From Perfect Conductor to Perfect Insulator: the Zero-Plateau QH State in Graphene

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NSF, GIF

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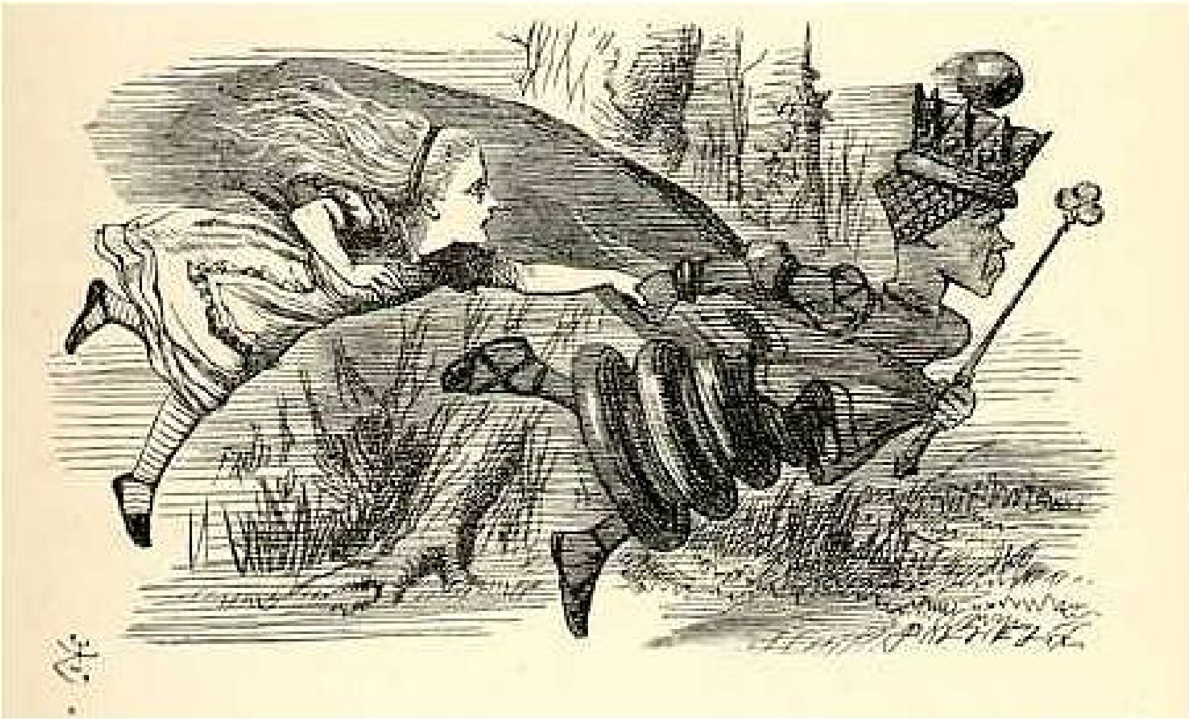
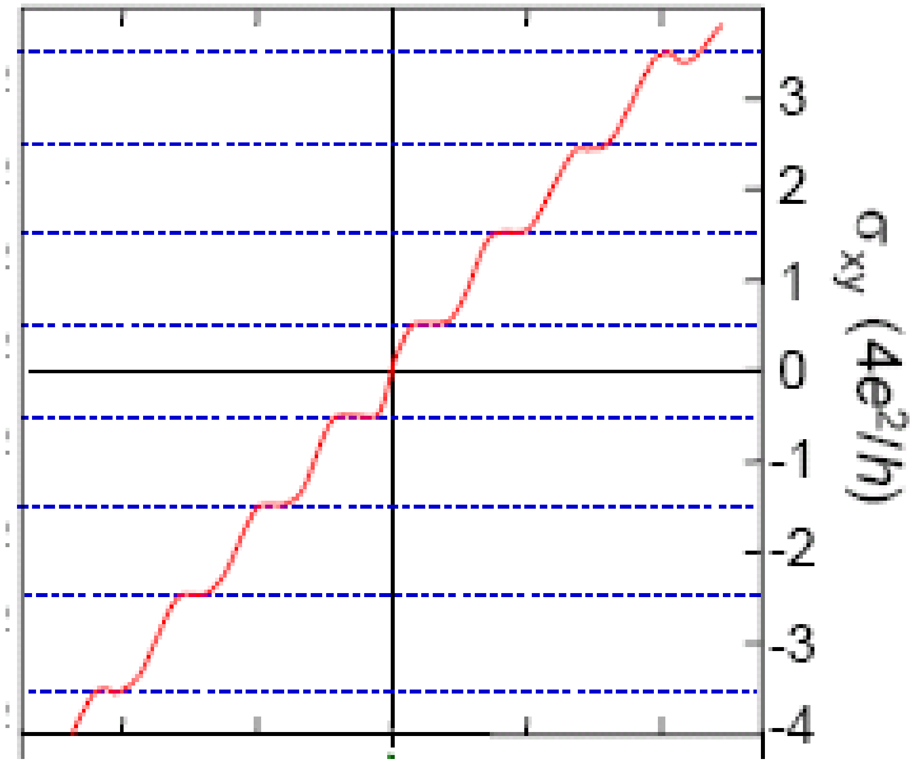
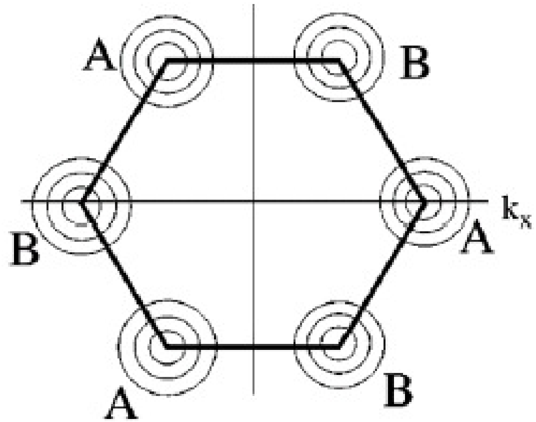


