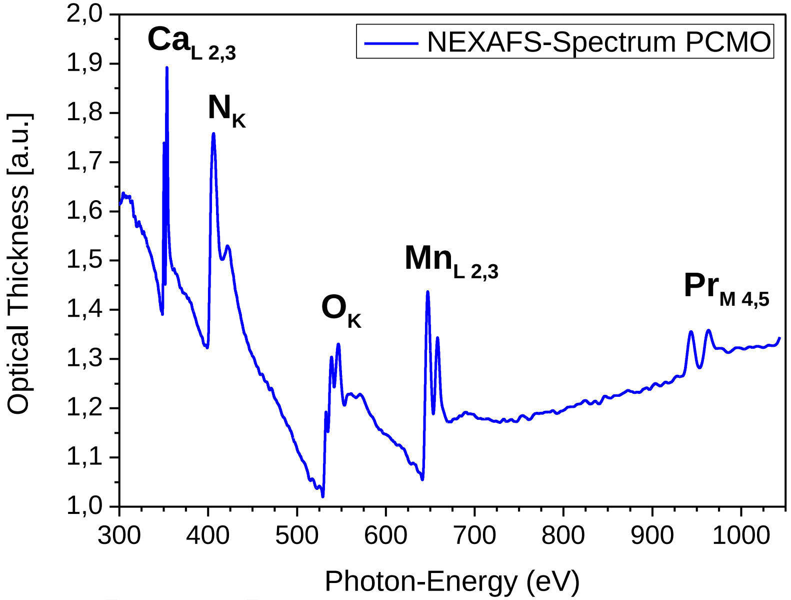
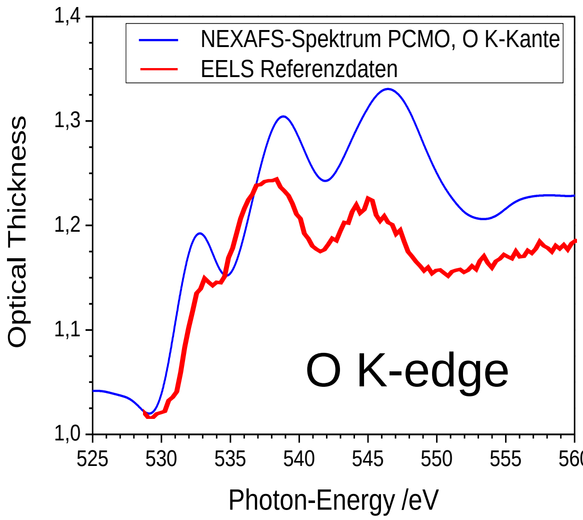
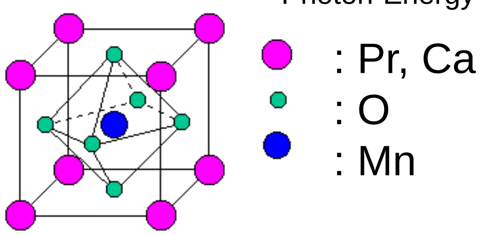


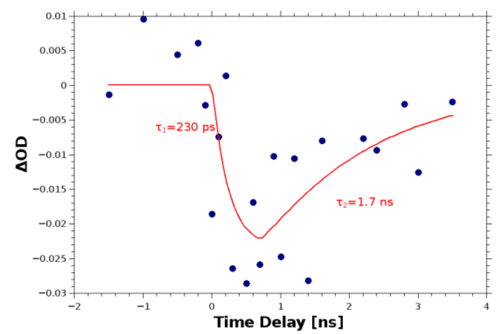


(S. Techert)



▲Perovskit-type Manganate
$Pr_{1-x}Ca_xMnO_3$

- High-Tc superconductor
- Every element visible
- Agreement with reference
- pump-probe experiments
  - Radiation-induced phase transition (~100K)



XUV source improvements:

