MYTHBUSTERS: PARADOXES FROM THE DAWN OF QUANTUM PHYSICS

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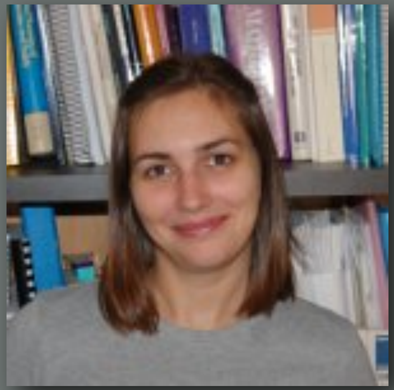
Coworkers



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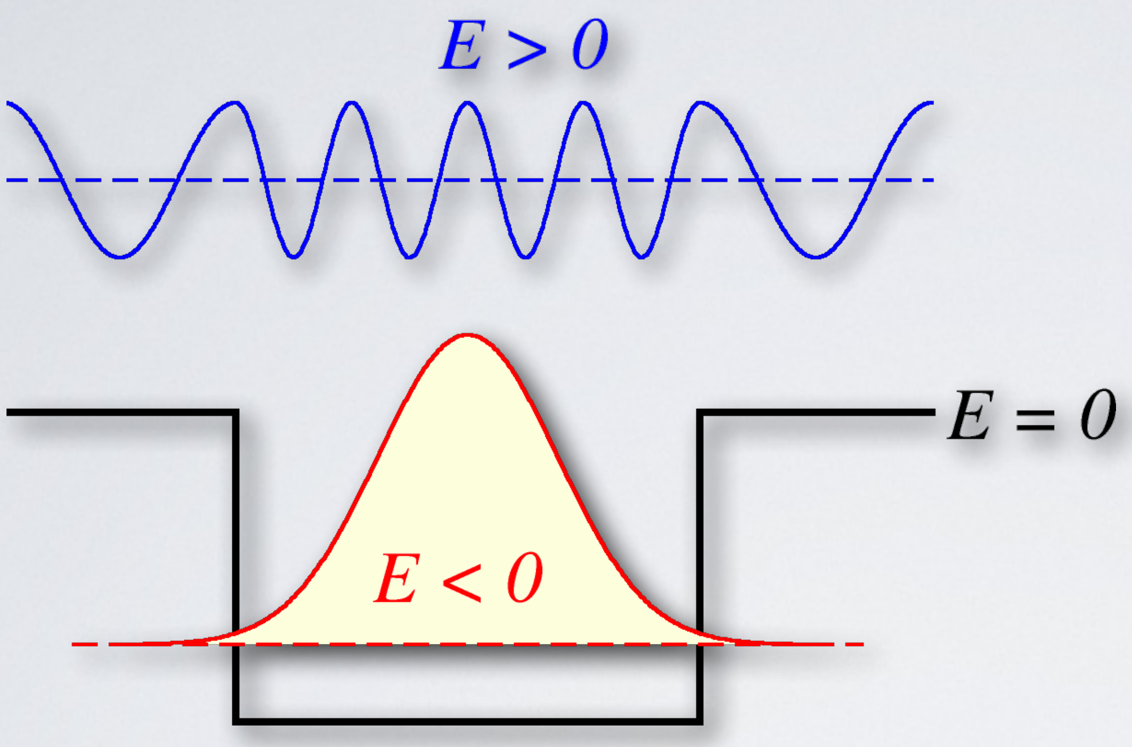
Santiago, Chile

OUTLINE

- First myth: Bound states in the continuum
- Second myth: Klein tunneling

BOUND STATES IN THE CONTINUUM



Always?

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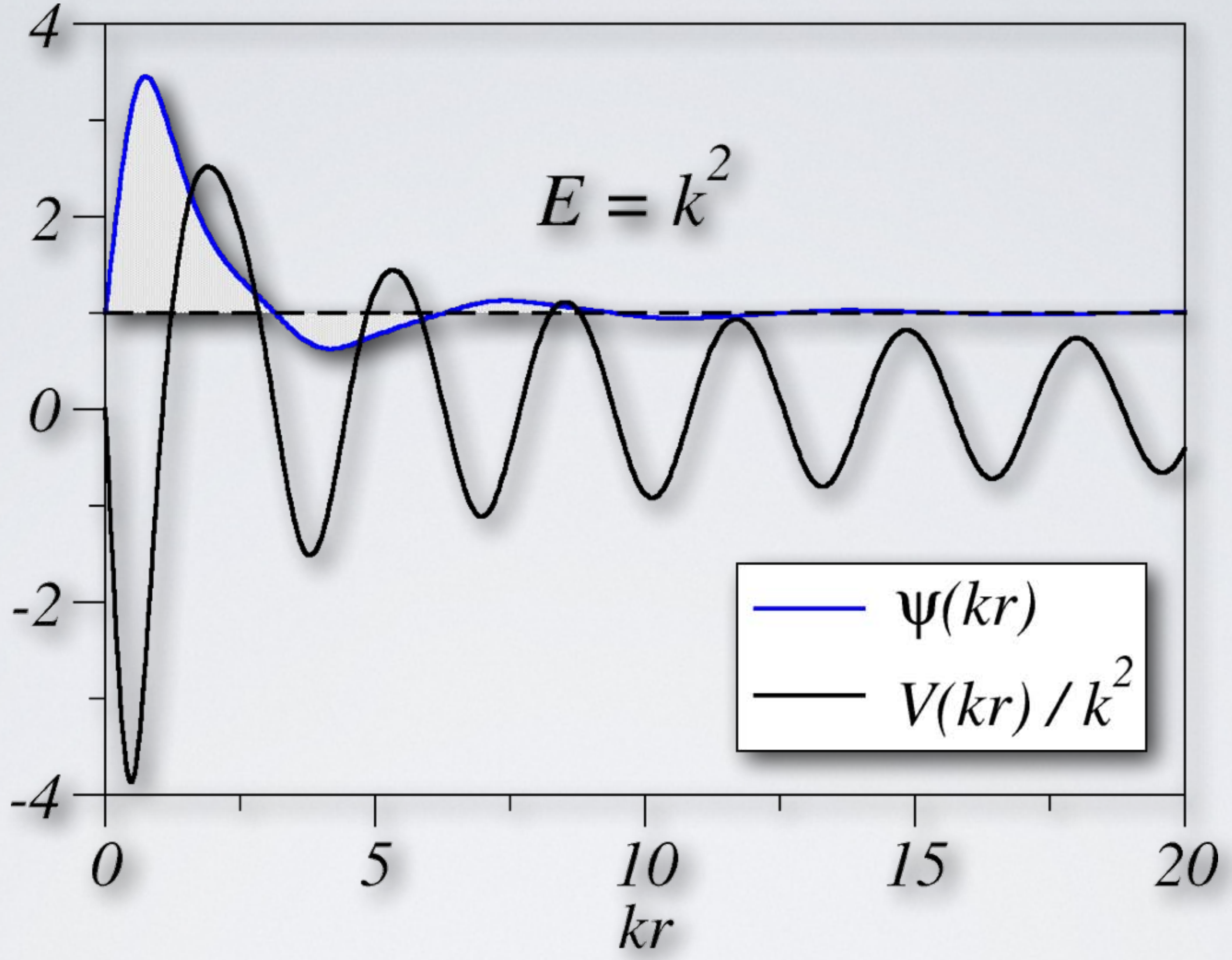
BOUND STATES IN THE CONTINUUM



