



Soft X-Ray Z-Pinch Submicron Microbeam Source

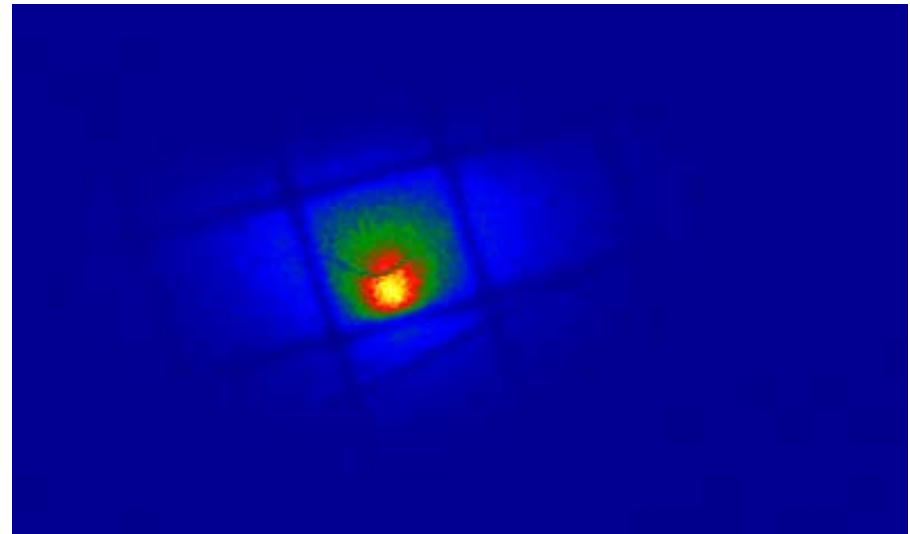
*7th International Workshop: Microbeam Probes of
Cellular Radiation Response
Steve Horne, Paul Blackborow*

Who we are

- Energetiq: Supply advanced light sources for Semiconductor applications

- Very experienced semi R&D group
- Strong connections to LBL (CXRO, ALS) & MIT (PSFC, C-Mod, Spectroscopy)

- Also developing soft X-ray sources for biological imaging



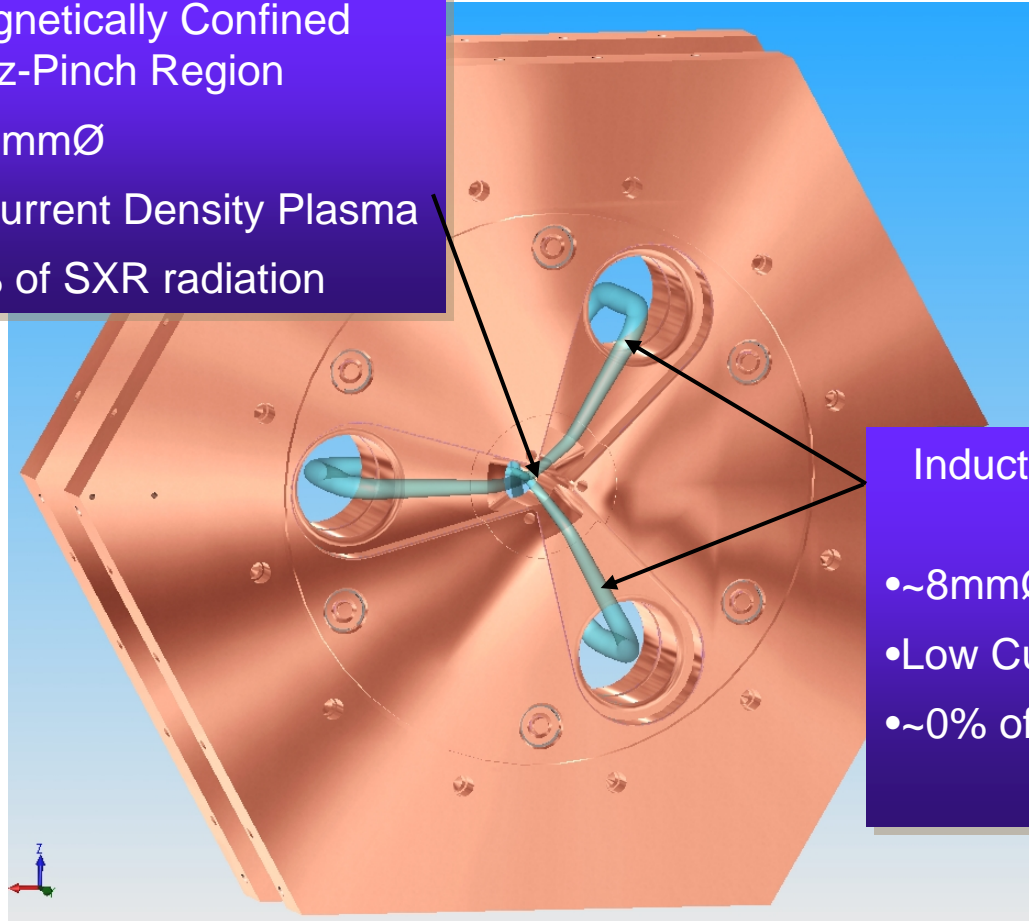
- Image of source (1 mm) in 2.88 nm light
- View through Ti foil supported by Ni mesh

