Laser-induced microexplosions: creating stellar conditions on an optical bench

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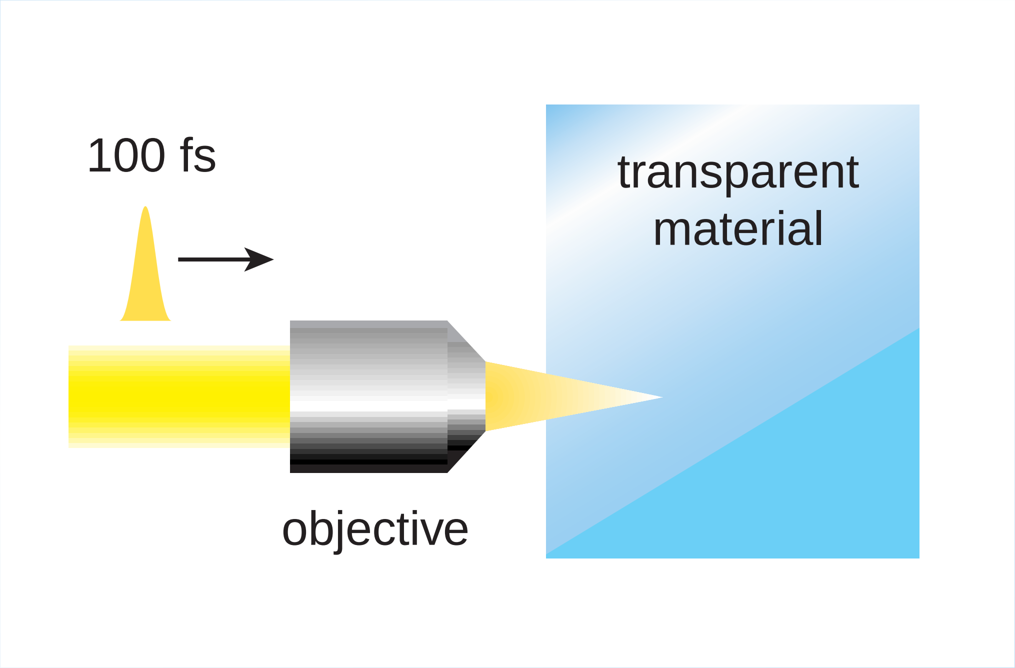
9 April 1999

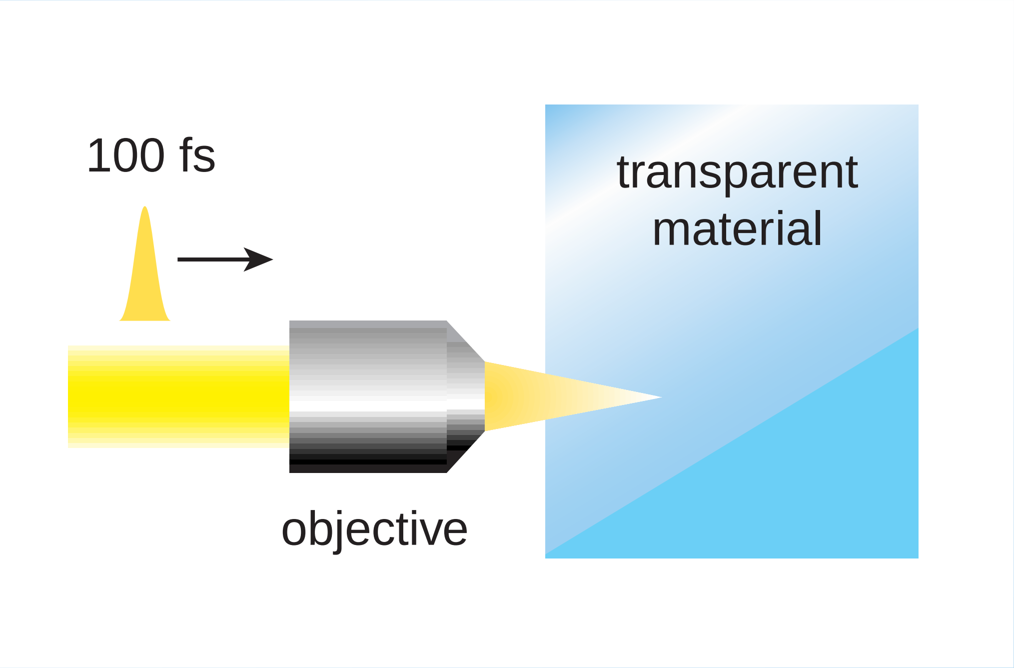
focus laser beam inside material…



Glezer, *et al.*, *Opt. Lett.* 21, 2023 (1996)

Introduction

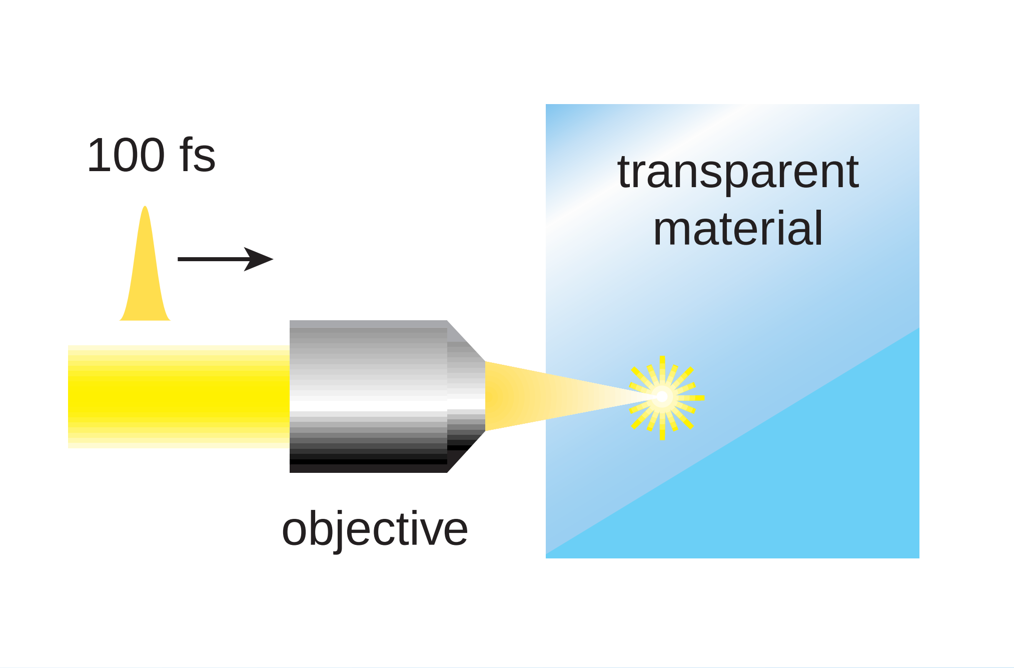
high intensity at focus…



Glezer, *et al.*, *Opt. Lett.* 21, 2023 (1996)

Introduction

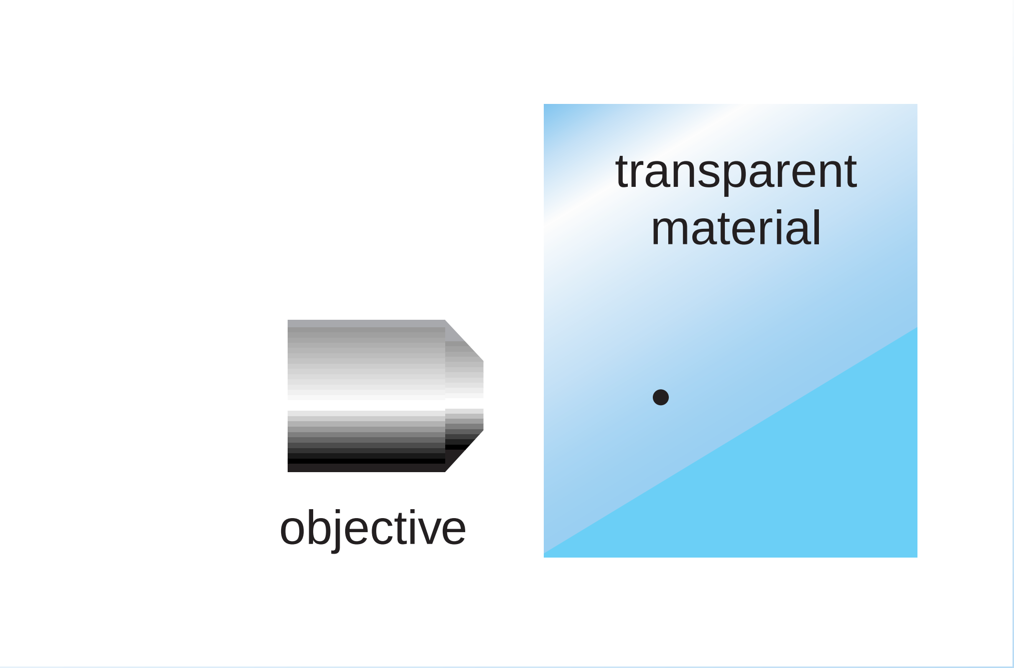
… causes nonlinear ionization…



Glezer, *et al.*, *Opt. Lett.* 21, 2023 (1996)

Introduction

and microscopic bulk damage



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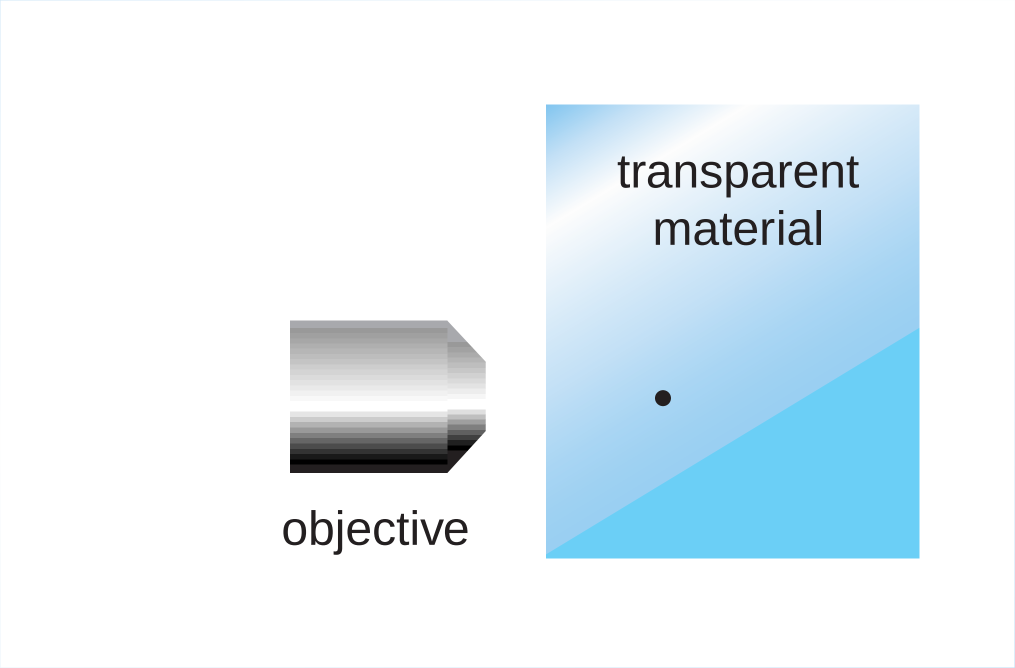
Introduction

What are the conditions at focus?



Introduction

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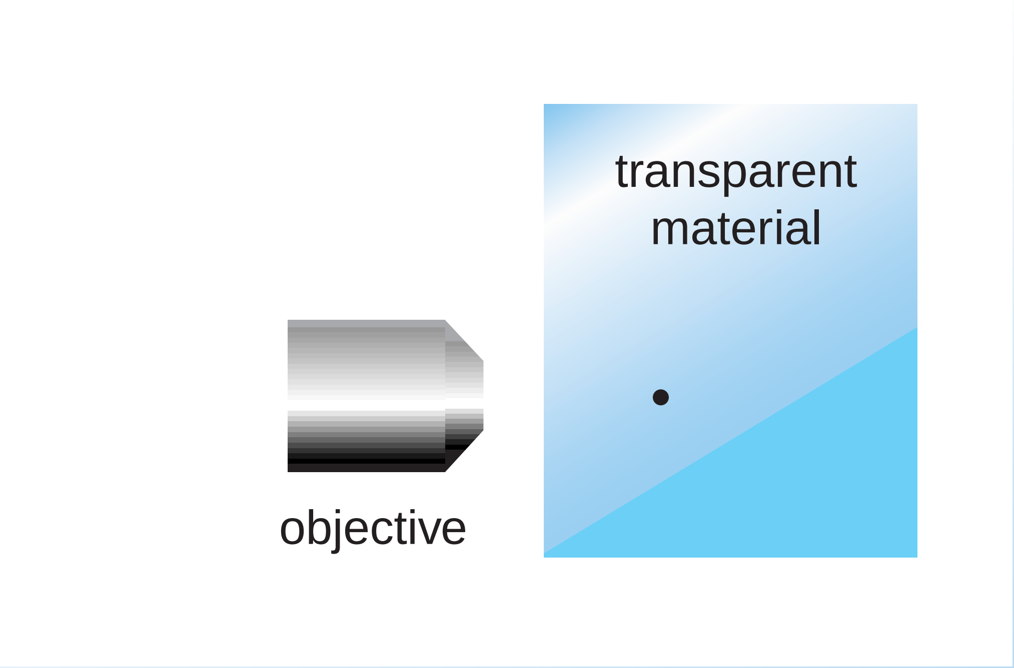

laser deposits energy in ~1 μm^3

Introduction

What temperature?

Introduction

What temperature?

$$\Delta E = C_V \rho V \, \Delta T$$

Introduction

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$$\Delta E = C_V \rho V \Delta T$$

$$C_V = 0.75 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$$

$$\rho = 2.2 \times 10^3 \text{ kg/m}^3$$

Introduction

What temperature?

$$\Delta E = C_V \rho V \, \Delta T$$

$$C_V = 0.75 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$$

$$\rho = 2.2 \times 10^3 \text{ kg/m}^3$$

So, 1 μJ in 1 μm^3 gives

~1,000,000 K!

Introduction

What pressure?

Introduction

What pressure?

Treat ionized material as an ideal gas:

$$pV = nRT$$

Introduction

What pressure?

Treat ionized material as an ideal gas:

$$pV = nRT$$

Gives

$$p = 10\,\mathrm{MBar!}$$

Introduction

So:

	microexplosion
T	≈ 1 MK
p	≈ 10 MBar
ρ	2.2×10^3 kg/m^3

Introduction

So:

	microexplosion	**sun**
T	$\approx$1 MK	2–15 MK
p	$\approx$10 MBar	
ρ	2.2×10^3 kg/m^3	$0.15–150 \times 10^3$ kg/m^3

So:

	microexplosion	sun
T	$\approx$1 MK	2–15 MK
p	$\approx$10 MBar	
ρ	2.2×10^3 kg/m^3	$0.15–150 \times 10^3$ kg/m^3

creating stellar conditions in lab!

Outline

- **Post-mortem analysis**
- **Energy deposition**
- **Microexplosion dynamics**

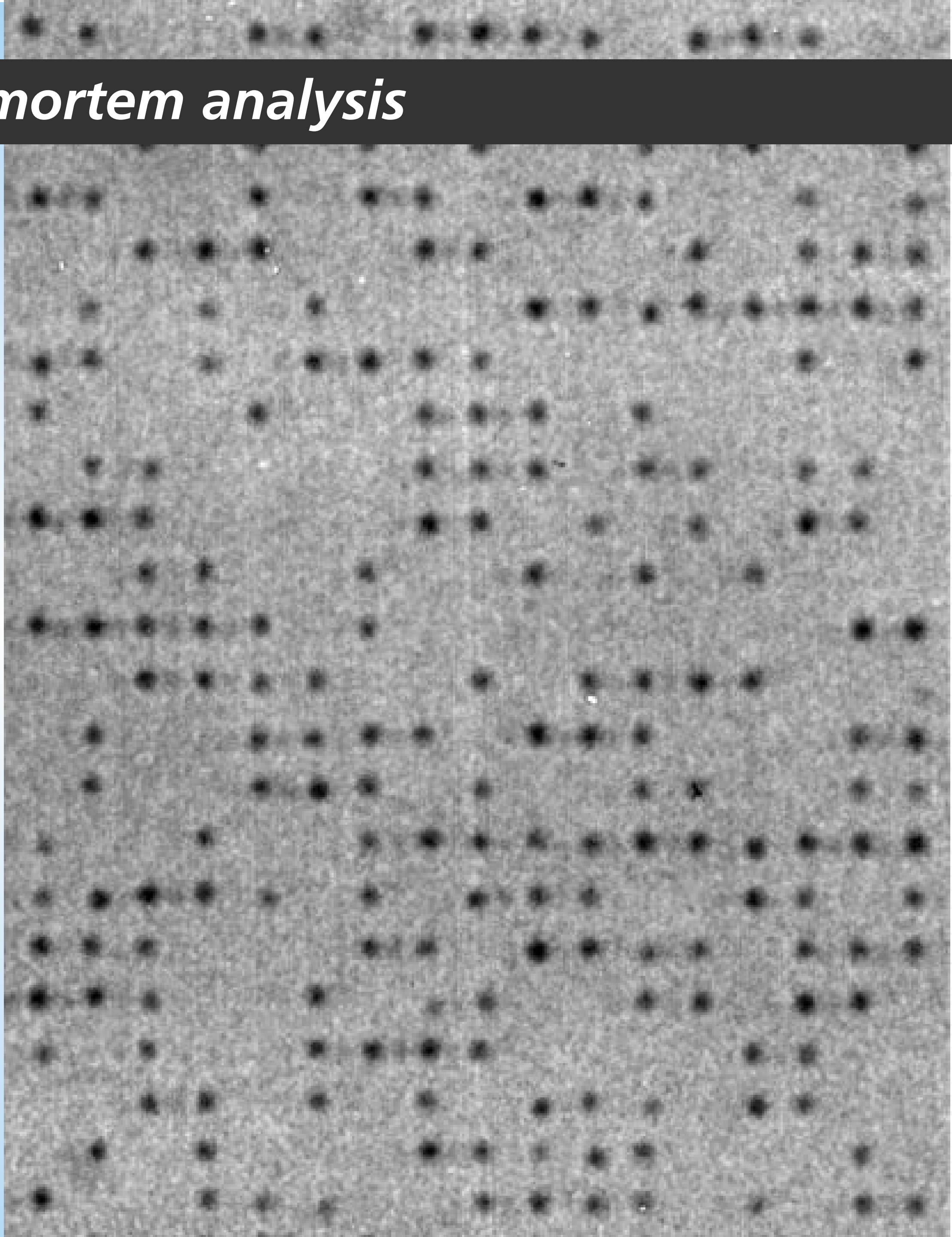
Post-mortem analysis

optical microscopy

2 x 2 µm array

fused silica

0.5 µJ, 100 fs, 800 nm



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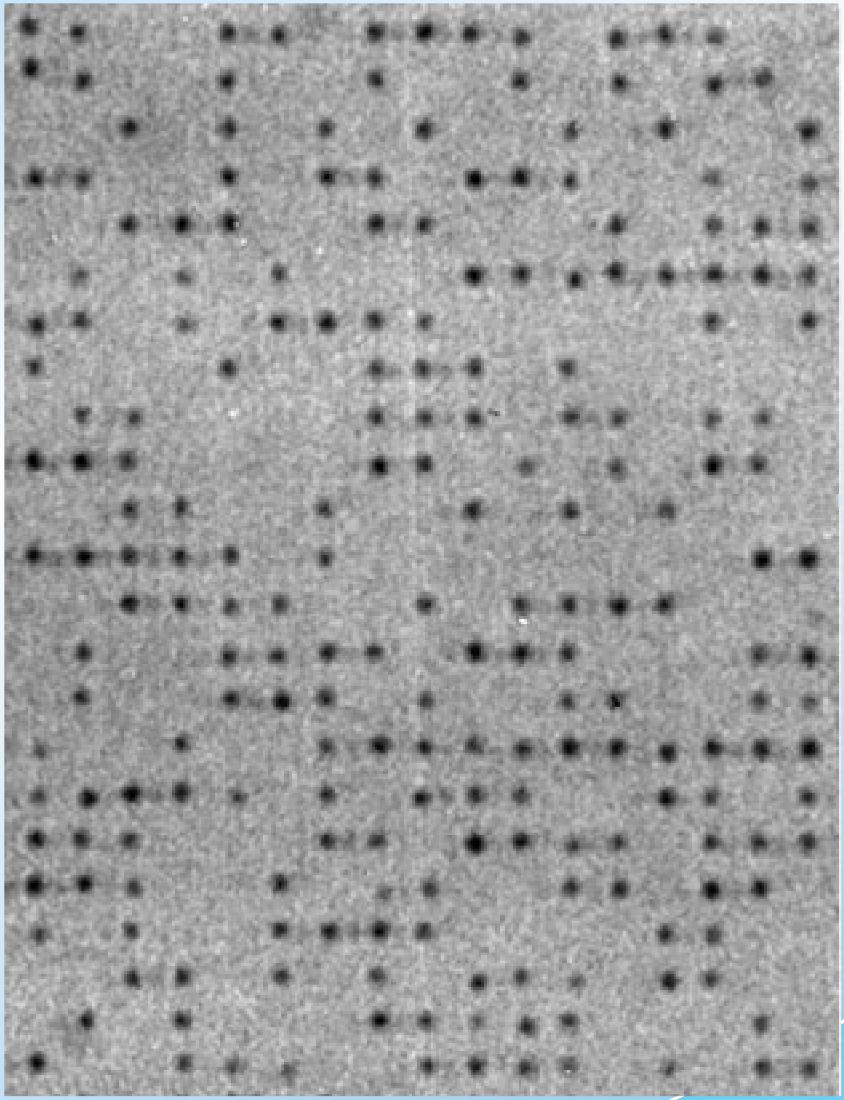

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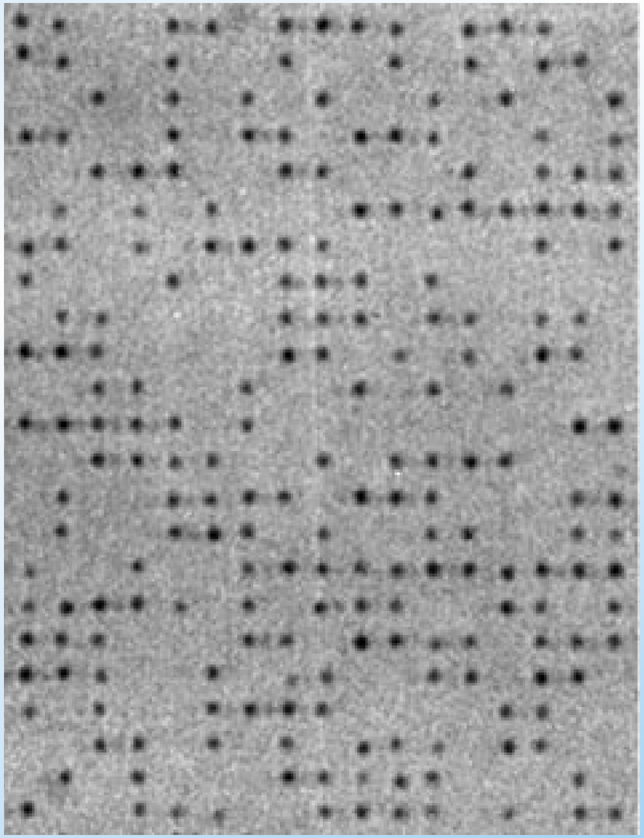

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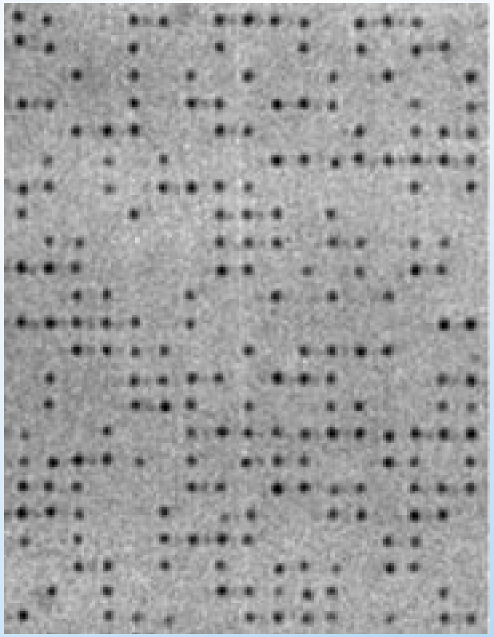

