The Atomic, Molecular & Plasma Physics Group
University College Dublin
Speclab

Soft X-ray Source for high speed soft x-ray tomography of cryo-frozen cells

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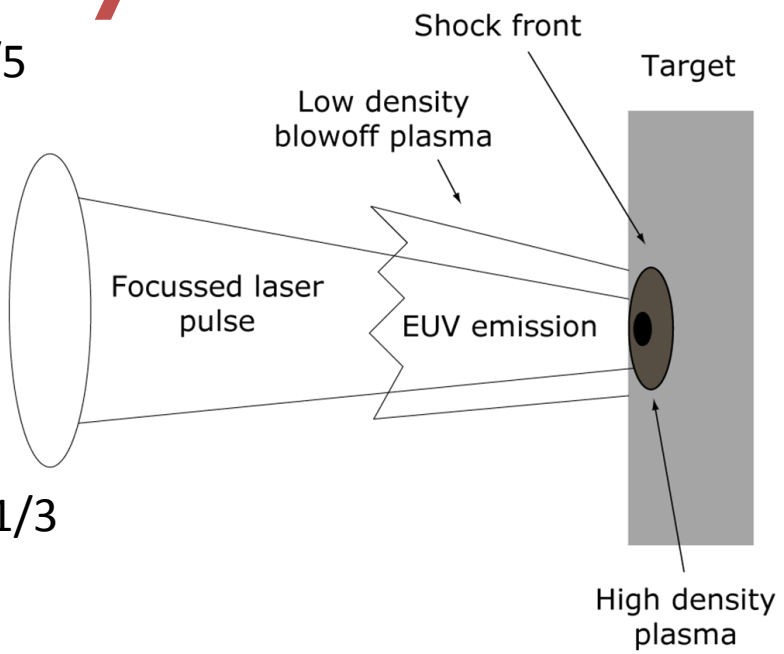
Laser Plasmas & Soft X-rays

$T_e(eV) \approx (\lambda^2\ PowerDensity)^{3/5}$

(Columbant & Tonan, JAP 44 1973)



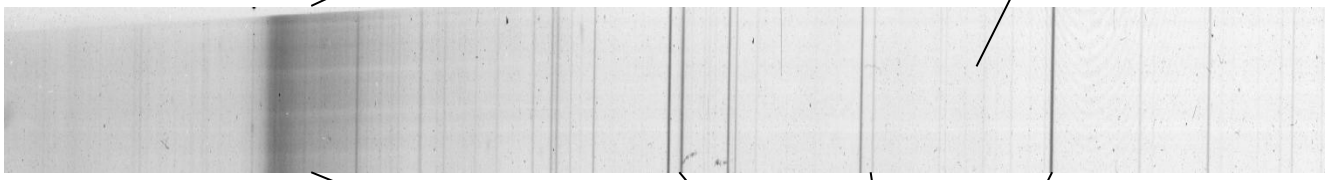
Average charge $\approx 0.67\ (AT_e)^{1/3}$

$n_e \sim 10^{19} - 10^{21}\ cm^{-3}\ (n_{ec} \sim 10^{21}/\lambda^2\ cm^{-3})$

Expansion velocity $\approx 10 - 100\ \mu m/ns$

$(\approx 10^6 - 10^7\ cm/s)$

Soft X-ray/EUV Spectrum

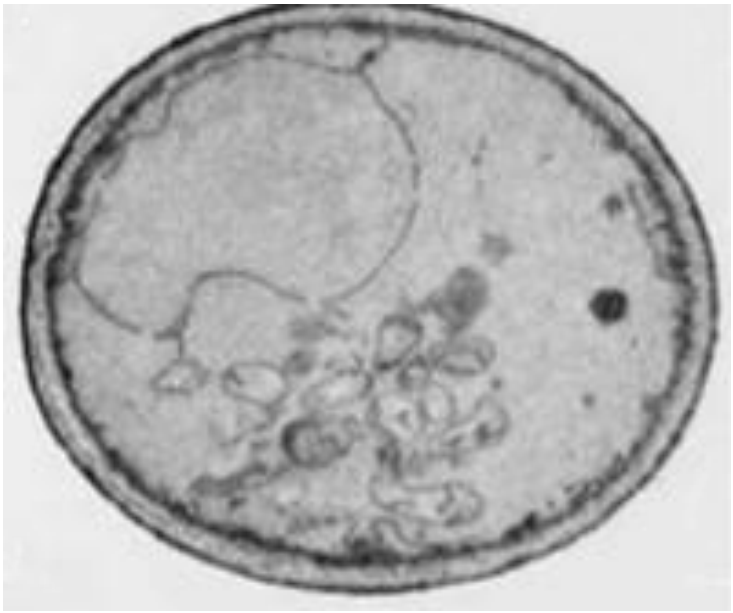


For an optically thin plasma:

$P_{lines}:P_{recomb}:P_{brem} = 100:10:1$

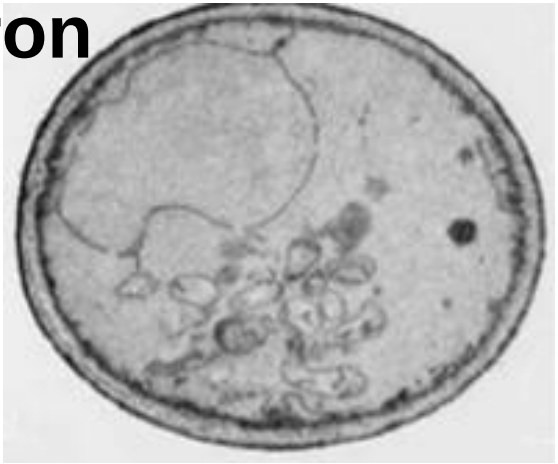
Biologists Requirements

Cell Diameter ~ 10 µm
Organelle size < 200 nm

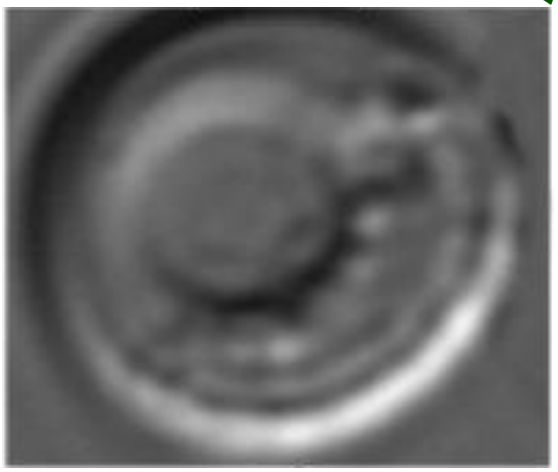


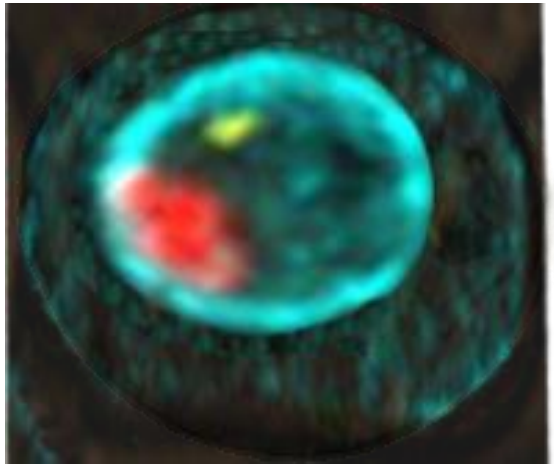
Different Microscopies

Electron

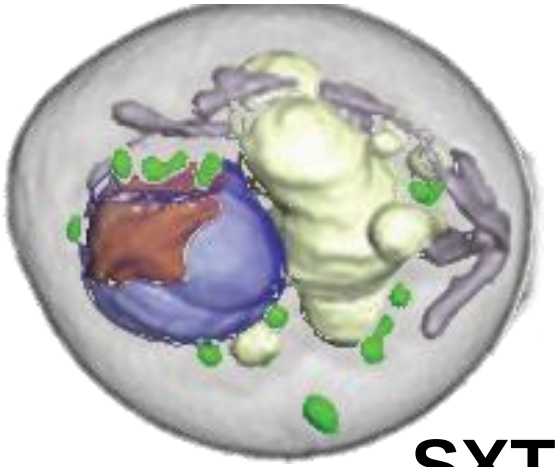


Visible





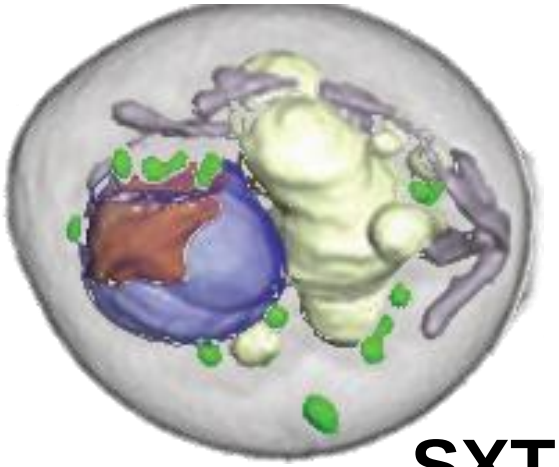
Fluorescence



SXT

Different Microscopies

Samples near native state - frozen
Unstained samples
Thick samples
High Resolution
3D
Fast



SXT

Annu. Rev. Phys. Chem. 2012. 63:225–39

Only at SynchrotronsToday

Huge Cost

Limited Access

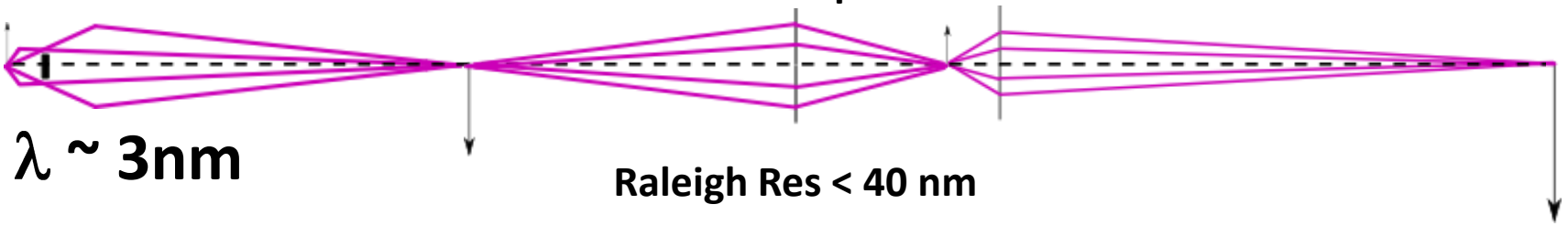
Our Mission: To bring synchrotron techniques to the lab

Microscope Requirements

Nyquist Res < 40 nm

Sample pixel size ~ 15 nm ← **Mag ~ 1000** ← CCD pixel size ~ 15 µm

FOV ~ 15 µm ← CCD ~ 1000X1000 Pixels



λ ~ 3nm

Raleigh Res < 40 nm

Objective NA > 0.03 ~ (0.61λ/Resolution)

DOF ~ a few microns

From Etendue Considerations

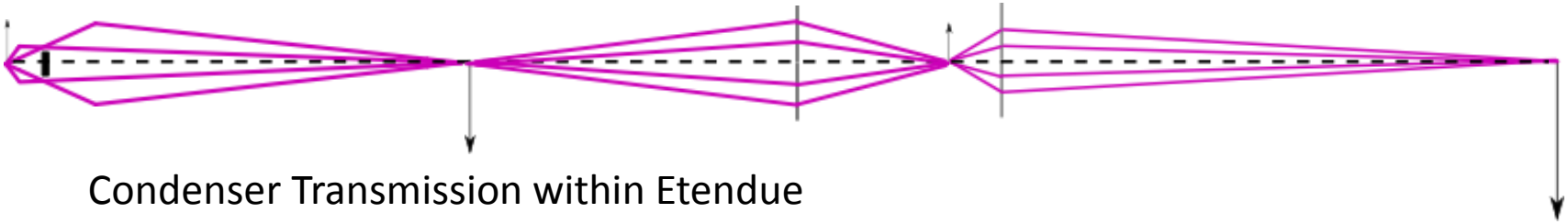
10 µm Source → 0.3% Photons to FOV

400 µm Source → 0.0002% Photons to FOV

100 W into 10 µm Source gives more **usable photons at sample** than 150 kW 400 µm Source

Photon Budget

Need > 5E4 photons/pixel at Sample
Total 5E10 photons in 30% Uniformity



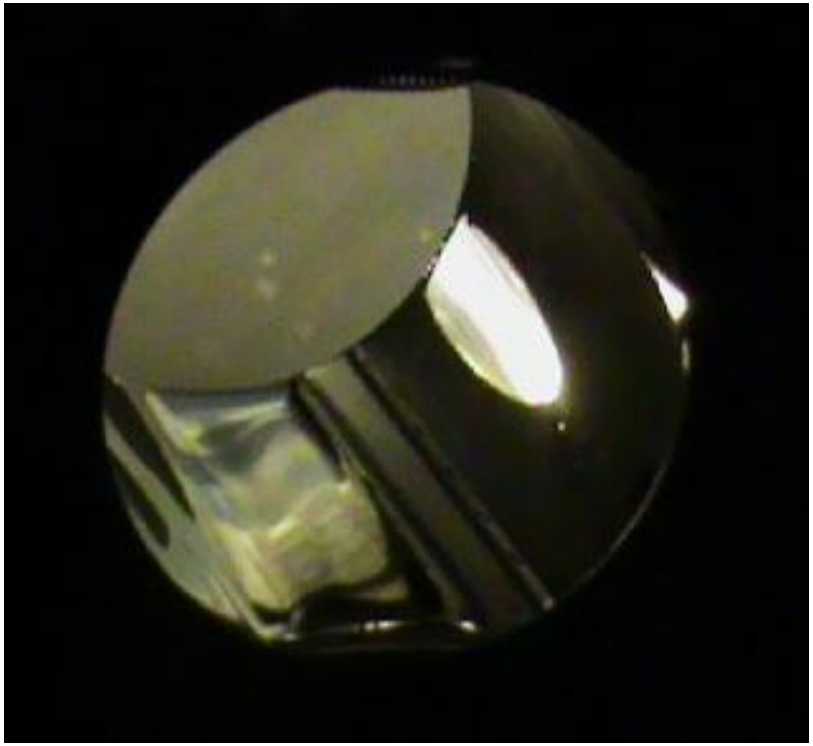
Condenser Transmission within Etendue
~ 0.1% of Total Photons from Source
Total 5E14 Photons/0.2% Bandwidth

