

Review of X-ray-laser activities at PALS

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Department of ultraintense lasers

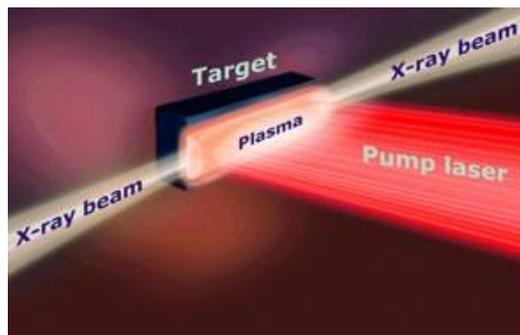
Former department of X-ray lasers

Section 5

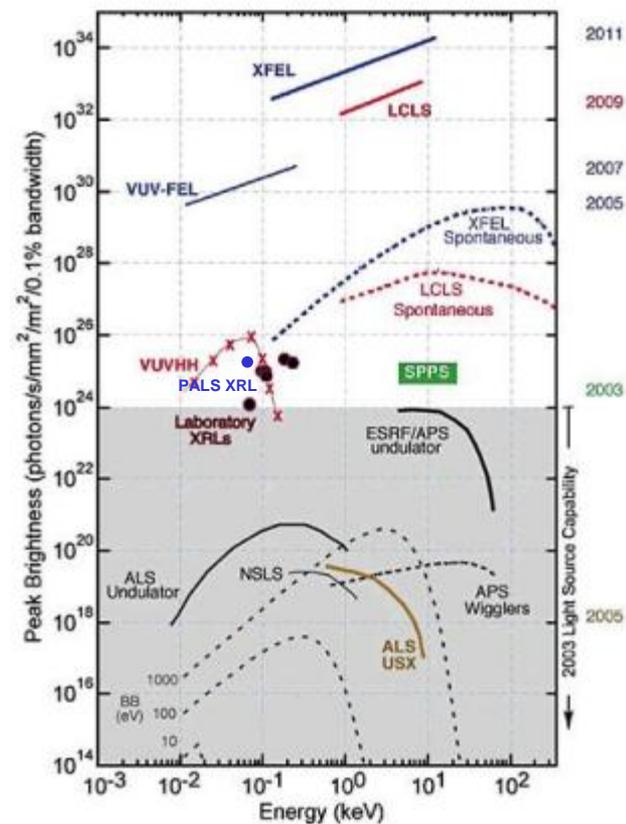
Institute of Physics AS CR

- **Introduction**
- **X-ray lasers driven by Asterix laser system**
 - Ne-like zinc X-ray laser beam-line
- **Application experiments**
 - Dense plasma metrology
 - Ablation and micro-patterning
 - WDM
 - Experimental astrophysics
 - DNA irradiation by XRL
- **Future prospects**

- **Plasma based X-ray lasers**
 - Laser driven, or capillary discharge

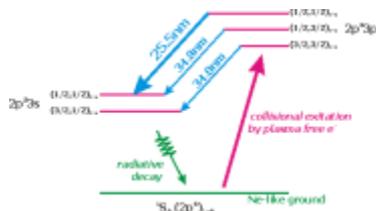


- **Low-cost laboratory XUV - soft X-ray sources**
- **Currently operating at 20-100eV**
 - aiming to water window 285–532eV (2.3-4.4nm)
- **Most of them use stable ions (Ne-like, Ni-like)**
- **Based on ASE**
 - limited degree of spatial coherence
 - advanced schemes with HHG seed
- **High brightness**

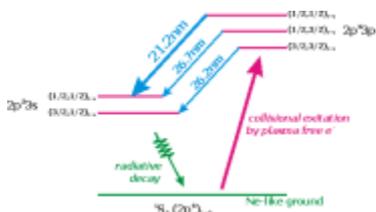


X-ray lasers pumped by Asterix (1.3 μm)

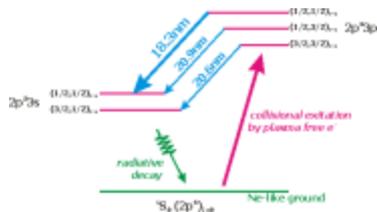
Ne-like Fe (Z=26)
@25.6nm



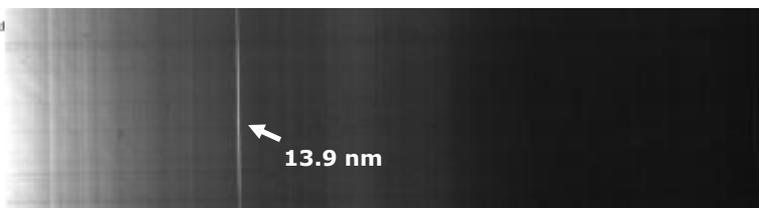
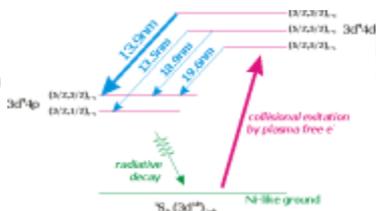
Ne-like Zn (Z=30)
@21.2nm