Comparison: ns – ps laser

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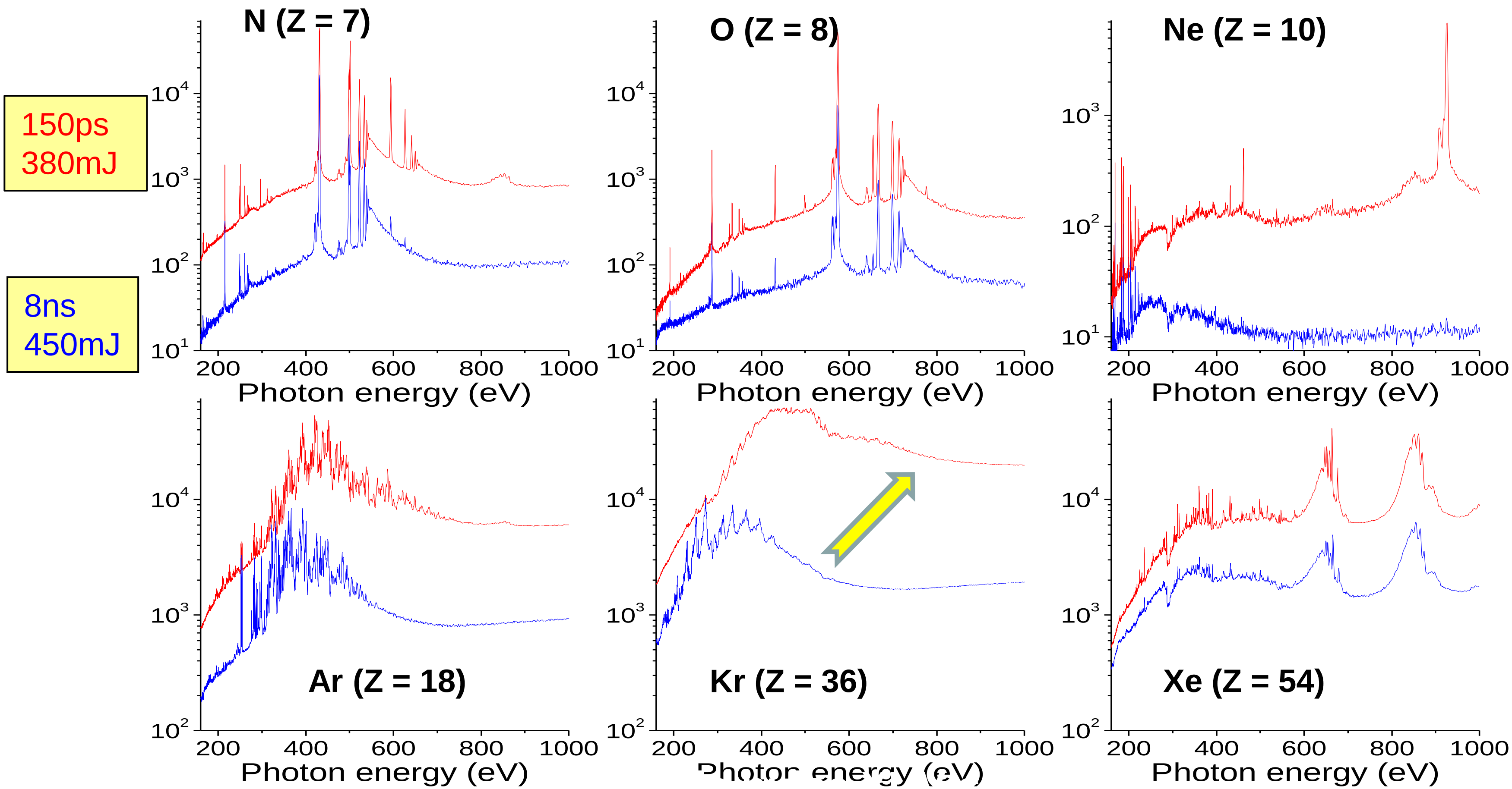
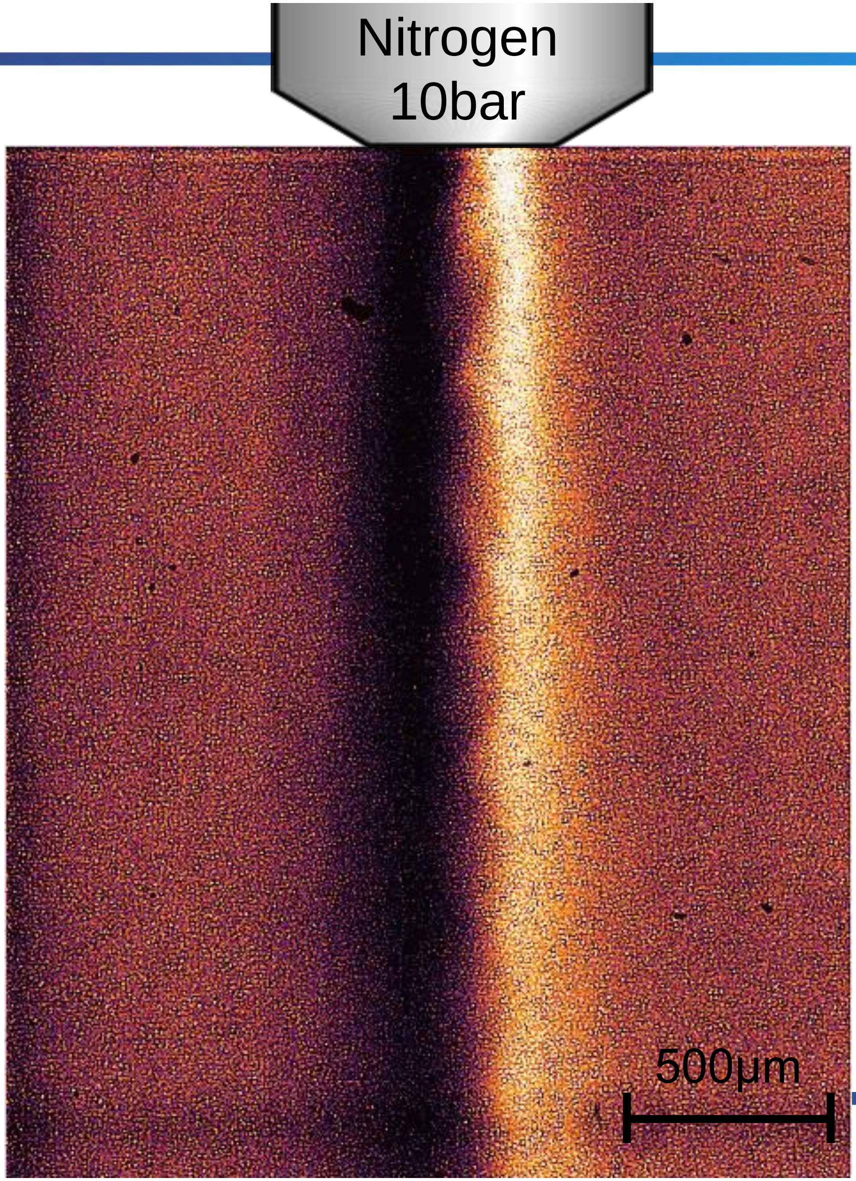
Single pulse spectra:



Peak brillance of isolated N line @ λ = 2.88nm:

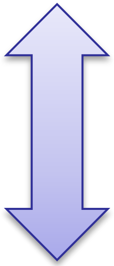
$6*10^{17}$ (ns-Laser) $\Rightarrow$ $1.2*10^{20}$ Ph./(s $mrad^2$ mm^2 0,1%BW) (ps-Laser)

The barrel shock – Schlieren images



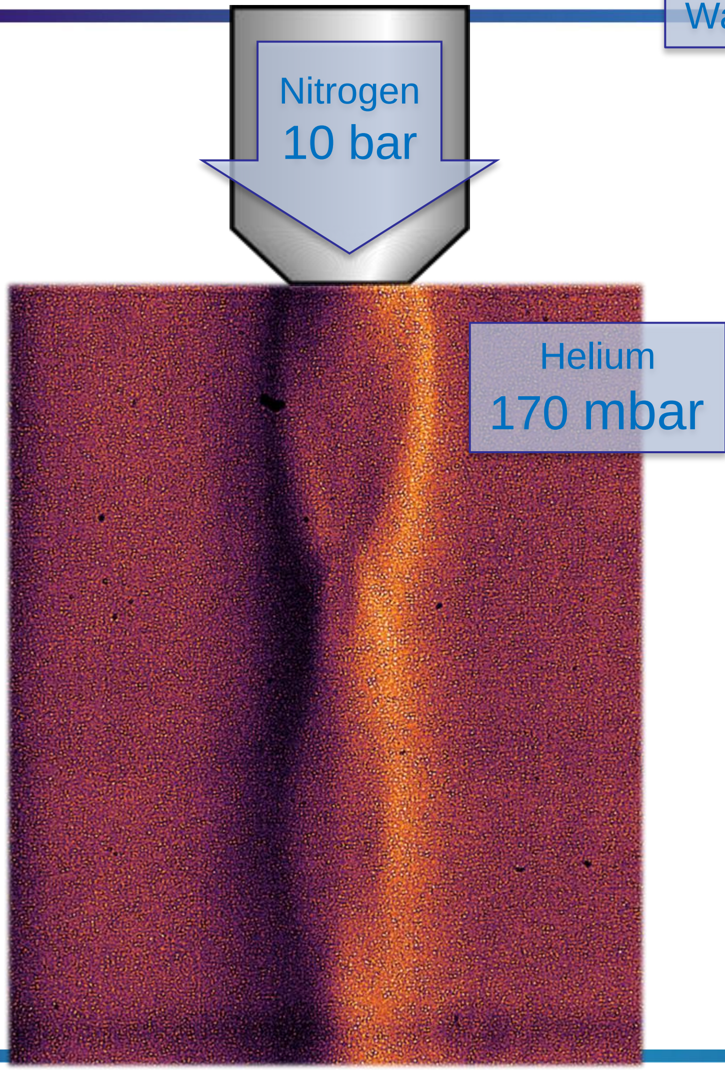
ambient pressure:

