Kansai Photon Science Institute

Reflection of Strong Long Wavelength Laser Pulses from Relativistic Mirrors

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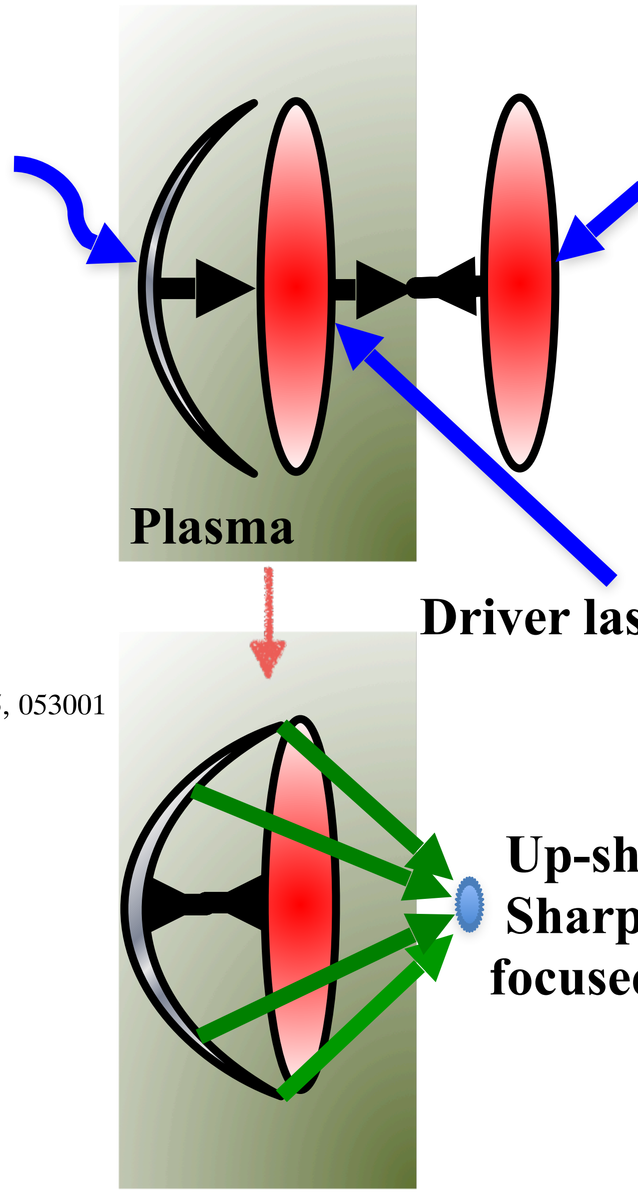
Introduction

Relativistic Flying Mirror

Breaking plasma wave



Low Intensity Counter-propagating laser pulse (Source Pulse)

Frequency ω_s

Spot size w_s

Driver laser pulse

S. V. Bulanov, et al., Phys. Rev. Lett. 91, 085001 (2003)
M. Kando et al., Phys. Rev. Lett. 99, 135001 (2007)
M. Kando, et al., Phys. Rev. Lett. 103, 235003 (2009)
S. V. Bulanov et al., Plasma Sources Sci. Technol. 25, 053001 (2016)

Phase velocity $\beta_{ph}c$

Up-shifted $\omega'' = \frac{1+\beta_{ph}}{1-\beta_{ph}}\omega_s \approx 4\gamma_{ph}^2\omega_s$

Sharply focused $w' = \sqrt{\frac{1-\beta_{ph}}{1+\beta_{ph}}}w_s \approx \frac{w_s}{2\gamma_{ph}}$

Source pulse

- Same wavelength as Driver
- Low intensity

- Long wavelength
  - Lower critical density→Better reflection
  - Finite existence time of wake→Few cycles
- Nonlinear regime
  - Harmonics

