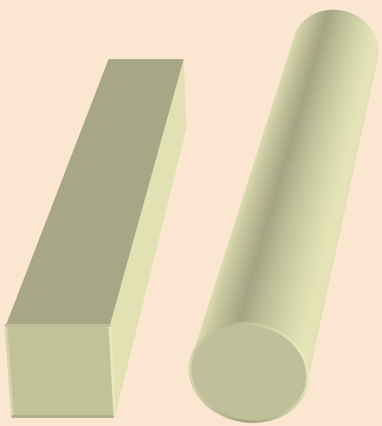
The effect of cross-sectional geometry and size on magnetostatic modes in nanorods

Maciej Krawczyk and Henryk Puszkarski

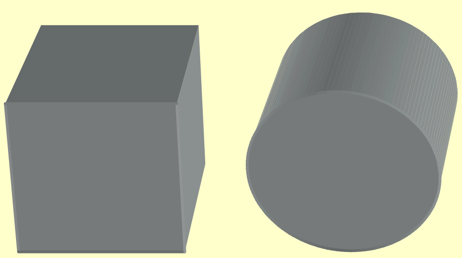
Surface Physics Division,
Faculty of Physics,
Adam Mickiewicz University,
Umultowska 85, Poznań, Poland

OUTLINE

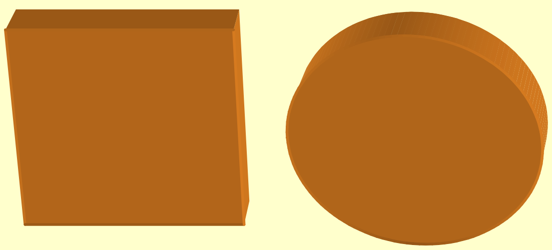
- The model of calculations
- Magnetostatic modes in nanorods
- The effect of cross-sectional geometry and size on
  - A) magnetostatic modes
  - B) effective dipolar field



Elongated rod



„Cube”

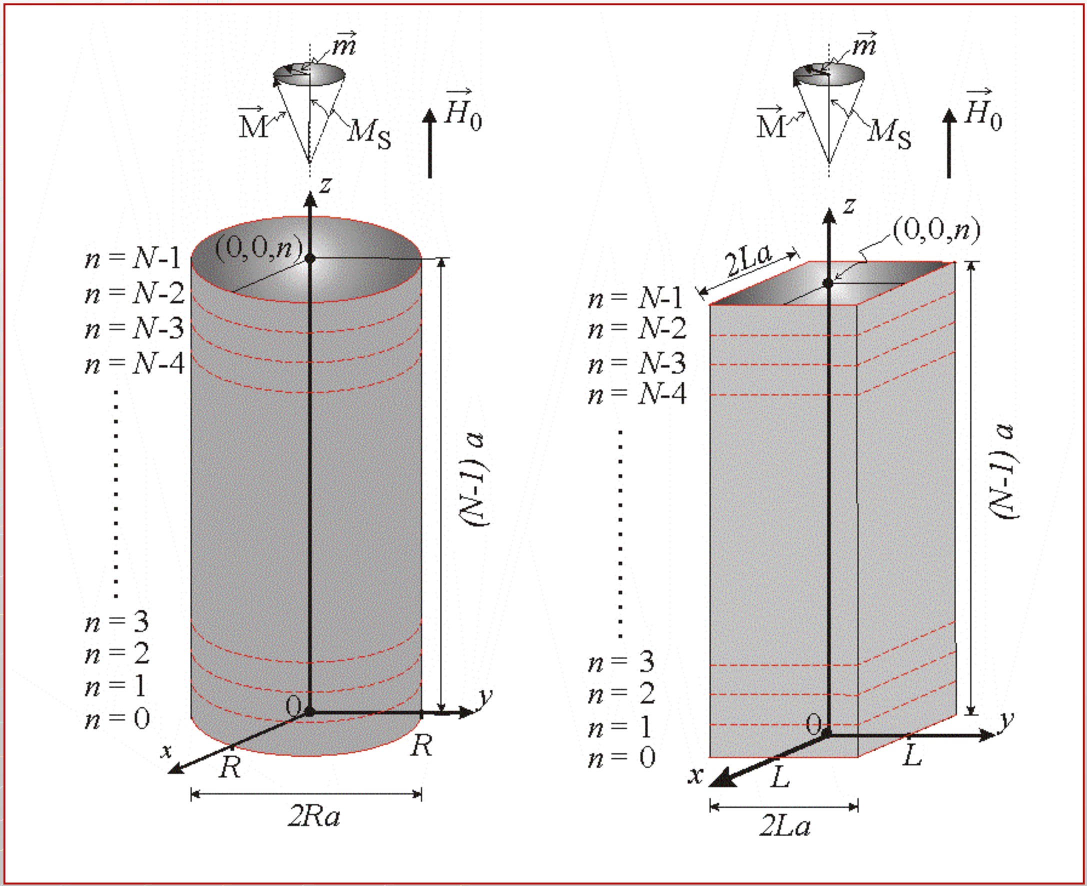


Thin film

Model assumptions:

- magnetic dipoles in planar arrangements,
- uniform magnetization,
- propagation along external magnetic field,
- uniform precession in each plane.

Central axis approximation.



Equations:

$$\frac{\partial \vec{M}_{n'}}{\partial t} = \gamma \mu_0 \vec{M}_{n'} \times \left(\vec{H}_0 + \vec{h}_{n'} \right)$$

Dipolar field in the central axis approximation:

$$\vec{h}_{n'} = \frac{1}{4\pi} \sum_n D_{n,n'} \left[\hat{i} M_n^x + \hat{j} M_n^y - 2\hat{k} M_n^z \right]$$

is obtained from a standard formulae: $$\vec{h}_{\vec{\rho}} = \frac{1}{4\pi} \sum_{\vec{r} \neq \vec{\rho}} \frac{3(\vec{r}-\vec{\rho})\left(\vec{\mu}_{\vec{r}} \cdot (\vec{r}-\vec{\rho})\right) - \vec{\mu}_{\vec{r}} |\vec{r}-\vec{\rho}|^2}{|\vec{r}-\vec{\rho}|^5}$$

We define **dipolar matrix**:

$$\delta = n - n'$$

$$D_\delta \equiv {\sum_{p,q}}' \frac{\frac{1}{2}\left(p^2+q^2\right) - \delta^2}{\left[p^2+q^2+\delta^2\right]^{\frac{5}{2}}}$$

$$\hat{D} = \begin{pmatrix} D_0 & D_1 & D_2 & \cdots & D_{N-2} & D_{N-1} \\ D_1 & D_0 & D_1 & \cdots & D_{N-3} & D_{N-2} \\ D_2 & D_1 & D_0 & \cdots & D_{N-4} & D_{N-3} \\ & & \cdot & & & \\ & & & \cdot & & \\ & & & & \cdot & \\ D_{N-2} & D_{N-3} & D_{N-4} & \cdots & D_0 & D_1 \\ D_{N-1} & D_{N-2} & D_{N-3} & \cdots & D_1 & D_0 \end{pmatrix}$$