Ne-like Se (Z=34)
@18.3nm, 20.6nm, 20.9nm

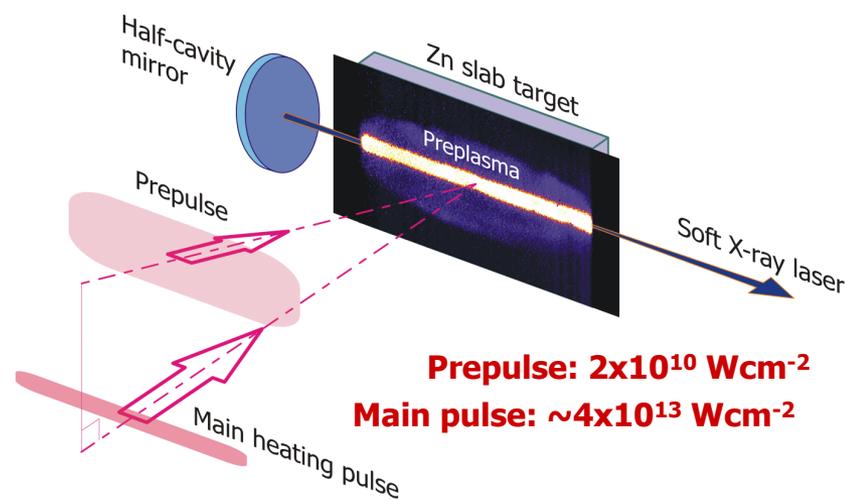


Ni-like Ag (Z=47)
@13.9nm



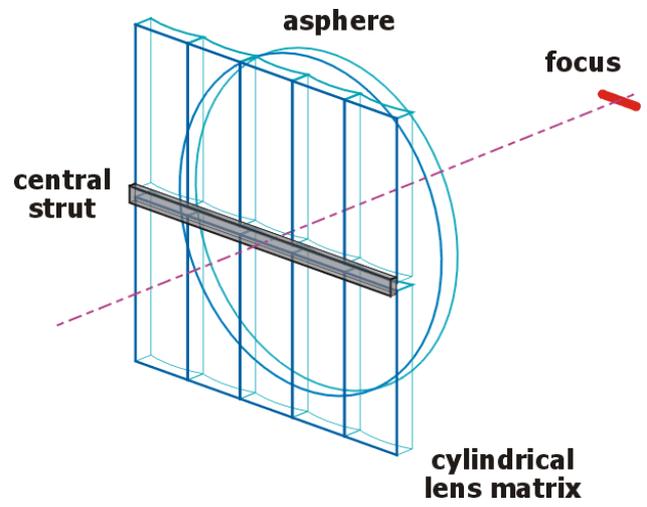
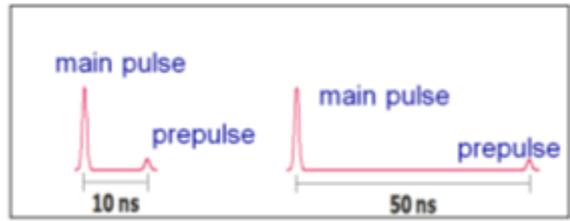
wavelength →

Ne-like Zn laser @ 21.2nm

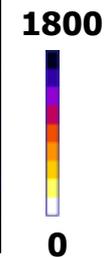
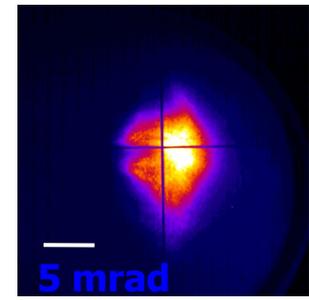


Prepulse: $2 \times 10^{10} \text{ Wcm}^{-2}$
Main pulse: $\sim 4 \times 10^{13} \text{ Wcm}^{-2}$

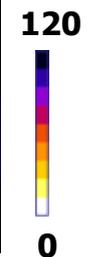
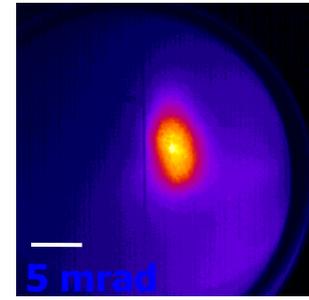
	Prepulse delay	
	10 ns	50 ns
XRL pulse energy	4 mJ	10 mJ
Pulse duration	100-120 ps	
Peak power	40 MW	80 MW
Photons per pulse	3×10^{14}	1.2×10^{15}



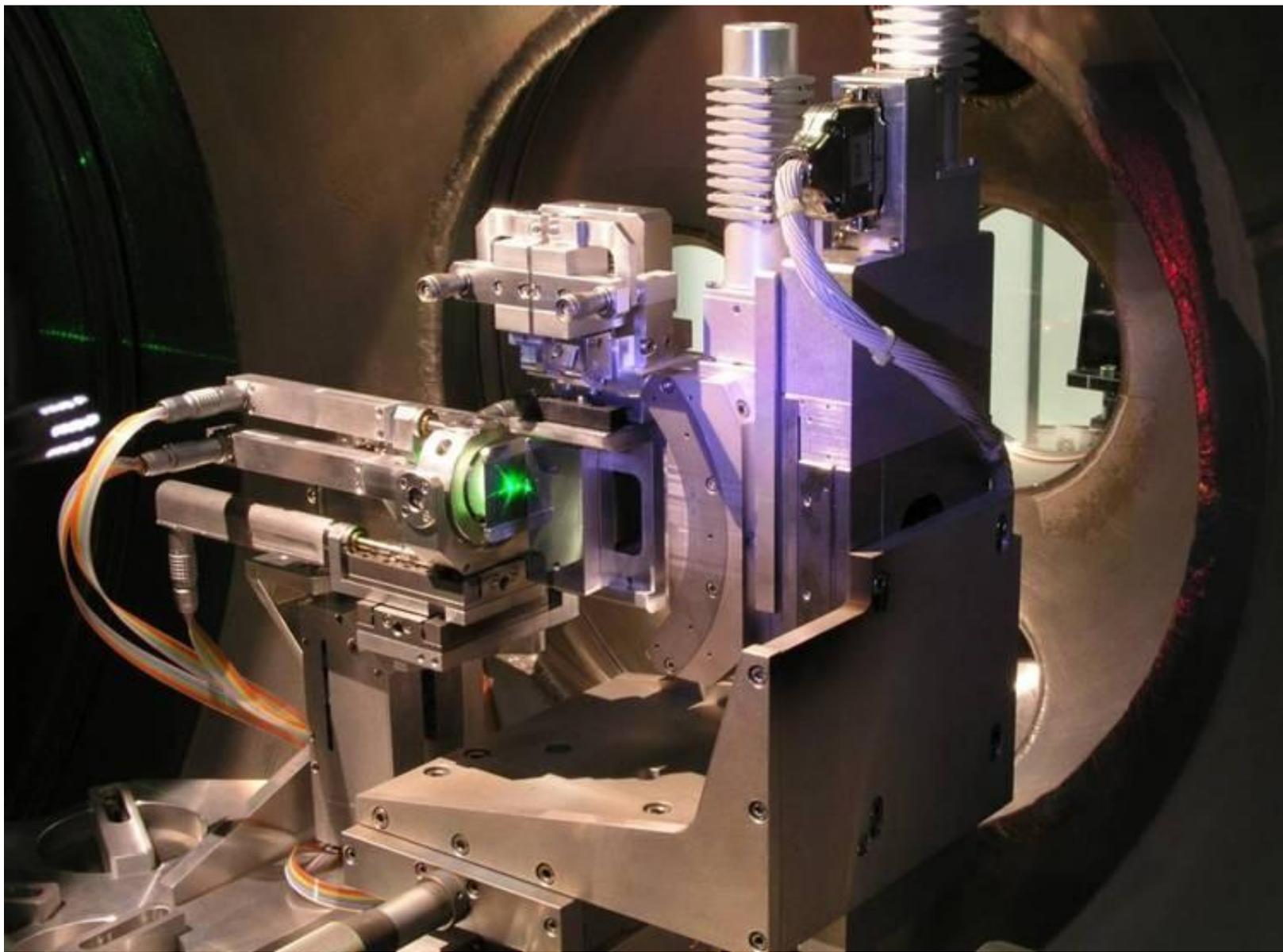
Double-pass beam



Single-pass beam

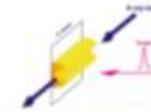
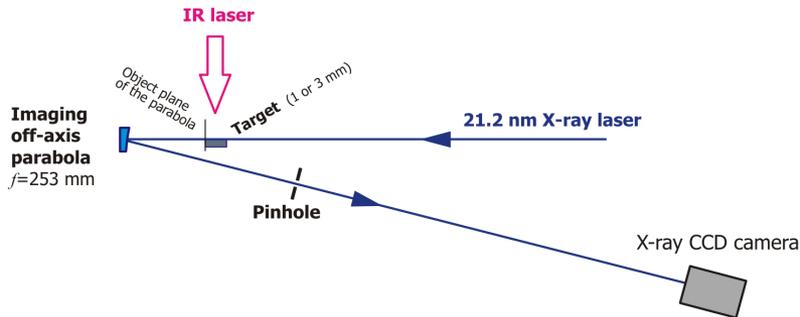