Parameters

- Plasma

$$L = 50\mu m$$

$$n_p = 5 \times 10^{19} cm^{-3}$$

- Driver laser

$$\lambda_D = 1\mu m$$

$$I_D = 2 \times 10^{19} W/cm^2$$

$$a_D = 3.8$$

$$l_D \approx 3.3\mu m$$

- Source laser

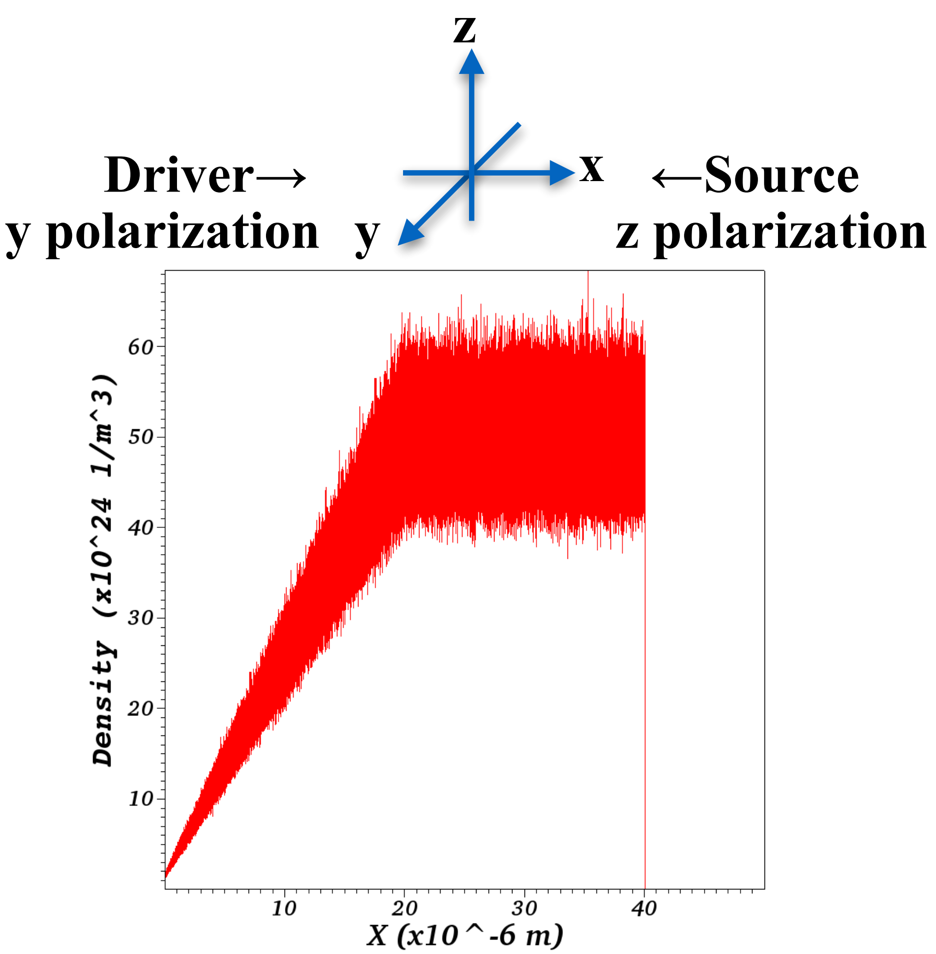
$$\lambda_S = 3\mu m$$

$$I_S = 10^{12} \sim 10^{18} W/cm^2$$

$$a_S = 2.5 \times 10^{-3} \sim 2.55$$

$$l_S \approx 10\mu m$$

- Simulation
- 1D $\Delta_x = 1/9000\mu m$
- 10 particles/cell



EPOCH code

Wave breaking

$a^{3/2} \geq (\omega/\omega_{pe})$ $a = 2.81$ $a_D > a$

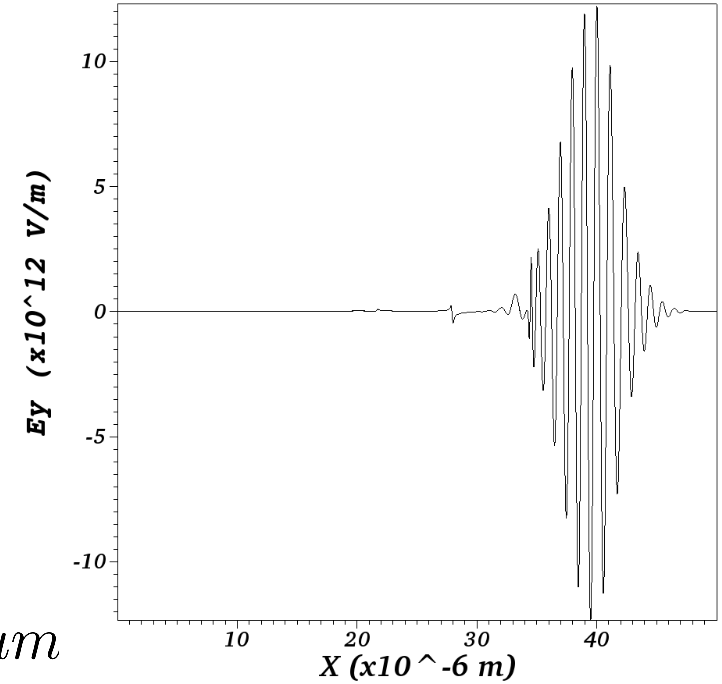
Optimal laser length

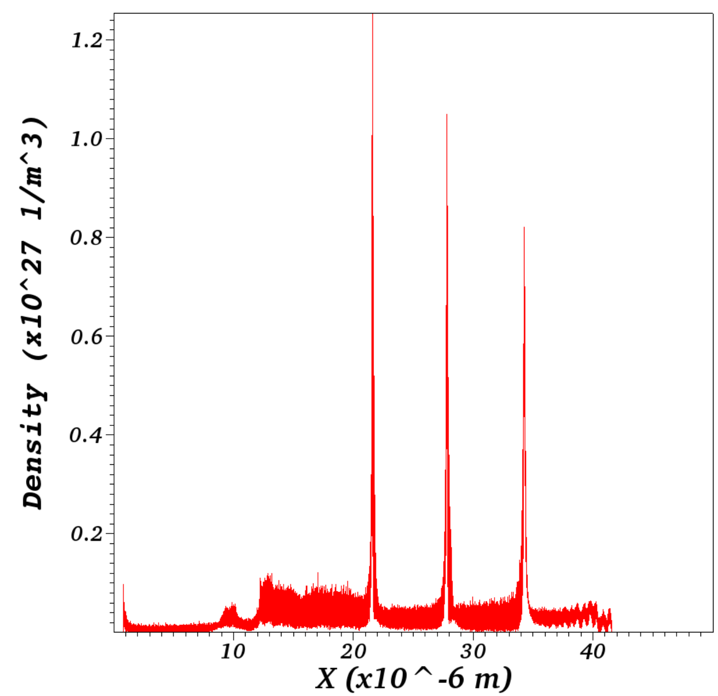
$a^2 >> 1$

$$l_{opt} = 2|a| + \left(\frac{1}{2} + 2\ln 2 - \ln|a|\right)\frac{1}{|a|} + O\left[\frac{1}{|a|}\right]^3 \qquad l_{opt} \approx 7.9\mu m$$

