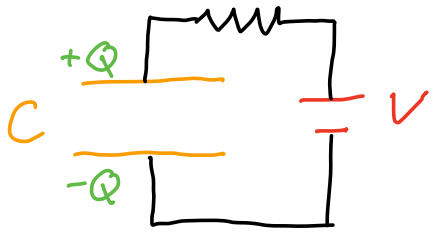
Single electron transistor (J. Weis tutorial 2003)

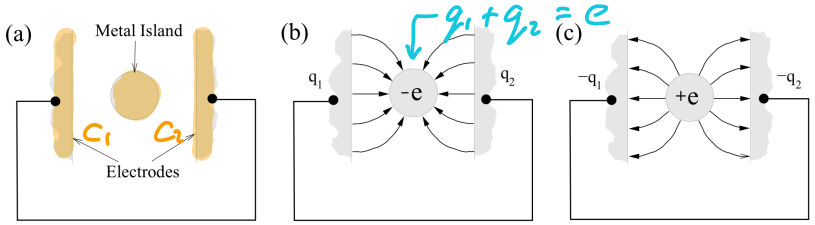
Capacitor charge $Q = CV$

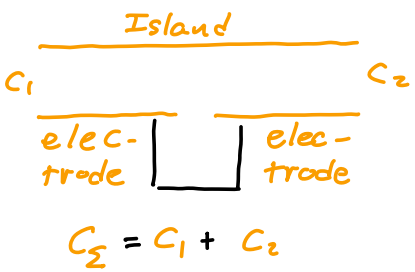
Battery energy $QV = CV^2$

Capacitor energy $E_c = \frac{Q^2}{2C} = \frac{1}{2}CV^2$



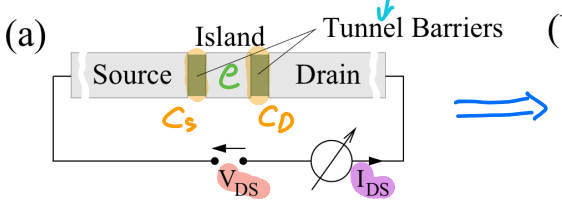