1 bar

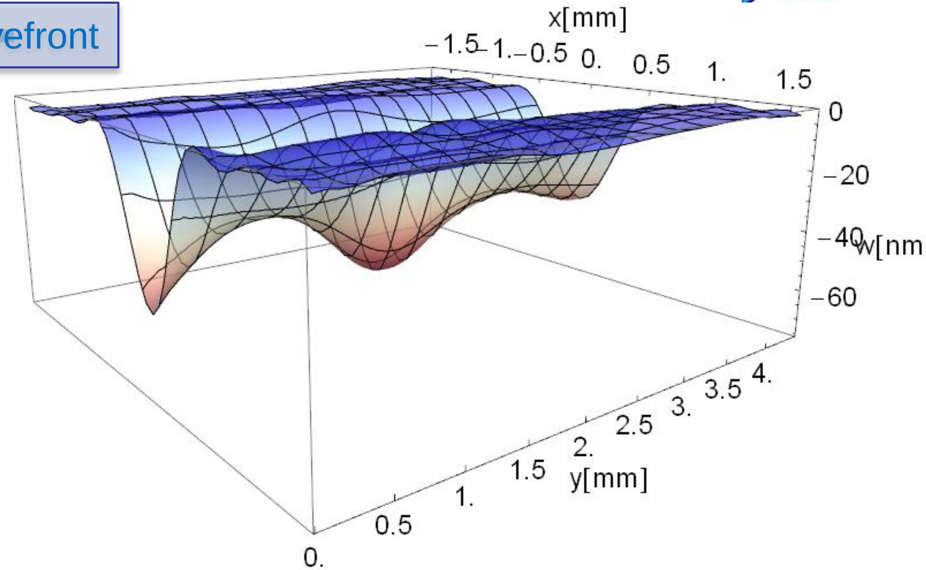


10^{-3}mbar

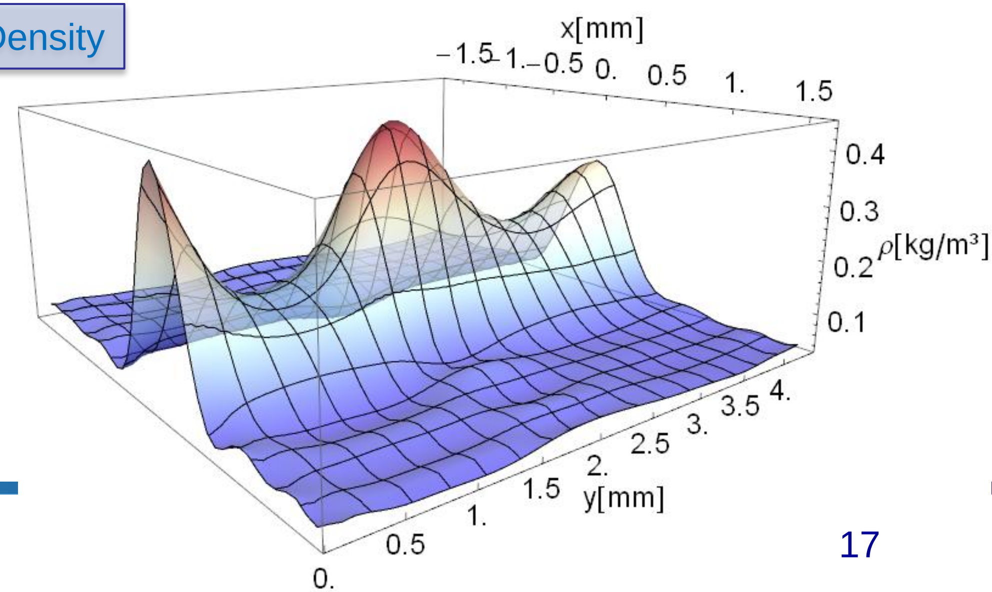
The barrel shock



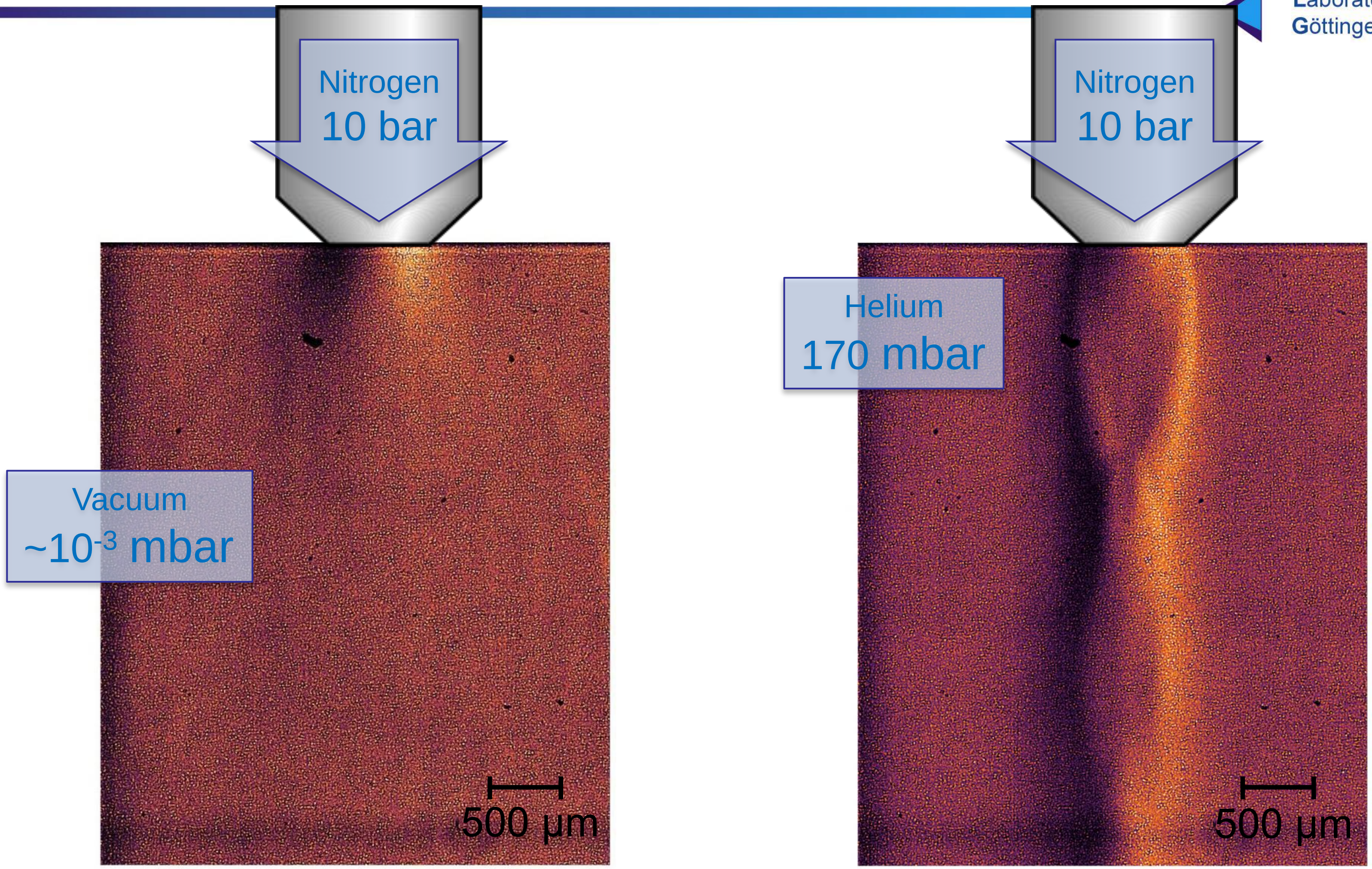
Wavefront



Density



Plasma generation with/without the barrel shock



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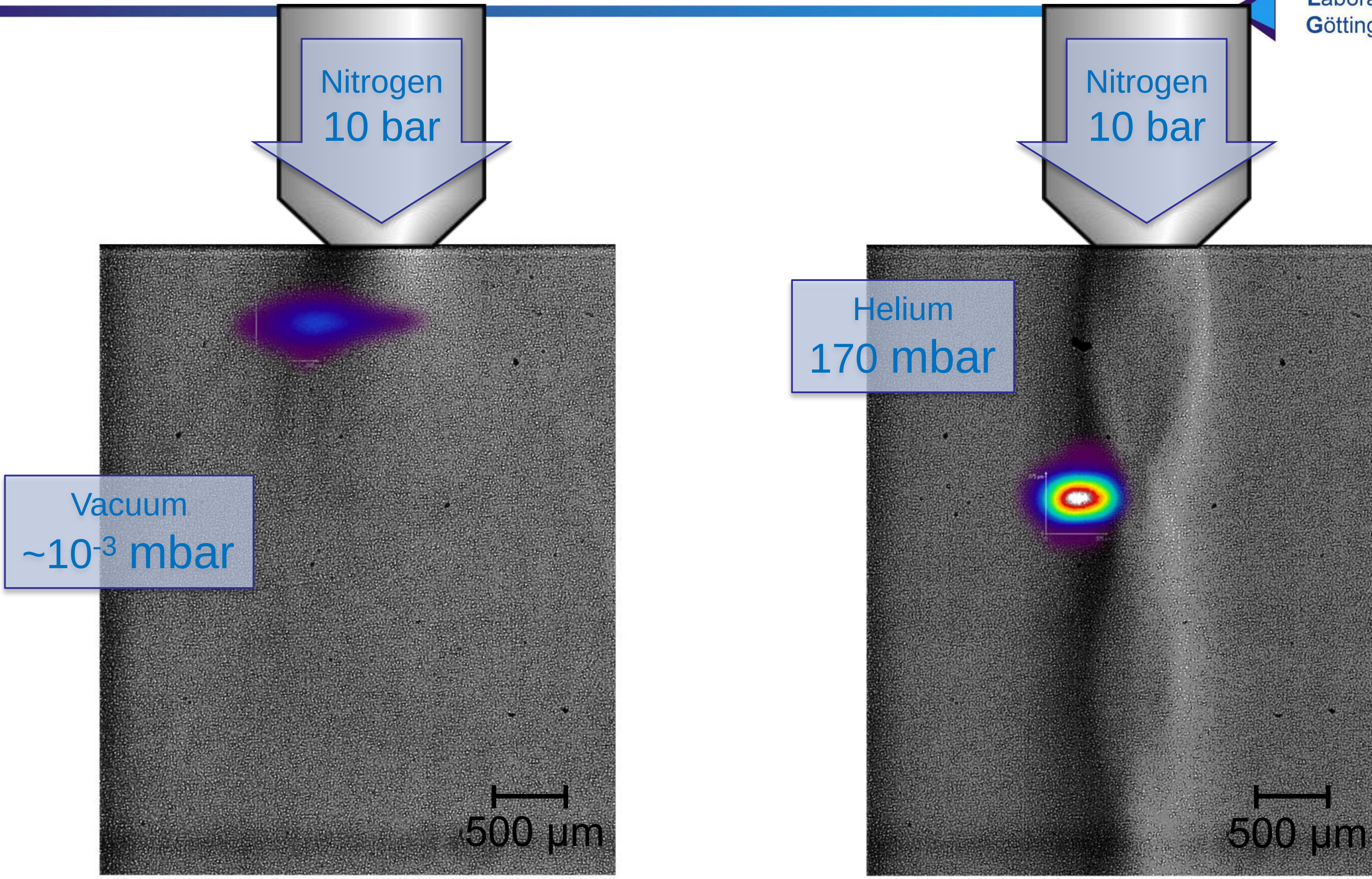
Plasma generation with/without the barrel shock



Enhancement of particle density in gas jet:

increased brillance from shock wave

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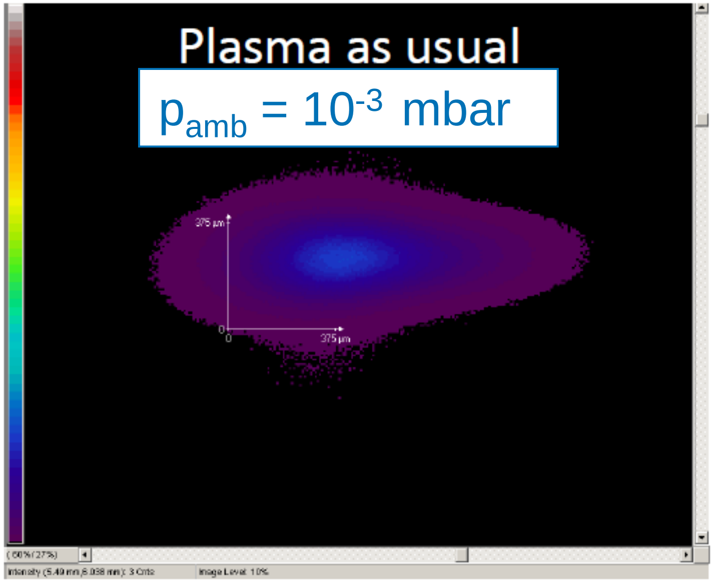
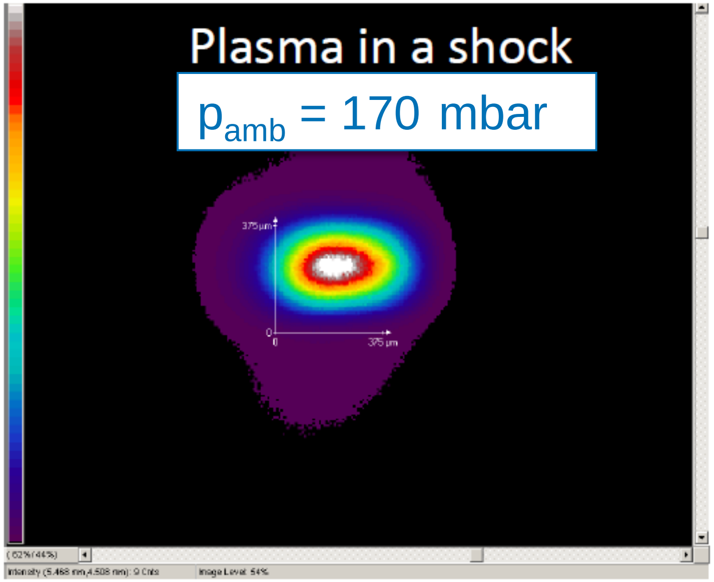
Pinhole camera image of Nitrogen plasma p=10bar / Ti-filtered





distance to nozzle	500 µm		1800 µm
FWHM	521 µm	·0.71	371 µm
E_{total}	1.02 MCnts	·3.35	3.42 MCnts
E_{max}	421 Cnts	·5.27	2220 Cnts

Summary and Outlook

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Courant Research Centre
Nano-Spectroscopy and X-Ray Imaging

SFB 755
Nanoscale Photonic
Imaging

- EUV / XUV source
  - Compact, clean, reliable
  - Line or broad-band radiation (1…20nm)
  - EUV: reflectometry, direct structuring / ablation studies
  - XUV: NEXAFS for chemical surface analysis
  - Further increase of brilliance / higher photon energies
  - Entire spectrum in single pulse / pump-probe
  - scanning spectro-microscopy

Thank You !

