Frontiers in Thermal Transport and Energy Conversion

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Plan for the Discussion Time

- 25 minutes - Talk & Summary
- 15 minutes - Panel Discussion
- 50 minutes - Questions and Discussion

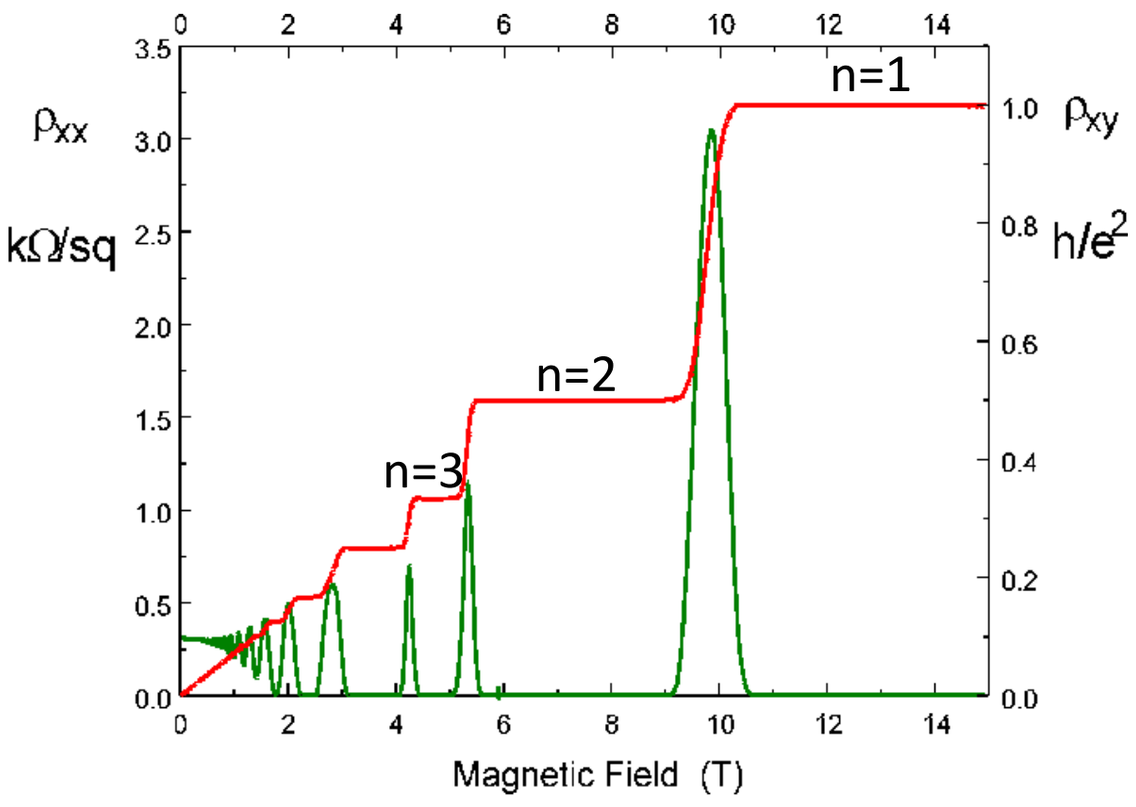
Summary

- Heat transport & Thermoelectric probes of exotic phases:
    - Quantum Spin Liquids [Savary, Ong]

