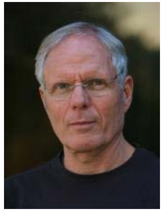

Moty Heiblum

ARTICLE

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Observation of half-integer thermal Hall conductance

Mitali Banerjee[1], Moty Heiblum[1*], Vladimir Umansky[1], Dima E. Feldman[2], Yuval Oreg[1] & Ady Stern[1]

2018

Quantum Limit of Heat Flow Across a Single Electronic Channel

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DOI: 10.1126/science.1241912

2013

Taras Patlatiuk

13.07.2018

Motivation

- non-Abelian sates of matter
- Topological quantum computation

Motivation

Topological states

topological invariants = quantized physical quantities

Electrical Hall conductance

fractional charge, anyonic statistic

✓ Abelian

? non-Abelian

$$|\psi_1\psi_2\rangle = e^{i\theta}\,|\psi_2\psi_1\rangle$$

$$|\psi_1\psi_2\rangle \neq e^{i\theta}\,|\psi_2\psi_1\rangle$$

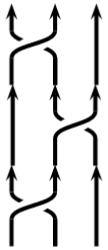
3D: fermions (-1) or bosons (1)

2D: anyons ($e^{i\theta}$)

Thermal Hall conductance

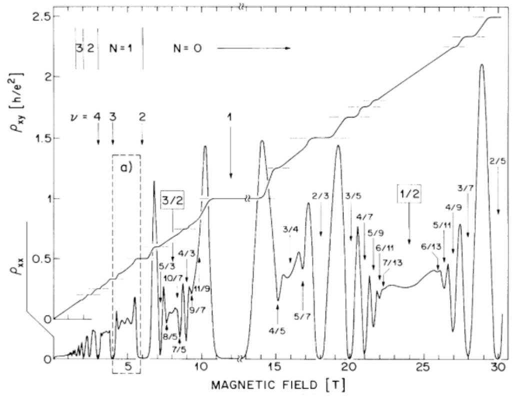
non-Abelian state, $\nu = 5/2$

degenerate ground state



= topological quantum computation

$\nu = 5/2$ background



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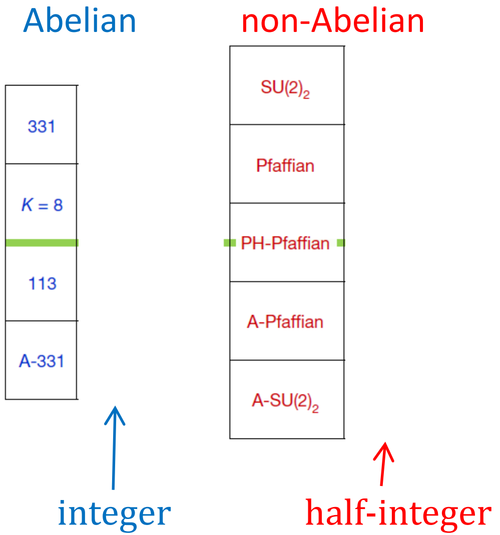
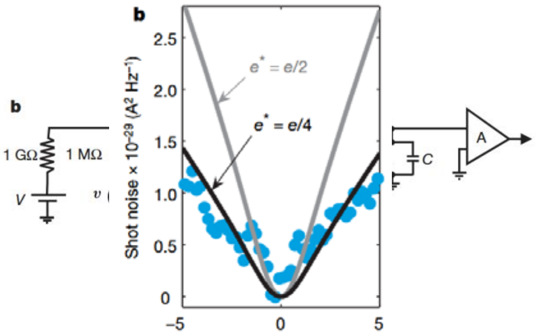
Nonabelions in the fractional quantum Hall effect

G. Moore, N. Read
Nucl. Phys. B **360**, 362–396 (1991)



Quasiparticle charge e/4



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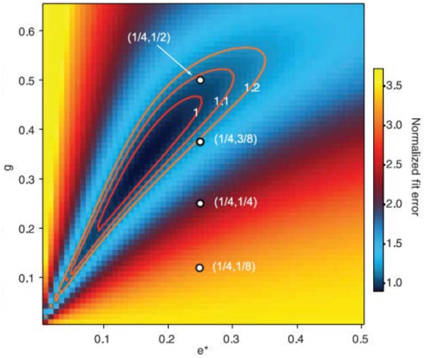
Quasiparticle charge e/4



