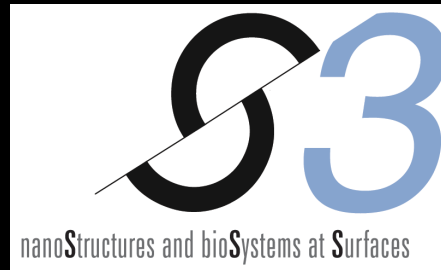
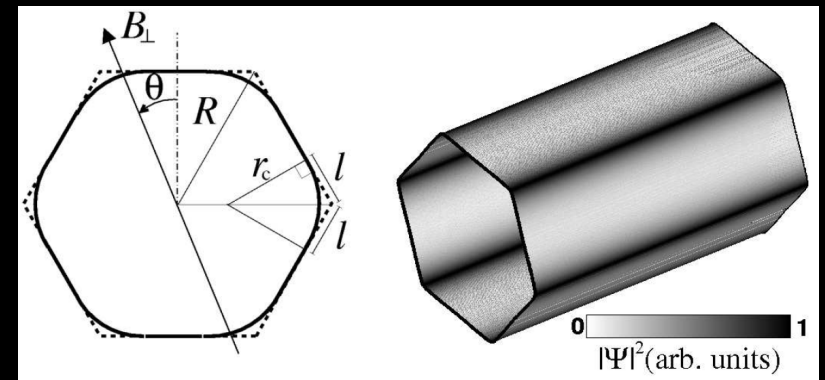
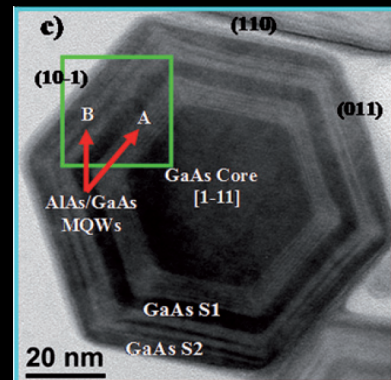
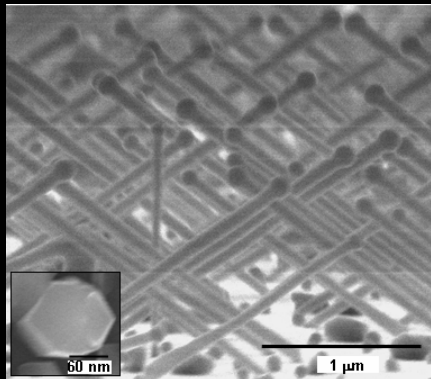


Prismatic core-shell nanowires: excitons and magnetic states

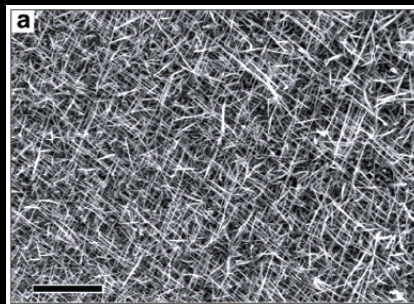
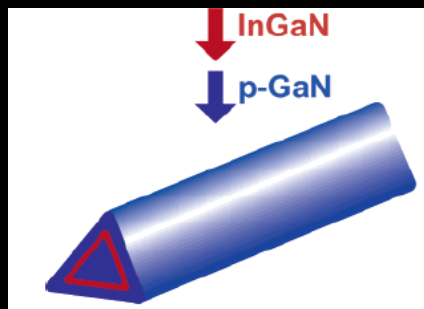


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Via Campi 213/A, 41125 Modena - Italy

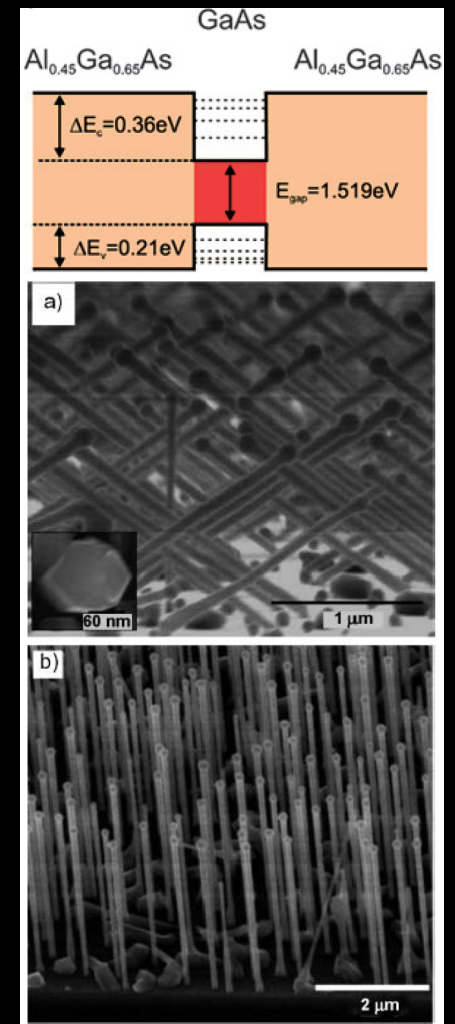
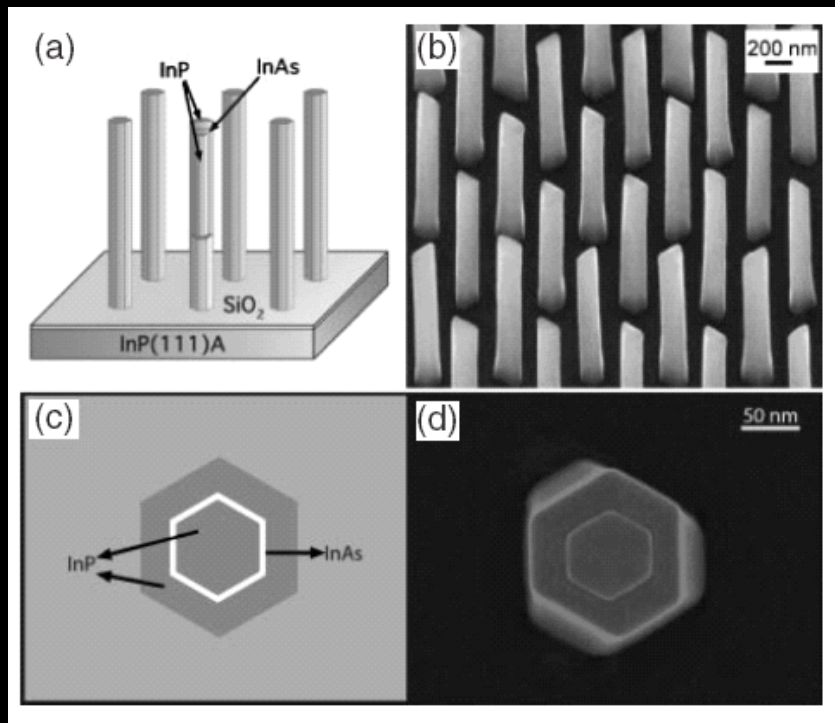


