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LETTERS

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Solids of quantum Hall skyrmions in graphene

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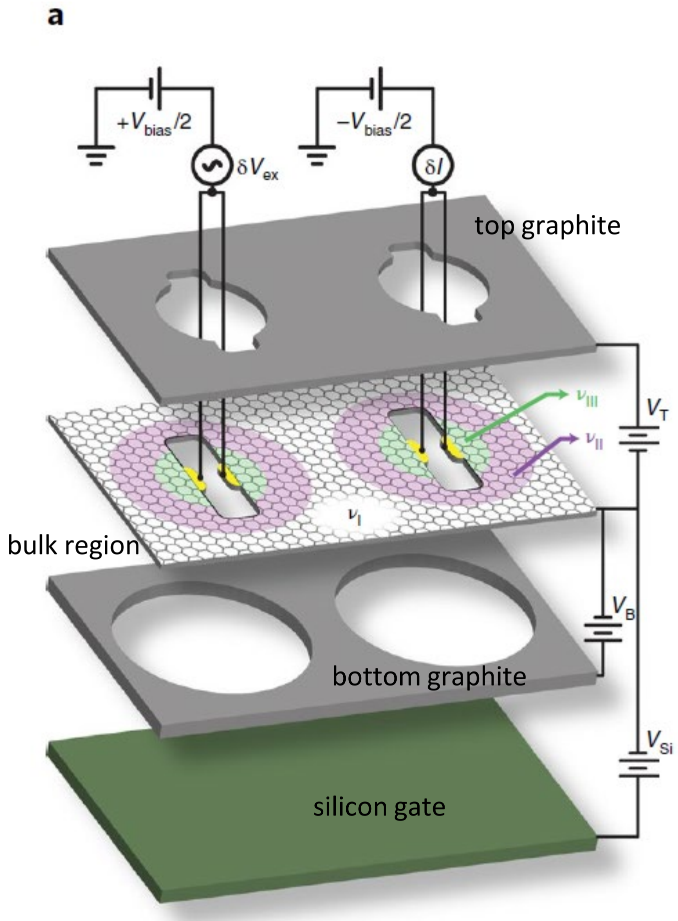
Motivation

- electron solid with non-collinear spin structure
- elementary excitations of skyrmion solids
- magnon propagation length
- fractional skyrmion solids

Graphene

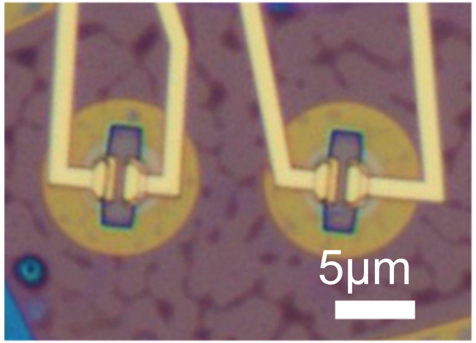
- electrostatic tunability
- exposed surface – direct magnetic imaging
- high sample quality
  broad range of electron density
- high Landau levels – electron solids (was shown before)
- lowest Landau level – skyrmion solids (in this paper)