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Post-mortem analysis

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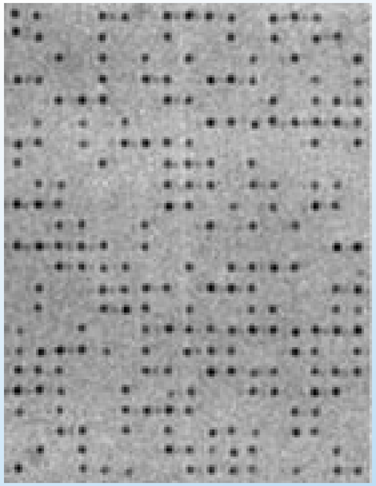

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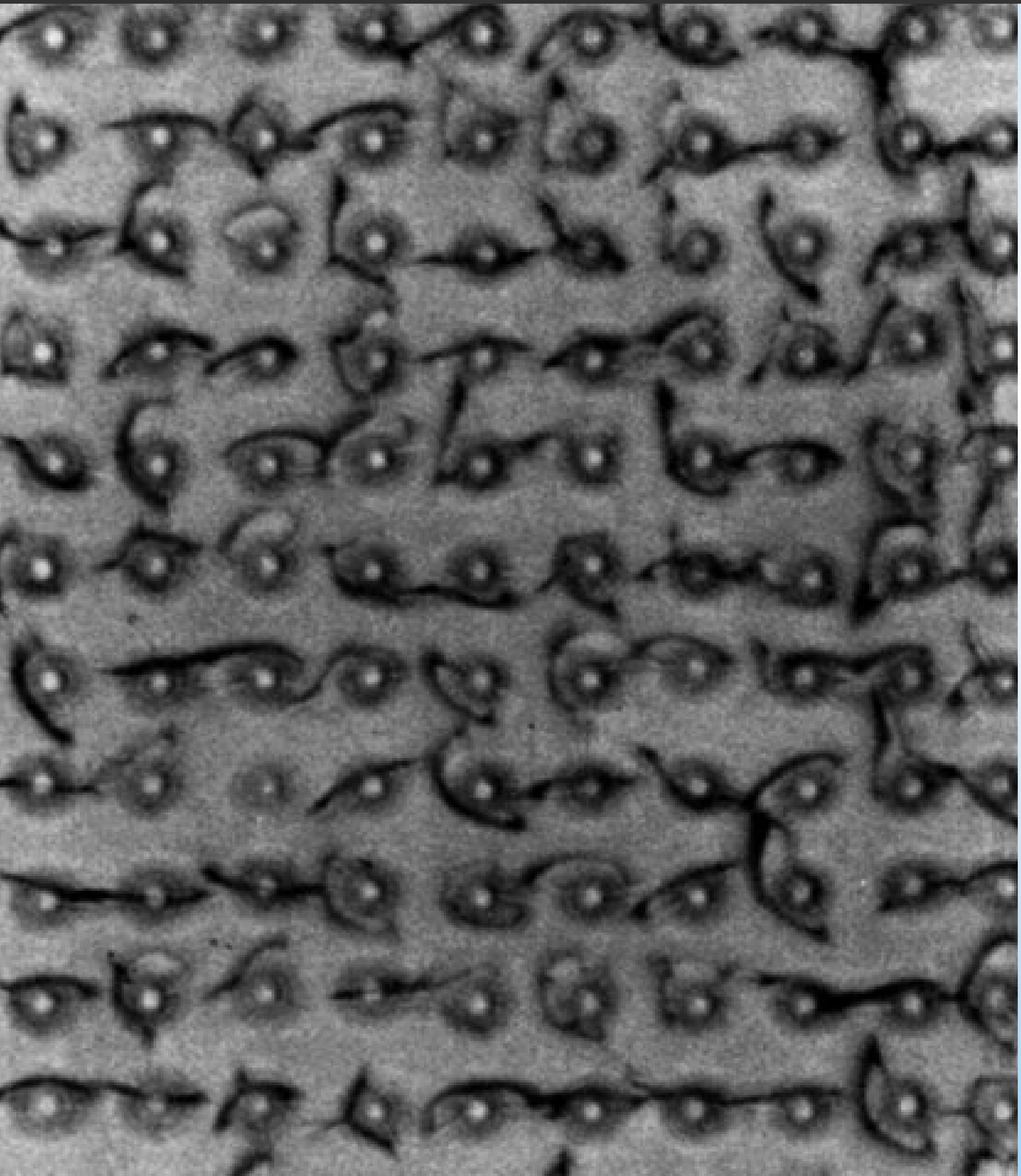
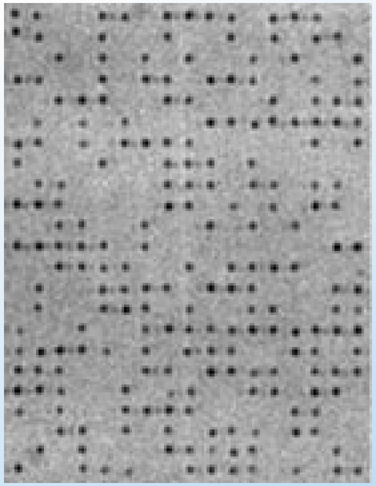
Post-mortem analysis

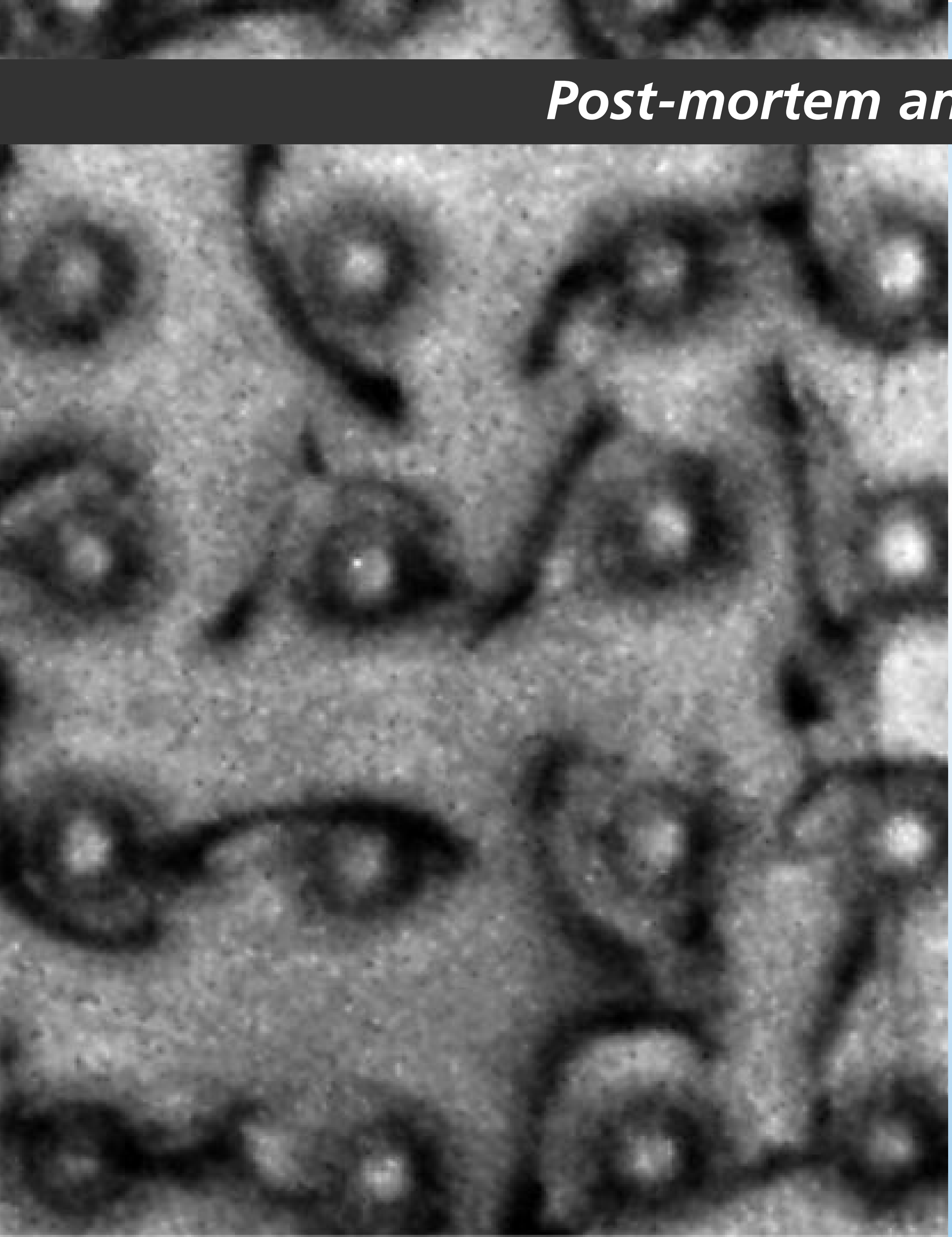


200 ps



100 fs

Post-mortem analysis



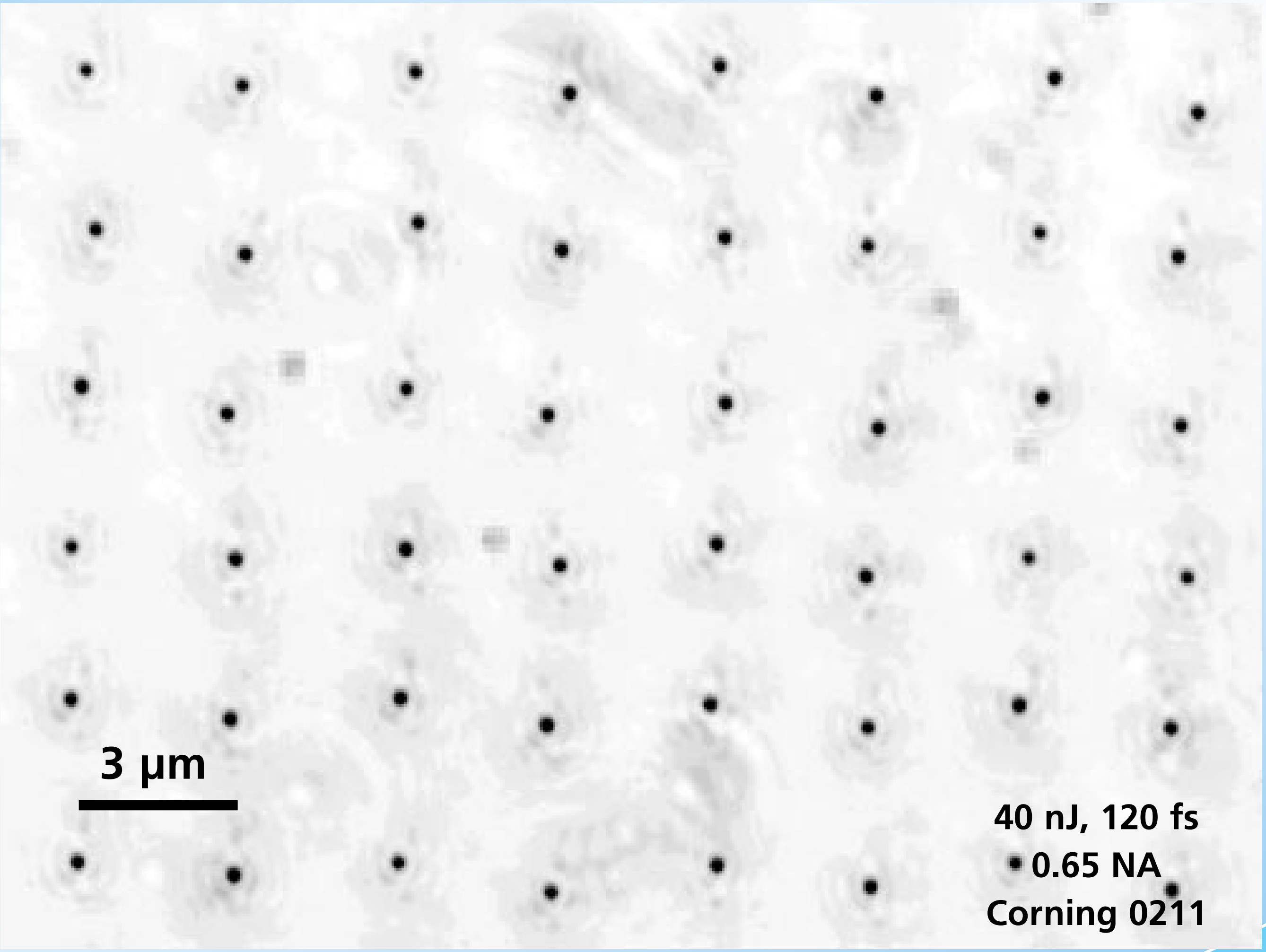
optical microscopy

10 x 10 µm array

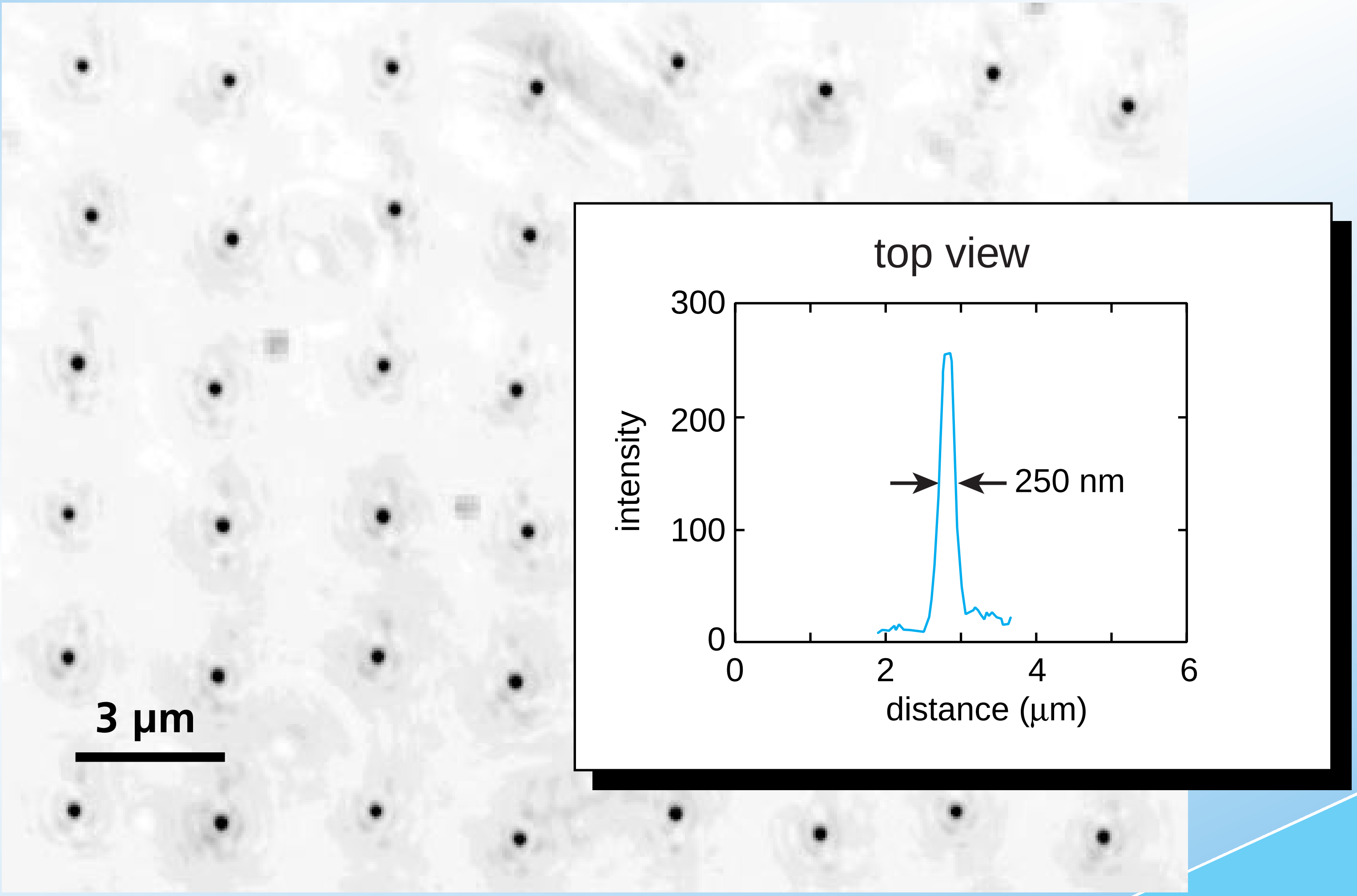
fused silica

9 µJ, 200 ps, 800 nm

Post-mortem analysis



Post-mortem analysis



Post-mortem analysis

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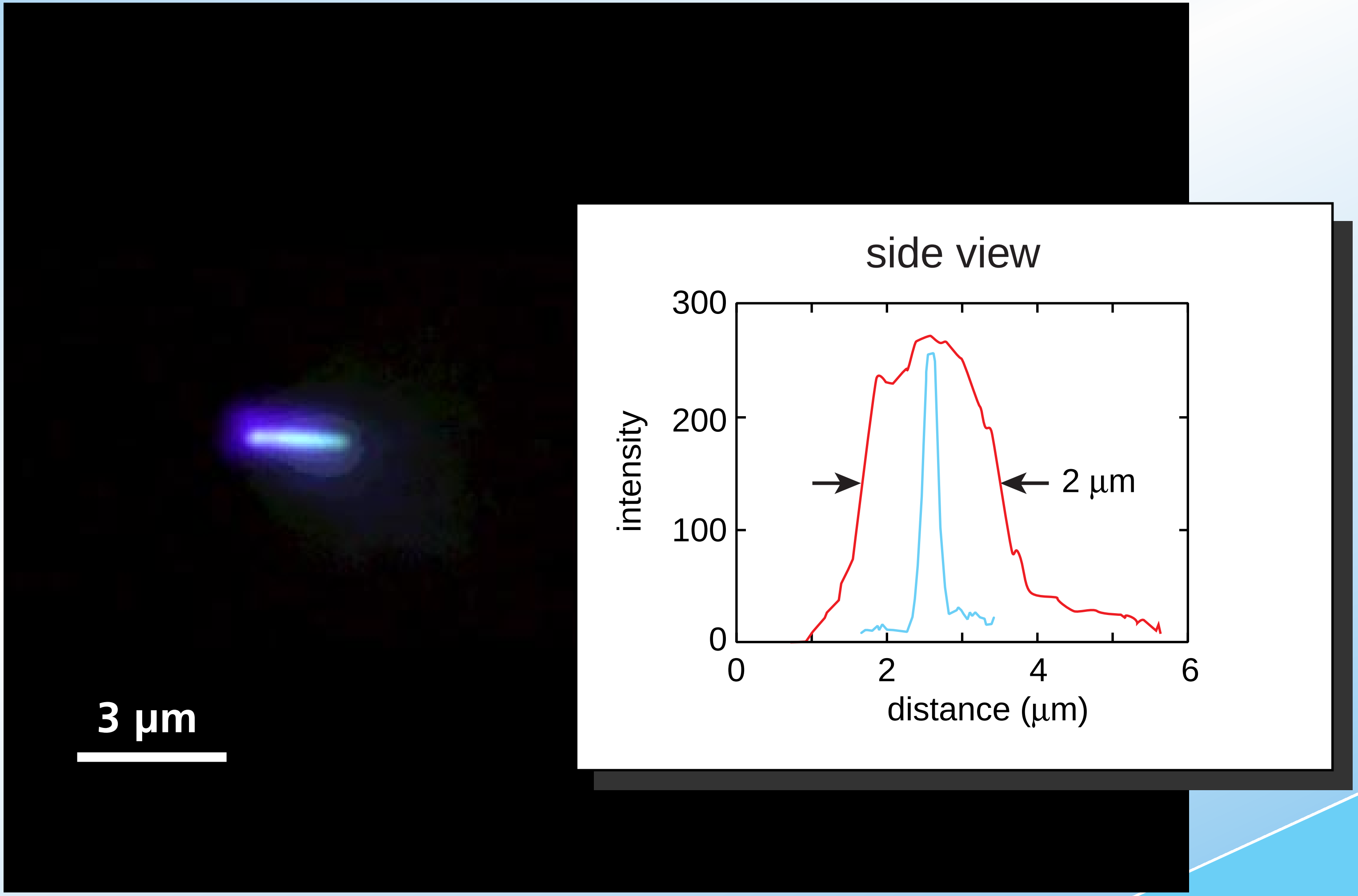

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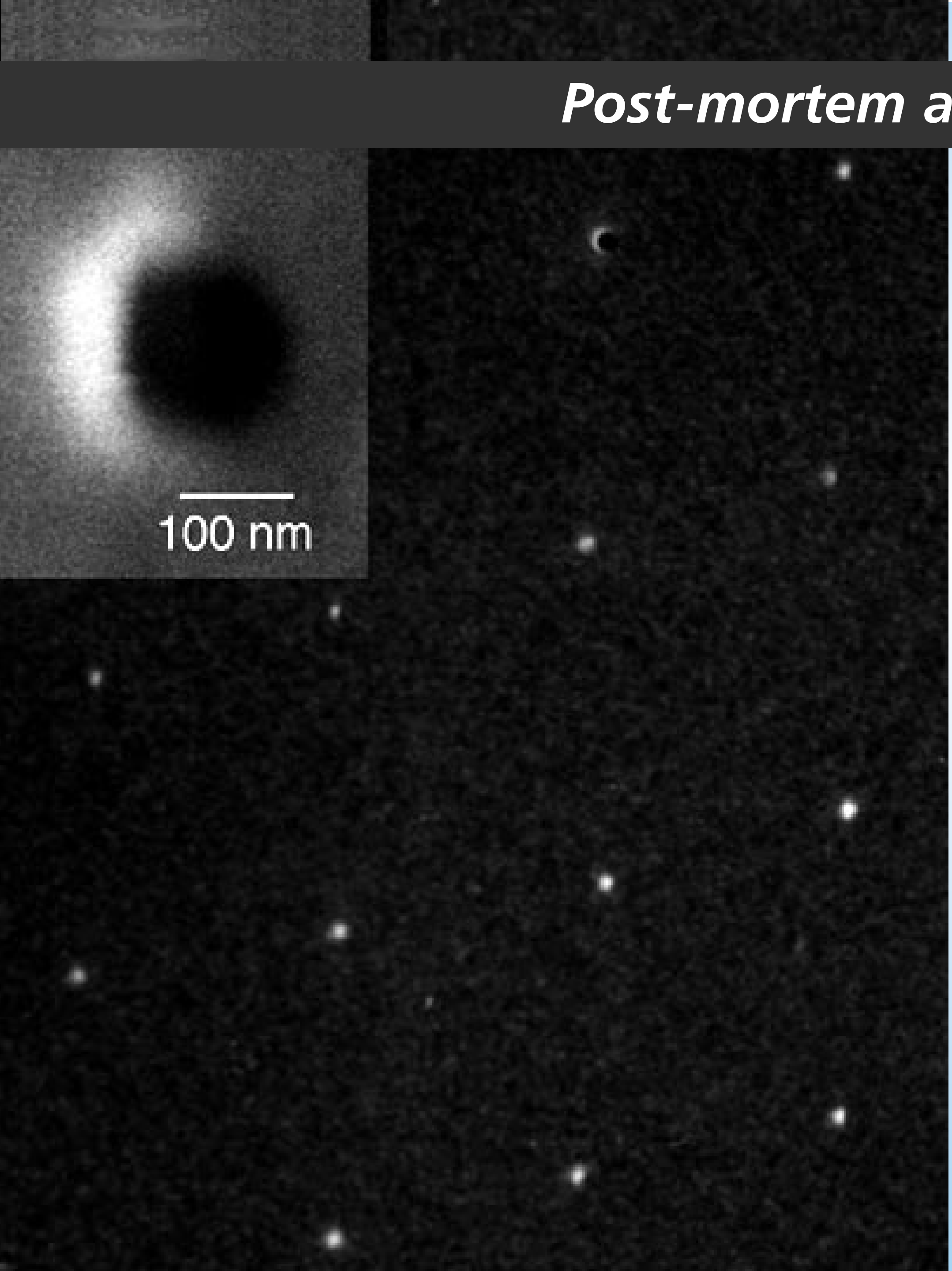
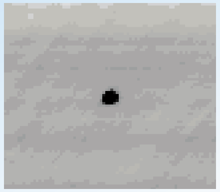


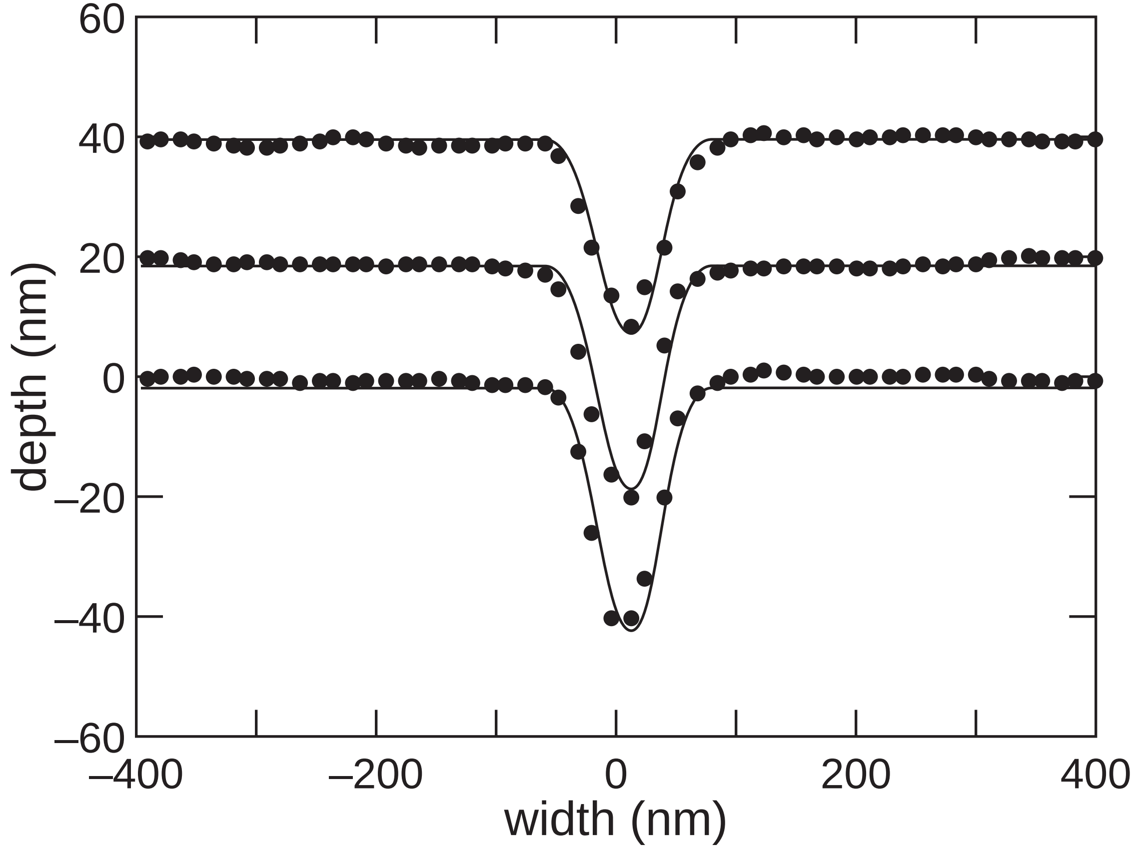
SEM:

bumps & pits!