Experimental samples



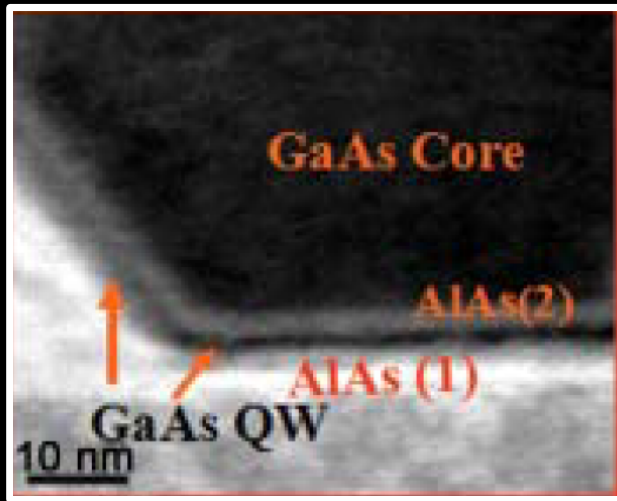
F. Qian *et al.*
Nano Lett. **4**, 1975 (2004)

K. Tsumura *et al.*
Jpn. J. Appl. Phys. **46**, L440 (2007)



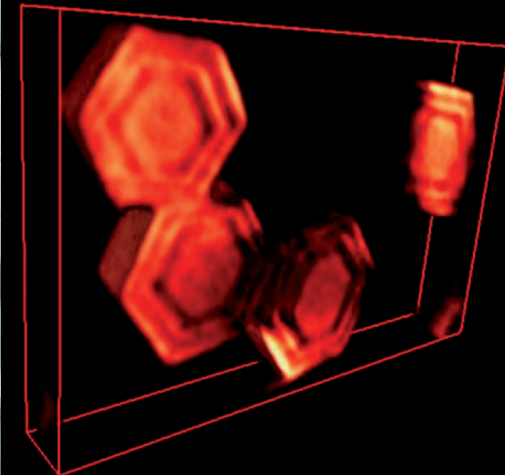
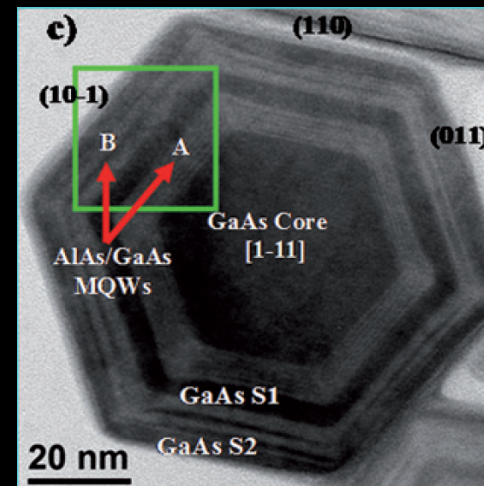
A. Fontcuberta i Morral *et al.*
Small **4**, 899 (2008)

Formation of channels

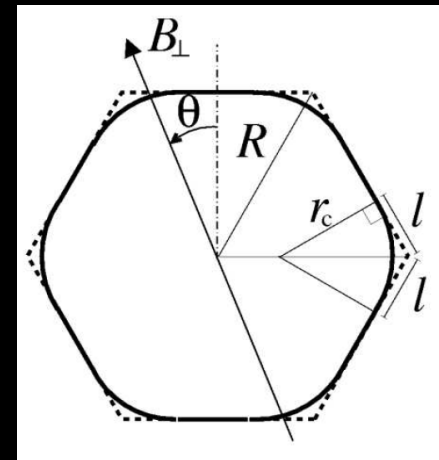
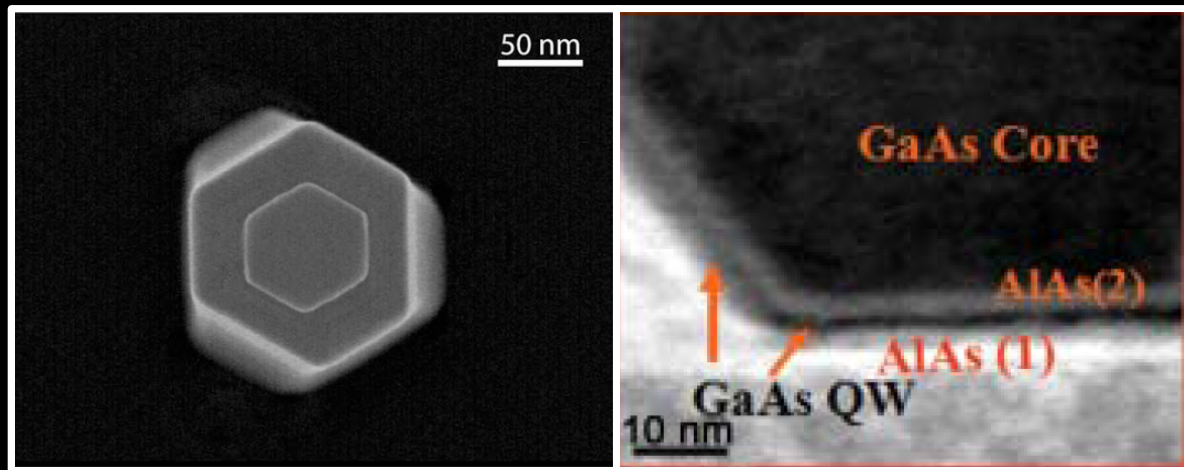


A. Fontcuberta i Morral *et al.*
Small **4**, 899 (2008)

M. Heigoldt *et al.*
J. Mater. Chem. **19**, 840 (2009)



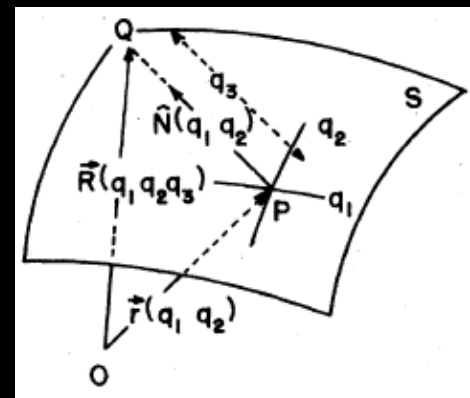
Modelling the edges



H. Jensen *et al.*, Ann. Phys. **63**, 586 (1971)

R.C.T. da Costa, Phys. Rev. A **23**, 1982 (1981)

A. Marchi *et al.*, Phys. Rev. B **72**, 035403 (2005)

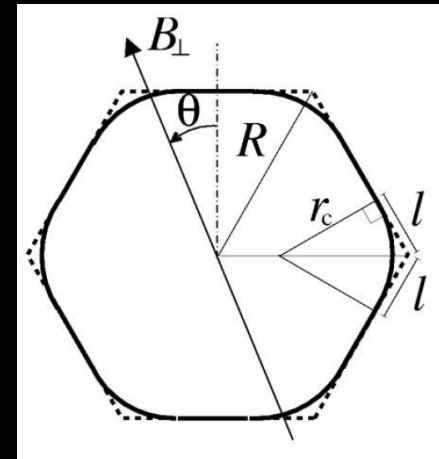
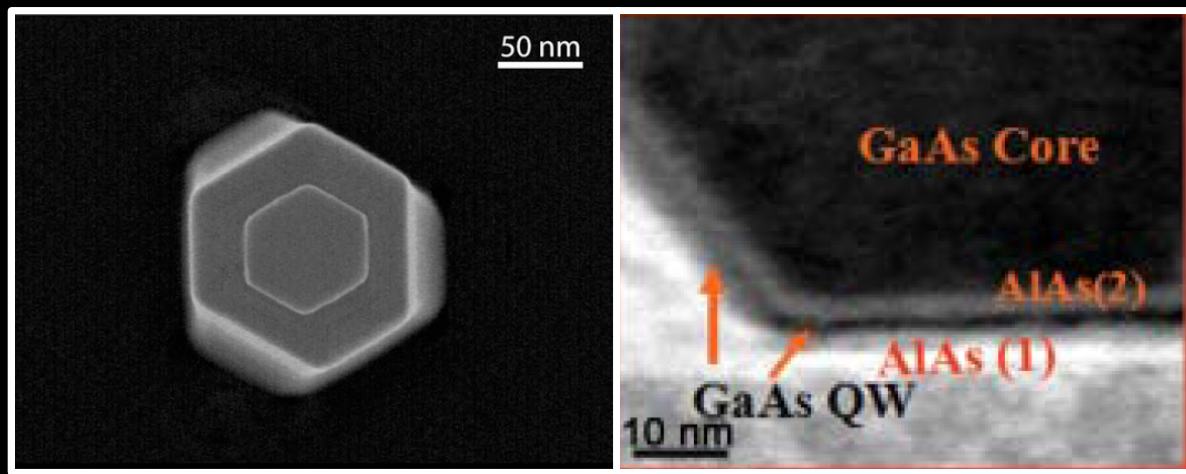