Parallel circuit

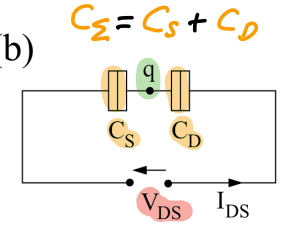




$C_\Sigma = C_1 + C_2$

Electron localization quantizes charges

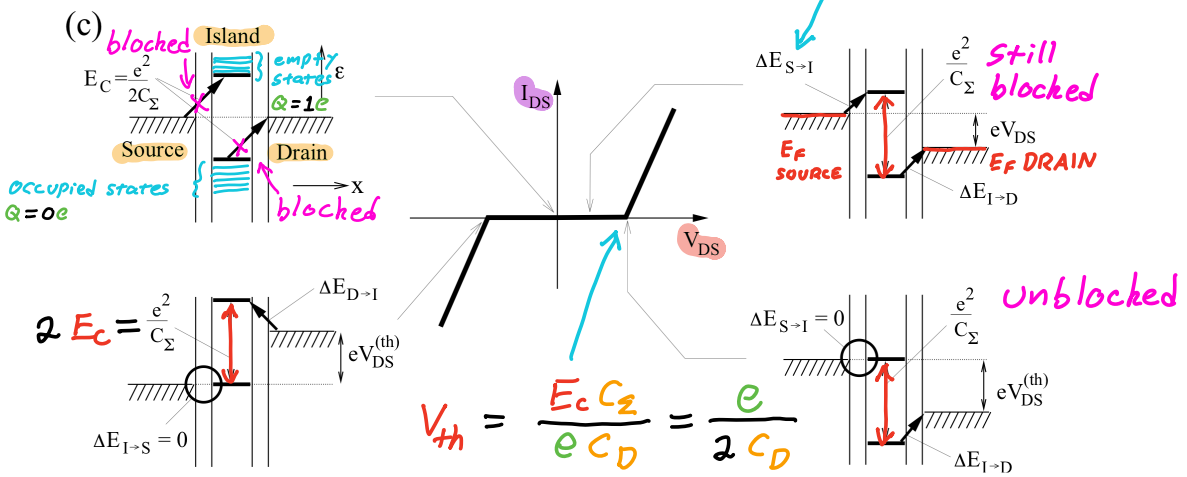




$C_\Sigma = C_S + C_D$

$E_C = \frac{e^2}{2C_\Sigma}$

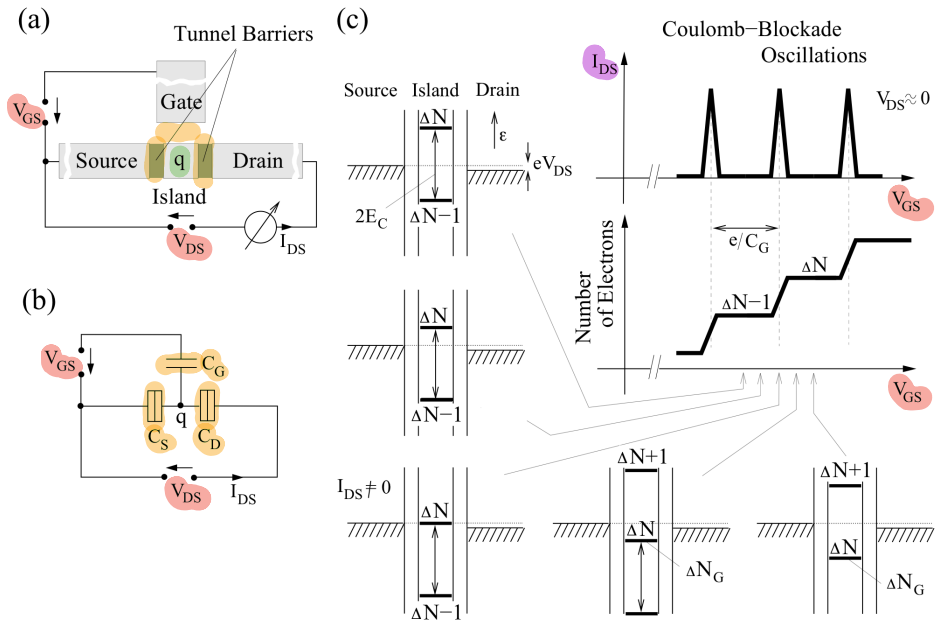
$\Delta E_{SI} = E_c - \frac{C_S}{C_\Sigma} \cdot e V_{DS}$