Radu et al. Science **320**, 899–902 (2008)

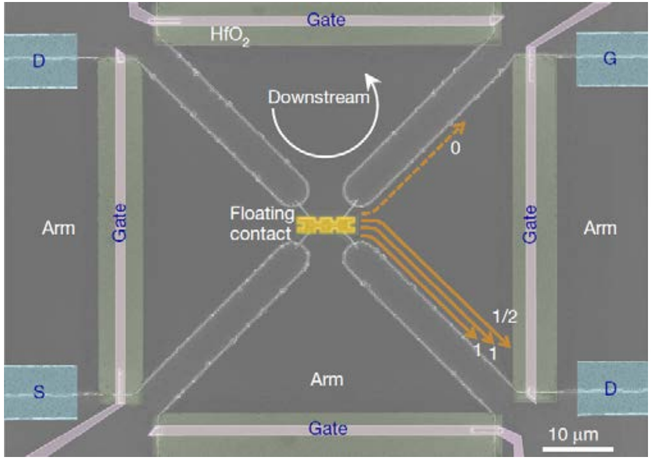
K/κ_0

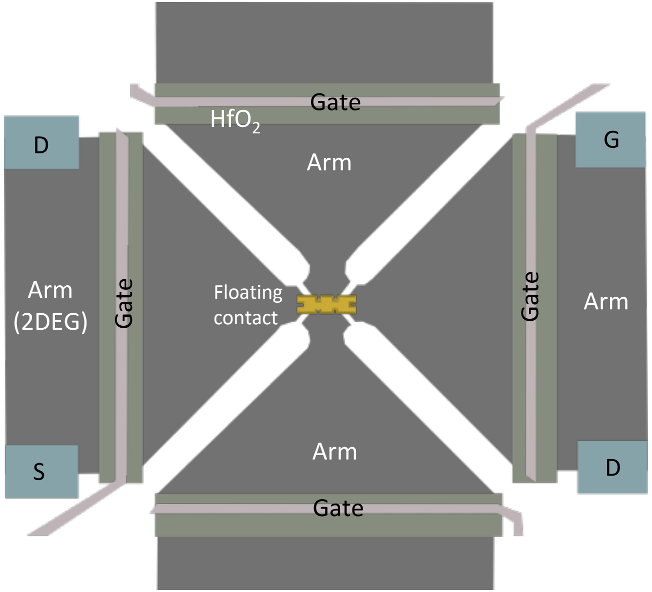
K - thermal conductance

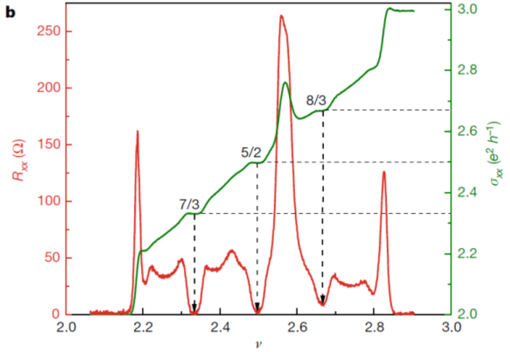
$$\kappa_0 = \pi^2 {k_B}^2/(3h)$$
$$dJ_Q/dT = KT$$