Ne-like Zn laser @ 21.2nm

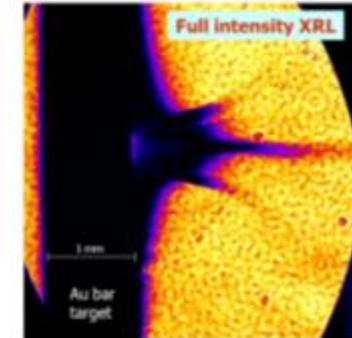
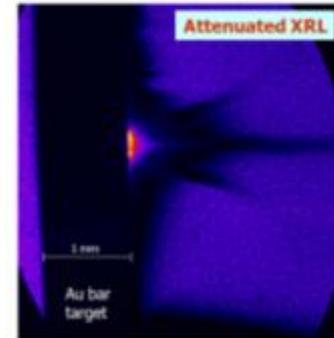


Application experiments at PALS Center with Ne-like zinc XRL beam

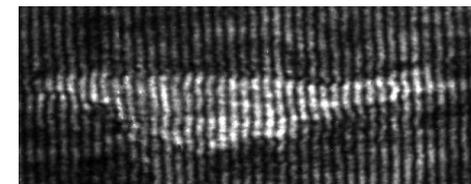
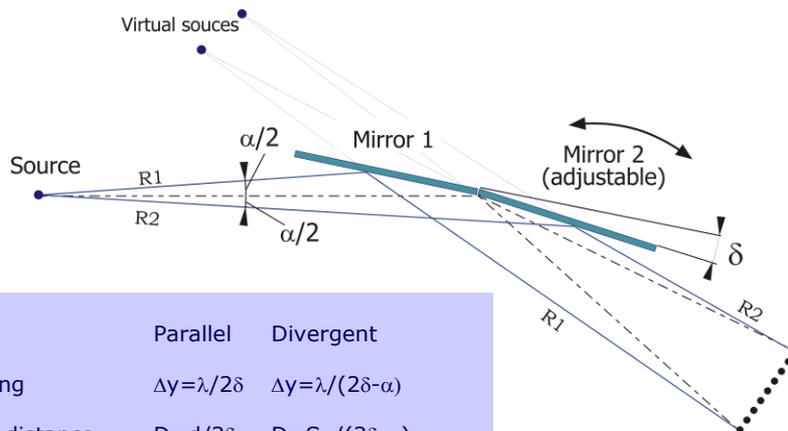
- Backlighting of linear plasmas**
 collaboration with M.Fajardo, J. Davies (IST, Portugal)



$I_{1.2\mu m} = 4 \times 10^{13} \text{ Wcm}^{-2}$, 250 μm peak-to-peak modulation
 XRL probe injected 16 ns after the IR pulse



- Wave-front division interferometry**
 - Double Lloyd's mirror**

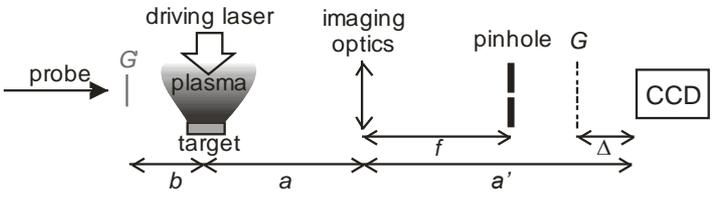
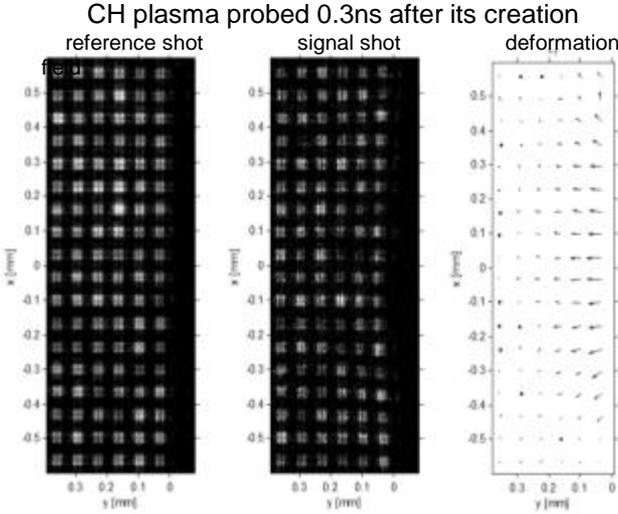


	Parallel	Divergent
Fringe spacing	$\Delta y = \lambda / 2\delta$	$\Delta y = \lambda / (2\delta - \alpha)$
Intersection distance	$D = d / 2\delta$	$D = S\alpha / (2\delta - \alpha)$

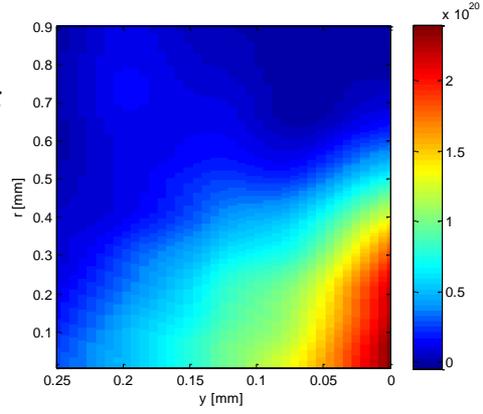
Dense-plasma probed by 21-nm beam

Deflectometry

collaboration with J. Davies (IST), D. Batani (Uni. Bicocca)

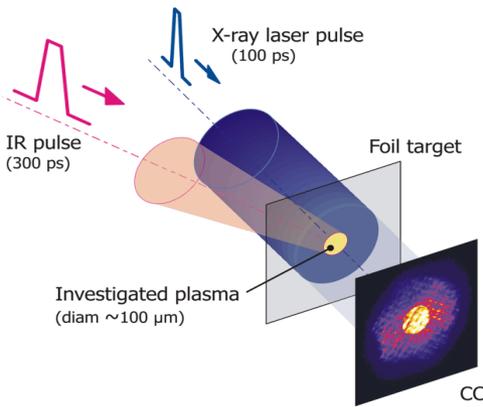


$$n(r,y) = 1 - \frac{1}{\pi} \int_r^{r_m} \frac{\phi_x(x,y)}{\sqrt{x^2 - r^2}} dx$$