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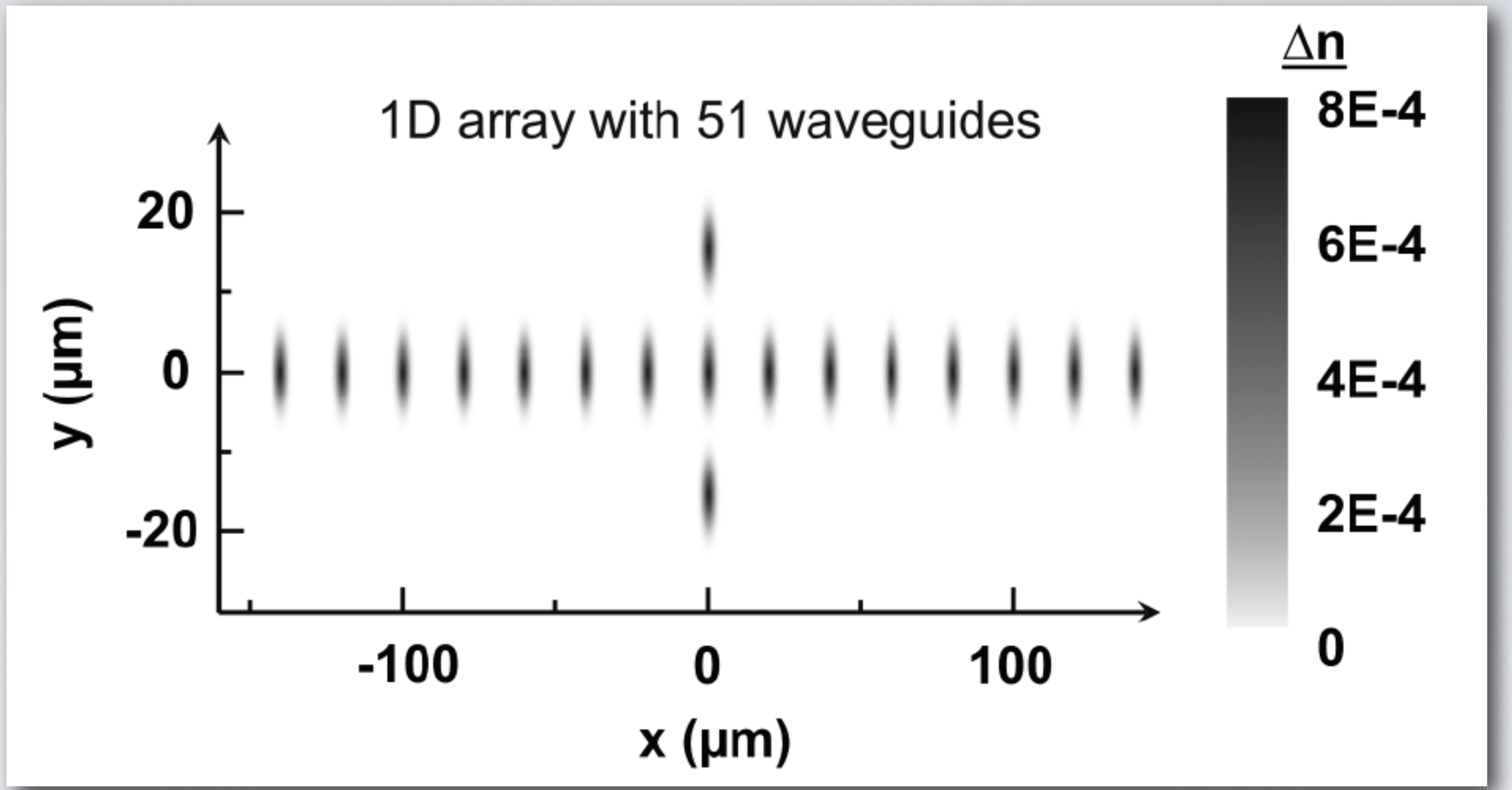