In linear approximation we obtain eigenvalue problem

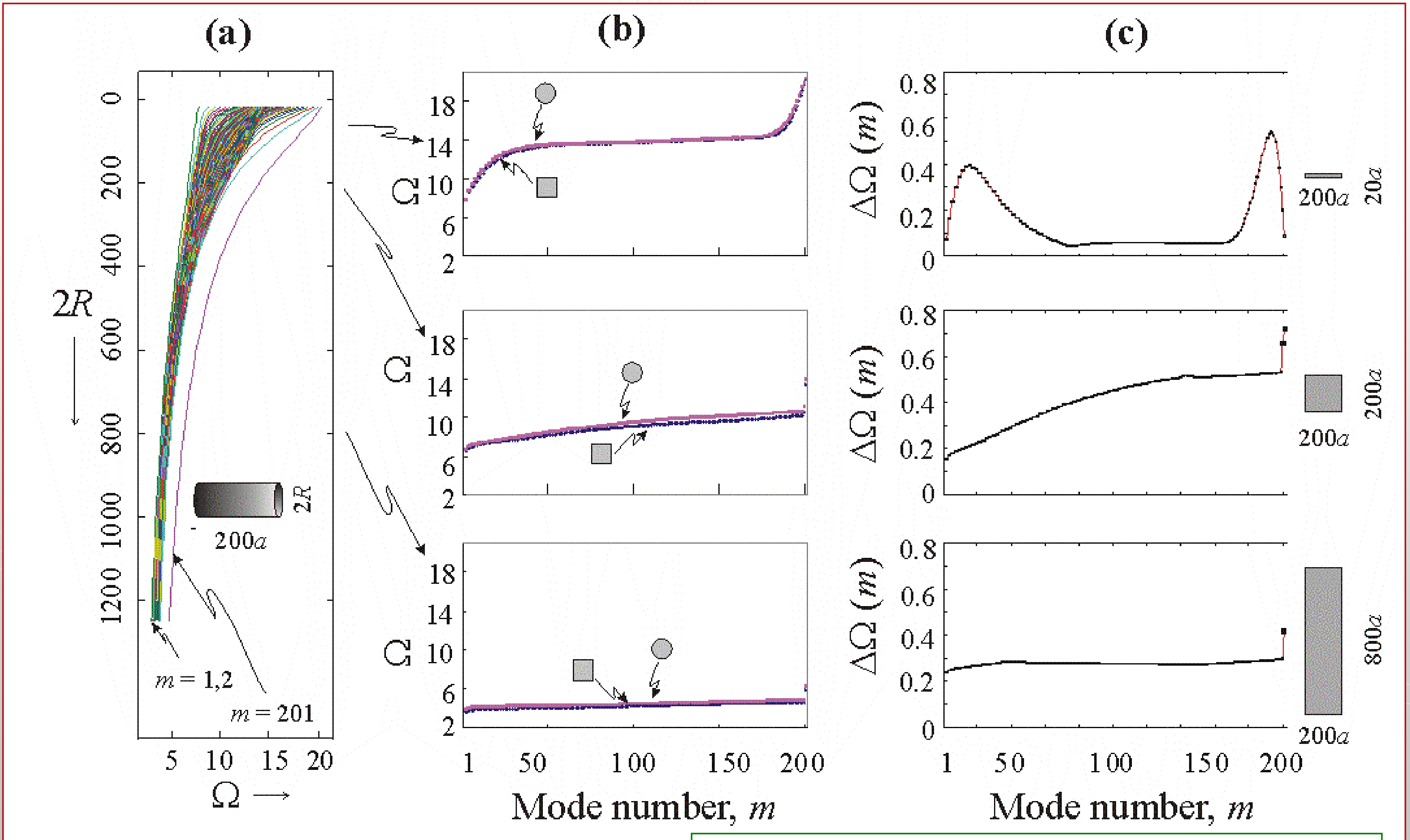
$$\hat{H}\vec{m}^{+} = \Omega\vec{m}^{+}$$

$$\begin{pmatrix} H(0) & D_1 & D_2 & \cdots & D_{N-2} & D_{N-1} \\ D_1 & H(1) & D_1 & \cdots & D_{N-3} & D_{N-2} \\ D_2 & D_1 & H(2) & \cdots & D_{N-4} & D_{N-3} \\ & & & \cdots & & \\ & & & \cdots & & \\ D_{N-2} & D_{N-3} & D_{N-4} & \cdots & H(N-2) & D_1 \\ D_{N-1} & D_{N-2} & D_{N-3} & \cdots & D_1 & H(N-1) \end{pmatrix} \begin{pmatrix} m_0^+ \\ m_1^+ \\ m_2^+ \\ . \\ . \\ m_{N-2}^+ \\ m_{N-1}^+ \end{pmatrix} = \frac{4\pi\omega}{\gamma\mu_0 M_S} \begin{pmatrix} m_0^+ \\ m_1^+ \\ m_2^+ \\ . \\ . \\ m_{N-2}^+ \\ m_{N-1}^+ \end{pmatrix}$$

Local dipolar field is defined as:

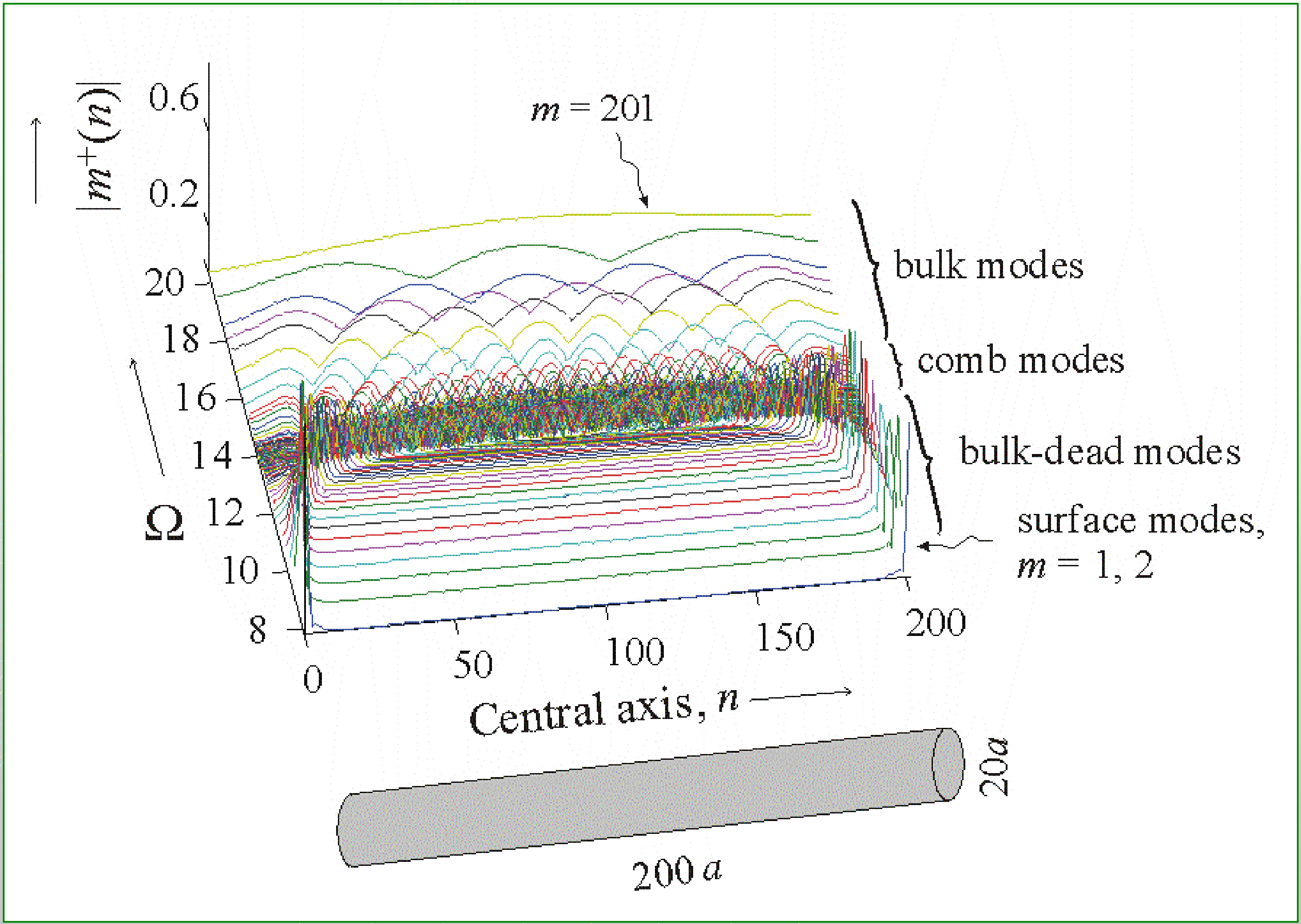
$$H(n') \equiv \Omega_H - D_0 - 2\sum_{\delta=0,\pm1,\ldots}^{n'} D_\delta$$

