Surface Plasmon Polaritons in Linear Chains of Metallic Nanoparticles

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Why Metal Nanoparticles are Useful?

- Field Enhancement
- Field Localization

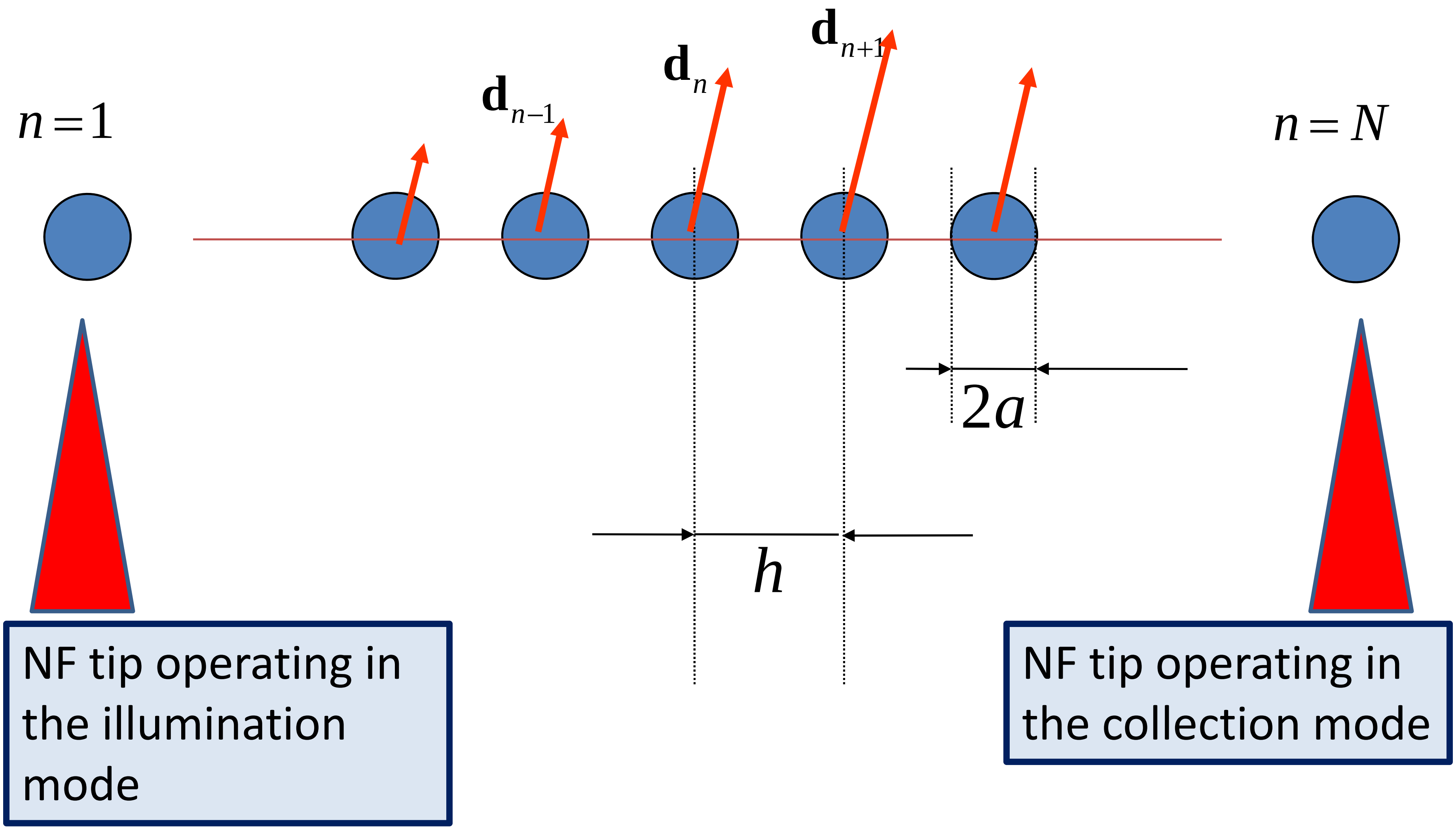
Potential Applications

- SERS
- Biosensors
- Imaging beyond the diffraction limit (near-field tomography)
- Integrated Optoelectronic Elements
- Subwavelength waveguides

What is the Role of Nonsphericity?