Device



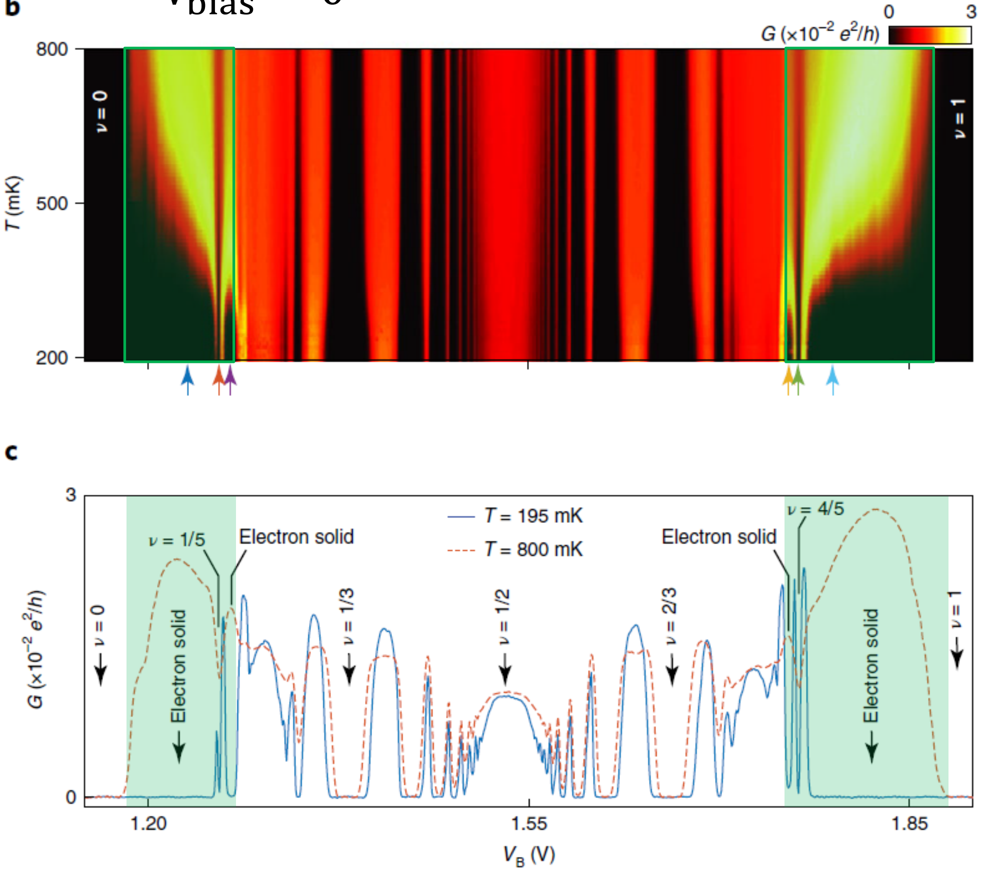
- monolayer graphene
- ultrahigh-quality
- graphite and hBN

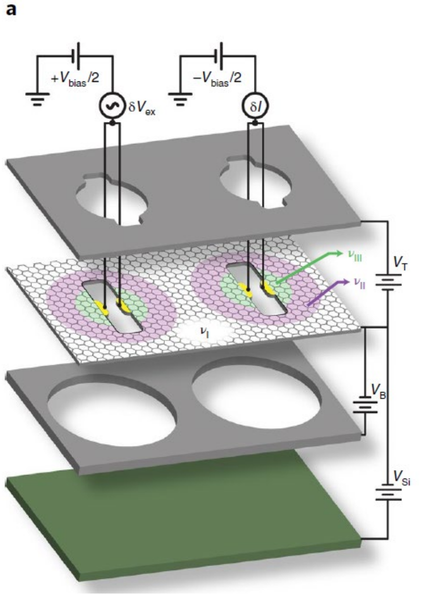
- region I – top and bottom graphite gates
- region II – top graphite and silicon gate
- region III – only silicon gate