Magnetostatic modes dependence on cross-sectional shape and size

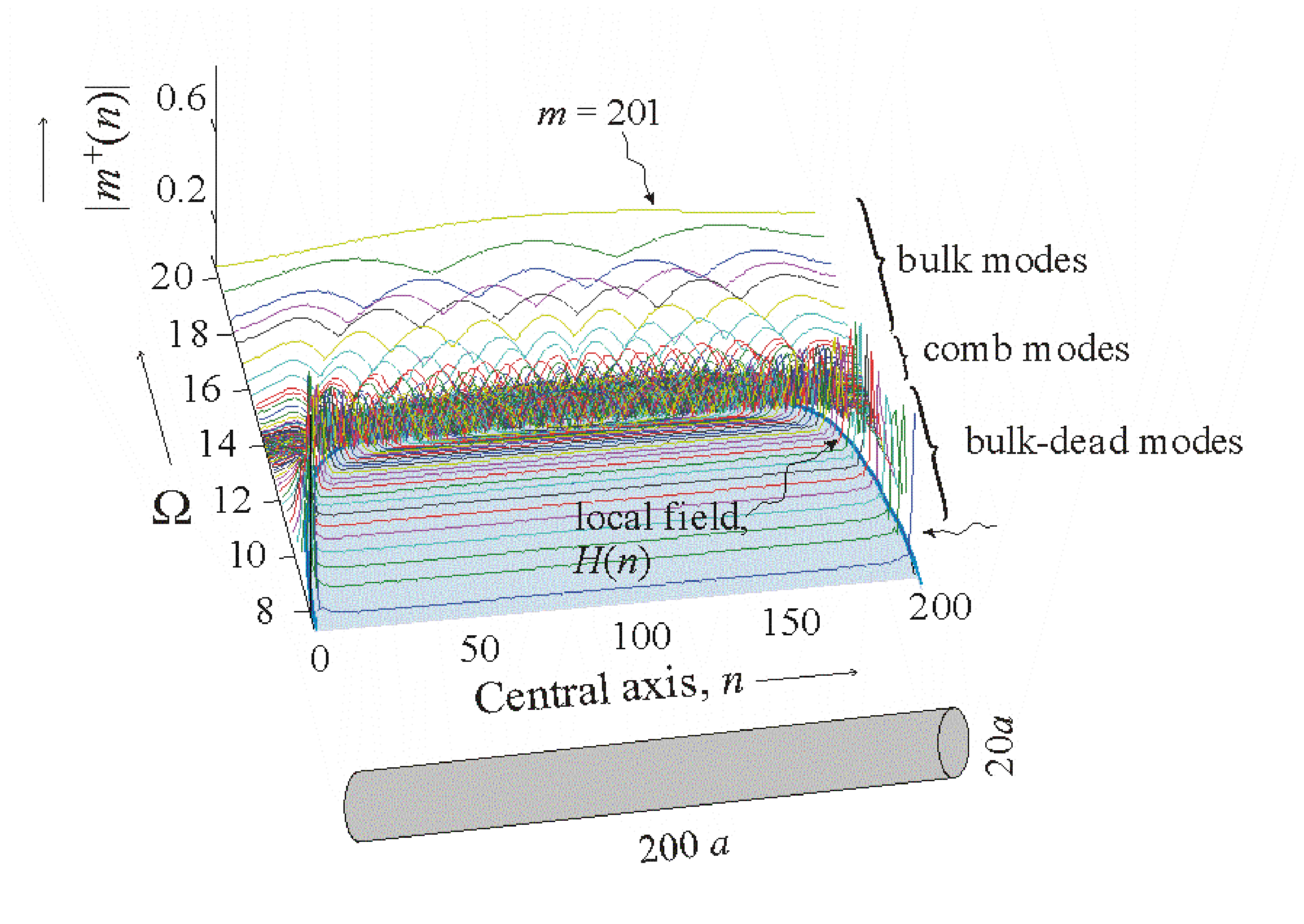


$$\Delta\Omega(m) = \Omega^{\text{circle}}(m) - \Omega^{\text{square}}(m)$$

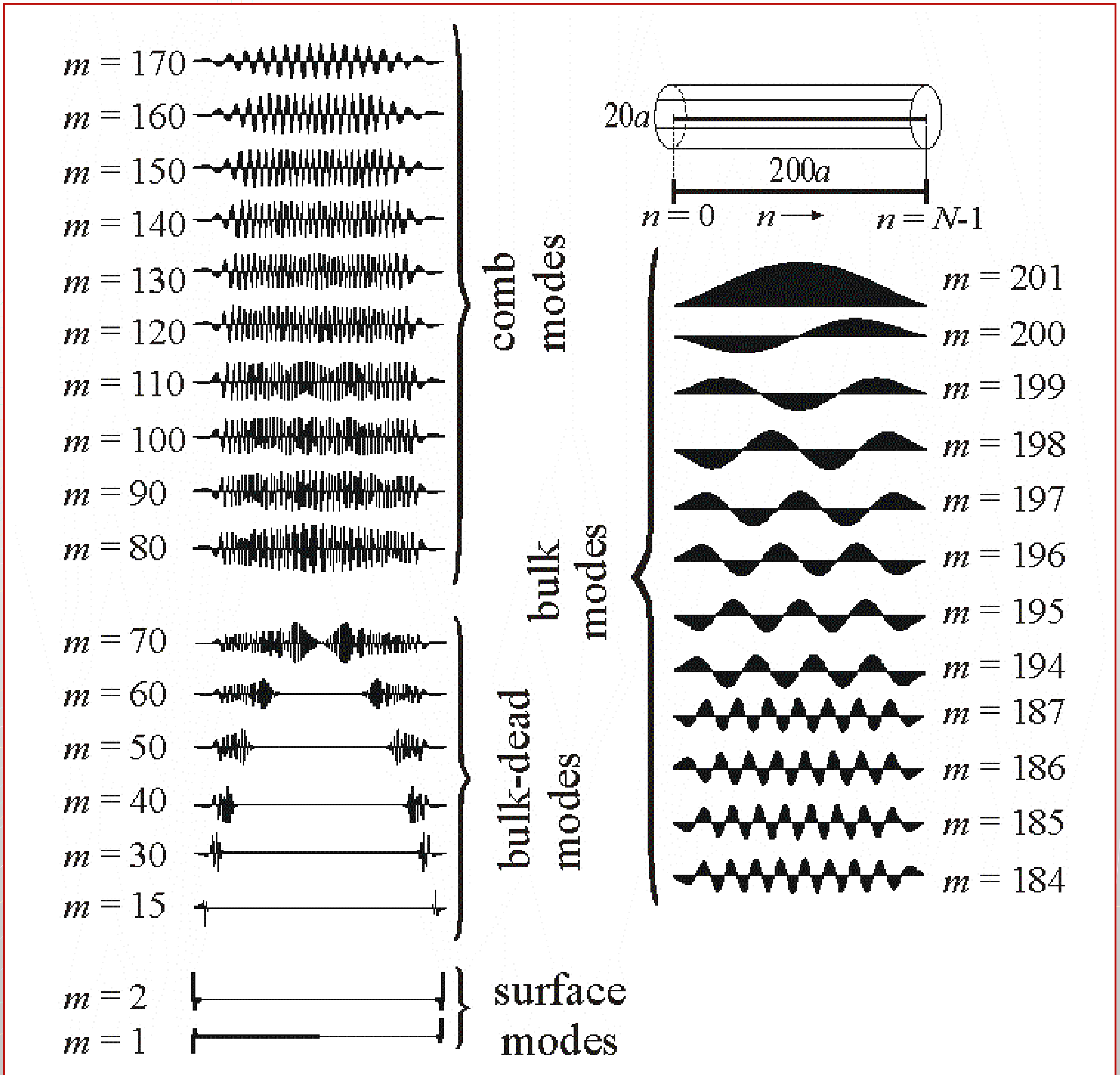
Magnetostatic modes



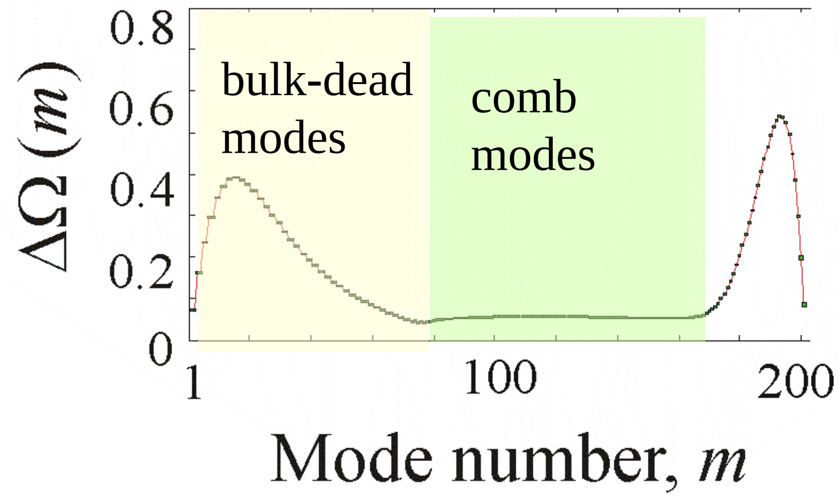