Wake wavelength

$$\lambda_w = 4ca/\omega_{pe} \qquad \lambda_w \approx 11\mu m$$

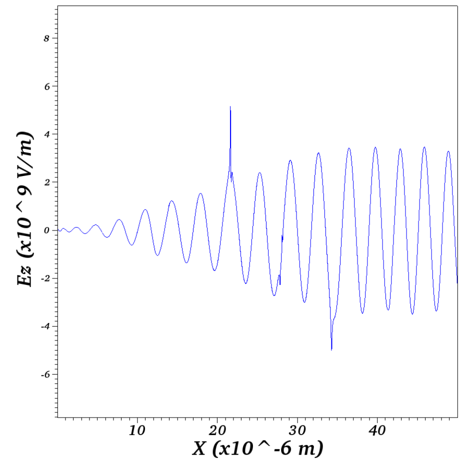


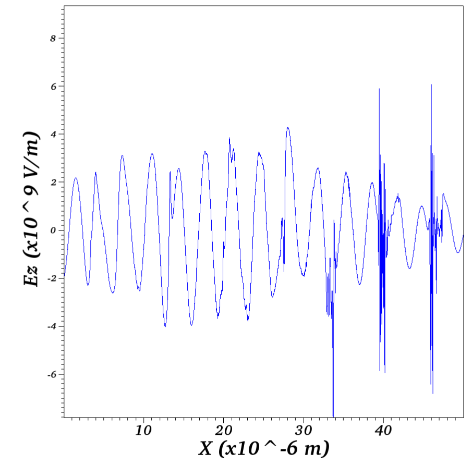


S. V. Bulanov et al., J. Plasma Phys. 82, 905820308 (2016)

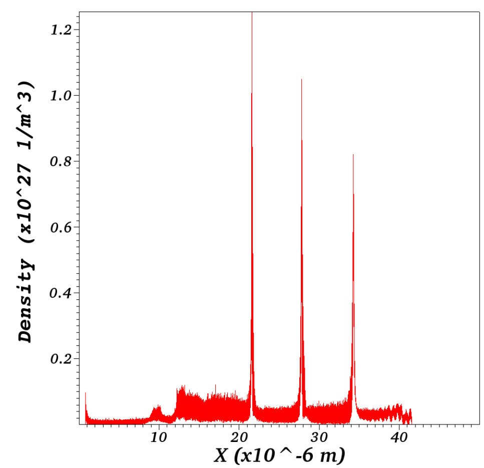
Weak Source pulse

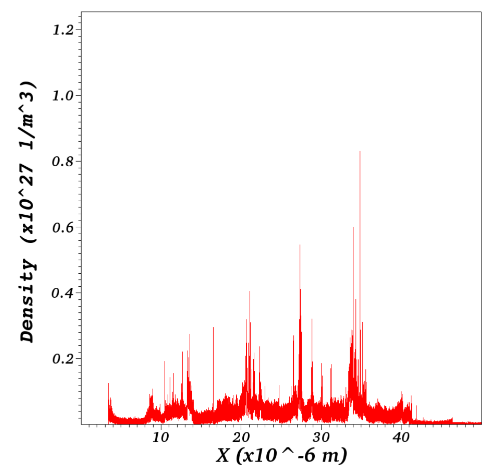
10^{12} W/cm^2





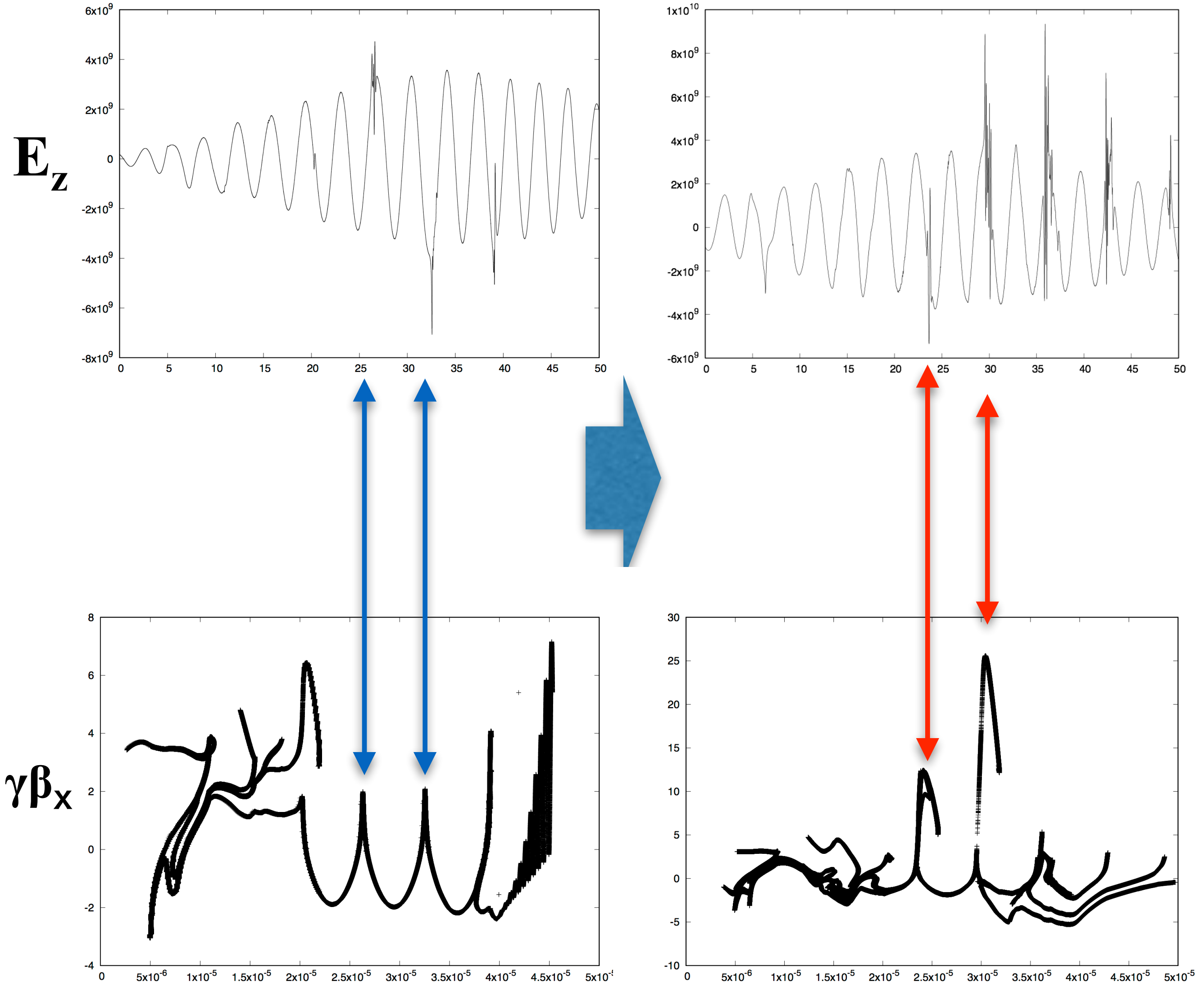
- Reflections can be seen
- Occur at various points





Phase Space

- Source pulse reflection from waves of various momenta
- non-breaking and breaking



Spectrum

- Fourier transform of source pulse (Hanning filter)
- Broad spectrum
- Circularly polarized pulse

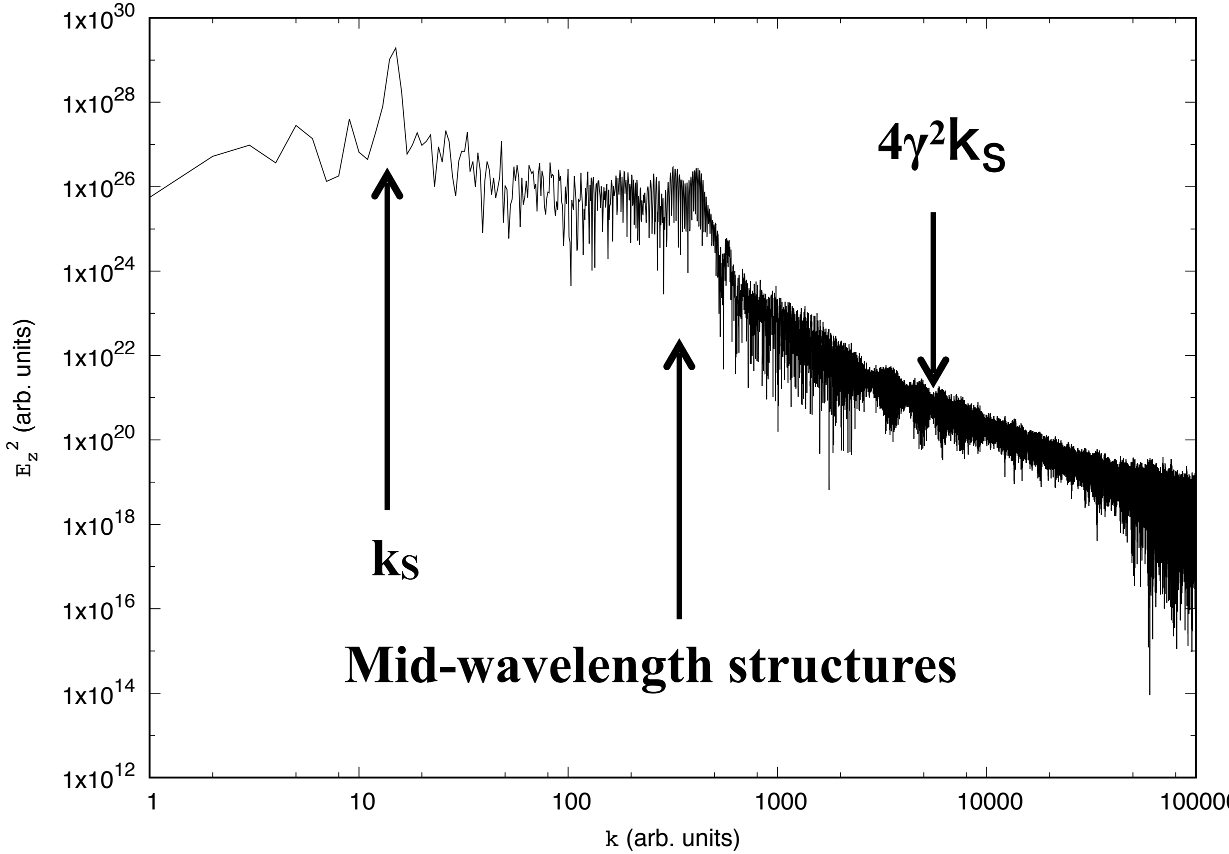
$$\gamma = (\frac{\omega}{\omega_{pe}})(1+a^2)^{1/4}$$