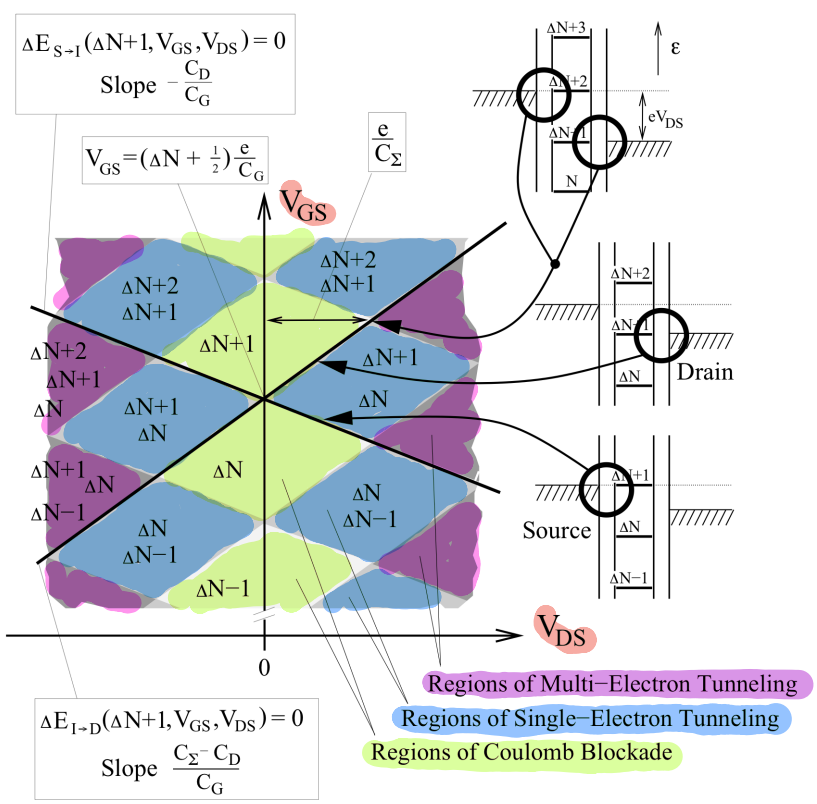


$V_{th} = \frac{E_c C_\Sigma}{e C_D} = \frac{e}{2 C_D}$

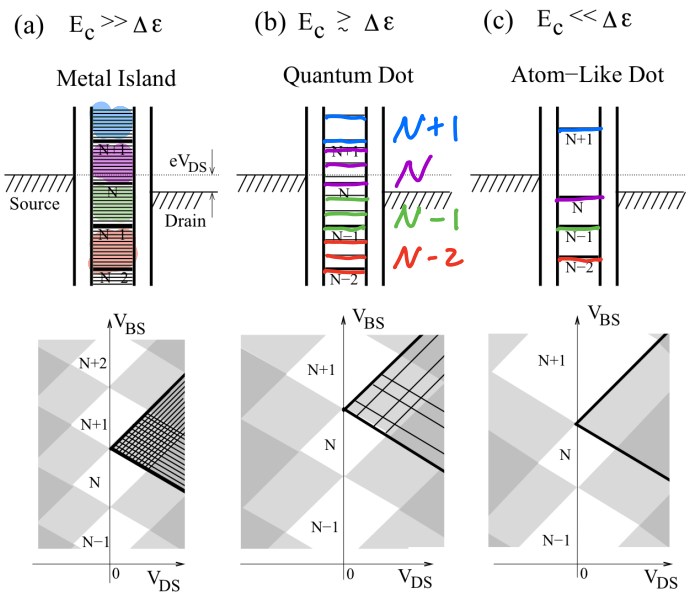
Single electron transistor

$$q = -\Delta N e \qquad E = -\Delta N e \left(\frac{C_G}{C_\Sigma} V_{GS} + \frac{C_D}{C_\Sigma} V_{DS} \right) + \frac{(\Delta N e)^2}{2 C_\Sigma}$$



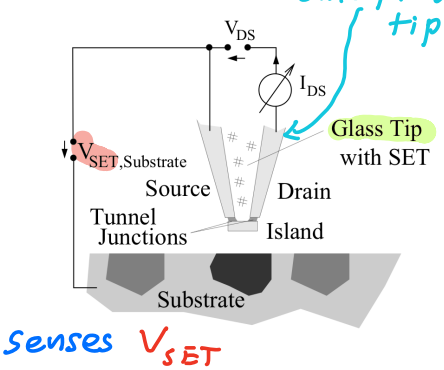


Quantization of levels

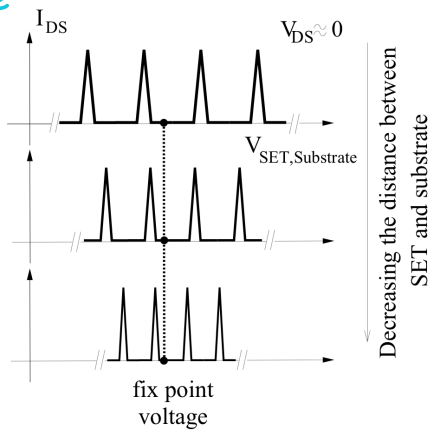


Scanning probe microscope

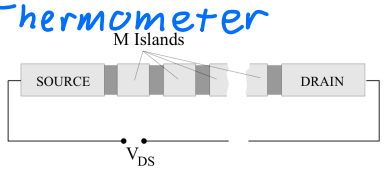
metal evaporated onto probe tip.



