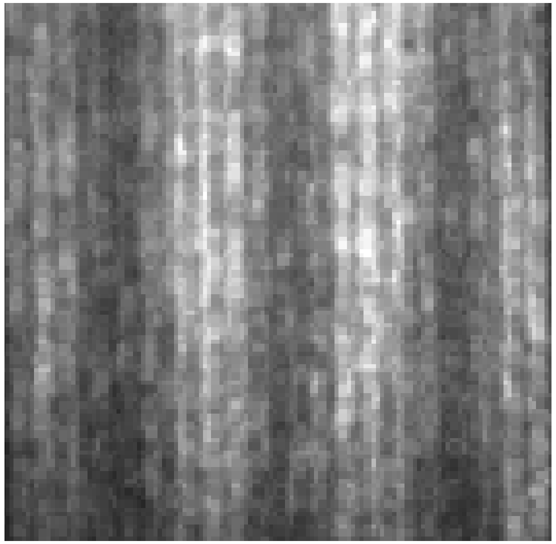
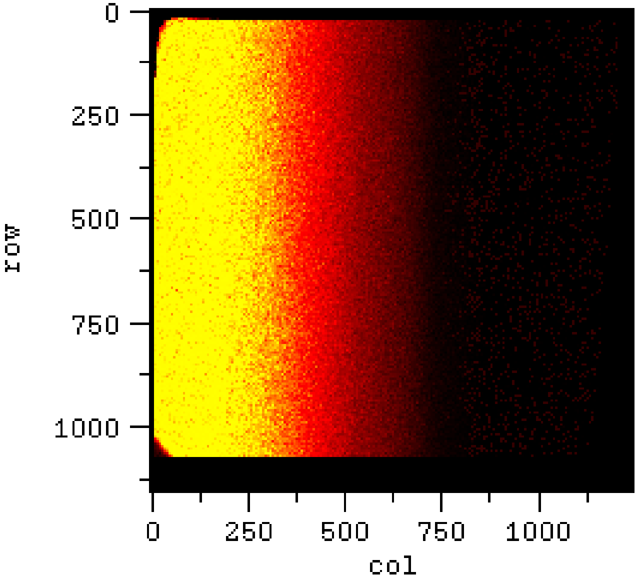
Ablative Rayleigh-Taylor Instability at Short Wavelengths

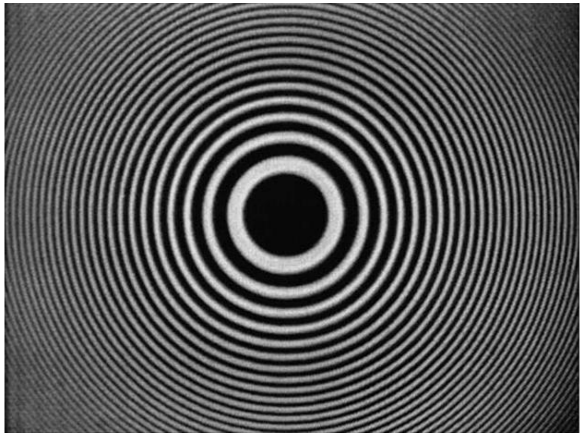
Moire Interferometry



Penumbral Imaging

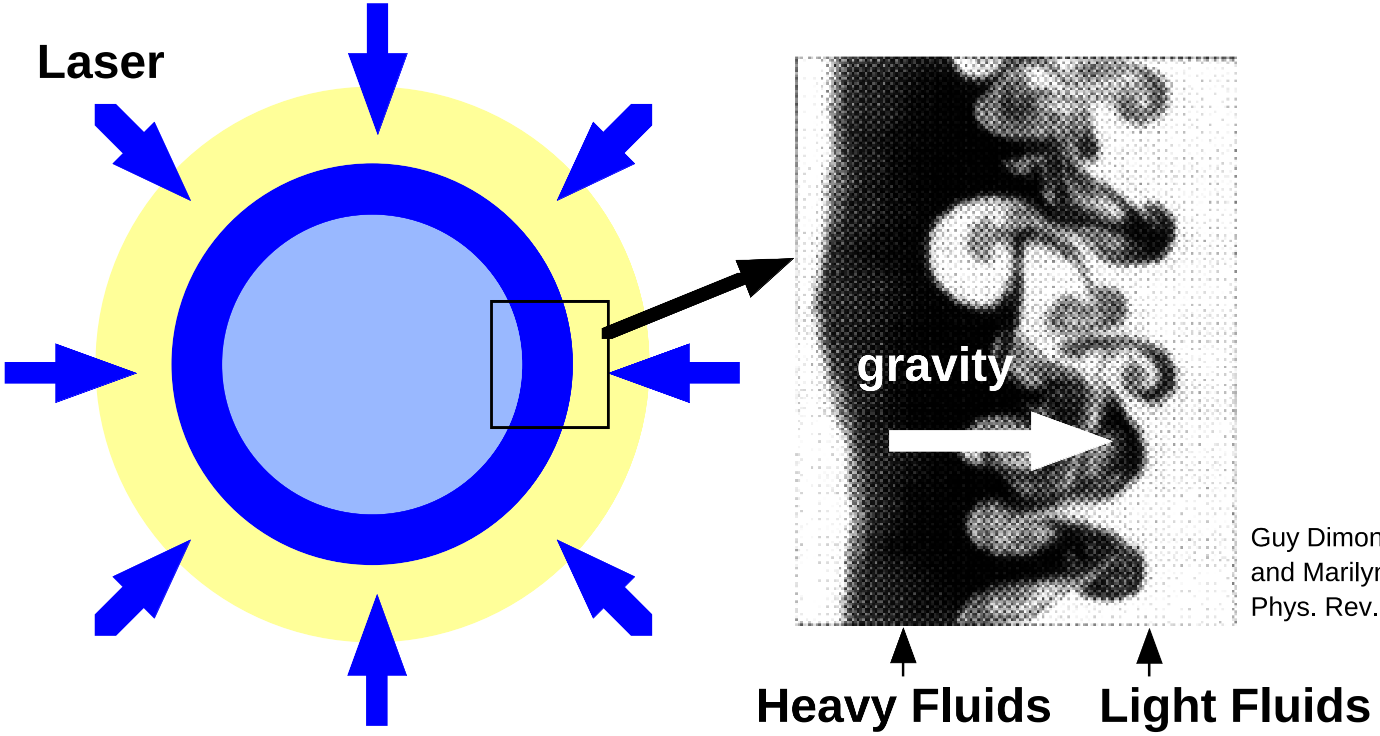


Fresnel Phase Zone Plate



H. Azechi *et al.*
Institute of Laser Engineering
Osaka University
IWPCTM 2001 Paper# E-45
9-14 Dec 2001,
Pasadena, USA

Primary obstacle of IFE is Rayleigh-Taylor instability.



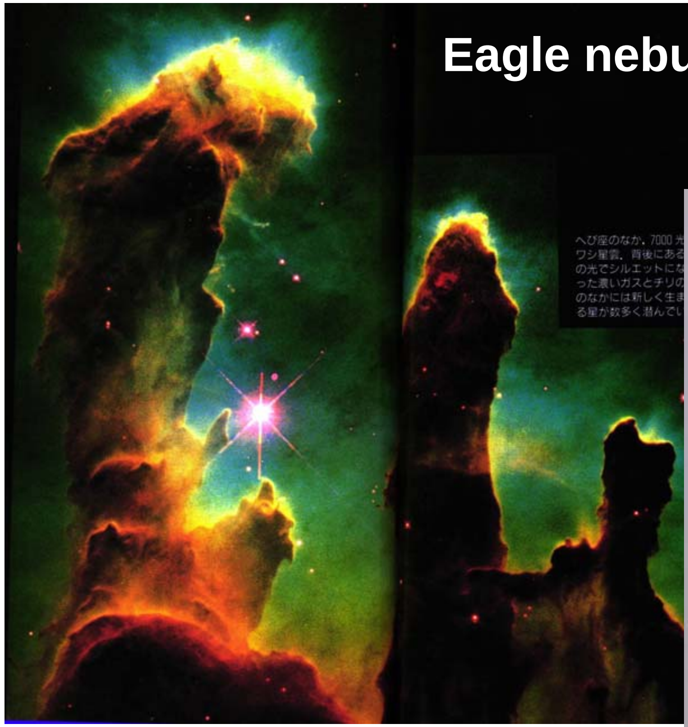
Guy Dimonte, C. Eric Frerking
and Marilyn Schneider,
Phys. Rev. Lett. **74**, 4855, (1995)

Typical wavelength = several tens μm
time scale = ns

High resolution advanced diagnostics are required.