$$a = 3.8$$

$$\frac{\omega}{\omega_{pe}} = 4.72$$

$$\gamma = 9.36$$

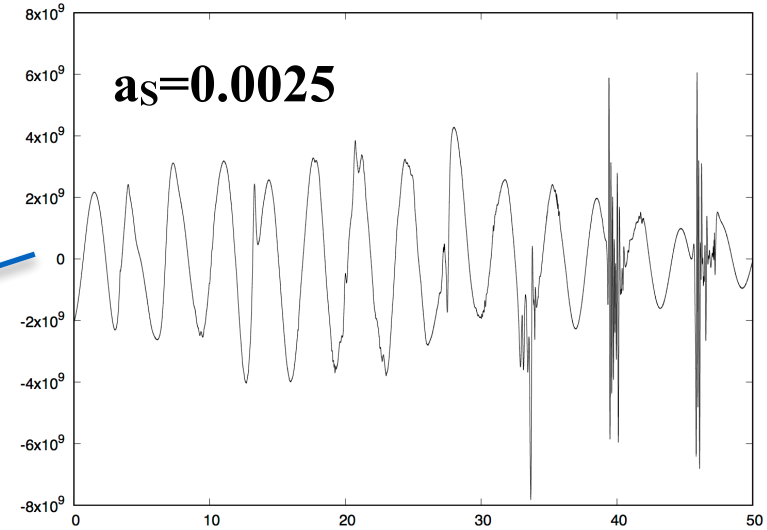
$$4\gamma^2 = 350.57$$

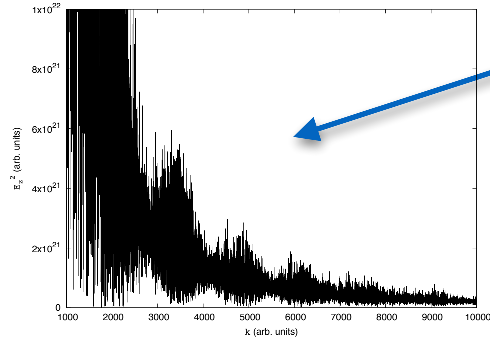


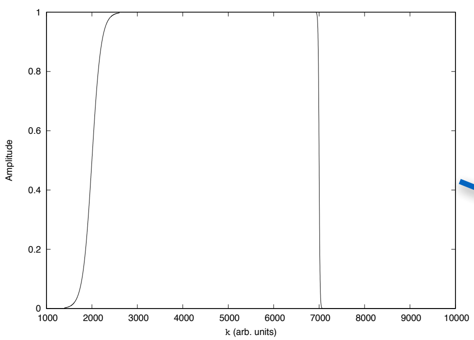
A. I. Akhiezer and R. V. Polovin, Sov. Phys. JETP 3, 696 (1956)

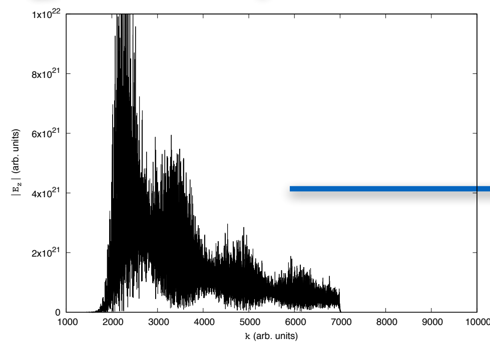
Weak Source pulse

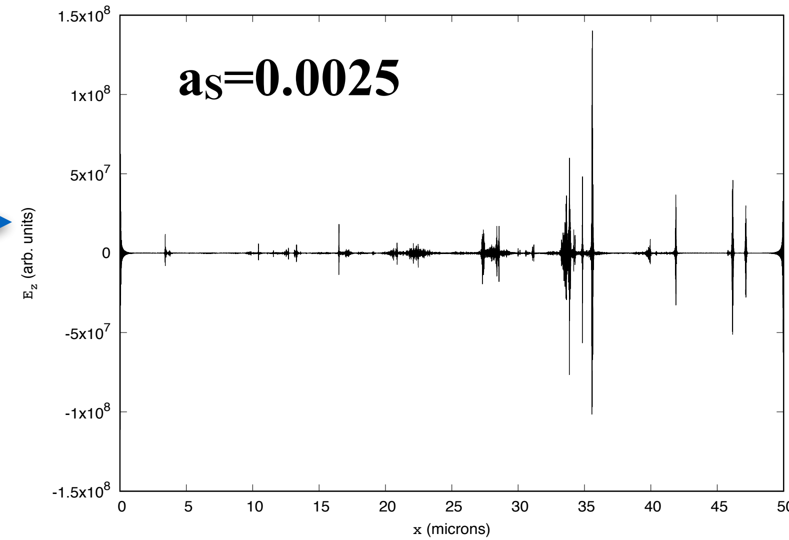
- High bandpass filter to locate source signal
- Tanh function at edges