J_Q - heat current

Device



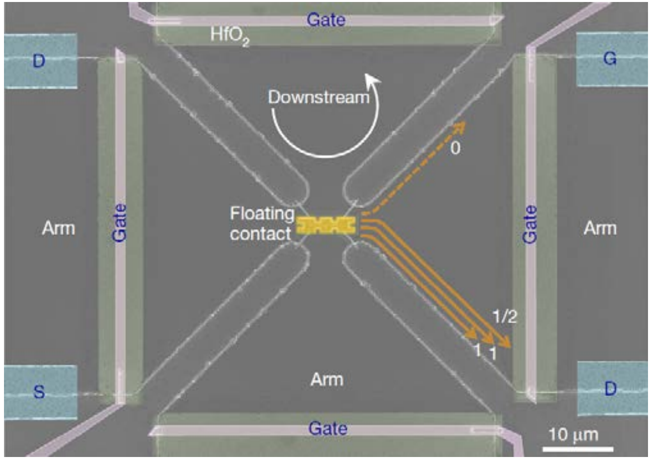


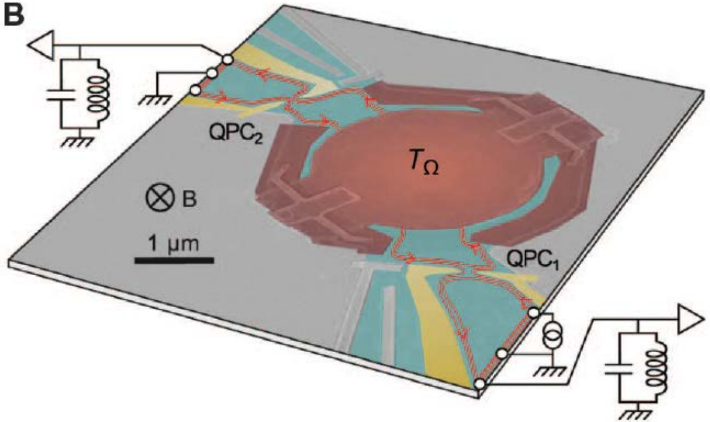


- GaAs/AlGaAs heterostructure
- $\mu = 20 \times 10^6 \ cm^2 V^{-1} s^{-1}$
- $n = 2.8 \times 10^{11} \ cm^{-2}$
- $T < 50 \, mK$

Experiment

Jezouin at al. Science **342**, 601–604 (2013)

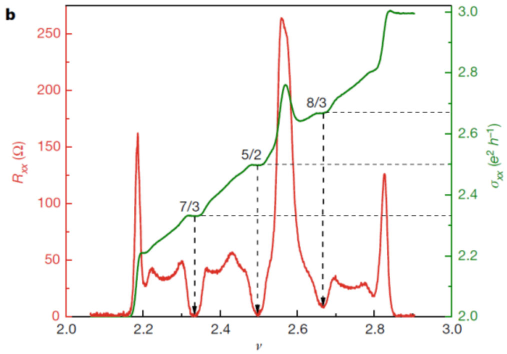




$\nu = 5/2, \quad 7/3, \quad 8/3$

Continuous gate vs QPC

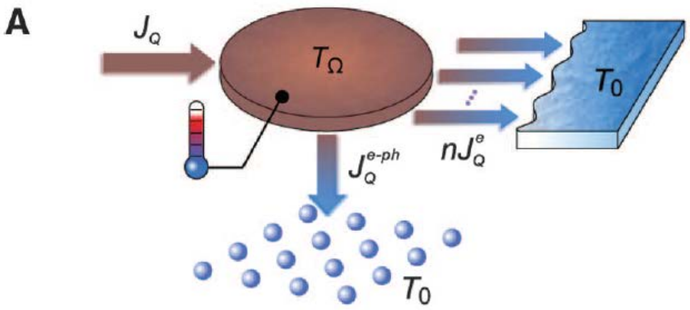
$\nu = 3, \quad 4$



Heat model

Jezouin at al. Science **342**, 601–604 (2013)