- Nanoparticle chains have been studied almost exclusively for the case of spherical particles
- However, nonsphericity can be expected to provide a useful additional pareameter to control:
  - SPP dispersion curves
  - SPP bandwidth
  - Propagation distance

Physical Model



The Dipole Approximation

$$\mathbf{d}_n = \alpha_n \left[\mathbf{E}_n + \sum_{m \neq n} \hat{G}_k(x_n, x_m)\mathbf{d}_\mathbf{m} \right]$$

The coupled-dipole equation in the frequency domain

$$k = \frac{\omega}{c} = \text{const}$$

α_n - Polarizability of the *n*-th particle

$\hat{G}_k(x_n, x_m)$ - Green's function for the electric field in vacuum

$\mathbf{E}_n \propto \delta_{n1}$ - Electric field produced by the firsrt tip (the incidentb field)

Model for the Polarizability, α

$$\frac{1}{\alpha} = \frac{4\pi}{\varepsilon_h V}\left(\nu + \frac{\varepsilon_h}{\varepsilon_m - \varepsilon_h}\right) - i\frac{2k^3}{3}$$

ε_h is the permittivity of the host medium (a transparent dielectric or vacuum)

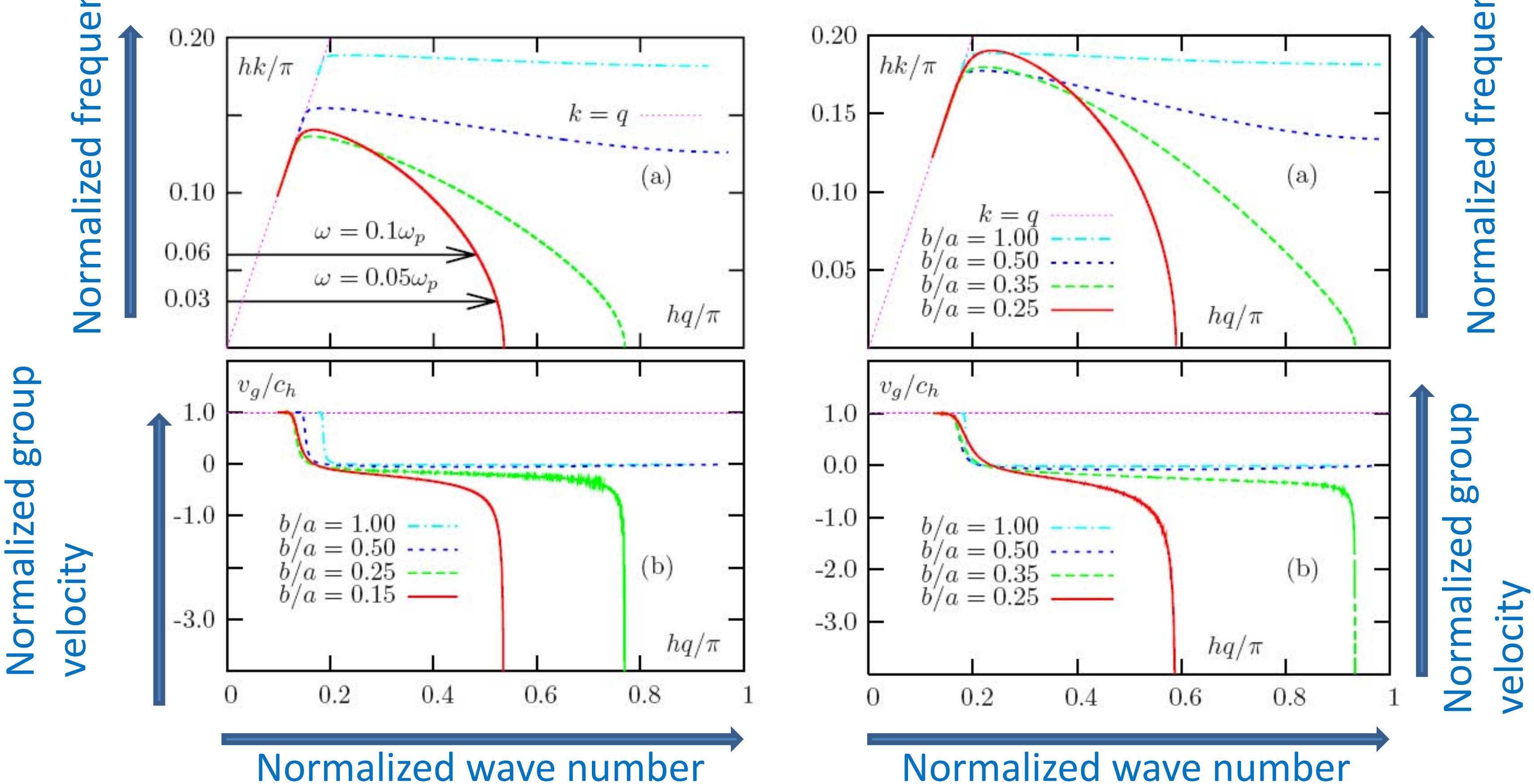
$\varepsilon_m = \varepsilon_0 - \dfrac{\omega_p^2}{\omega(\omega + i\gamma)}$ is the permittivity of metal (given by the Drude formula)

