# Soft X-Ray Z-Pinch Submicron Microbeam Source

*7'th International Workshop: Microbeam Probes of Cellular Radiation Response*

*Steve Horne, Paul Blackborow*

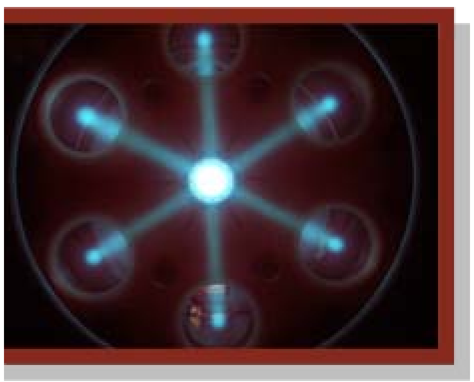
ENERGETIQ

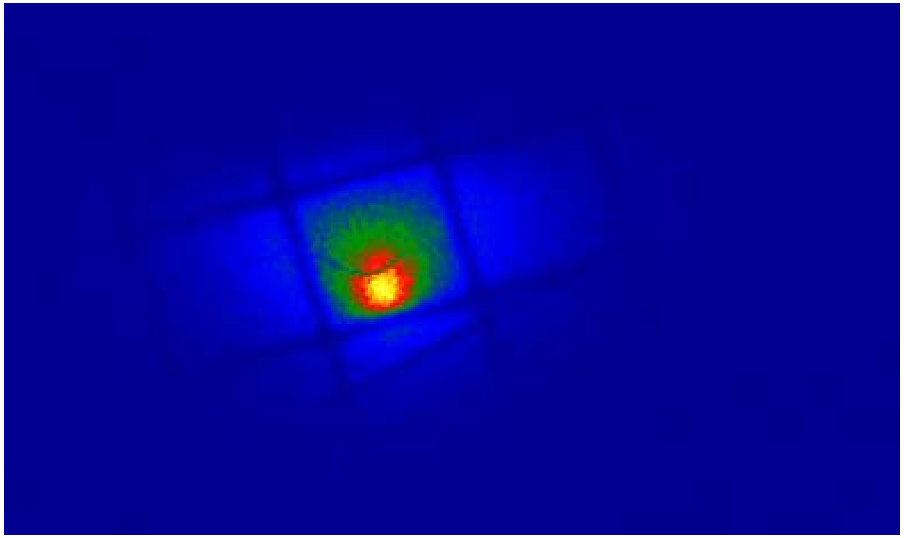
ENERGETIQ

# *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

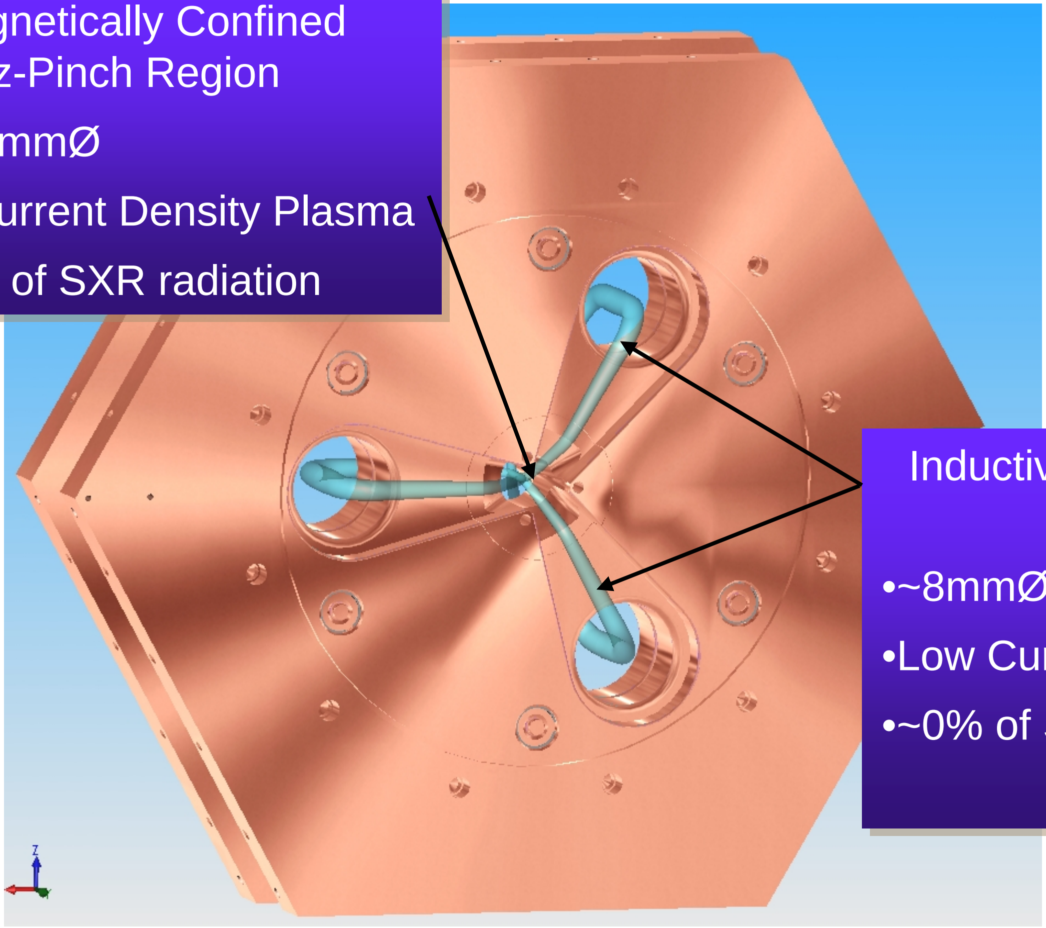
•View through Ti foil supported by Ni mesh