$$i\hbar \partial_t \psi = -\frac{\hbar^2}{2m} \frac{1}{\sqrt{G}} \partial_i (\sqrt{G} G^{ij} \partial_j \psi)$$

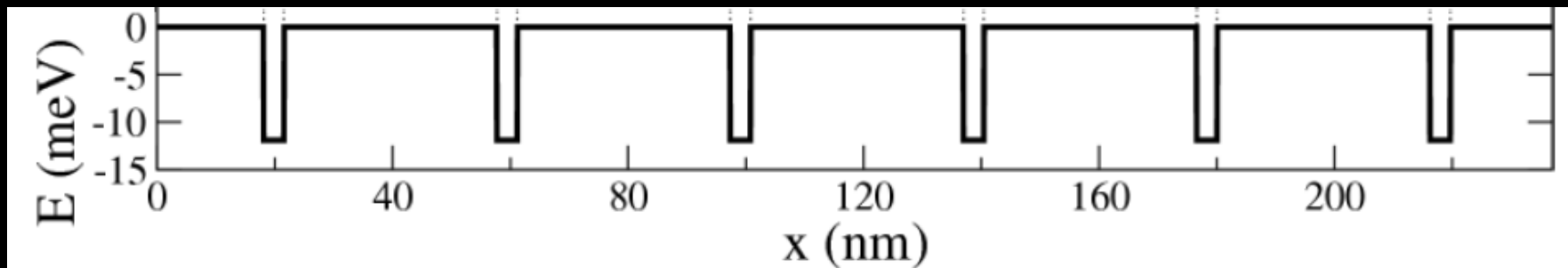
$$i\hbar \partial_t \chi_S = -\frac{\hbar^2}{2m} \left[\frac{1}{\sqrt{g}} \partial_i (\sqrt{g} g^{ij} \partial_j) \chi_S + (M^2 - K) \chi_S \right]$$

$$V_S = -\frac{\hbar^2}{2m} (M^2 - K) = -\frac{\hbar^2}{8m} (k_1 - k_2)^2$$

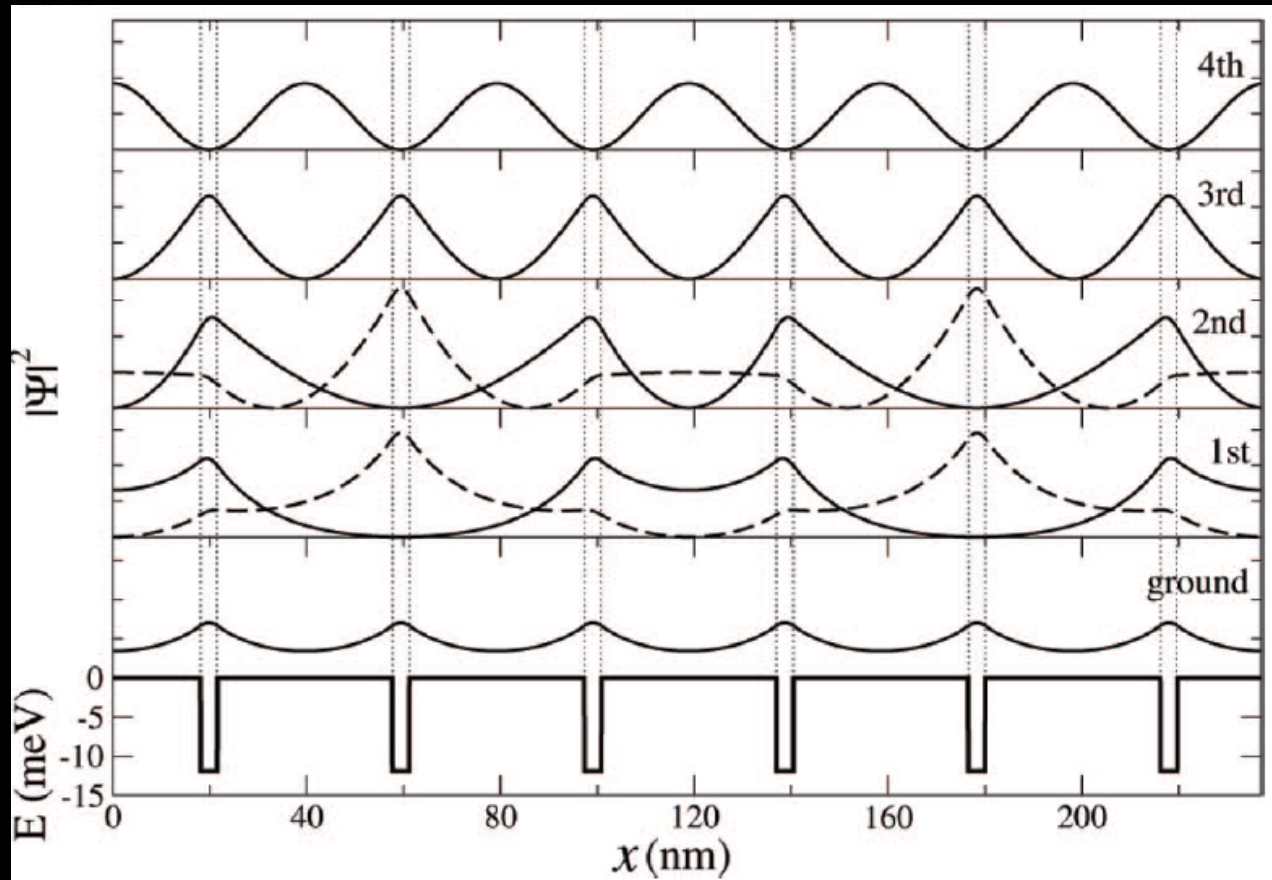
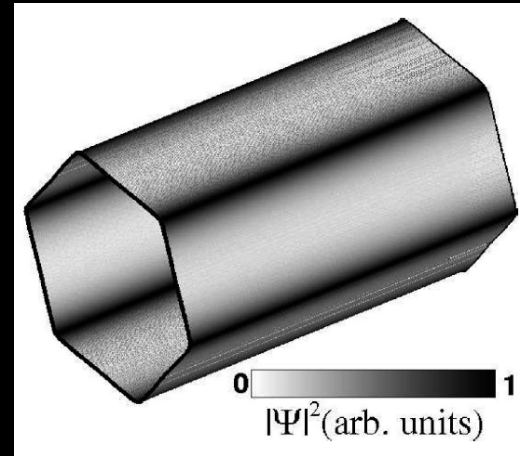
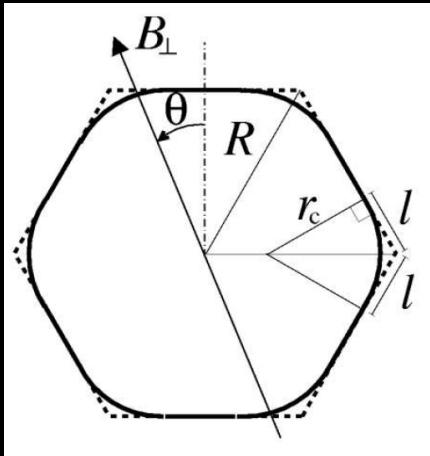
Geometric potential