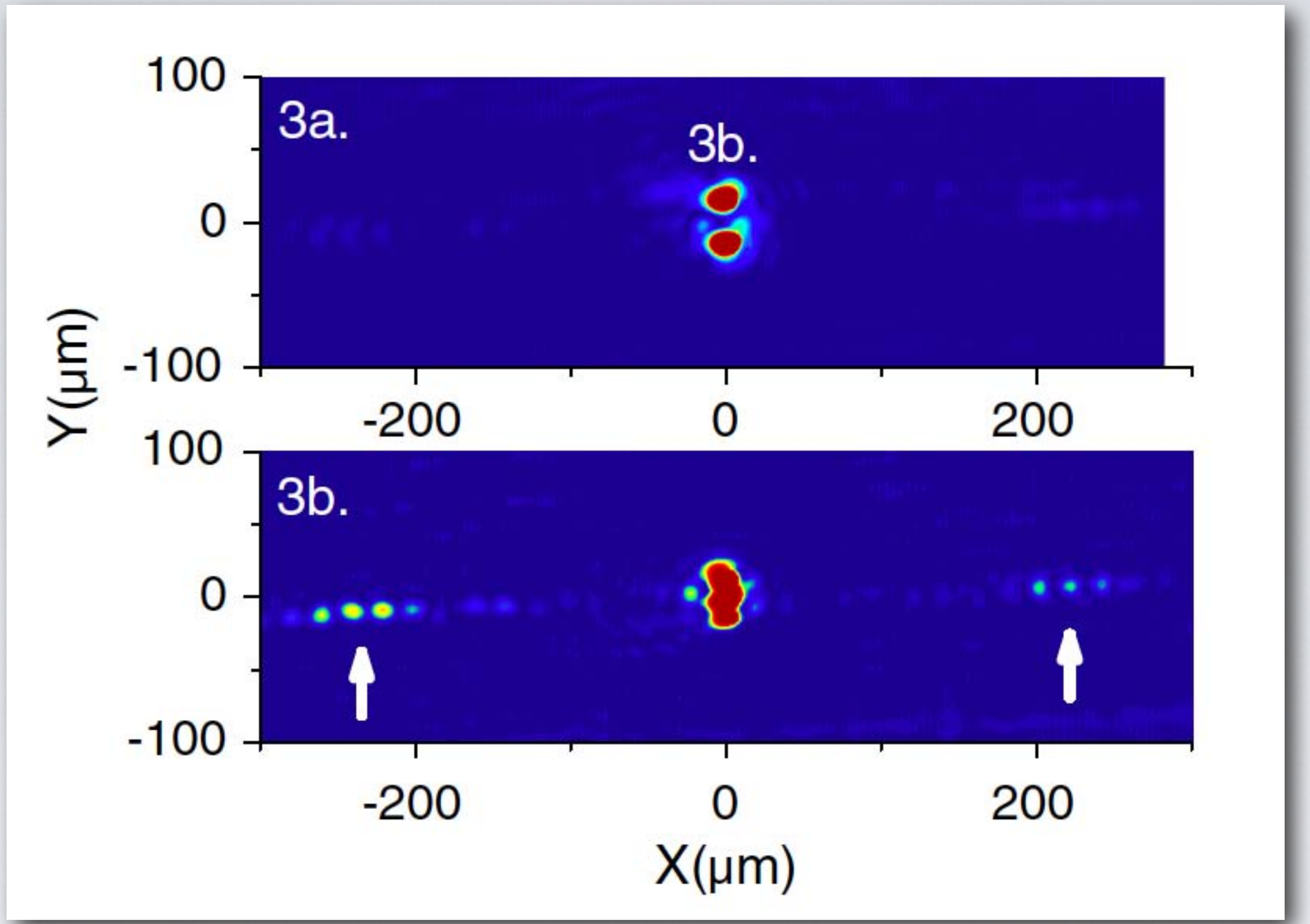
BOUND STATES IN THE CONTINUUM