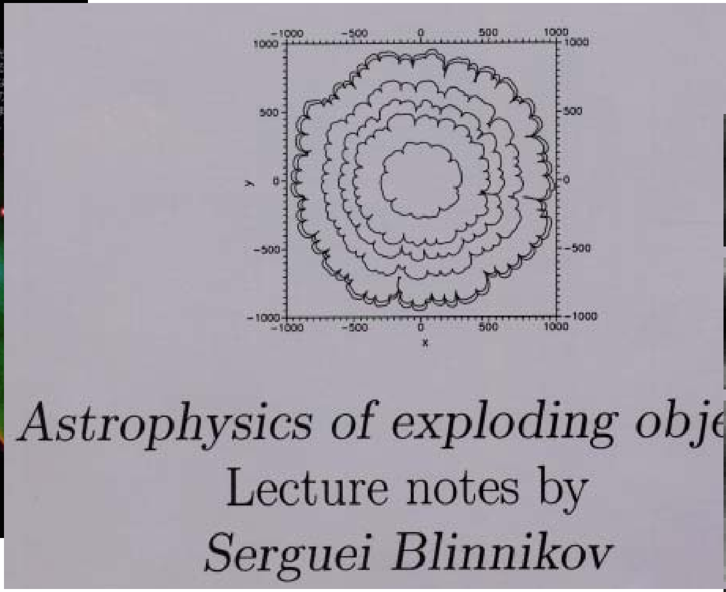
X-ray Moire interferometry
Fresnel phase zone plate
Penumbral imaging

Ablative Rayleigh-Taylor instabilities



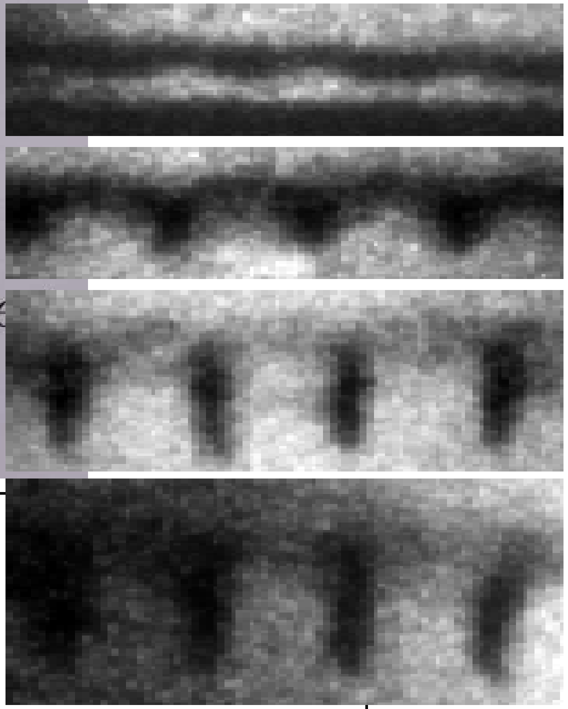
Eagle nebula

Type Ia supernovae



Astrophysics of exploding obje
Lecture notes by
Serguei Blinnikov

Laser exp't



Perturbation amplitude $a = a_0 e^{\gamma t}$

$$\gamma = \sqrt{\frac{kg}{1+kL}} - \beta k v_a$$

v_a=fluid velocity across the unstable surface

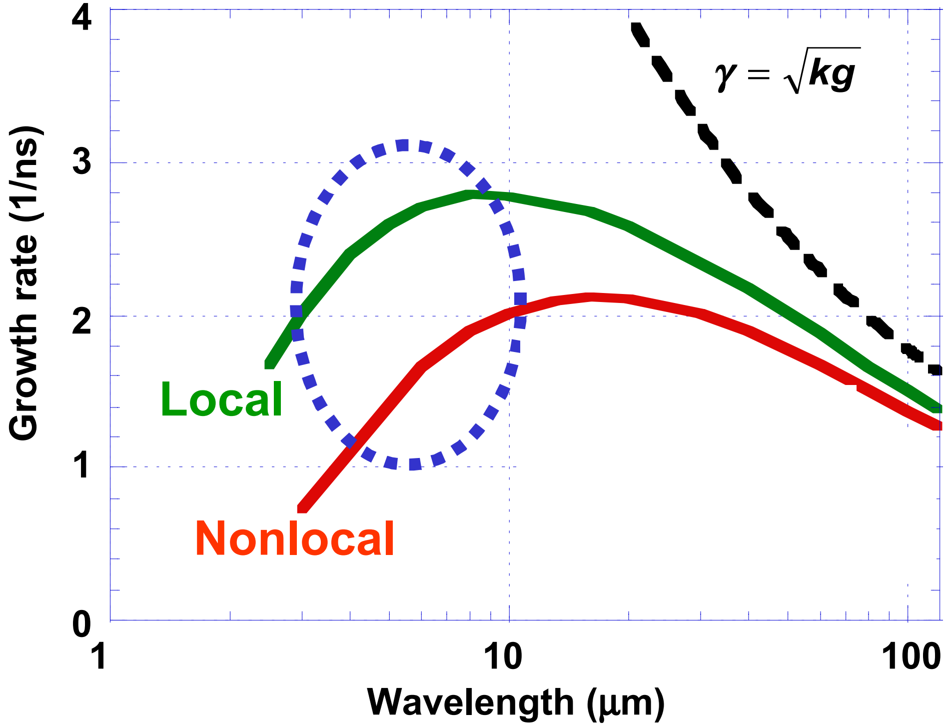
β = depends on the ablation structure.

Motivation

New method is needed for the measurement of short wavelength Rayleigh-Taylor (RT) Growth.

It is necessary to measure short wavelength RT growth in order to understand the mechanism of the ablative stabilization.

Dispersion curve of the Rayleigh-Taylor instability



- Short wavelength RT
  Moire interferometry

- Independent test
  Penumbral imaging
  Fresnel phase zone plate

Moire interferometry / short wavelength Rayleigh-Taylor

Experimental procedure

Schematic view of the experimental setup

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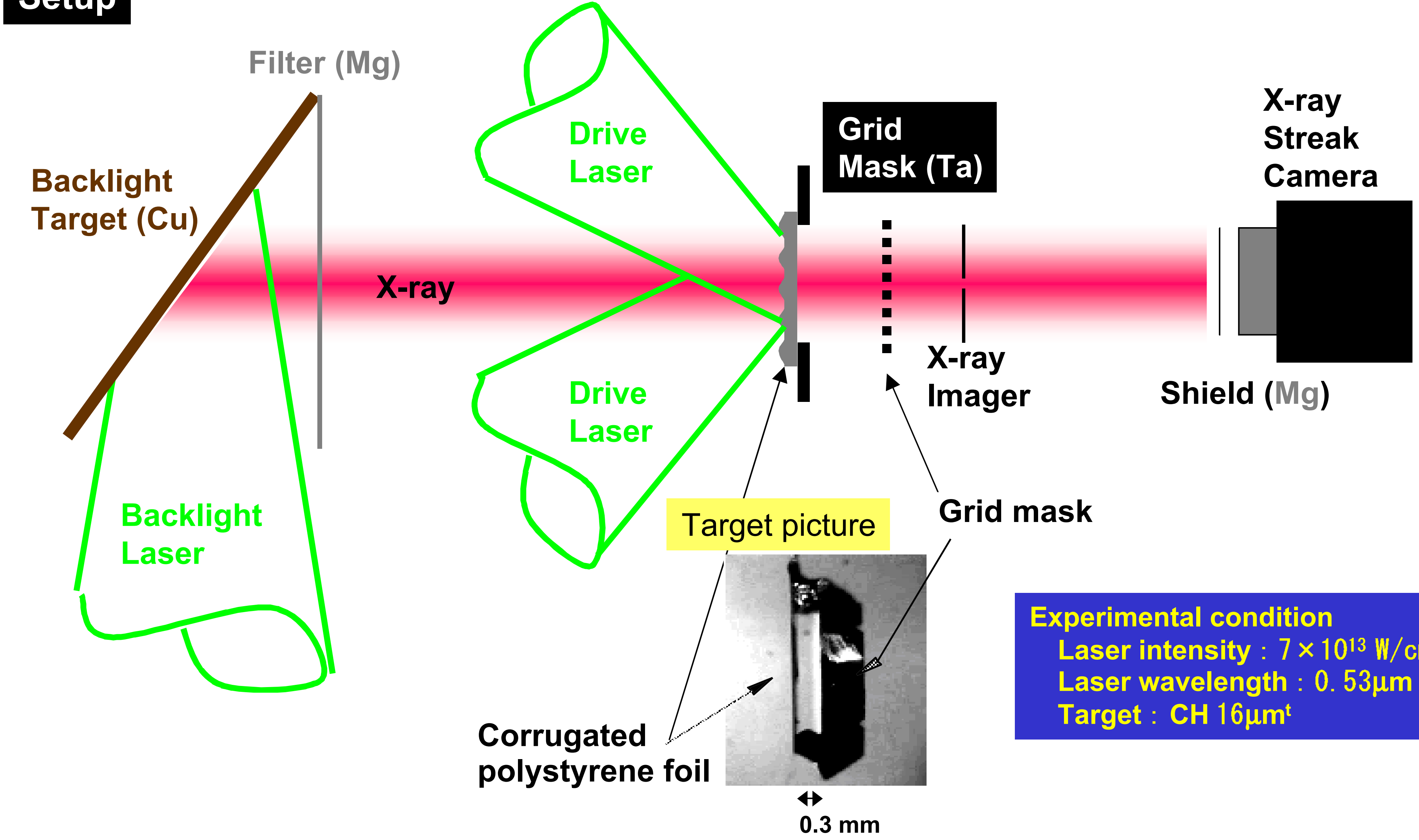
Setup