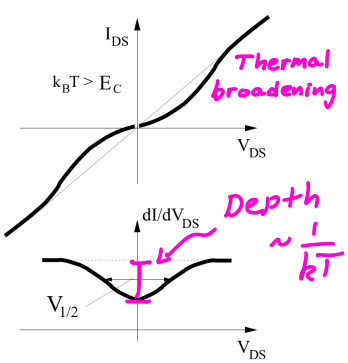
Senses V_{SET}



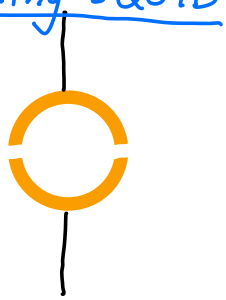
Thermometer



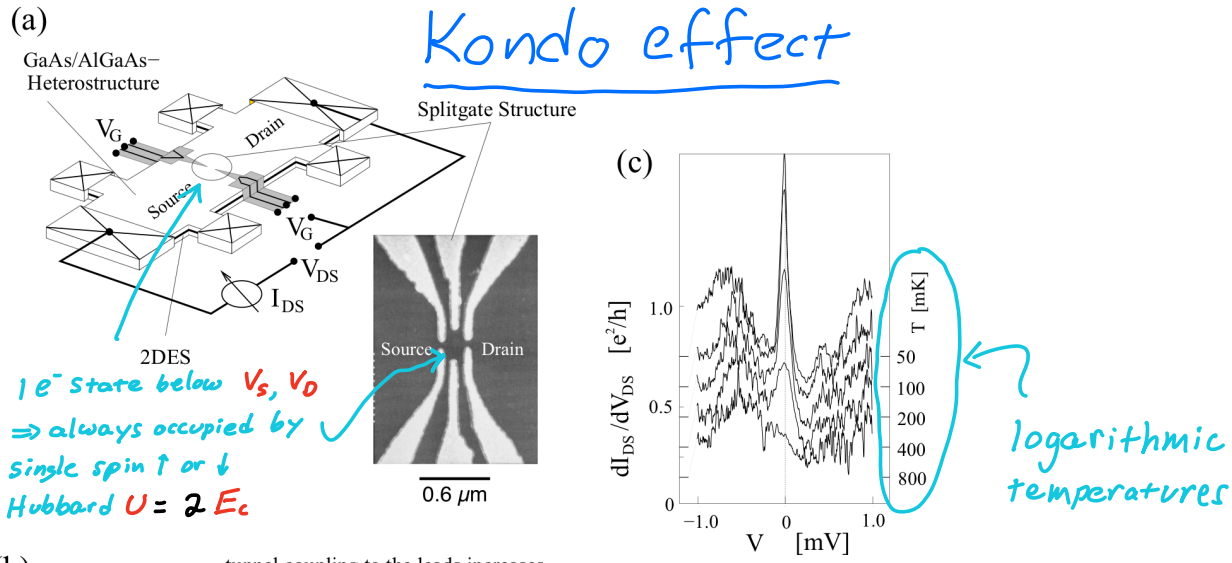
$$\frac{eV_{1/2}}{k_B T} = (M+1)\ 5.439...$$



Scanning SQUID

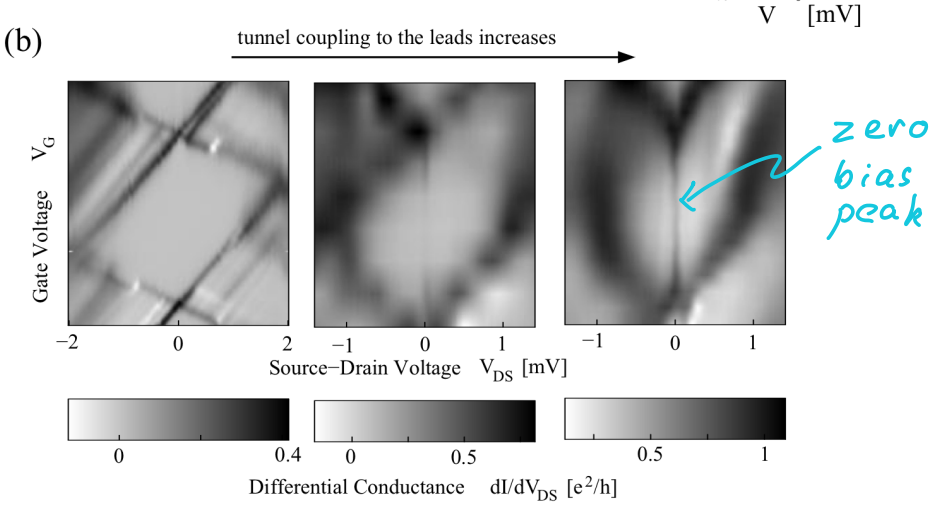


Kondo effect



1 e^- state below V_S, V_D
⇒ always occupied by single spin ↑ or ↓
Hubbard $U = 2E_c$