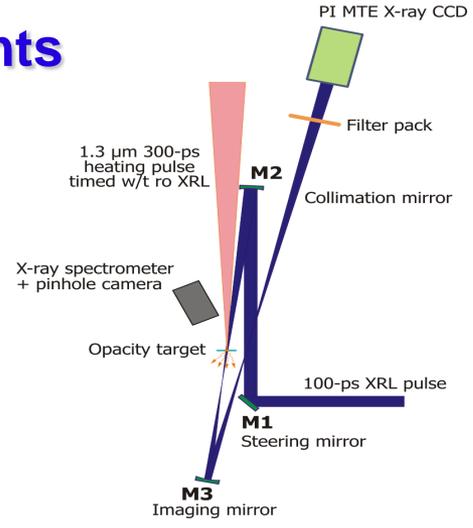
Opacity and ablation rate measurements

collaboration with G.Tallents (University of York)



$$T = e^{-\sigma \rho (L - \Delta L)}$$

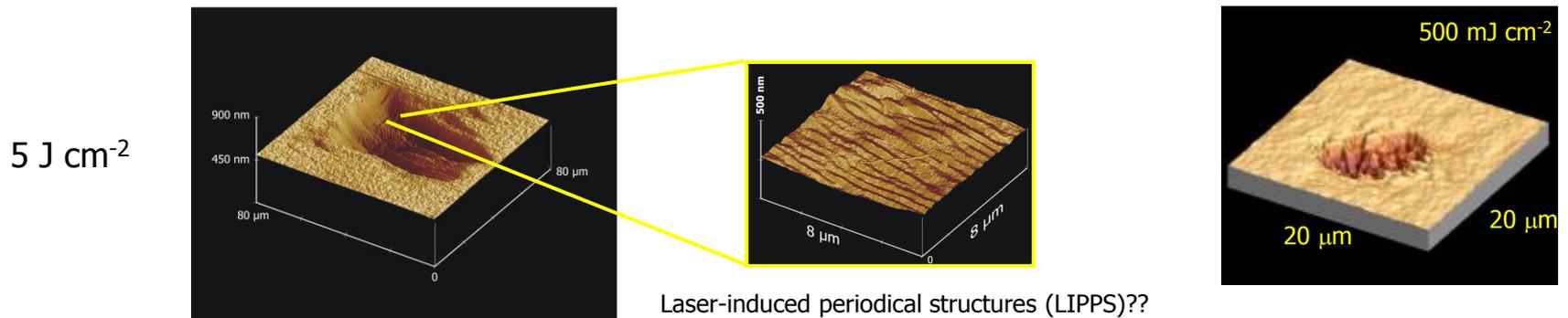
σ ... opacity of the unablated material
 ρ ... solid density
 L ... initial thickness
 ΔL ... depth of material ablated



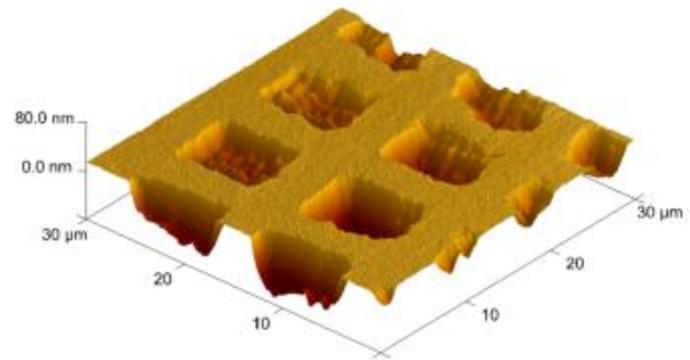
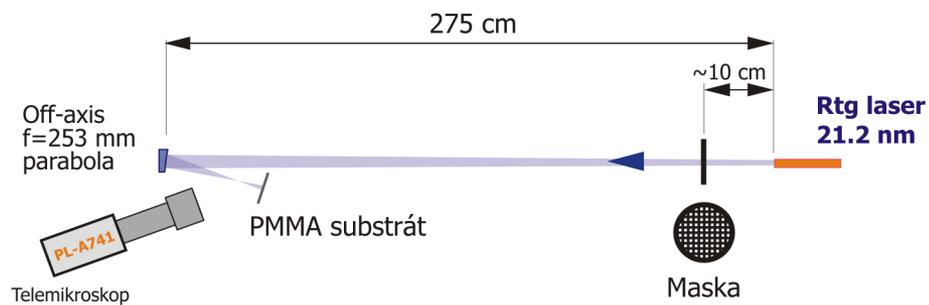
Single shot ablation and micro-structuring

- Ablation of PMMA**
collaboration with L. Juha's group (IoP AS CR)

Ablation depth and fine structure of PMMA as function of soft X-ray intensity



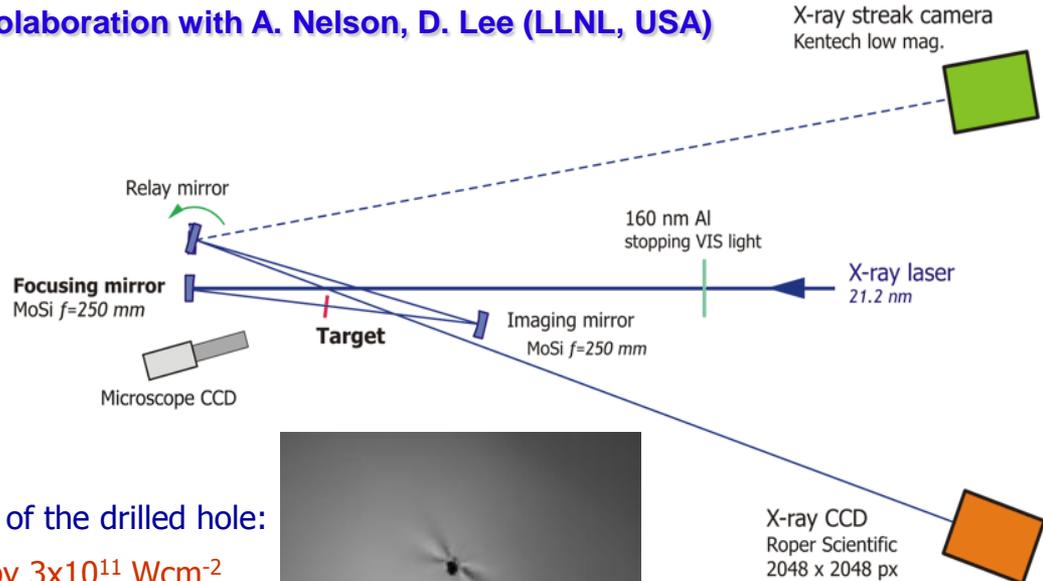
- Micro-structuring**
 - Demagnification of the mask to PMMA**