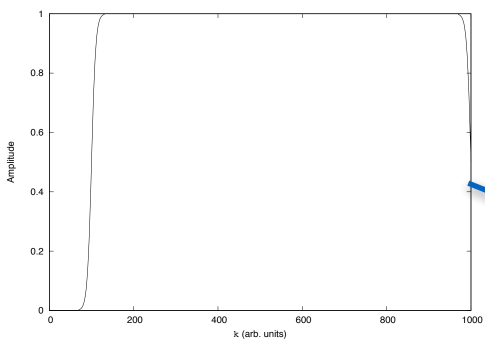


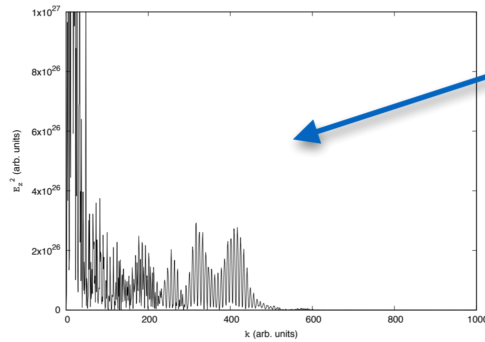


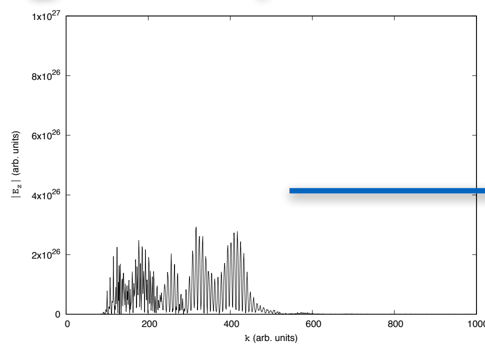


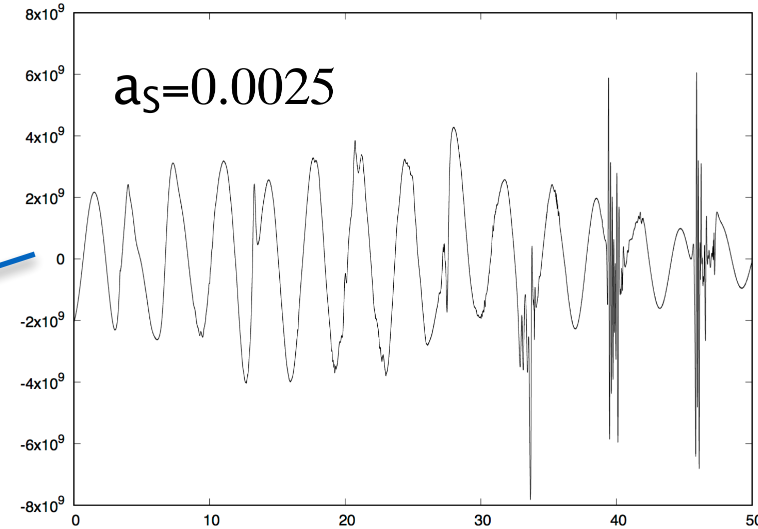
Weak Source pulse

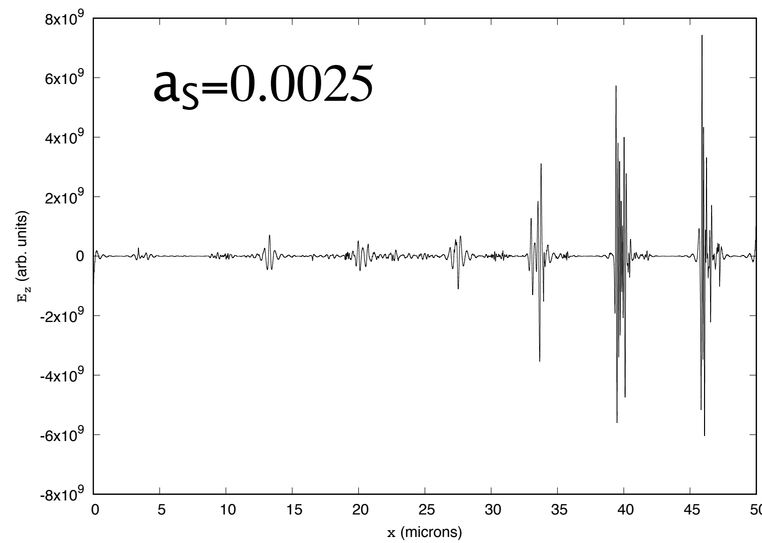
- Low bandpass filter
- Tanh function at edges