Experimental condition

Laser intensity: 7×10^{13} W/cm^2

Laser wavelength: 0.53μm

Target: CH 16μm^t

Moiré interferometry

Moiré interferometry is very useful for measurements of the RT instability at short wavelength.

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Principle

Perturbation wavelength

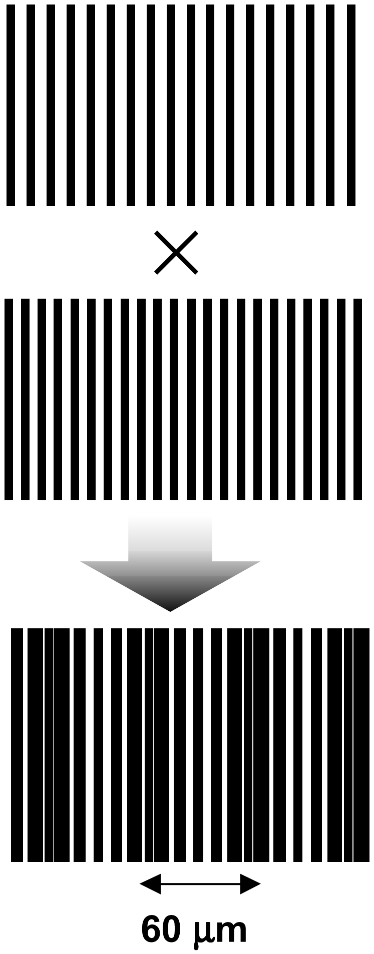
$\lambda_{Perturb.} = 12\ \mu m$

Grid mask

$\lambda_{Grid} = 10\ \mu m$

Moiré interferometry

$\lambda_{Moiré} = \underline{60}\ \mu m$

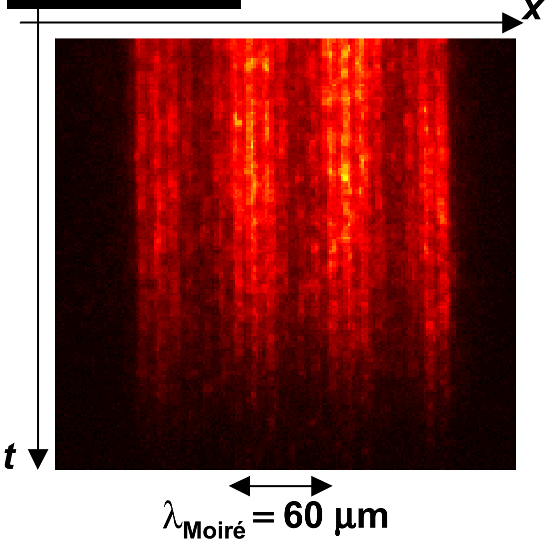


$$k_{Moire} = |k_{Perturb.} \pm k_{Grid}|$$

Due to the moiré interference, the short wavelength perturbation is converted to longer wavelength perturbation.