Magnetostatic modes *vs.* local dipolar field *H*(*n*) in nanorods



Magnetostatic modes in nanorods

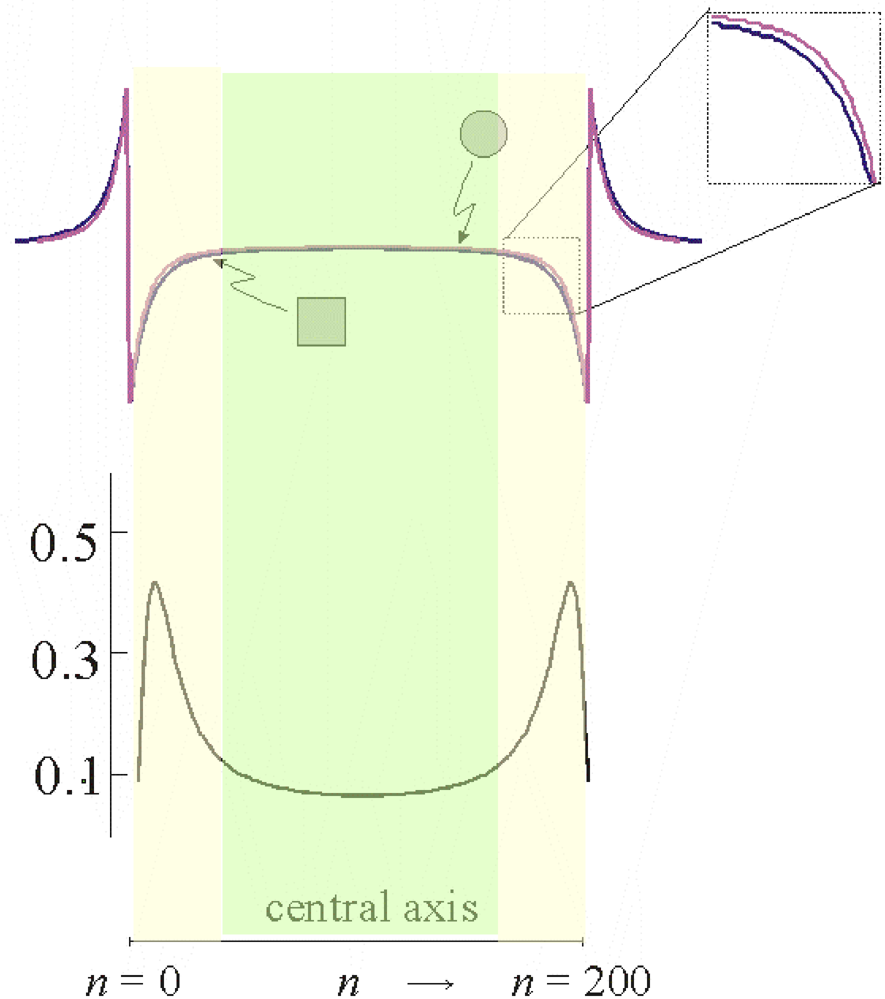


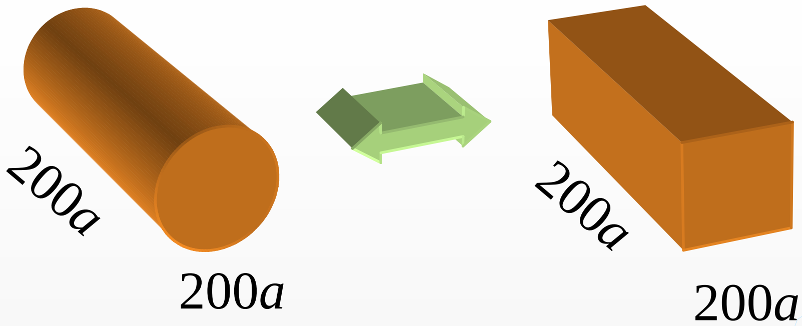
H. Puszkarski, M. Krawczyk, and J.C.S. Lévy, J. Appl. Phys. **101**, 024326 (2007) .