EQ-10M 10 Watt EUV Source

# *Electrodeless Z-Pinch SXR Source*

Magnetically Confined
z-Pinch Region

- <0.500mmØ
- High Current Density Plasma
- ~100% of SXR radiation



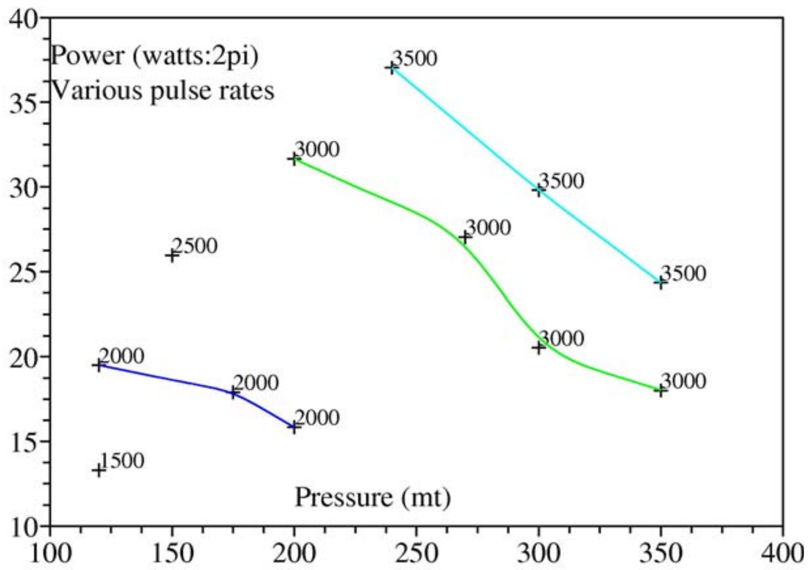
Inductively Coupled Plasma
Loops

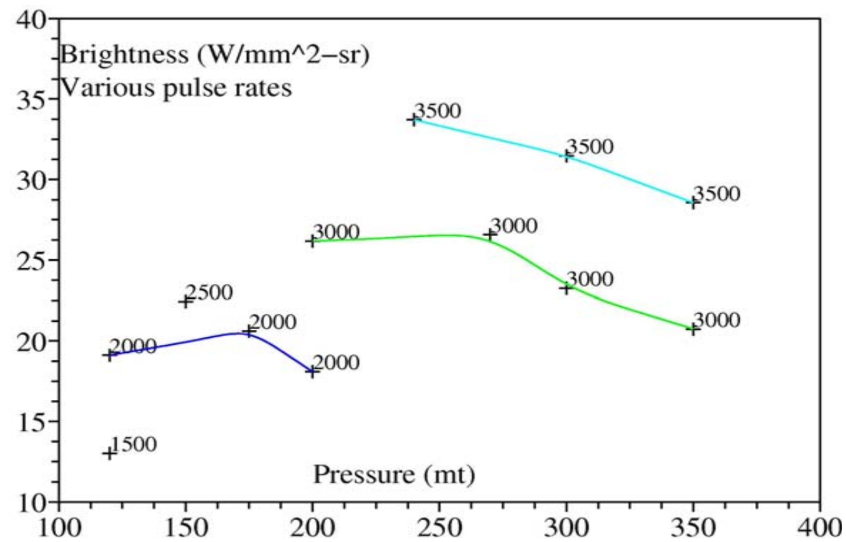
- ~8mmØ
- Low Current Density Plasma
- ~0% of SXR radiation