$V = \dfrac{4\pi abc}{3}$ is the volume of spheroid; $k = \dfrac{\omega}{c}$

ν is the depolarization factor

Dispersion Curves and Group Velocities for Transversely Polarized SPPs and Different Aspect Ratios *a/b* of Spheroids

(For the chain parameters see Slide 9)

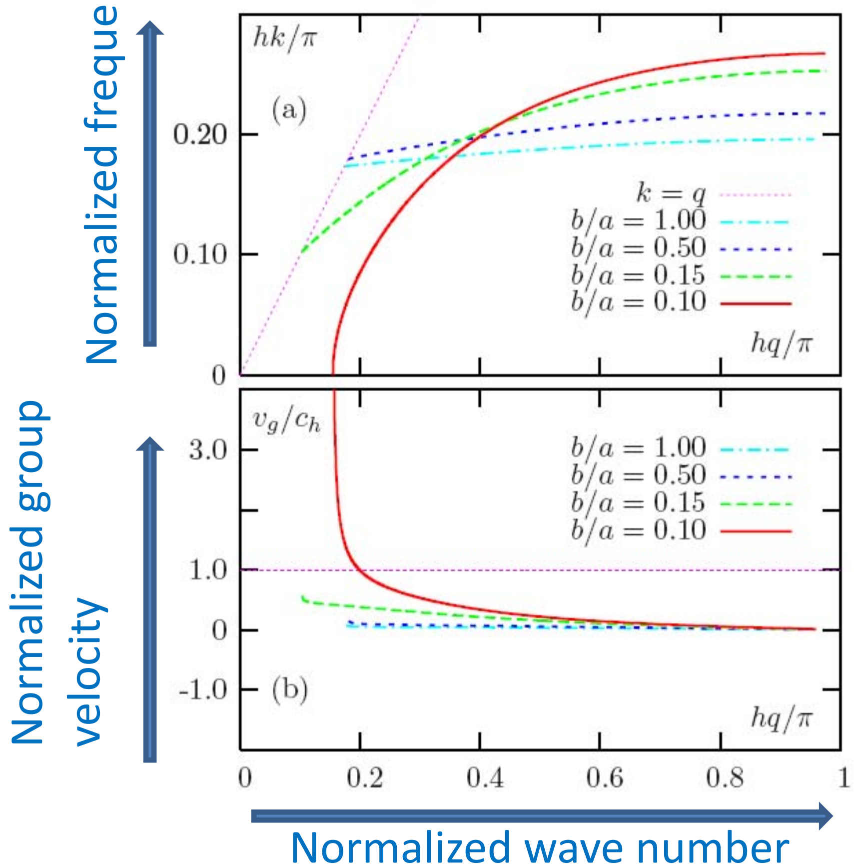


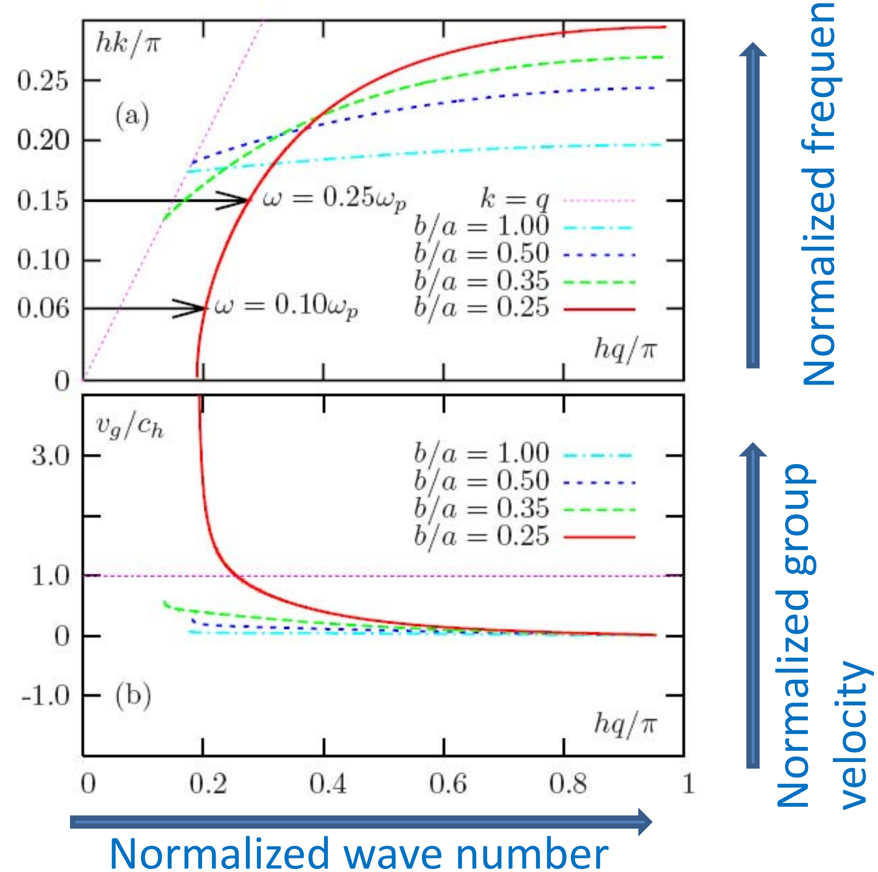
Prolate spheroids whose axis of symmetry is perpendicular to the chain

Oblate spheroids whose axis of symmetry is parallel to the chain

Dispersion Curves and Group Velocities for Longitudinally Polarized SPPs and Different Aspect Ratios *a/b* of Spheroids