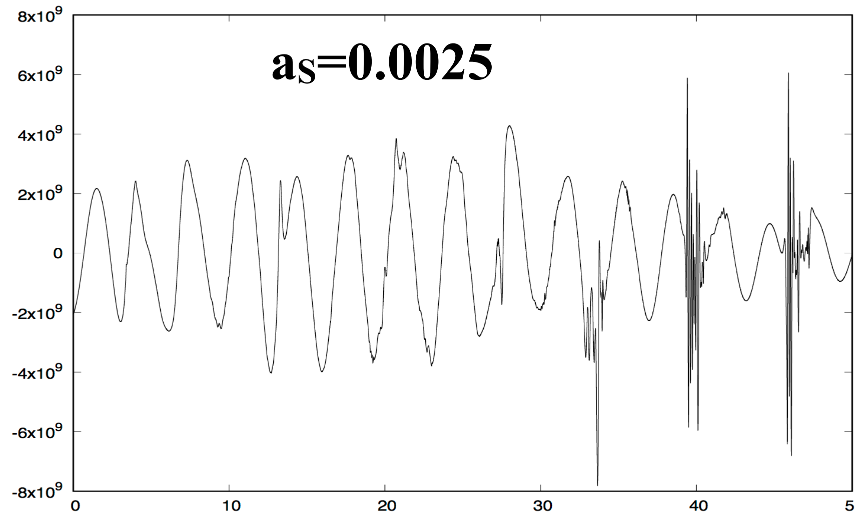




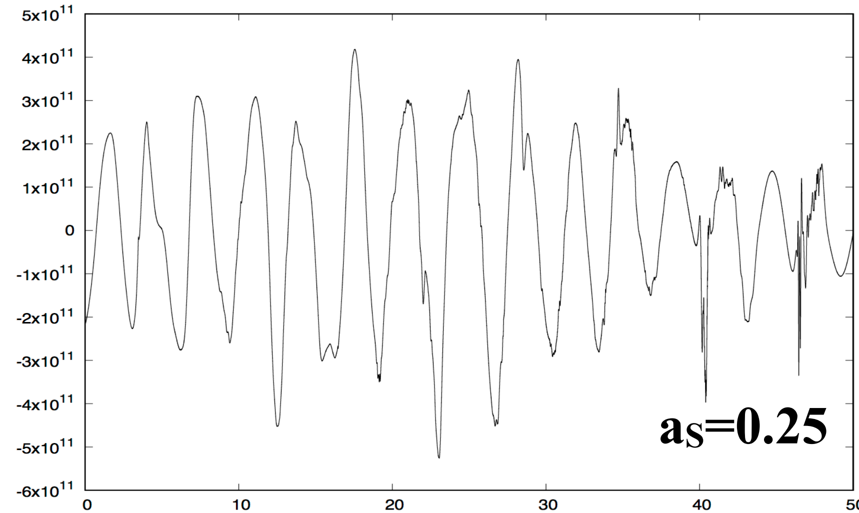


Higher Source Intensity

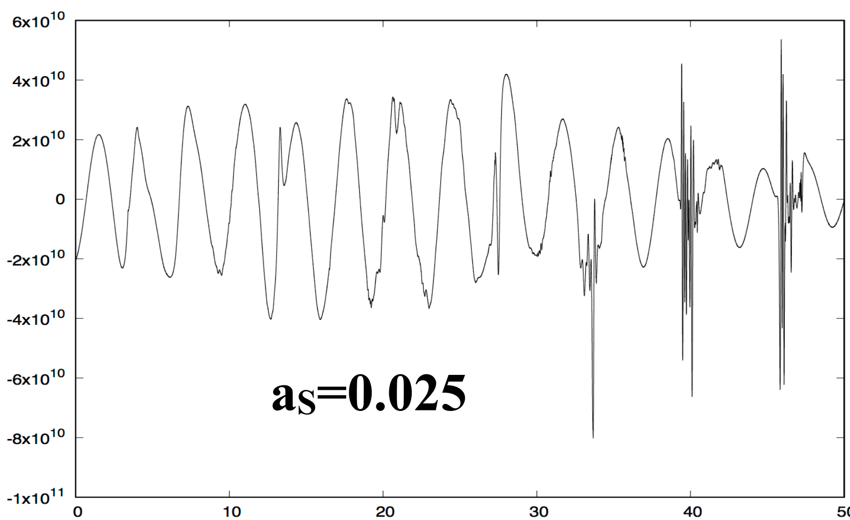
10^{12} W/cm^2



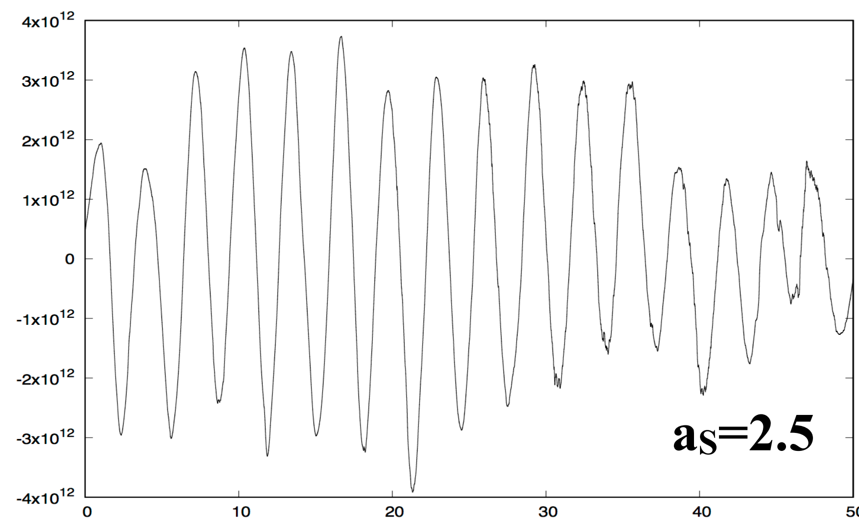
10^{16} W/cm^2



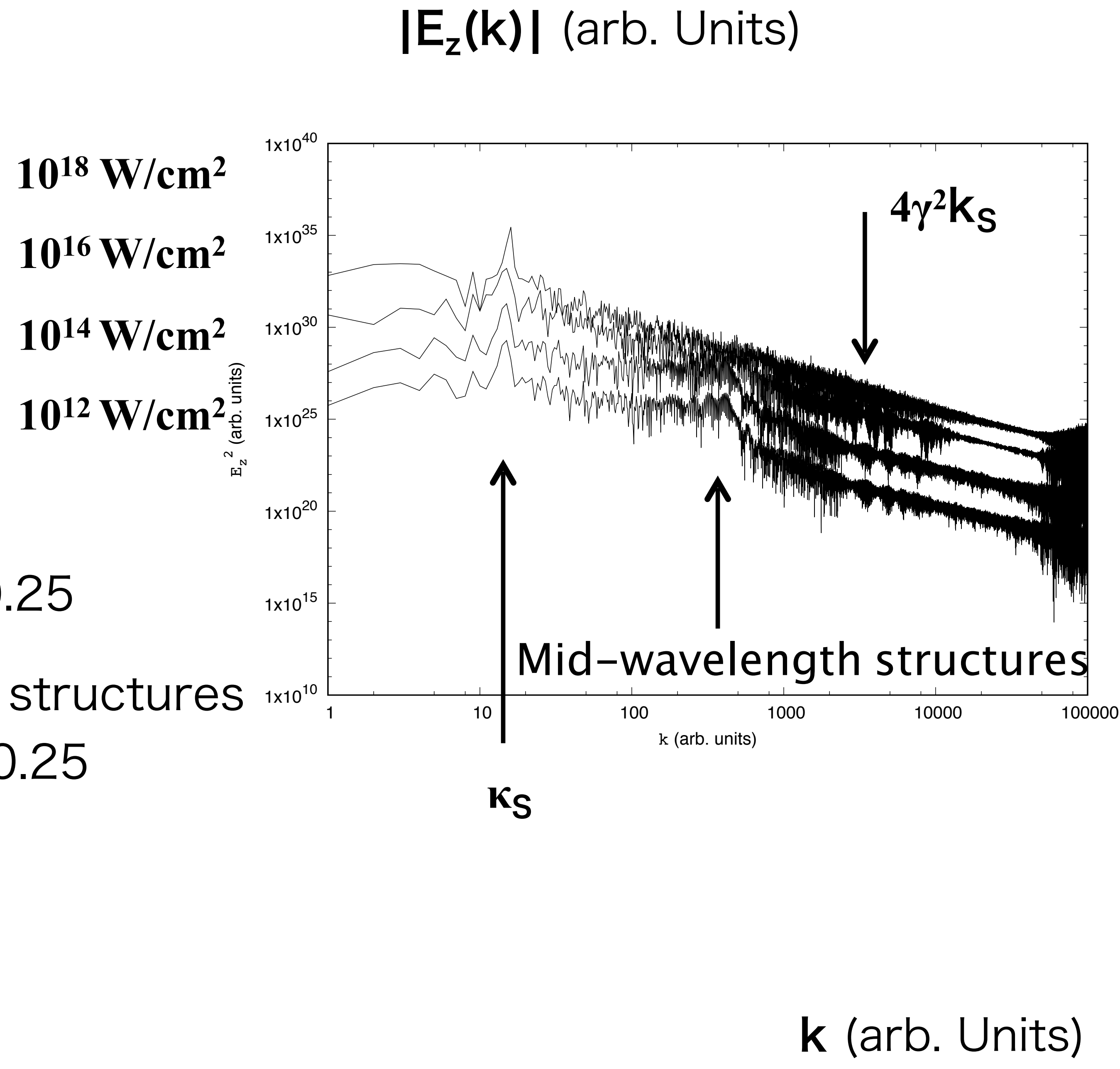
10^{14} W/cm^2



10^{18} W/cm^2



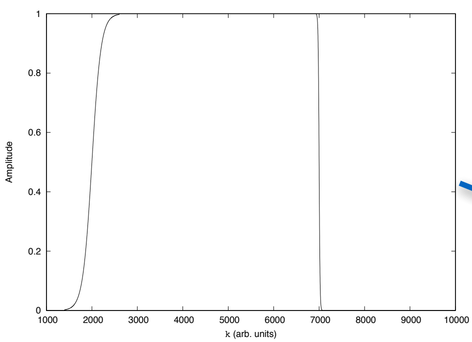
Spectra

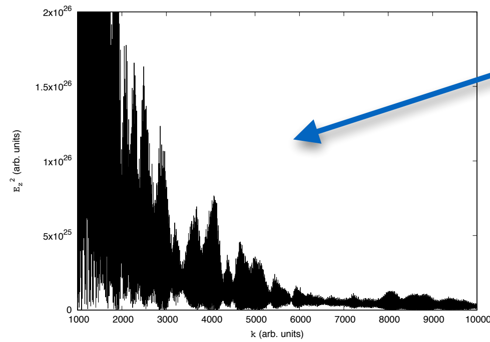


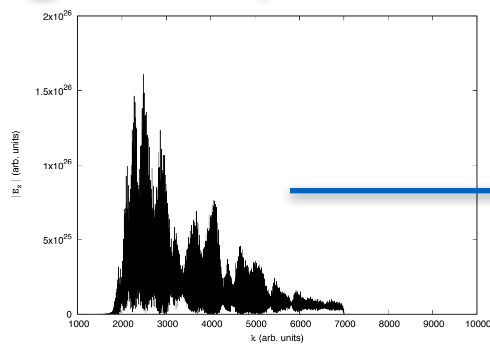
- Harmonics $a_S=0.25$
- Mid-wavelength structures not present $a_S>0.25$

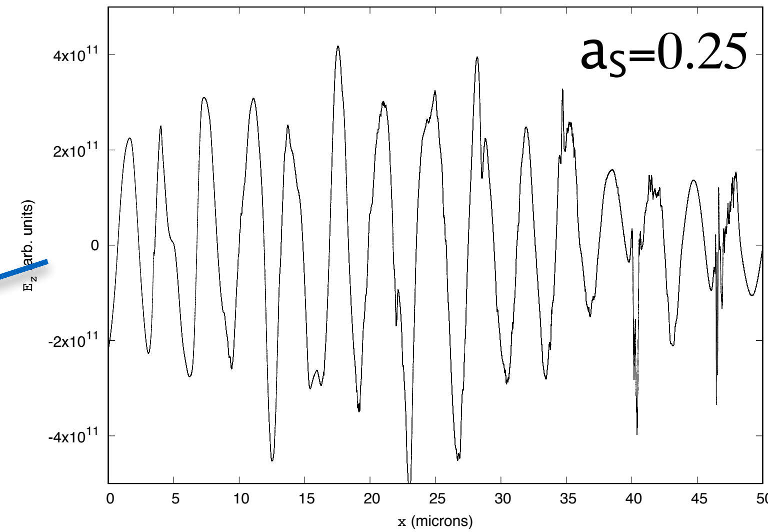
Moderate Source pulse

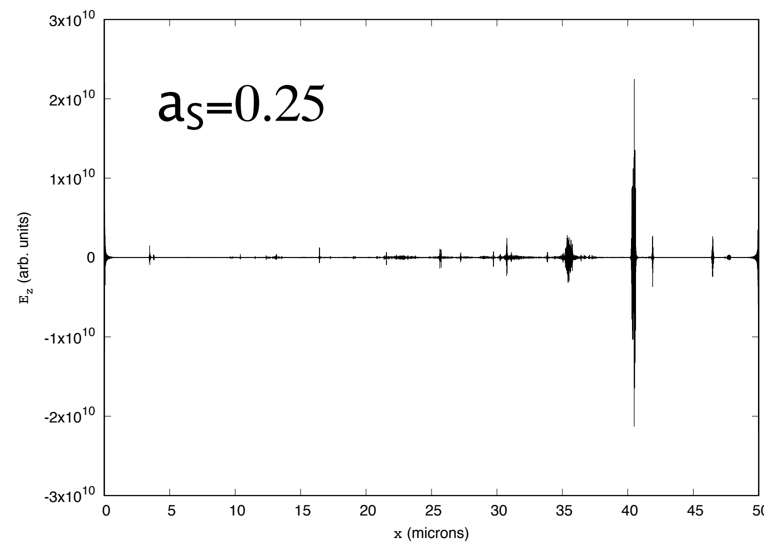
- High bandpass filter
- Tanh function at edges