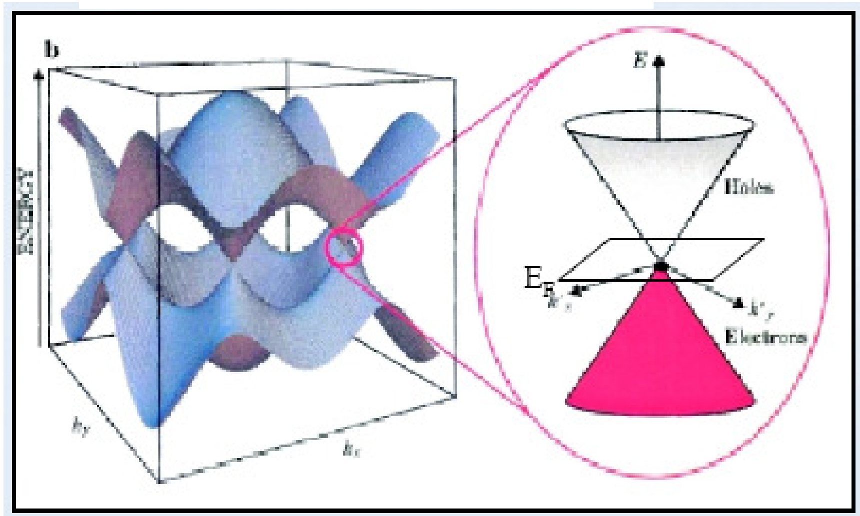
"…*Now, **here**, you see, it takes all the running **you** can do, to keep in the same place…* " (L. Carroll, from "Alice's Adventures through the Looking Glass")

The Quantum Hall Effect in Graphene

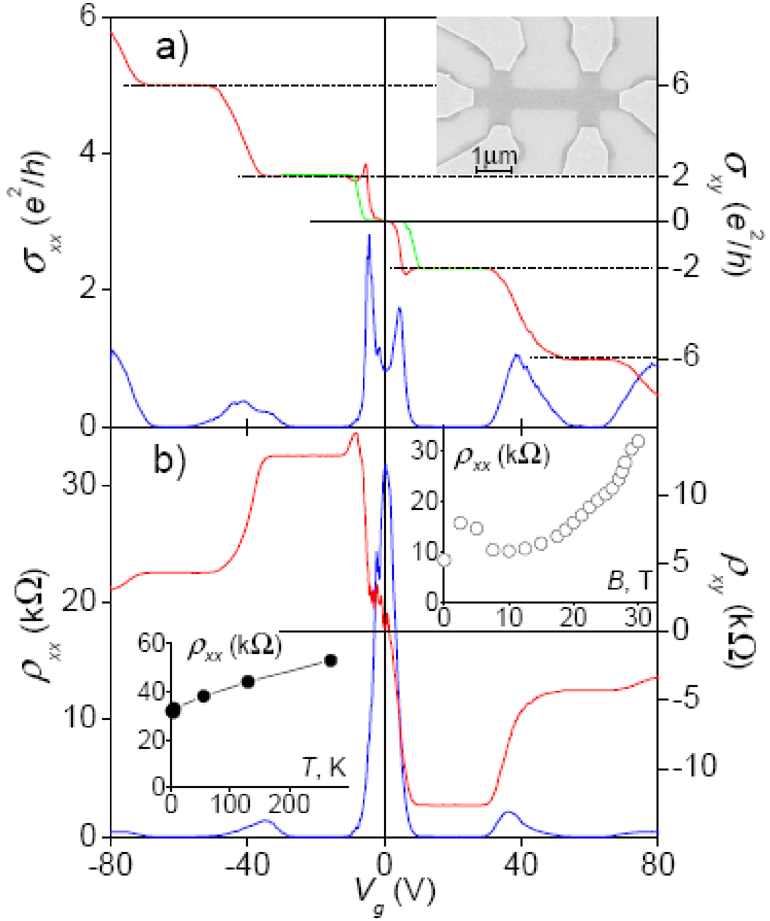


Novoselov, Geim et al., Nature **438**, 197 (05)





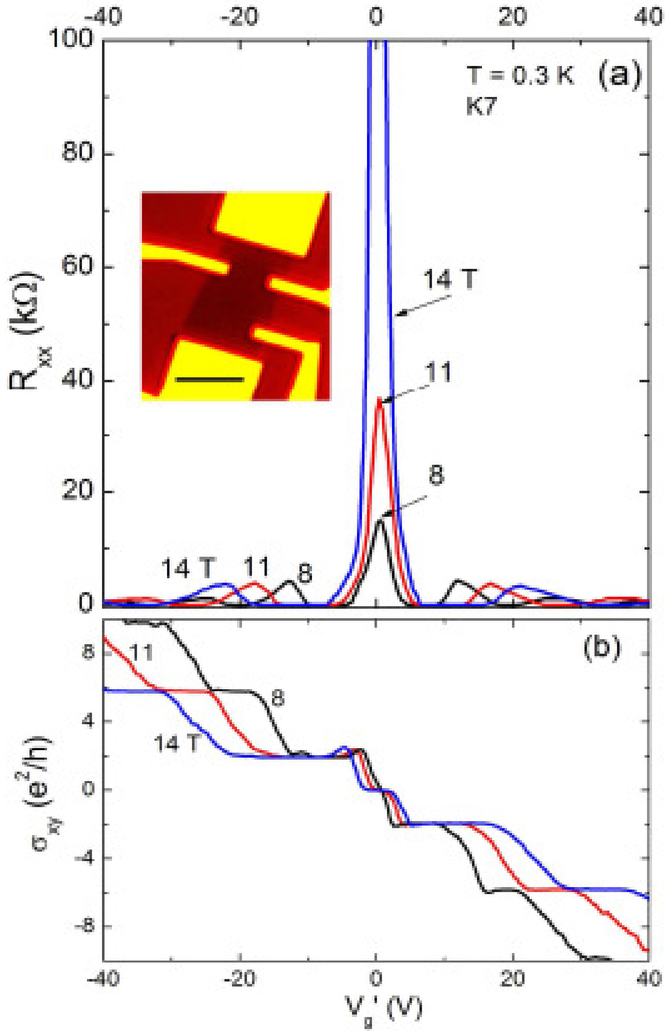
Stronger B: Dissipative QHE at the Dirac Point