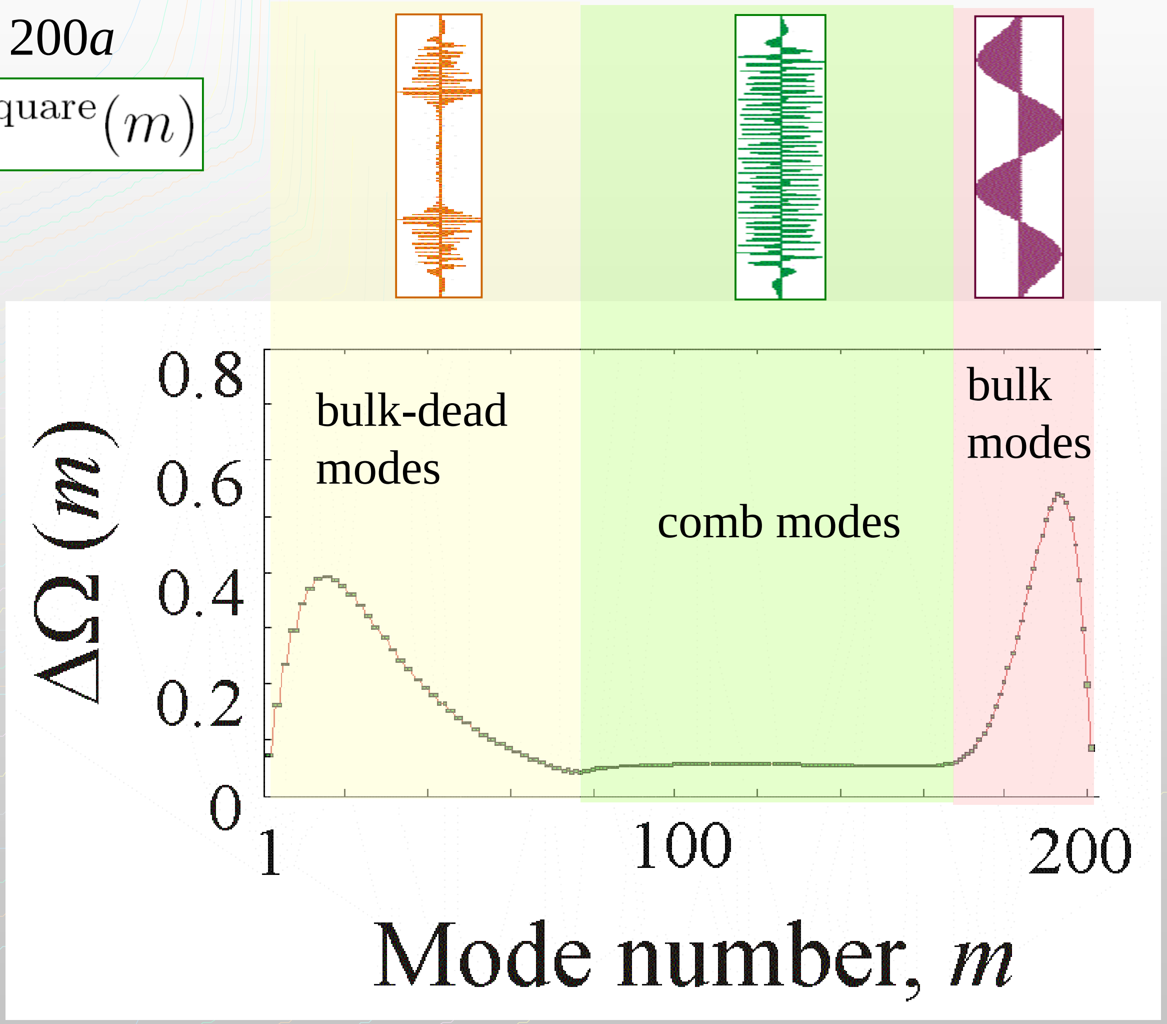
local field, $H(n)$

local field difference, $\Delta H(n)$

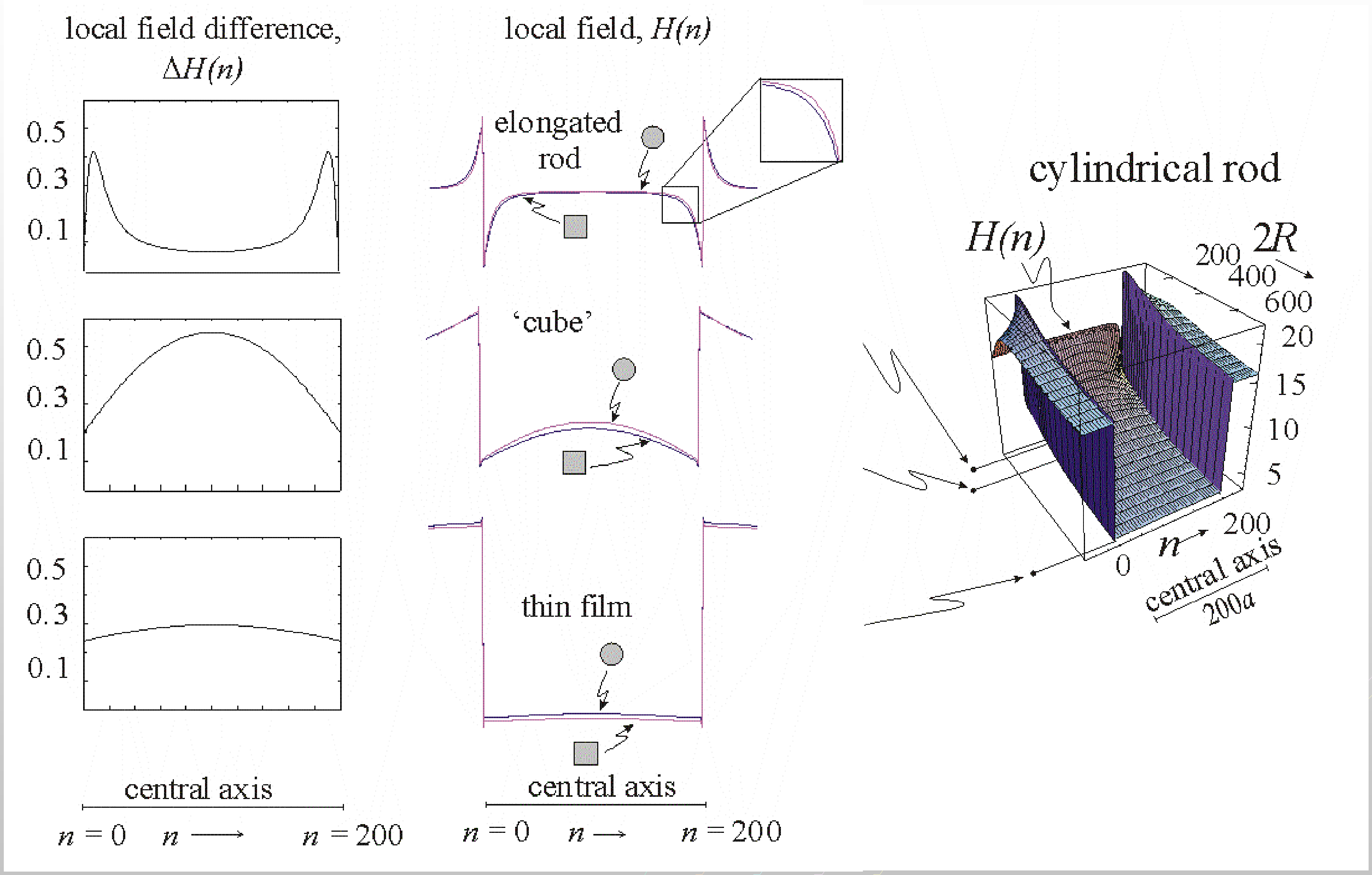




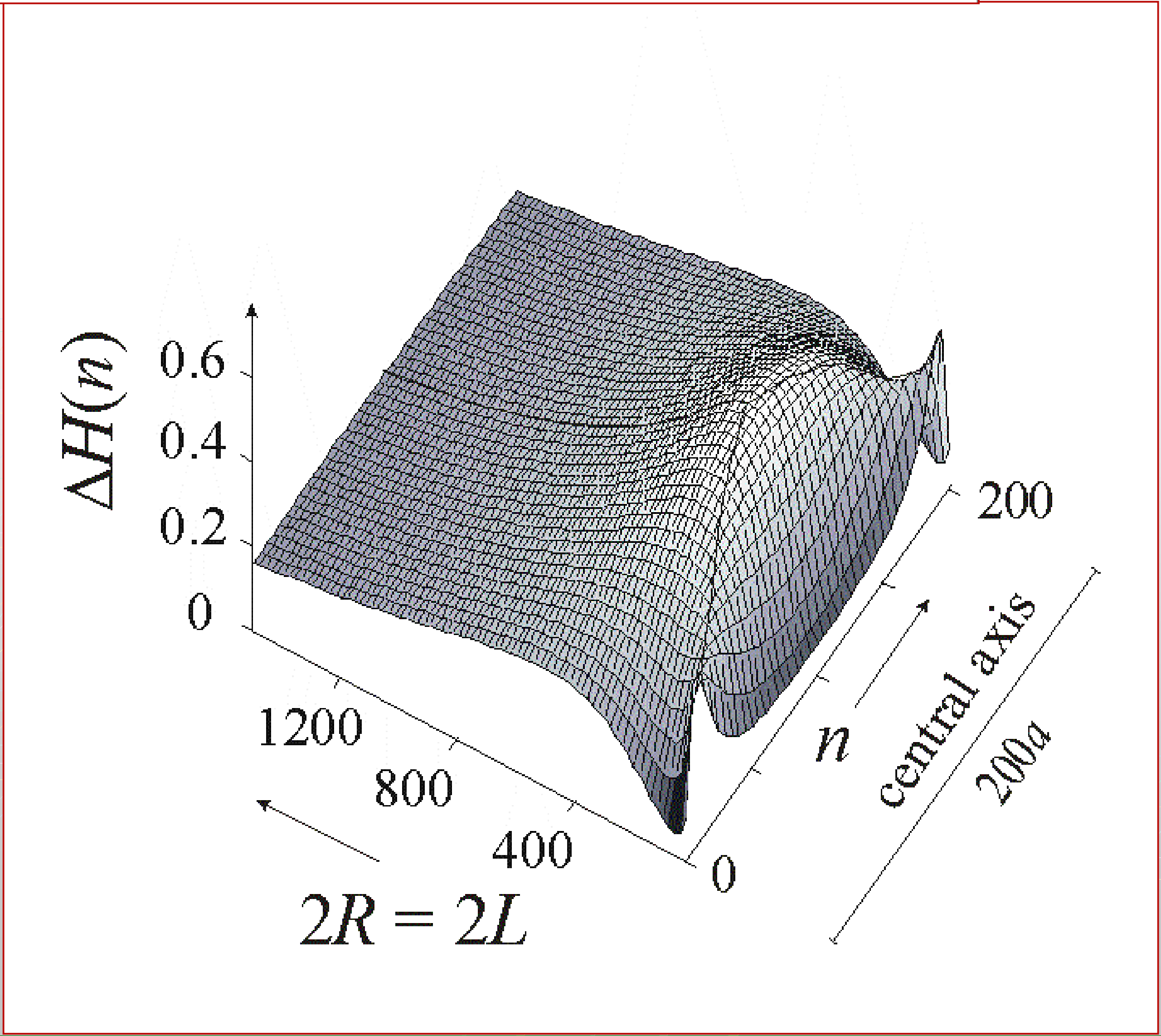
$$\Delta\Omega(m) = \Omega^{\text{circle}}(m) - \Omega^{\text{square}}(m)$$



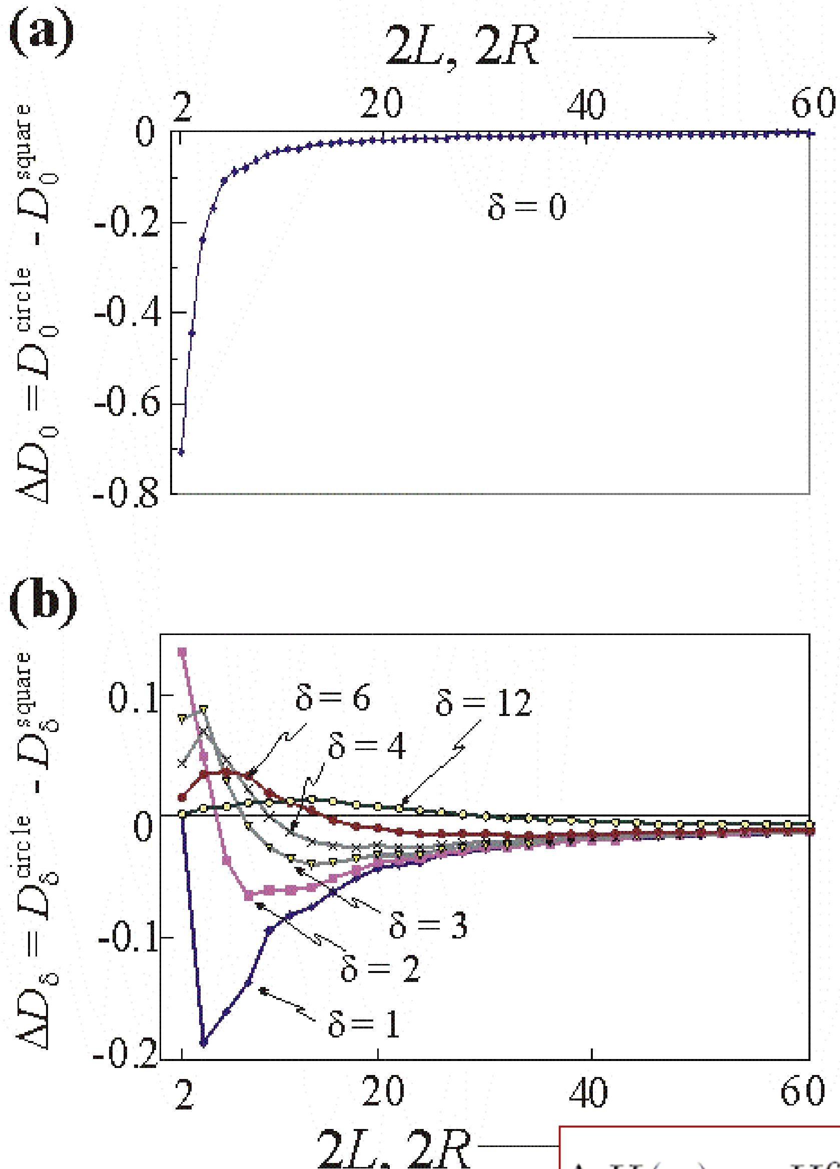
Effective dipolar field dependence on cross-sectional shape and size