# Operation at 13.5 nm, 92 eV in Xe

## Pulsed mode operation

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




Peak powers well above 10W are available for short bursts. These data are 20% duty cycle; 1 second bursts. Peak power approaching 40W:2pi have been measured.

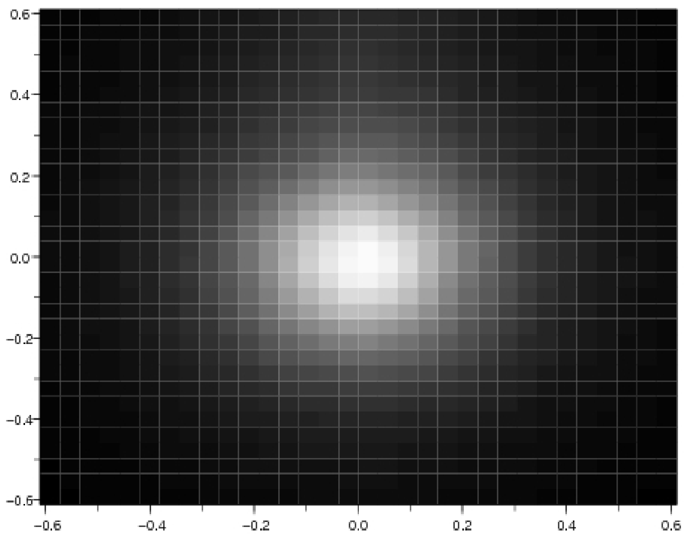
Power and Brightness optimize at different pressures.

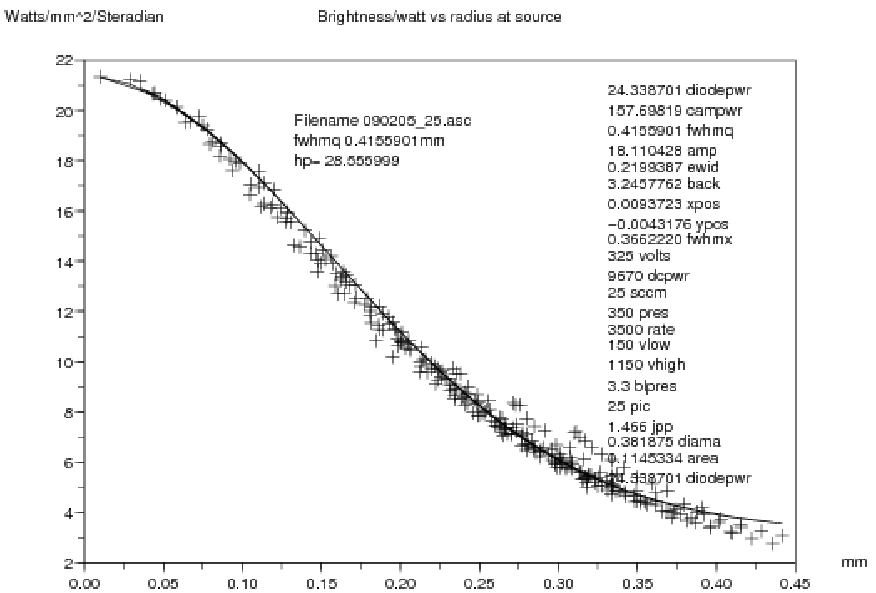
Source size determined by pinhole camera is likely an overestimate –

hence “brightness” is probably conservative.