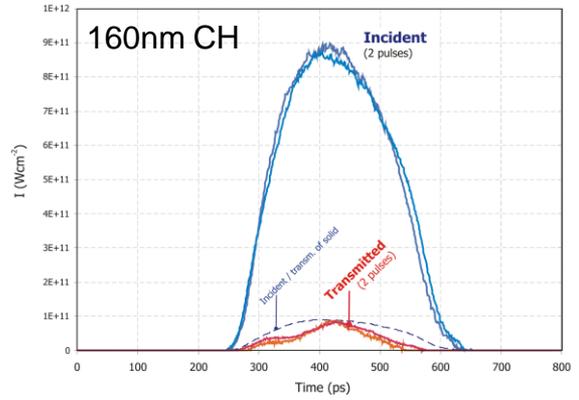
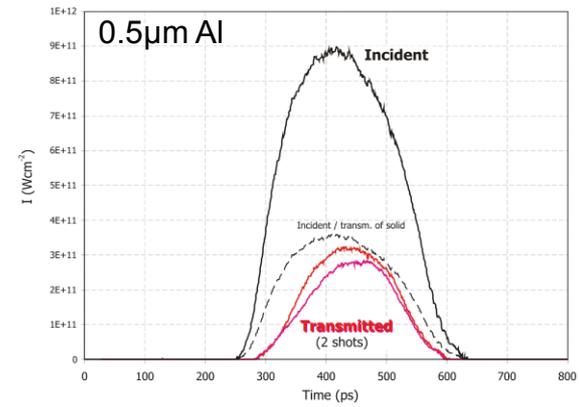
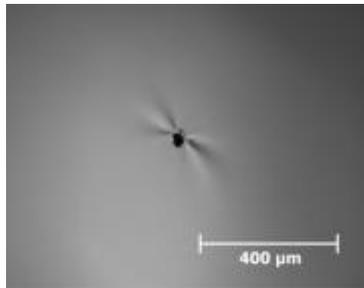
10x demagnification of mask with period 100 μm

Warm dense matter studies

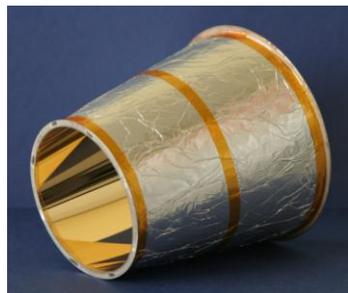
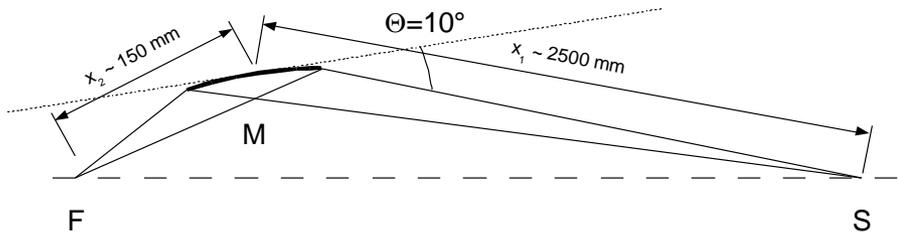
- Volumetric heating of thin foils by 21.2nm XRL beam** 10^{12} Wcm^{-2} peak intensity
 collaboration with A. Nelson, D. Lee (LLNL, USA)



Typical image of the drilled hole:
 Al irradiated by $3 \times 10^{11} \text{ Wcm}^{-2}$



New focusing optics: elliptical grazing incidence mirror



10^{13} Wcm^{-2} peak intensity

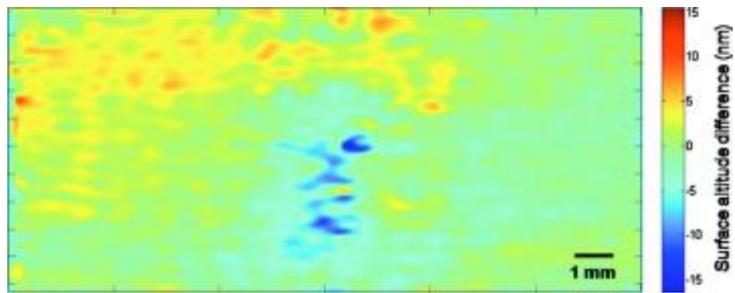
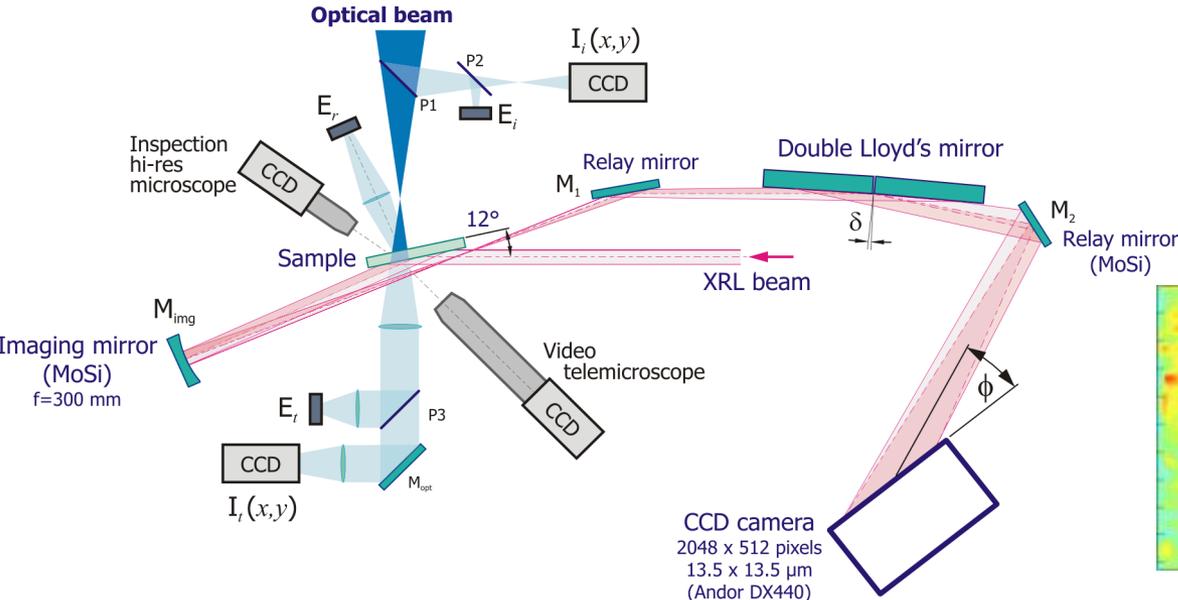
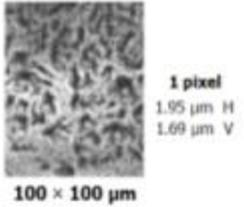
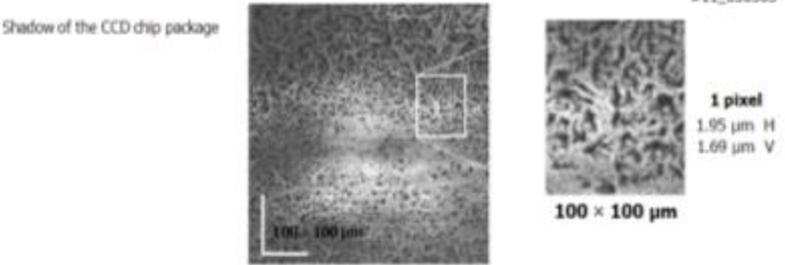
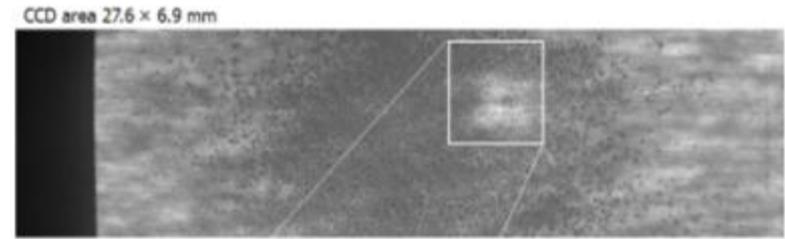
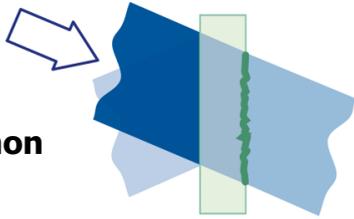
Optical damage studies using XRL interferometric microscopy