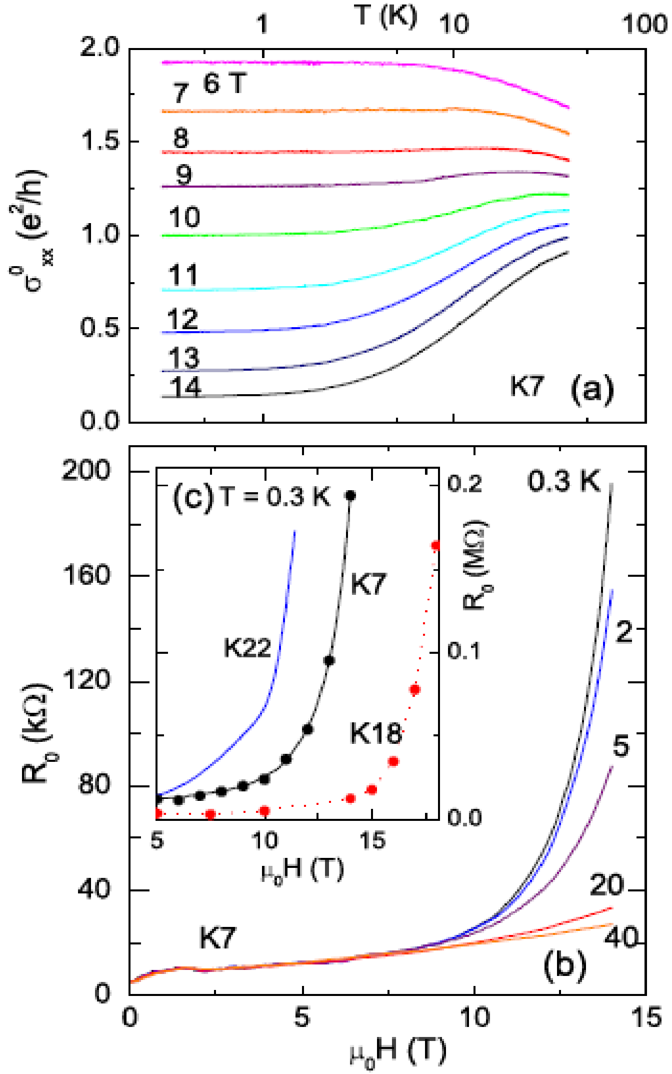


Abanin *et al.* (2007)

- Plateau at ν=0, but $\rho_{xx} \neq 0$!
- ρ_{xx} increases with T $\Rightarrow$ Metal
- ρ_{xx} increases with B

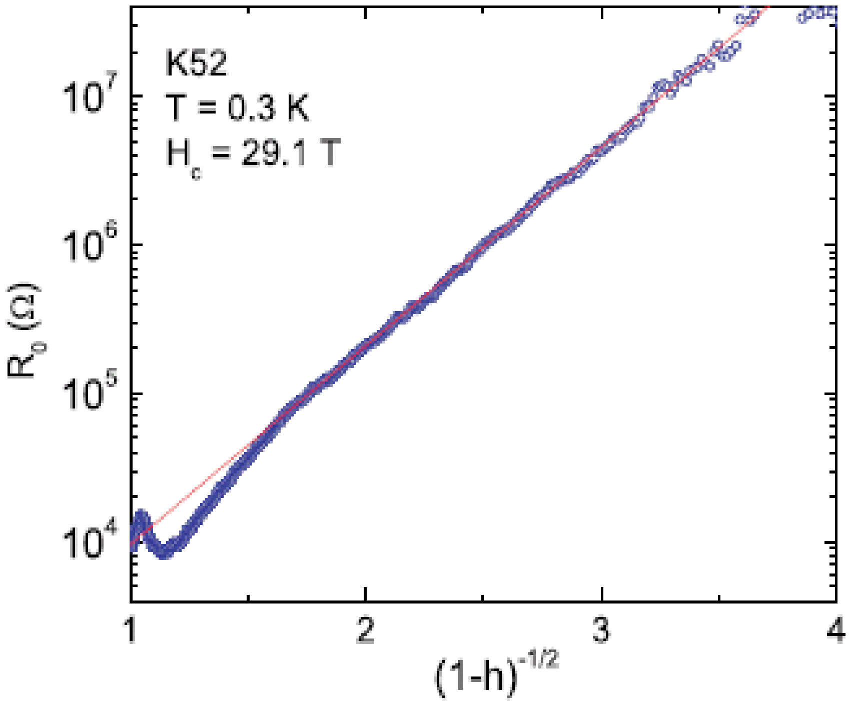
Checkelsky, Li and Ong (2007):