$$V_{bent} = -\frac{\hbar^2}{8m r_c^2}$$

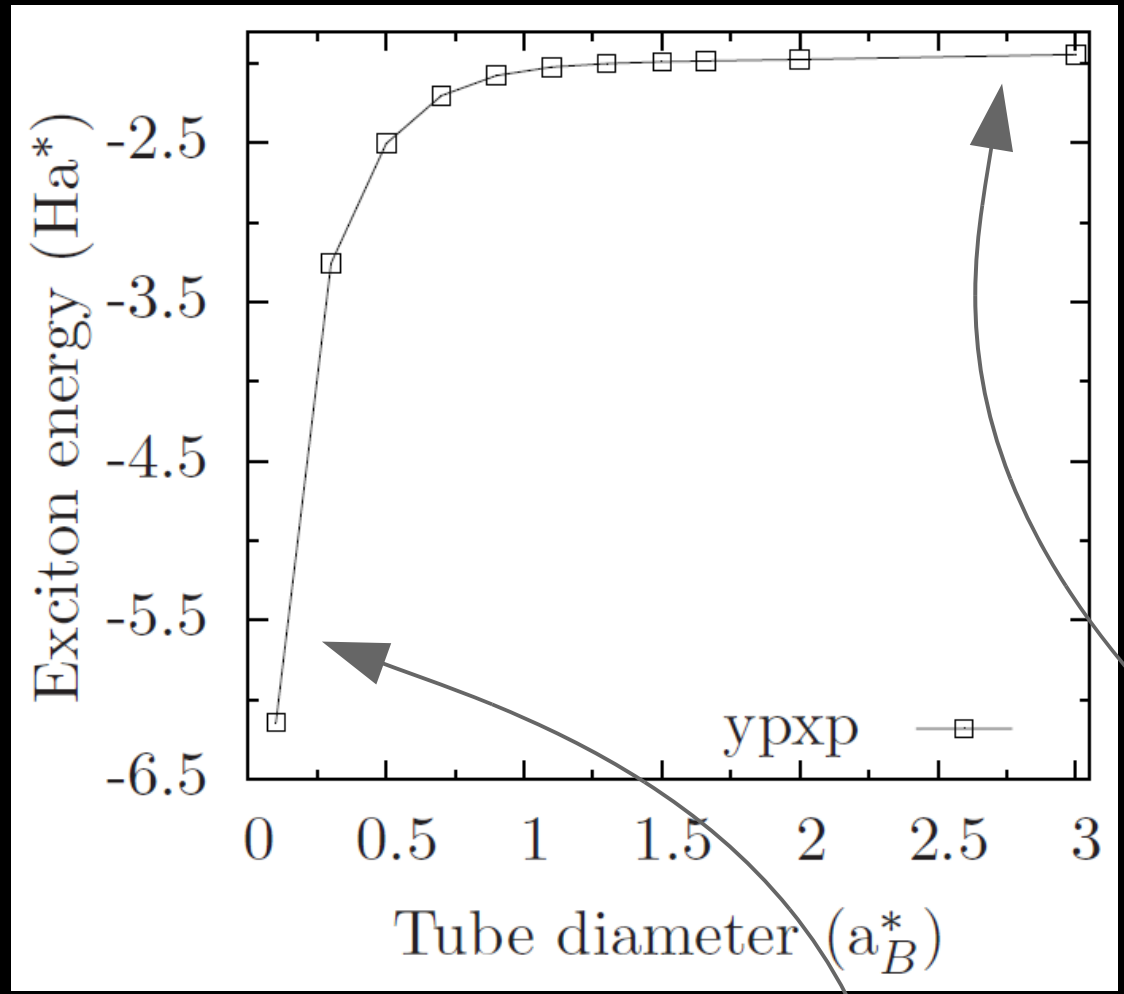


Edge localization

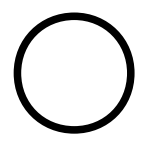
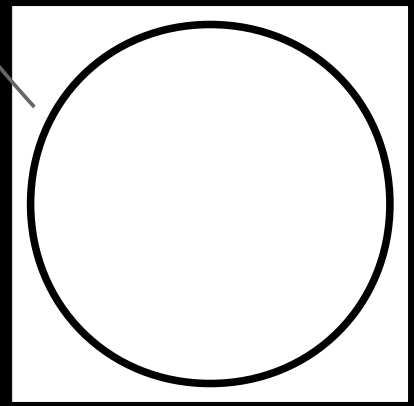


Localization independent of the carrier charge

Excitons: binding energy vs tube diameter



quasi-2D system



quasi-1D system

Excitons in prismatic NW shell

$$H(x_1, x_a, y_{1a}) = -\frac{1}{2} \frac{\partial^2}{\partial y_{1a}^2} - V(x_1 - x_a, y_{1a}) \quad \sigma = m_e/m_h$$
$$+ \frac{1}{1+\sigma} \left[-\frac{1}{2} \frac{\partial^2}{\partial x_1^2} + V_{\text{bent}}(x_1) \right] + \frac{\sigma}{1+\sigma} \left[-\frac{1}{2} \frac{\partial^2}{\partial x_a^2} + V_{\text{bent}}(x_a) \right]$$