M. Matsuoka *et al.*, Rev. Sci. Instrum., **70**, 637 (1999)

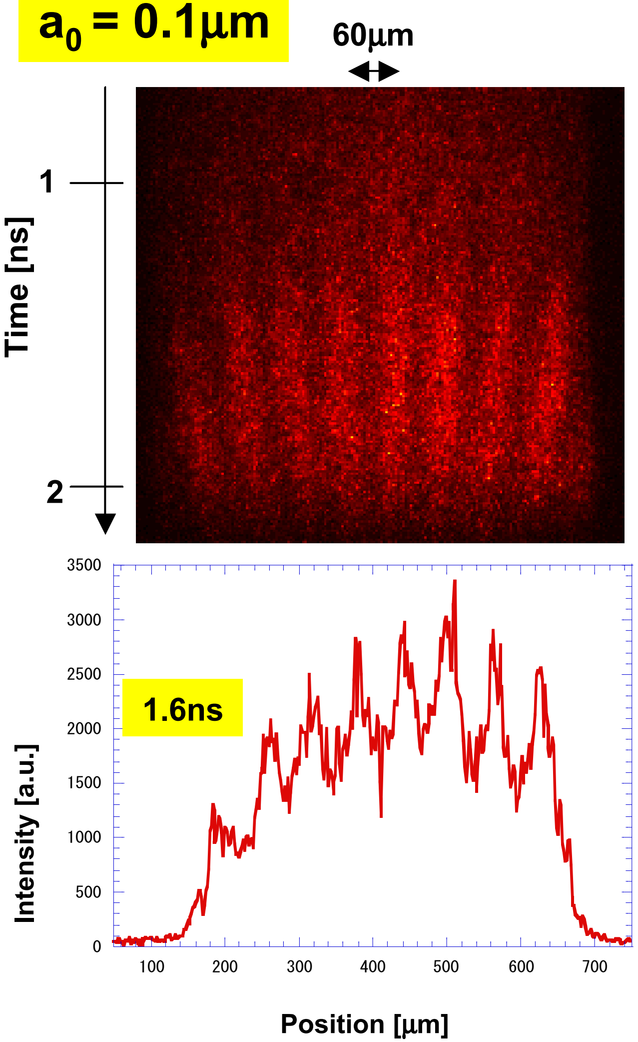
Raw image



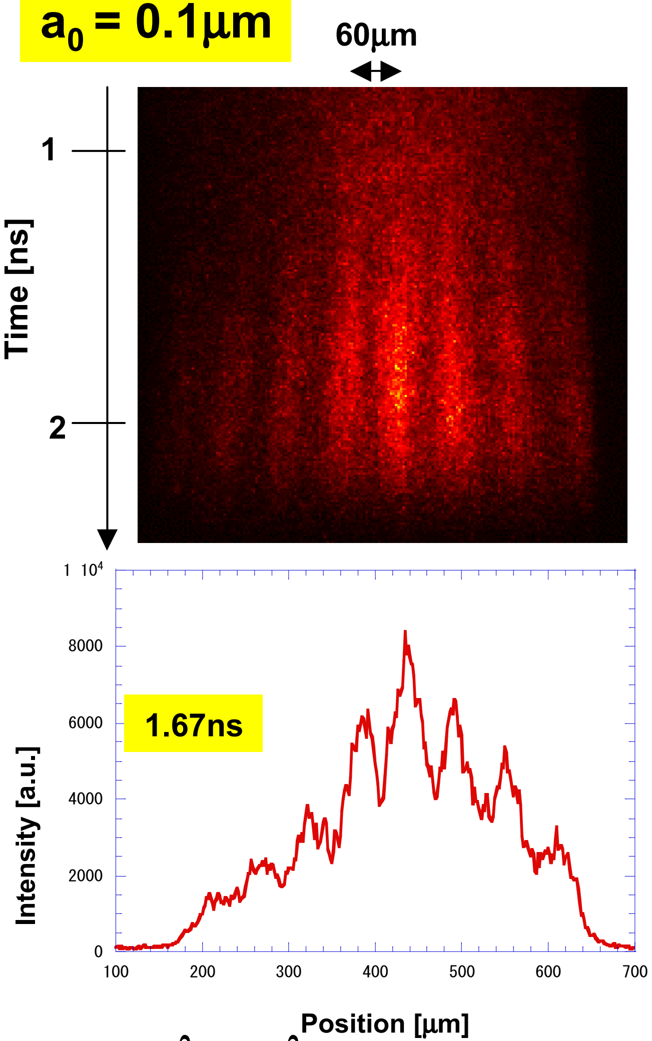
Experimental results

Raw data of Rayleigh-Taylor instability observed with moiré interferometry

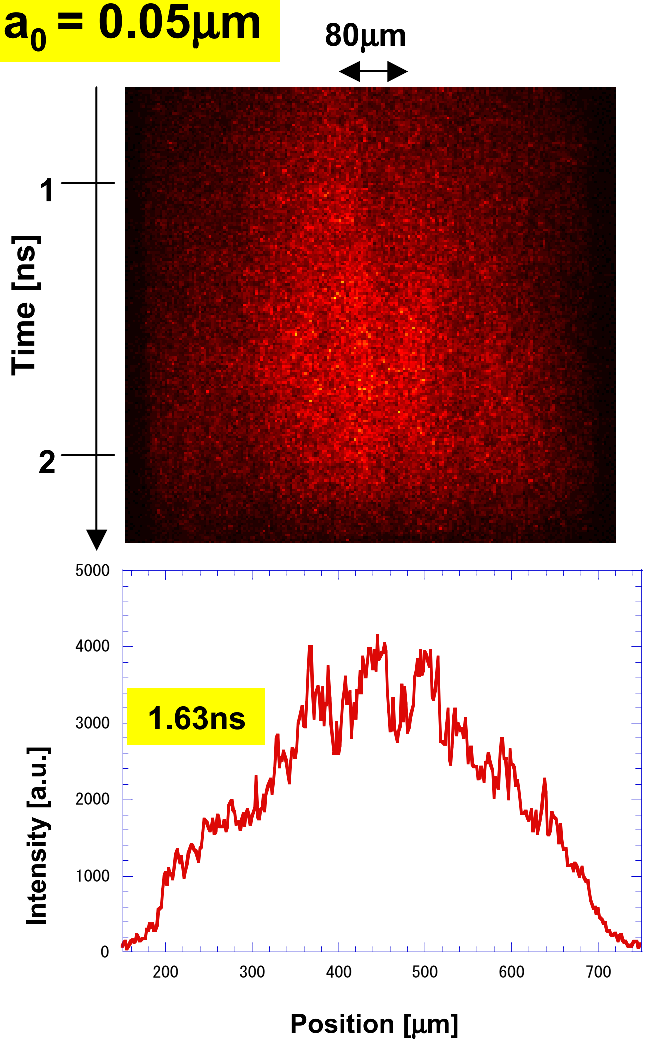
$\lambda = 12\mu m$
$a_0 = 0.1\mu m$



$\lambda = 8.5\mu m$
$a_0 = 0.1\mu m$



$\lambda = 4.7\mu m$
$a_0 = 0.05\mu m$



$$\lambda_M = \frac{\lambda_1 + \lambda_2}{\lambda_1 - \lambda_2}$$ **sensitive to $\Delta\lambda$**

Short Wavelength RT

Large Rayleigh-Taylor growth was observed up to 5-μm wavelength.

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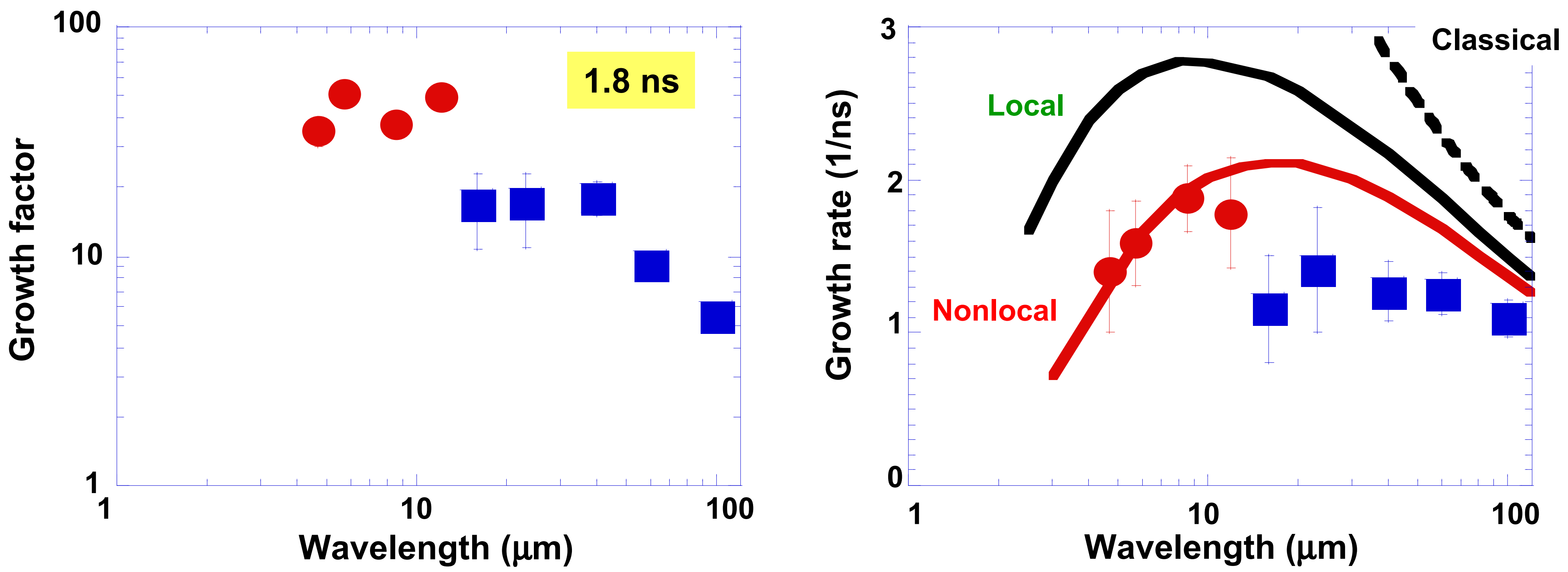

- This exp’t suggests that nonlocal heat transport plays a role in ablative stabilization.
- However, for unambiguous clarification, we need to make independent observation.

Reduction of the target density with nonlocal heat transport

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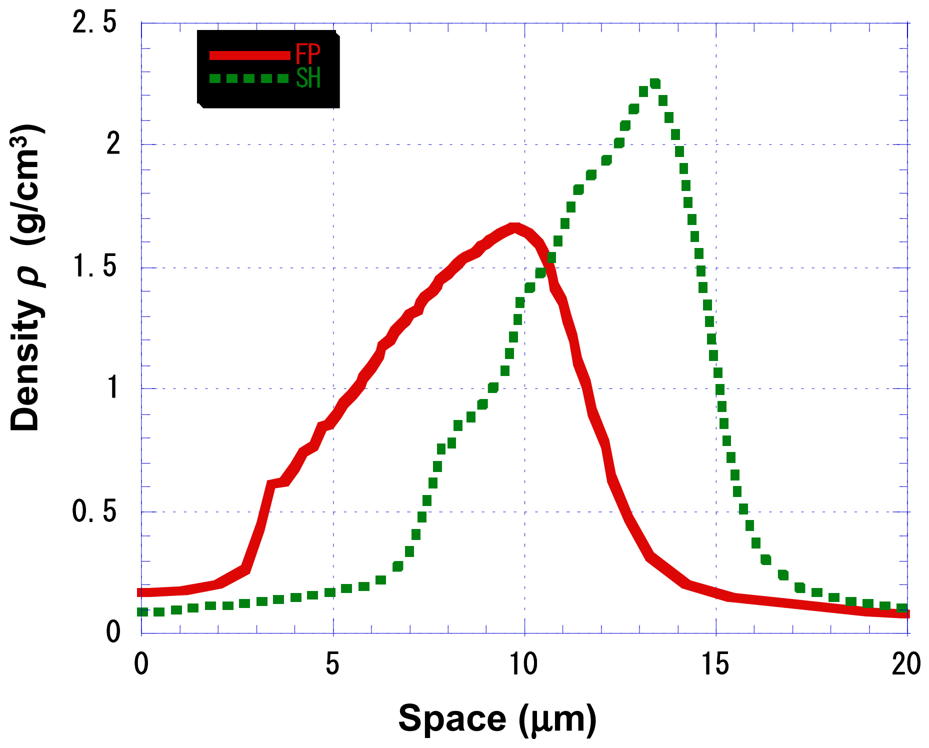
Density profile at 1.3 ns