# Source size via X-Ray pinhole camera

## Xenon operation – 13.5 nm, 92 eV

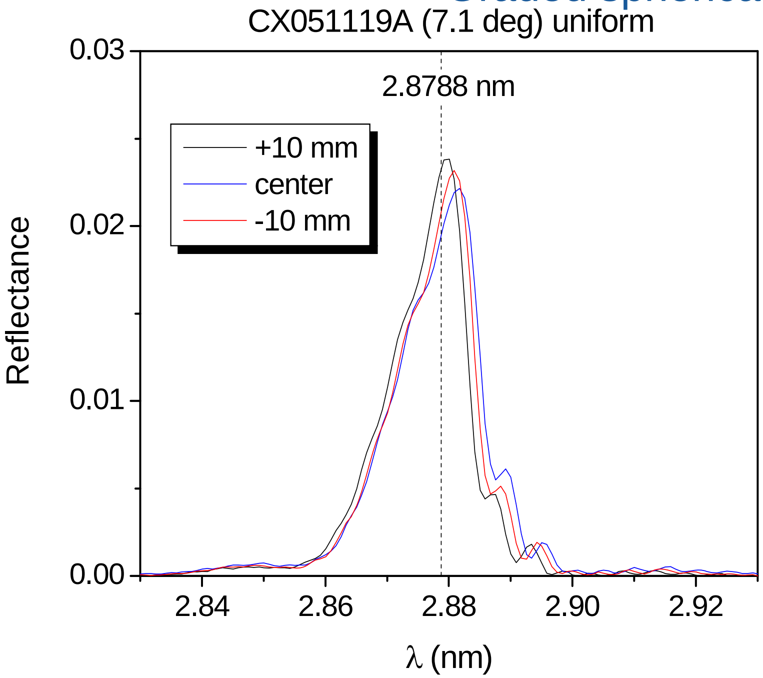


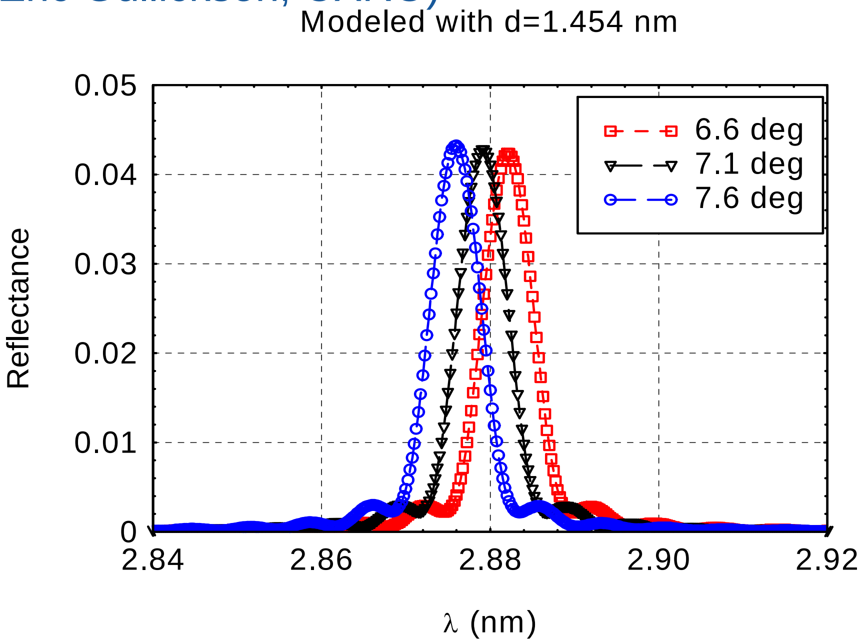



# “Water Window” microscopy source

- 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)



# 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.

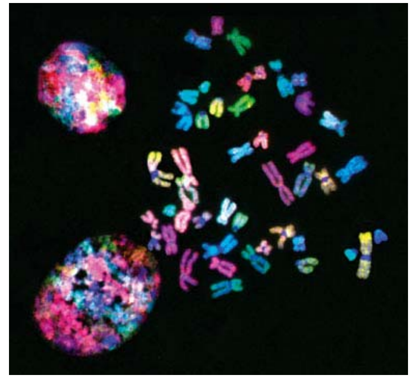
"Here", not "somewhere along that track"