Heat balance: $J_Q = nJ_Q^e(T_\Omega, T_0) + J_Q^{e\text{-}ph}(T_\Omega, T_0)$

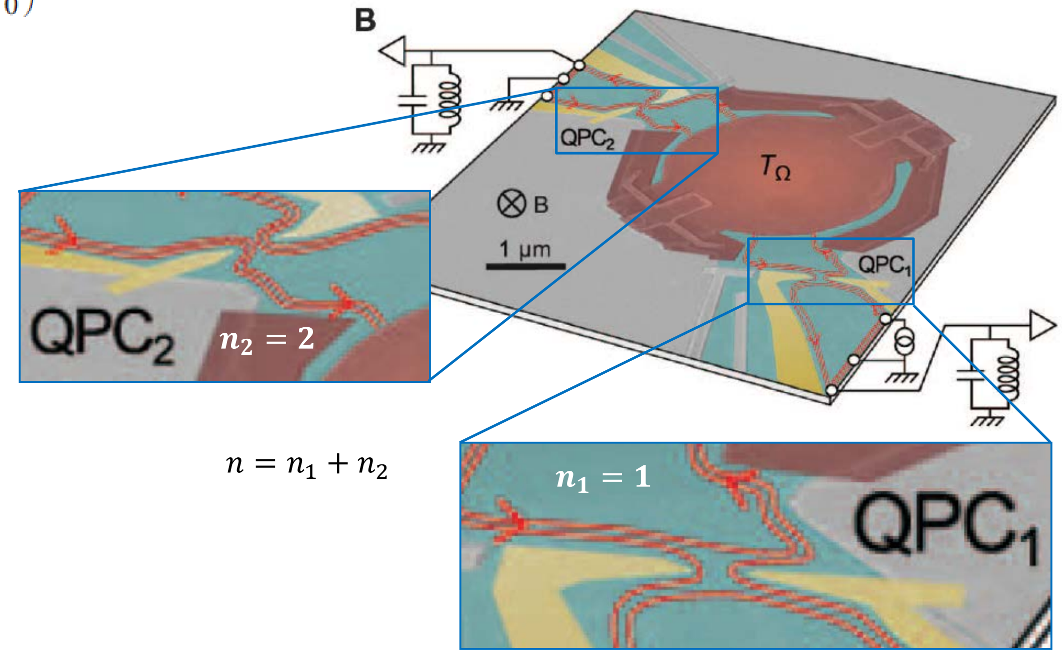


- J_Q - Joule power
- $J_Q{}^{e-ph}$ - electron-phonon cooling
- $nJ_Q{}^e$ - across n ballistic quantum channels

$$J_Q = \frac{1}{2}\frac{G_e V_{DC}^2}{1/n_1 + 1/n_2} \qquad V_{DC} = I_{DC}/\nu G_e$$

$$J_Q^{e\text{-}ph}(T_\Omega, T) = \Sigma\Omega(T_\Omega^5 - T_0^5)$$

$$J_Q^e(T_\Omega, T_0) = \frac{\pi^2 k_B^2}{6h}(T_\Omega^2 - T_0^2)$$

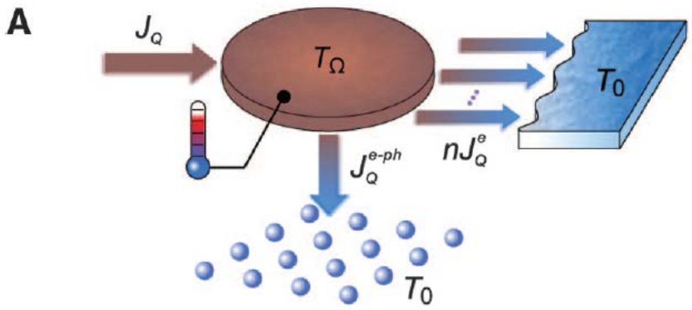


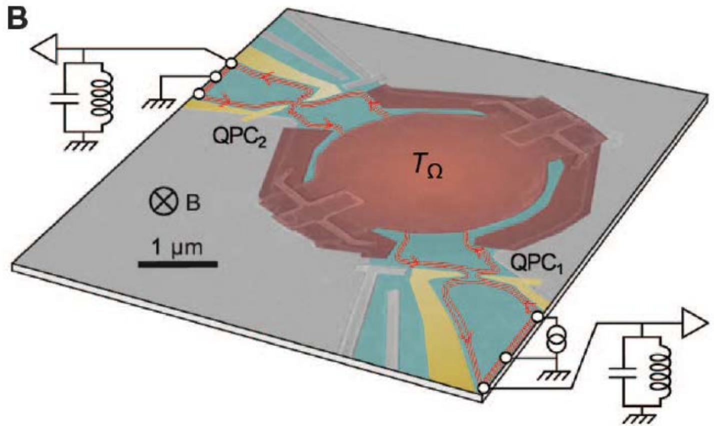
$n = n_1 + n_2$

Heat model

Heat balance: $J_Q = nJ_Q^e(T_\Omega, T_0) + J_Q^{e\text{-}ph}(T_\Omega, T_0)$

Jezouin at al. Science **342**, 601–604 (2013)





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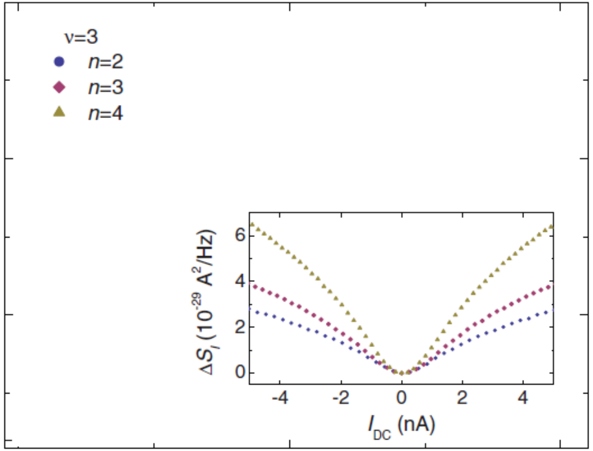
Measere T_Ω using
excess current noise spectral density