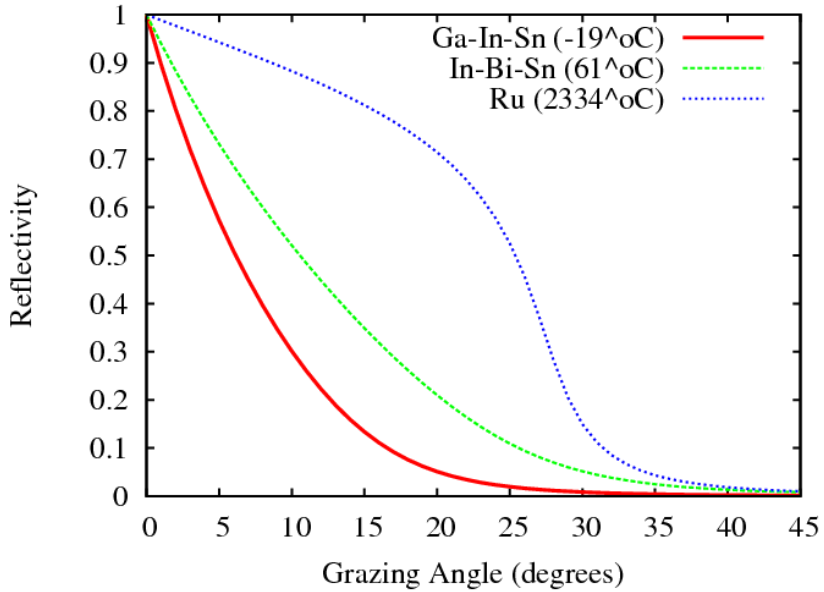
Need > **1000 photons/pixel at CCD**

100W 10µm laser plasma with 0.05% CE will provide these photons in a few seconds

"Compact x-ray microscope for the water window based on a high brightness laser plasma source", Opt Expr. 30, 18362-18369 (2012)

Liquid Metal Coated Soft X-ray Collector Optic



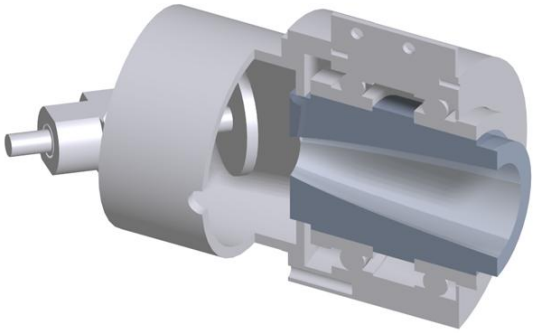


GI Reflectivity at 13.5 nm

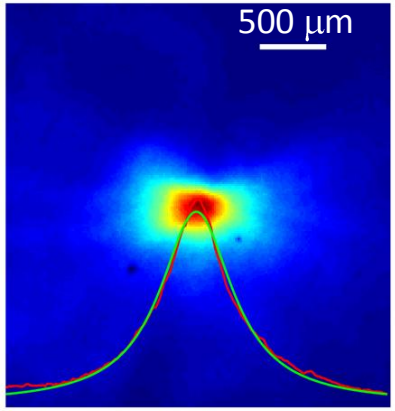
Solves debris problem for output EUV photons

Output After Collector

a)

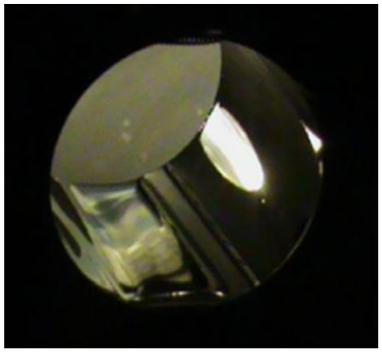


b)

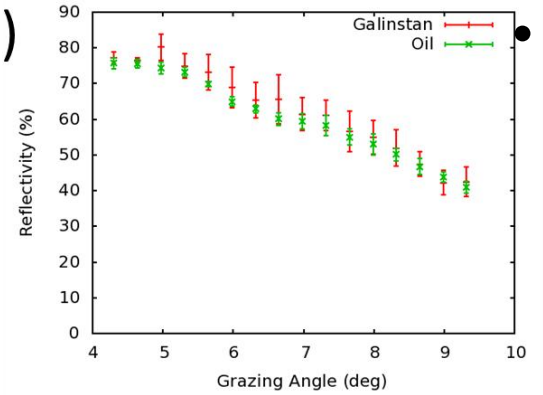


- IF spot size 300 x 600 µm
- Zemax Modeled System

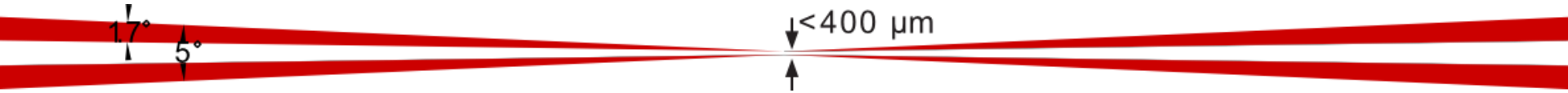
c)



d)