Checkelsky, Li and Ong (2008): more on the “Insulator” -

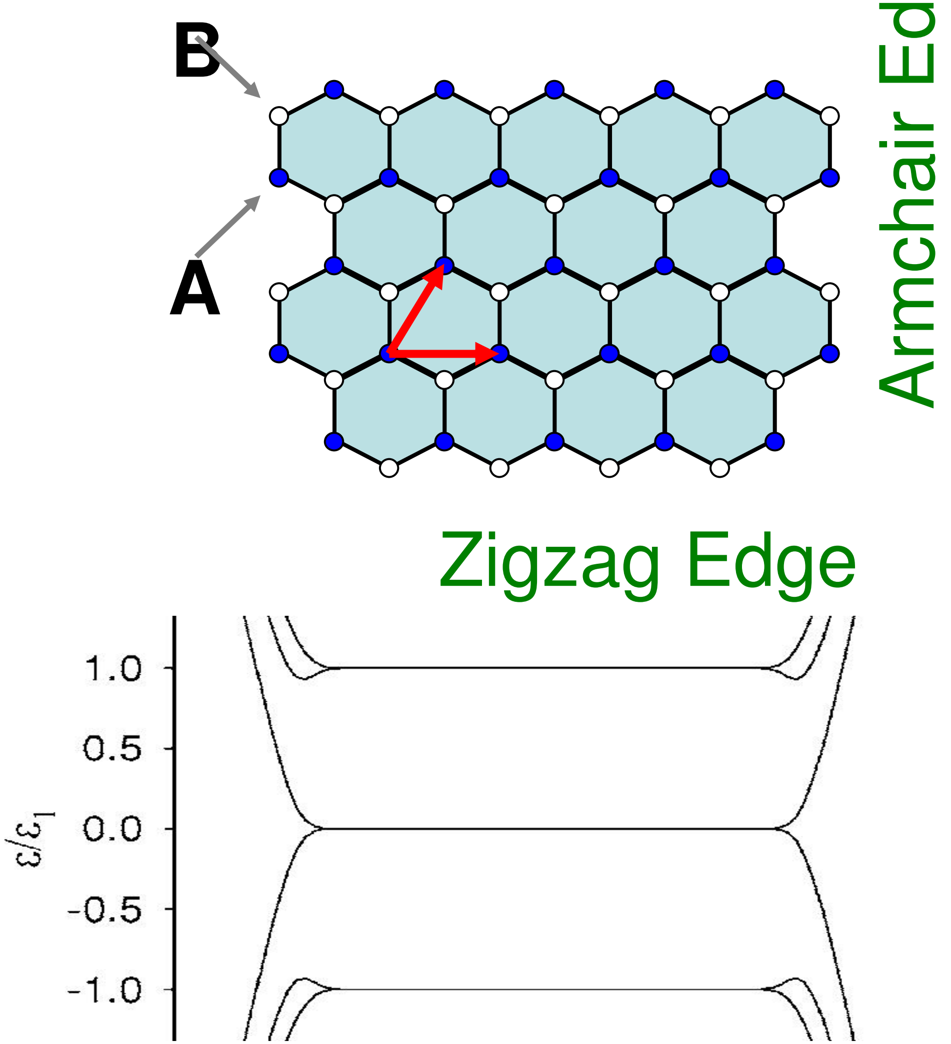
Divergence of R_0 at high H

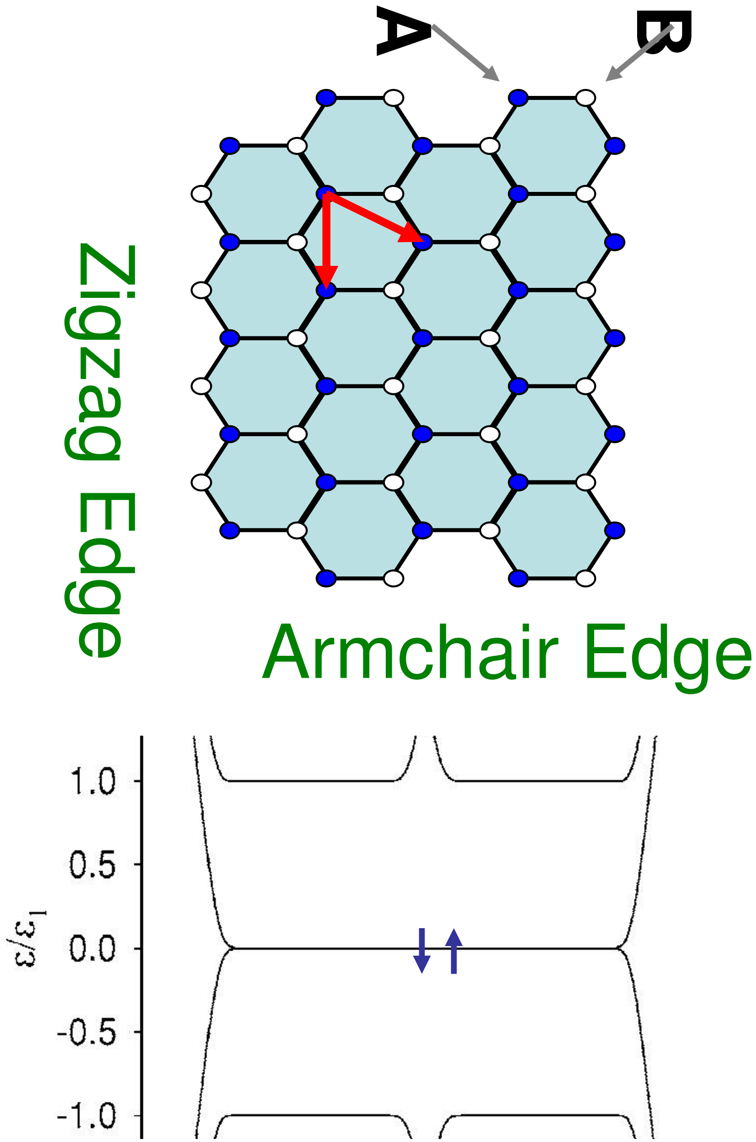


$$\underbrace{R_0 \propto \exp\left\{\frac{2C}{\sqrt{(H_c - H)}}\right\}}_{\xi_{KT}^2\ !!}$$