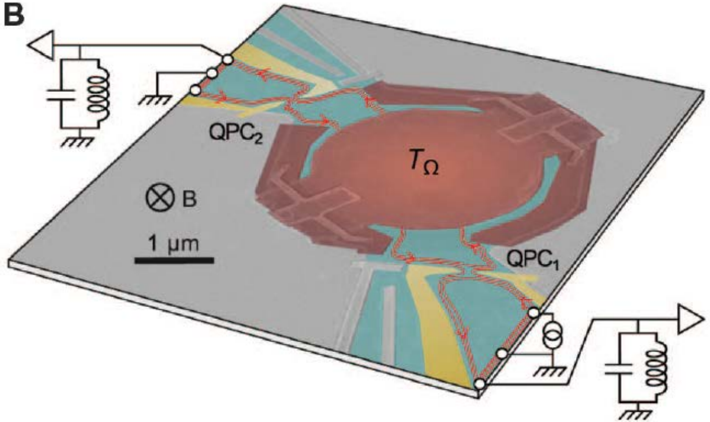
$$\Delta S_I = 2k_B(T_\Omega - T_0)\frac{G_e}{1/n_1 + 1/n_2}$$

Temperature measurements

Jezouin at al. Science **342**, 601–604 (2013)

Heat balance: $J_Q = nJ_Q^e(T_\Omega, T_0) + J_Q^{e\text{-}ph}(T_\Omega, T_0)$





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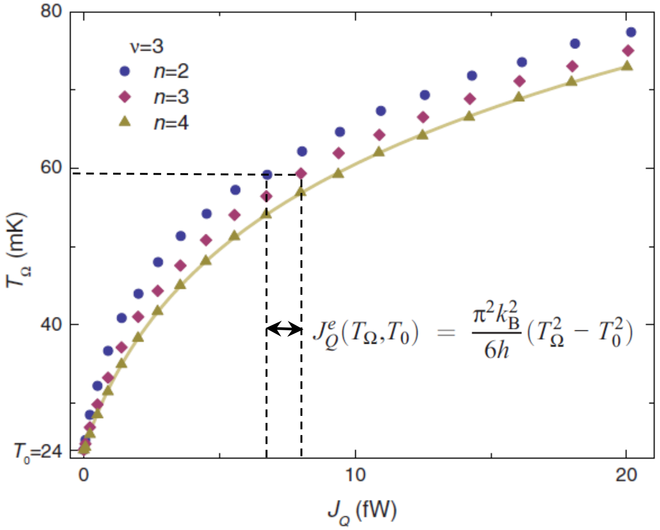
Measere T_Ω using
excess current noise spectral density

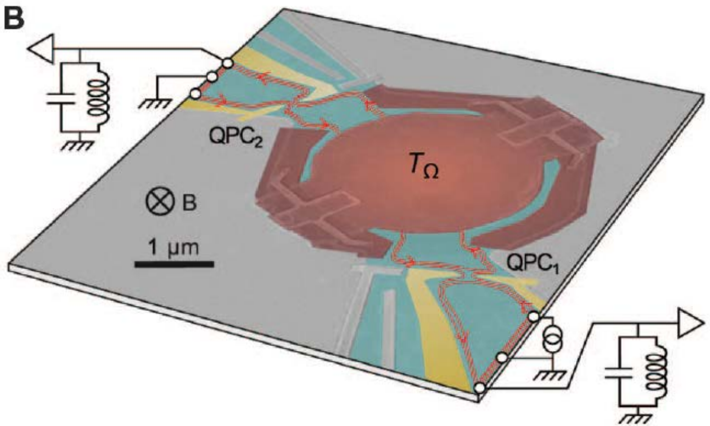
$$\Delta S_I = 2k_B(T_\Omega - T_0)\frac{G_e}{1/n_1 + 1/n_2}$$

Single heat channel

Jezouin at al. Science **342**, 601–604 (2013)