Y. Plotnik *et al*. Phys. Rev. Lett. **107**, 183901 (2011)

BOUND STATES IN THE CONTINUUM



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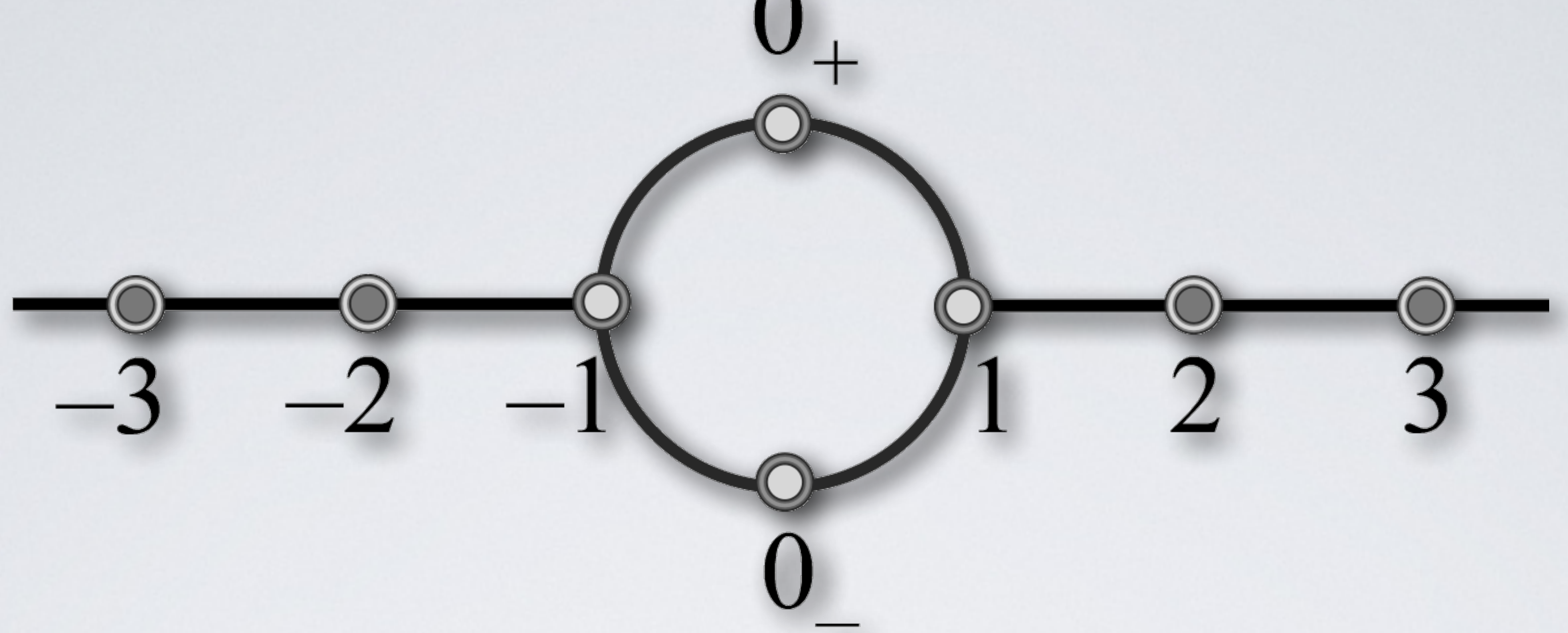
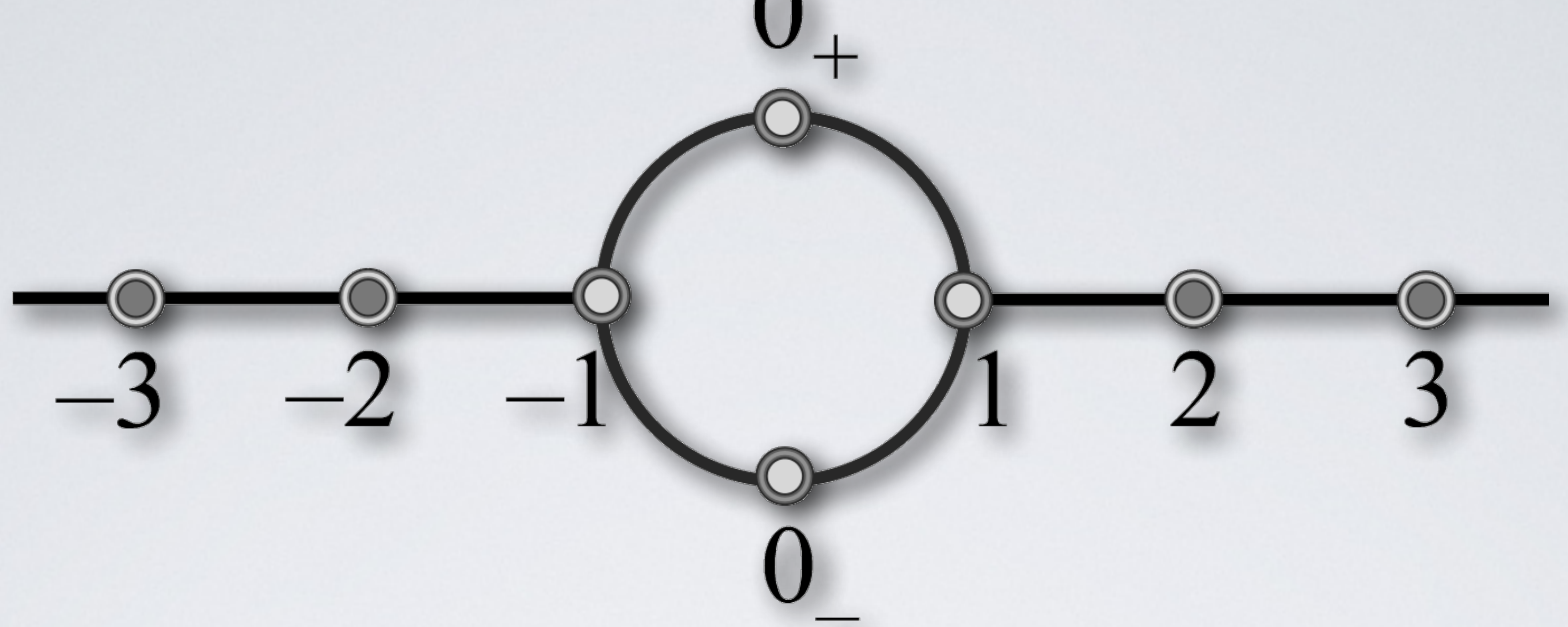


$$i\dot{\psi}_j = \varepsilon_{\pm}(t)\delta_{j,0_\pm}\psi_j - \sum_{i(j)} \psi_{i(j)}$$

$$\varepsilon_{\pm}(t) = \pm 2\Delta \cos \omega t$$

BOUND STATES IN THE CONTINUUM



DC gates (w = 0)

$$T(E) = \frac{E^2}{E^2 + \Delta^4} \longleftarrow \text{Transmission}$$

$$\text{LDOS} \longrightarrow \rho_0(E) \sim \frac{E^2}{E^2 + \Delta^4} + \frac{4\Delta^2}{E^2 + \Delta^4}$$