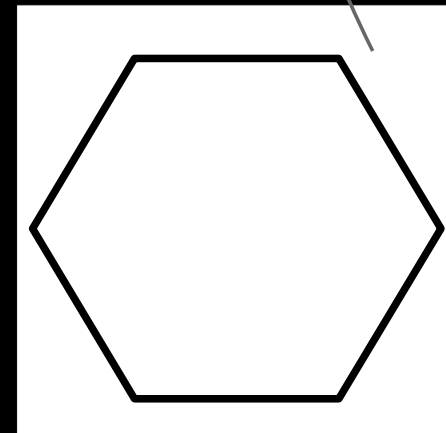
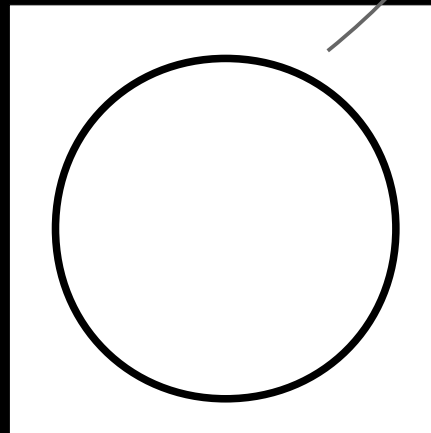
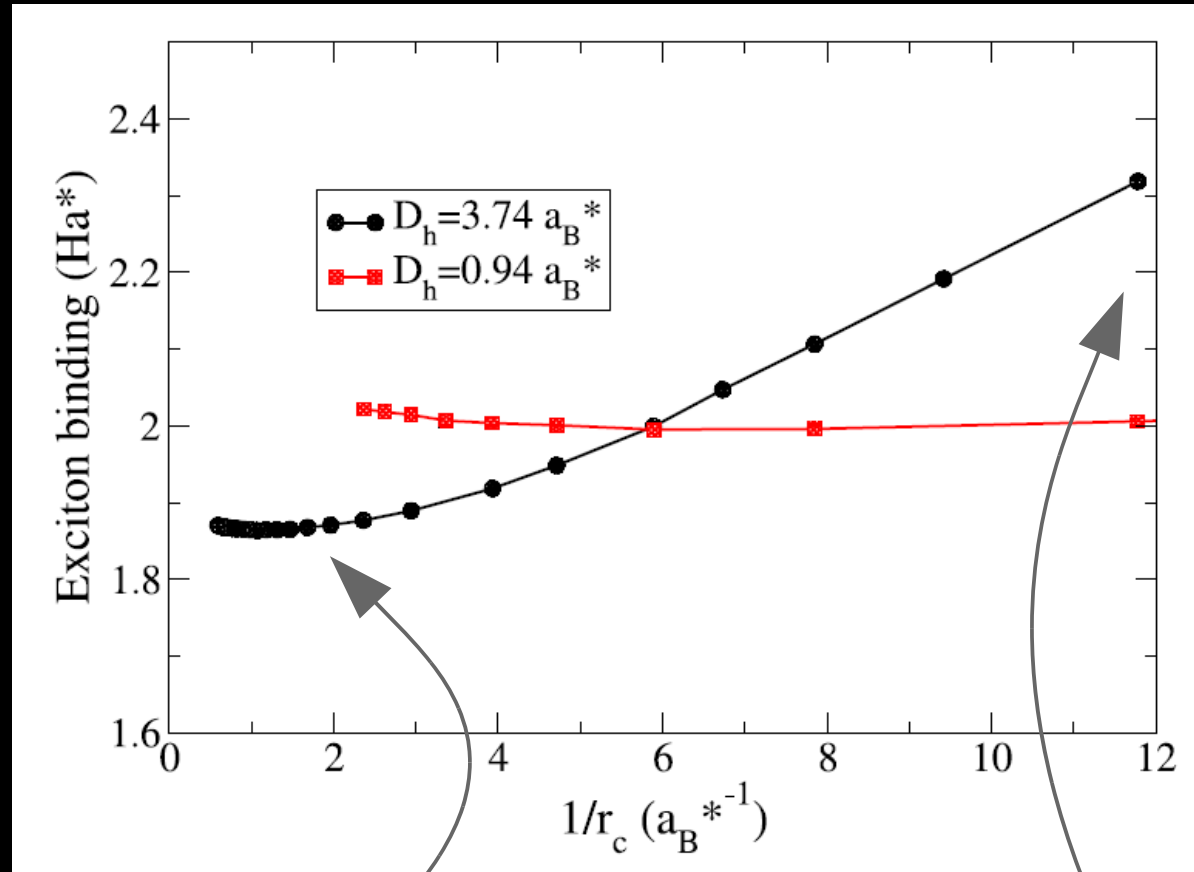
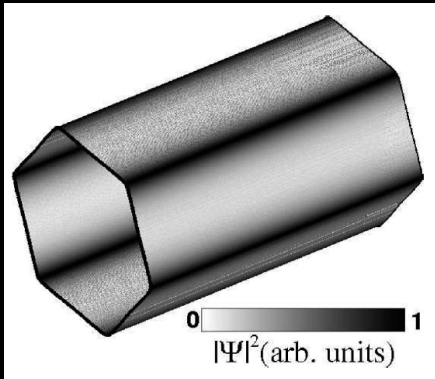
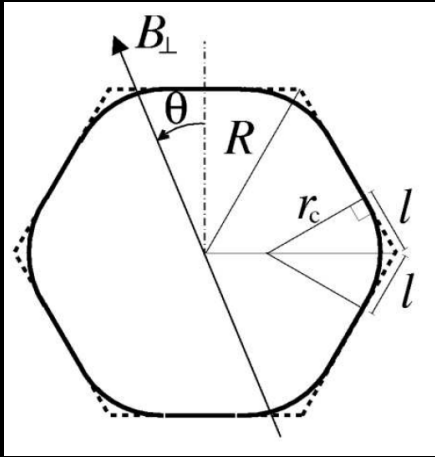
$$\psi_j(x_1, x_a, y_{1a}) = \frac{1}{2\pi R} \sqrt{\frac{\Delta k}{4\pi}} \sum_{\alpha=0}^{\alpha_{\max}} \sum_{\beta=0}^{\beta_{\max}} \sum_{p=-P}^P D_{\alpha,\beta,p}^j \Phi_{\alpha}(x_1) \Phi_{\beta}(x_a) e^{ip\Delta k y_{1a}}$$

$$\sum_{\alpha',\beta'} \sum_{p'} \left\{ \left[\frac{1}{2} (p\Delta k)^2 + \frac{1}{1+\sigma} E_{\alpha} + \frac{\sigma}{1+\sigma} E_{\beta} \right] \delta_{\alpha,\alpha'} \delta_{\beta,\beta'} \delta_{p,p'} - U_{\alpha',\beta',p'}^{\alpha,\beta,p} \right\} D_{\alpha',\beta',p'}^j = E_j D_{\alpha,\beta,p}^j$$

$$U_{\alpha',\beta',p'}^{\alpha,\beta,p} = \frac{\Delta k}{(2\pi)^2} \sum_{\Delta m=-2M}^{2M} \sum_m G_m^{\alpha} G_{m-\Delta m}^{\alpha'} \sum_n G_n^{\beta} G_{n+\Delta m}^{\beta'} g_{|\Delta m|}(|p-p'|)\Delta k, R, R)$$