Heat balance: $J_Q = nJ_Q^e(T_\Omega, T_0) + J_Q^{e\text{-}ph}(T_\Omega, T_0)$





$n = n_1 + n_2$

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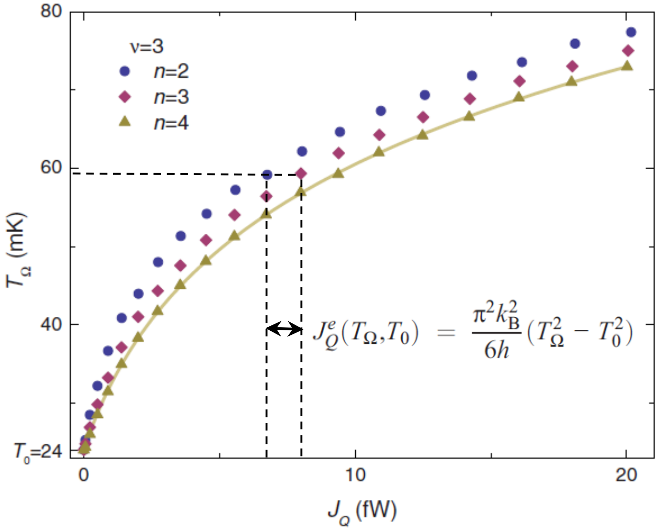
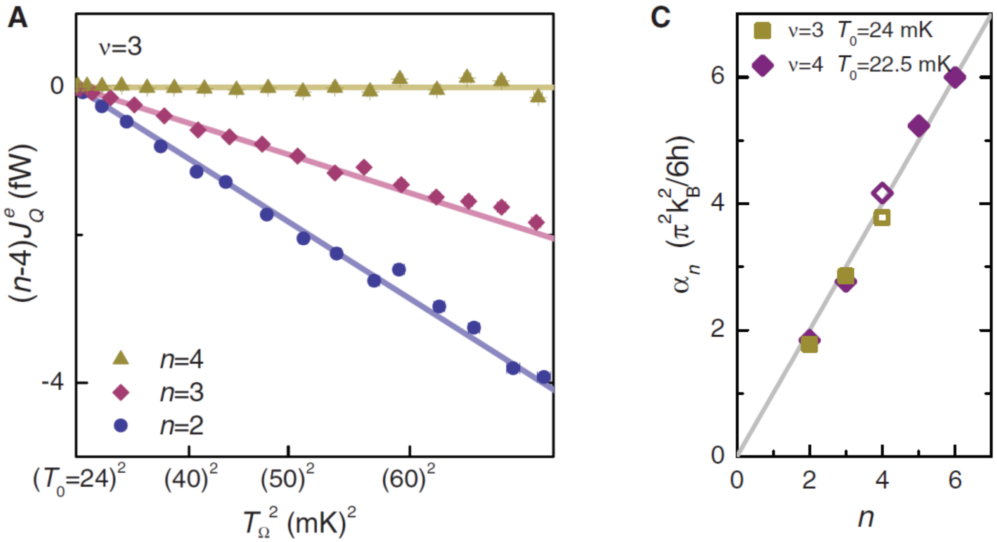
Measere T_Ω using
excess current noise spectral density