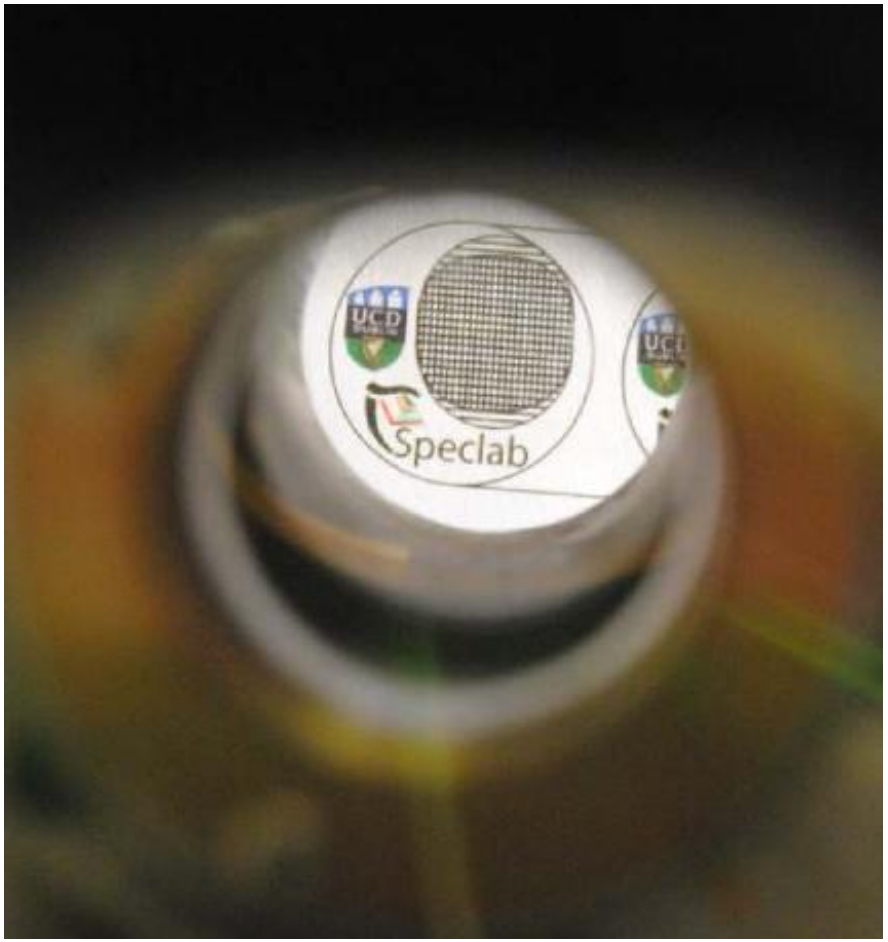


- Output brightness > 30 W/mm²sr



Permanent Clarity Window

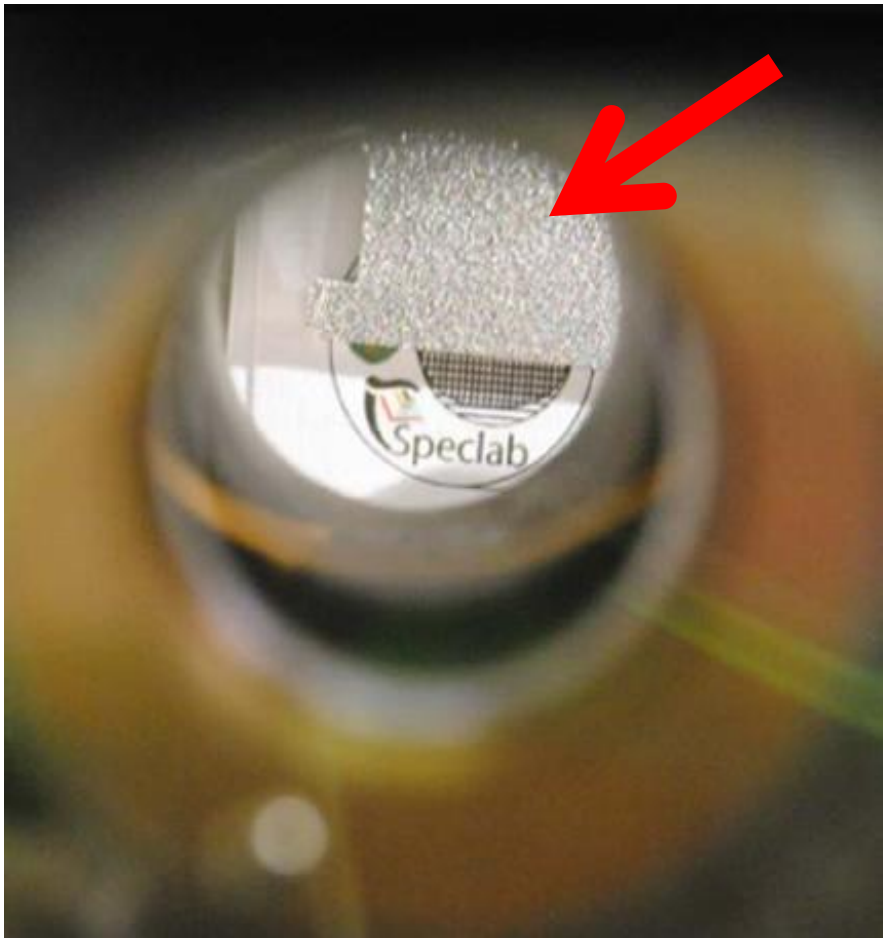
This window was in front of a liquid metal laser plasma for > 50 hours



Solves debris problem for input laser photons

Permanent Clarity Window

This microscope slide was in front of the same plasma for 1 hour

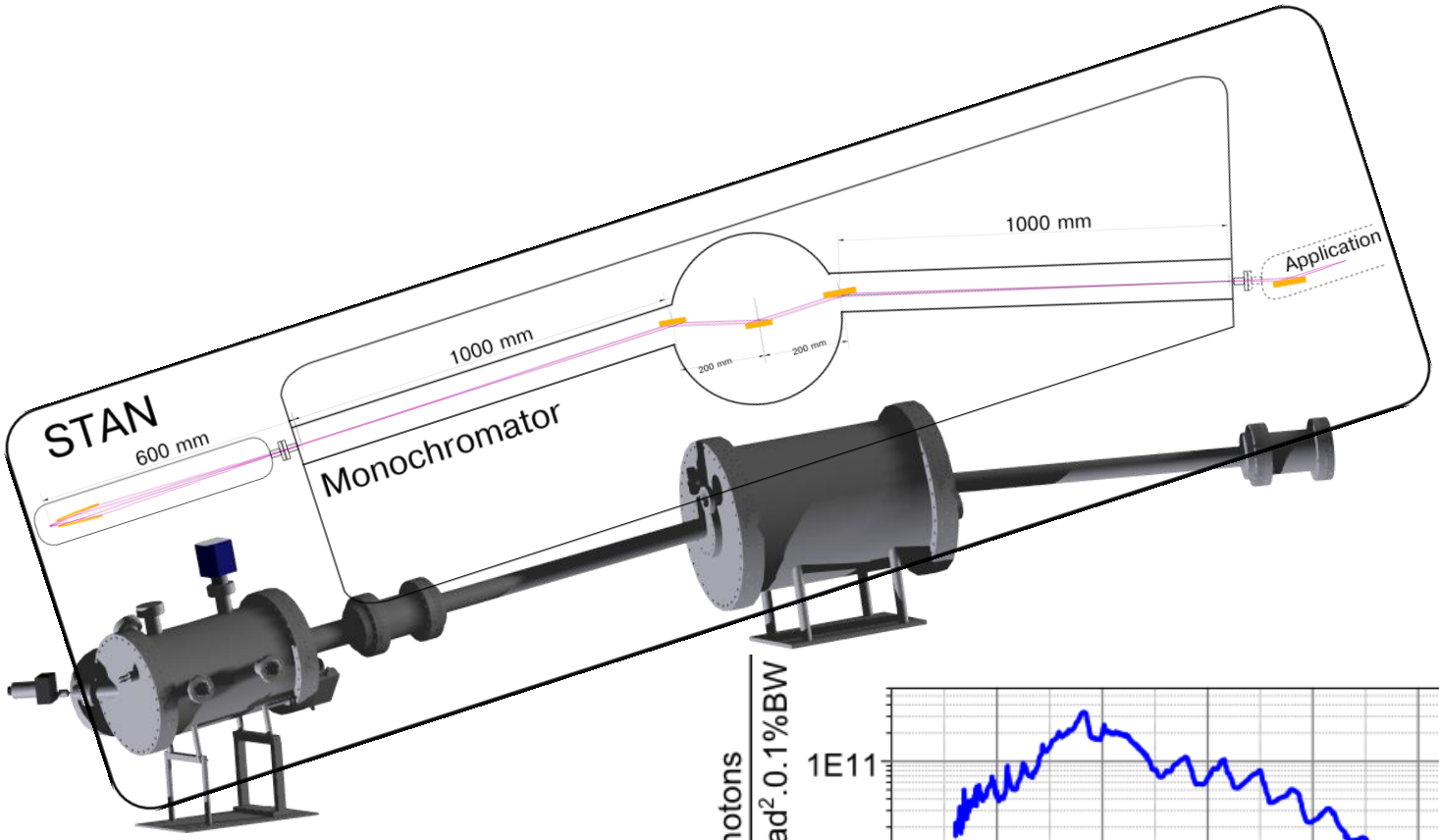


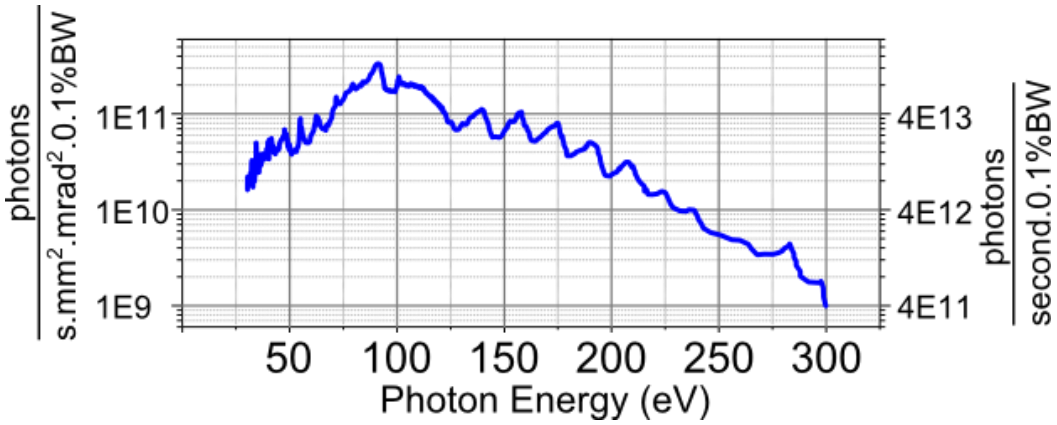
Solves debris problem for input laser photons