collaboration with G. Jamelot's group (LIXAM, France) and C. Danson (CRL RAL, UK)

LID is most often observed to occur on the rear surface of the beamsplitter

Not really understood phenomenon

Need for diagnostic technique able to distinguish damage occurring at the very surface from that below the surface



Experimental astrophysics: Radiative shocks

collaboration with Ch. Stehlé (LERMA, Observatoire de Paris, France)

- There is a transformation of scales that keeps hydrodynamic equations (Euler's equations) invariant

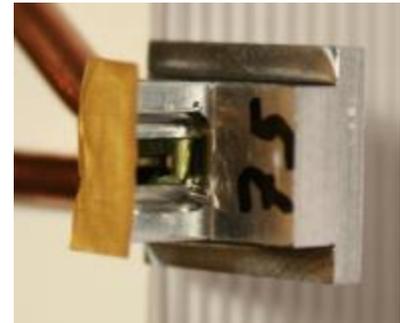
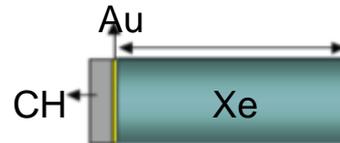
$$r = ar_{lab} \quad \rho = b\rho_{lab} \quad p = cp_{lab}$$

$$t = a\sqrt{b/c} t_{lab} \quad v = \sqrt{c/b} v_{lab}$$

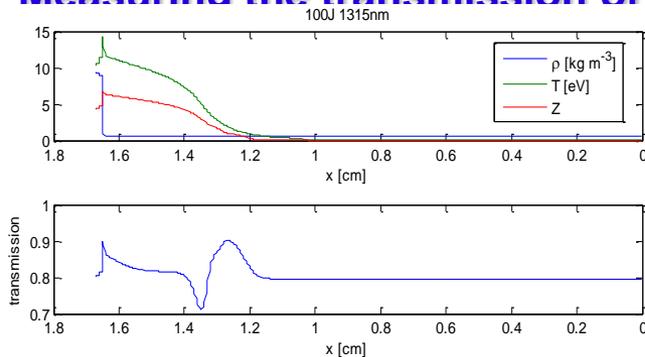
Not valid for radiation transport, EOS → Rad. Shocks not directly scalable

Experiment 2010:

- gas cell with 150nm SiN₄ windows filled with 0.1-0.5bar Xe



- Strong 1D shock with radiative precursor
→ different ionization states along the cell + expected higher absorption of Xe⁺³
- Measuring the transmission of 21.2nm radiation



More in the talk of Ch. Stehlé

DNA damage by soft X-ray radiation

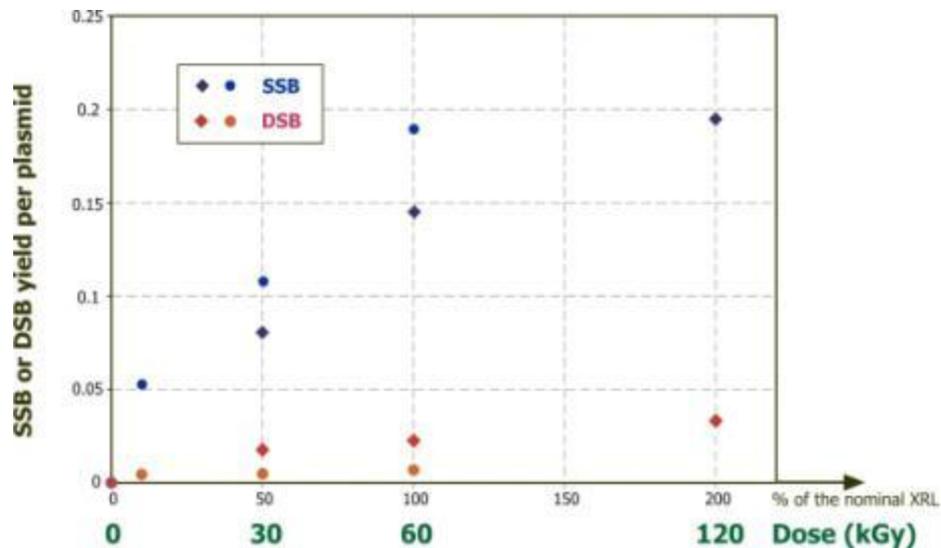
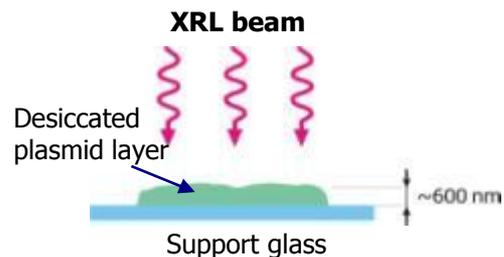
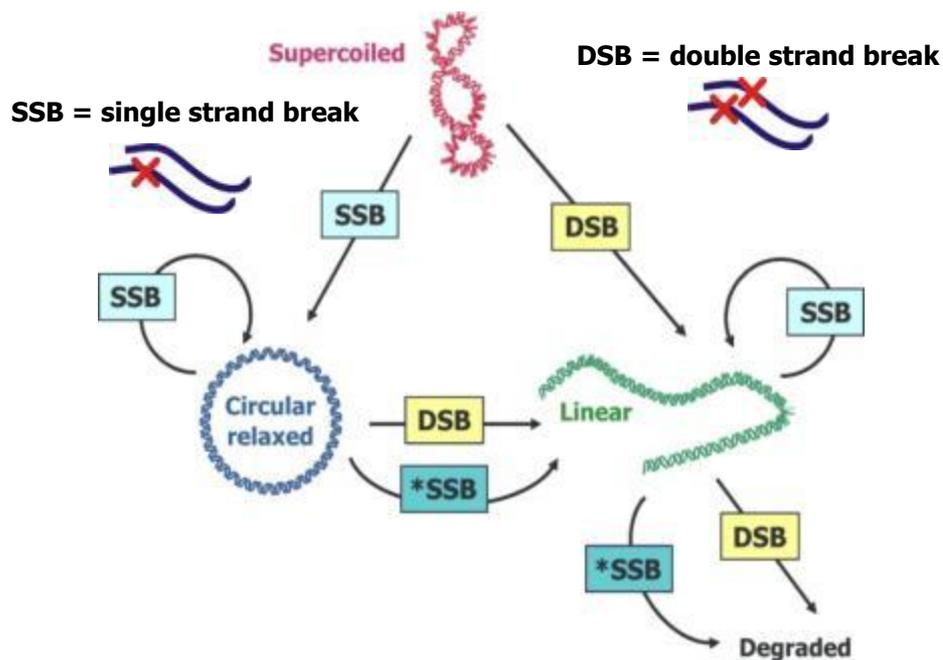
collaboration with M. Davidkova (Nuclear Phys. Inst.), E. Sage (Inst. Curie), D. Ros, (LIXAM)