EQ-10M 10 Watt EUV Source

Electrodeless Z-Pinch SXR Source

Magnetically Confined
z-Pinch Region

- <math><0.500\text{mm}\varnothing</math>
- High Current Density Plasma
- ~100% of SXR radiation



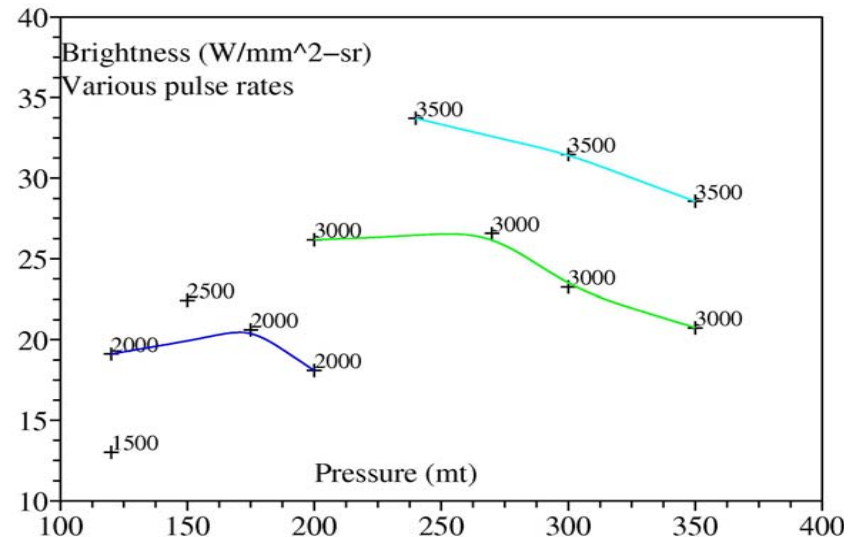
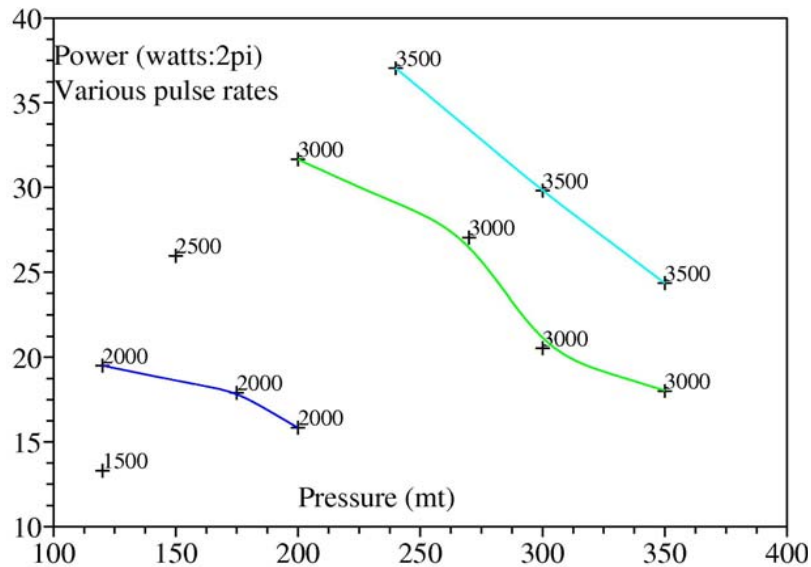
Inductively Coupled Plasma
Loops