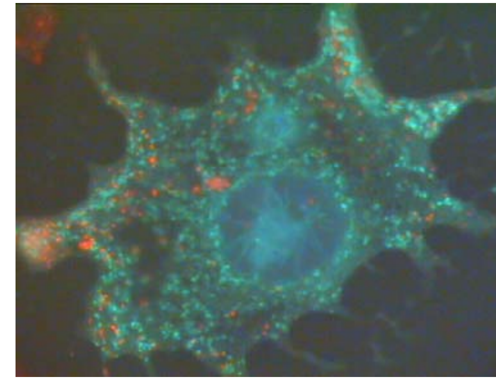
"Local" – full dose delivered to a specific cubic micron

- If broad area exposure is required, can defocus to simulate high energy, low LET damage.

# Why

## Superior Spatial Resolution
**Existing beams typically > 1 μm**
**Our goal: 0.25 μm**

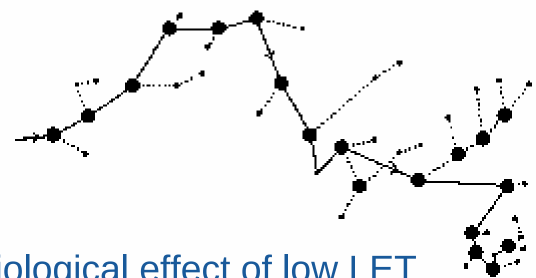




**Fundamental Radiobiology**

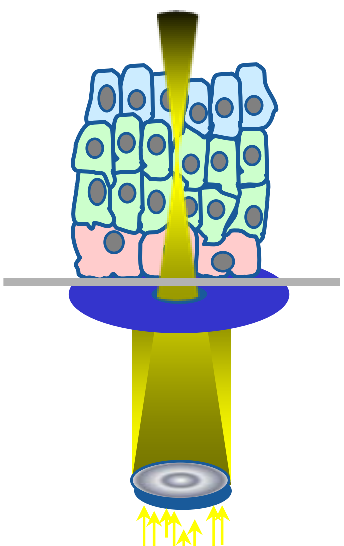
Investigate radiosensitivity of subcellular targets such as mitochondria or specific chromosomes

**Energy (430-920 eV)**
**Low LET studies**

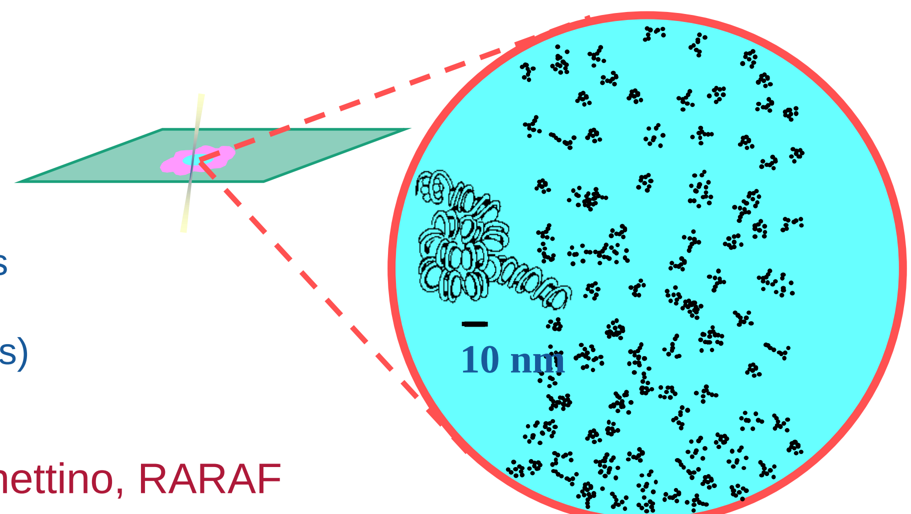



Biological effect of low LET irradiation dominated by the end-track electrons (100s eV)