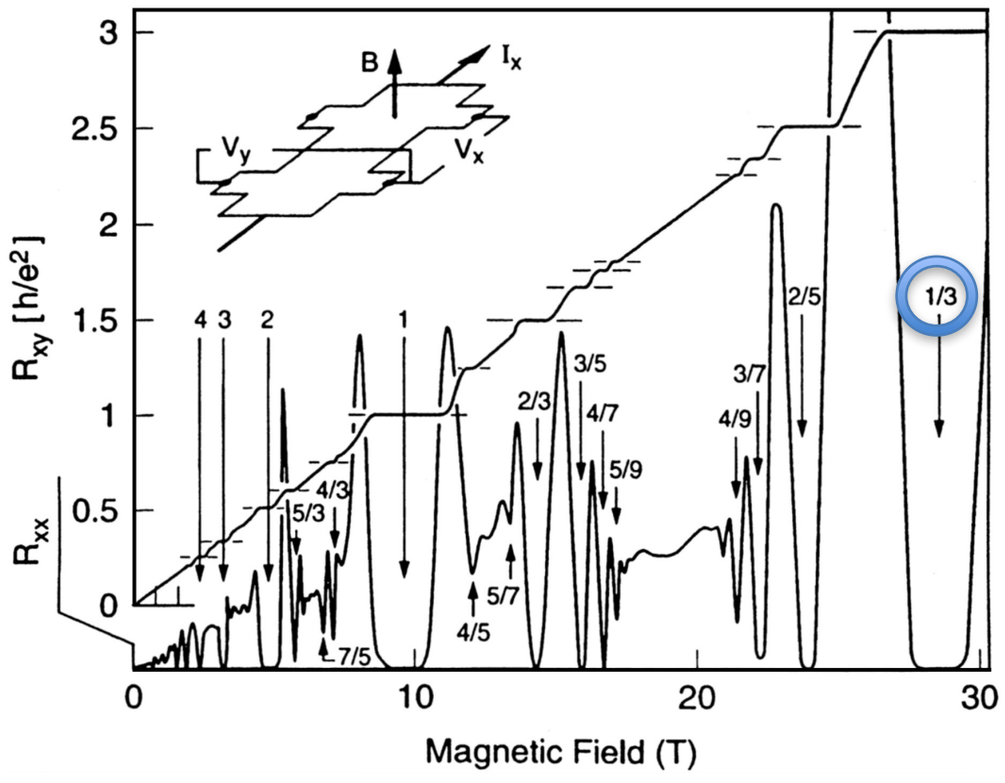
Thermal Transport
Probe of Topological Orders:
"Dark Matter" of Condensed Matter

- Quantum Spin Liquids [Savary, Ong] -> Quantum Hall

Integer Quantum Hall (1980)