- **First ever DNA damage experiments >10 eV returning relevant data**

Why XRL ?

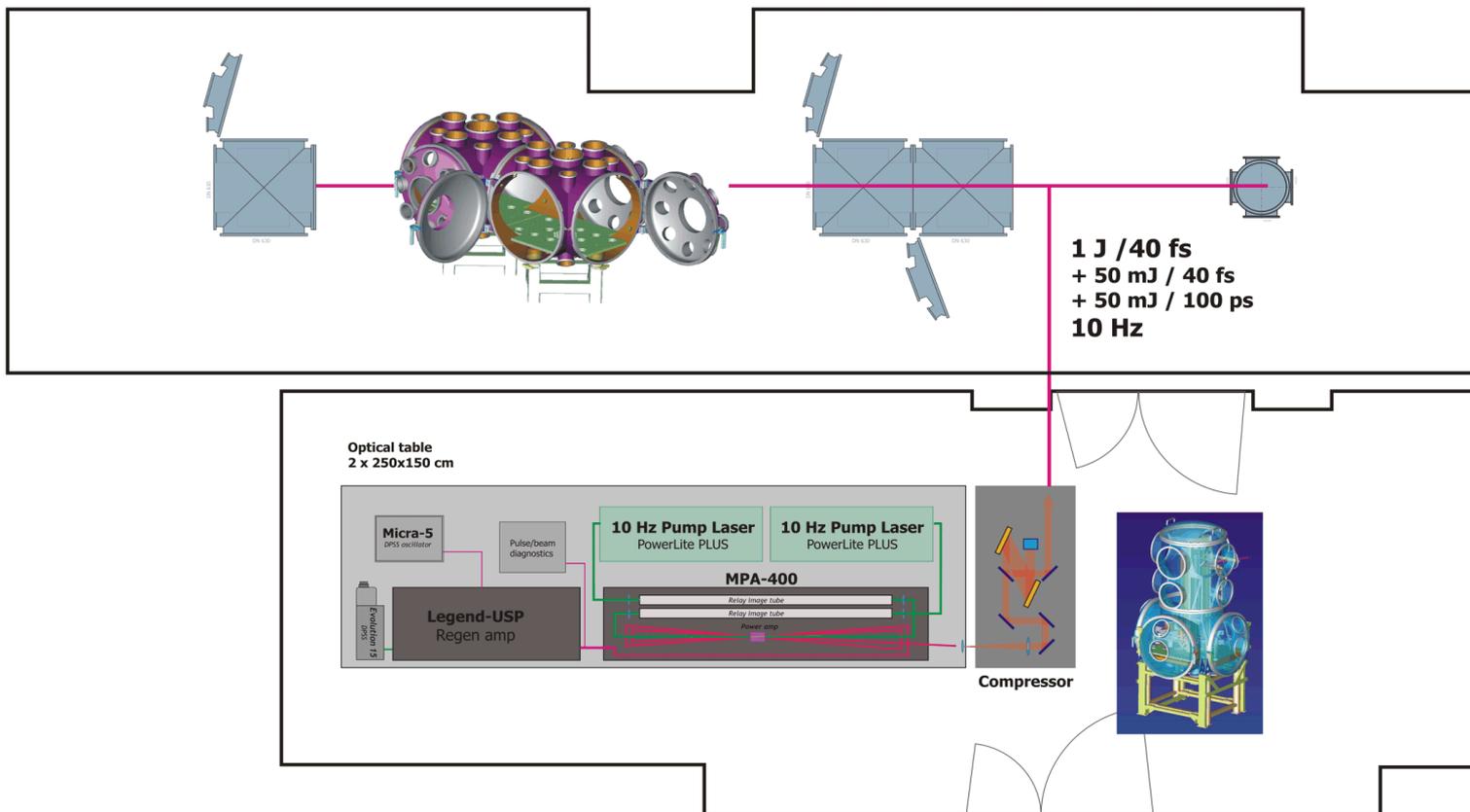
→ Synchrotron radiation inapplicable due to prohibitively long exposure times

Plasmid: extrachromosomal form of DNA



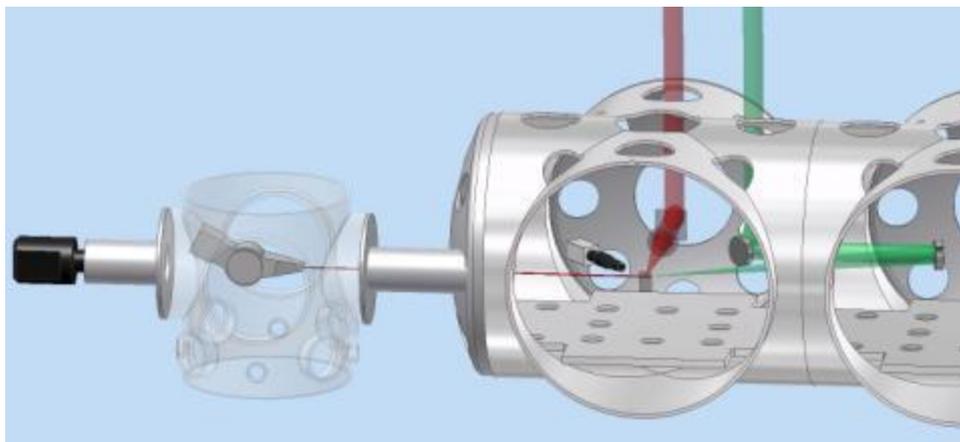
Future prospects on XRL activities at PALS