Post-mortem analysis

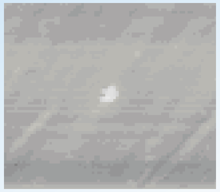
AFM scans of pits

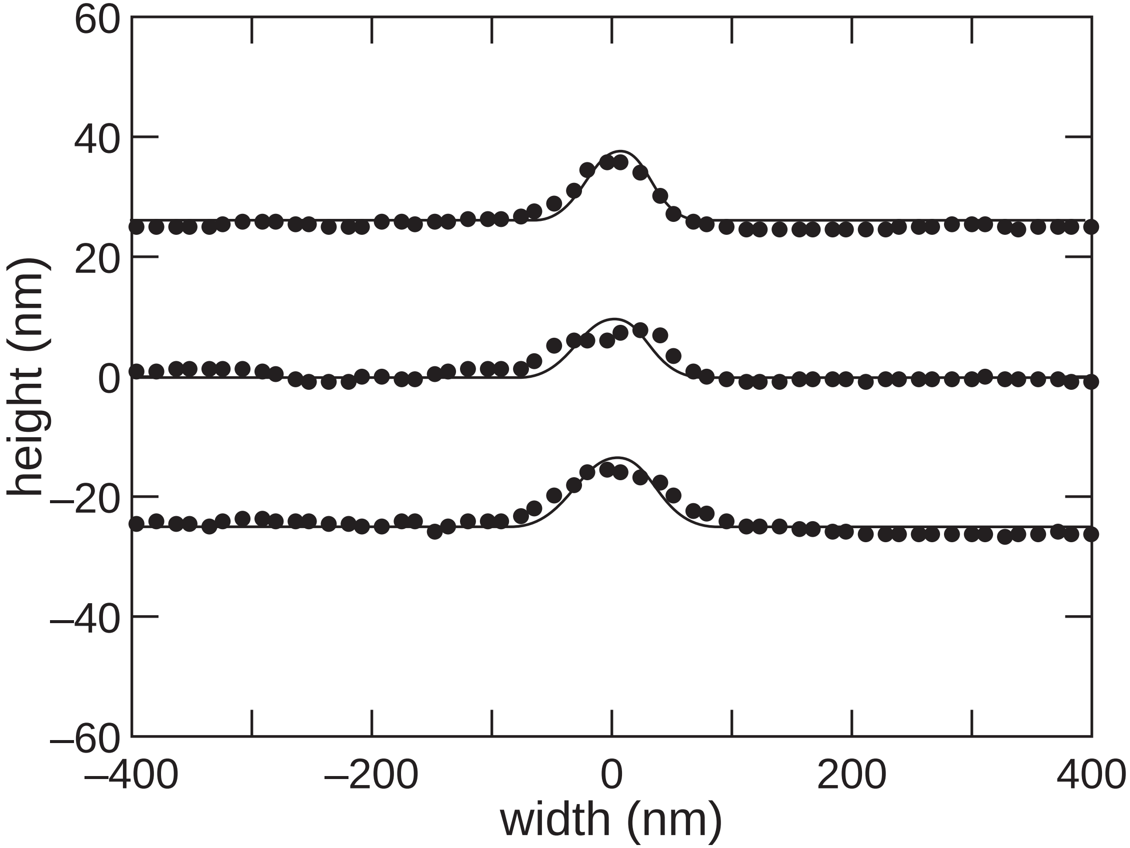




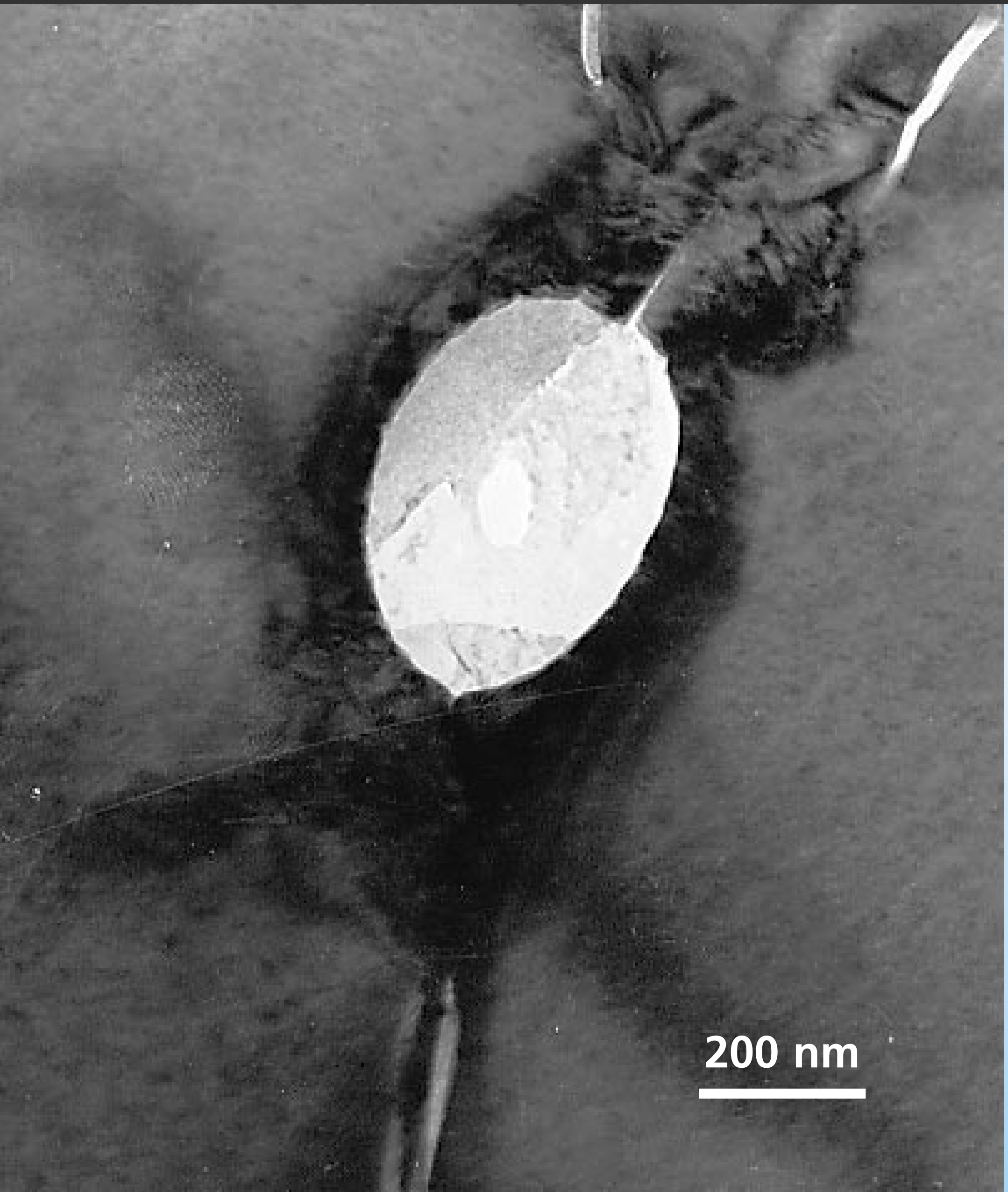
Post-mortem analysis

AFM scans of bump





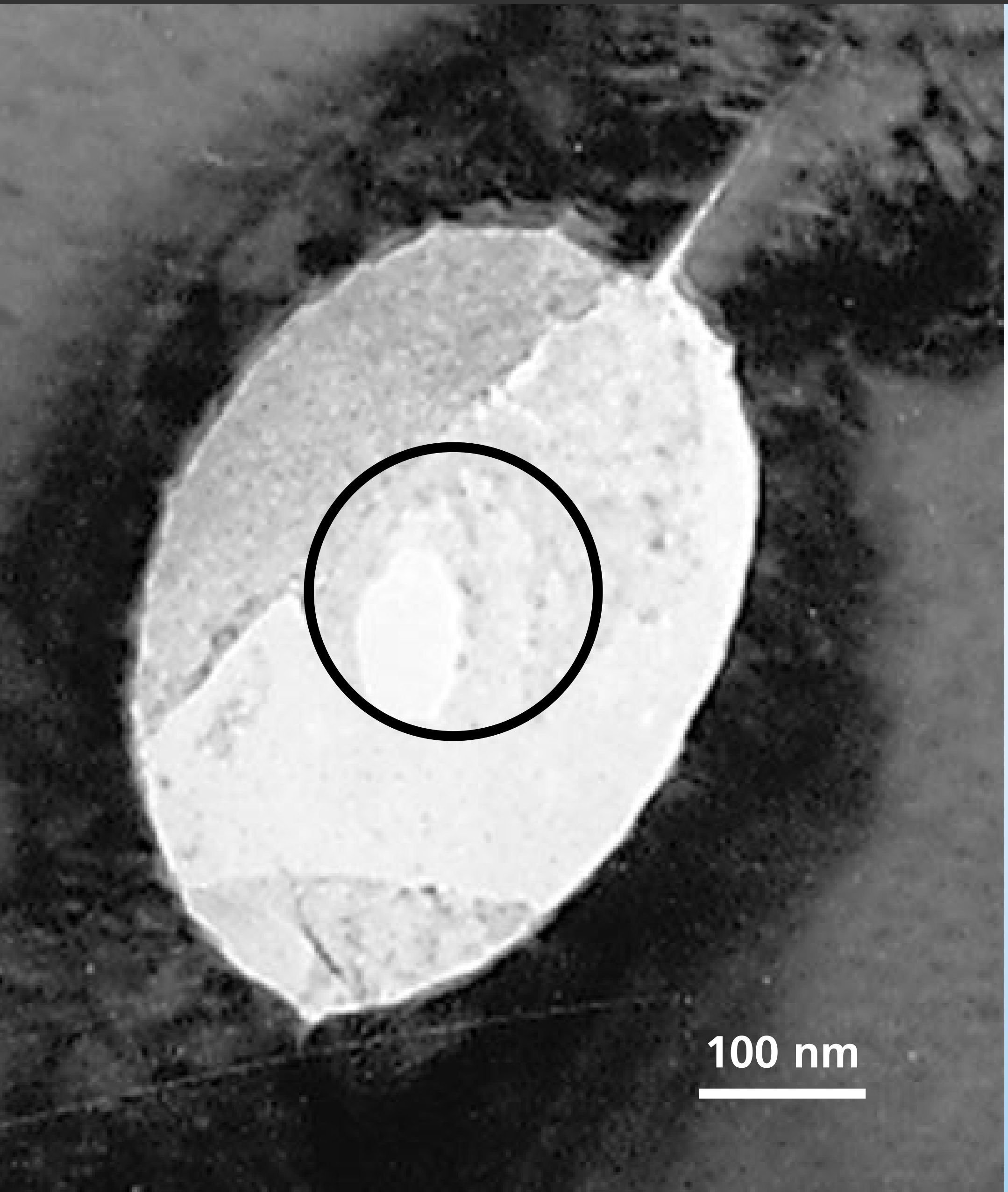
Post-mortem analysis



TEM picture

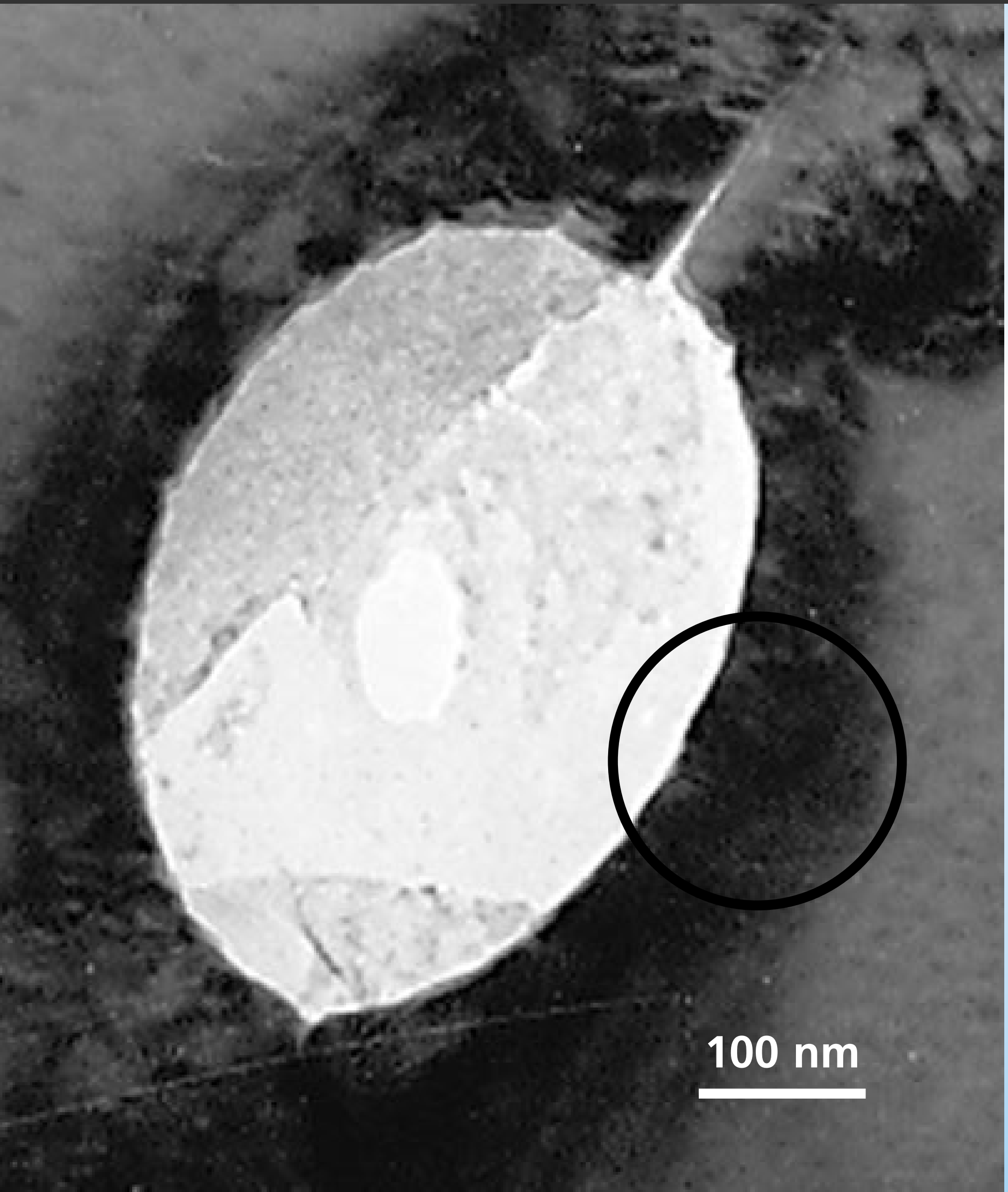
sapphire

Post-mortem analysis

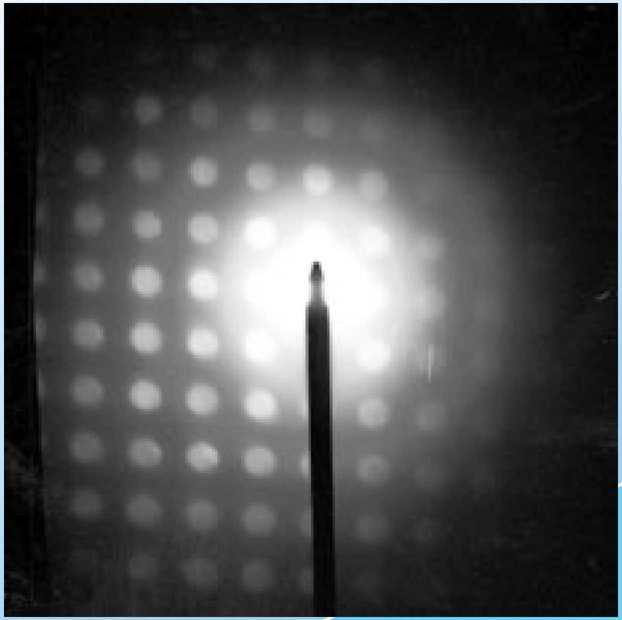


electron diffraction: amorphous?

Post-mortem analysis



electron diffraction: crystalline



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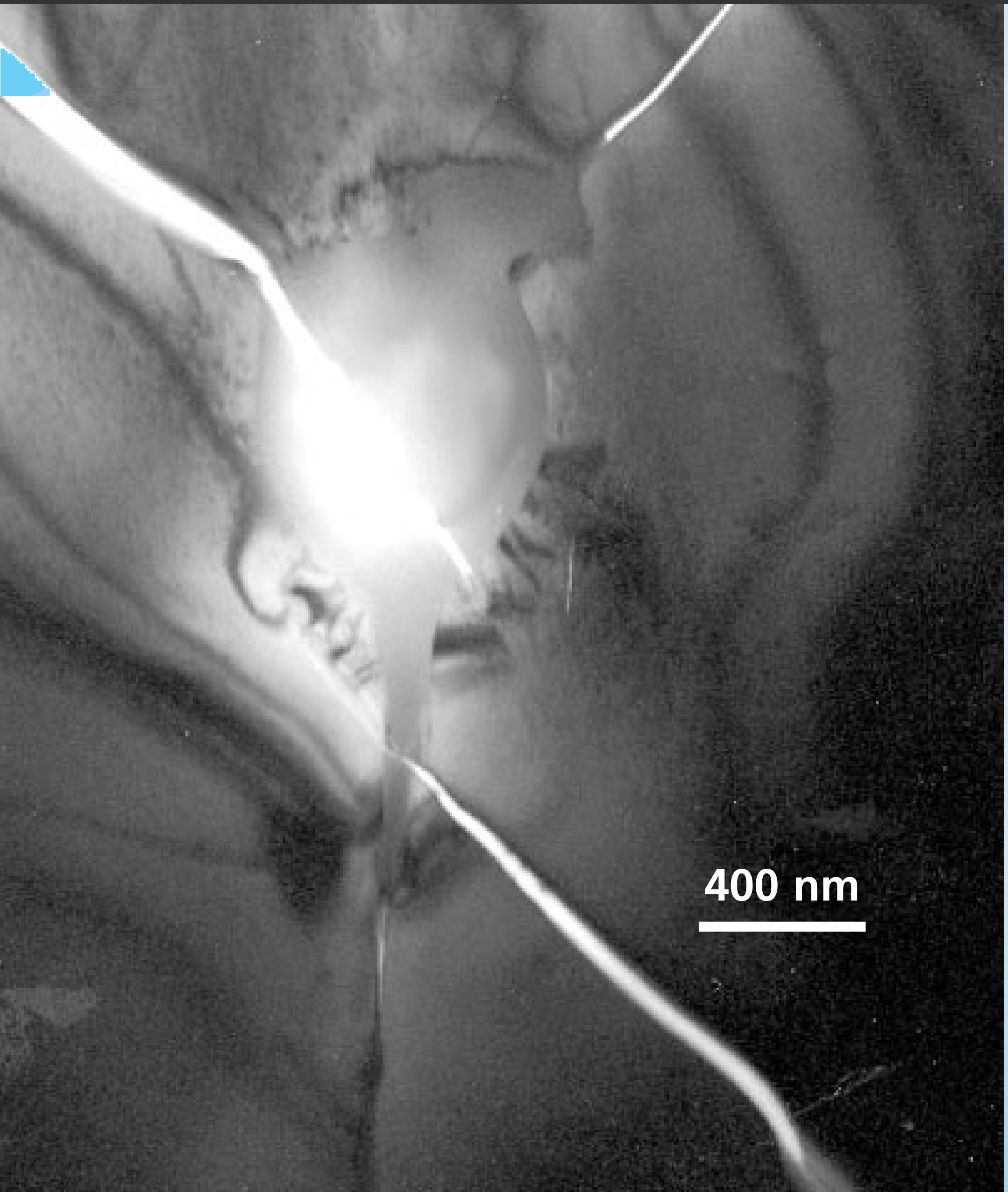
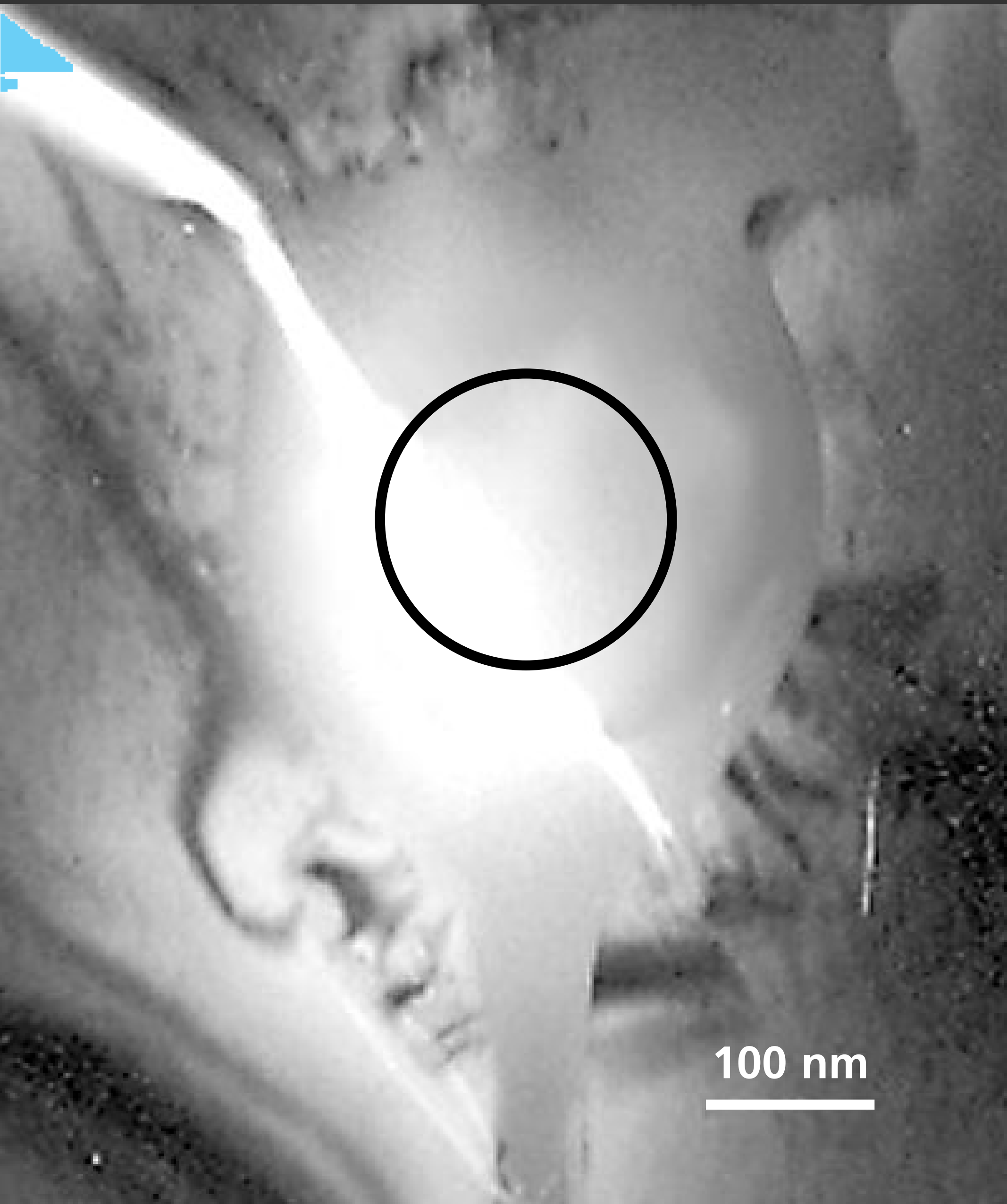