Electron solid phase

$V_{\mathrm{bias}} = 0$

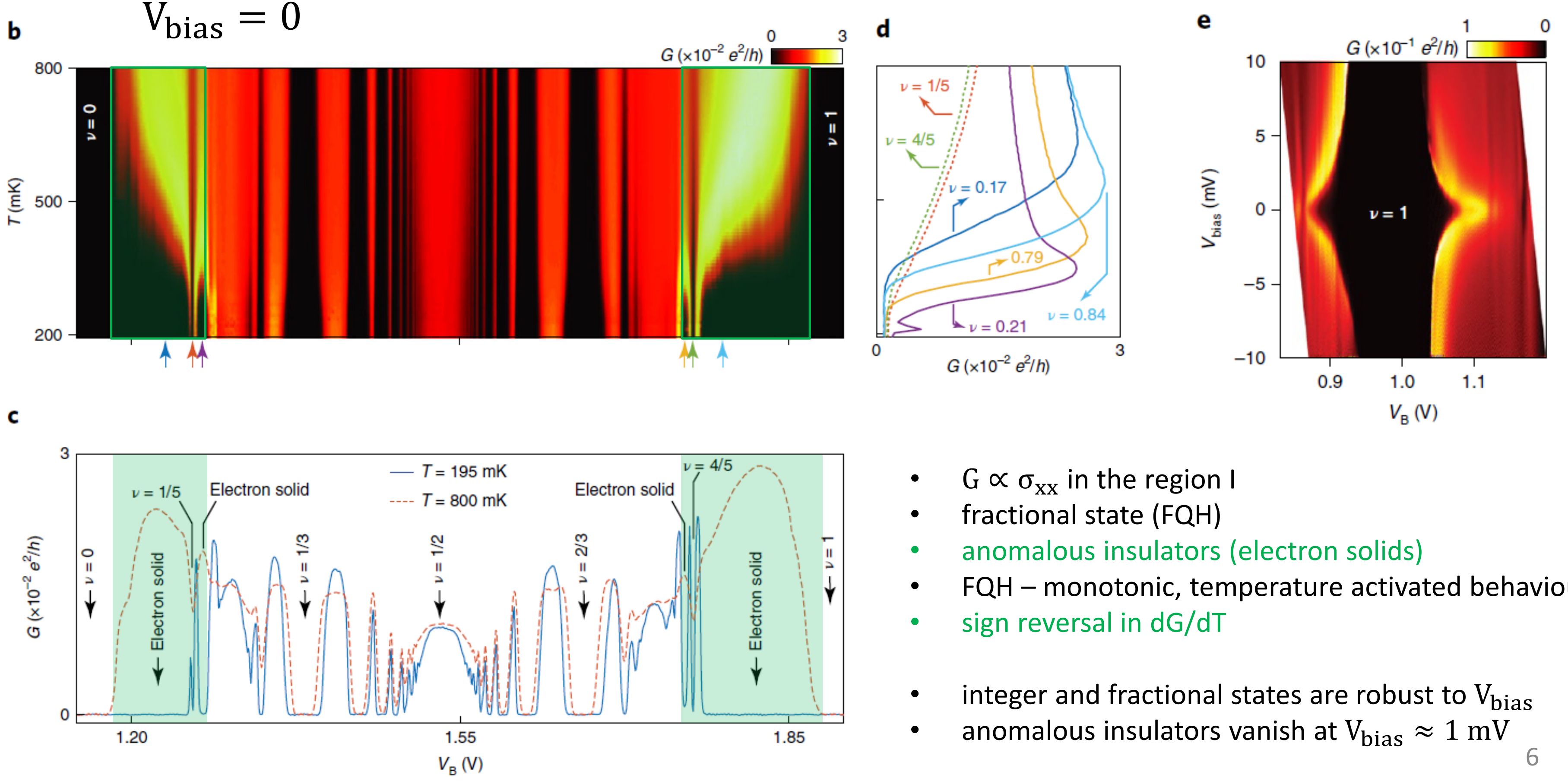




- $G \propto \sigma_{xx}$ in the region I
- fractional state (FQH)
- anomalous insulators (electron solids)
- FQH – monotonic, temperature activated behaviour
- sign reversal in dG/dT

Electron solid phase

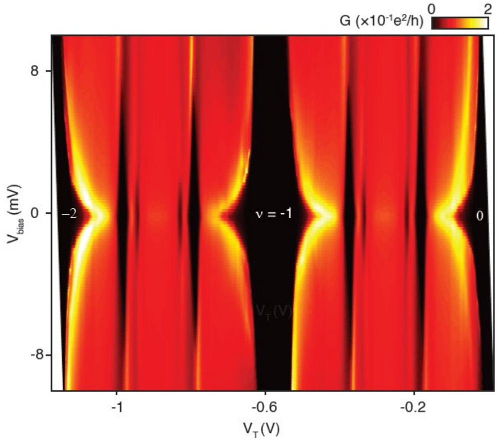
$V_{bias} = 0$

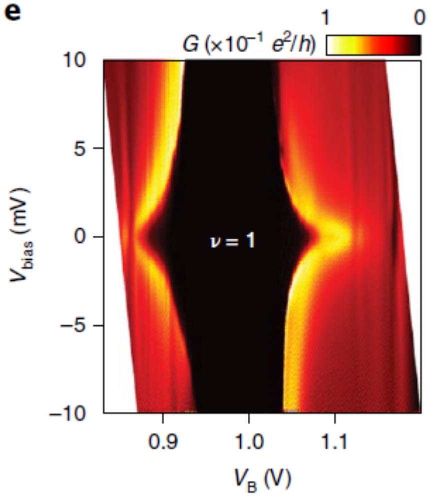


- $G \propto \sigma_{xx}$ in the region I
- fractional state (FQH)
- anomalous insulators (electron solids)
- FQH – monotonic, temperature activated behaviour
- sign reversal in dG/dT