EUV Source

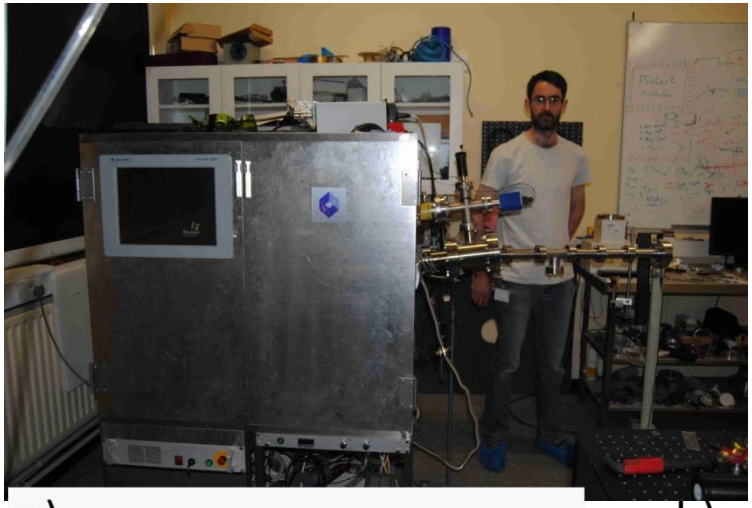
- High Brightness LPP
- Clean Output Photons
- Stand Alone Small Lab-scale Unit
- Affordable

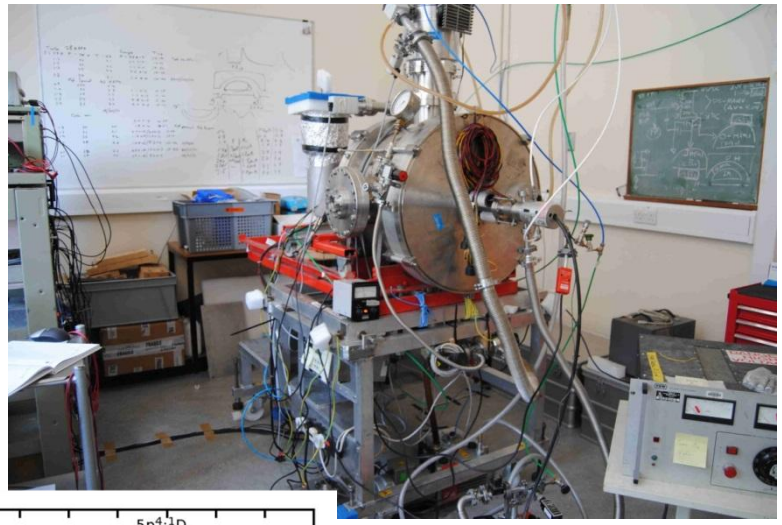
Beamline

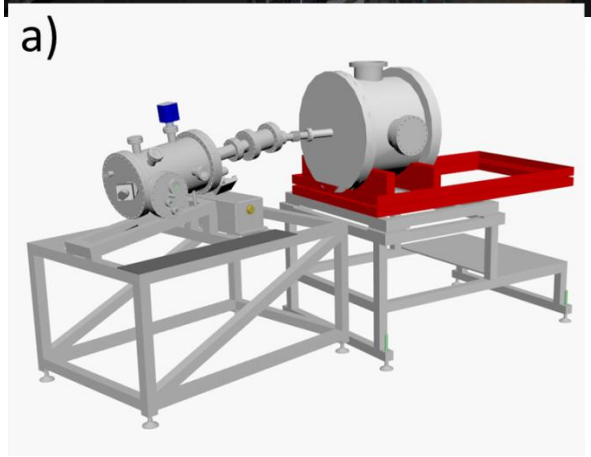

STAN
600 mm
Monochromator
1000 mm
1000 mm
Application
200 mm
200 mm

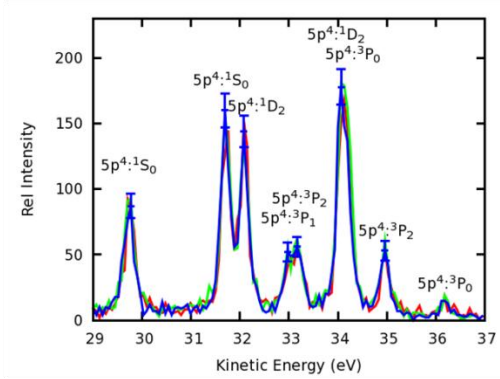

photons
s.mm².mrad².0.1%BW
1E11
1E10
1E9
4E13
4E12
4E11
photons
second.0.1%BW
50
100
150
200
250
300
Photon Energy (eV)