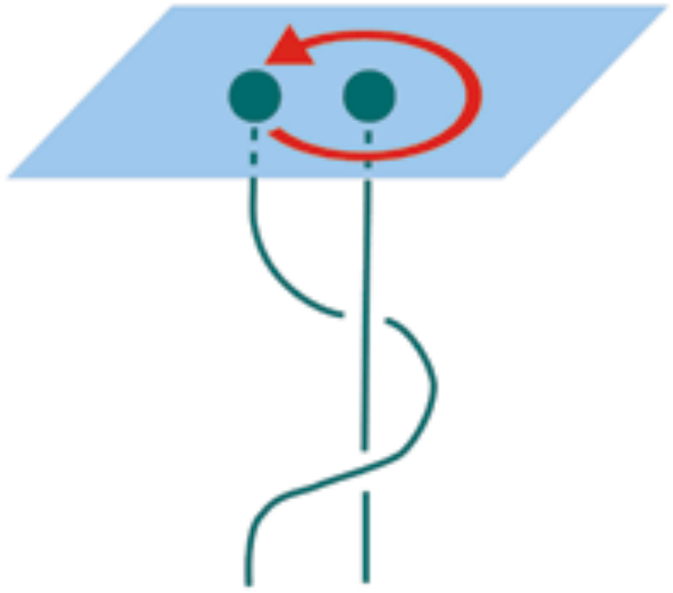


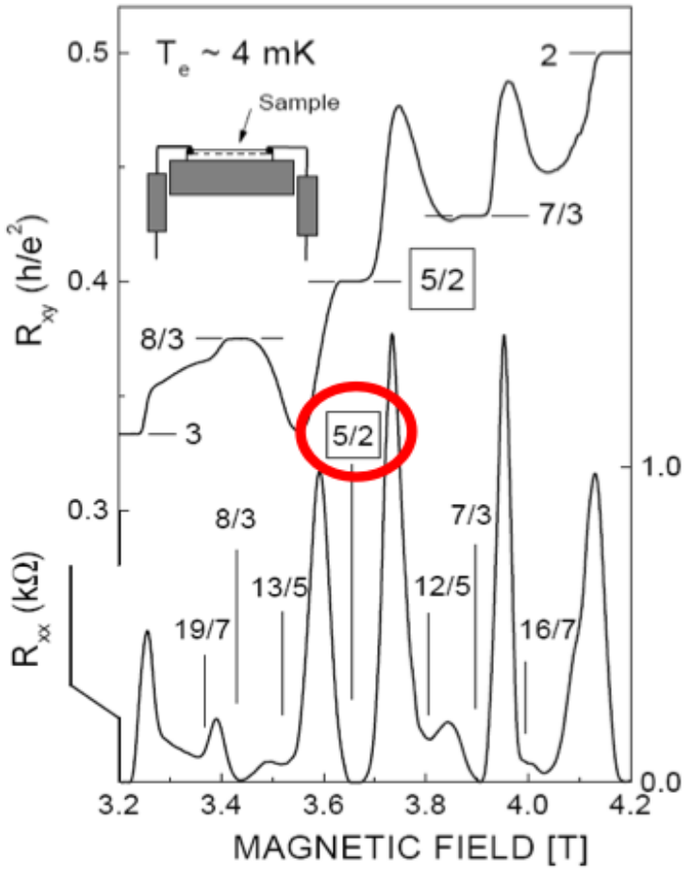
Fractional Quantum Hall



$$\sigma_{xy} = n\sigma_o \qquad \kappa_{xy} = m\kappa_o \qquad \sigma_{xy} = \frac{p}{2q+1}\sigma_o$$

Non Abelian Quantum Hall States





Pan et al. PRL 83, (1999)

Non-Abelian quasiparticles:
Excitations creates new ground states.

$$e^{i\phi} \rightarrow U_{12}$$

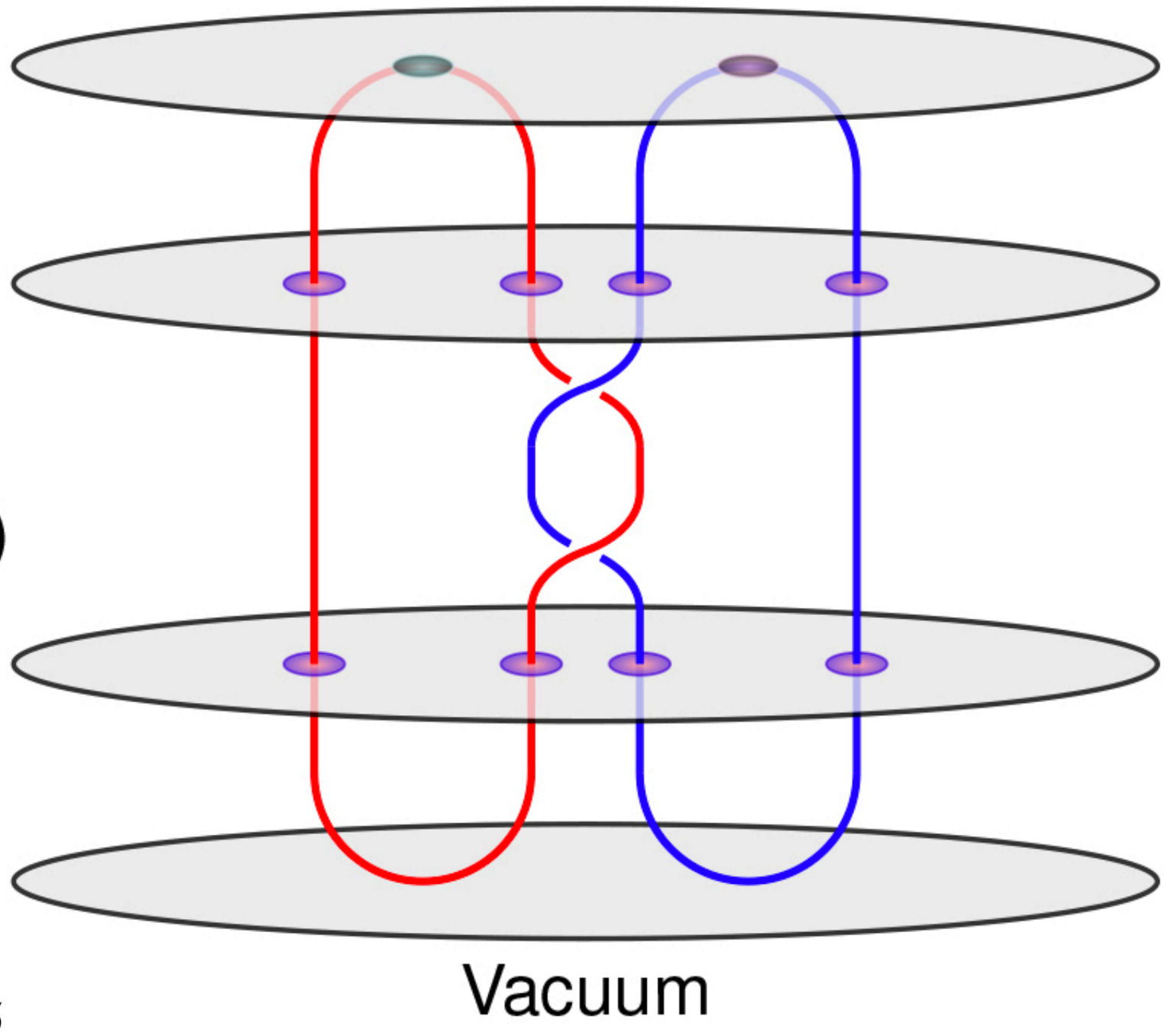
- **Pfaffian state - NonAbelian phase.** $\nu = 5/2$**.** [Read, Moore, Wilczek, Wen, Greiter]

$$\kappa_{xy} = (m + \frac{1}{2})\kappa_o$$

Non-Abelian States: Topologically Protected Quantum Computing

Computation | **Physics**

Output — Measure (fusion)