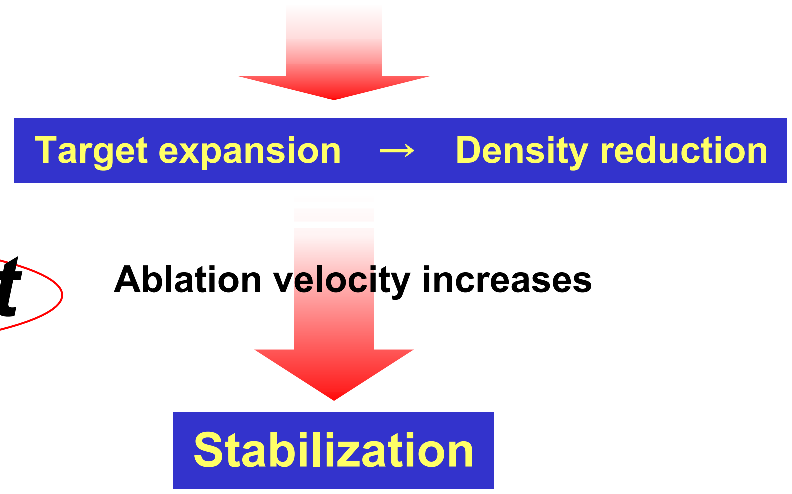


Spitzer-Härm (SH)
Local heat transport :

- Diffusion approximation of electron thermal conduction

Fokker-Planck (FP)
Nonlocal heat transport :

- High-energy electrons in the tail of Maxwellian distribution penetrate into the target and preheat it.



Target expansion → Density reduction

Ablation velocity increases

Stabilization

if $$\dot{m} = \rho_a v_a \cong const$$

A. Sunahara *et al.*, “Nonlocal Electron Transport” (2000)

Method of Density Measurement

Density profile was obtained from the x-ray backlighting image of the planar target.

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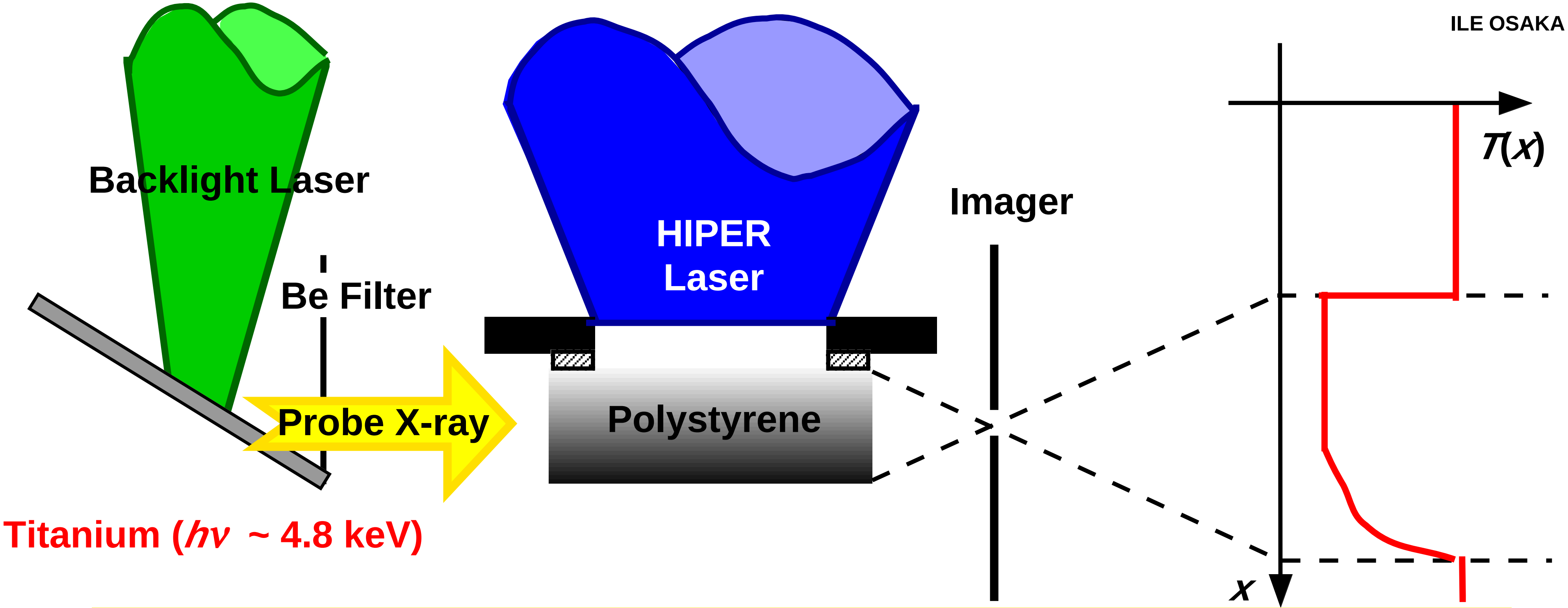


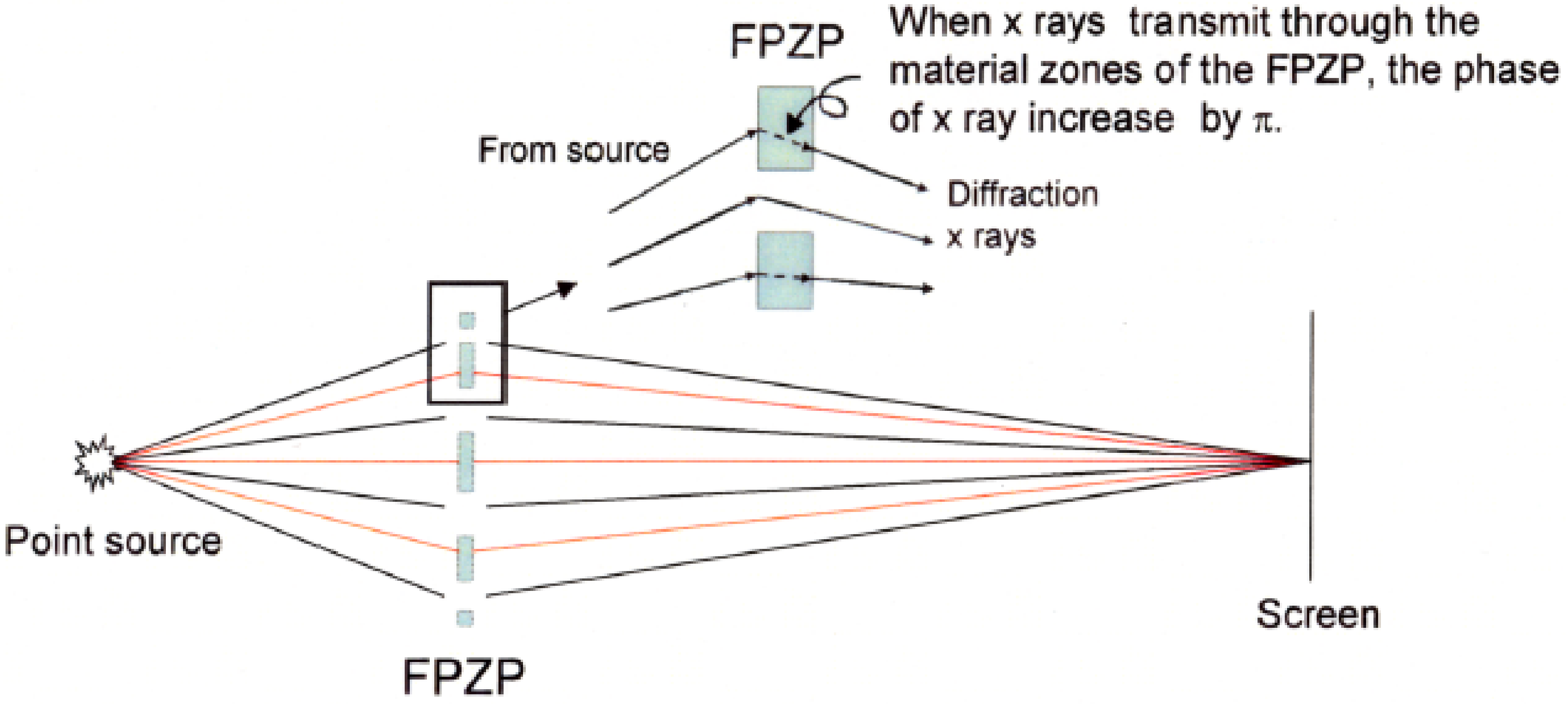
$$T = \exp(-\mu\rho l)$$

T **: Transmission**, ***μ*** **: mass absorption coeff.**

l **: material thickness,** ***ρ*** **: density**

Fresnel phase zone plate / density profile

The principle of the FPZP imaging



When x rays transmit through the material zones of the FPZP, the phase of x ray increase by π.