**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.

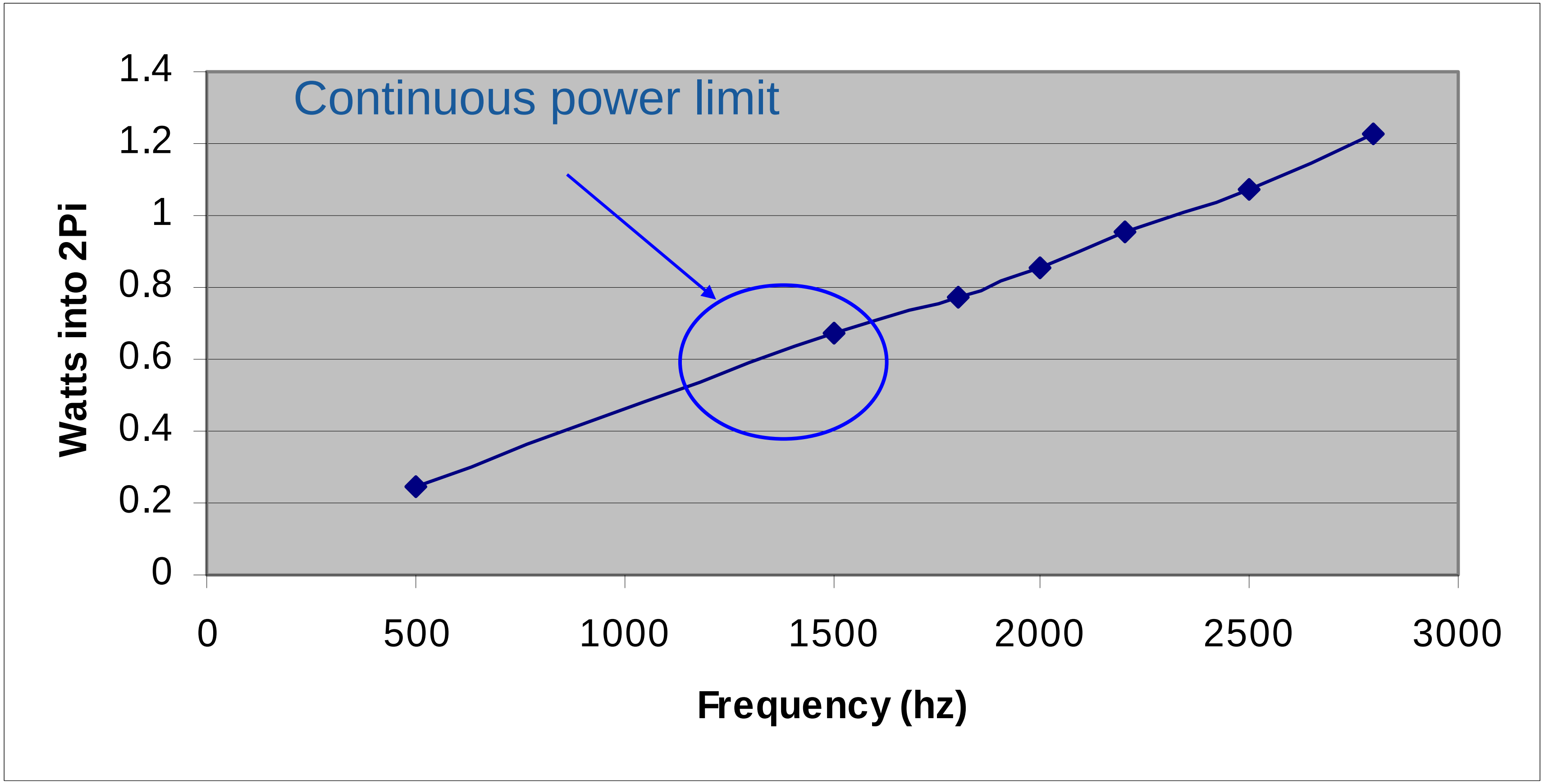


Higher X-ray energies will make it possible to perform microbeam studies using tissues samples (bystander relevance in complex 3D cell structures)