$$\Delta S_I = 2k_B(T_\Omega - T_0)\frac{G_e}{1/n_1 + 1/n_2}$$

Conductance heat quantum

Heat balance: $J_Q = nJ_Q^e(T_\Omega, T_0) + J_Q^{e\text{-}ph}(T_\Omega, T_0)$





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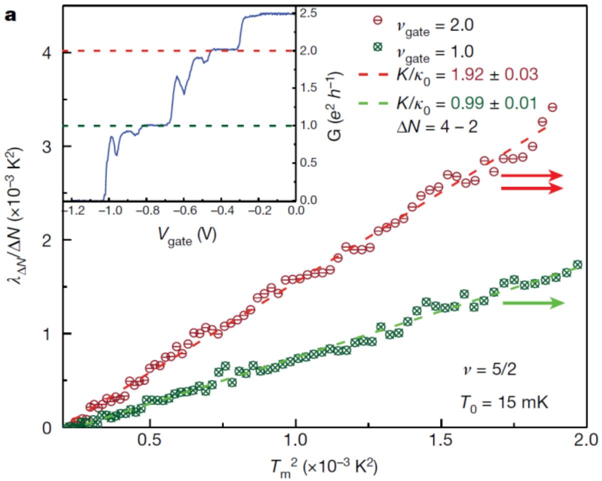
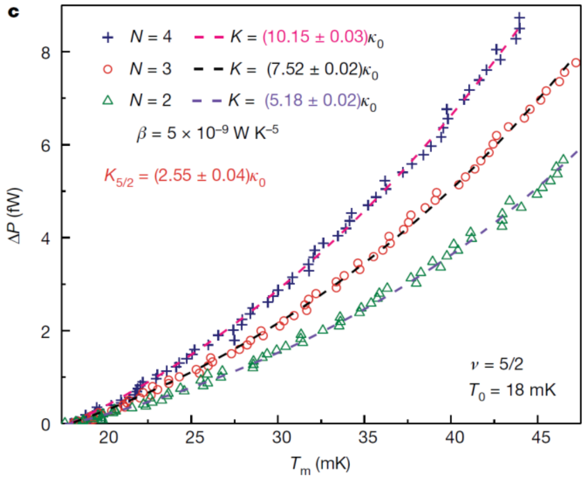
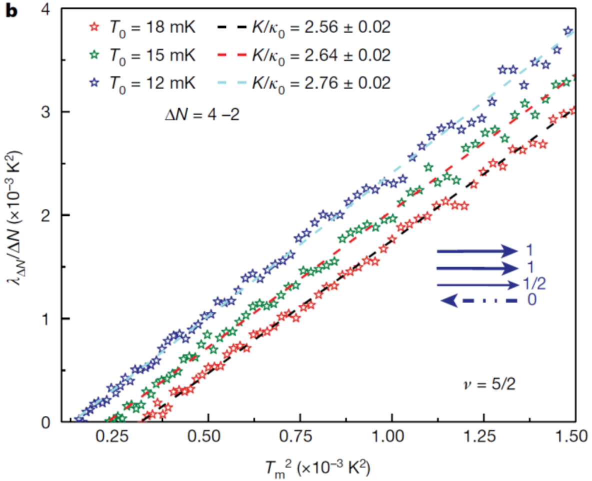
Measere T_Ω using
excess current noise spectral density

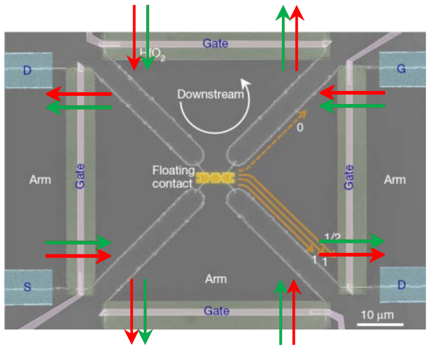
$$\Delta S_I = 2k_B(T_\Omega - T_0)\frac{G_e}{1/n_1 + 1/n_2}$$