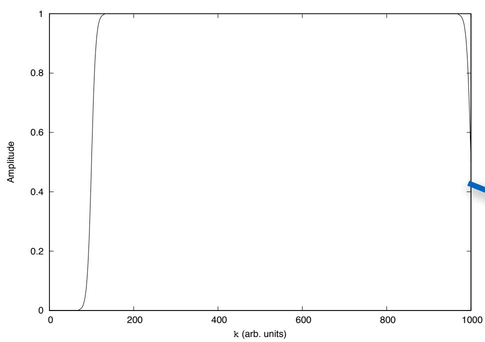


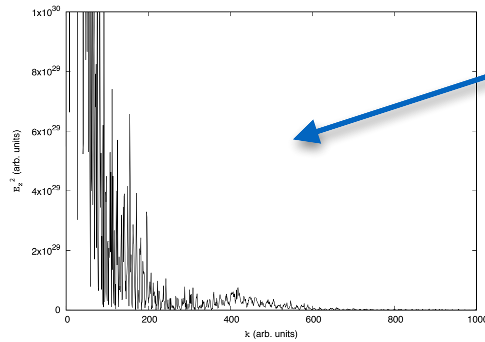


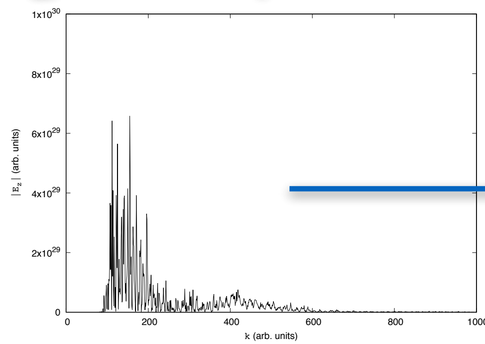


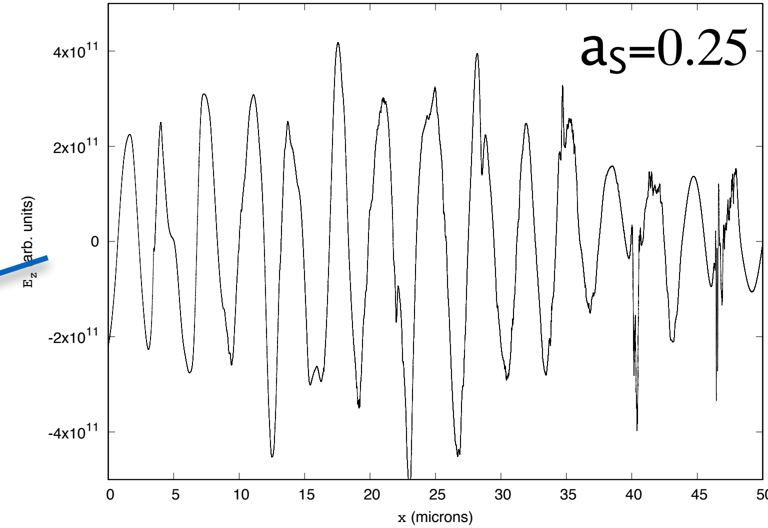
Moderate Source pulse

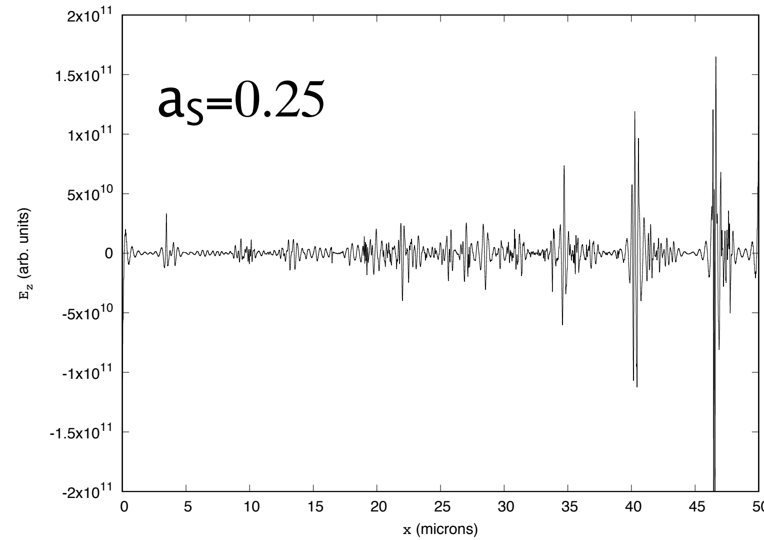
- Low bandpass filter
- Tanh function at edges