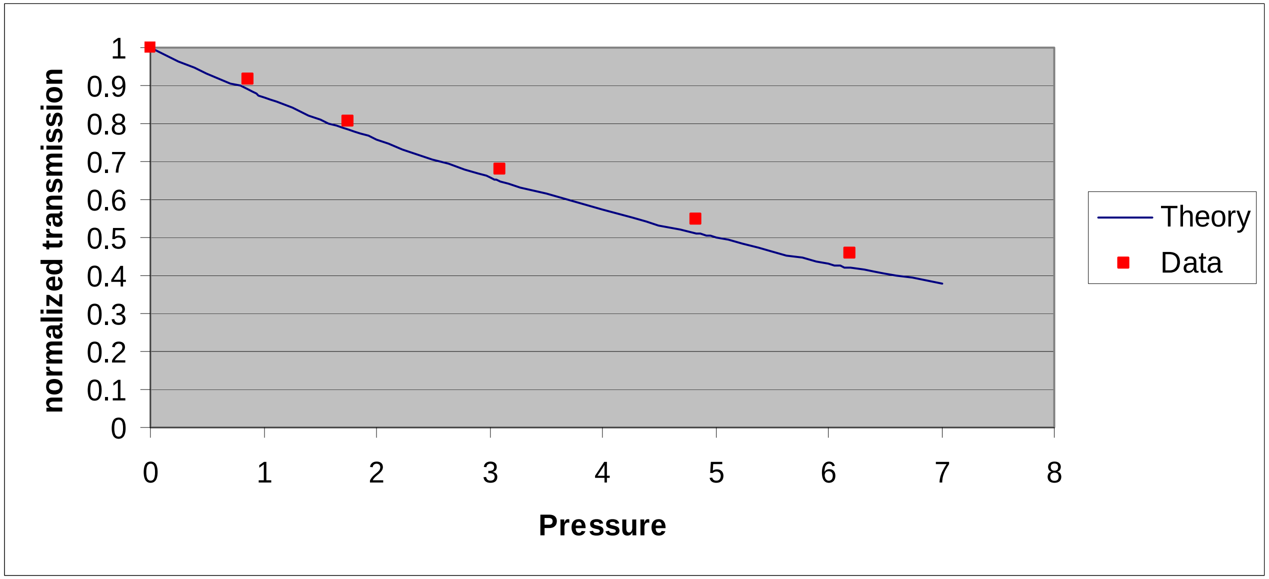

Giuseppie Schettino, RARAF

# Nitrogen @ 430 eV – burst mode data




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

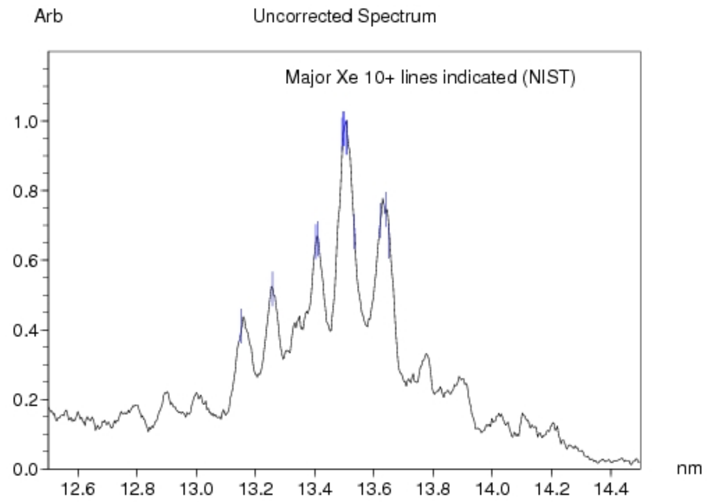
Binding energy of Xe 10th electron 229 ev