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Coworkers:

- *Dr. B. Schäfer*
- *Dr. A. Bayer*
- *Dr. U. Leinhos*
- *Dr. F. Barkusky*
- *J.O. Dette*
- *M. Lübbecke*
- *M. Reese*
- *B. Flöter*
- *P. Grossmann*
- *M. Olschewski*
- *S. Döring*
- *T. Mey*
- *J. Sudradjat*

Outline

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1. Table-top EUV/XUV source
   - experimental
2. Metrology applications
   - reflectometry
   - Damage of EUV optics
   - NEXAFS spectroscopy
3. Source improvements
4. Characterization of EUV/XUV radiation (FLASH)
   - wavefront measurement / Hartmann(-Shack) sensor
   - optics alignment

Hartmann-Shack wavefront sensor:

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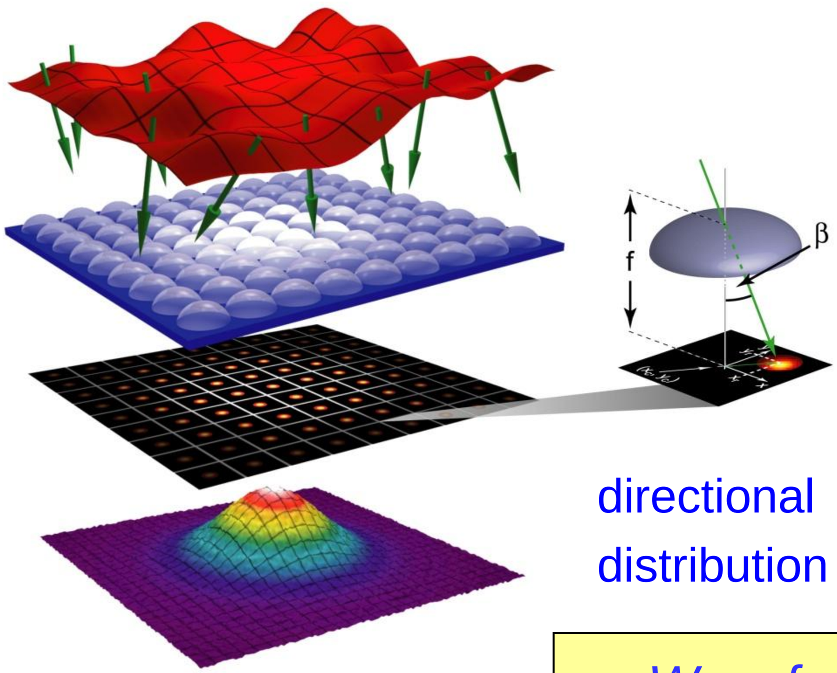
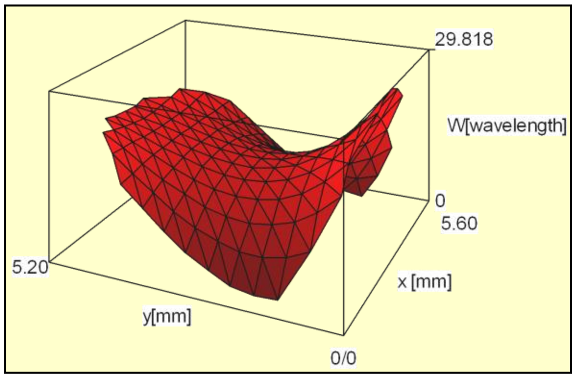


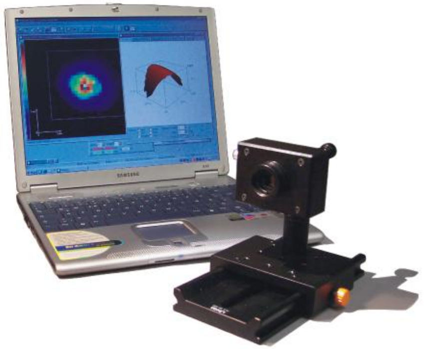
directional distribution

intensity distribution

wavefront:



LOT
LOT ORIEL GRUPPE EUROPA



$\Rightarrow$ *Wavefront* w(x,y)

= surface ⊥ Poynting-Vektor S(x,y)

(ISO 15367-2)

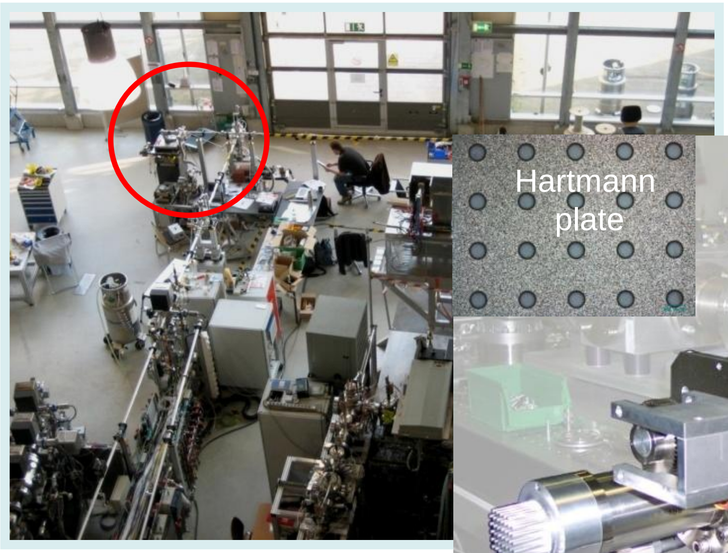
Beam characterization of Free Electron Laser FLASH

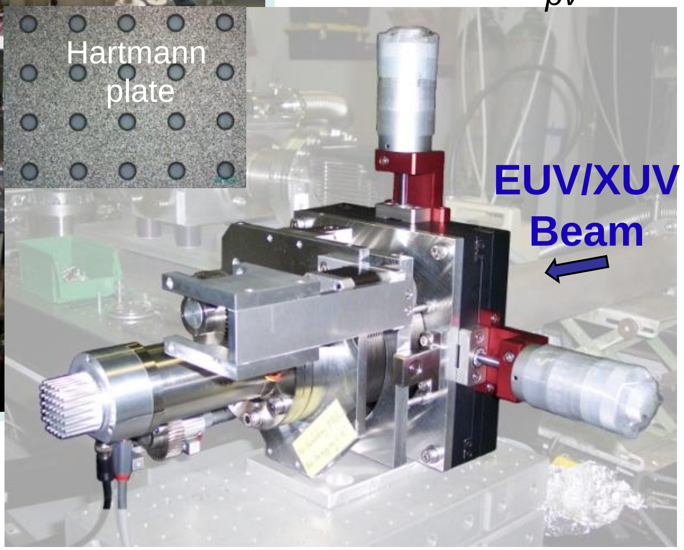
EUV-Hartmann sensor:

λ= 5 – 30nm

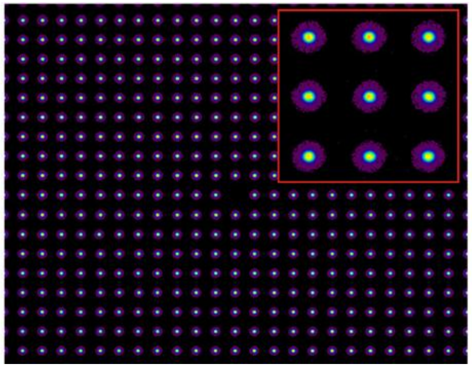
Accuracy:

- ~λ/15 w_{pv} for EUV

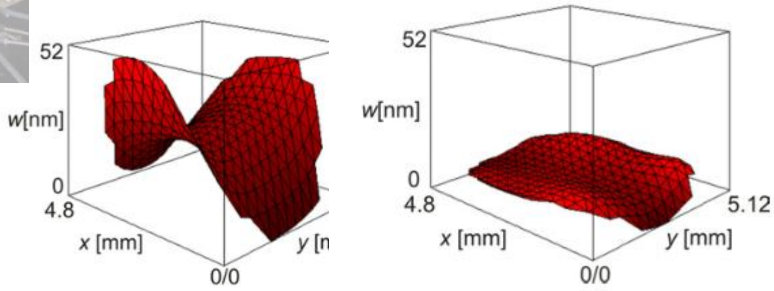




- Spot distribution:



- Adjustment of beam line optics:



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

Ablation / damage thresholds @13.5nm

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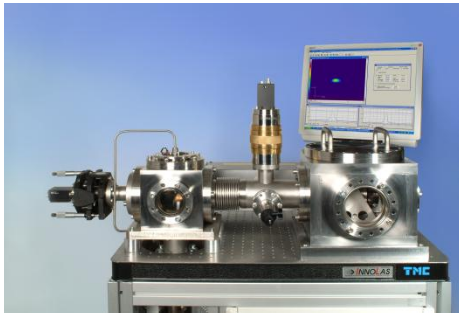
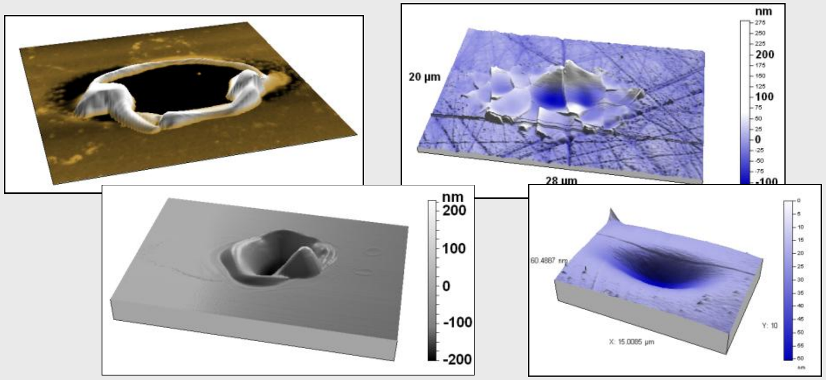
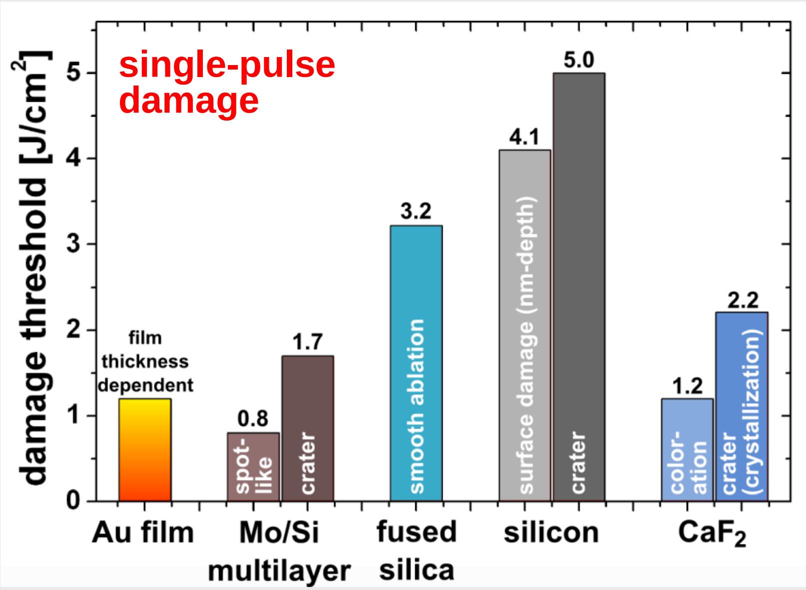
- Laser driven EUV/XUV plasma source setup
  - 1.2 J/cm^2 (@ 13,5 nm, 2 % bandwidth)
  - 7.4 J/cm^2 (filtered by 2 Mo/Si mirrors)