Applications



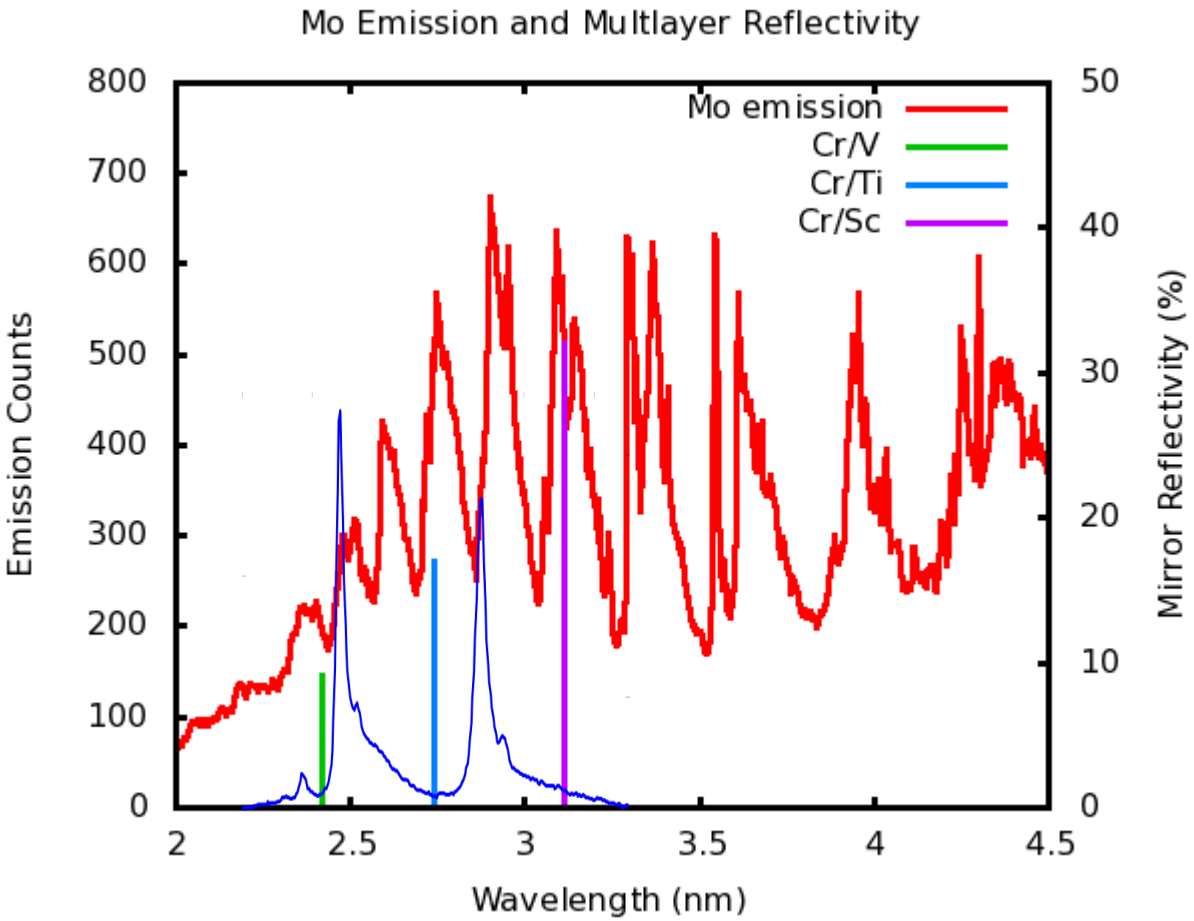




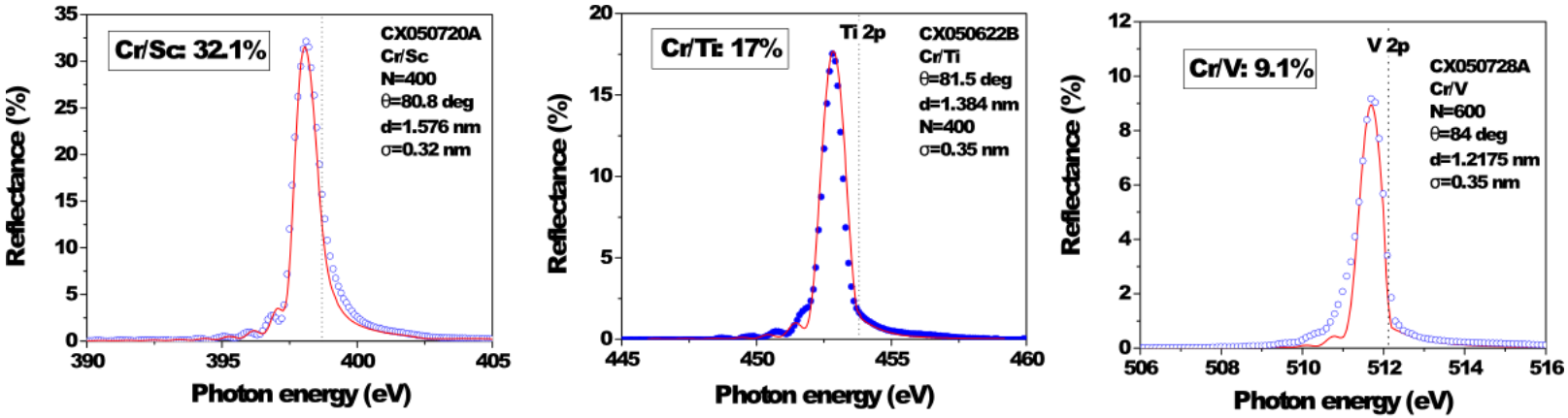


Gas Phase PES 2013/2014

Water Window Sources



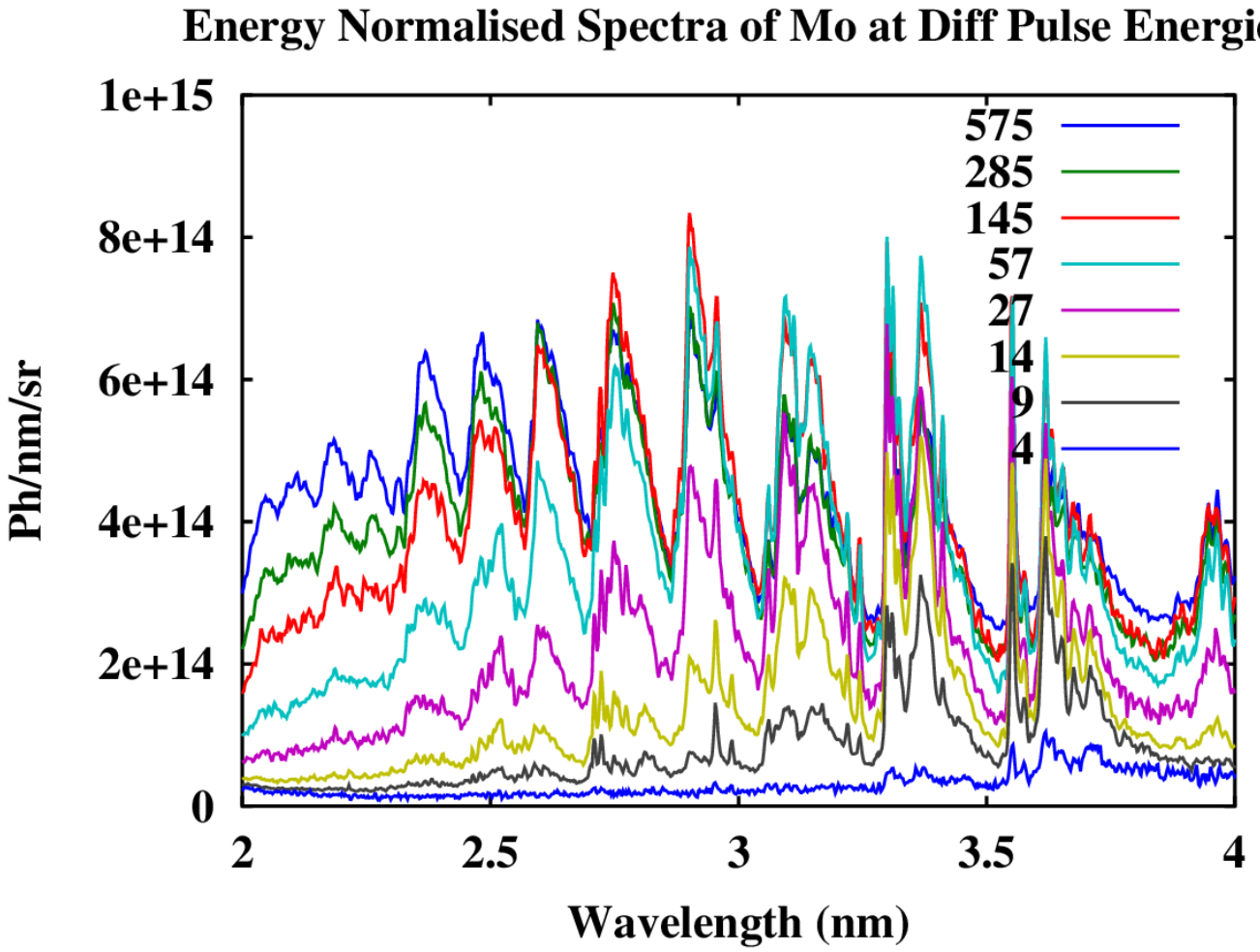
Multilayer Mirrors for bandwidth selection