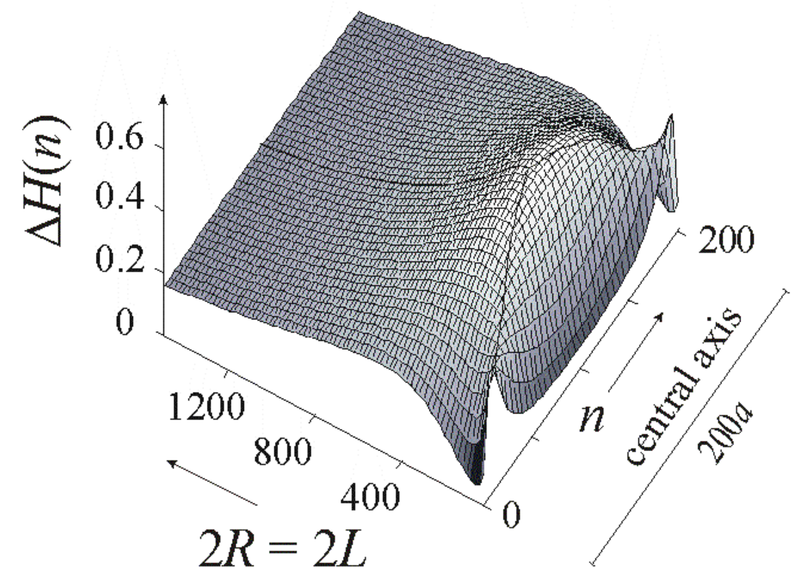


$$\Delta H(n) \equiv H^{\text{circle}}(n) - H^{\text{square}}(n) = -3\Delta D_0 - 2 \sum_{\delta=\pm 1,\ldots} {}^{n}\Delta D_\delta$$



$$D_\delta \equiv \sum_{p,q}{}' \frac{\frac{1}{2}\left(p^2+q^2\right)-\delta^2}{\left[p^2+q^2+\delta^2\right]^{\frac{5}{2}}}$$