- Damage thresholds of mirrors / substrates

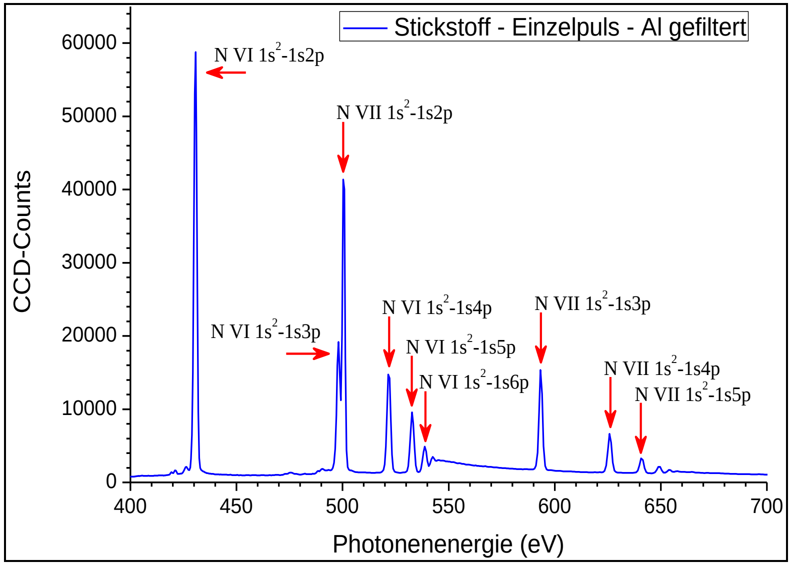


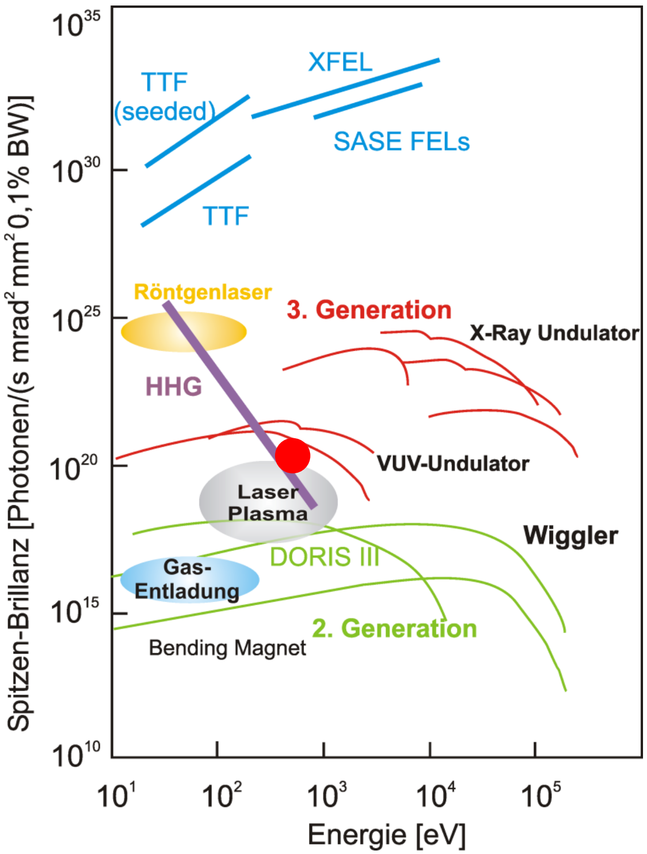


KLA Tencor

F. Barkusky, K. Mann et al., Optics Express 18, 4347 (2010) (OSA Spotlight)

Peak brillance of laser plasma source





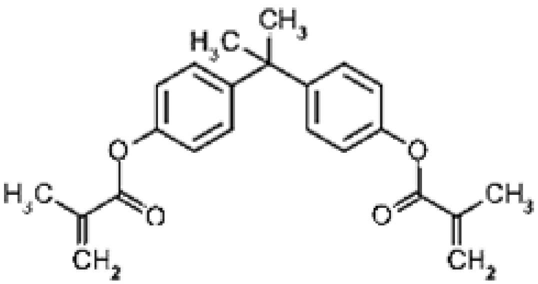
- Isolated **N VI 1s²-1s2p** line @ 2.8787nm (Ti filtered)
- Peak brillance *[Photons/(s mrad² mm² 0,1%BW)]*
  - *ns-Laser: $6*10^{17}$ (LLG, T. Wilhein)*
  - *ps-Laser: $1{,}2*10^{20}$ (LLG)* ●

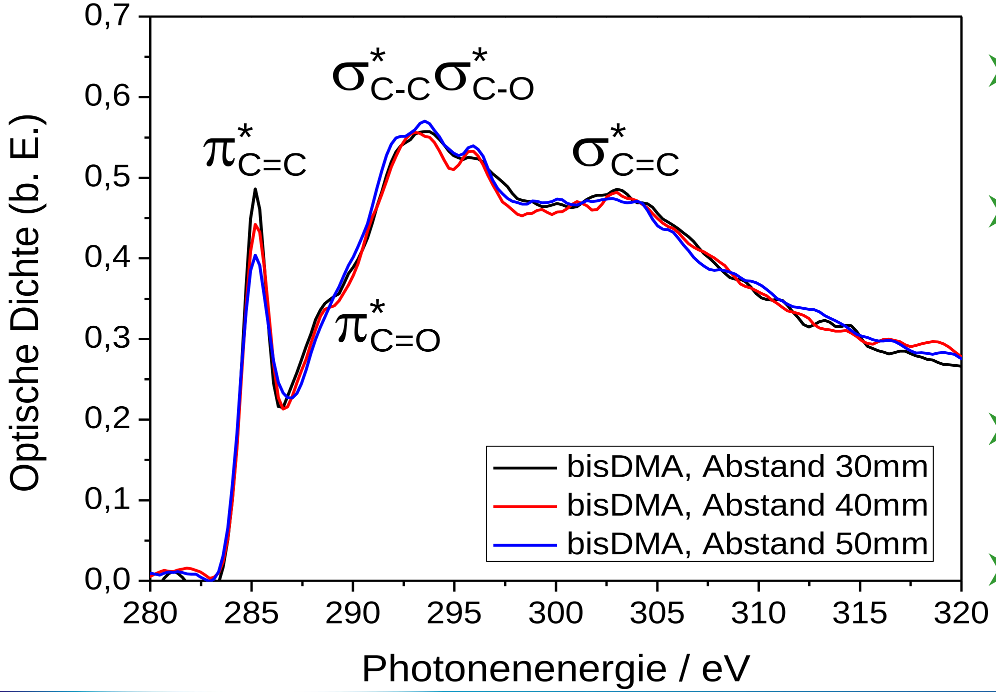
NEXAFS-Spektrum bisDMA

IMP INSTITUT FÜR MATERIALPHYSIK

Laser-Laboratorium Göttingen e.V.

- Dünne Schichten bisDMA (Weichmacher)
  - Beeinflussung Polymerkettenlänge z.B. PMMA
  - Suche nach optimalem PLD – Parametersatz
  - Variation Target - Substratabstand





- Parameter-Abhängigkeit der C=C Bindungen
- C=C Bindungen als Maß für die Unversehrtheit des bisDMA
- Kürzerer Abstand → besseres Ergebnis?
- Weitere Untersuchungen nötig

Compact NEXAFS spectrometer

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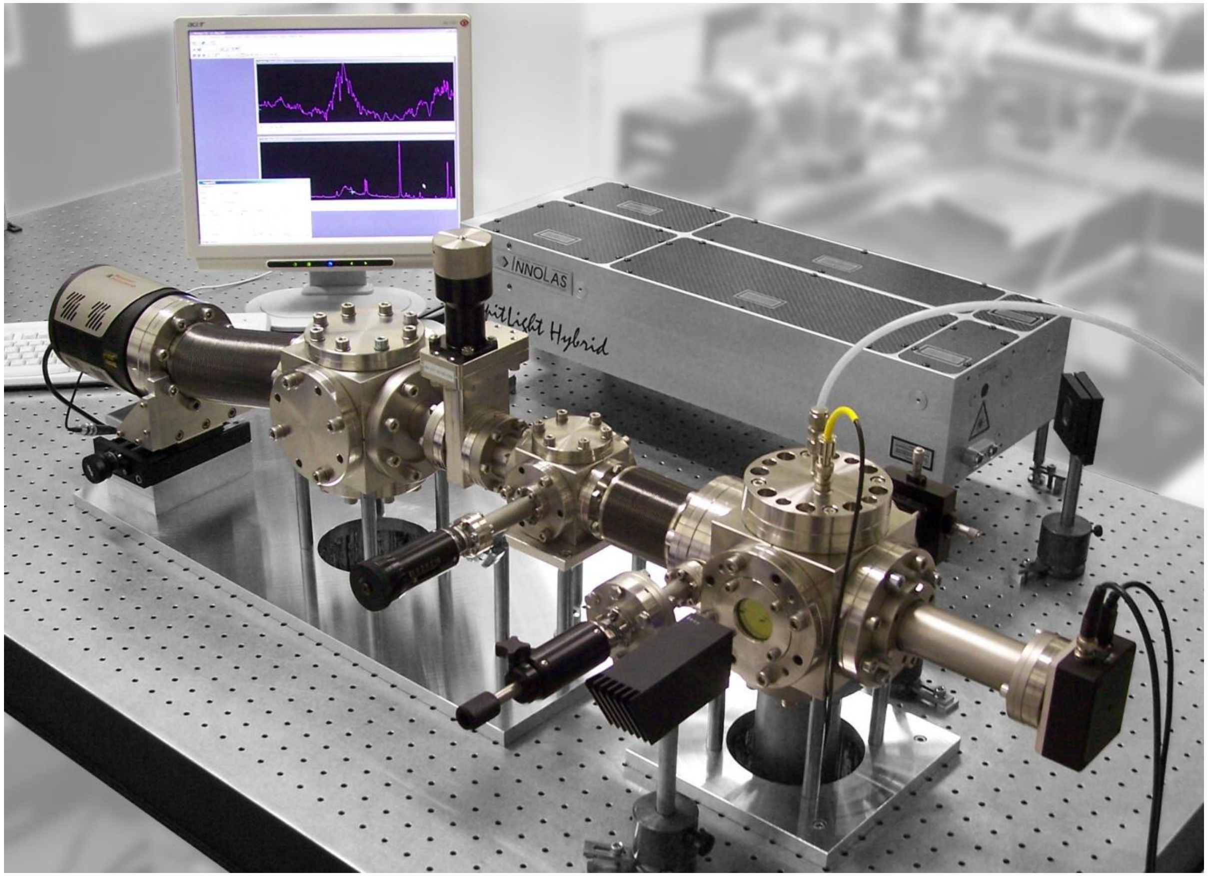
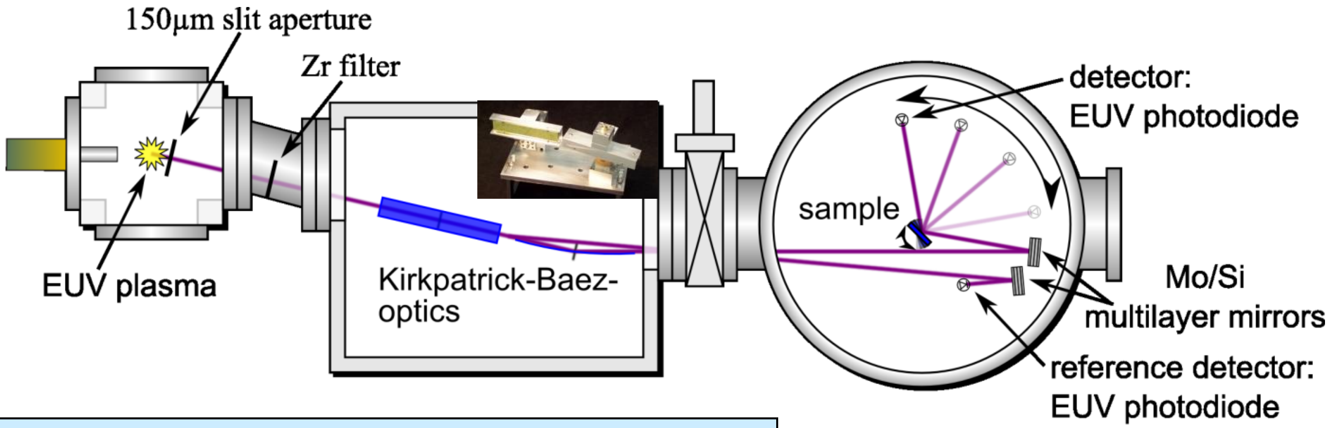
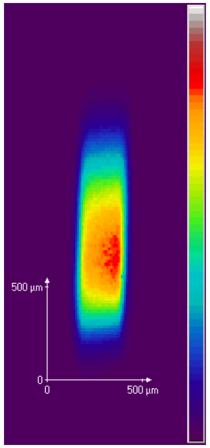