BOUND STATES IN THE CONTINUUM

AC gates (w ≠ 0)

$$\psi_j(t) = \sum_{n=-\infty}^{\infty} A_{n,j} e^{-iE_n t} \qquad A_{n,j} = \begin{cases} \delta_{n0} e^{ik_n j} + r_n e^{-ik_n j} \,, & j \leq -1 \,, \\ f_n^{\pm} \,, & j = 0_{\pm} \,, \\ t_n e^{ik_n j} \,, & j \geq 1 \,. \end{cases}$$

$$E_n = E + n\omega = -2\cos k_n$$

Time-averaged transmission probability

$$T_\omega(E) = \sum_n \frac{\sin k_n}{\sin k_0} |t_n|^2$$

BOUND STATES IN THE CONTINUUM

AC gates (w ≠ 0)

$$\alpha_n t_n - \frac{\Delta^2}{E_{n-1}} t_{n-2} - \frac{\Delta^2}{E_{n+1}} t_{n+2} = 4i\delta_{n0} \sin k_0$$

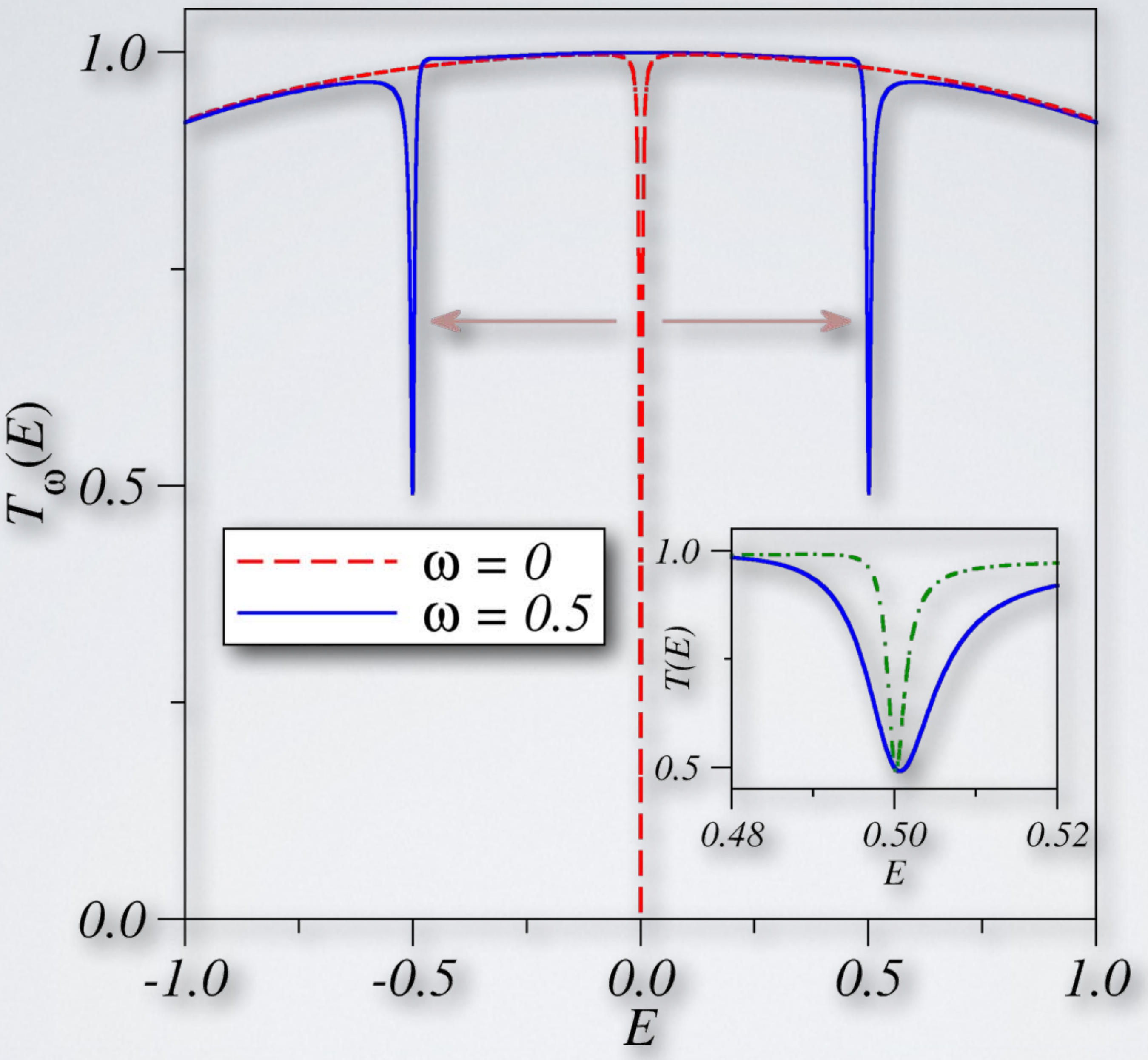
$$\alpha_n = 4i \sin k_n - E_n - \Delta^2 \left(\frac{1}{E_{n+1}} + \frac{1}{E_{n-1}} \right)$$

5 channels approach

$$T_\omega(E) \simeq \frac{1}{2} + \frac{1}{2} \frac{(x - \omega/4)^2}{1 + x^2} , \quad x = \frac{E - \omega}{\Delta^2/2}$$ ← Transmission