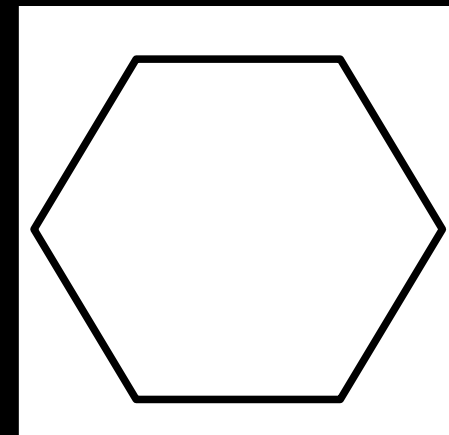
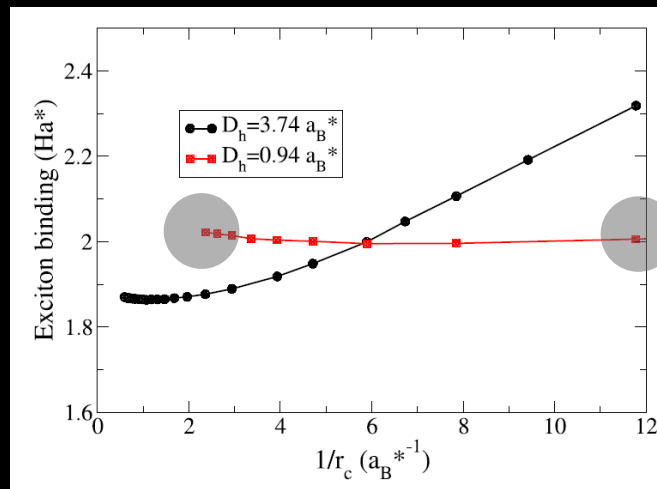
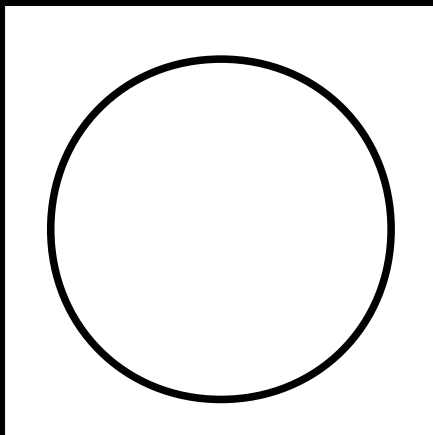
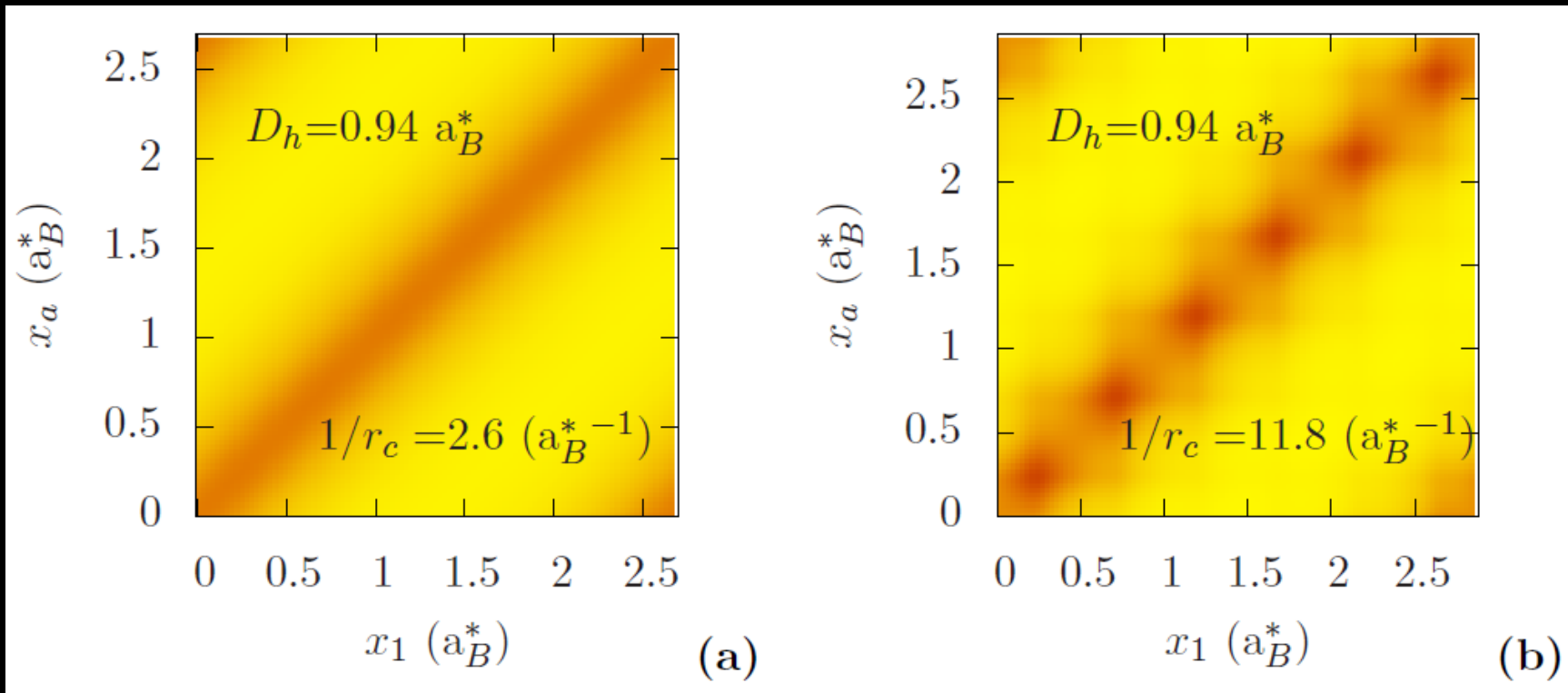
look for David Kammerlander articles in APS reviews

Binding energy and edge localization



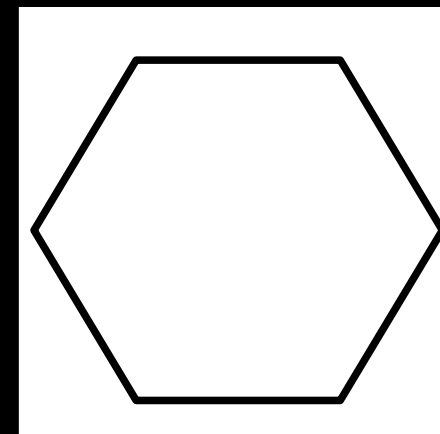
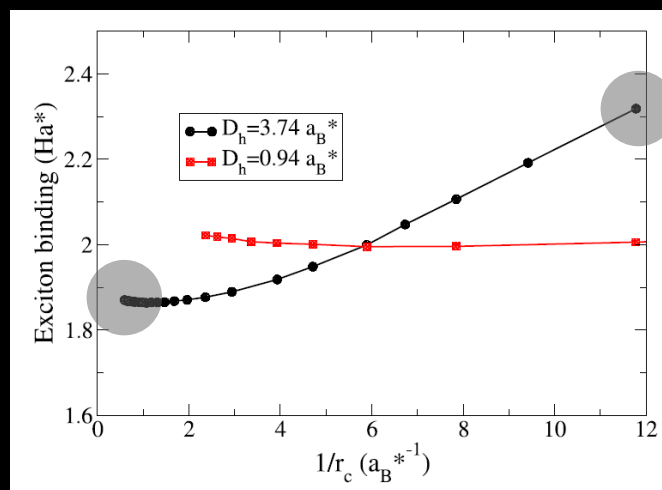
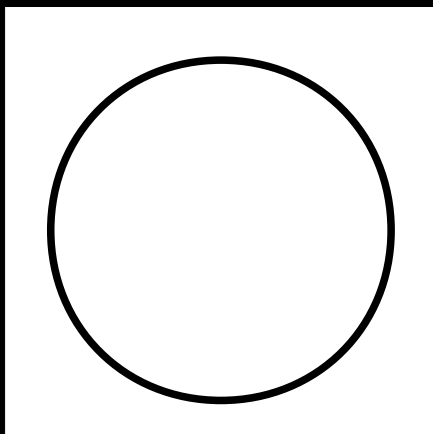
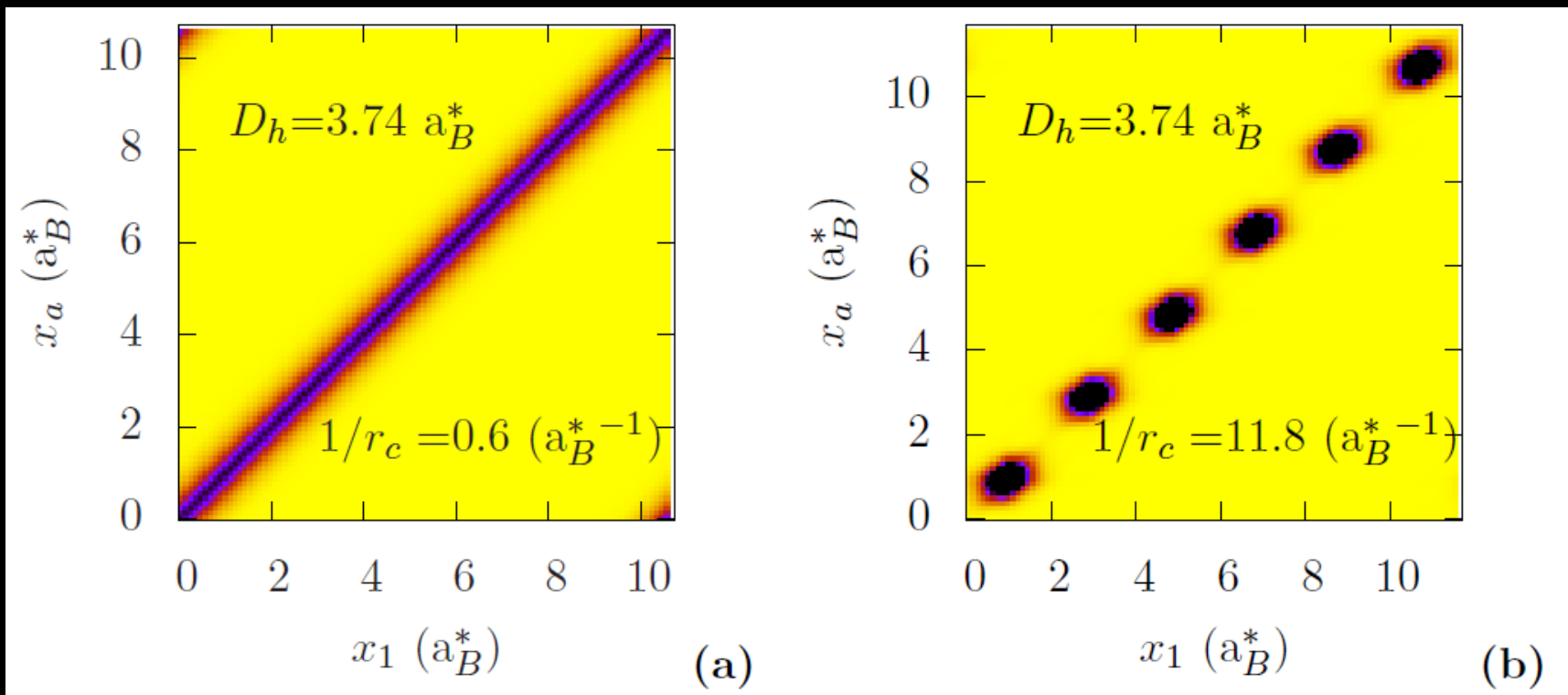
Electron-hole correlation: small D