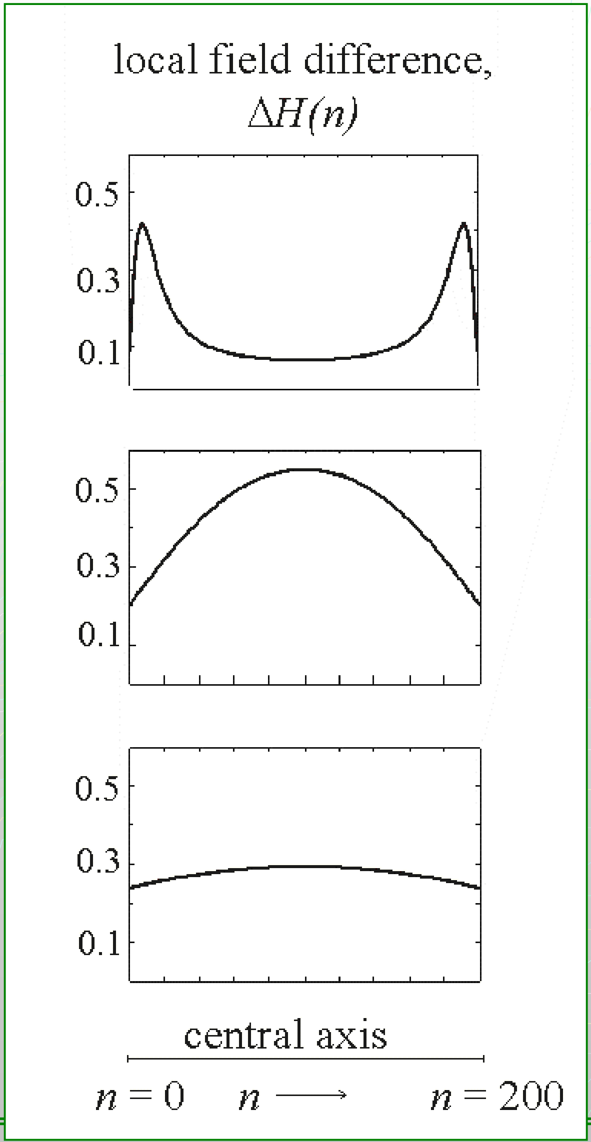


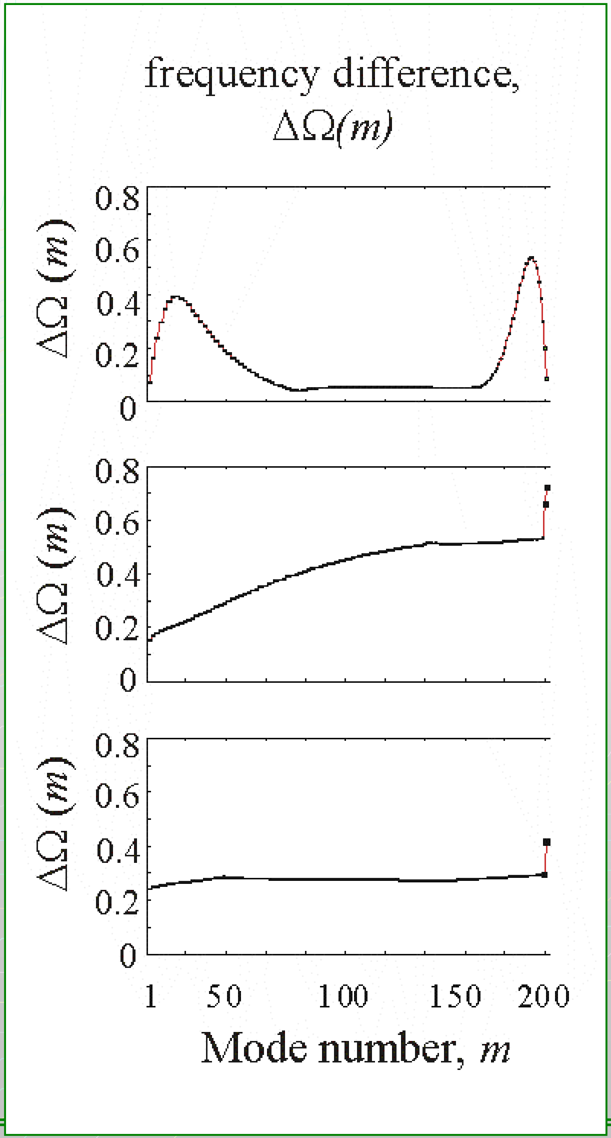
$$\Delta H(n) \equiv H^{\rm circle}(n) - H^{\rm square}(n) = -3\Delta D_0 - 2 \sum_{\delta=\pm1,\ldots} {}^{n}\Delta D_\delta$$

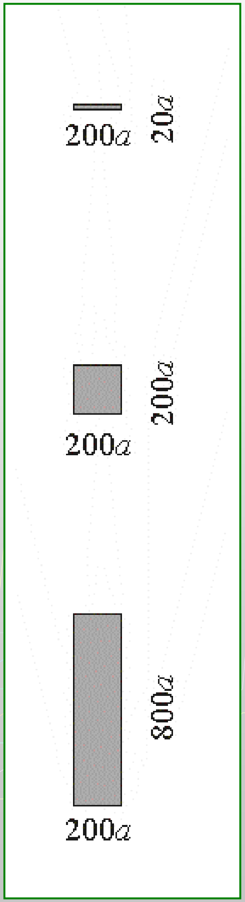
Conclusion

Magnetostatic modes localized in the wells of local dipolar field, so-called *bulk-dead modes*, are most sensitive to the cross-sectional shape of nanorods.

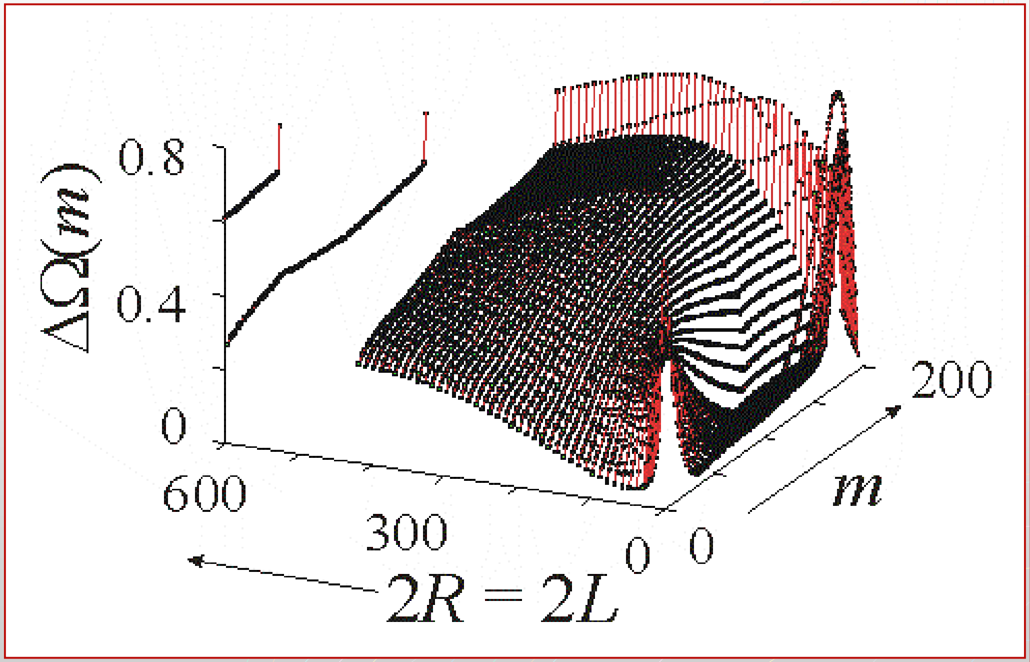
Differences of local dipolar field and frequencies of magnetostatic modes