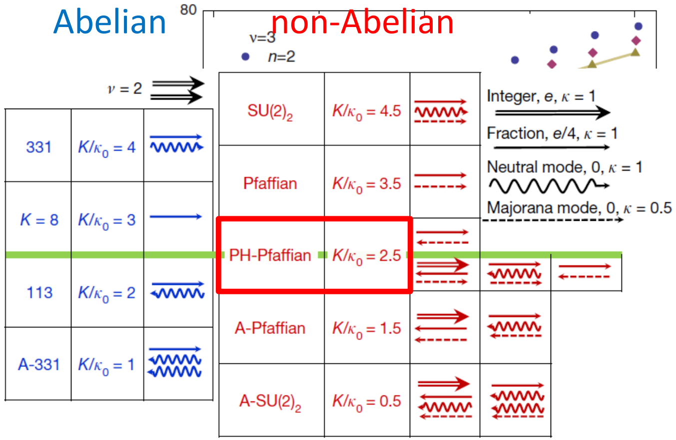
ν = 5/2 heat conductance

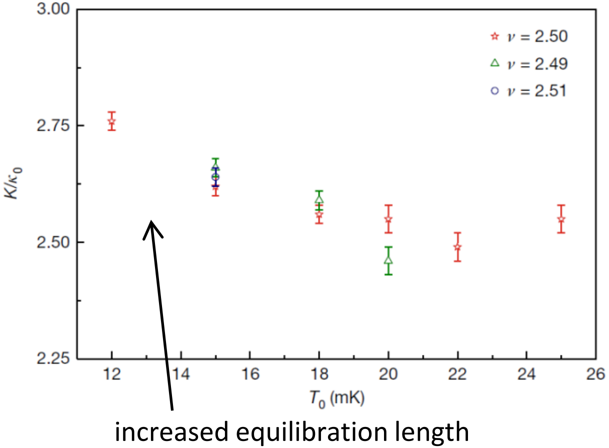




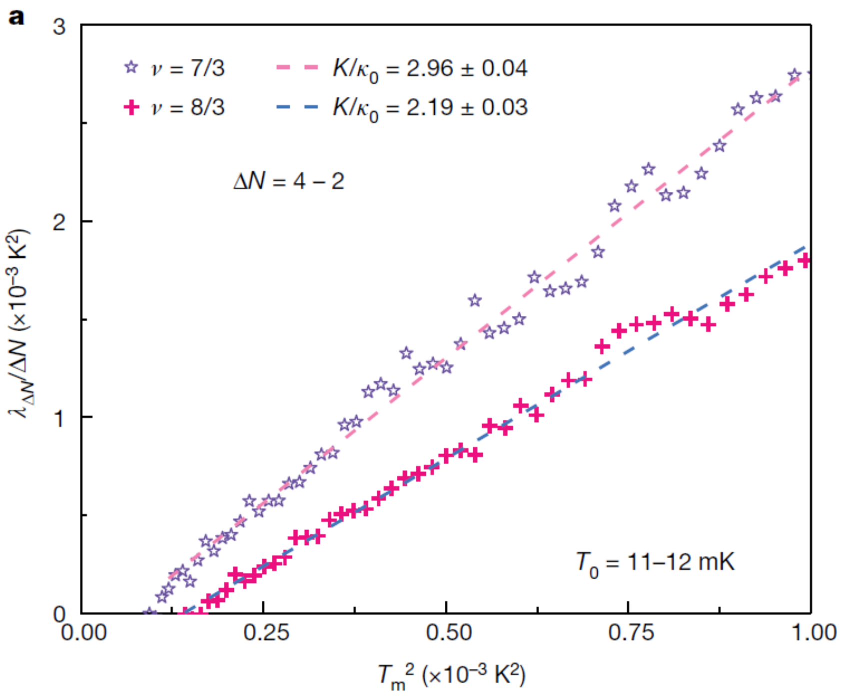


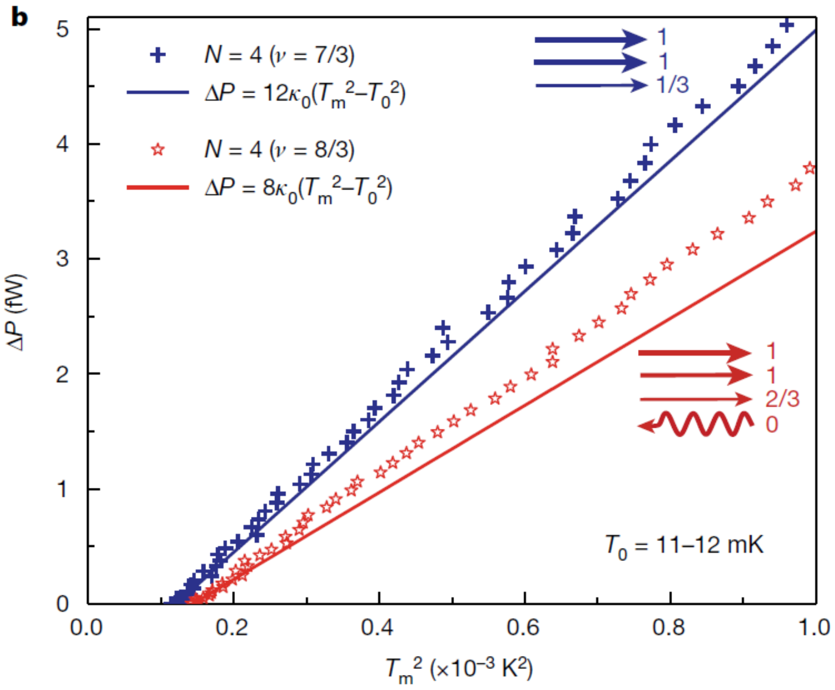






$\nu = 7/3, \;\; 8/3$





Above 30 mK

- phonon contribution
- non-equilibrated heat transport
- bulk transport, $R_{xx} \neq 0$

Conclusion

- $\nu = 5/2$ particle-hole Pfaffian liquid
- non Abelian state, K fractional