$$|\psi_0(x_1, x_a)|^2 = \int dy_{1a} \psi_0^*(x_1, x_a, y_{1a}) \psi_0(x_1, x_a, y_{1a})$$



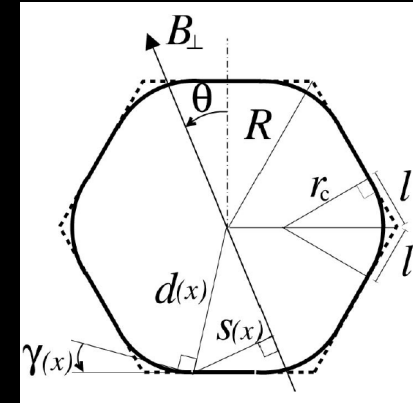
Electron-hole correlation: large D

$$|\psi_0(x_1, x_a)|^2 = \int dy_{1a} \psi_0^*(x_1, x_a, y_{1a}) \psi_0(x_1, x_a, y_{1a})$$

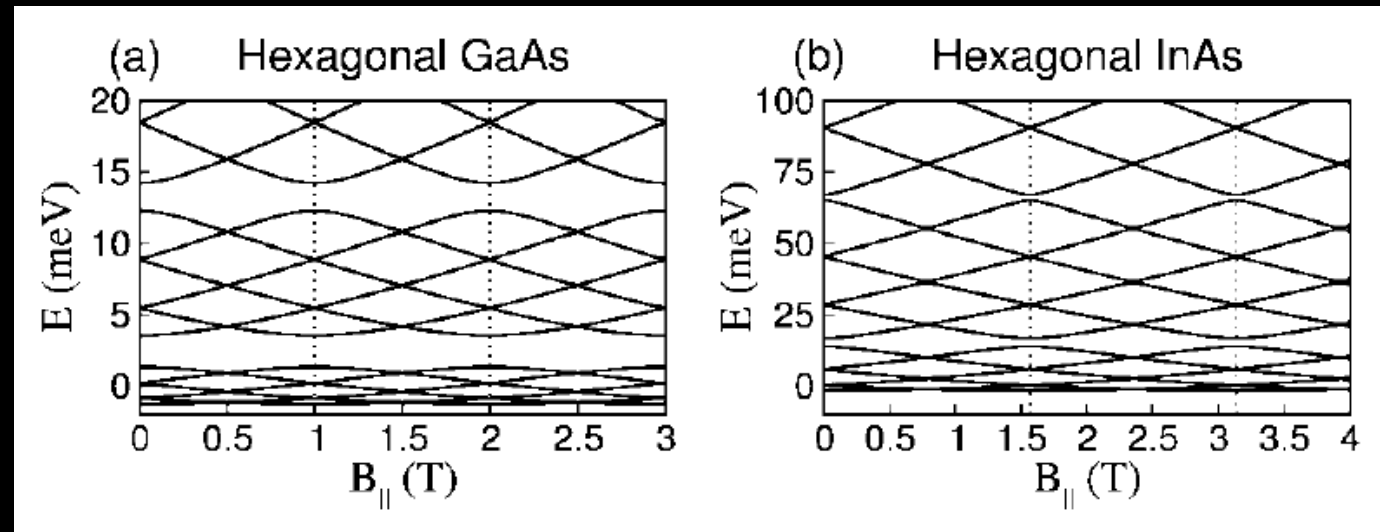
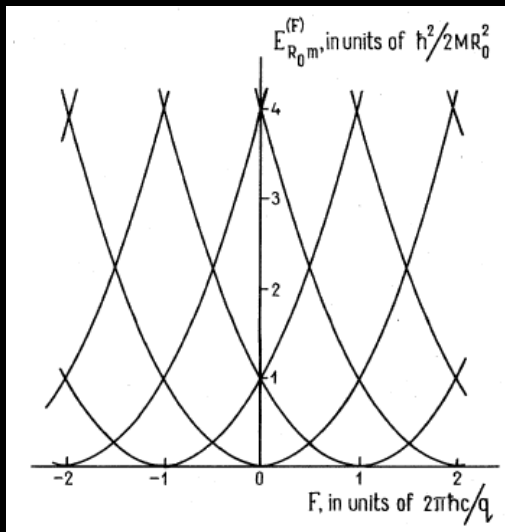


Edge-modified AB oscillations

$$H_{B_{\parallel}} = \frac{1}{2m^*} \left[-\hbar^2 \partial_x^2 + iq\hbar B_{\parallel} d(x) \cos \gamma(x) \partial_x + \left(\frac{1}{2} qd(x) \cos \gamma(x) B_{\parallel} \right)^2 \right] + V_{eff}(x)$$



Giulio Ferrari *et al.*, Phys. Rev. Lett. **100**, 230403 (2008)