Advantage

- High spatial resolution 2.2 µm
- Hard x-ray imaging 4.7 keV

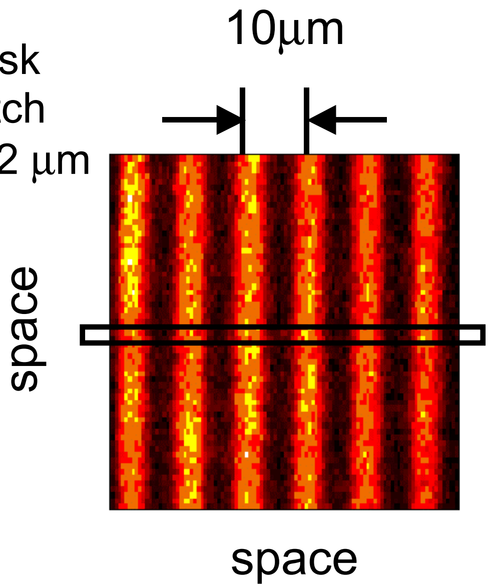
Disadvantage

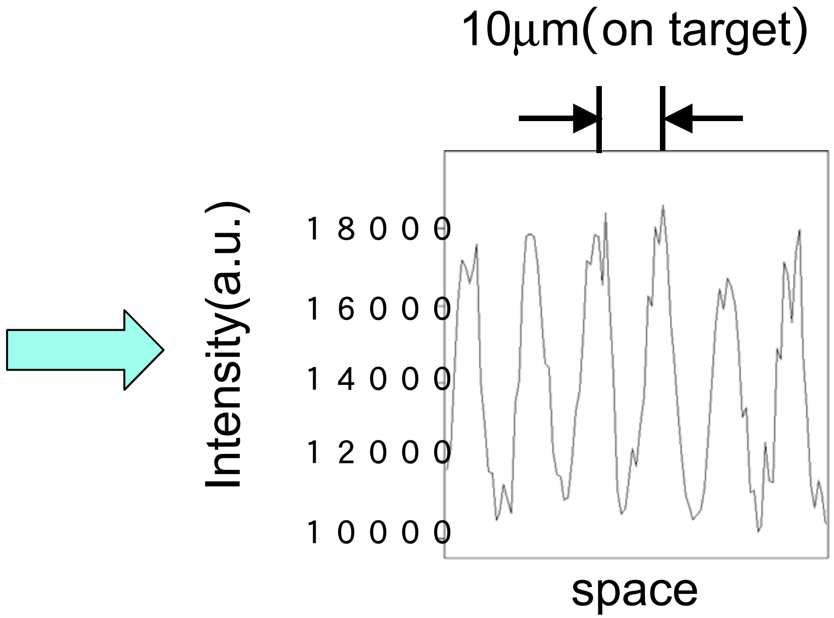
- Chromatic aberration
- Background

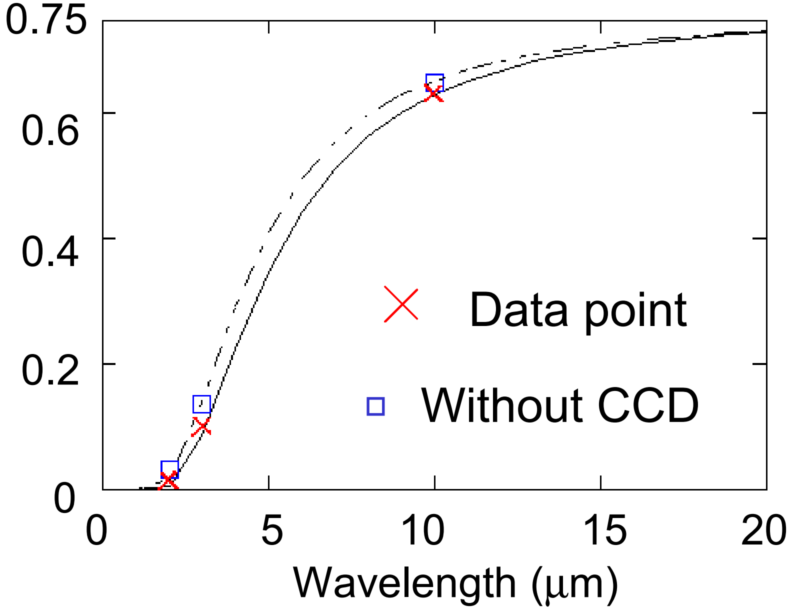
Possible to obtain ~µm spatial resolution

Spatial resolution test of FZP

Ta grid mask
10.0 µm pitch
Thickness: 2.2 µm





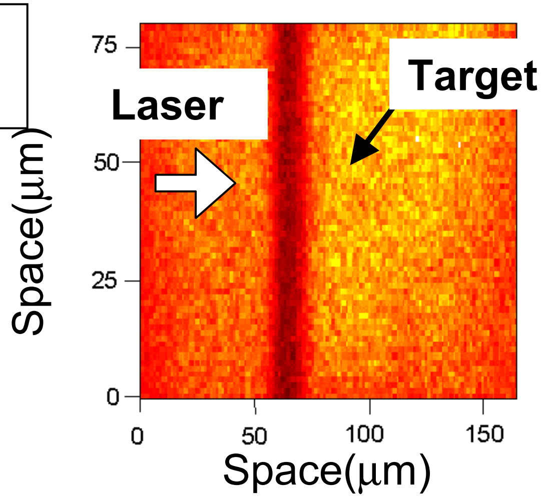


CCD camera MTF is removed by Calculation.

The wavelength at which the MTF becomes 5 % is 2.2 µm.

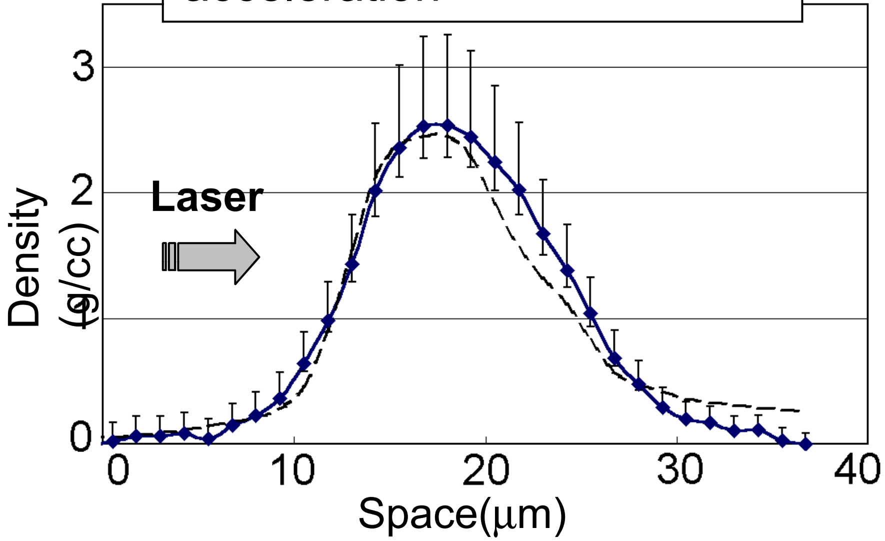
Ablation density profile

Obtained data

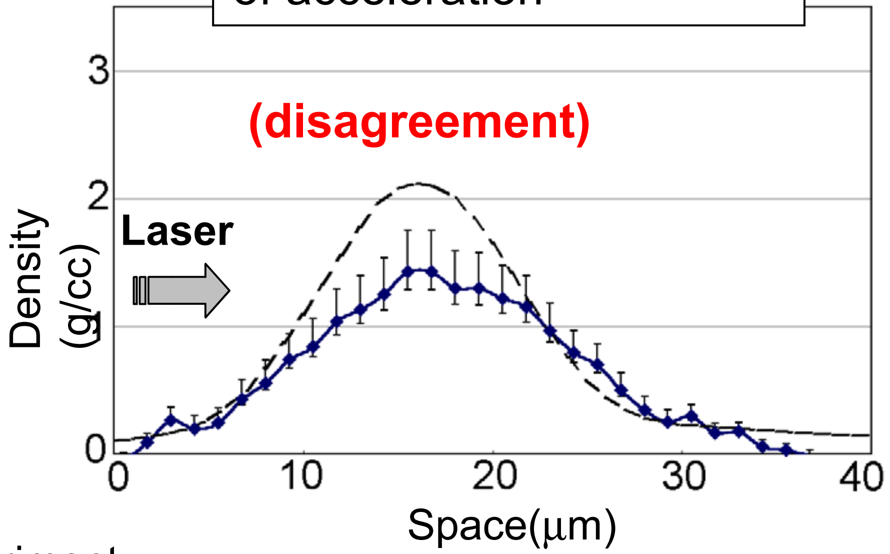


Spectrum breadth	2~3 %
Target thickness	2~3 %
The target bend	negligible
Intensity profile of the probe x rays	<1 %
Contribution of the background	**<20 %**