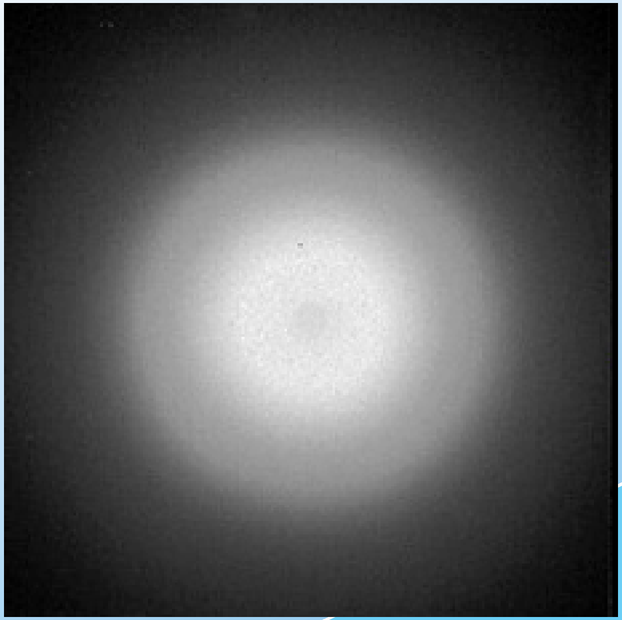
TEM picture

quartz

Post-mortem analysis



electron diffraction: amorphous



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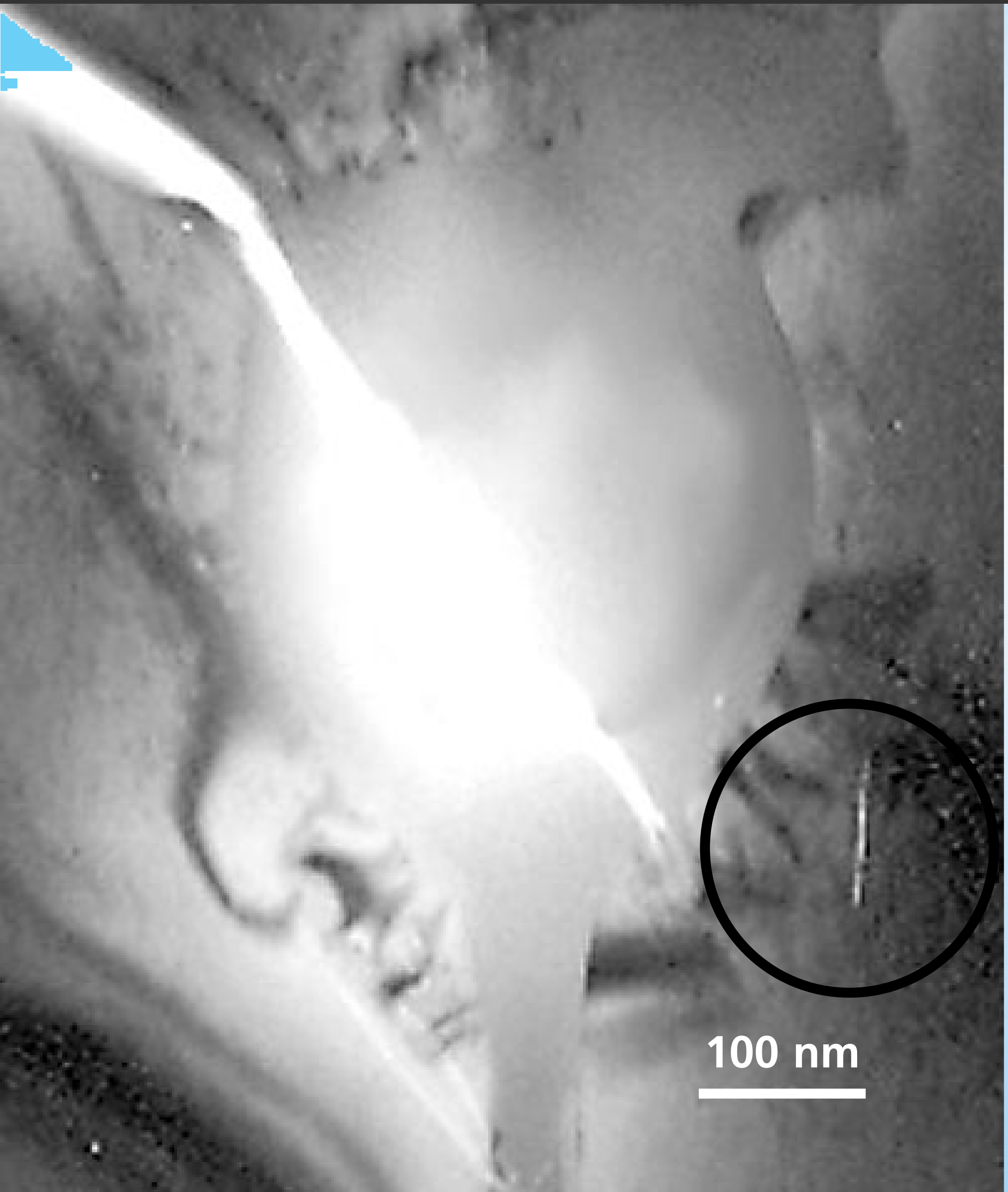
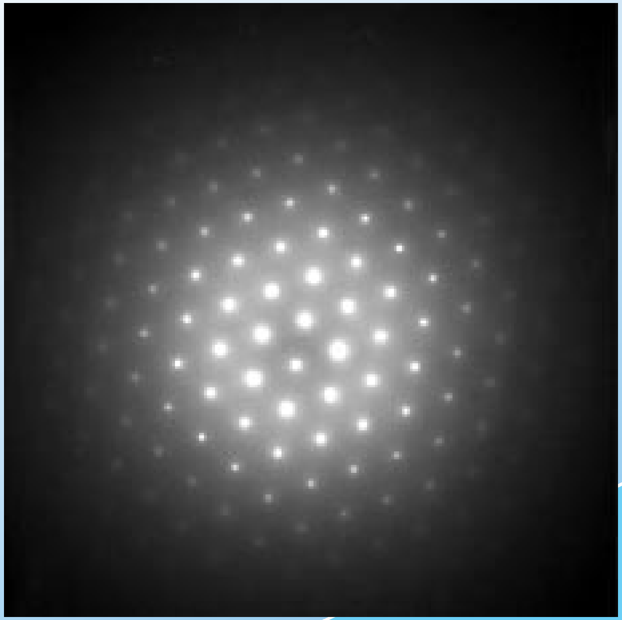


electron diffraction: crystalline



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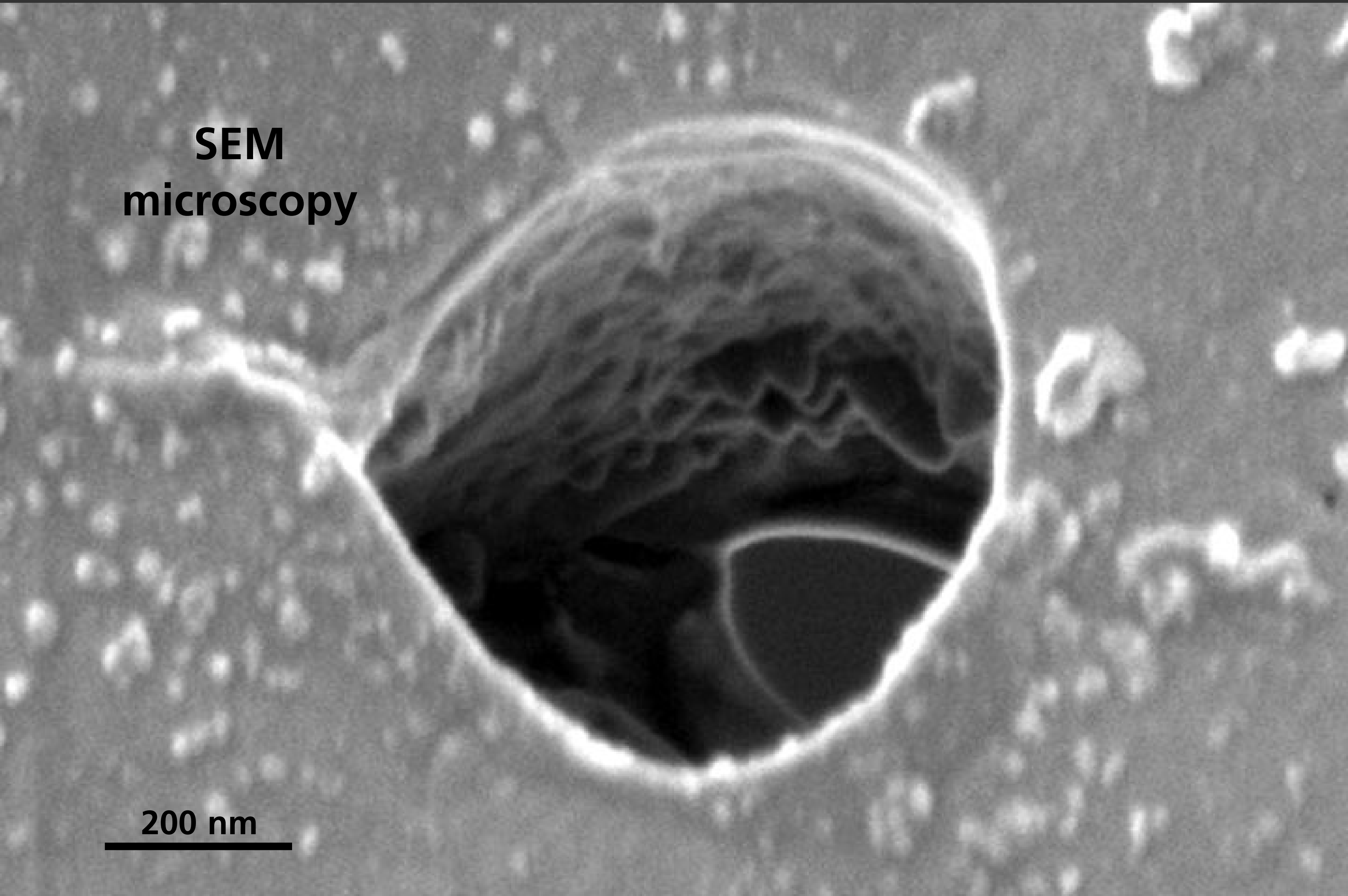
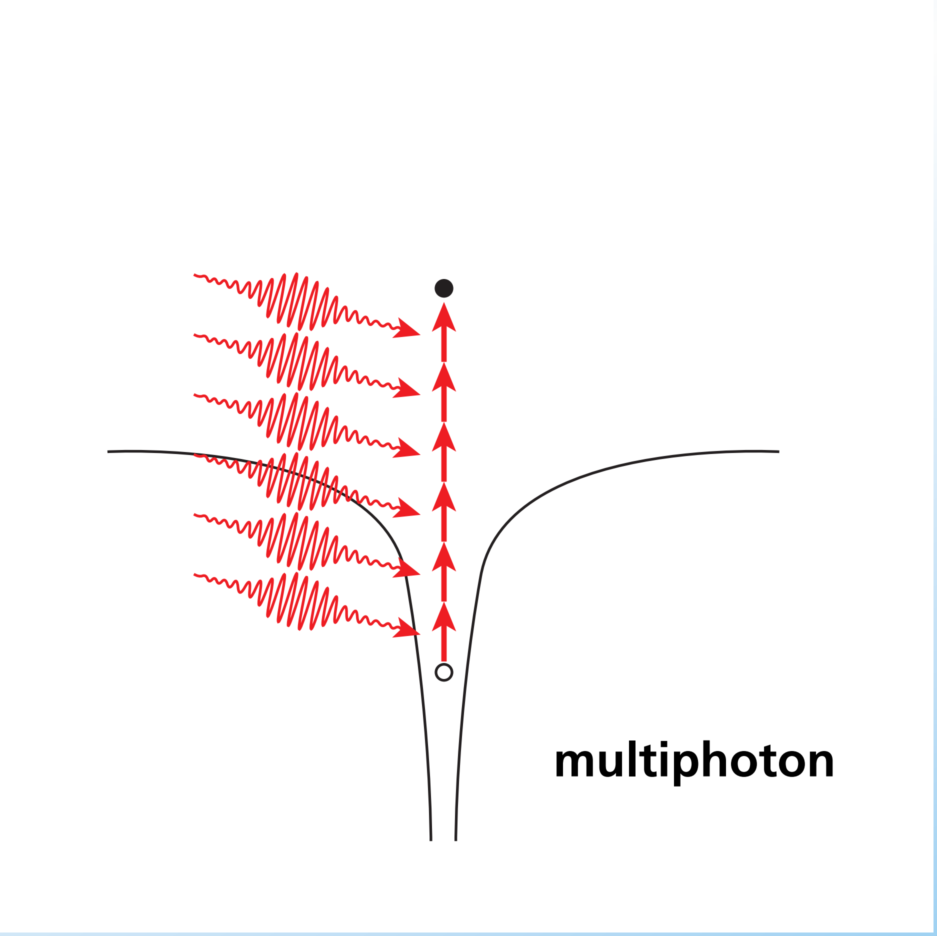


Energy deposition

how little energy produces permanent changes?