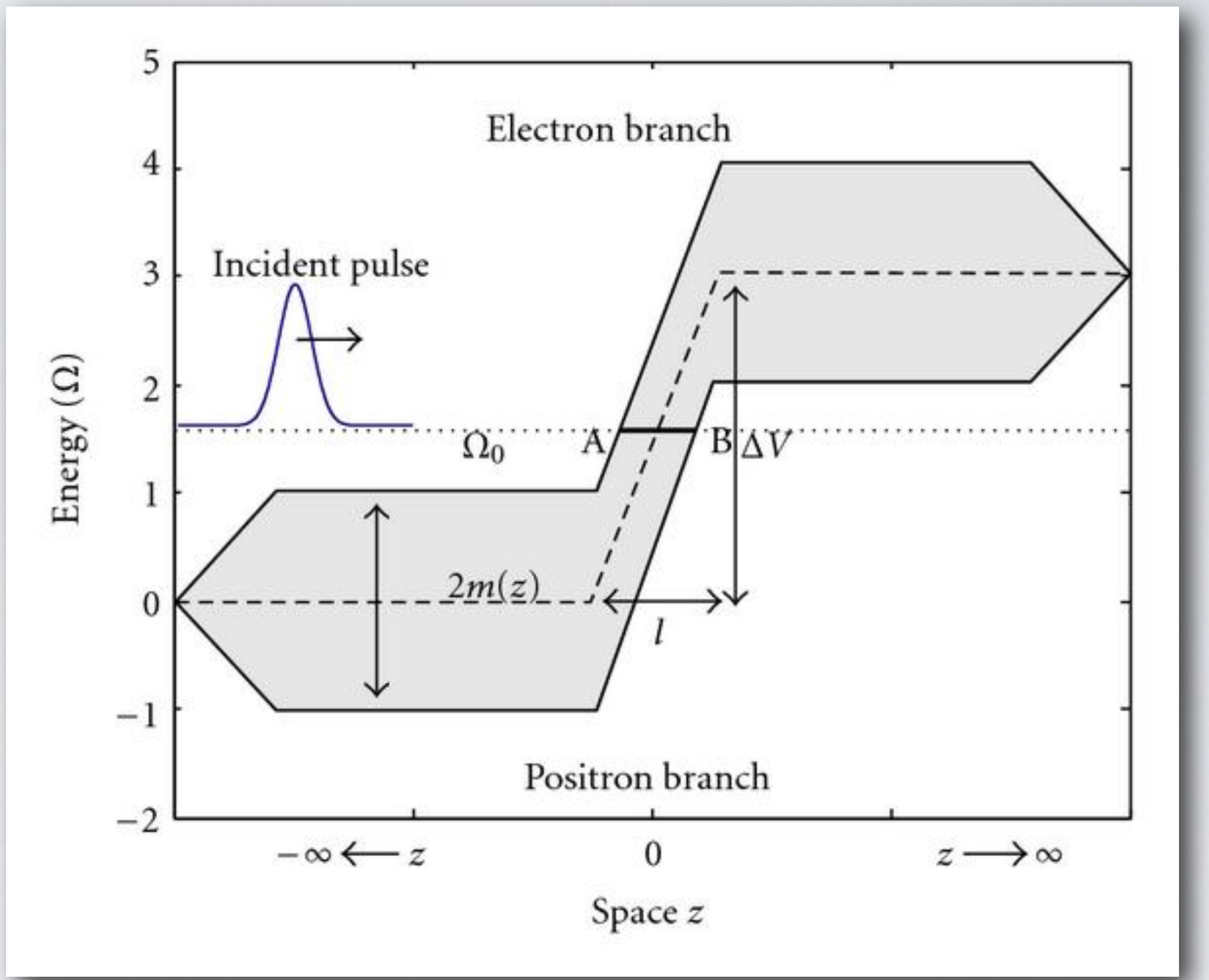
LDOS ⟶ $$\overline{\rho_{0\omega}}(E) \sim \frac{1}{2} T_\omega(E) + \frac{\Delta^2/2}{(E - \omega)^2 + \Delta^4/4}$$