- ~8mm \varnothing
- Low Current Density Plasma
- ~0% of SXR radiation

Operation at 13.5 nm, 92 eV in Xe

Pulsed mode operation

$$''\text{Brightness}'' = \frac{\text{Power} (2\pi)}{2\pi * \text{fwhm area}}$$



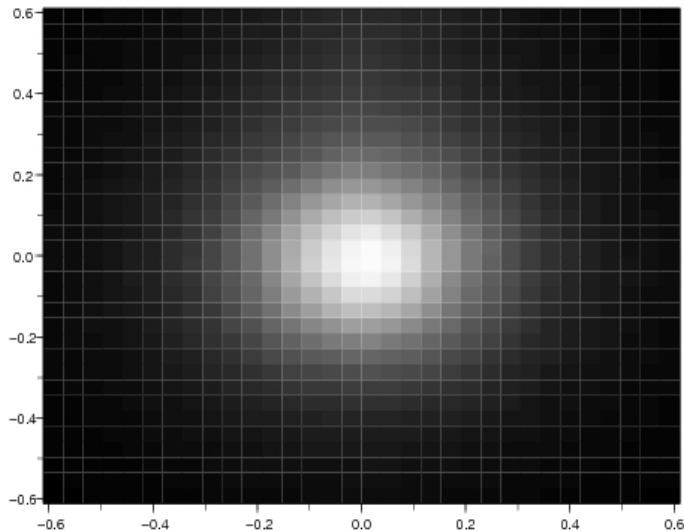
Power and Brightness optimize at different pressures.

Source size determined by pinhole camera is likely an overestimate –

hence “brightness” is probably conservative.

