High-brightness Liquid-jet Laser-plasma Enabling 10-second-exposure Water-window Cryo Microscopy

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Main results

Bright laboratory soft x-ray source

Short exposure time imaging

Aquisition time: 10 s
Stockholm X-ray Microscope

Background | Source | Microscope | Results | Summary
**Water-window**

+ **Resolution:** $0.61\lambda/\text{NA}$
+ **Contrast:** Absorption water $\ll$ absorption protein
+ Possibility to study thick ($\sim 10 \mu\text{m}$) objects

- Lack of laboratory high-brightness sources

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**Background** | **Source** | **Microscope** | **Results** | **Summary**
SNR – Signal to noise ratio

Background | Source | Microscope | Results | Summary
Source

Measured spectrum from source

$K_\alpha: \lambda/\Delta\lambda = 500-1000$

$10^{10}$ ph/pulse x sr x pm

$\lambda$ (nm)

2.2 2.4 2.6 2.8 3.0 3.2 3.4

Jet

Regenerative target

Back pressure: ≈ 20 bar
\[ \rightarrow \text{Jet speed: } \approx 50 \text{ m/s} \]

Tapering optimized to avoid turbulence.

Breakup length: 3-5 mm

Background | Source | Microscope | Results | Summary
Jet delivery system & Laser

Fused-silica capillary nozzle

LN$_2$

Cryostat

N$_2$

Pump

Fraunhofer ILT - Institut für Lasertechnik

Wavelength: 1064 nm
(SHG option: 532 nm)

Pulse duration: 1 ns

Max pulse energy: 100 mJ

Max power: 200 W

Repetition rate: 250 – 2000 Hz

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1.5 \times 10^{12} \text{ photons / (s \times mm^2 \times mrad^2 \times line )}

\frac{\lambda}{\Delta \lambda} = 500-1000

Microscope
**Multilayer condenser mirror**

Cr/V - Multilayer

- Ø 58 mm
- 350 mm radius of curvature
- 200 bilayers
- $\lambda/\Delta\lambda \approx 300$
- Good uniformity
- Good $\lambda$ match

Reflectivity: ~0.6%

Thanks to S. Yulin, FhG Jena
Sample

Standard TEM-grids

Standard TEM-sample holder

Cryo:

Non-cryo:
Zone plate

Circular diffraction gratings

Material: Nickel
Diameter: 50 – 100 μm
Outermost zone width: 25 – 50 nm
Diffraction efficiency: ~7-8 %

$\Delta r_{Rayl.} = 1.22 dr_N$

Background | Source | Microscope | Results | Summary
Detector

PI-SX – Princeton Instruments

- Cooled (-30° C) CCD
- 2048 × 2048 px, 13.5 × 13.5 μm²
- Quantum efficiency: ~60 %
- AD-converter: 16 bit
Cryo microscopy (old system)

Parasites

- **Giardia intestinalis**
- **Spironucleus salmonicida**

![Images of Giardia and Spironucleus](image1.jpg)

- 10 µm
- 5 µm

- 5-10 min exposure time / image


Tomography

- **Human kidney cell**

![2D image of human kidney cell](image2.jpg)

- 5 µm

- 58 × 120 s
- 1.5° tilt increments


Reconstructed volume

Surface rendering

Background | Source | Microscope | Results | Summary
Short exposure times

Human immune system B-cells - 10 seconds exposure images

10 µm
Summary

- Highest-average-brightness laboratory source operating in the water-window demonstrated

- Short exposure times, approaching that of microscopes based on early synchrotron sources