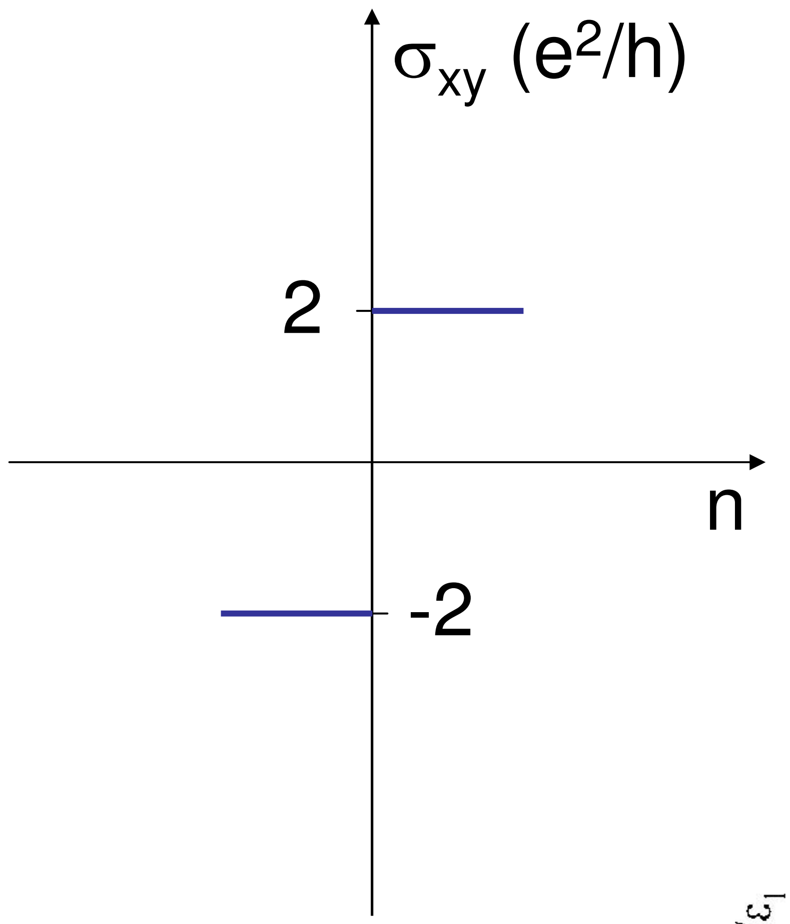
QH Edge-States in Graphene Ribbons

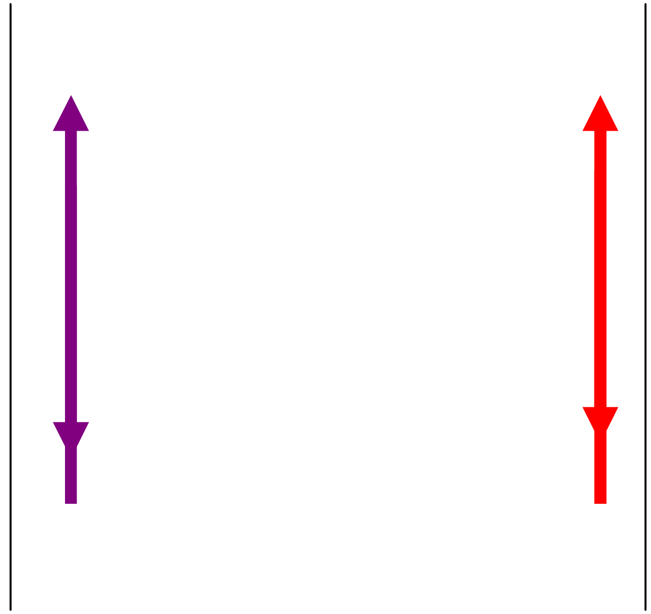
Brey and Fertig (2006):