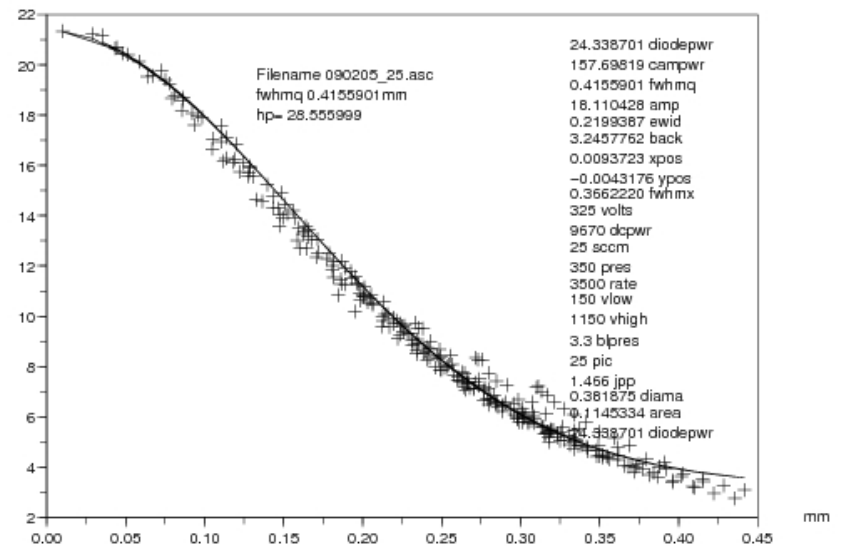
Source size via X-Ray pinhole camera

Xenon operation – 13.5 nm, 92 eV



Watts/mm²/Steradian

Brightness/watt vs radius at source

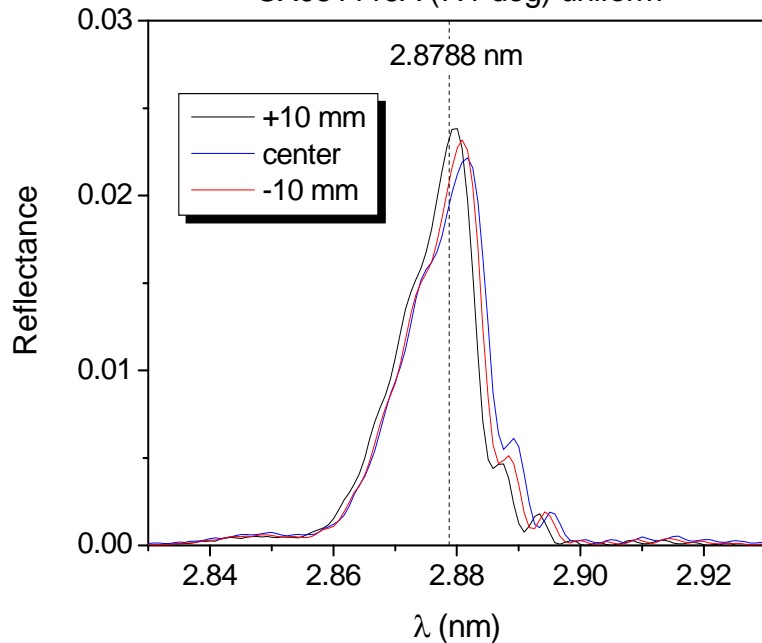


"Water Window" microscopy source

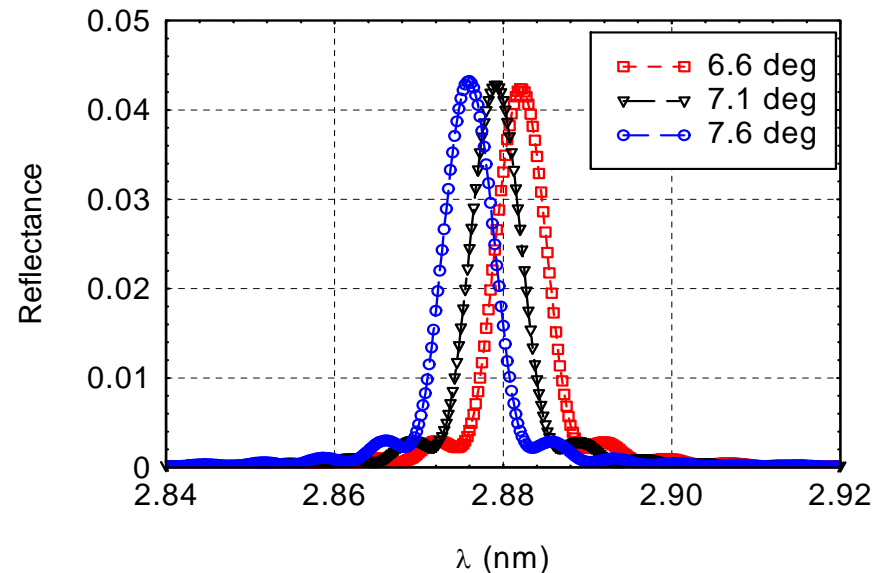
- Ongoing program to develop illuminator (source + first optic) for soft x-ray microscopy
- Microbeam source requirements are similar!
- Ongoing collaboration with LBL CXRO for optics

Graded spherical MLM (Eric Gullickson, CXRO)

CX051119A (7.1 deg) uniform



Modeled with $d=1.454$ nm



Why soft X-ray Microbeam?

- Radiation damage associated with secondary electrons (100 ev or so).
- Low LET, high energy particle creates secondaries through a large volume.
- Soft X-ray beams can “stop down” and focus to sub-micron region, producing low energy, short range secondary electrons – damage is localized.
 - “Here”, not “somewhere along that track”
 - “Local” – full dose delivered to a specific cubic micron
- If broad area exposure is required, can defocus to simulate high energy, low LET damage.

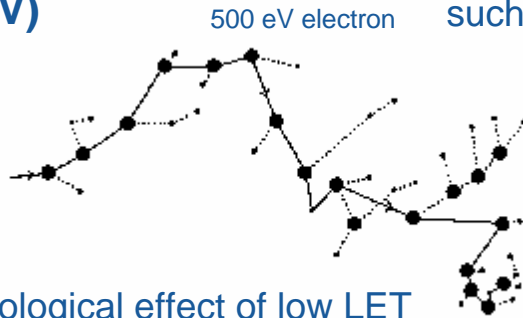
Why

Superior Spatial Resolution
Existing beams typically $> 1 \mu\text{m}$
Our goal: $0.25 \mu\text{m}$

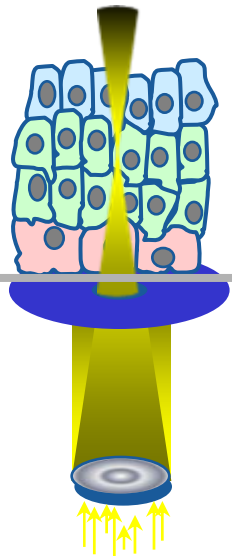
Fundamental Radiobiology

Energy (430-920 eV)