t= 1.3 ns: the early phase of acceleration



t= 2.2 ns: the late phase of acceleration



Experiment
Simulation+Smear

Penumbral Imaging / density profile

Proof of Principle experiment

The proper density profile of the laser-undriven polystyrene target was obtained with penumbral imaging coupled with a side-on x-ray backlighting.

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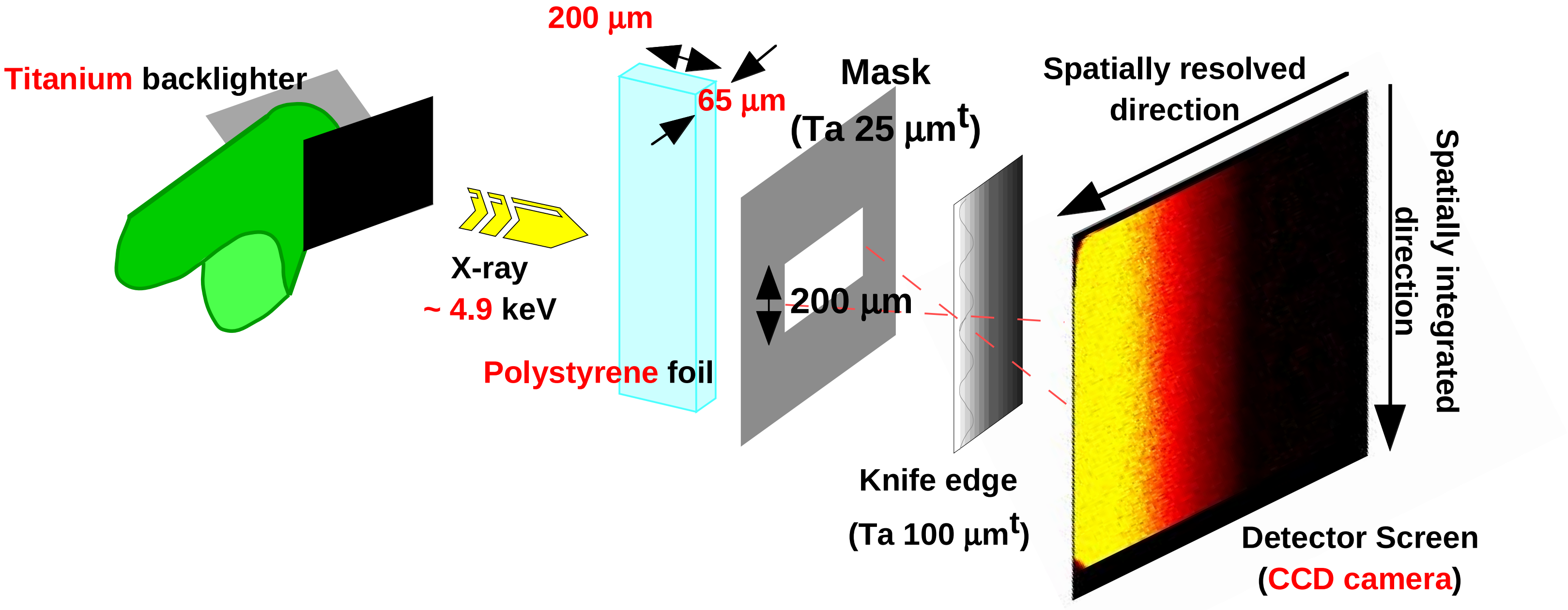
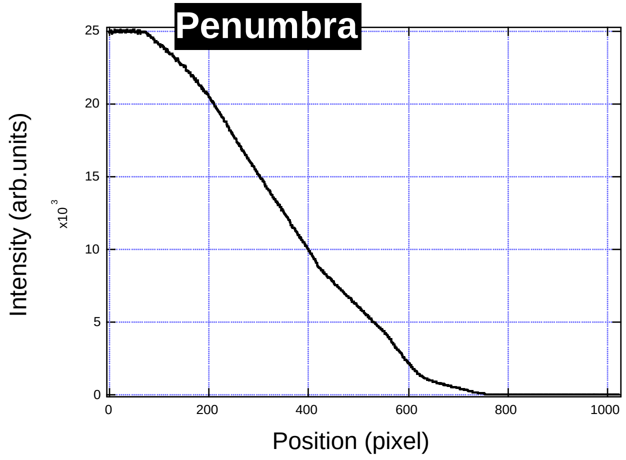
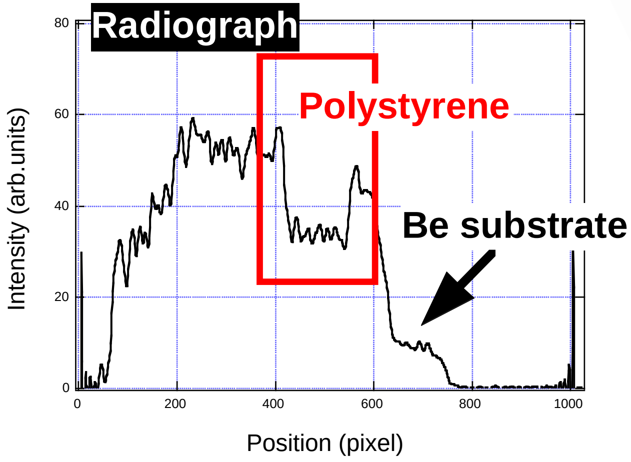
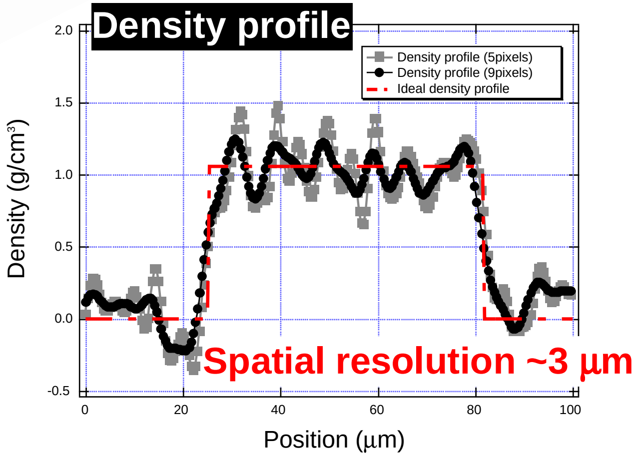