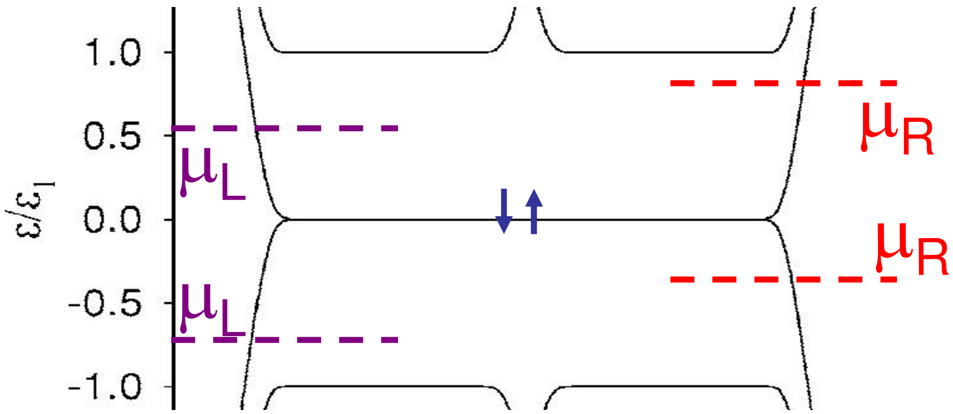




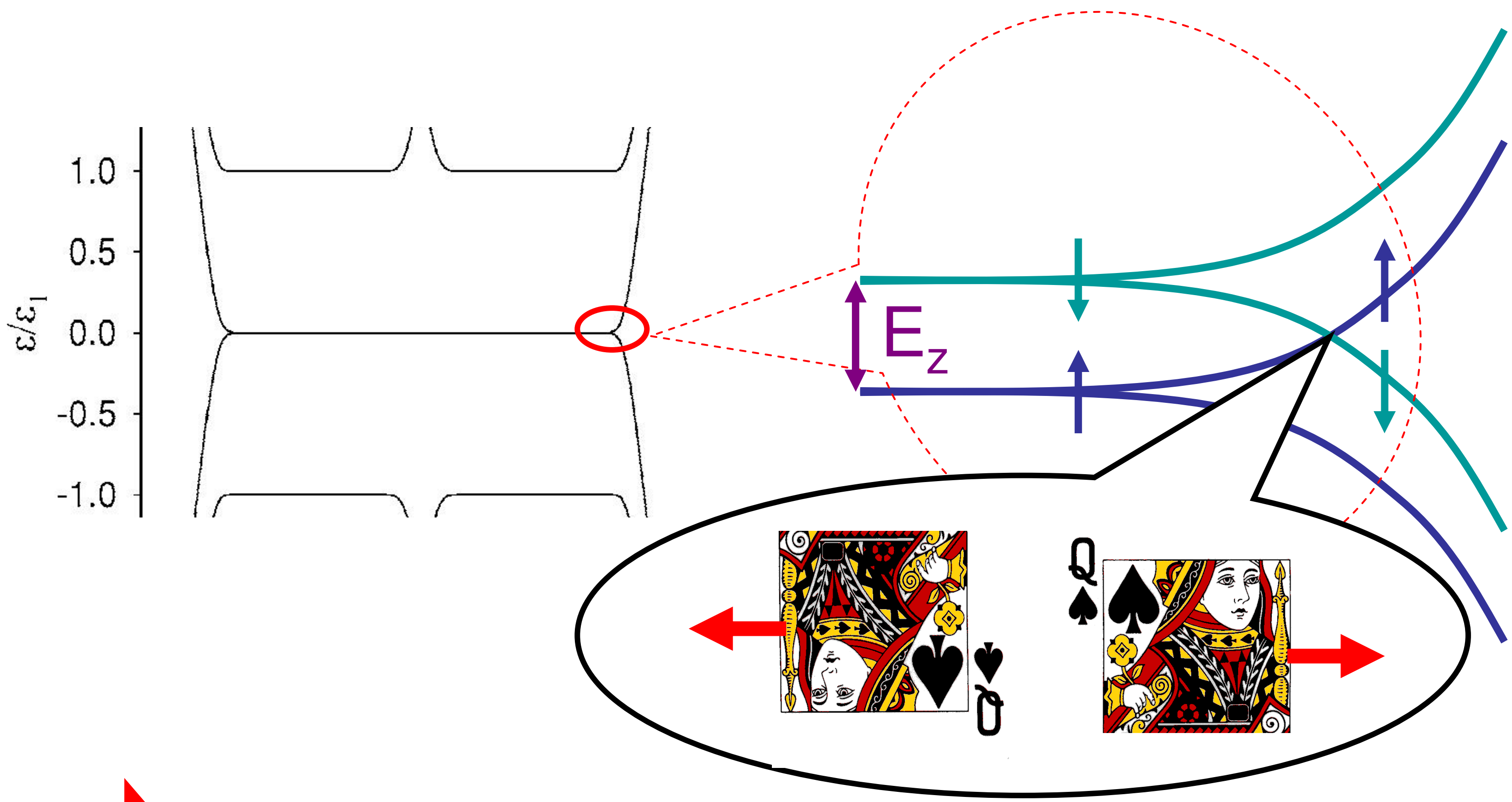
QH Edge-States in Graphene Ribbons





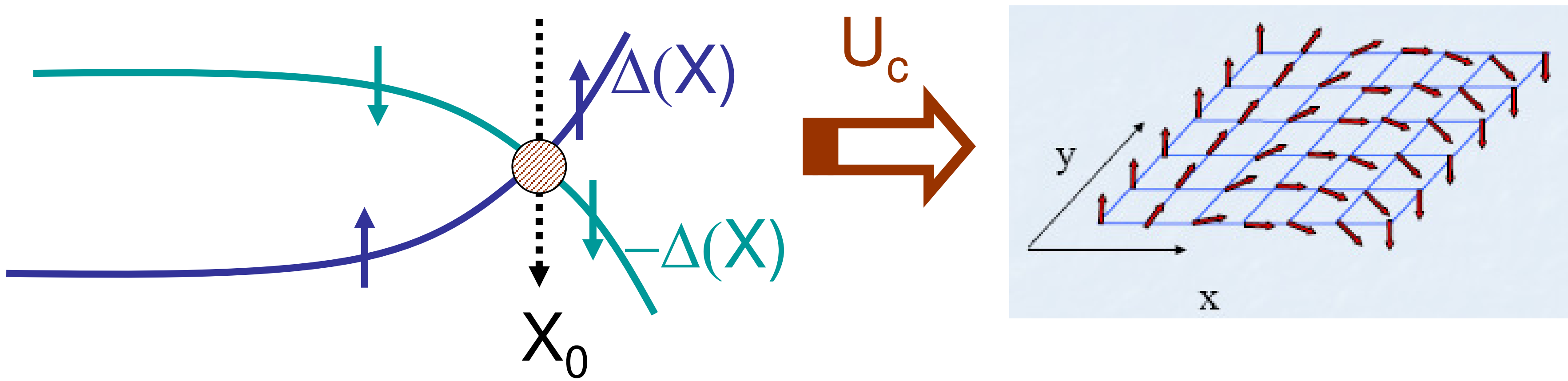


Origin of ν=0 plateau at high H: Zeeman splitting



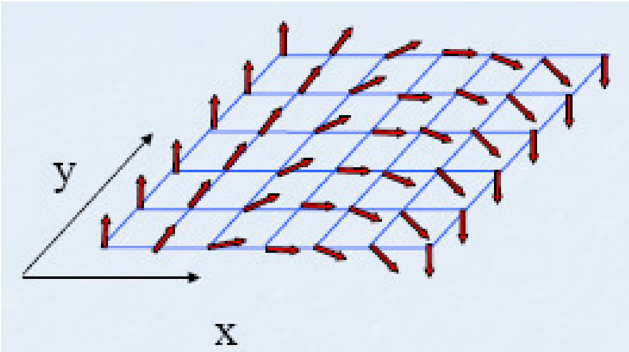
Spin-flip impurities → Finite ρ_{xx}
(Abanin, Levitov & Lee)