BOUND STATES IN THE CONTINUUM



5 channels approach

KLEIN TUNNELING



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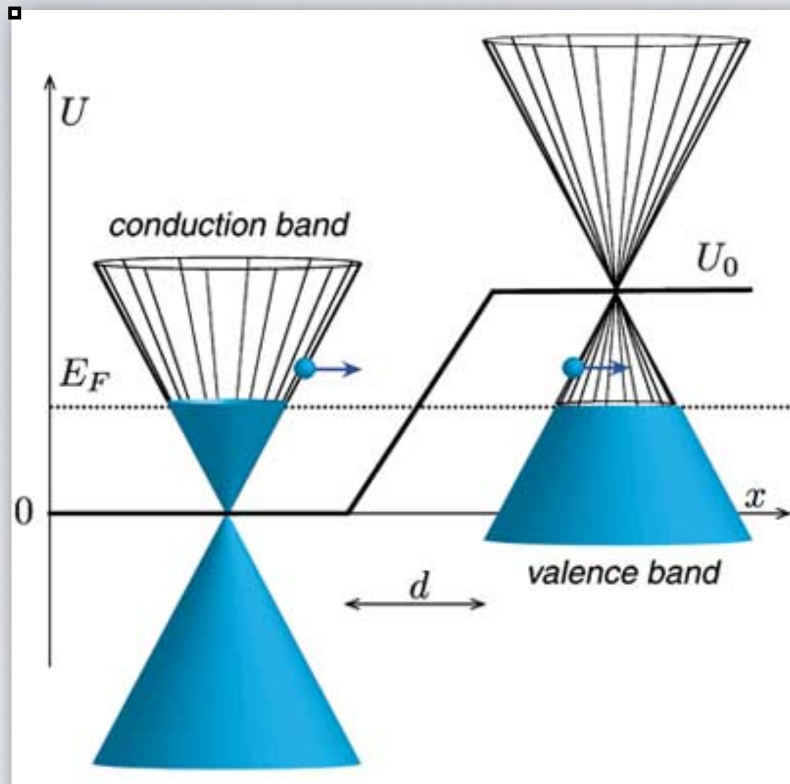
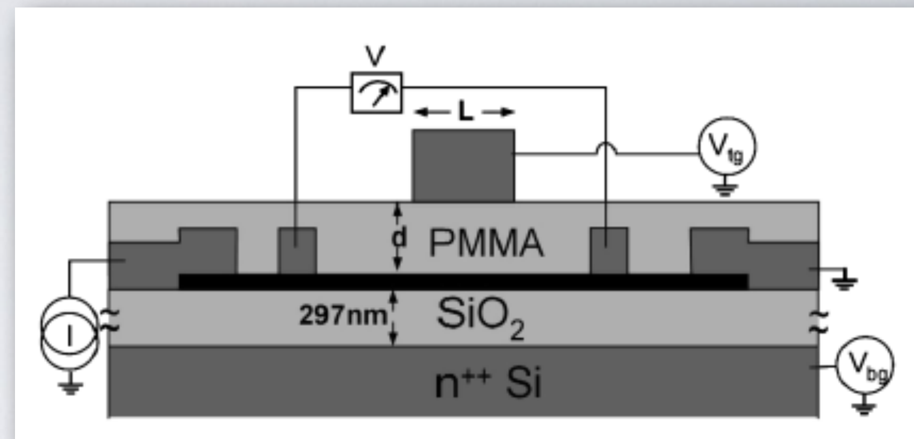
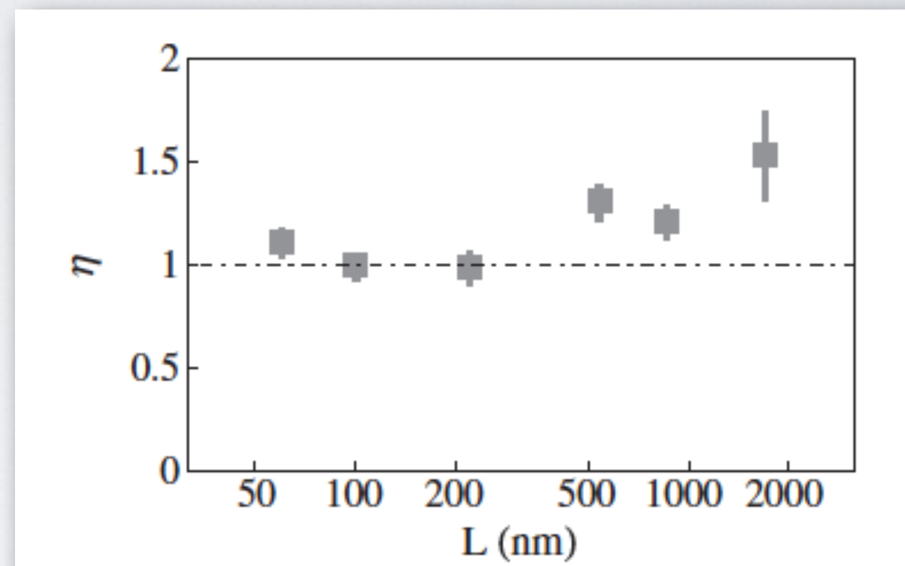
KLEIN TUNNELING







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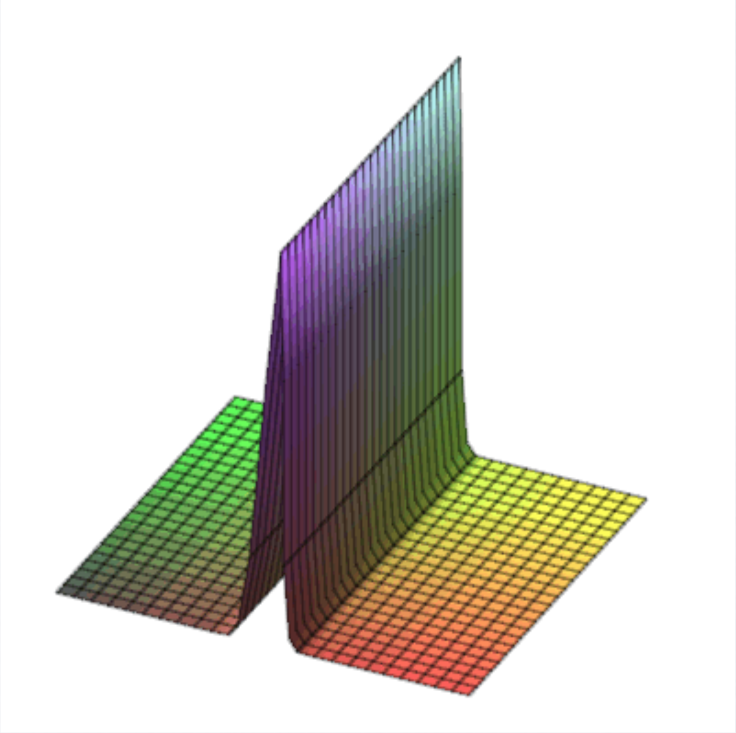
Experiment: N. Stander *et al*. Phys. Rev. Lett. **102**, 026807 (2009)