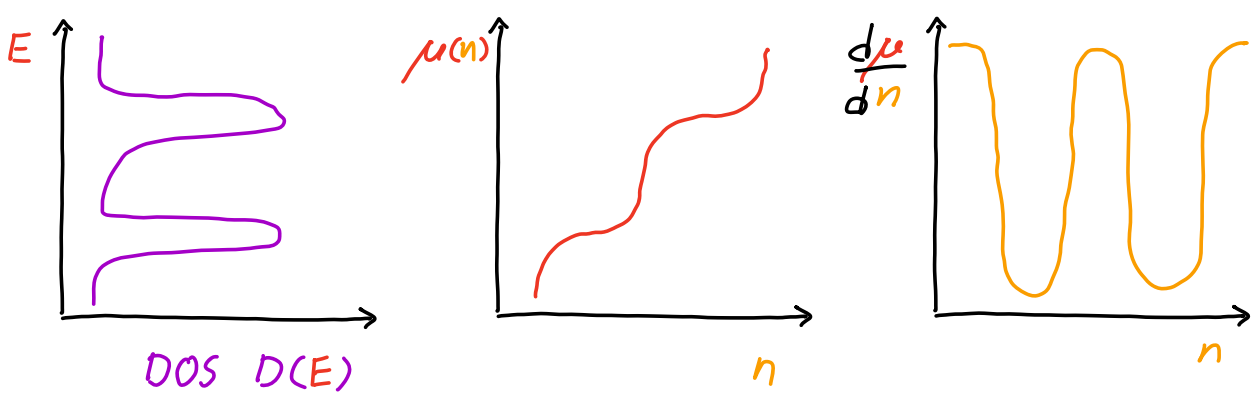
logarithmic temperatures



zero bias peak

Compressibility

$\kappa = dn/d\mu$ $\quad \kappa^{-1} = n^2\, d\mu/dn$



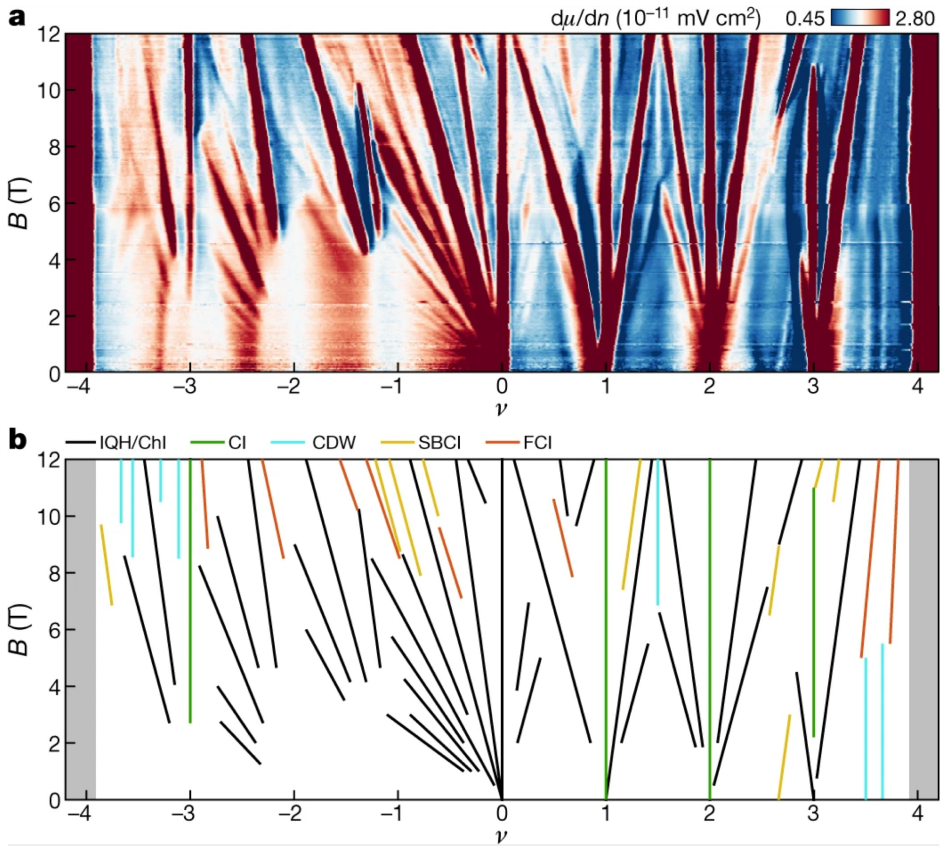
Incompressible electron gas: Integer QHE, Insulators, Wigner crystals, …

Yonglong Xie PhD Princeton (2018, Yazdani)

PostDoc Joint Harvard (Yacoby)

MIT (Jarillo-Herrero)