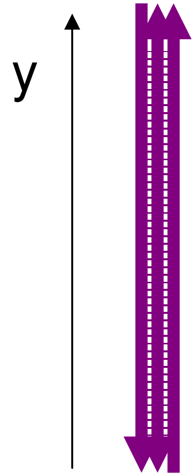
Role of Coulomb interactions (Fertig & Brey, 2007):



Finite width Domain Wall

Our Theory: Effective 1D Model for the Domain Wall





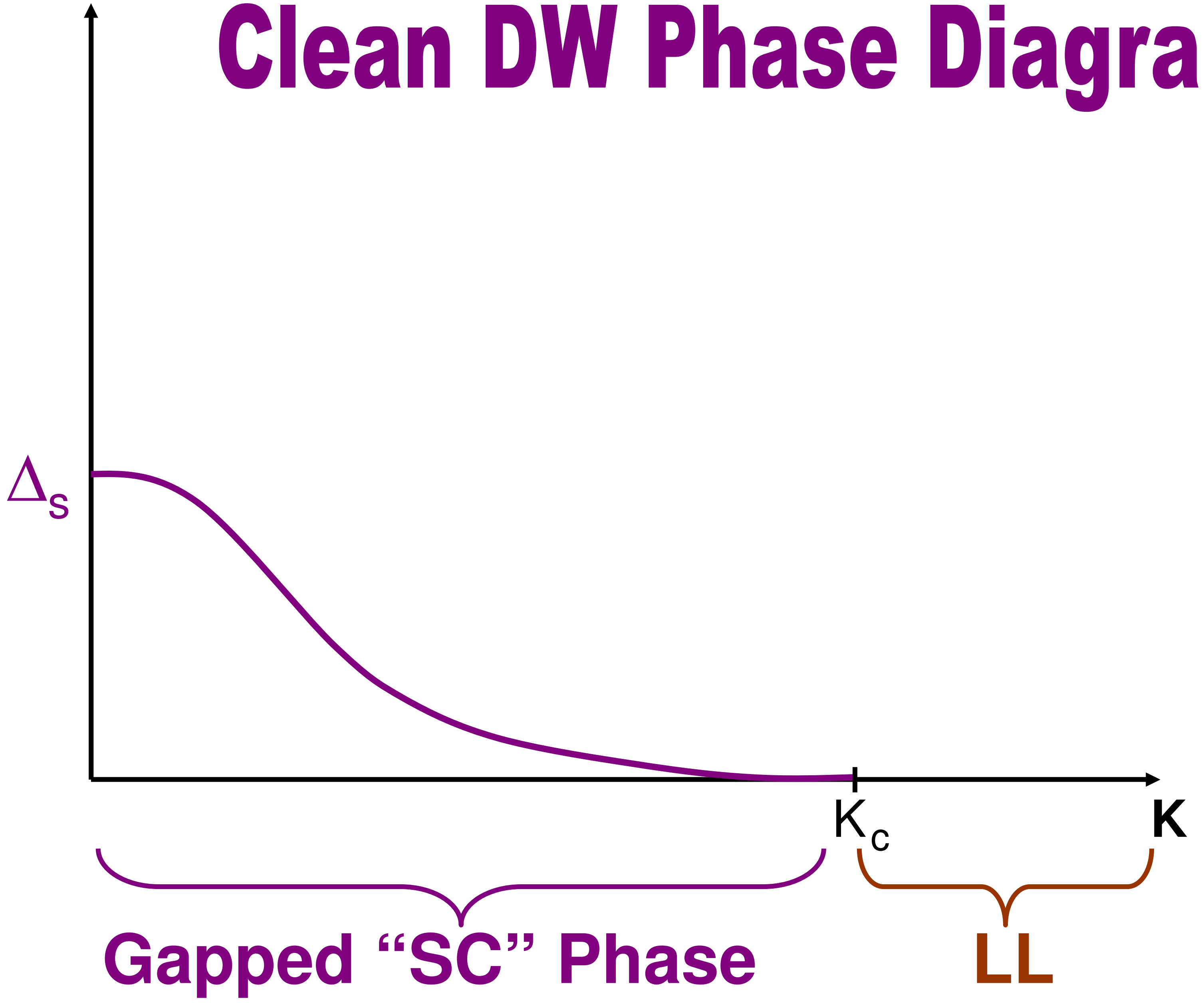
$(j_e \,\square\, S_z)$

$$H_{DW} = \int \frac{dy}{2\pi}\left(uK\left(\partial_y \theta\right)^2 + \frac{u}{K}\left(\partial_y \phi\right)^2 - \boxed{g\cos[4\phi]} \right)$$