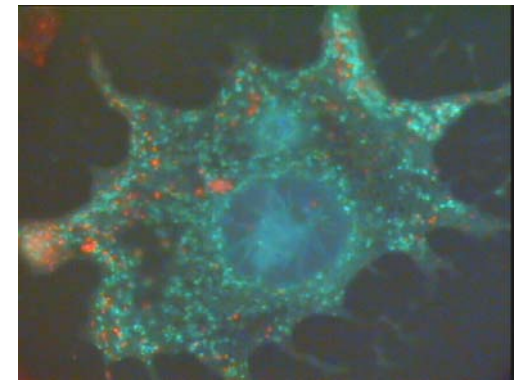
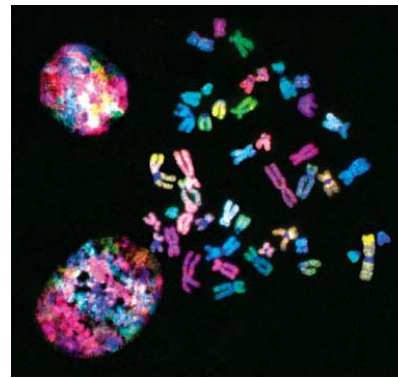
Low LET studies



Biological effect of low LET irradiation dominated by the end-track electrons (100s eV)



Higher X-ray energies will make it possible to perform microbeam studies using tissues samples (bystander relevance in complex 3D cell structures)

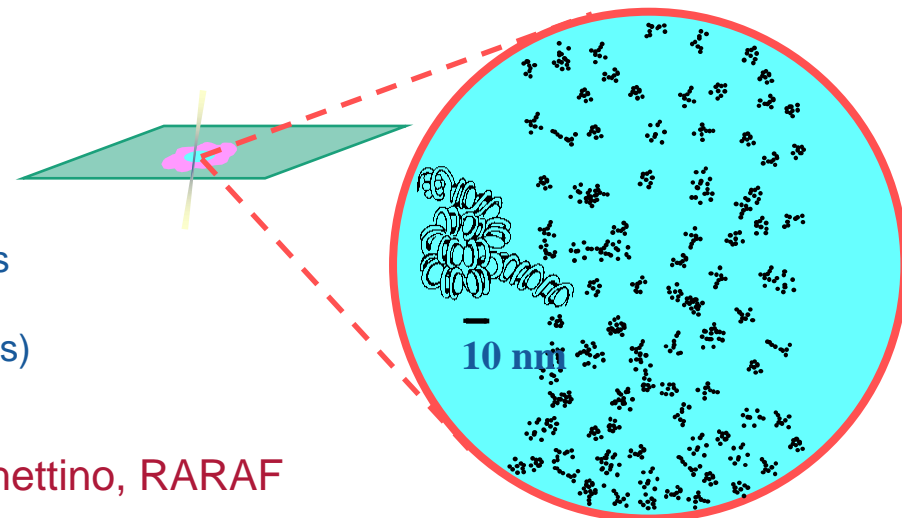


Investigate radiosensitivity of subcellular targets such as mitochondria or specific chromosomes