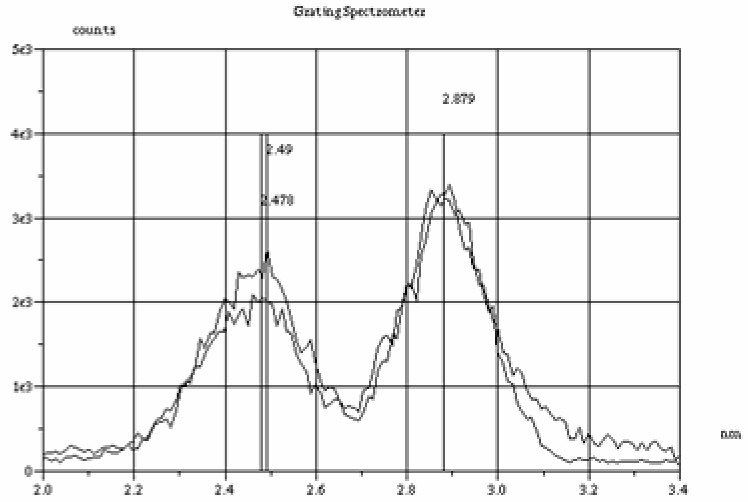
Many excited states around 92 ev

“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 | | | |
|---|---|---|---|
| Source power, watts/2pi | 0.25 | 0.25 | 0.10 |
| lam (nm) | 2.88 | 2.88 | 2.48 |
| eng (ev) | 430.00 | 430.00 | 500.00 |
| Source diameter, microns | 500.00 | 500.00 | 500.00 |
| | | | |
| **Zone Plate Characteristics** | | | |
| dr, nm | 30.00 | 30.00 | 30.00 |
| diam, mm | 0.12 | 0.12 | 0.12 |
| # zones | 1000.00 | 1000.00 | 1000.00 |
| Focal Length, mm | 1.25 | 1.25 | 1.45 |
| | | | |
| **System Geometry** | | | |
| Source-sample, mm | 800.00 | 800.00 | 800.00 |
| 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 |

| Throughput | | | |
|---|---|---|---|
| Power incident on zp | 7.05E-10 | 7.05E-10 | 2.82E-10 |
| zp efficiency | 0.08 | 0.08 | 0.08 |
| Window & substrate transmission | 0.1 | 0.1 | 0.1 |
| 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 |
| MeV/sec/micron^2 | 73.30 | 73.30 | 21.67 |
| Mask (effective spot diameter) | 1.00 | 0.25 | 0.25 |
| Masked power to sample | 5.64E-12 | 5.76E-13 | 1.70E-13 |
| **Target Dimensions** | | | |
| HaCat | **cytoplasm** | **nucleus** | **nucleus** |
| halfaxis | 4.35 | 3.5 | 3.5 |
| halfaxis | 7.3 | 6.25 | 6.25 |
| length | 15 | 9.5 | 9.5 |
| Volume | 1496.42 | 652.86 | 652.86 |
| **Dose, Gy/sec** | **3.77** | **0.88** | **0.26** |
| | | | |

Convenient geometry –

Source, stage, etc. in the same room!

Dose rates

# Specifications of proposed device

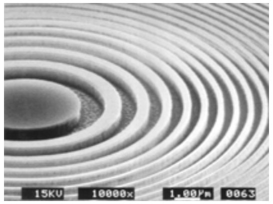
- Z-Pinch X-Ray Source, using Nitrogen and/or Neon
- Dose range: <.01 Gy/sec  to a few  Gy/sec
- Beam size: optically controllable; < 1 $\mu$m
  - allow very high energy deposition in sub-micron$^3$ volume
- Energy range: 430 eV, 500 eV (Nitrogen) , ~1Kev (Neon  -- maybe)
  - 5 KeV unlikely
- Fast (>10000 cells/h) and accurate ($\pm$0.5 $\mu$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

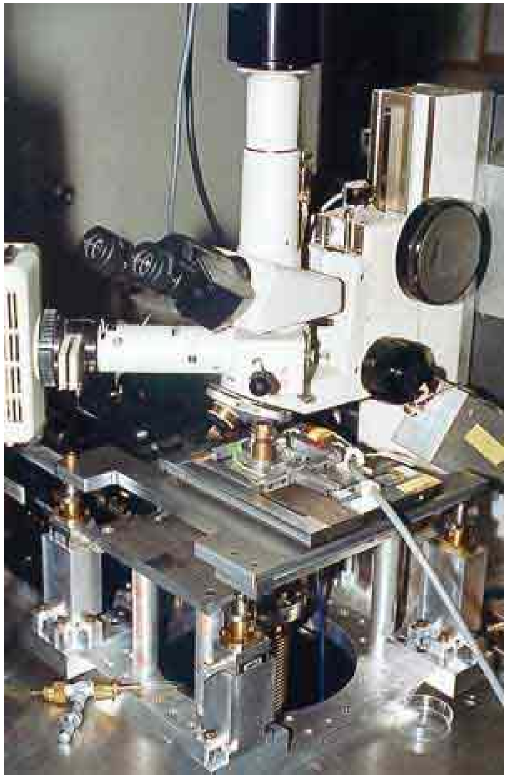
ENERGETIQ

**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**

Giuseppie 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