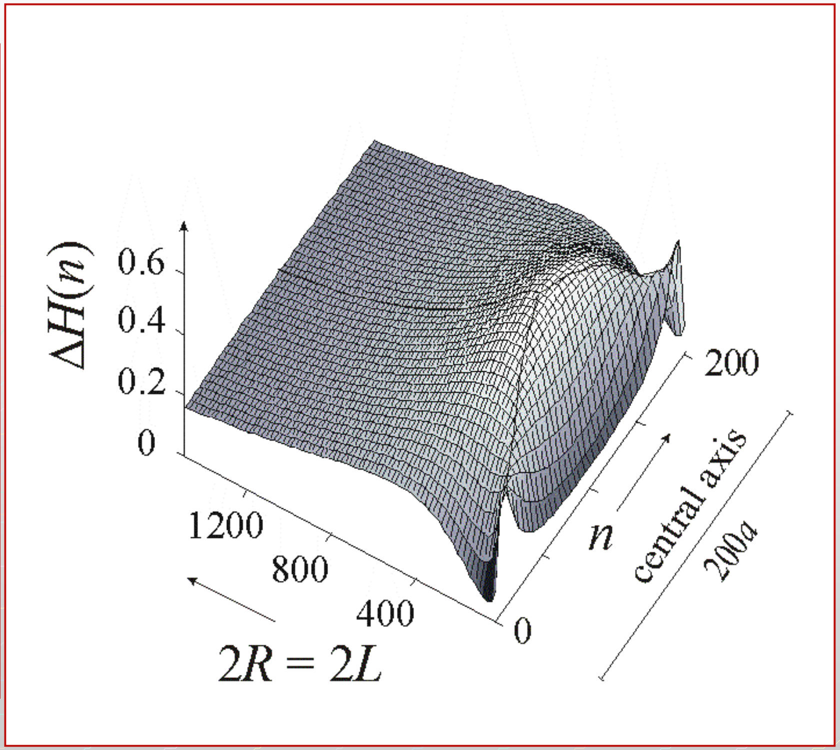




Difference of the frequencies



Difference of the local fields



Dipolar matrix dependence on cross-sectional shape and size

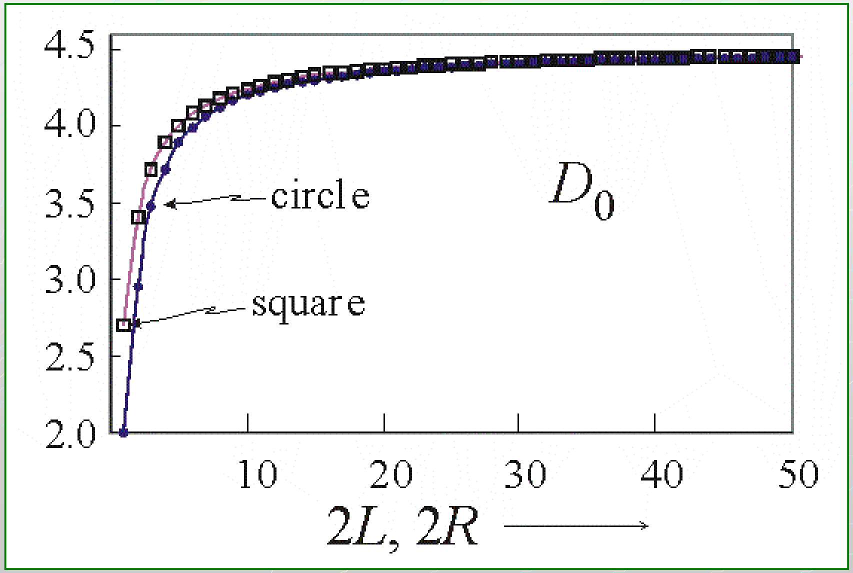
$$D_\delta \equiv \sum_{p,q}{}' \frac{\frac{1}{2}(p^2+q^2)-\delta^2}{[p^2+q^2+\delta^2]^{\frac{5}{2}}}$$

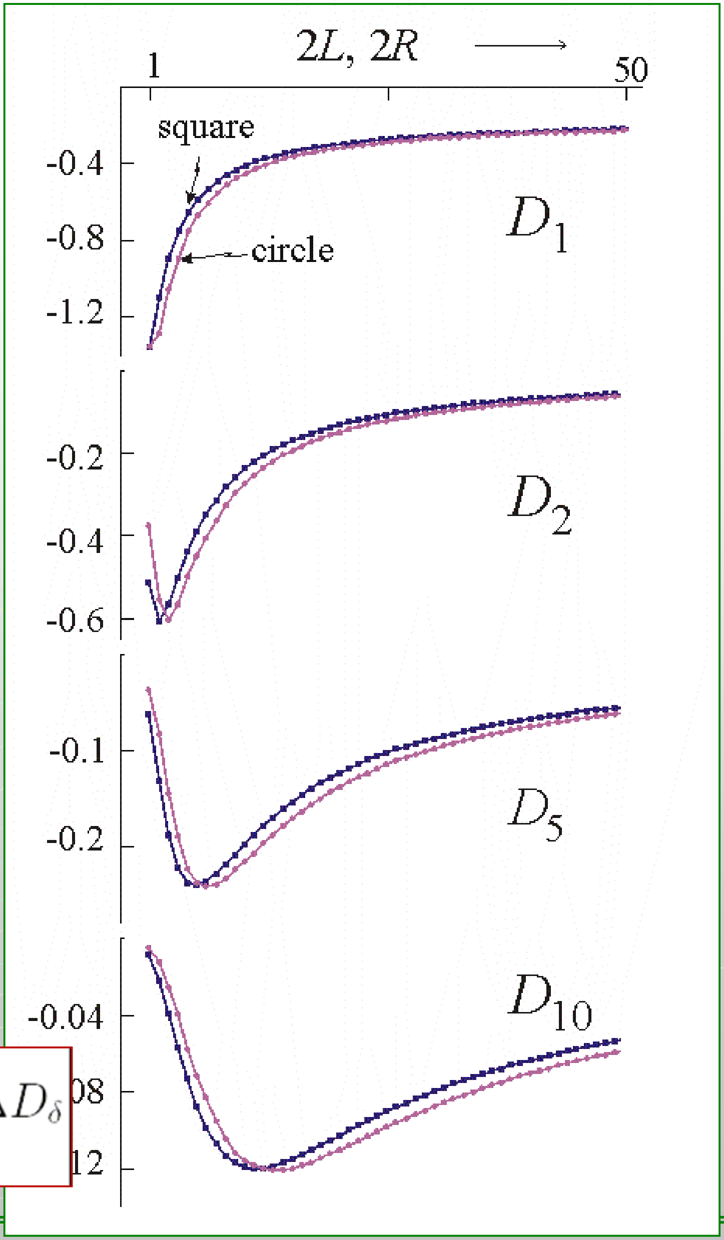
square

$$-L \le p, q \le L$$

circle

$$p^2 + q^2 \le R^2$$





$$\Delta H(n) \equiv H^{\text{circle}}(n) - H^{\text{square}}(n) = -3\Delta D_0 - 2\sum_{\delta=\pm1,\ldots}{}^{n} \Delta D_\delta$$