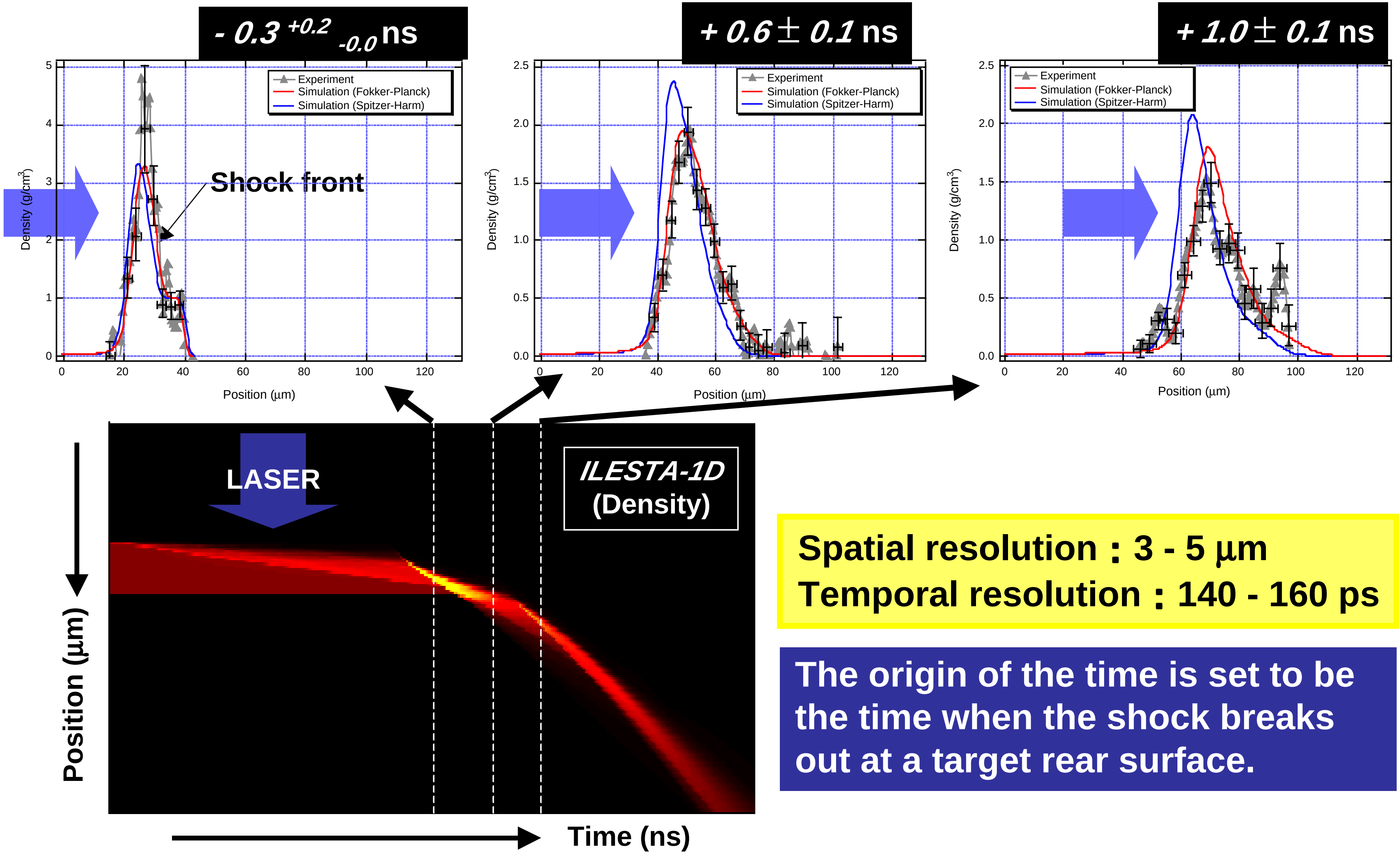




Density measurement with penumbral imaging

The density profiles in target plasmas driven by the HIPER laser were observed from shock transit to target acceleration.

S. Fujioka
(ILE. Osaka)



Spatial resolution : 3 - 5 μm
Temporal resolution : 140 - 160 ps

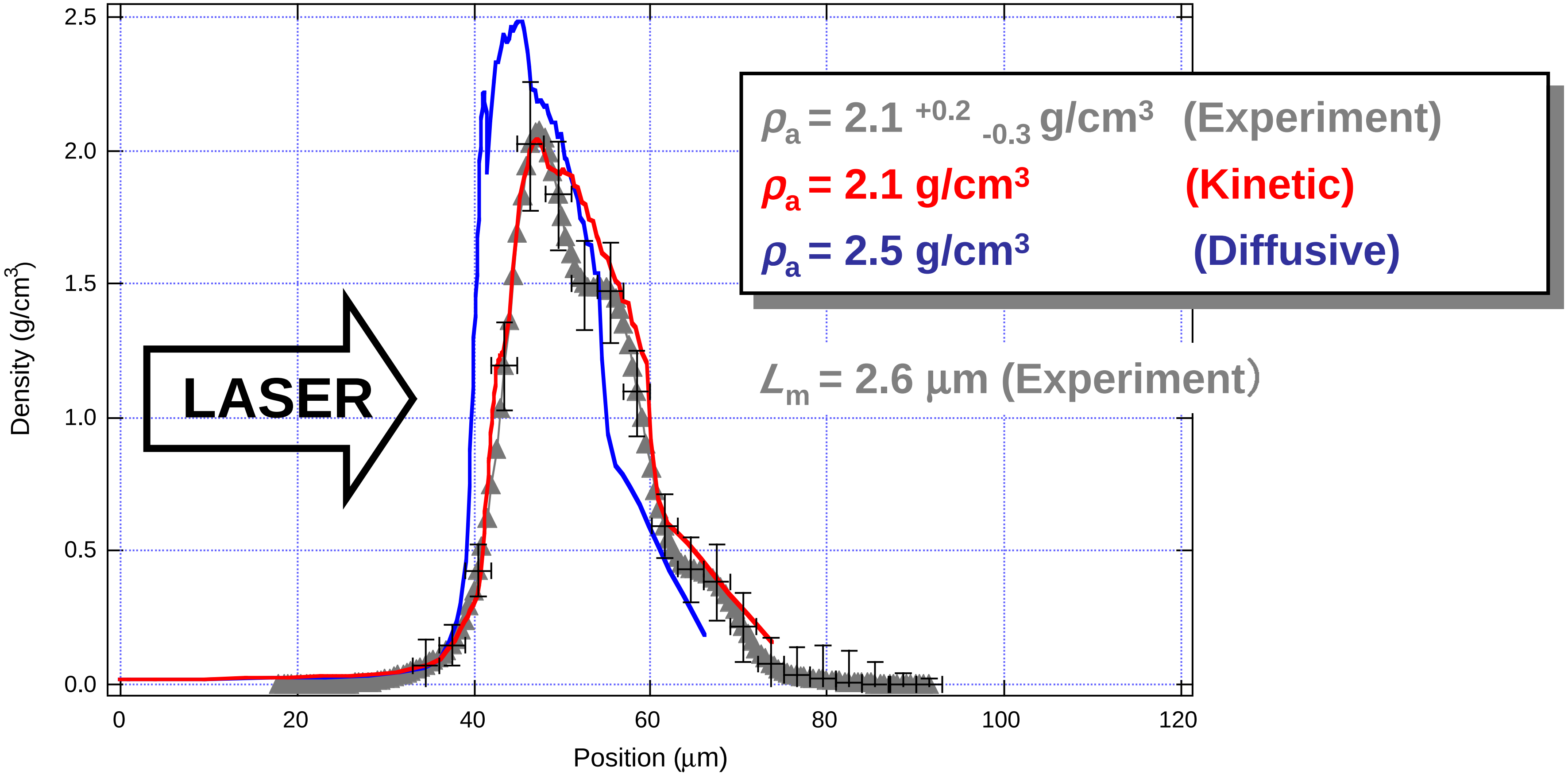
The origin of the time is set to be the time when the shock breaks out at a target rear surface.

Density measurement with penumbral imaging

Kinetic effects on electron energy transport are not negligible even in the case of relatively low intensity blue laser irradiation (I_L = 0.7 x 10^{14} W/cm^2, λ_L = 0.35 μm).

S. Fujioka
(ILE. Osaka)

+ 0.6 ns (corresponding to the beginning of a target acceleration)



ρ_a = 2.1 $^{+0.2}_{-0.3}$ g/cm^3 (Experiment)
ρ_a = 2.1 g/cm^3 (Kinetic)
ρ_a = 2.5 g/cm^3 (Diffusive)

L_m = 2.6 μm (Experiment)

Motion blurring were cleared away by a deconvolution process with measured temporal history of backlight x-rays and velocity of targets.

summary

With advanced diagnostic techniques, we are approaching to better understanding of the Raylei-Taylor instability.

- Rayleigh-Taylor (RT) is the critical physics for high-gain IFE
- Energy transport can modify the RT growth at short wavelengths.
- Moire interferometry first observed the short wavelength RT growth.
- The observed RT growth suggests that nonlocal transport plays a role in ablative stabilization. But there is some ambiguity due to saturation.
- For independent test of the transport effect, we are measuring the ablation density with high-resolution imaging techniques.
- Initial test result is supportive to the nonlocal transport.

Our strategy is to measure all necessary quantities (γ, k, g, m, ρ_a, L) to test various RT theories.