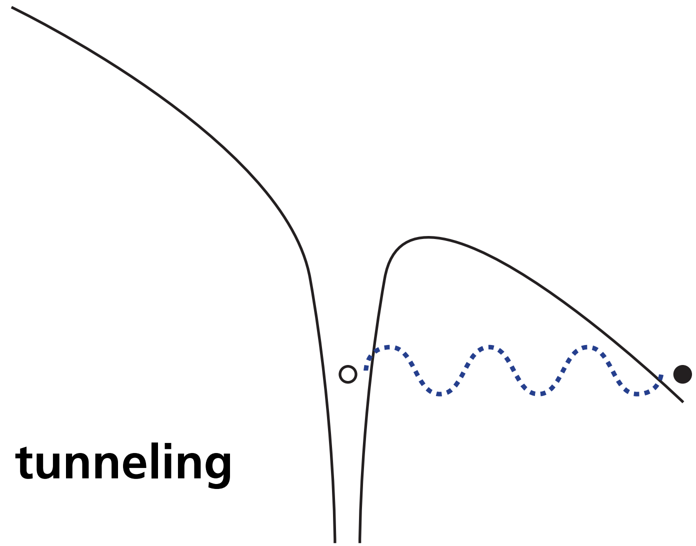
Energy deposition

laser field ionization



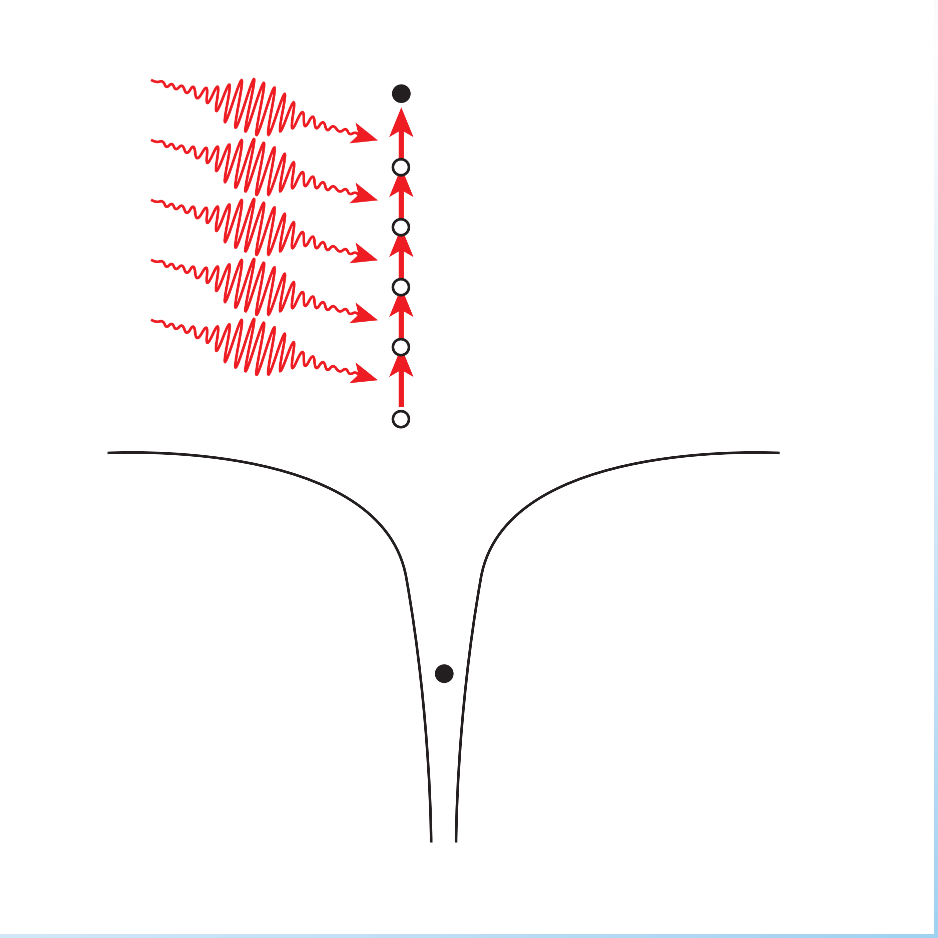
Energy deposition

laser field ionization



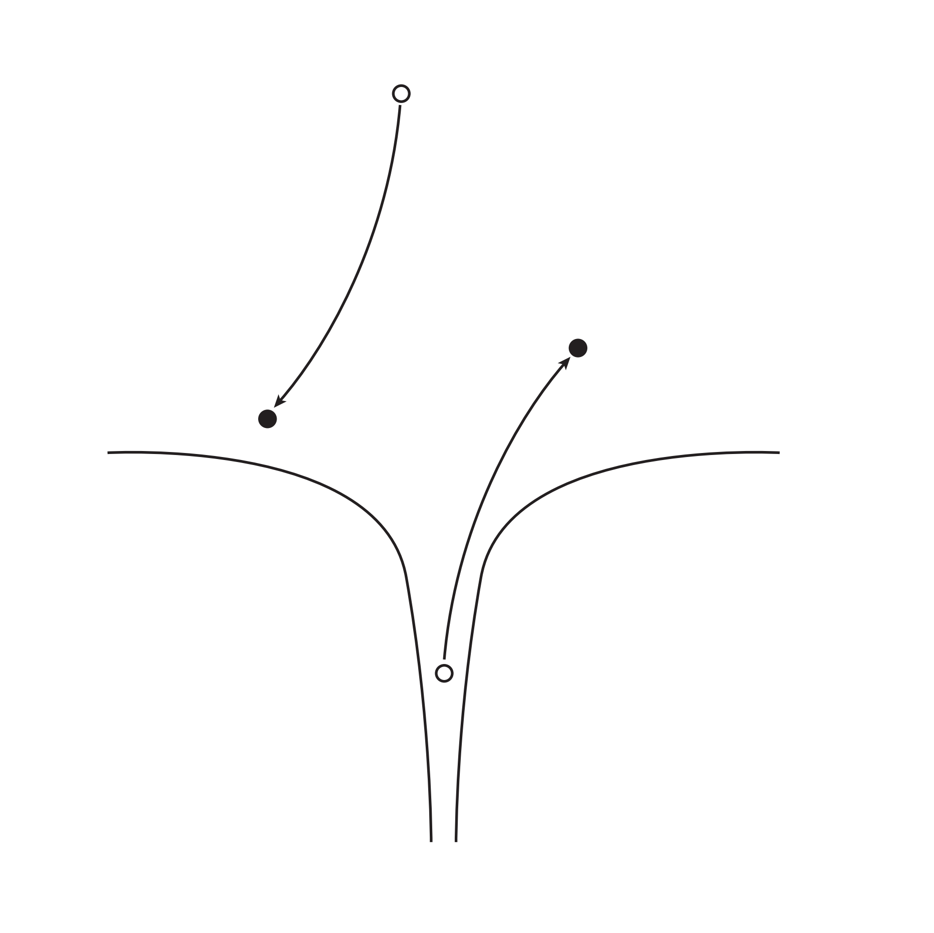
Energy deposition

impact ionization



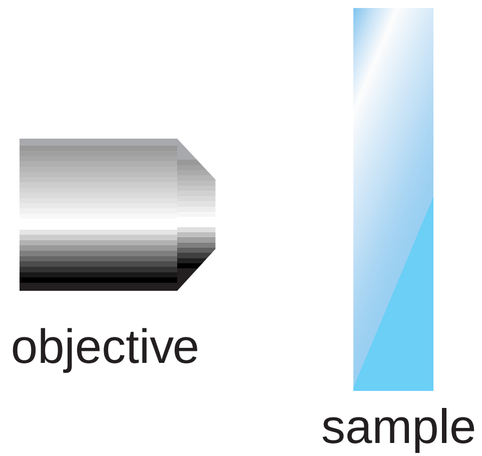
Energy deposition

impact ionization

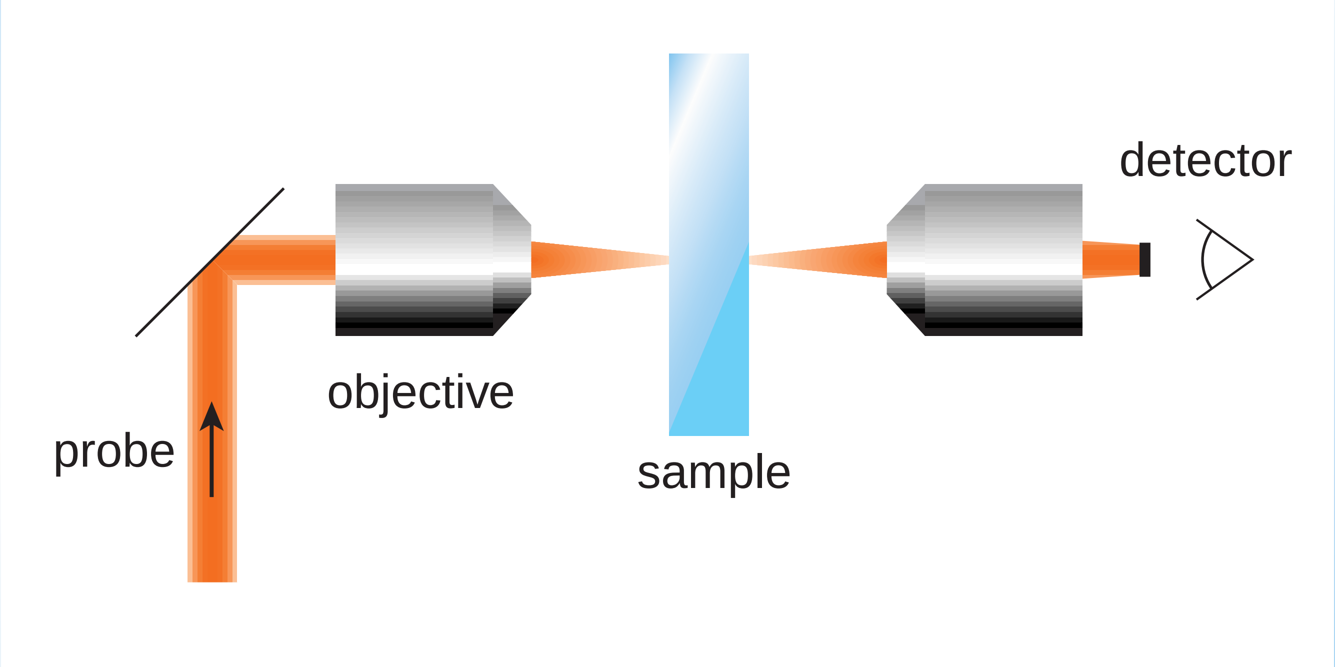


Energy deposition

Dark-field scattering

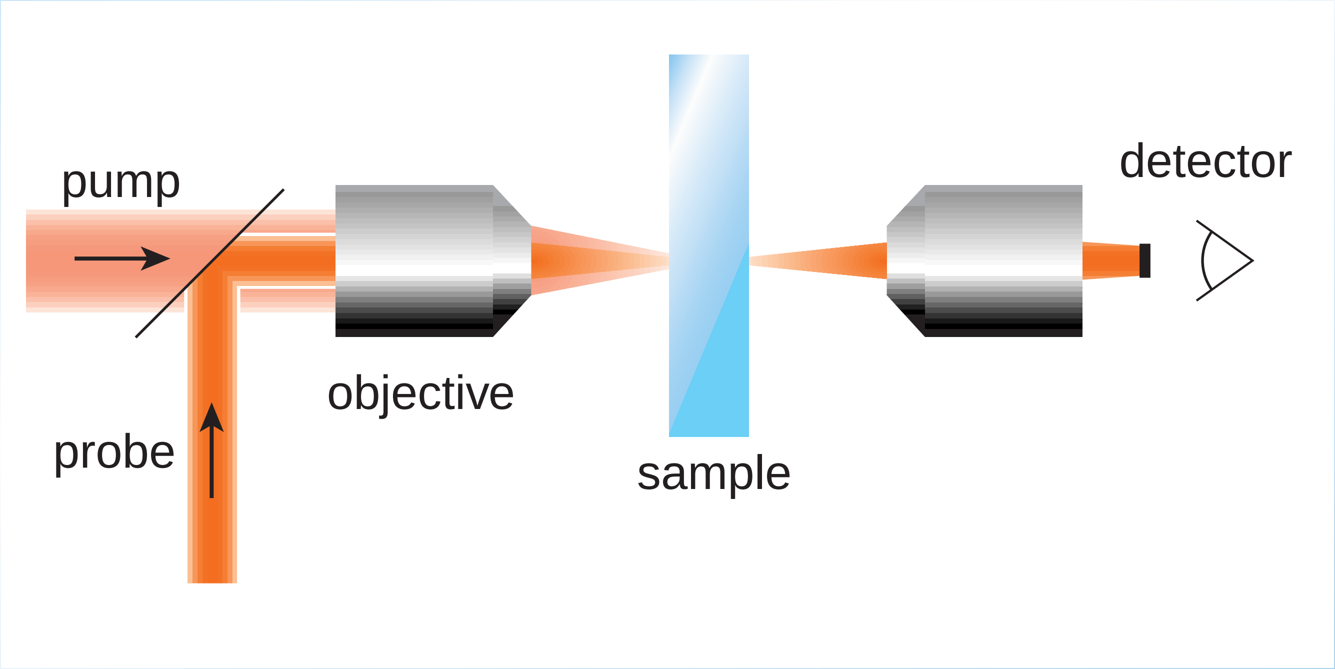


block probe beam…



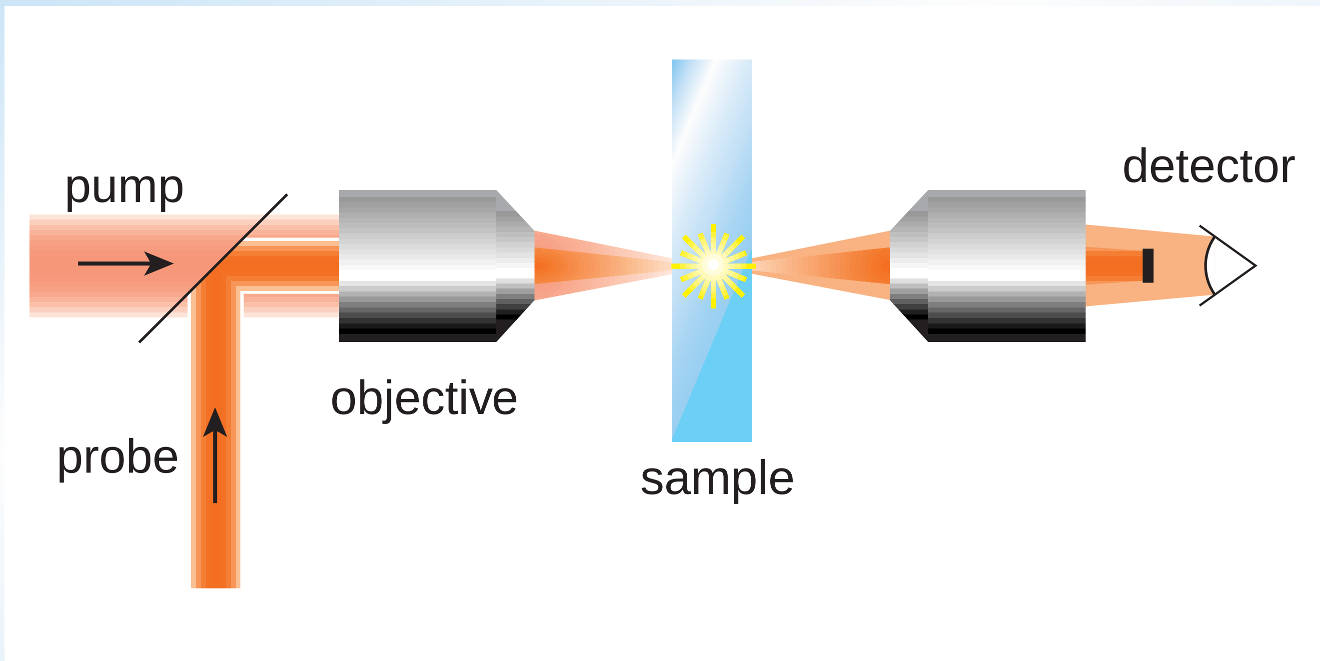
Energy deposition

…bring in pump beam…

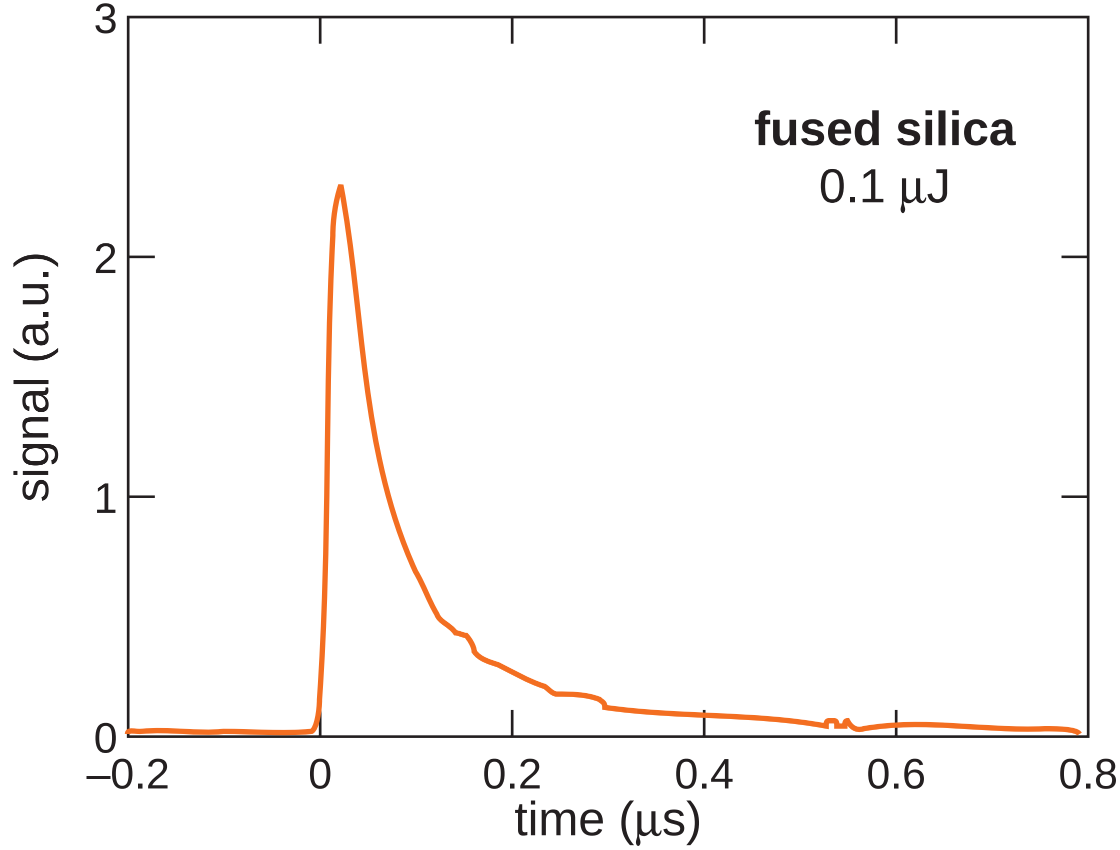


Energy deposition

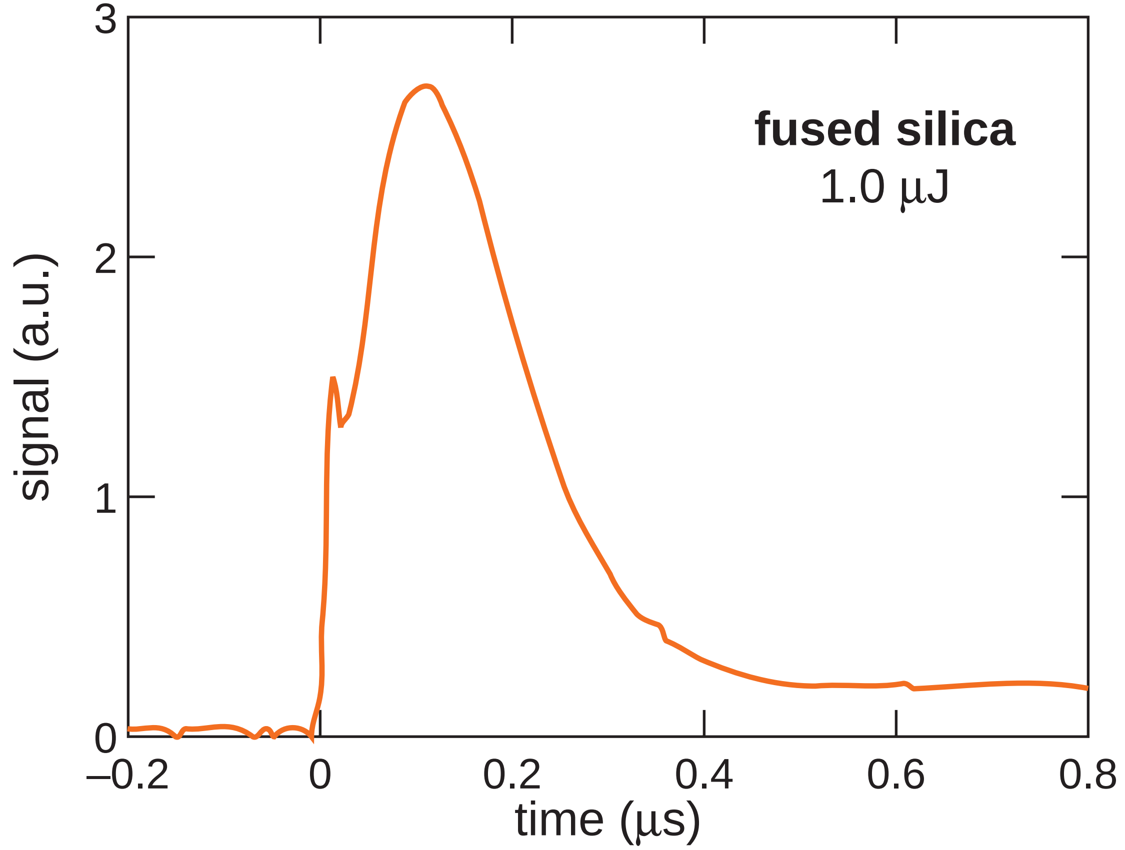
…damage scatters probe beam



Energy deposition



Energy deposition



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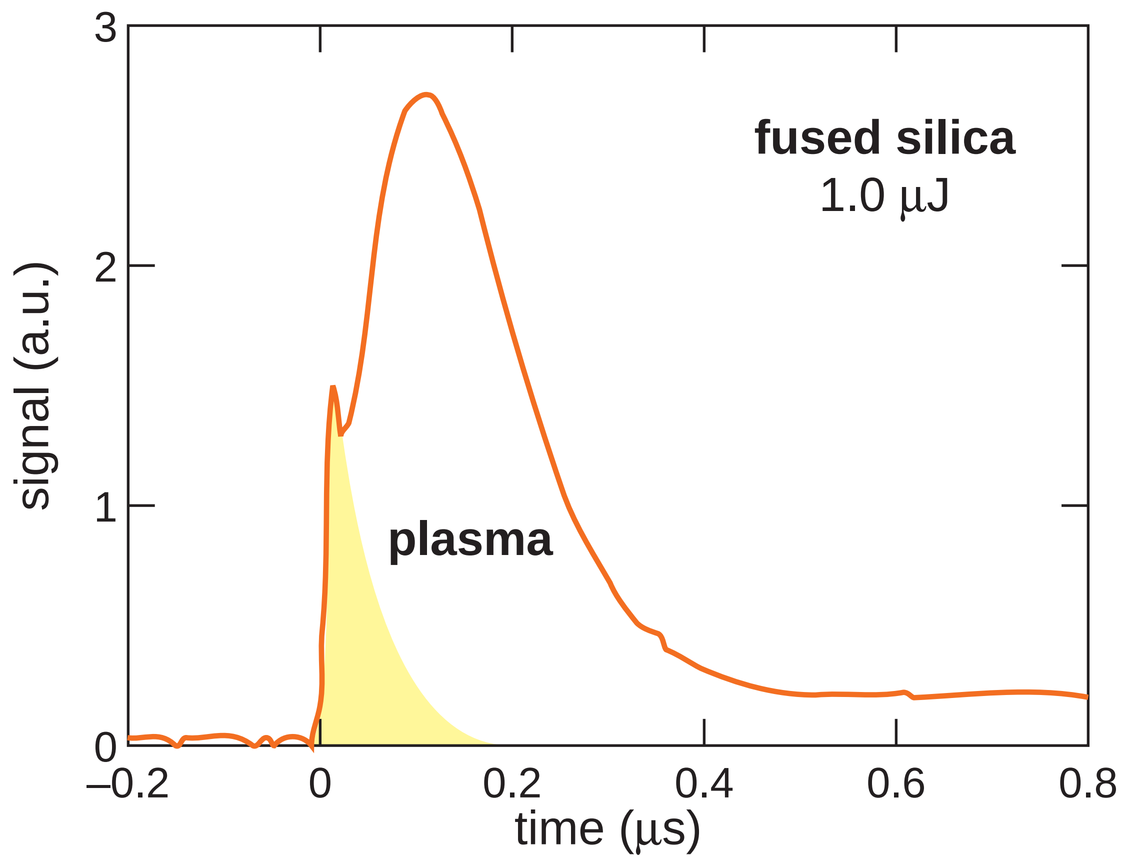
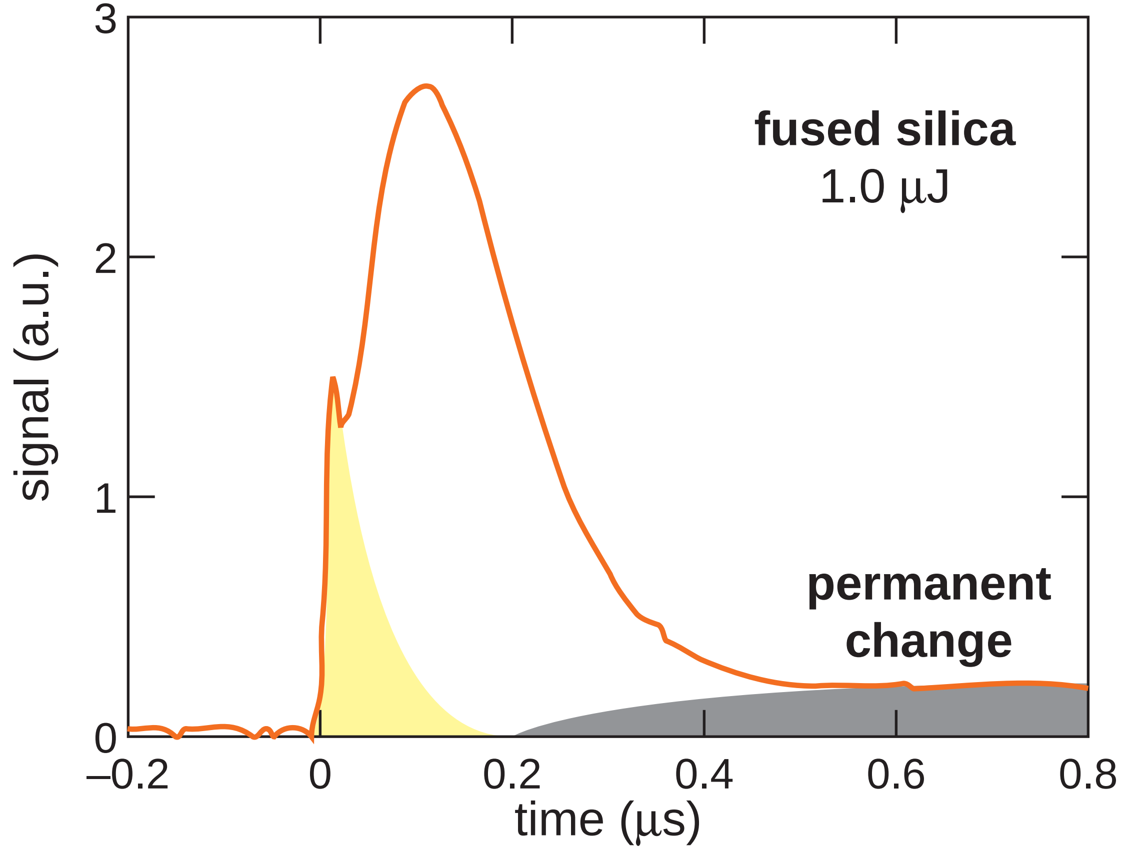


Energy deposition



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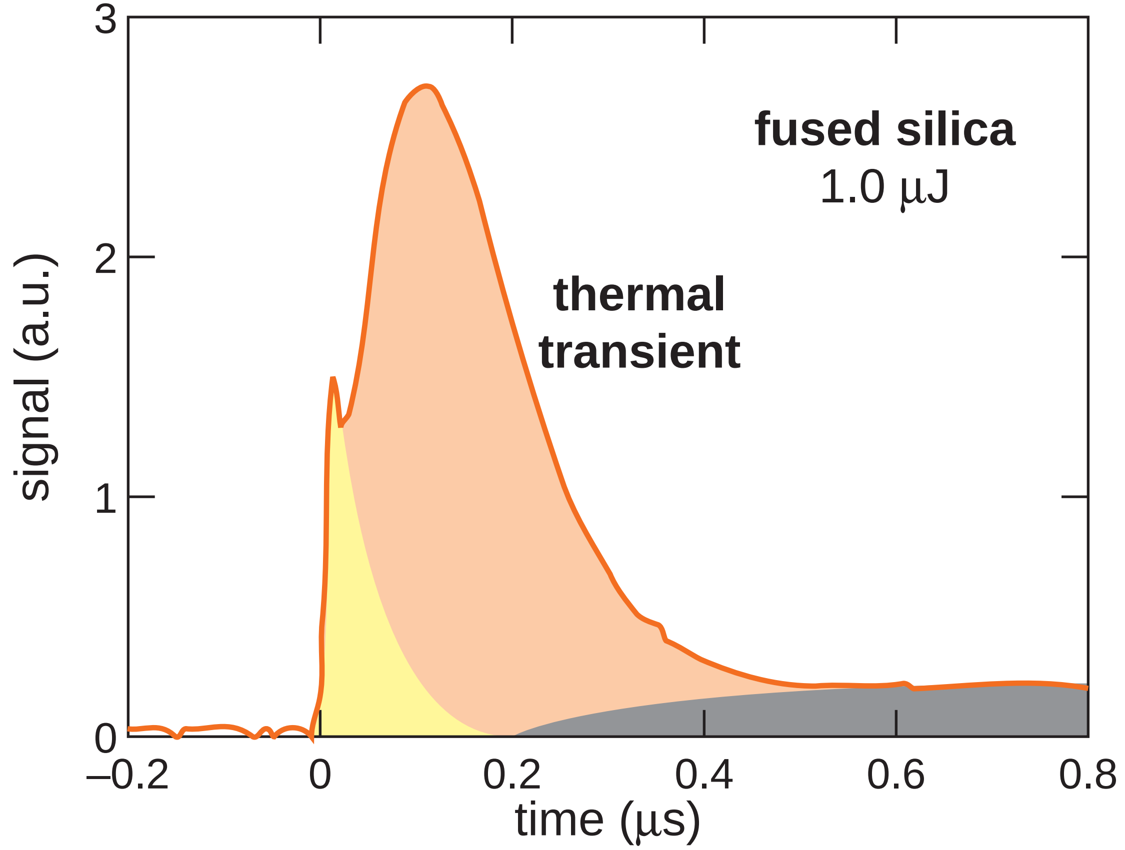
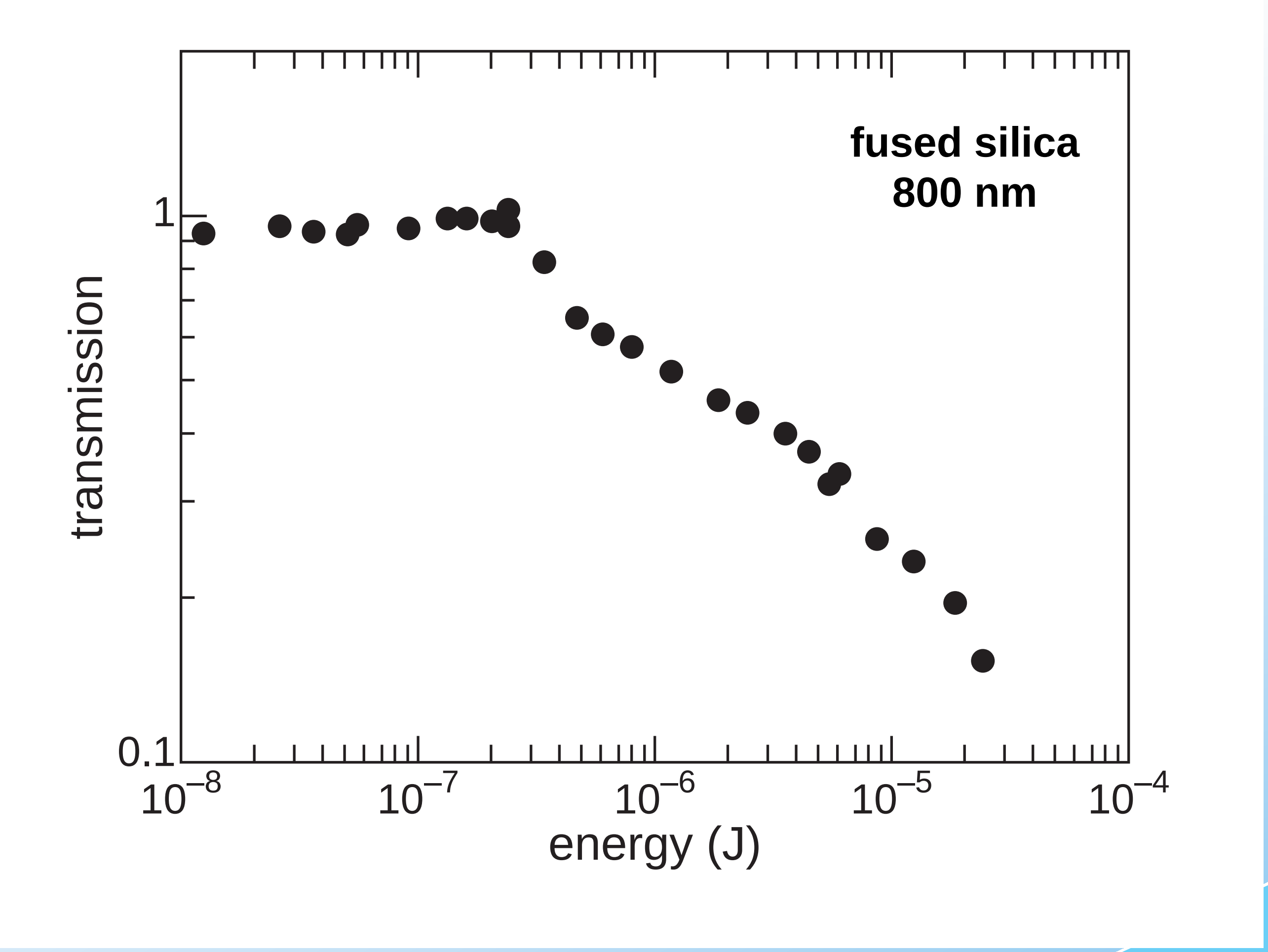