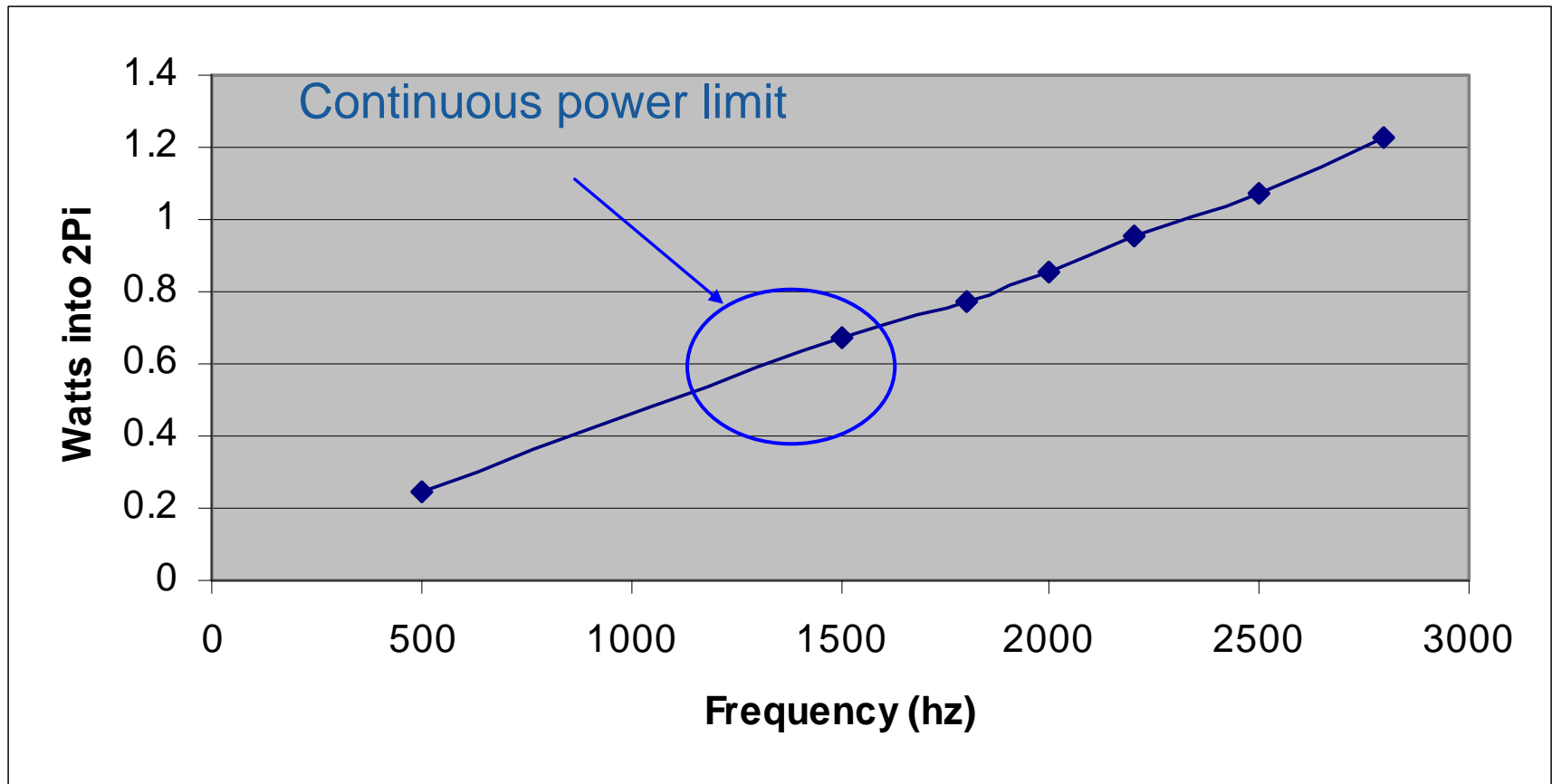
High Intensity

High LET simulation

As the extent of the clusters of DNA damage can be precisely controlled by adjusting the X-ray source size and/or energy.