- **25TW Ti:Sapphire laser (10Hz)**
 - 900mJ / 42fs
 - Synchronized with the kJ laser



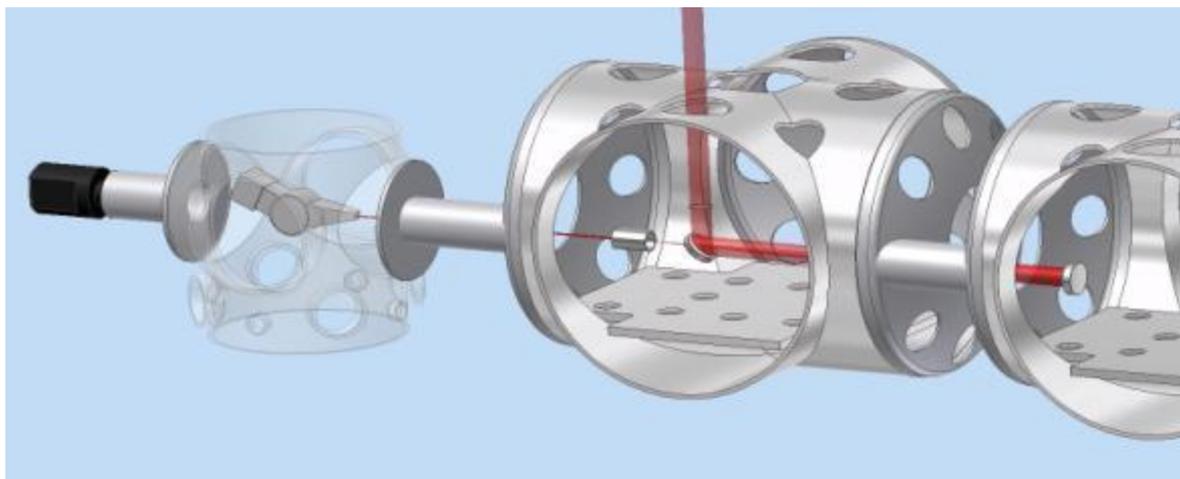
Availability from late 2010, including new target room

- **25TW Ti:Sapphire laser (10Hz)**
 - **transient XRL's:**
 - **slab targets: Grazing incidence pumping (GRIP)**



- **Ne-like Ti (32.6nm)**
- **Ni-like Mo (18.9nm)**
- **Ni-like Ag (13.9nm)**

- **gaseous targets: Optical field ionization (OFI) XRLs**



- **Ni-like Kr (32.8nm)**
- **Pd-like Xe (41.8nm)**

- **25TW Ti:Sapphire laser (10Hz)**
 - **XRL's seeded by high-order harmonics**

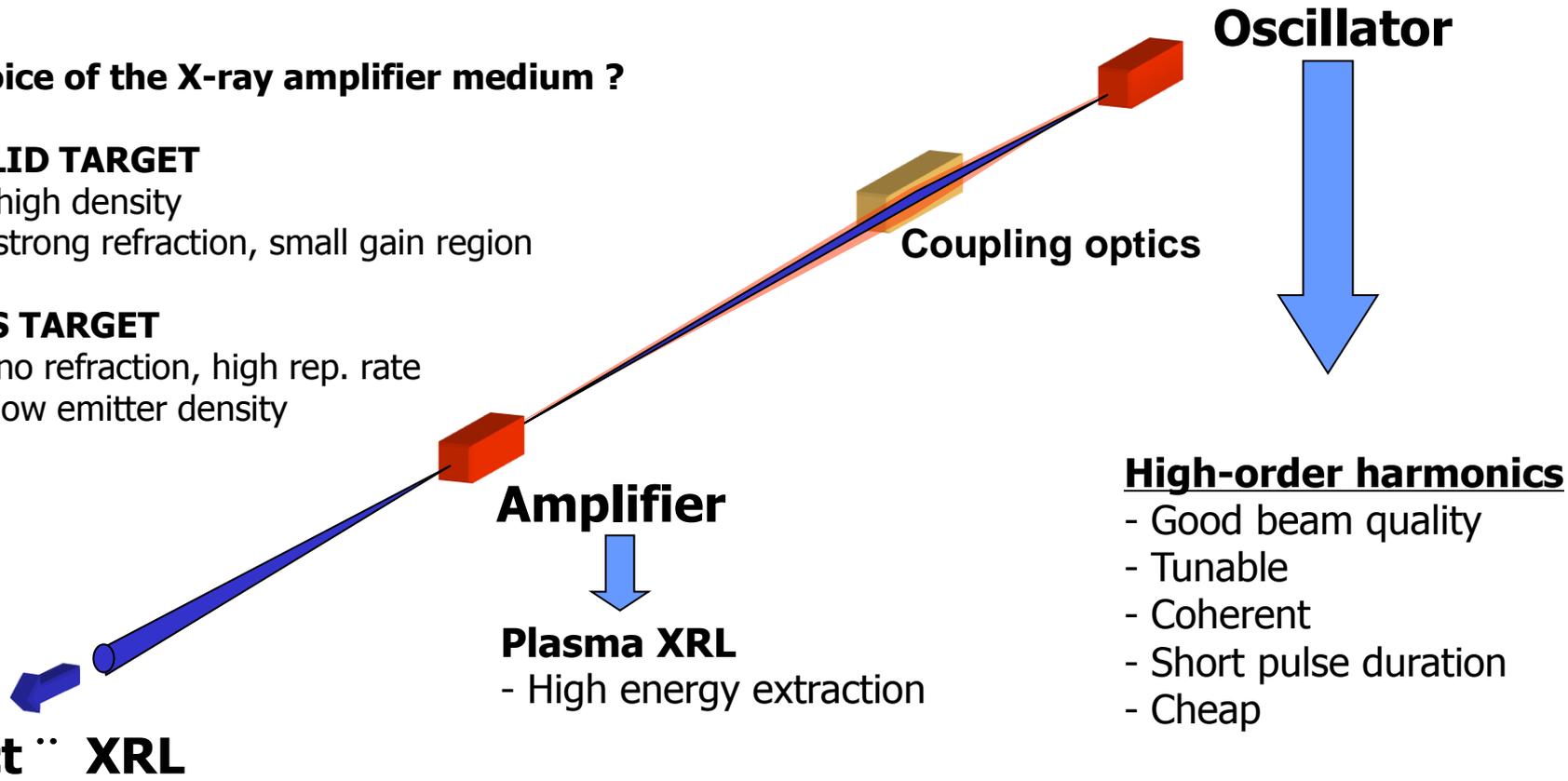
Choice of the X-ray amplifier medium ?

SOLID TARGET

- + high density
- strong refraction, small gain region

GAS TARGET

- + no refraction, high rep. rate
- low emitter density



- Farther future

- After the synchronization of the two system (jitter ~10ps)

→ Amplification of HHG beam by the kJ-plasma amplifier

→ multi-mJ fourier limited XRL beam with high degree of spatial coherence