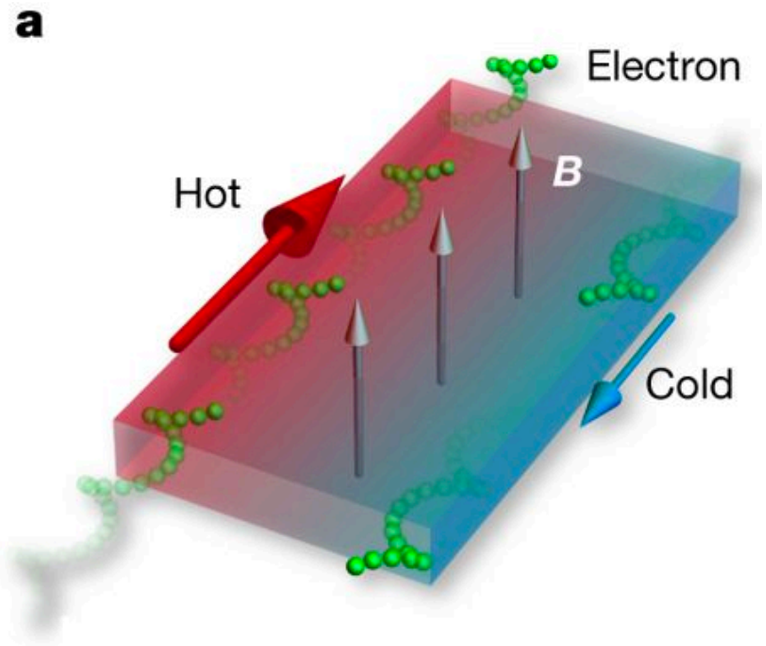
Compute (apply gates) — Braid anyons

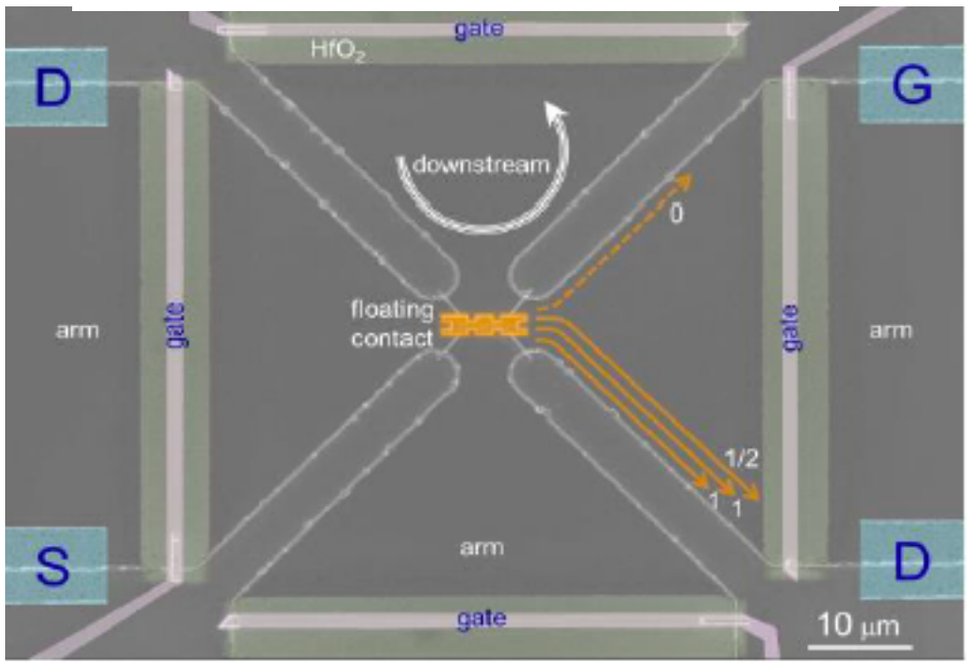
Initialize — Create anyons

Vacuum

$\nu = 5/2$ and $\nu = 12/5$

Signature of Non-Abelian Topological Phase





Banerjee, Heiblum… Nature (2018)