Energy deposition

transmission of pump beam in fused silica



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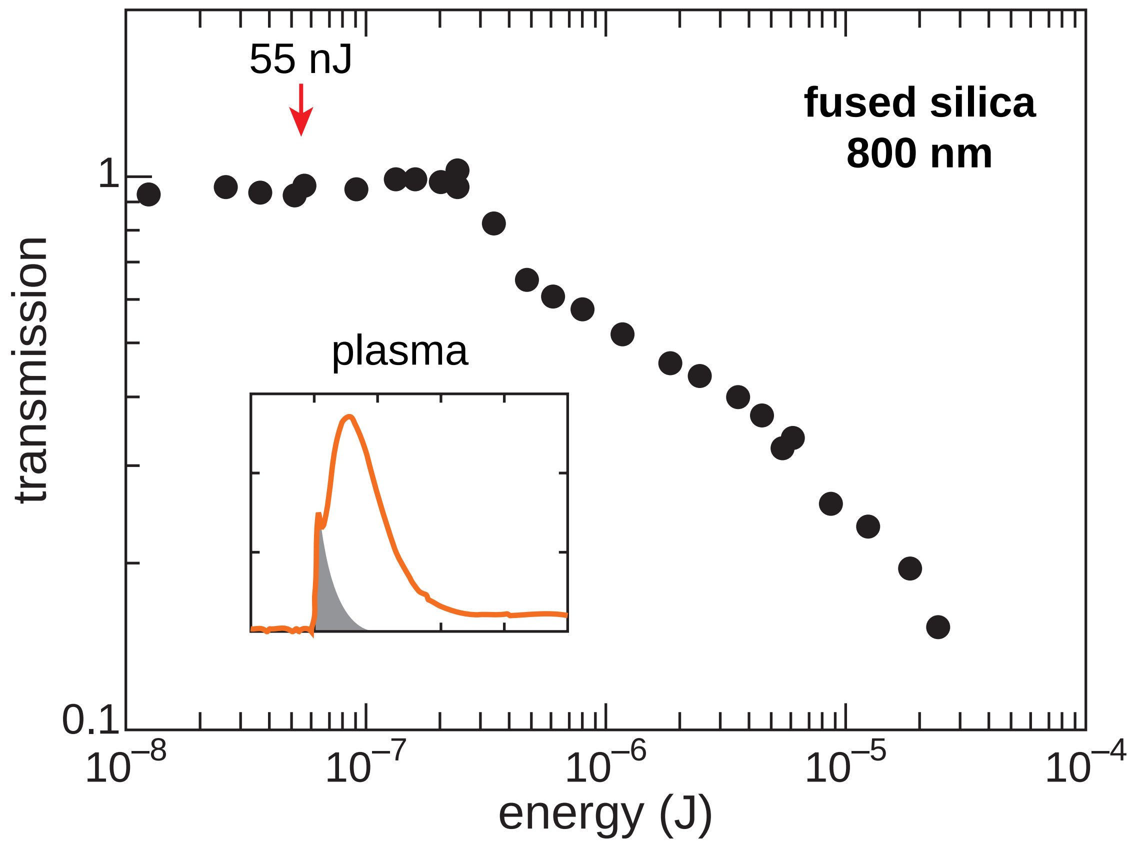

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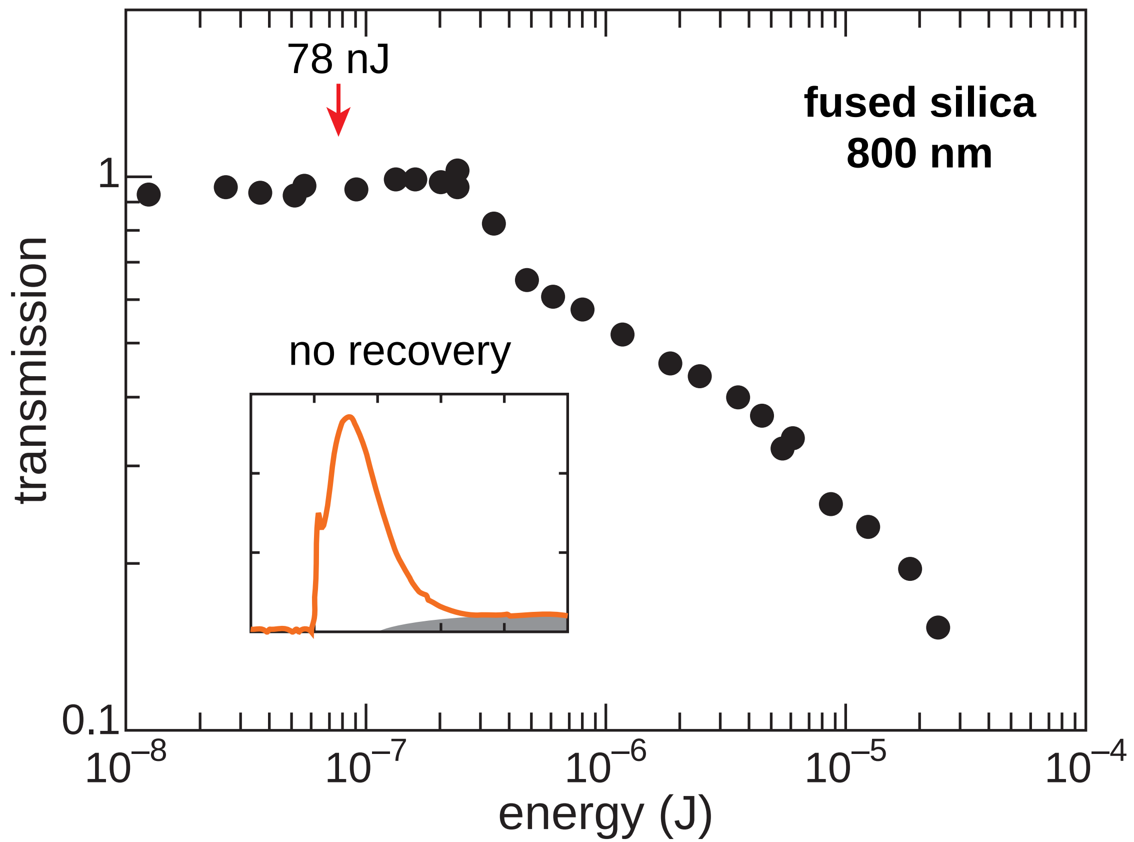

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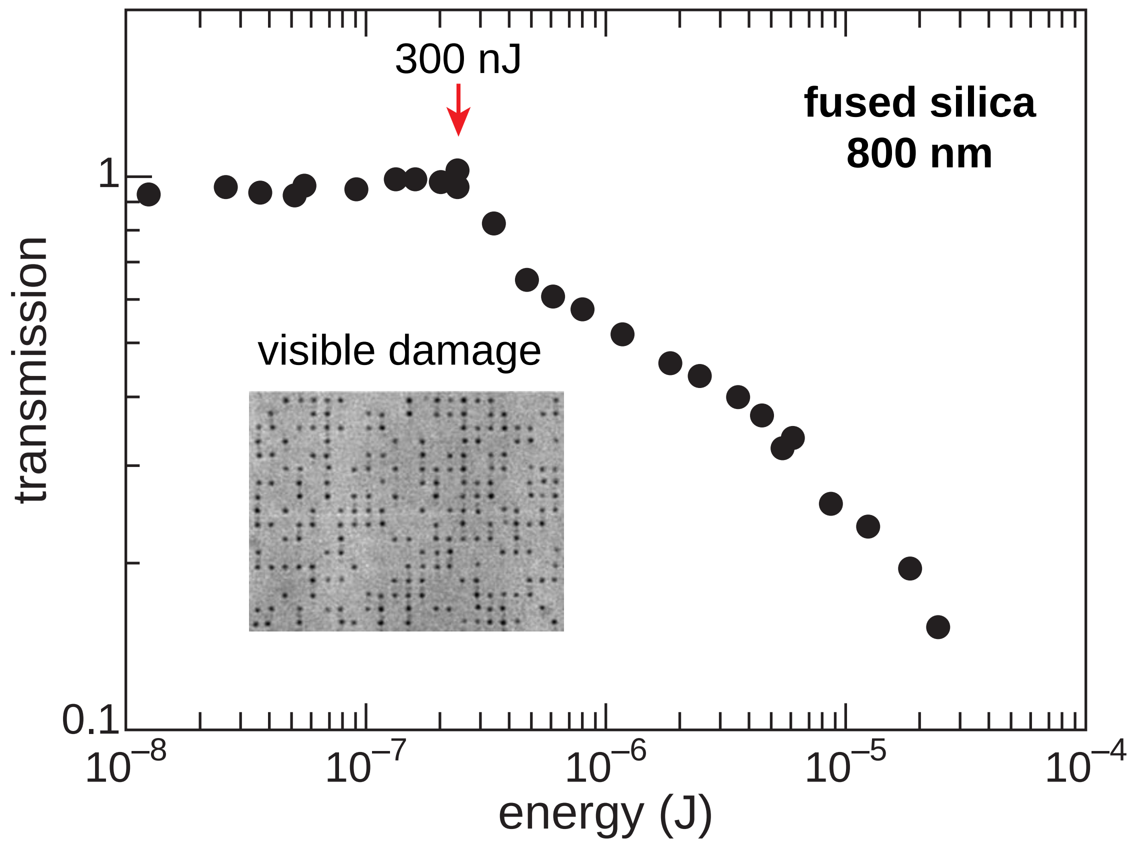
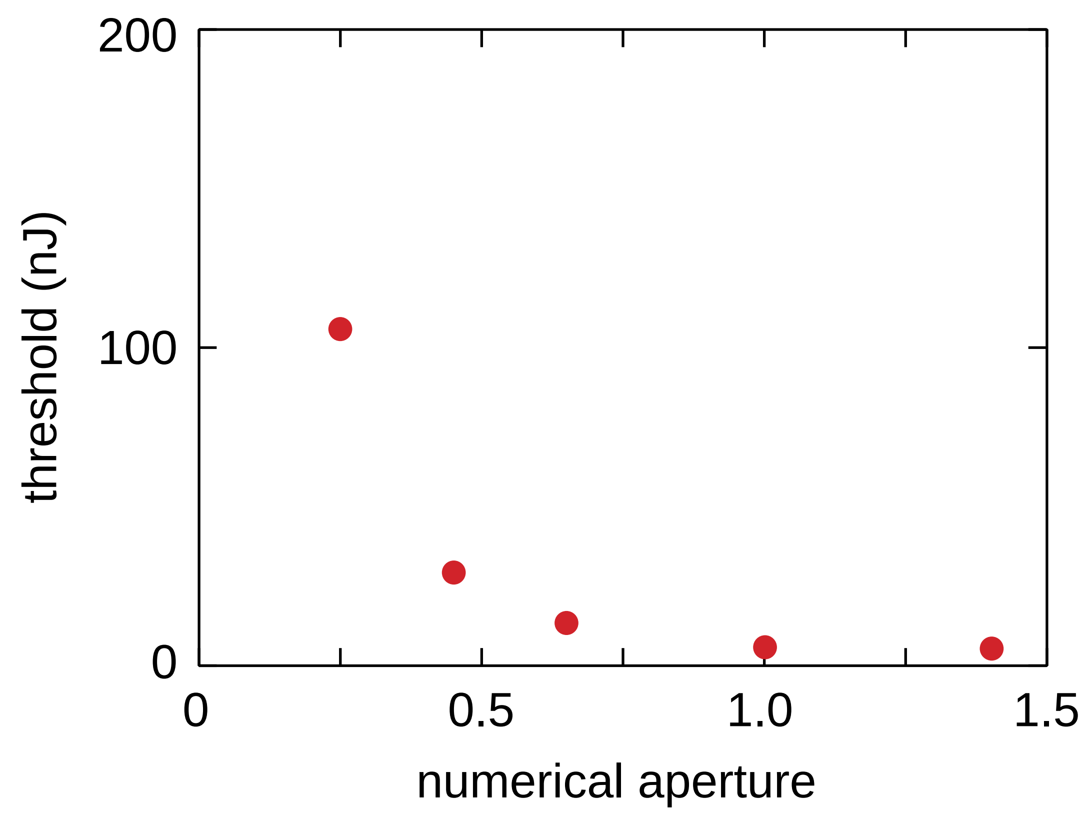
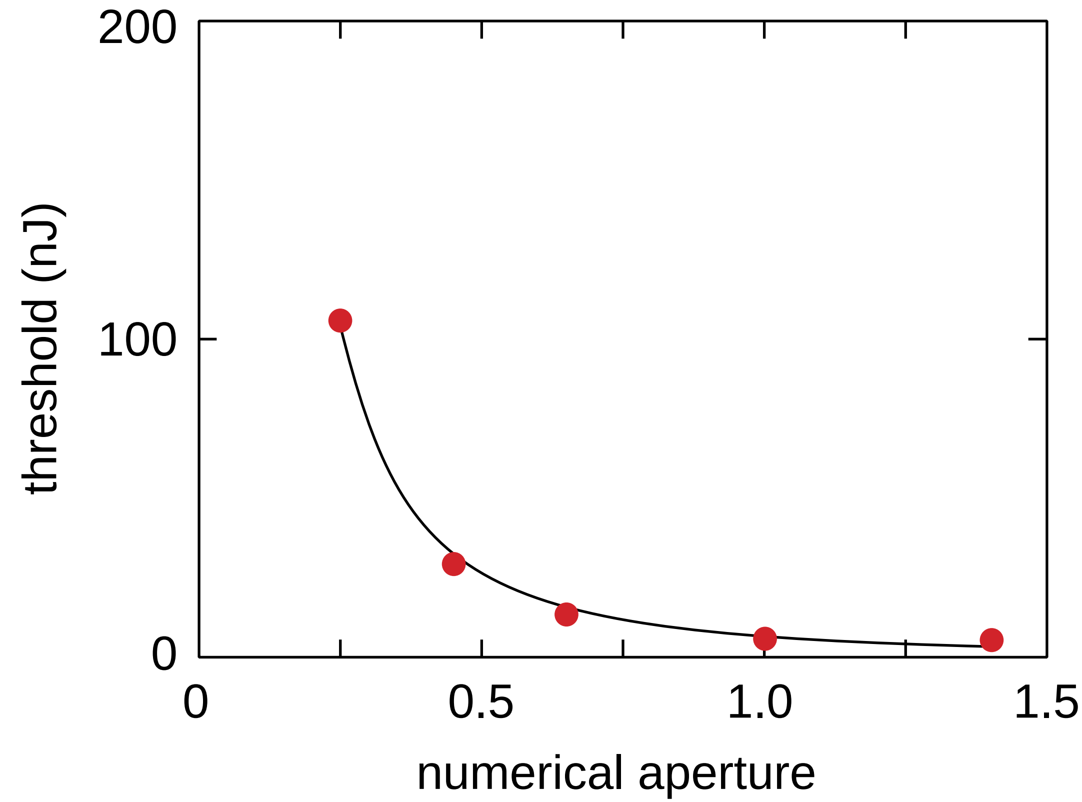