Fractional Chern Insulators in MATBG



— Integer QHE Chern insulators

— Correlated insulators

— Charge density waves

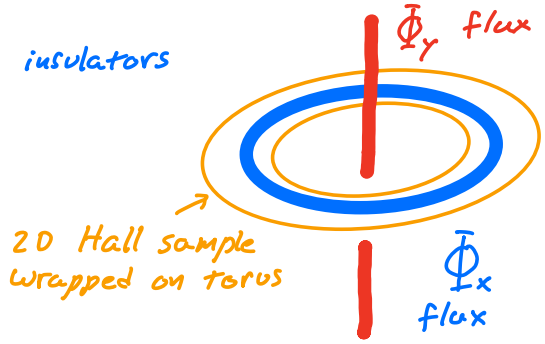
— Symmetry-broken Chern insulators

— Fractional Chern insulators

Integer quantum Hall states are Chern insulators

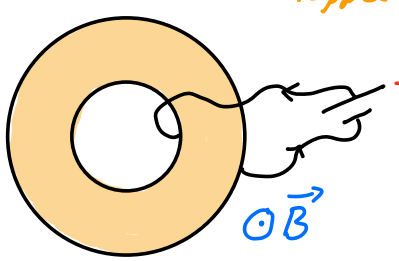
$\sigma_{xy} = \frac{e^2}{h} C \qquad C \in \mathbb{Z} \qquad C = \int_{T^2} \frac{d\vec{\theta}}{2\pi} F_{xy}$

$\vec{\theta} = 2\pi \vec{\Phi}/\Phi_0 \qquad F_{xy}$ = Berry curvature



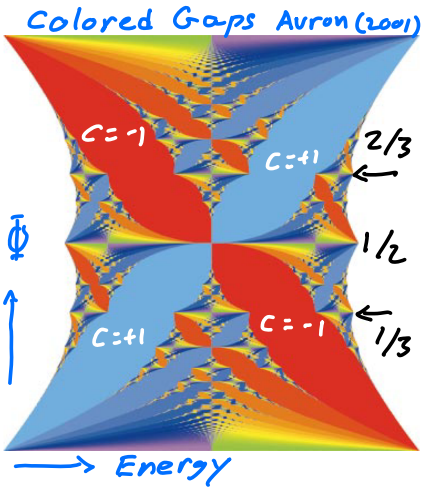
Note: IQHE is insulator

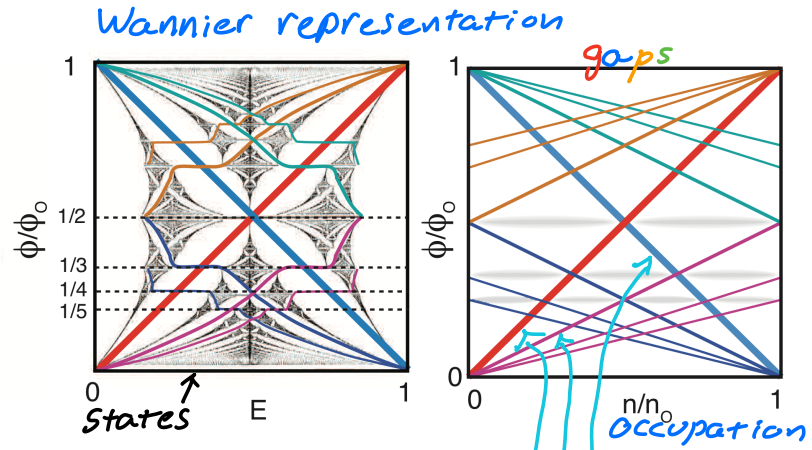
No edges ⇒ no current



"Corbino geometry"

Hofstadter's Butterfly: States are boundaries of gaps





At $\Phi/\Phi_0 = p/q$ spectrum splits into q sub-bands

Filling factor $\nu \equiv n/n_0 = t\,\Phi/\Phi_0 + s$

n: occupied states; n_0: states per Bloch band

$t=-1$ $s=1$

$t=1$ $s=0$

$t=2$ $s=0$

5 cases:

$t=0$ integer $s\neq 0$ $\Rightarrow$ topologically trivial correlated insulators

integer $t\neq 0$ integer s $\Rightarrow$ integer QH states $C=t$

$t=0$ fractional s $\Rightarrow$ charge density wave (Trans-sym broken)

integer $t\neq 0$ fractional s $\Rightarrow$ trans-sym broken Chern insulator

fractional t fractional s $\Rightarrow$ fractional Chern insulator