$$\kappa_{xy} = (m + \frac{1}{2})\kappa_o$$

ν	predicted K	measured $\lvert K \rvert$
2	$2 = 2 - 0$	$1.96 \pm .06$
1	$1 = 1 - 0$	$.90 \pm .09$
1/3	$1 = 1 - 0$	$1.00 \pm .045$
2/3	$0 = 1 - 1$	$0.328 \pm .024$ See text
3/5	$-1 = 1 - 2$	$1.040 \pm .041$
4/7	$-2 = 1 - 3$	$2.045 \pm .052$
7/3	$3 = 3 - 0$	$2.86 \pm .03$
8/3	$2 = 3 - 1$	$2.11 \pm .01$

A Puzzle

- Two leading theory candidates - Pfaffian and anti-Pfaffian
- Expect either 7/2 or 3/2 respectively [NOT 5/2!]
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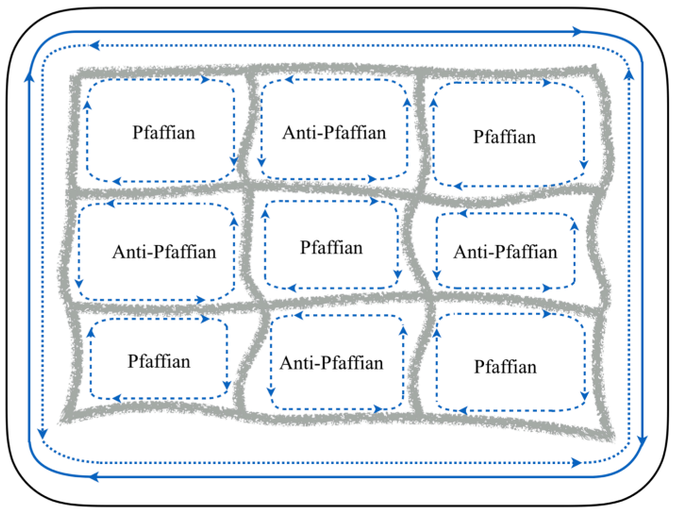
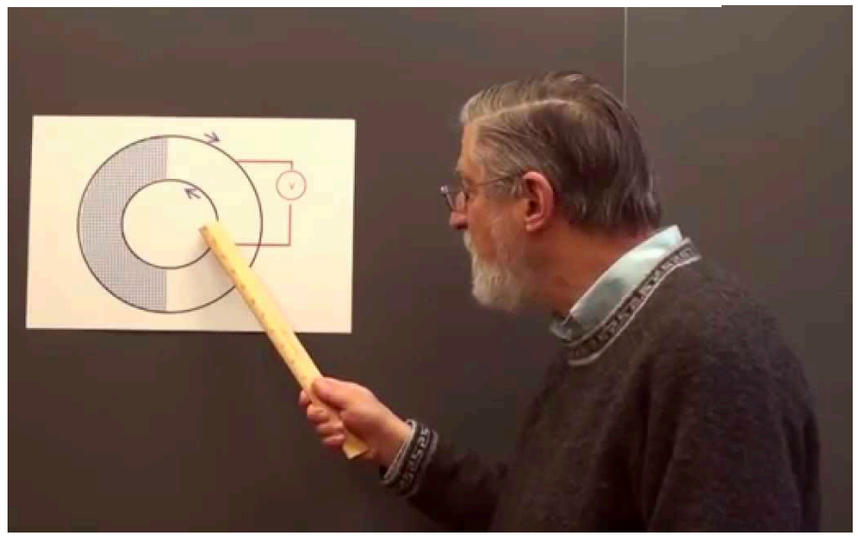




Chong Wang, A. V. & B. I. Halperin, arXiv: 1711.11557

Thermoelectric Probes of the Half Filled (n=1/2) Landau Level

- Thermoelectric probe of `Dirac' Composite Fermions [D.T.Son, PRX'15]

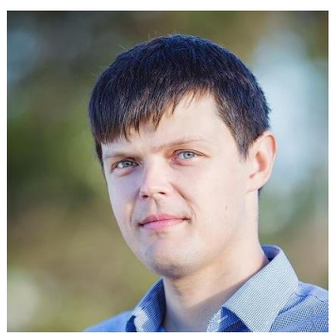
$$\vec{E} = \hat{S} \cdot \vec{\nabla} T$$