vary numerical aperture in Corning 0211



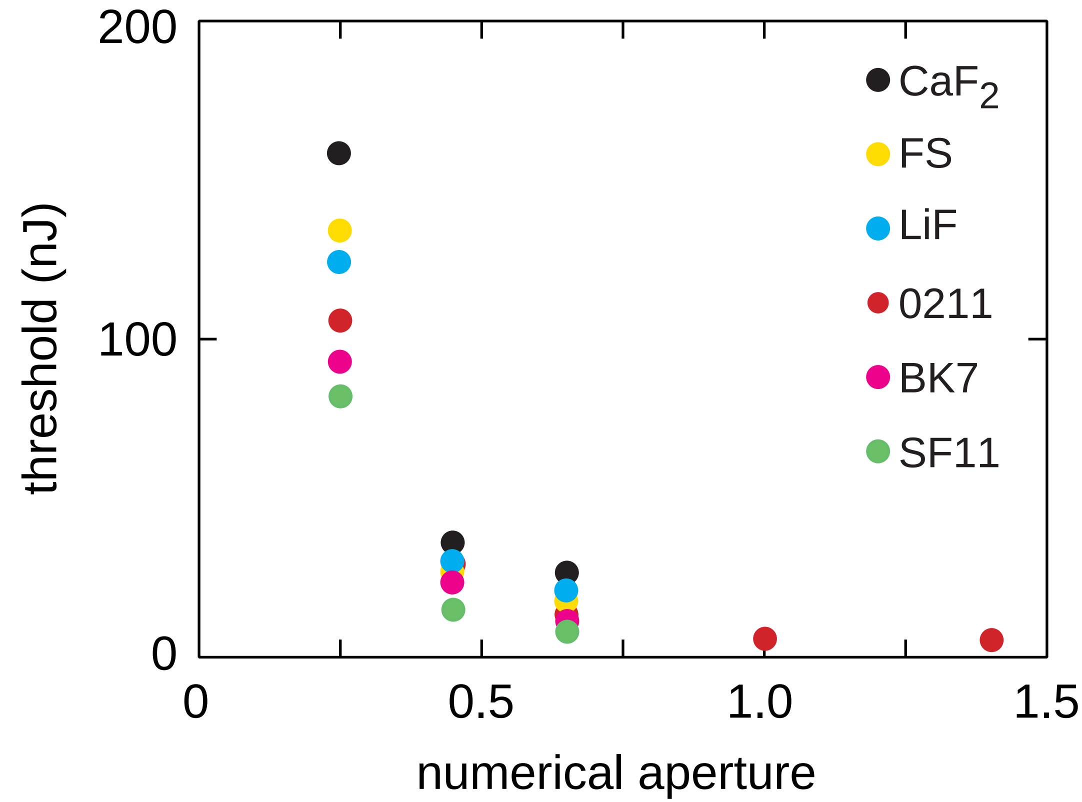
Energy deposition

fit gives threshold intensity: I_o **= 2.7 x 10^{17} W/m^2**



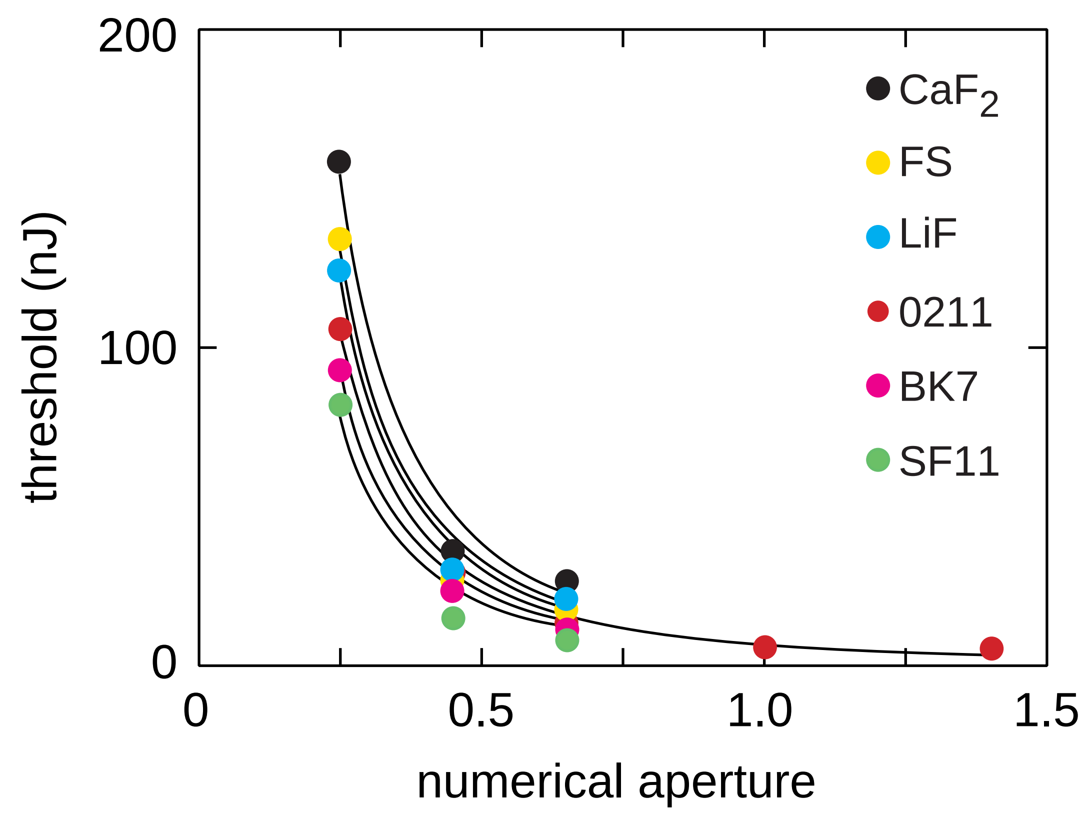
Energy deposition

other materials…



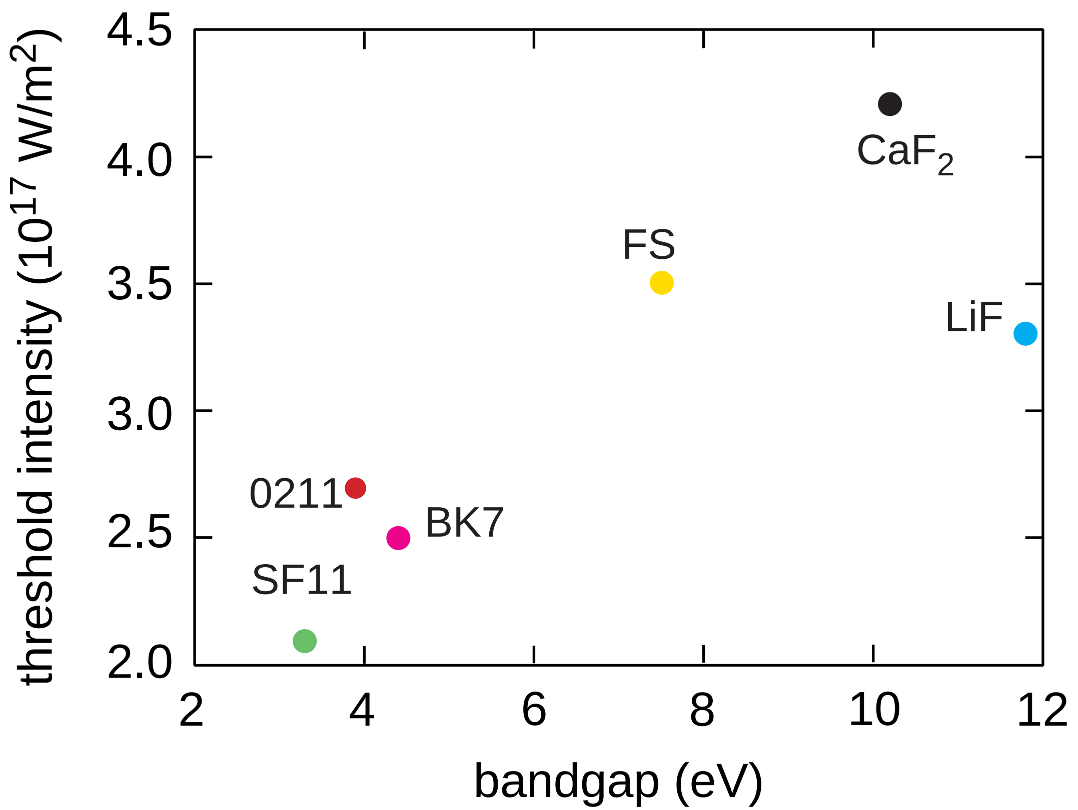
Energy deposition

… give other thresholds



Energy deposition

threshold increases with bandgap



Energy deposition

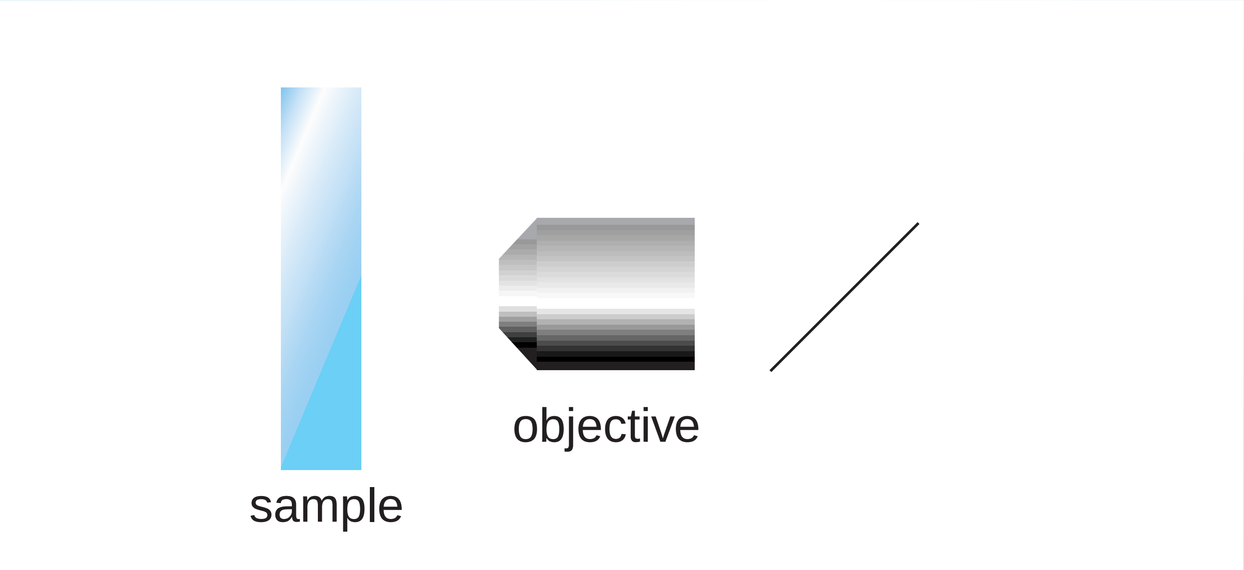
- plasma below damage threshold
- damage with only tens of nanojoules
- weak dependence on bandgap
- no shot-to-shot variation

Microexplosion dynamics

what happens after the energy is deposited?