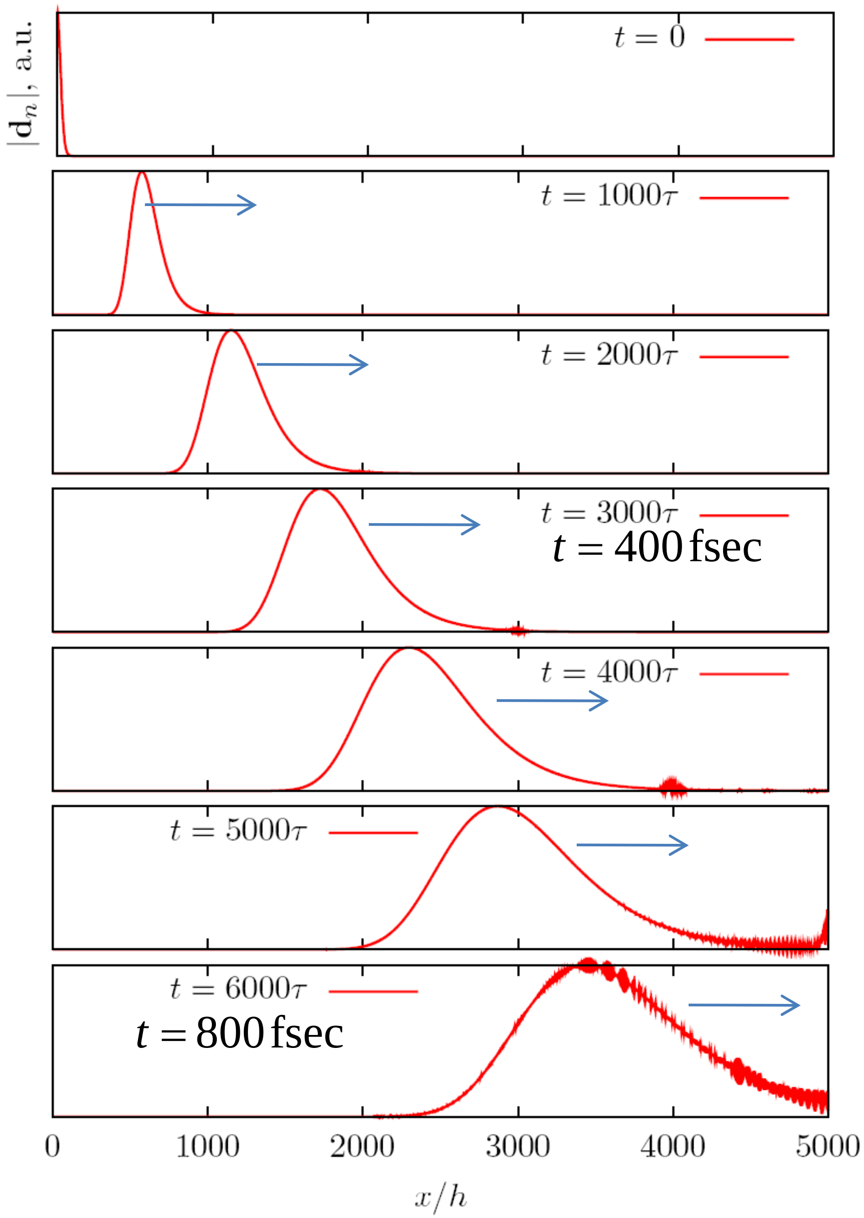
(For the chain parameters see Slide 9)





Prolate spheroids whose axis of symmetry is perpendicular to the chain

Oblate spheroids whose axis of symmetry is parallel to the chain



$v_g \approx 0.58c$

$L = 200\,\mu\text{m}$

Chain Parameters:

$h = 40\,\text{nm}$

$b = 10\,\text{nm}$

$\xi = \dfrac{b}{a} = 0.15$

$N = 5000$

$\tau = \dfrac{h}{c} = 0.133\,\text{fsec}$

Metal Parameters (Ag)

$\varepsilon = \varepsilon_0 - \dfrac{\omega_p^2}{\omega(\omega + i\gamma)}$

$\lambda_p = \dfrac{2\pi c}{\omega_p} = 136\,\text{nm}$

$\gamma/\omega_p = 0.002$

$\varepsilon_0 = 5$

Host Medium:

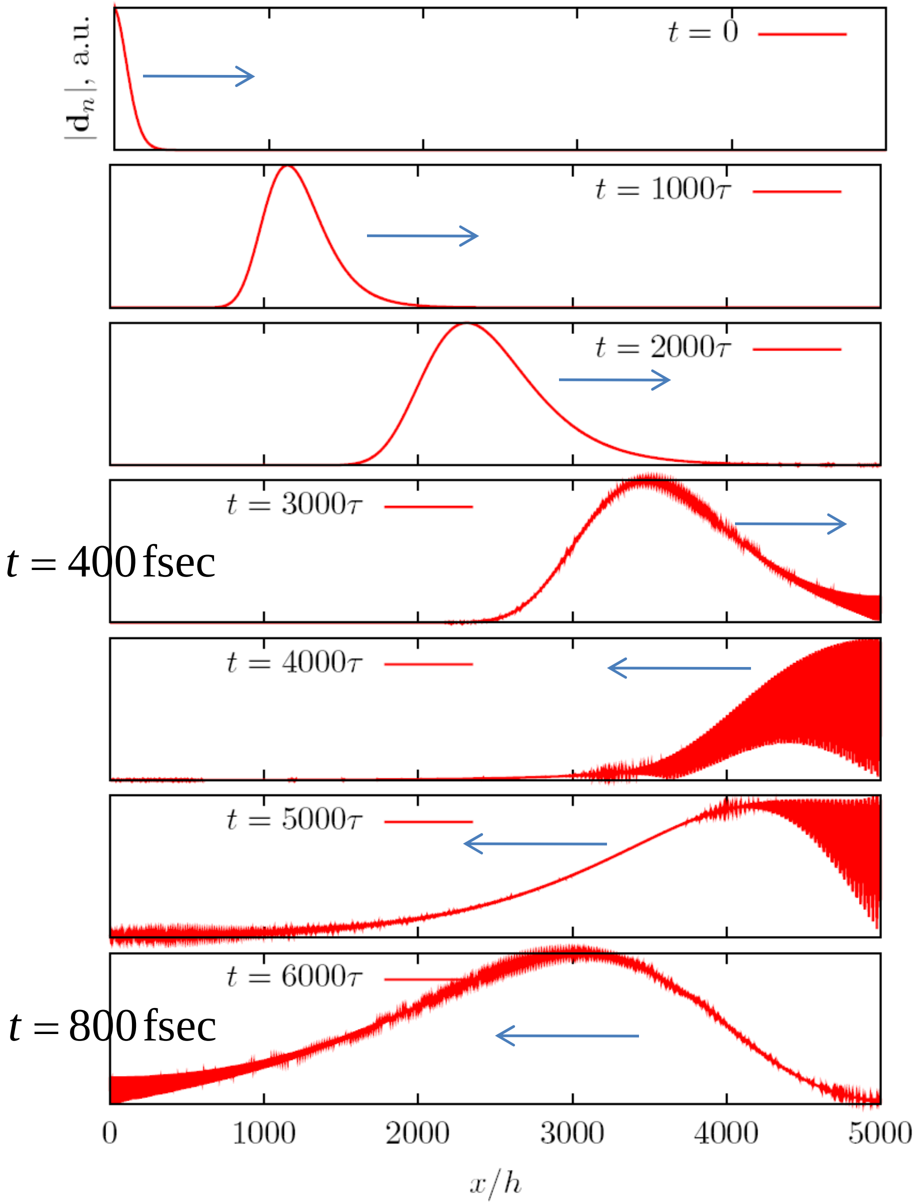
$\varepsilon_h = 2.5$

Pulse Parameters:

$\omega_0 = 0.1\omega_p\ [\lambda_0 = 1.36\,\mu\text{m}]$

$\Delta t = 7.2\,\text{fsec}$

$\Delta\omega/\omega_0 = 0.2$



$v_g \approx 1.17c$

Pulse Parameters Different from the Previous Graph:

$\omega_0 = 0.05\omega_p$ $[\lambda_0 = 2.72\,\mu\text{m}]$

$\Delta t = 14.2\,\text{fsec}$

$\Delta\omega/\omega_0 = 0.2$ [same as before]

(But note that special relativity
Is not violated. You can ask me why.)

PROPAGATION DISTANCES

Frequency	Prolate spheroid chain, transverse SPP *b/a*=0.15 *a*=40nm, *h*=25nm	Cylindrical wire R=25nm $\gamma \ll \omega \ll \omega_p$
$\omega = 0.1\omega_p$	7microns	3microns
$\omega = 0.05\omega_p$	15microns	3microns

Propagation distances in chains and in wires are generally comparable, but it seems that in the special case of prolate spheroids, the propagation distance can be increase by a factor of 2 – 5, depending on the working frequency.

A Few References to Previous Work

- V.A.Markel, "Coupled-dipole approach to scattering of light from a one-dimensional periodic dipole structure," ***Journal of Modern Optics* 40(11), 2281-2291 (1993)**
- V.A.Markel, "Divergence of dipole sums and the nature of non-Lorentzian exponentially narrow resonances in one-dimensional periodic arrays of nanospheres," ***Journal of Physics B* 38(7), L115-L121 (2005)**
- V.A.Markel and A.K.Sarychev,"Pr opagation of surface plasmons in ordered and disordered chains of metal nanospheres," ***Physical Review B* 75(8), 085426 (2007)**
- A.A.Govyadinov and V.A.Markel , "From slow to superluminal propagation: Dispersive properties of surface plasmon polaritons in linear chains of metallic nanospheroids , " ***Physical Review B* 78(3), 035403 (2008)**