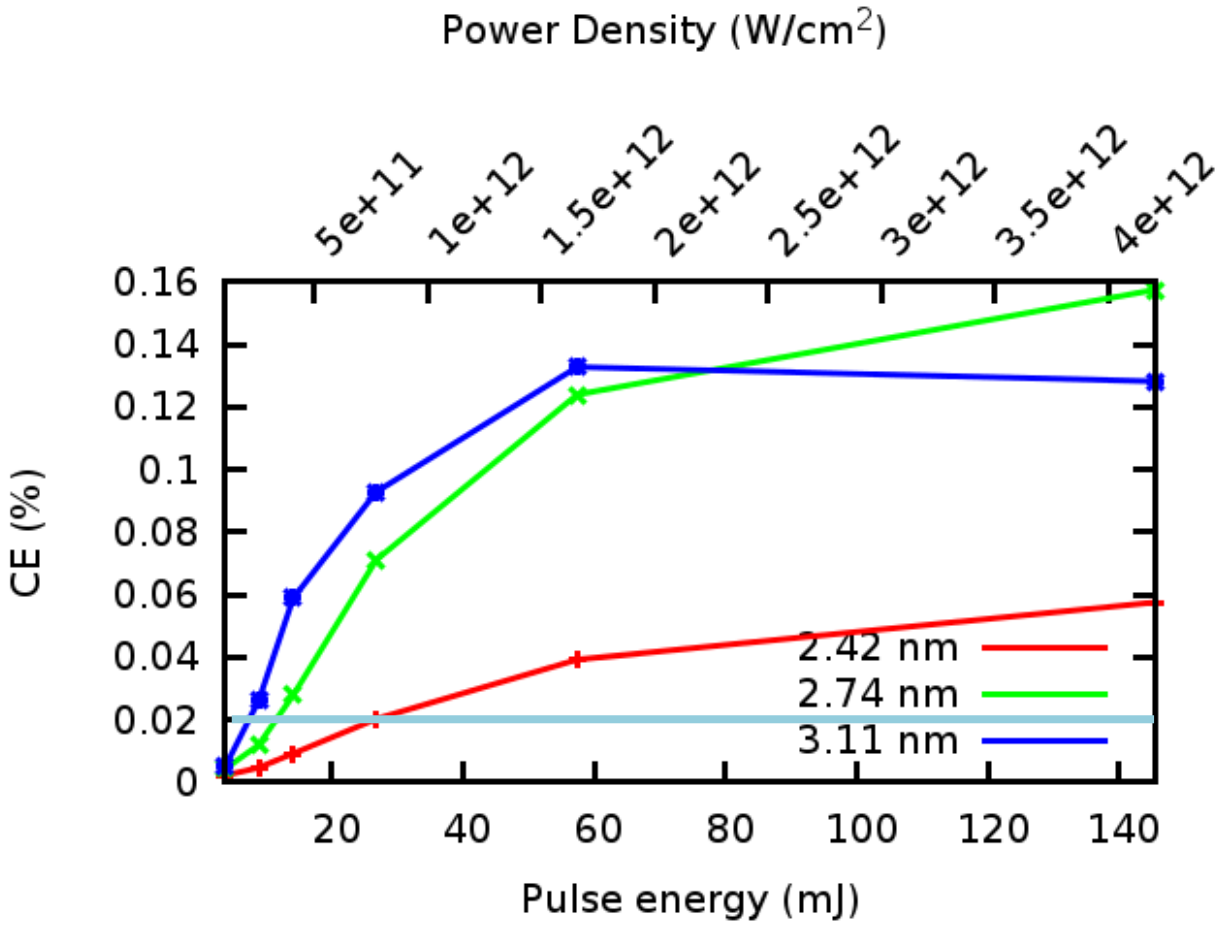
E. Gullikson PXRMS 2006

$\lambda/\Delta\lambda > 500$

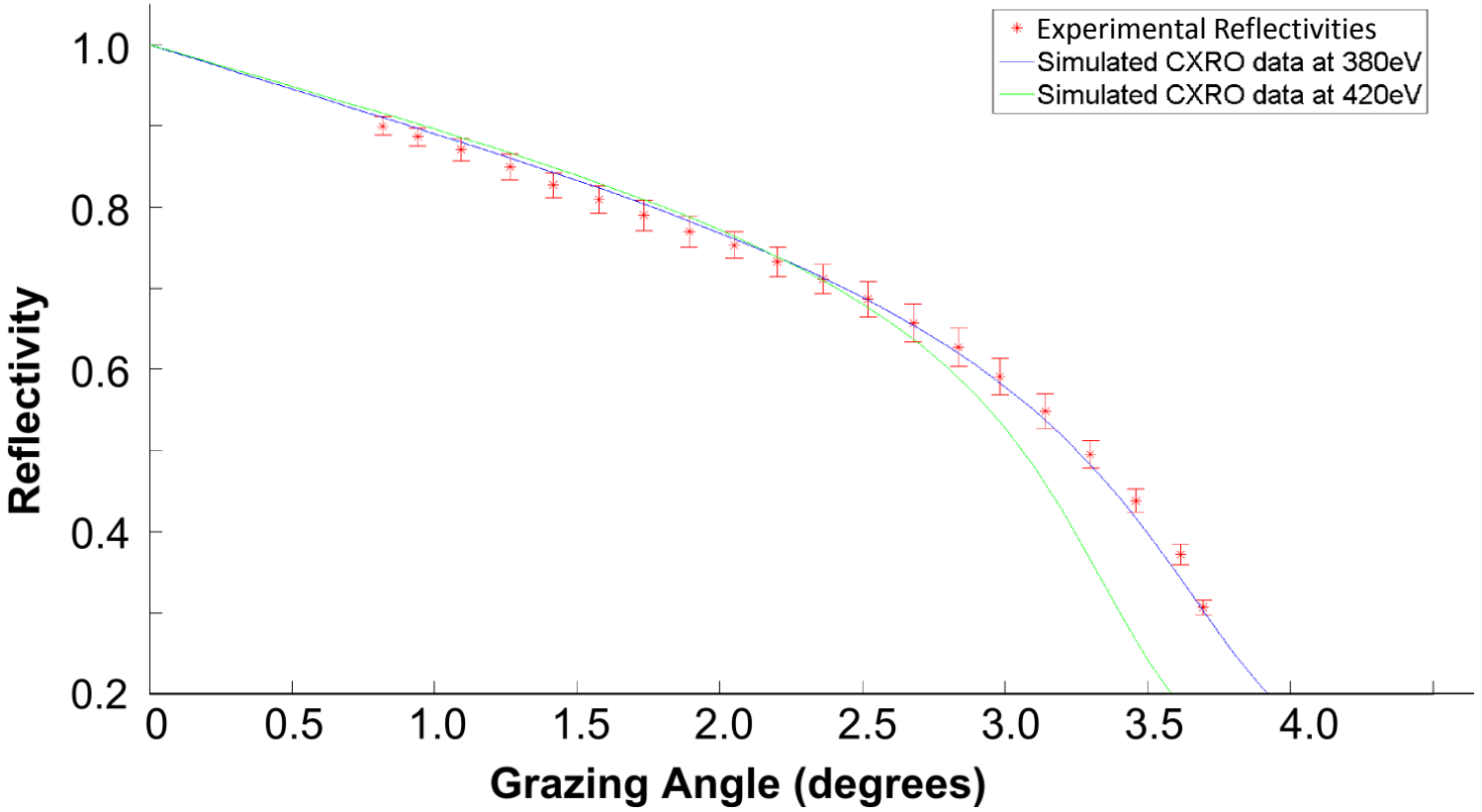
Power Density & Efficiency



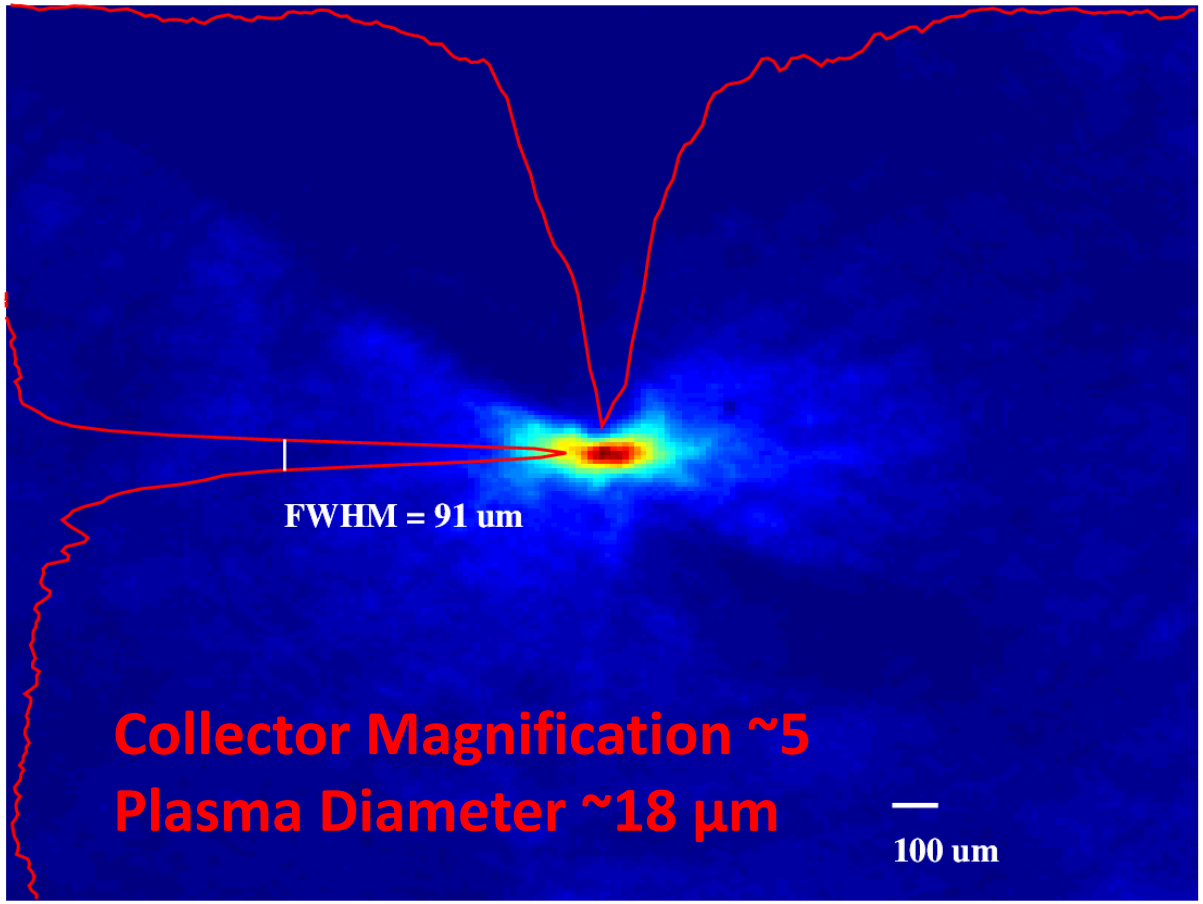
Conversion Efficiency Mo



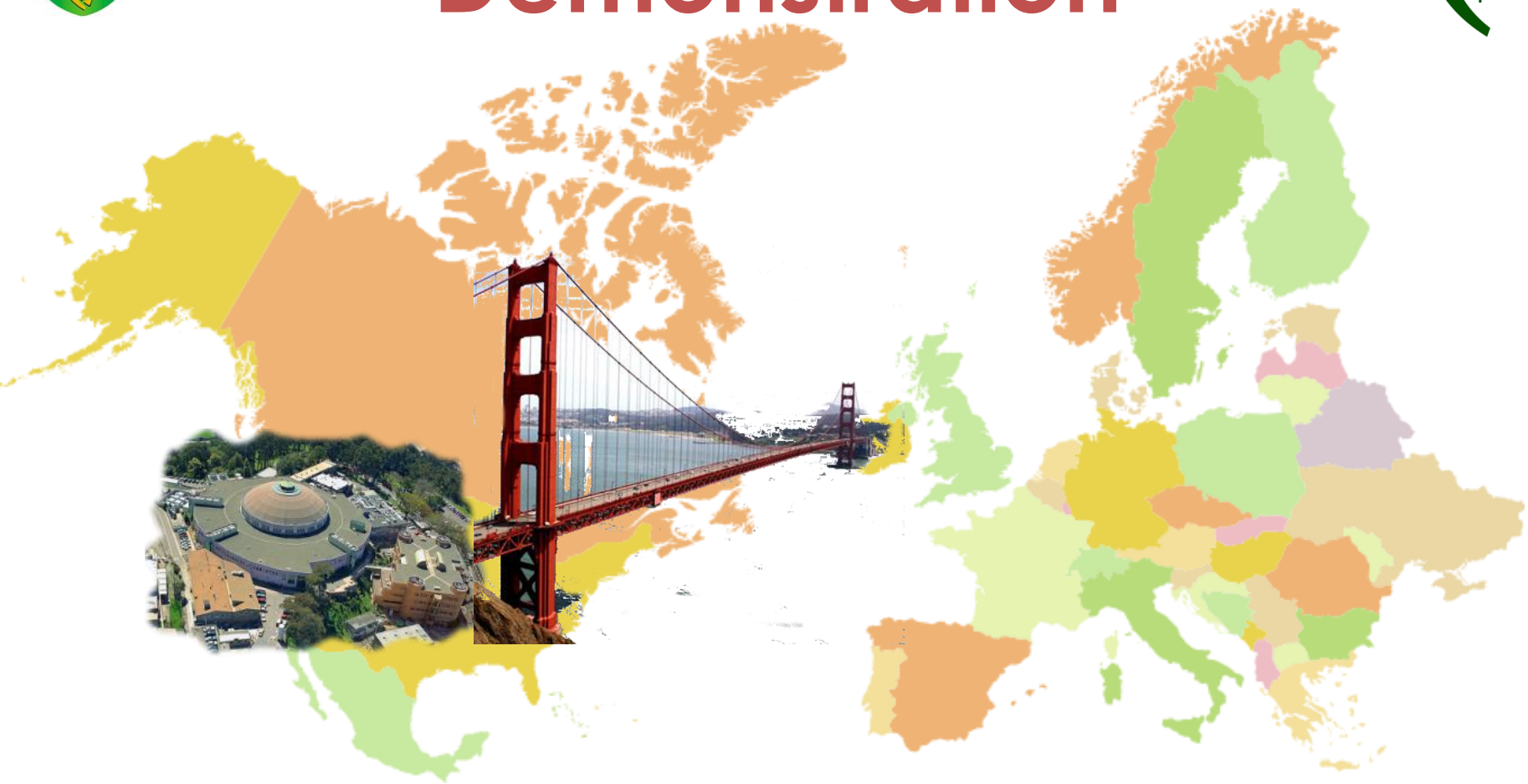
Reflectivity of Liquid in WW



Focused WW Photons



Demonstration



Our Next Step: To bring our lab source to a synchrotron

Acknowledgements

We would like to acknowledge the kind support of Edgewave Lasers GmbH; Regina Soufli, Howard Scott, LLNL;Fredrik Eriksson, Linköping University; Larissa Juschkin, RWTH Aachen; University of Utsunomiya; EUVLitho Inc; Eric Gullikson, LBL; Carolyn Larabell, Mark Le Gros, UCSF;

All in the Spec Group, UCD
and the technical workshop, UCD School of Physics
SFI under PI Research Grant No. 07/IN.1/1771
Enterprise Ireland Commercialisation Fund Award - CF 2012 2340

Thank you for listening