- integer and fractional states are robust to V_{bias}
- anomalous insulators vanish at $V_{bias} \approx 1$ mV

Electron solid phase





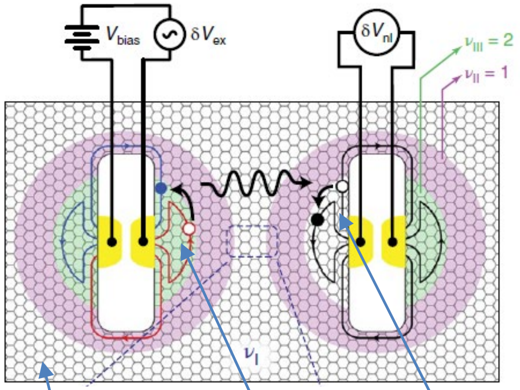
$$E_Z = g\mu_B B_T$$

$$E_X = \sqrt{\frac{\pi}{2}}\frac{e^2}{\epsilon\, l_B}$$

$$l_B = (eB_\perp/\hbar)^{-1/2}$$

- electron solids proximal to $\nu = \pm 2,\ \ \nu = \pm 1,\ \ \nu = 0$
- only quantitative differences in electrical transport
- originate from quasiparticles with different spin textures
  - near $\nu = \pm 2$: solidification of bate electrons or holes, ferromagnetic ground state, exchange interaction is weaker than T → paramagnetic state
  - near $\nu = 0$: depend on the ground state, non-collinear or paramagnetic
  - near $\nu = \pm 1$: charge excitations are spin reversals, nature depends on $\kappa = \frac{E_Z}{E_X}$
    - large κ: single branch polarized solid
    - small κ: excitations are skyrmions, long-wave non-colinear spin texture

Magnon transport



magnon launcher

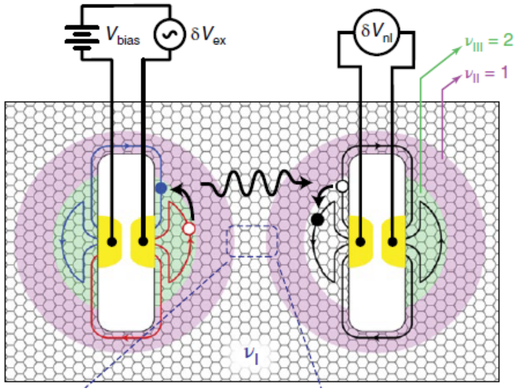
magnon detector

electrically insulating $\nu = 1$ region

δV_{nl} can be suppressed by:

- absence of compatible neutral modes in region I
- presence of additional magnon decay channels