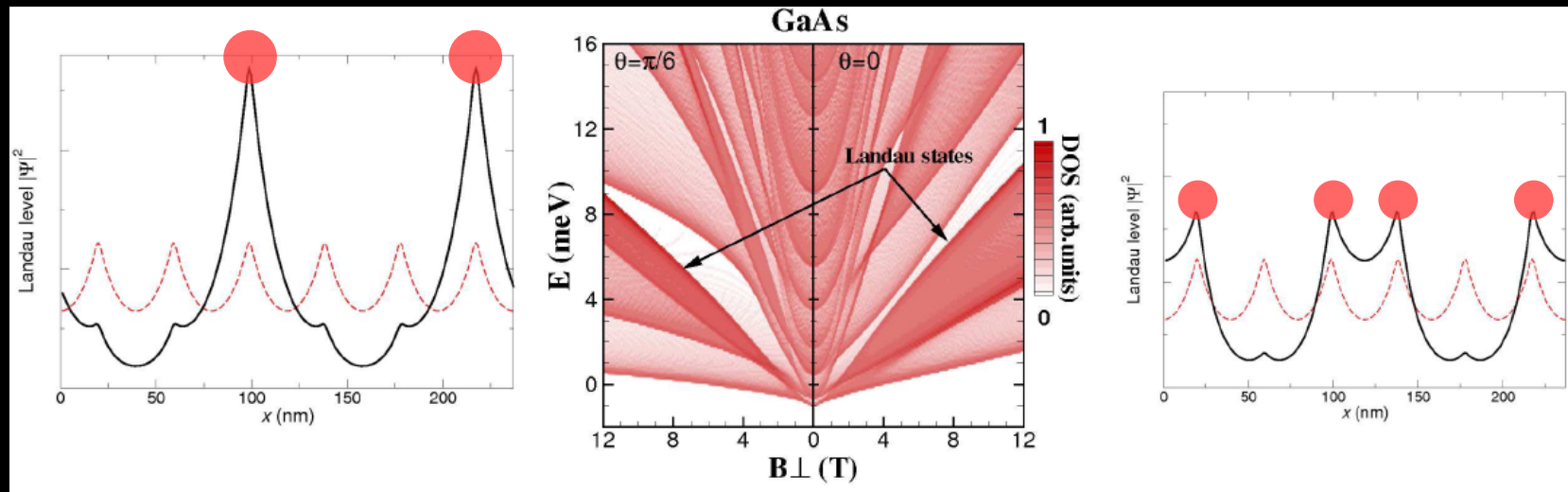
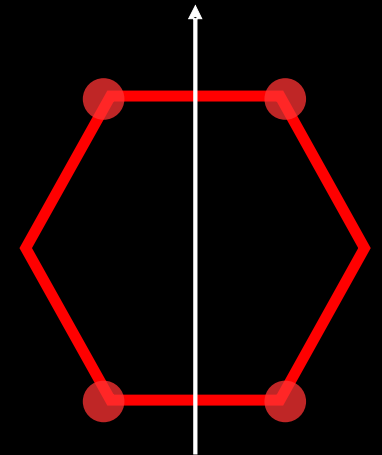
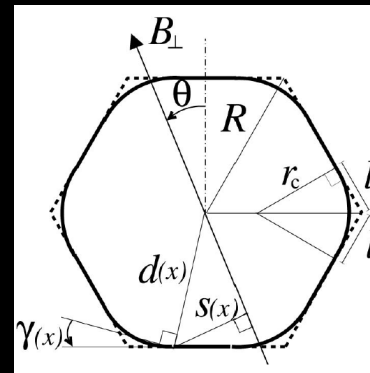
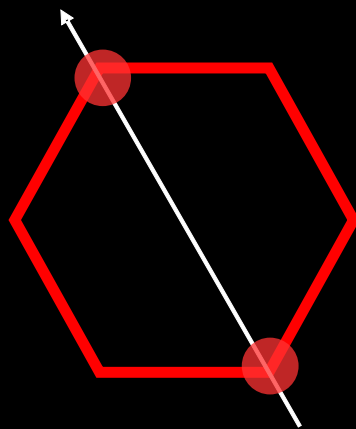


Giulio Ferrari *et al.*, Nano Lett. **9**, 1631 (2009)

Edge-modified Landau levels

$$H_{B\perp} = \frac{1}{2m^*} \left[-\hbar^2 \partial_x^2 + (\hbar k_y - qB_{\perp} s(x))^2 \right] + V_{eff}(x)$$

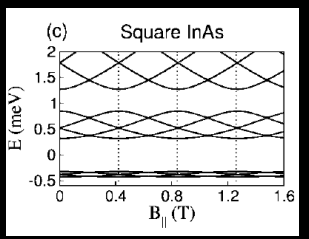
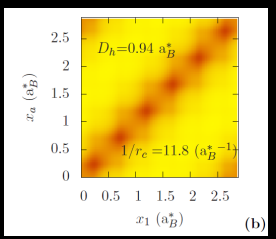
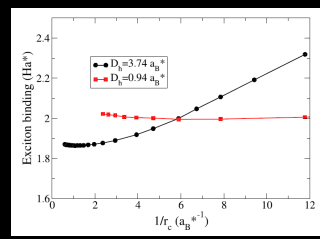
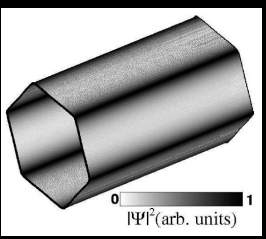
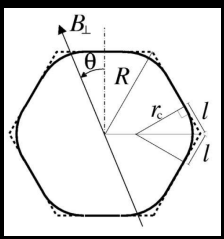
Giulio Ferrari *et al.*, Phys. Rev. Lett. **100**, 230403 (2008)



Giulio Ferrari *et al.*, Nano Lett. **9**, 1631 (2009)

Summary

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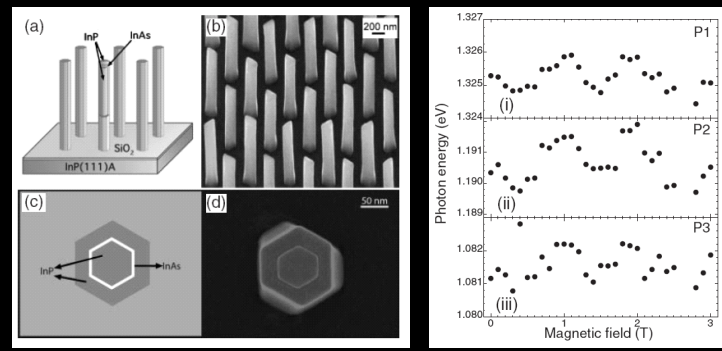


- ✓ Experimental samples
- ✓ Model for prismatic nanowires
- ✓ 1D localization at the edges
- ✓ Excitons on quantum tubes
- ✓ Exciton binding energy
- ✓ Electron-hole correlation
- ✓ Single particle magnetic states

Giulio Ferrari *et al.*, Phys. Rev. Lett. **100**, 230403 (2008)
 Giulio Ferrari *et al.*, Phys. Rev. B **78**, 115326 (2008)
 Giulio Ferrari *et al.*, Nano Lett. **9**, 1631 (2009)
 David Kammerlander, PhD Thesis, University of Modena (2010)

Next step

K. Tsumura *et al.*
 Jpn. J. Appl. Phys. **46**, L440 (2007)
 "Aharonov-Bohm oscillations in photoluminescence from charged exciton in quantum tubes"



Binding energy and tube diameter