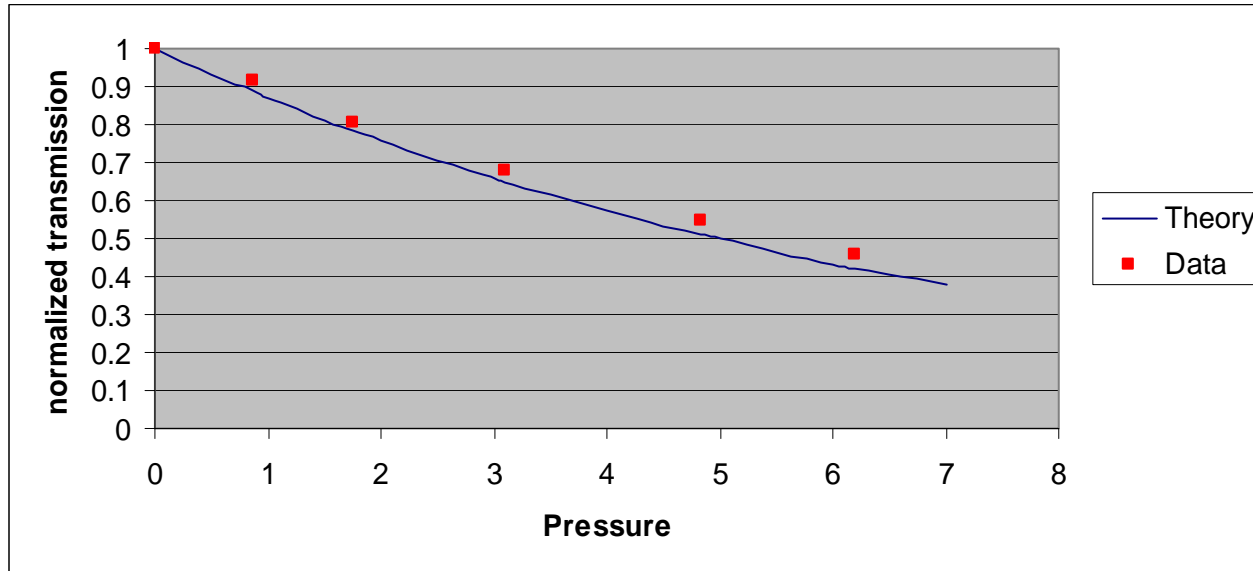


Giuseppe Schettino, RARAF



We have not reached saturation in the power output of the source.

Attenuation vs O2 pressure matches theory



Further confirmation that it's really 430 ev radiation...

Difference theory vs experiment consistent with temperature rise of gas cell

Energetics: Xe vs N vs Ne

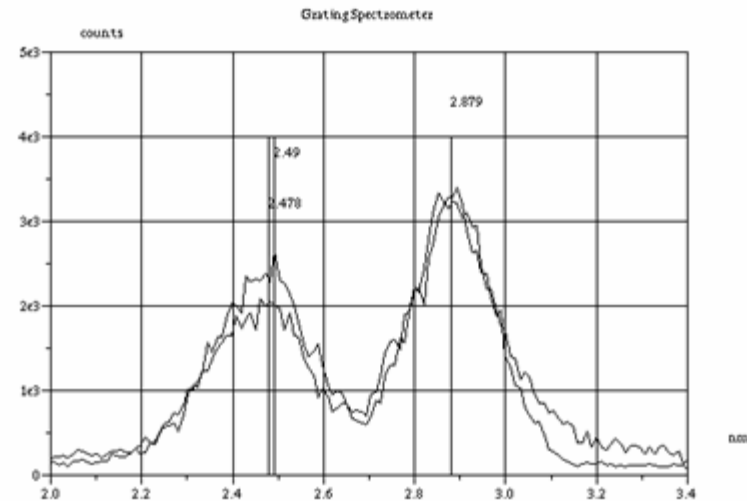
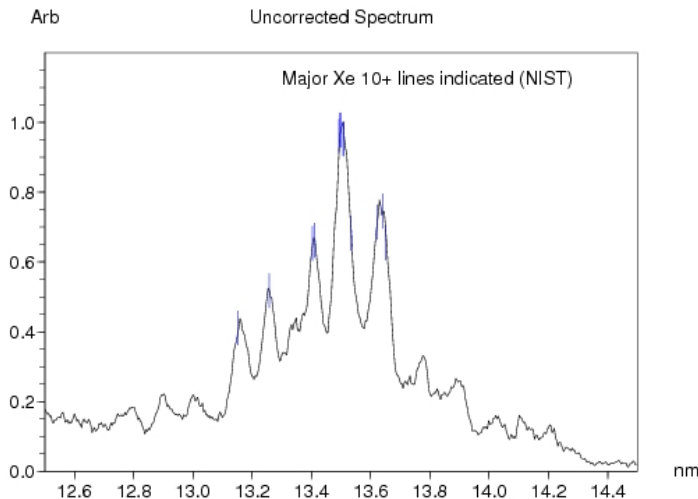
Binding energy of Xe 10th electron 229 eV

Many excited states around 92 eV

“thousands” of transitions

Helium-like N -- Binding energy of 5th electron - 97 eV ; well defined lines.

Excited states at 430, 500 eV



- Helium-like Neon – binding energy of 7th electron - 239 eV – similar to Xe
- Excited states at 922, 1074 eV. Can we excite them?