Potter,Serbyn,AV Phys. Rev. X (2016)

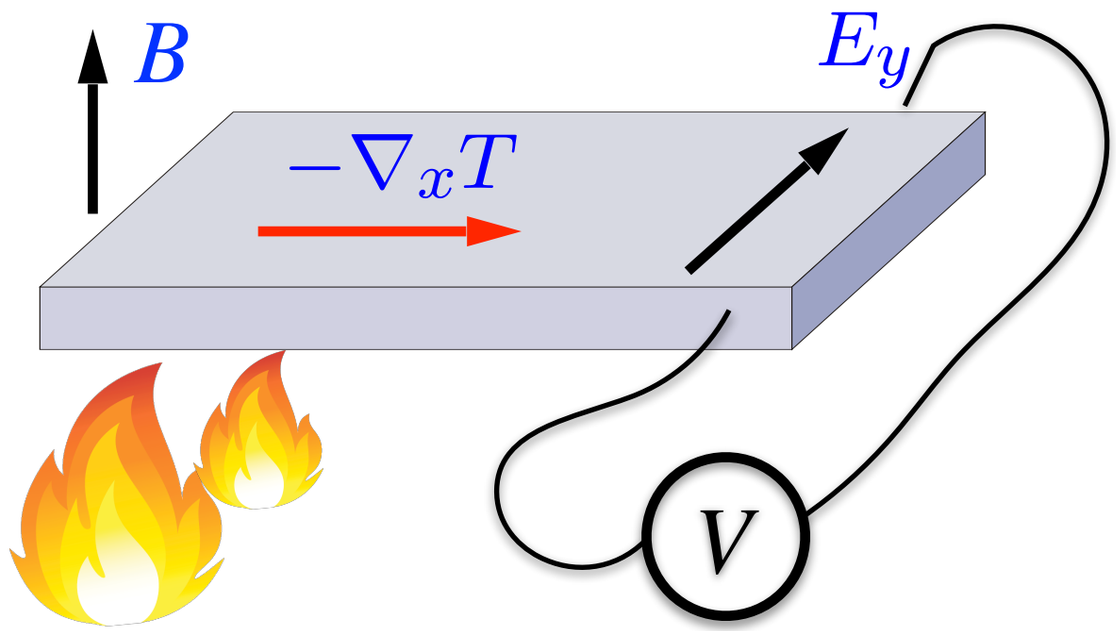
- S_{xx}: thermopower
- S_{xy}: Nernst effect

$$\frac{S_{xy}}{S_{xx}\sigma_{xx}} = 2\frac{h}{e^2}$$

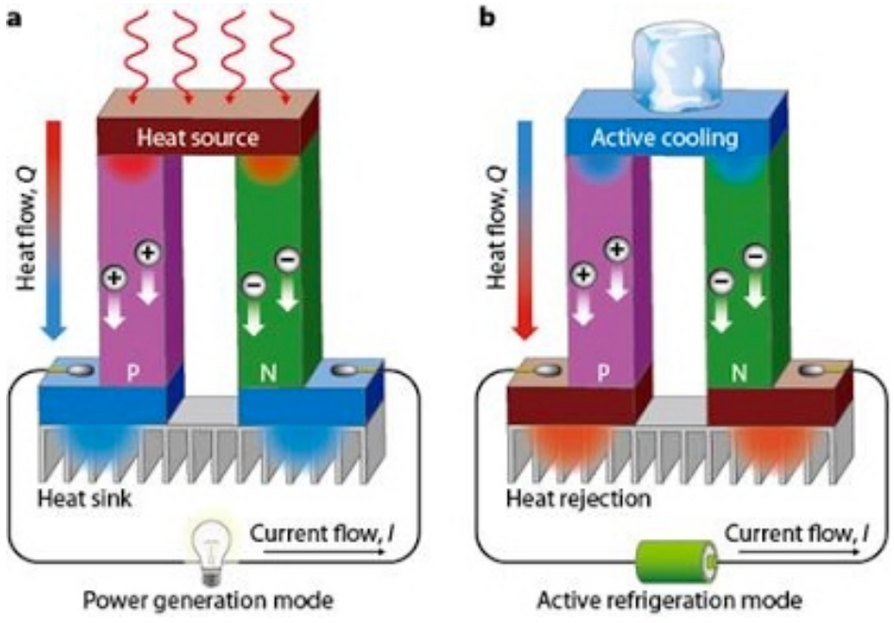
Drew Potter
(UTAustin)