KLEIN TUNNELING

$$i\dot{\psi}(x,t) = \left[-i\sigma_x \frac{\partial}{\partial x} + \sigma_z m + g(t)F(x)\right]\psi(x,t)$$

$$g(t) = g_0 + g_1 \cos\omega t \qquad F(x) \to \delta(x)$$

$$\psi(0^-,t) = \left[M_0(g_0) + g_1 M_1(g_0)\cos\omega t\right]\psi(0^+,t)$$



KLEIN TUNNELING

Massless particles or gapless graphene

$$\psi(x,t) = \sum_{n=-\infty}^{\infty} A_n(x) e^{-iE_n t} \ , \quad x \neq 0$$

$$\alpha_n t_{n-1} + t_n + \alpha_{n+1} t_{n+1} = \delta_{n0}$$

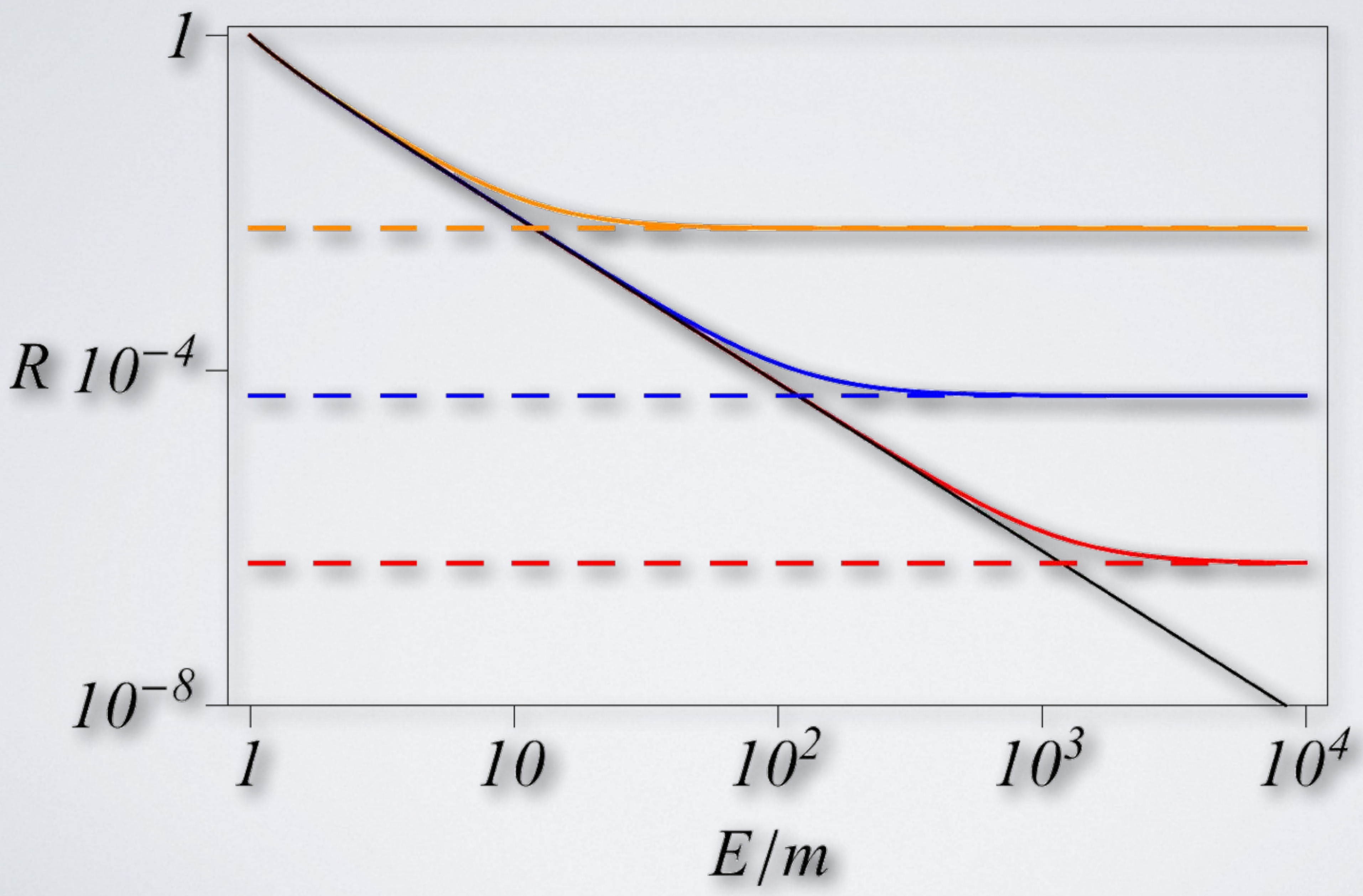
$$\alpha_n = (ig_1/4)(s_{n-1} + s_n) \qquad s_n = \mathrm{sgn}(E_n)$$

$$T(E) = \sum_{n=-\infty}^{\infty} s_0 s_n |t_n|^2$$

$$R(E) = 1 - T(E) \simeq \begin{cases} g_1^2/4 \ , & 0 < E < \omega \ , \\ g_1^2/2 \ , & E > \omega \ . \end{cases}$$

KLEIN TUNNELING

Massive particles or gaped graphene



CONCLUSIONS

- Both "myths" are very, very real:

- Limitations: e-e interaction, decoherence, finite-width barrier...

References

C. González-Santander *et al*. arXiv:1301.5776 (2013).
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