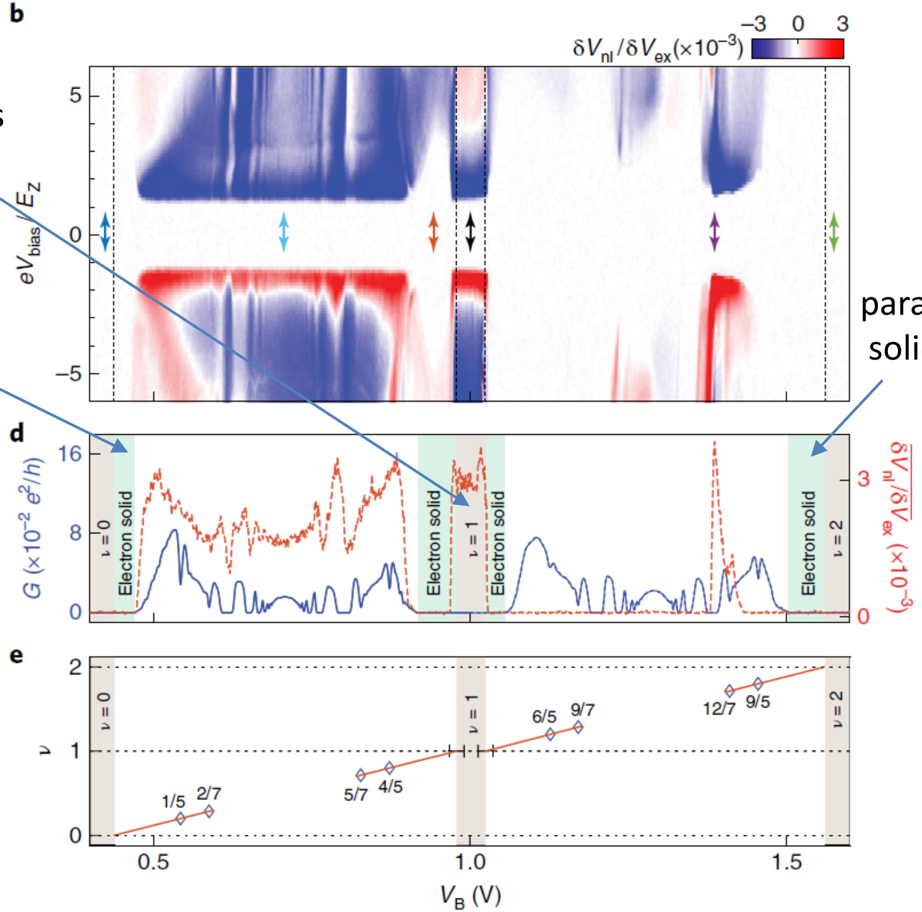
Magnon transport



QHFM conducts magnons

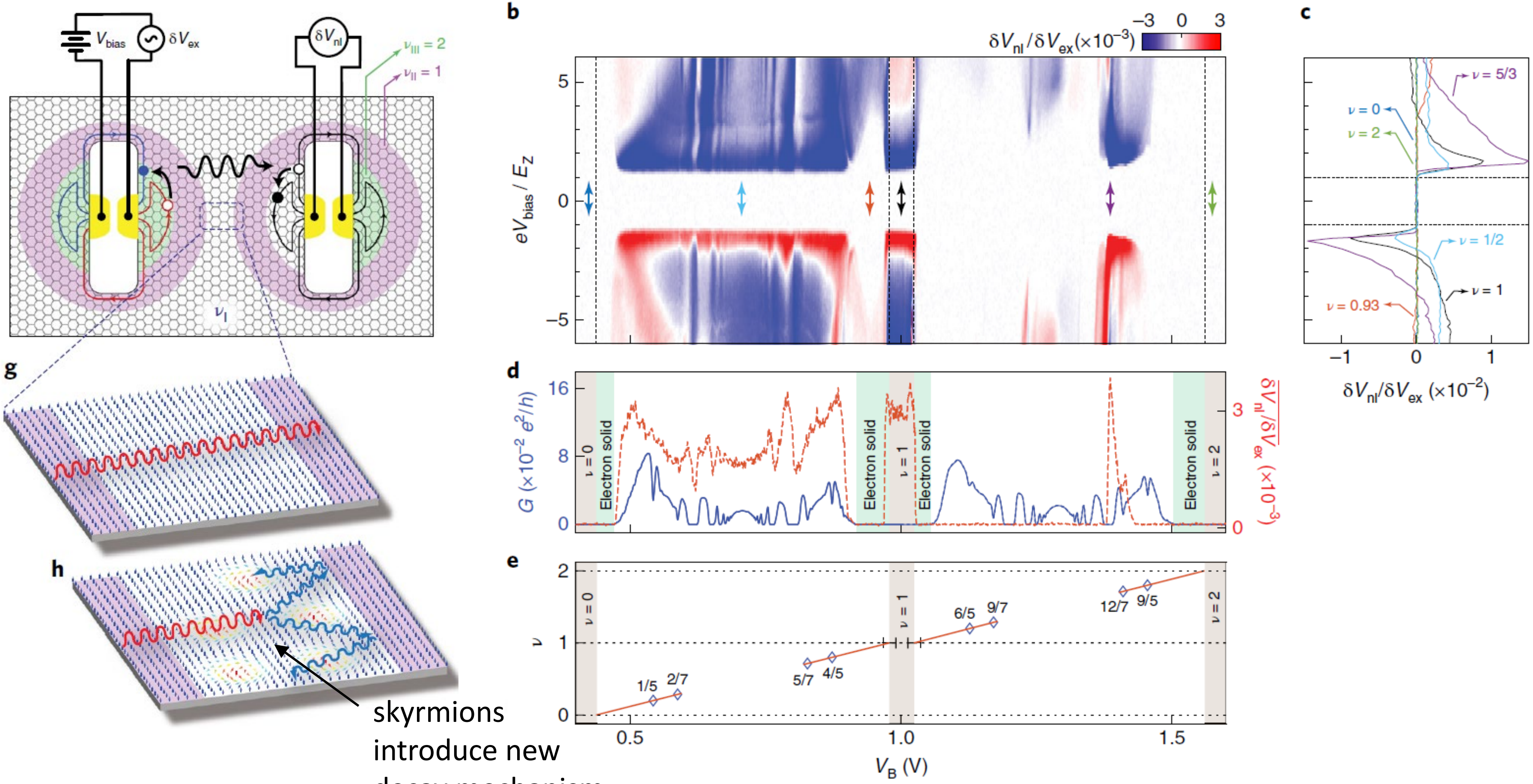
non-colinear or paramagnetic solid

paramagnetic solid



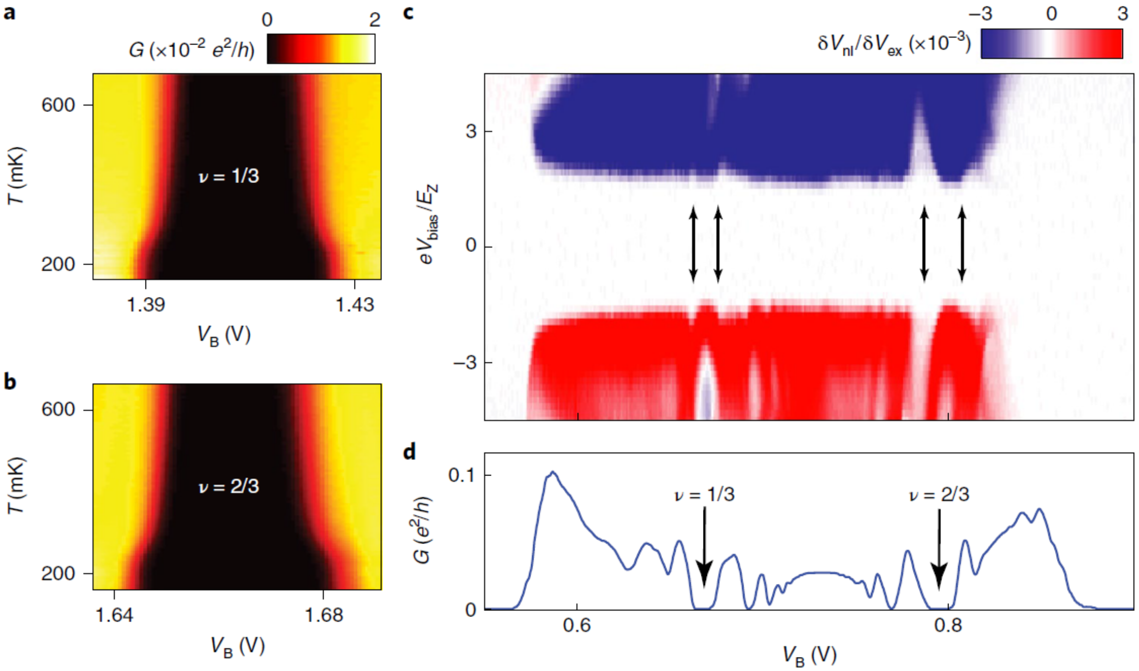
- $\delta V_{nl} = 0$ for $eV_{bias} < E_Z$
  indicating magnon transport
- no non-local response in the non-magnetic $\nu = 2$ or $\nu = 0$
- strong response at $\nu = 1$ or $\nu = \frac{5}{3}$
  fully spin-polarized states, QHFM
- compare $0 < \nu < 1$ and $1 < \nu < 2$
- electron solids suppers magnon transport

Magnon transport



skyrmions
introduce new
decay mechanism

Fractional skyrmion solid phase



- predicted in vicinity of FQH states
- low $\mathrm{V_{bias}}$ threashold
- lower temperatures – additional spin-textured phases

Conclusion

- electron solids that suppress magnon propagation
- fractional solids
- show how to map-out interacting phase diagram