EUV reflectometry

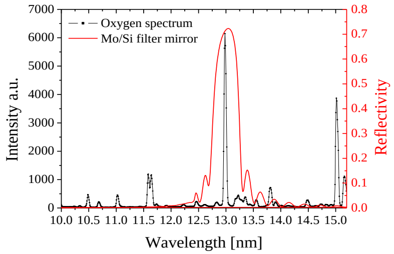


EUV spot on sample @ λ=13nm:

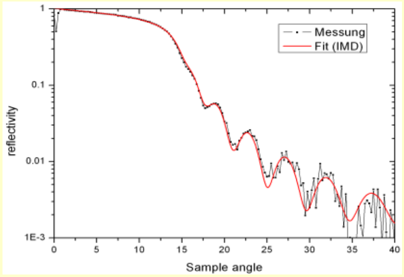


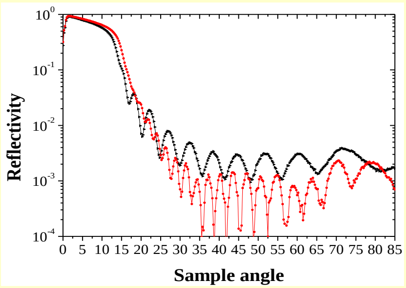
Specifications:

- *wavelength:* 12.98nm (oxygen line)
- *angular resolution:* 0.3°
- *angular range:* *1° - 85°*
- *dynamic range:* *4 orders of mag.*

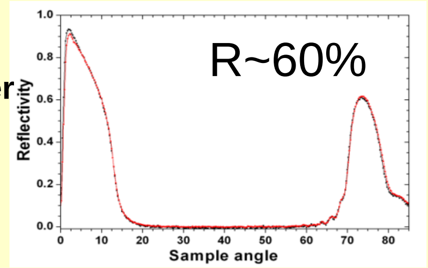


► **EUV Reflectivity** of 75 nm thick carbon layer





Mo/Si multilayer mirrors @13nm



„Water window“ (2,2nm – 4,4nm)

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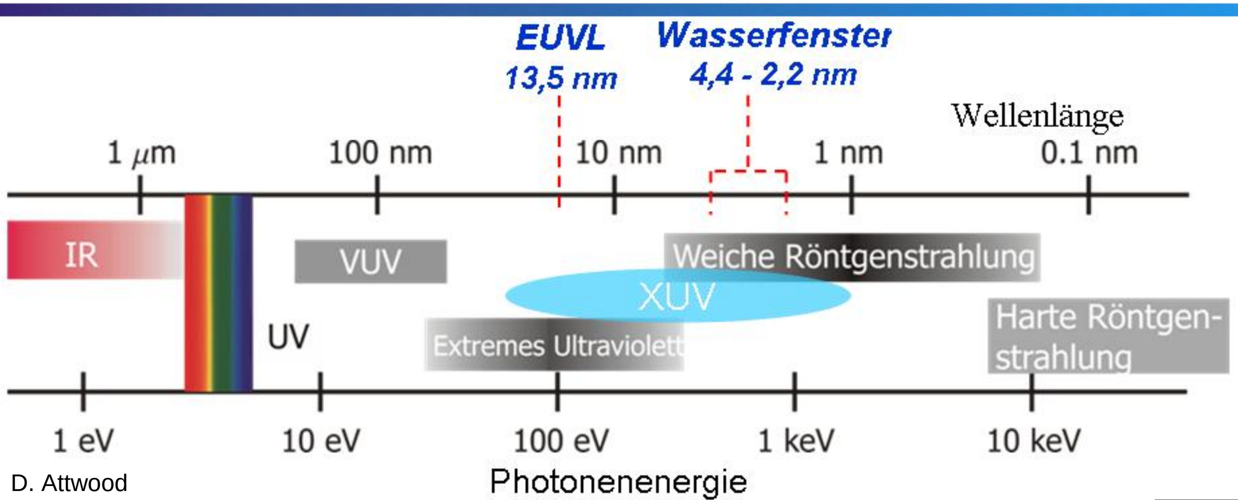
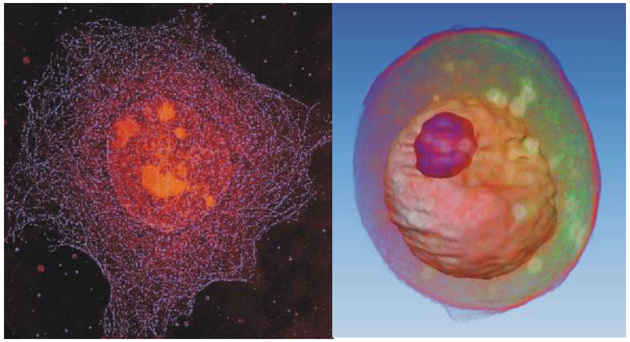


D. Attwood

▼Soft x-ray microscopy



▼Absorption edges