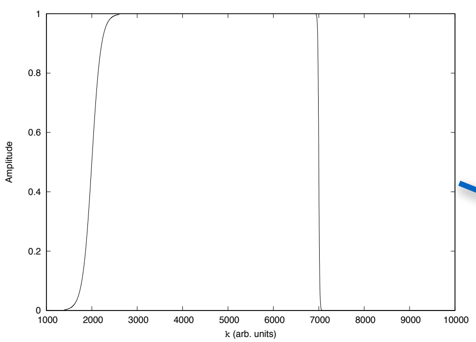


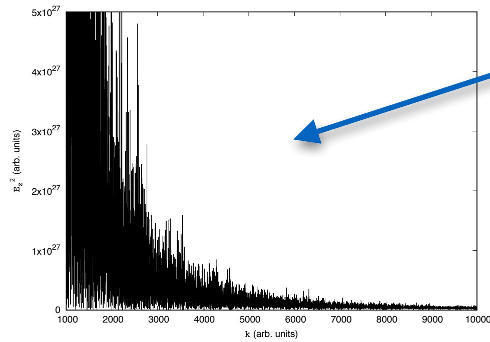


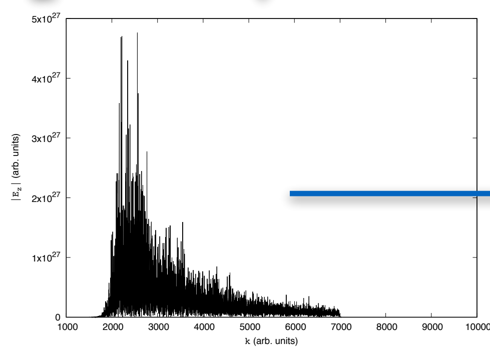


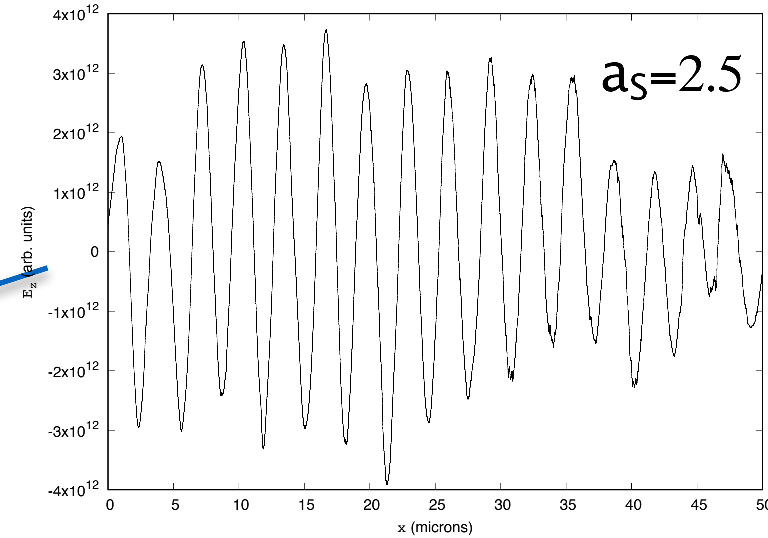
Strong Source pulse

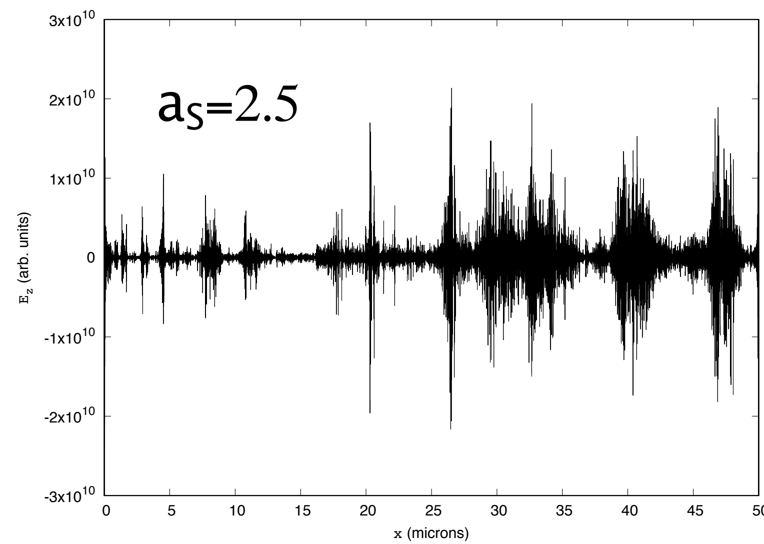
- High bandpass filter
- Tanh function at edges





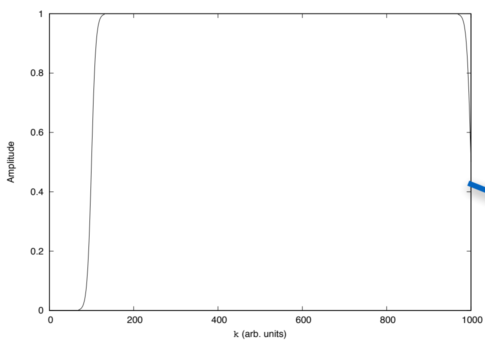


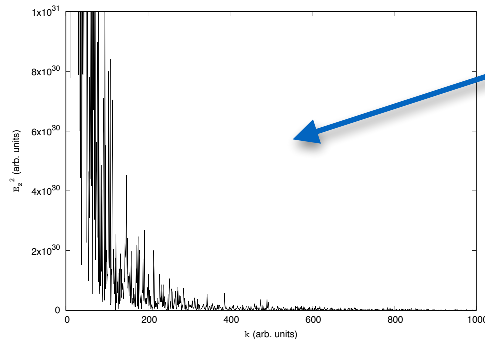


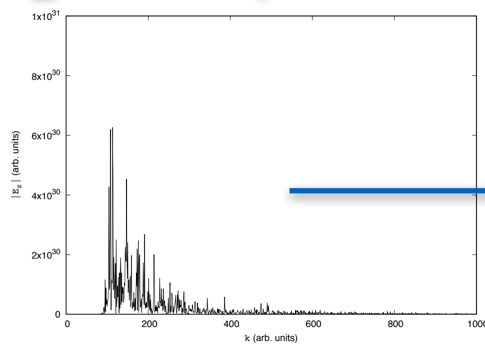


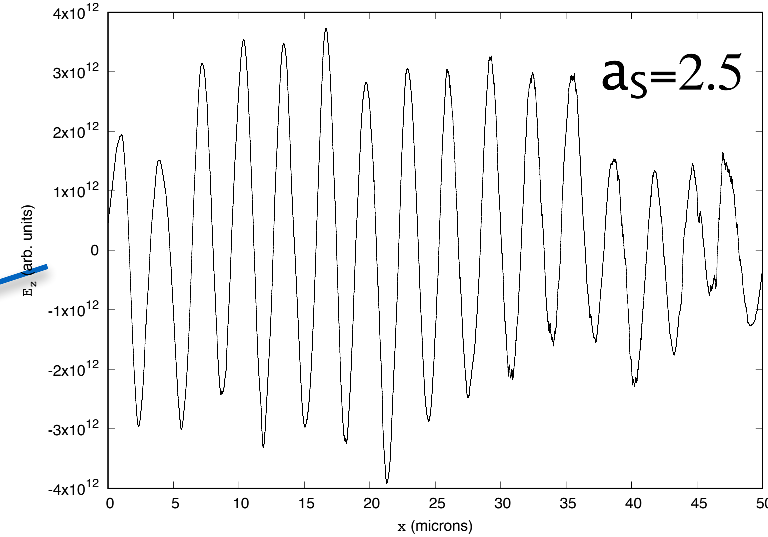
Strong Source pulse

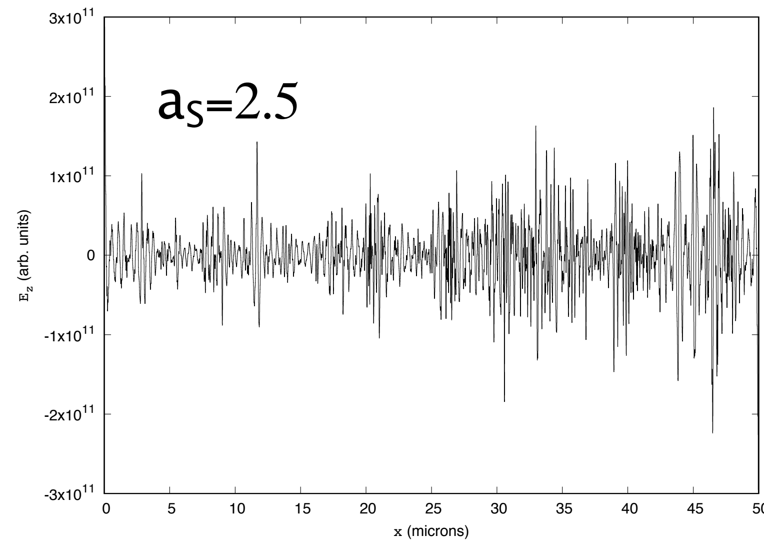
- Low bandpass filter
- Tanh function at edges











Conclusions

- Reflection from relativistic flying mirror
- Long wavelength/nonlinear regime
- Broad spectrum observed
- Reflection from non-breaking and breaking waves
- Harmonics appear at a_s=0.25
- High bandpass filter position of reflected pulses
- Low bandpass filter position of mid-wavelength structures
- At higher source intensities mid-wavelength structures not present
- Source pulse is generating its own wake at high intensities
- Next
- More detailed analysis of 1D results
- 2D Simulations
- After that Radiation Reaction effects

Simulations performed on "SGI ICE X" super computer at Japan Atomic Energy Agency