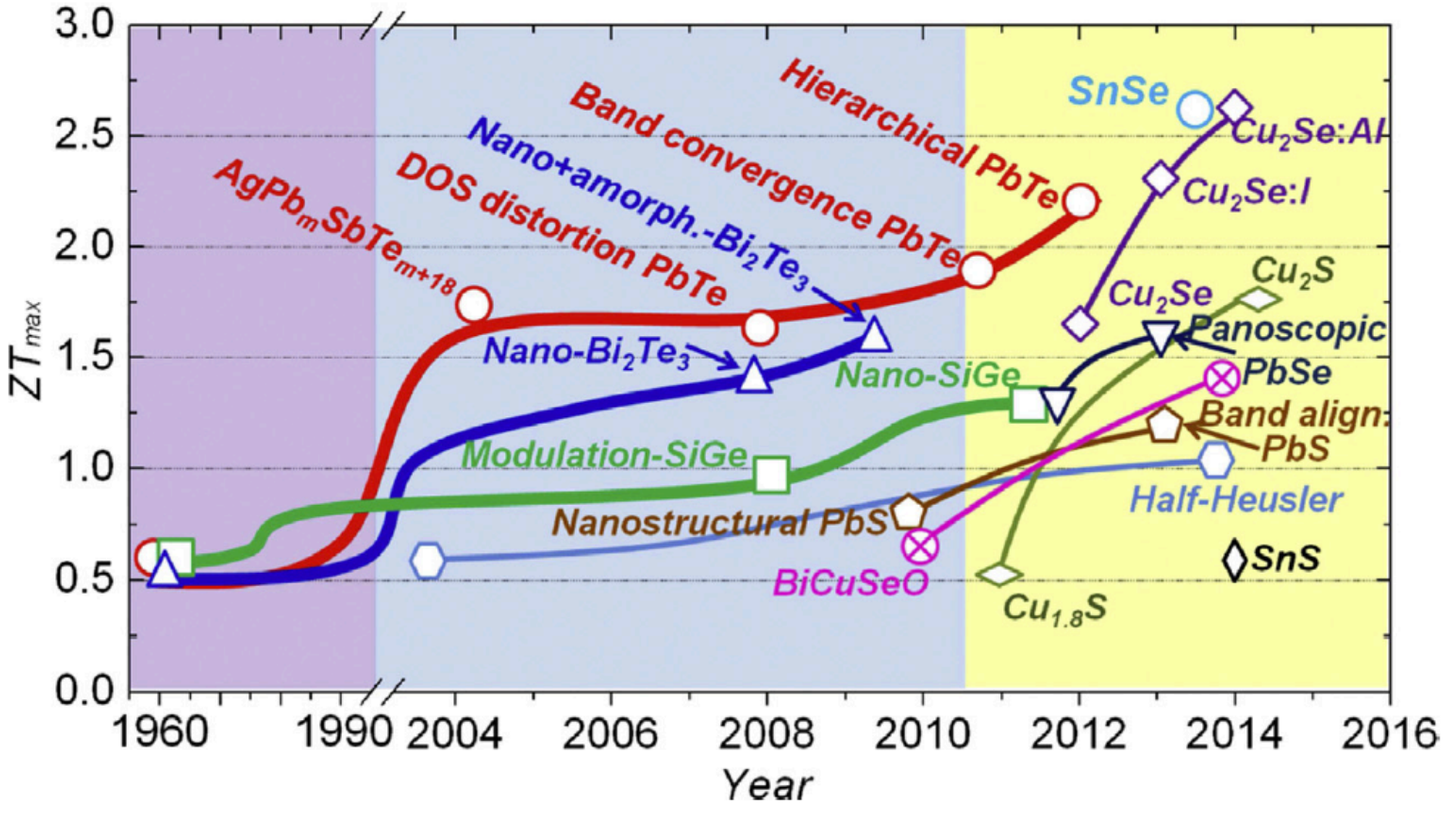


Maksym Serbyn
(IST Austria)