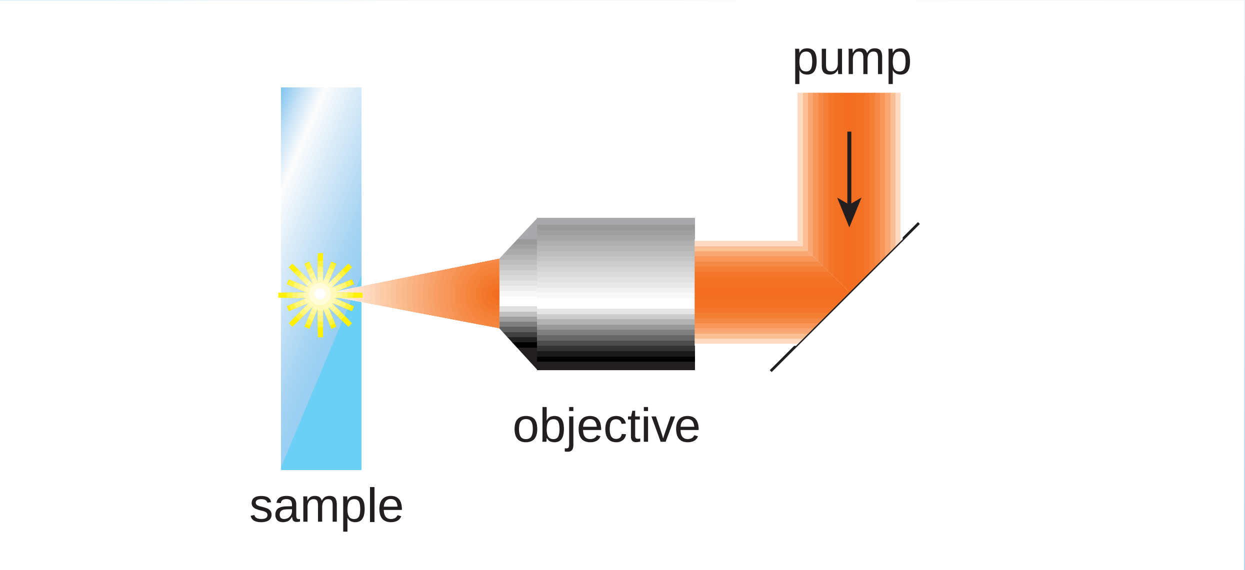
Microexplosion dynamics

imaging setup



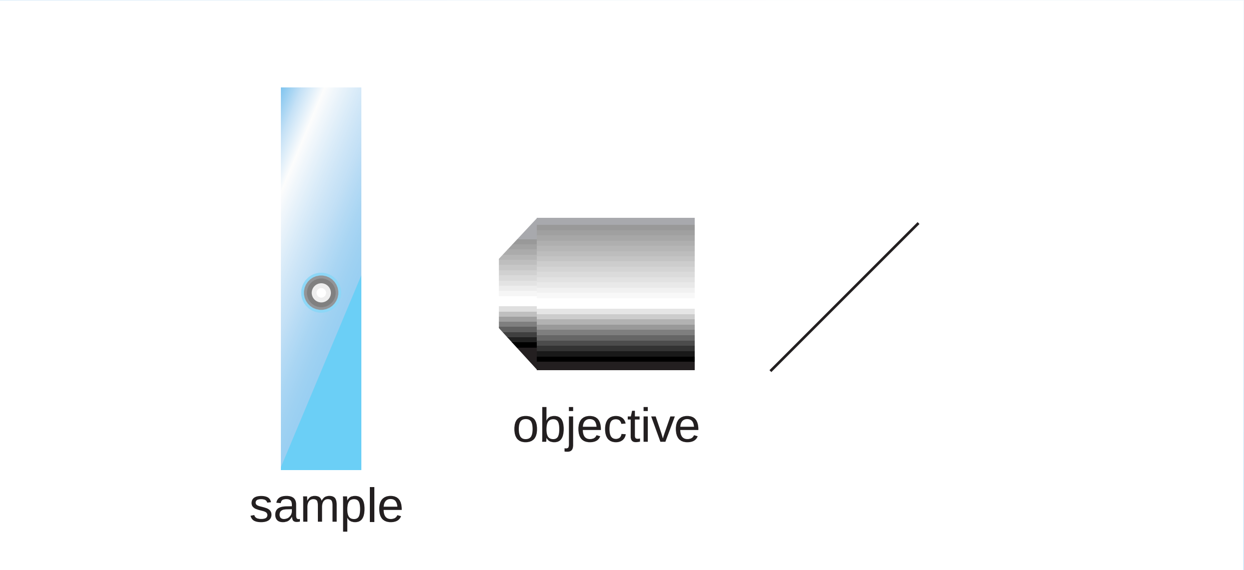
Microexplosion dynamics

imaging setup



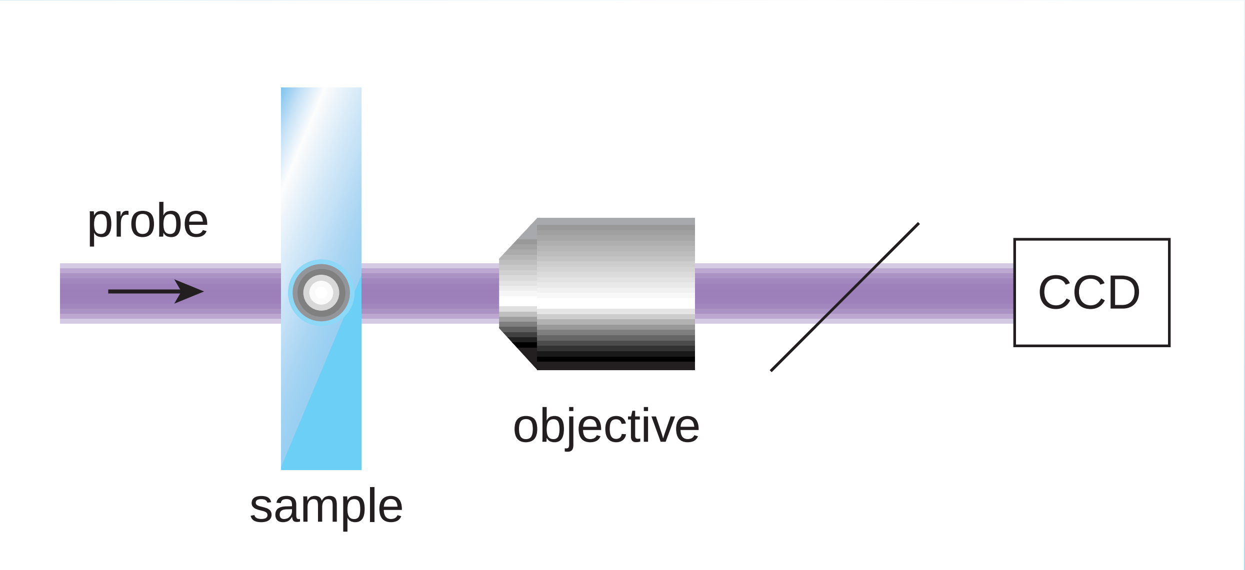
Microexplosion dynamics

imaging setup



Microexplosion dynamics

imaging setup



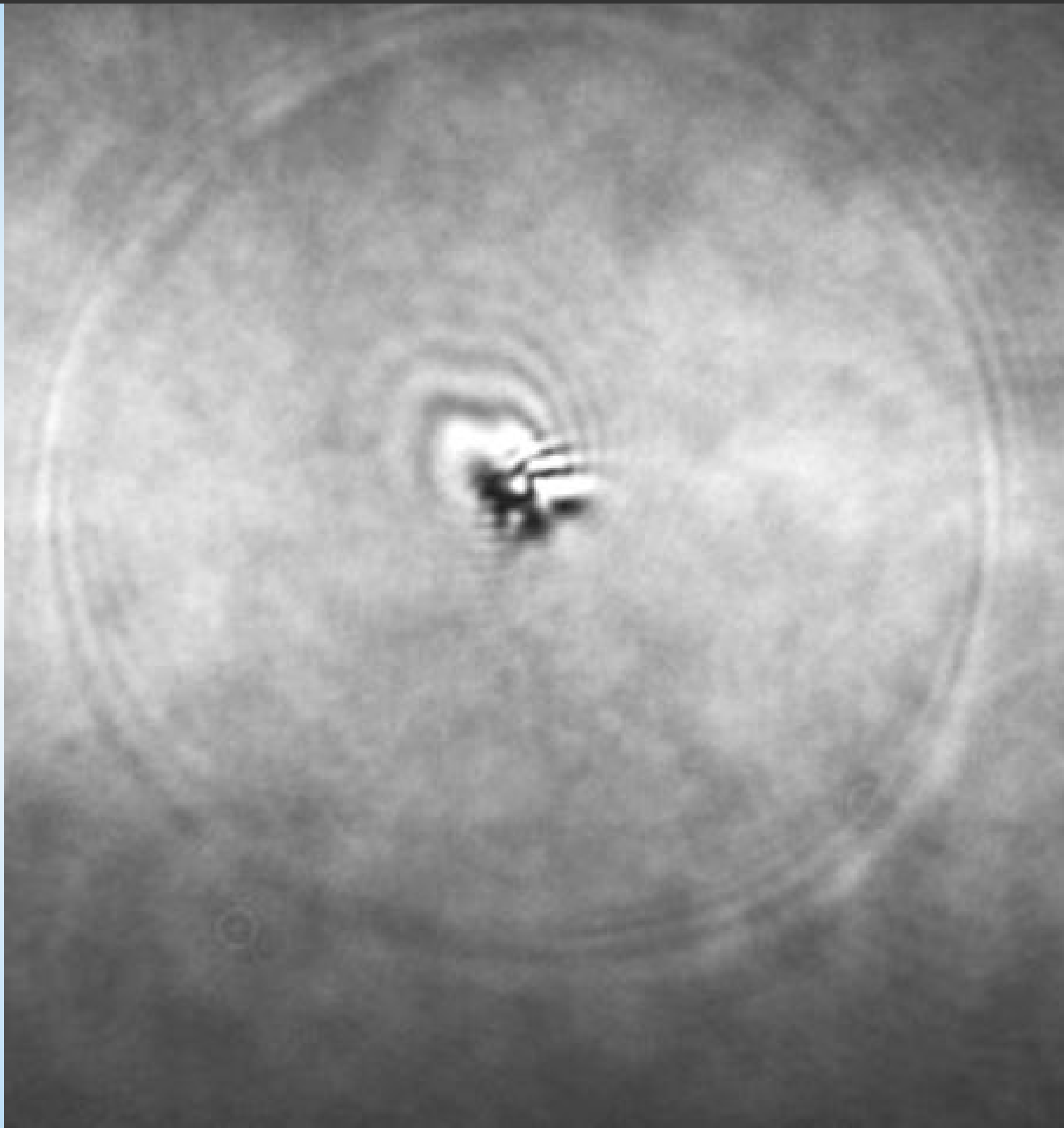
Microexplosion dynamics

sapphire

3 µJ pulse

3.8 ns delay

40 µm radius



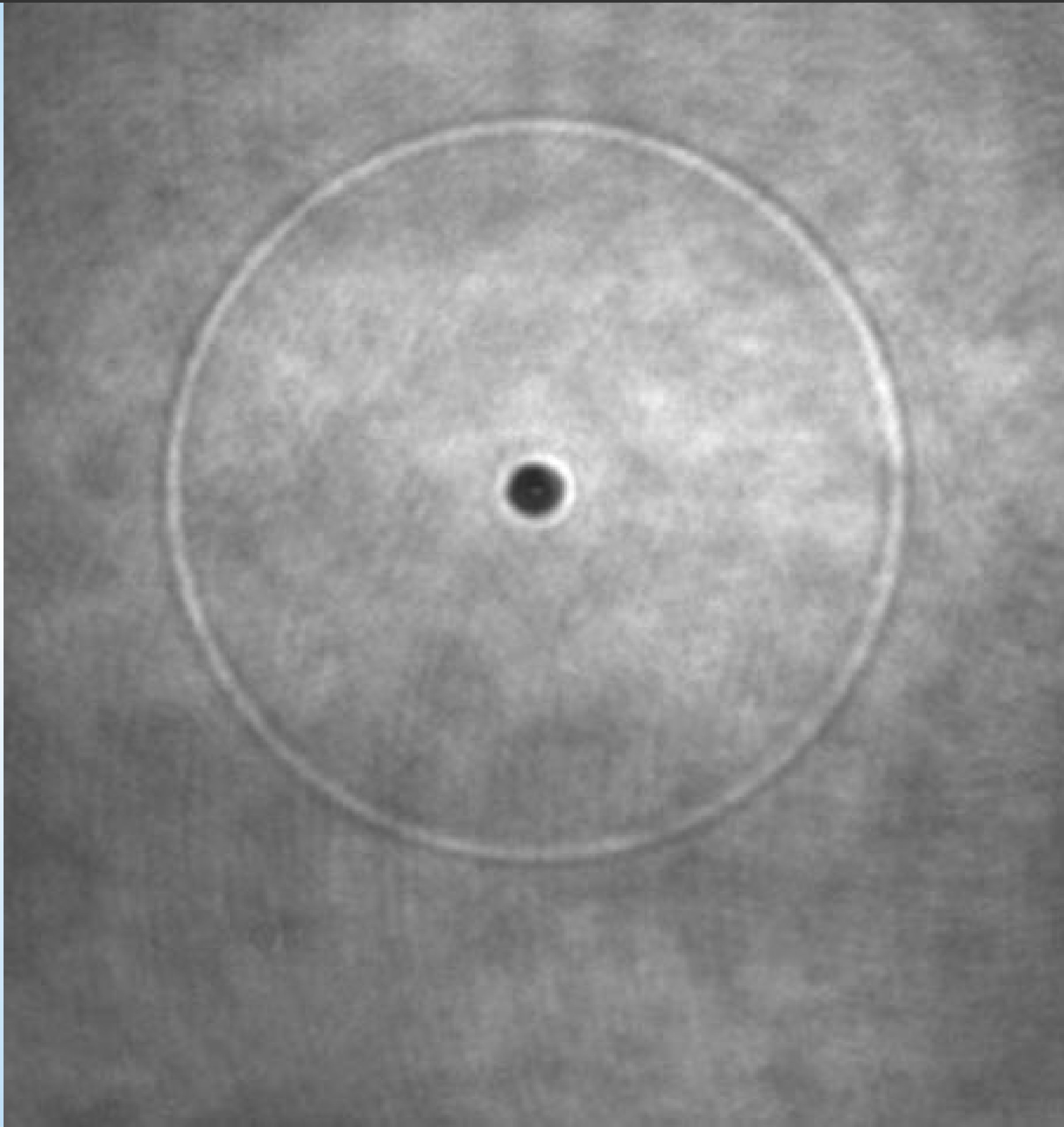
Microexplosion dynamics

water

1.0 μJ pulse

35 ns delay

58 μm radius



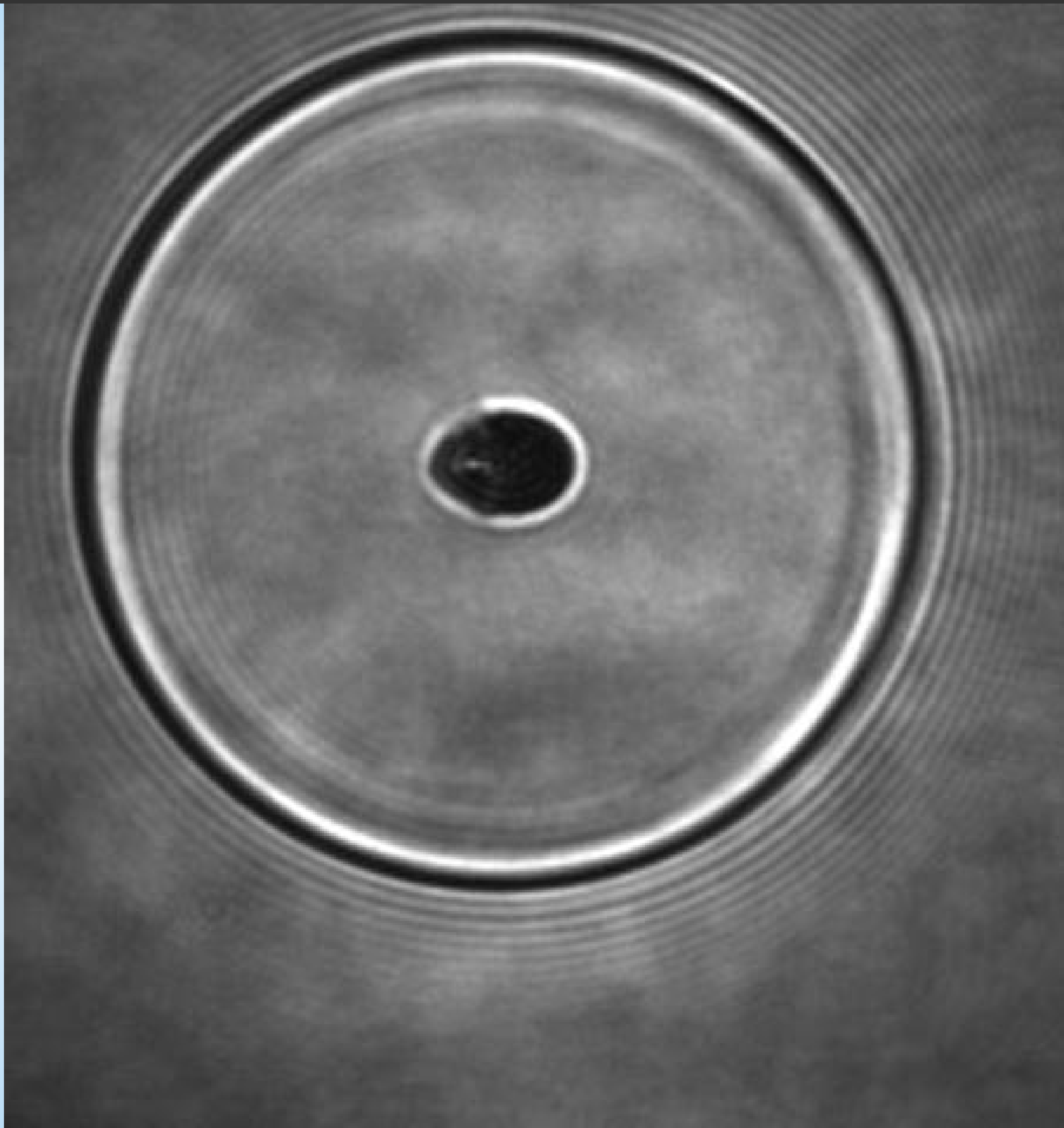
Microexplosion dynamics

water

14 μJ pulse

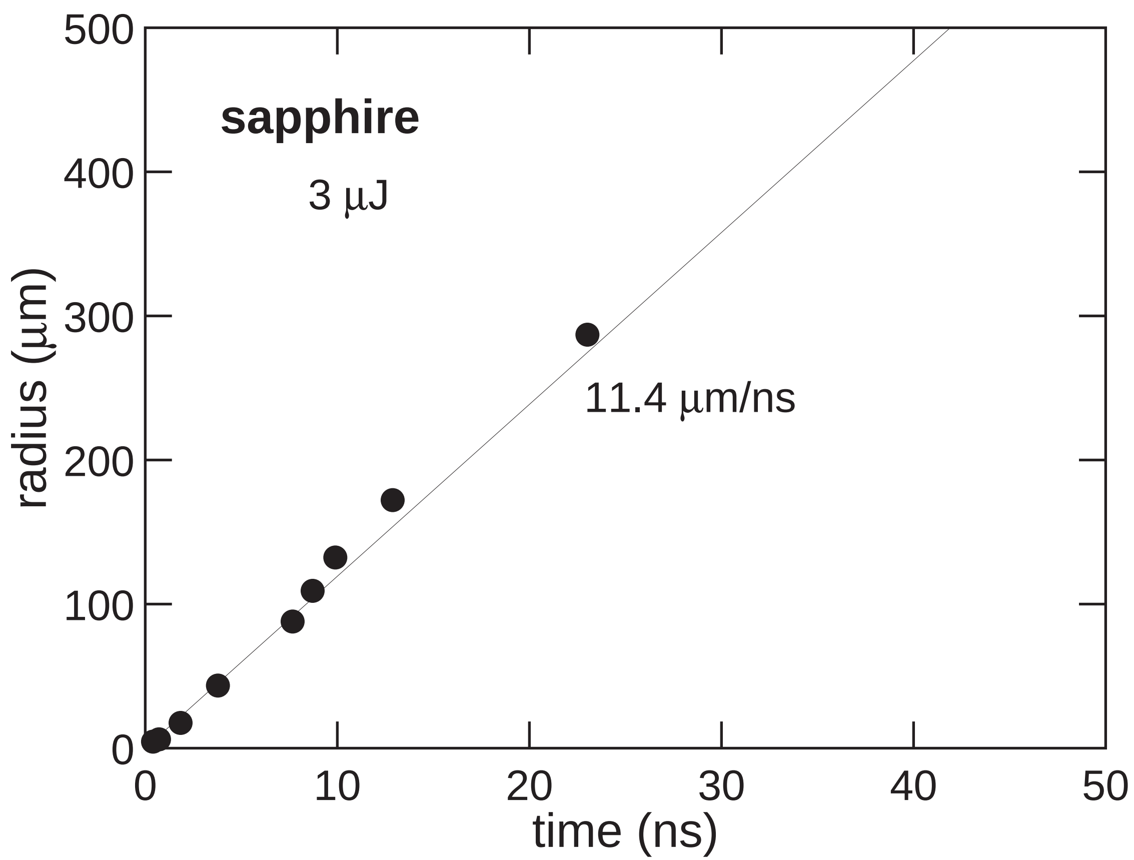
35 ns delay

64 μm radius

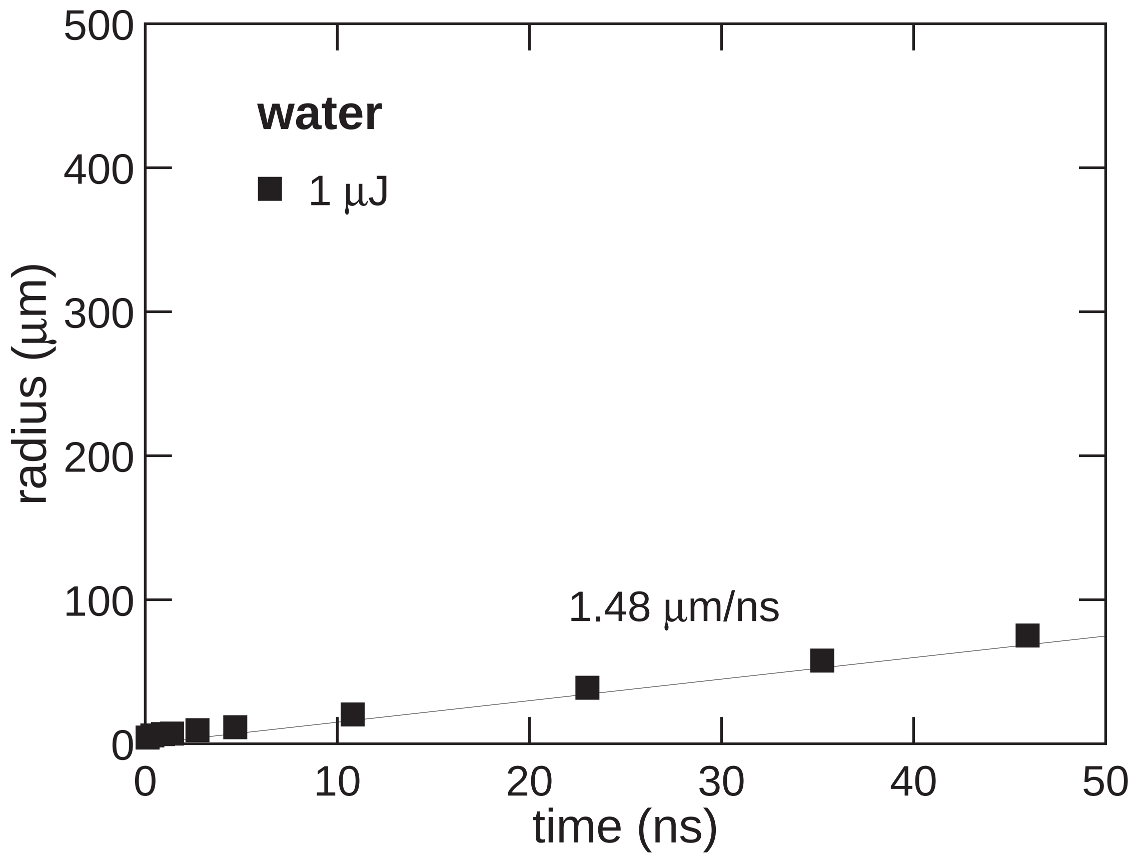


Microexplosion dynamics

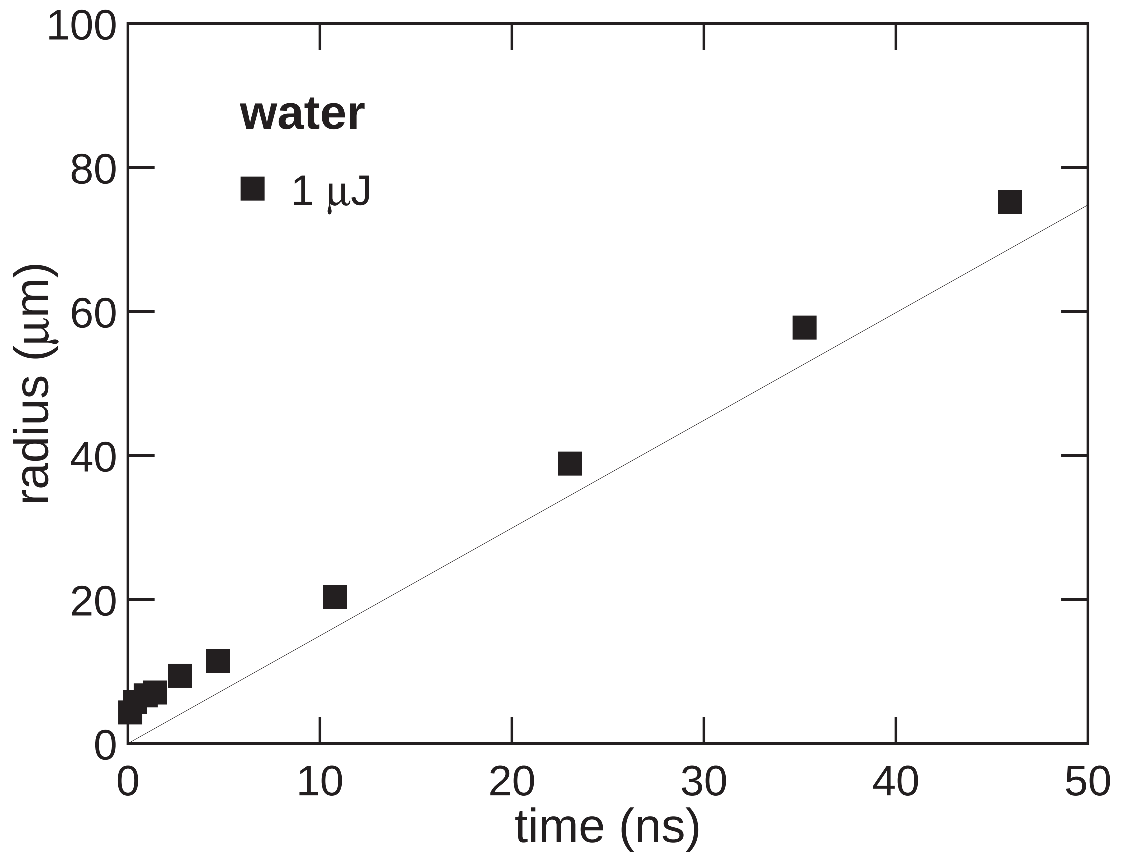
Microexplosion dynamics



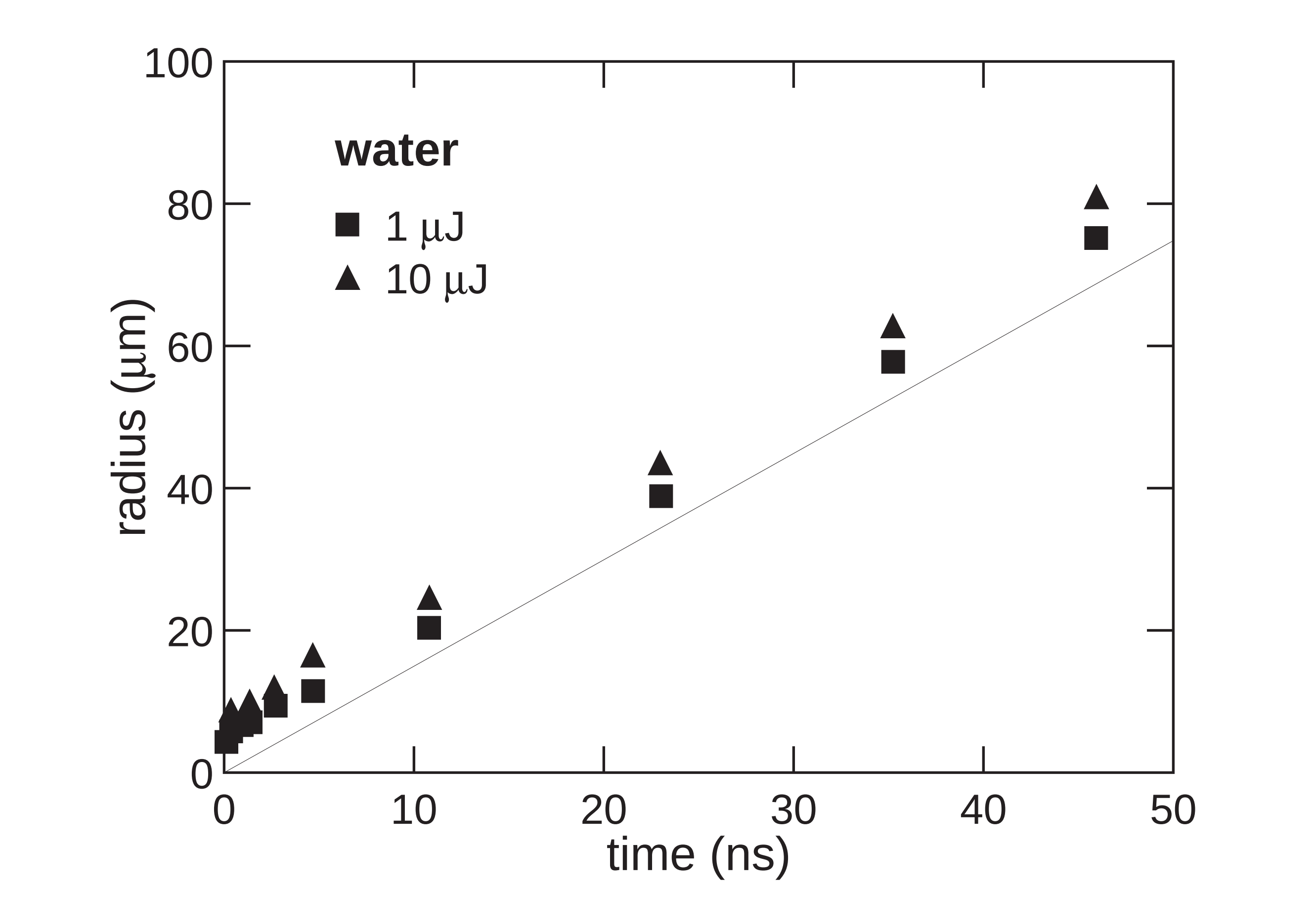
Microexplosion dynamics



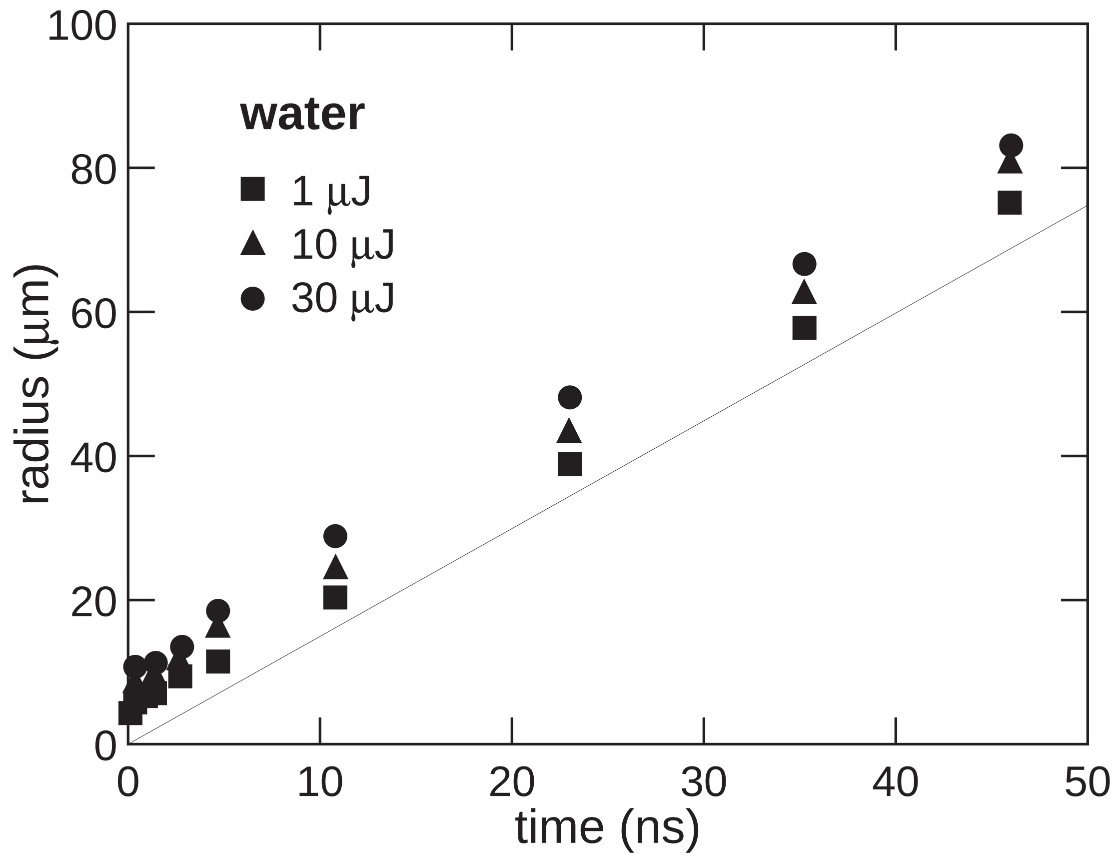
Microexplosion dynamics



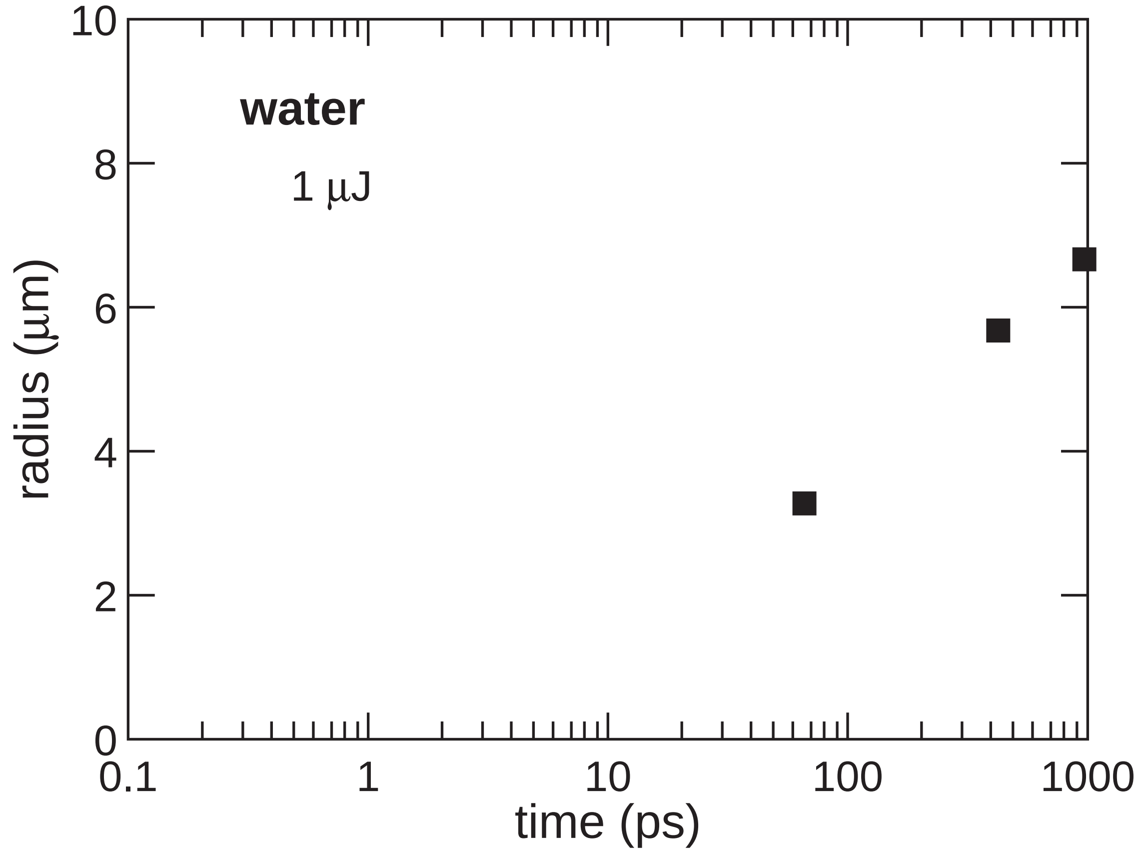
Microexplosion dynamics



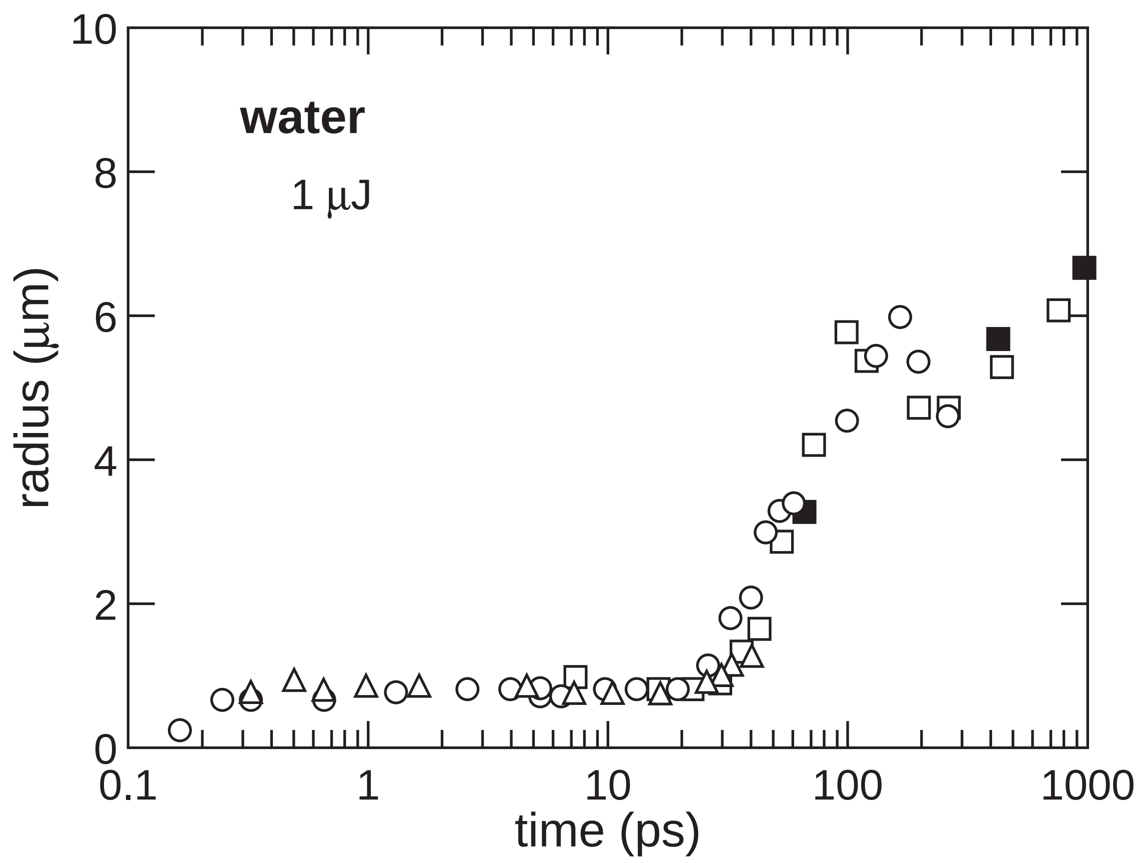
Microexplosion dynamics



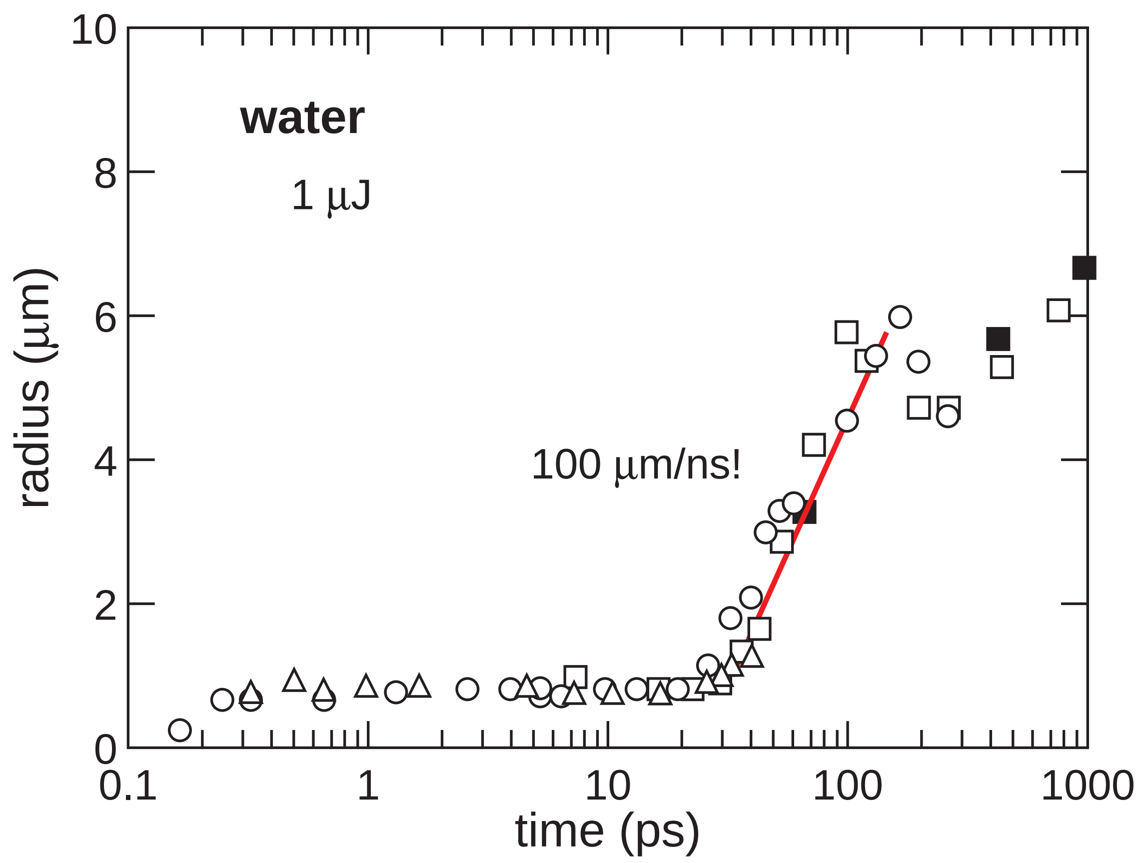
Microexplosion dynamics



Microexplosion dynamics



Microexplosion dynamics



Summary

- extreme conditions with only nanojoules
- microstructuring without amplifiers
- view into dynamics

Applications

- data storage (17 GBits/cm^3)
- internal microstructuring
- microsurgery

Questions

- **stellar conditions?**
- **material dependence?**
- **models?**

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For a copy of this talk and
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http://mazur-www.harvard.edu