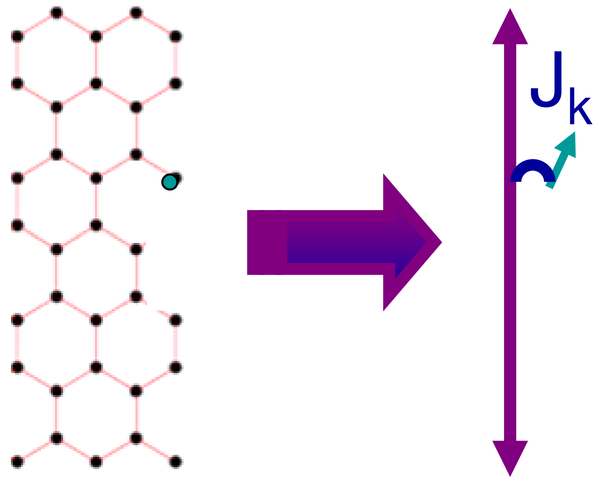
“charging energy” “SC stiffness” “Josephson Coupling”

$K[H, U_c, \Delta'(X_0)]$, $u[H, U_c, \Delta'(X_0)]$, $g[H, U_c, \Delta'(X_0)]$

Clean DW Phase Diagram



Theory for Transport: adding Spin-Flip Interaction



$H = H_{DW} + H_{\sigma} + H_{int}$

$H_{\sigma} = \varepsilon_z \sigma_z$

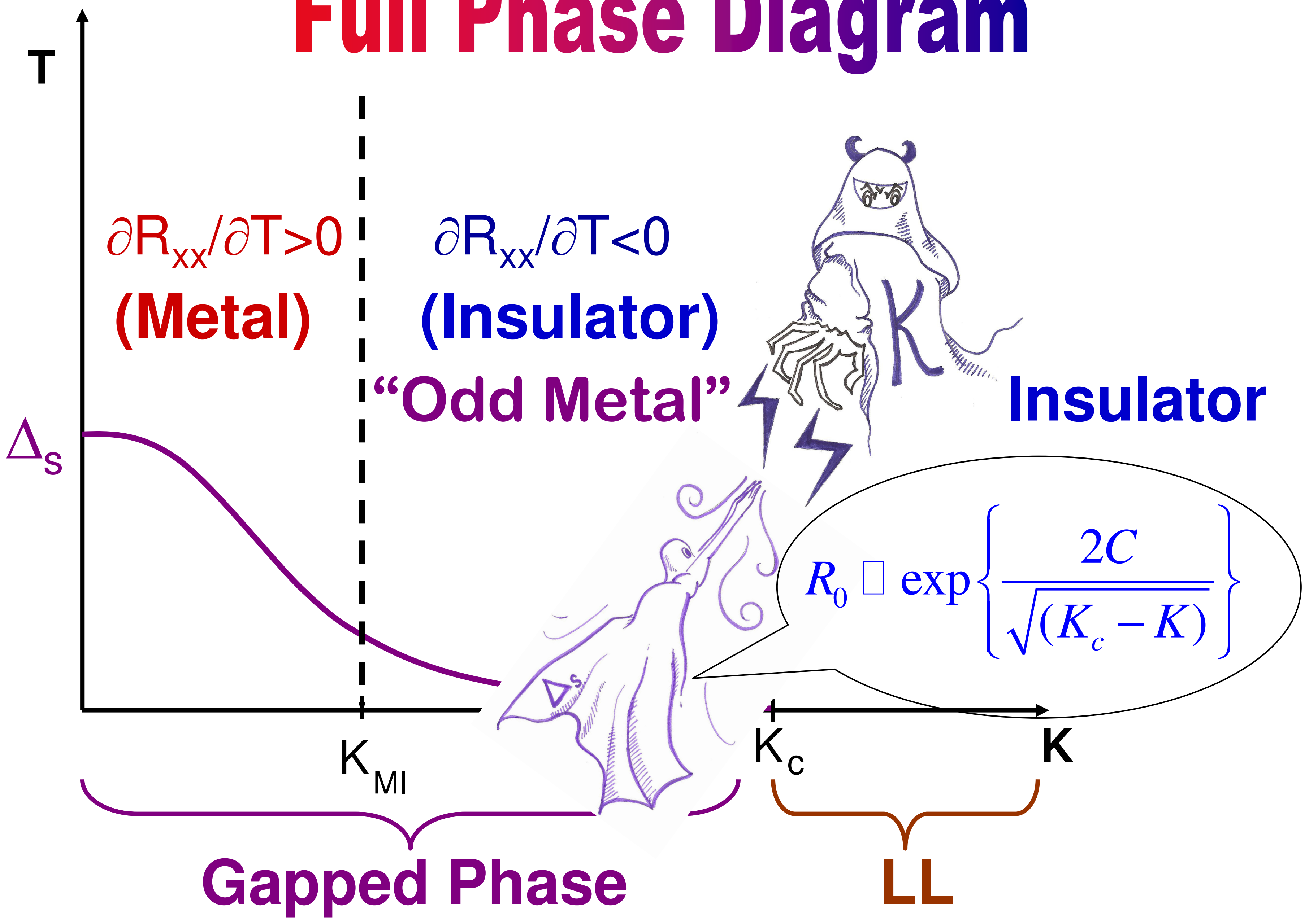
$H_{int} = J_k \mathbf{S} \cdot \sigma$

Back-scattering induced resistance for $T > \Delta_s$:

$$R_{xx} \approx g^2 T^{\nu(K)} F[\epsilon_z / T] \qquad (g \sim J_k)$$

$$\nu(K_{MI}) = 0$$

Full Phase Diagram



Summary

- ♠ Finite R_{xx} at the ν=0 QH state induced by "chiral Kondo effect": Spin-flip = Charge backscattering
- ♠ New type of edge state: spin Domain Wall = a <u>non-chiral</u> perfect conducting channel
- ♠ Diverse transport phenomena: $R_{xx}(T)$ is metallic, insulating or "odd metal" depending on K.
  Divergence of R_0 => quantum KT-transition (in 1+1d)