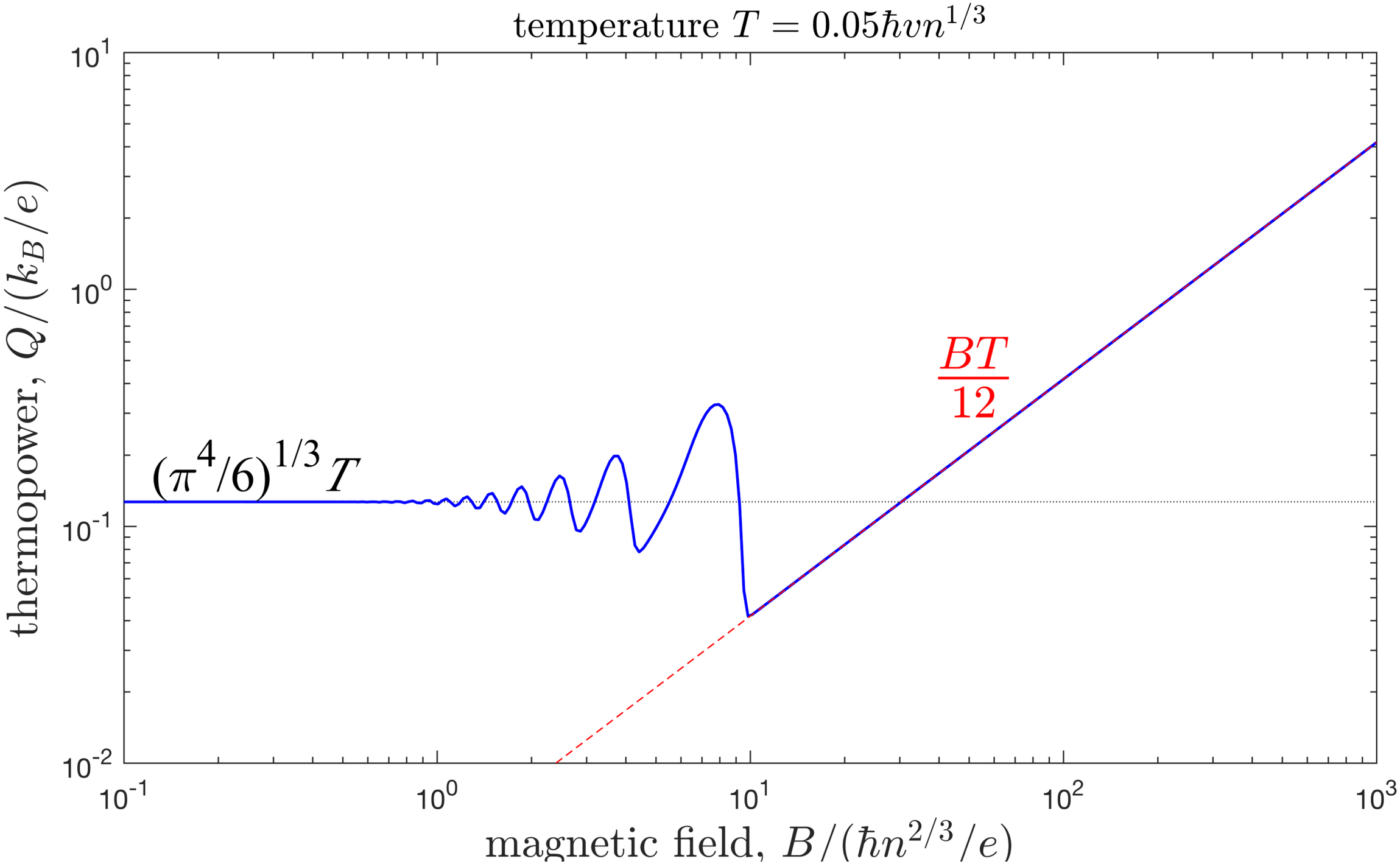
Other Topics: Thermoelectric Properties of Nodal Semimetals





Generally, nodal semimetals poor thermoelectrics.
But improved in a strong magnetic field (in the quantum limit).
Courtesy: Brian Skinner (MIT)

Other Topics: Thermoelectric Properties of Nodal Semimetals



Summary

- Heat transport & Thermoelectric probes of exotic phases:
    - Quantum Spin Liquids [Savary, Ong]
    - Quantum Hall - non-Abelian states

Discussion Topics

Which scientific question you would like answered in the near future [2-5 year time frame] ?

A theoretical model of an *electronic* phase (a) without quasiparticles and (b) of a strange metal (linear T)

Experimental establishment of (a) quantum spin liquid and (b) non-Abelian quantum phases.

How can we use 21st century science to inform applications?

What unusual properties can have applications? eg. Wave propagation of heat?

Can we come up with other measures like ZT?

Some Questions

- Turbulence in hydrodynamic flows of phonons/electrons?
- Quantum entanglement & Information propagation vs transport - relations and bounds? [Hartnoll - Diffusion constants and butterfly velocity]
- Rigorous derivation of bounds on transport - like the bound on chaos.