Dose rate estimates for 430, 500ev

Conservative power assumptions

Spot size set by upstream aperture

Basic Source Characteristics				Throughput				
Source power, watts/2pi	0.25	0.25	0.10	Power incident on zp	7.05E-10	7.05E-10	2.82E-10	
lam (nm)	2.88	2.88	2.48	zp efficiency	0.08	0.08	0.08	
eng (ev)	430.00	430.00	500.00	Window & substrate transmission	0.1	0.1	0.1	
Source diameter, microns	500.00	500.00	500.00	Unmasked power to sample	5.64E-12	5.64E-12	2.26E-12	
				Watts/micron^2 on sample	1.17E-11	1.17E-11	3.47E-12	
Zone Plate Characteristics				MeV/sec/micron^2	73.30	73.30	21.67	
dr, nm	30.00	30.00	30.00	Mask (effective spot diameter)	1.00	0.25	0.25	
diam, mm	0.12	0.12	0.12	Masked power to sample	5.64E-12	5.76E-13	1.70E-13	
# zones	1000.00	1000.00	1000.00	Target Dimensions				
Focal Length, mm	1.25	1.25	1.45	HaCat		cytoplasm	nucleus	nucleus
				halfaxis	4.35	3.5	3.5	
				halfaxis	7.3	6.25	6.25	
				length	15	9.5	9.5	
System Geometry				Volume	1496.42	652.86	652.86	
Source-sample, mm	800.00	800.00	800.00	Dose, Gy/sec	3.77	0.88	0.26	
lens-sample	1.25	1.25	1.45					
Source-lens	798.75	798.75	798.55					
Unmasked spot size, microns	0.78	0.78	0.91					

Convenient geometry –

Source, stage, etc. in the same room!

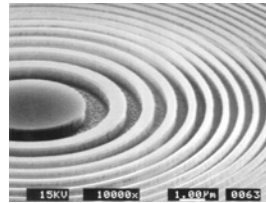
Dose rates

Specifications of proposed device

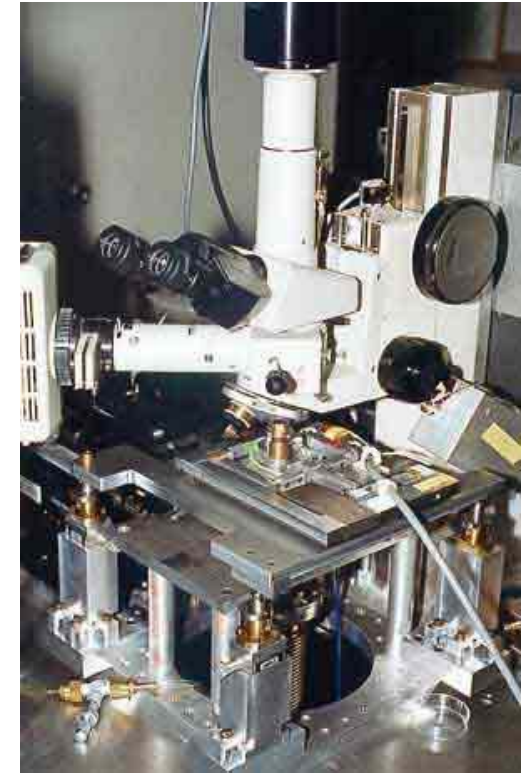
- Z-Pinch X-Ray Source, using Nitrogen and/or Neon
- Dose range: $<.01$ Gy/sec to a few Gy/sec
- Beam size: optically controllable; $< 1 \mu\text{m}$
 - allow very high energy deposition in sub-micron³ volume
- Energy range: 430 eV, 500 eV (Nitrogen) , ~ 1 KeV (Neon -- maybe)
 - 5 KeV unlikely
- Fast (>10000 cells/h) and accurate ($\pm 0.5 \mu\text{m}$) image and micropositioning station.
- Facility fully software controlled (single experimenter required).
- Primary applications:
 - Fundamental radiobiological studies
 - Medical/Cancer research (radiotherapy, radioprotection research)

Energetiq + RARAF - proposal

Our goal is to develop a self contained soft X-ray microbeam for radiobiological applications.



- Energetiq Z-pinch bright X-ray source
- Diffraction X-ray optics
- Columbia microbeam experience & tools
- image analysis
- fast & accurate micropositioning



Giuseppe Schettino, RARAF

Current Status

- Ongoing work on source for Water Window Microscopy
 - Similar source requirements – optimize 13.5 nm source for SXR
 - Microscope optics more demanding than for microbeam
 - Testing graded spherical MLM
 - Considering Wolter-style (type II) condenser
- Neon experiments –
 - Diagnostics in planning stage
- Collaboration with Columbia, RARAF for prototype source