From vortex glasses and gauge dualities to quantum brain: following in MPAF footsteps

$: Simons Investigator

123rd Rutgers, 18-20 December 2022

MPAF – a person…

Matthew: *"Hey Leo, how old are you?" (cir 2000)*

me: *"36, why?"*

Matthew: *"You're getting up there buddy!"*

me: *"hhhmmm…🤔…😟?"*

A "drug" for tempering mania and bipolar disorder, (discovered in 1949, FDA approved mid 1970's)

Over the years...

Over the years…

MPAF – a physicist…

- "$Nick_{Read}$, I don't know group theory, I don't like group theory,…"

Birds-eye view: influential & decorated

Matthew P A Fisher

FOLLOW

UC Santa Barbara
Verified email at kitp.ucsb.edu - Homepage
physics

TITLE	CITED BY	YEAR
Dynamics of the dissipative two-state system AJ Leggett, S Chakravarty, AT Dorsey, MPA Fisher, A Garg, W Zwerger Reviews of Modern Physics 59 (1), 1	5741	1987
Boson localization and the superfluid-insulator transition MPA Fisher, PB Weichman, G Grinstein, DS Fisher Physical Review B 40 (1), 546	4411	1989
Thermal fluctuations, quenched disorder, phase transitions, and transport in type-II superconductors DS Fisher, MPA Fisher, DA Huse Physical Review B 43 (1), 130	3046	1991
Vortex-glass superconductivity: A possible new phase in bulk high-T_c oxides MPA Fisher Physical review letters 62 (12), 1415	1965	1989
Non-Abelian statistics and topological quantum information processing in 1D wire networks J Alicea, Y Oreg, G Refael, F Von Oppen, M Fisher Nature Physics 7 (5), 412-417	1671	2011
Transmission through barriers and resonant tunneling in an interacting one-dimensional electron gas CL Kane, MPA Fisher Physical Review B 46 (23), 15233	1534	1992
Deconfined quantum critical points T Senthil, A Vishwanath, L Balents, S Sachdev, MPA Fisher Science 303 (5663), 1490-1494	1439	2004
Transport in a one-channel Luttinger liquid CL Kane, MPA Fisher Physical review letters 68 (8), 1220	1357	1992
Experimental evidence for vortex-glass superconductivity in Y-Ba-Cu-O RH Koch, V Foglietti, WJ Gallagher, G Koren, A Gupta, MPA Fisher Physical review letters 63 (14), 1511	1186	1989
Quantum phase transitions in disordered two-dimensional superconductors MPA Fisher Physical Review Letters 65 (7), 923	954	1990
Quantum criticality beyond the Landau-Ginzburg-Wilson paradigm T Senthil, L Balents, S Sachdev, A Vishwanath, MPA Fisher Physical Review B 70 (14), 144407	832	2004
Integer quantum Hall transition: An alternative approach and exact results AWW Ludwig, MPA Fisher, R Shankar, G Grinstein Physical Review B 50 (11), 7526	799	1994
Coulomb interactions and mesoscopic effects in carbon nanotubes C Kane, L Balents, MPA Fisher Physical review letters 79 (25), 5086	784	1997
Z_2 gauge theory of electron fractionalization in strongly correlated systems T Senthil, MPA Fisher Physical Review B 62 (12), 7850	717	2000
Presence of quantum diffusion in two dimensions: Universal resistance at the superconductor-insulator transition MPA Fisher, G Grinstein, SM Girvin Physical review letters 64 (5), 587	713	1990

Buckley Prize → (Quantum phase transitions in disordered two-dimensional superconductors)

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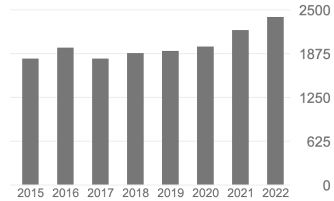

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- Steven M. Girvin — Professor of Physics, Yale Unive…
- Daniel S Fisher — bell laboratories harvard stanford…
- Wilhelm Zwerger — Professor of Theoretical Physics,…
- Yaodong Li — Stanford University
- Subir Sachdev — Herchel Smith Professor of Physi…
- Ashvin Vishwanath — Professor of Physics, Harvard U…
- Allan H. MacDonald — University of Texas Austin, Indian…

- **Waterman**
- **Buckley**
- **NAS**
- **…**

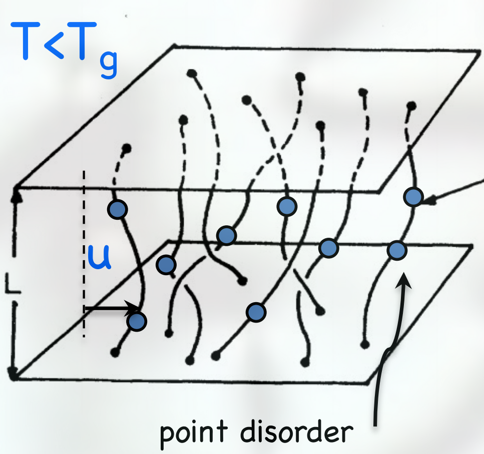
Vortex glass

VOLUME 62, NUMBER 12 PHYSICAL REVIEW LETTERS 20 MARCH 1989

Vortex-Glass Superconductivity: A Possible New Phase in Bulk High-T_c Oxides

Matthew P. A. Fisher
M Research Division, T. J. Watson Center, Yorktown Heights, New York 10598
(Received 31 October 1988)

cited: *2000*



EW B VOLUME 43, NUMBER 1

Thermal fluctuations, quenched disorder, phase transitions, and transport in type-II superconductors

Daniel S. Fisher*
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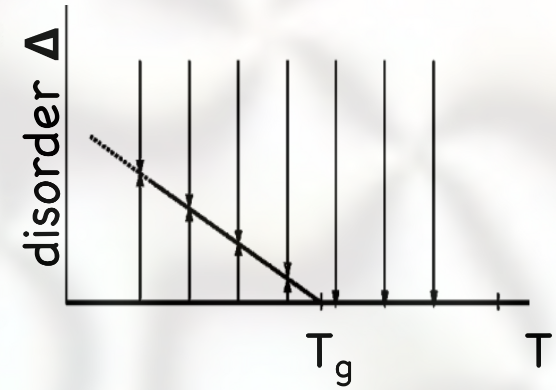
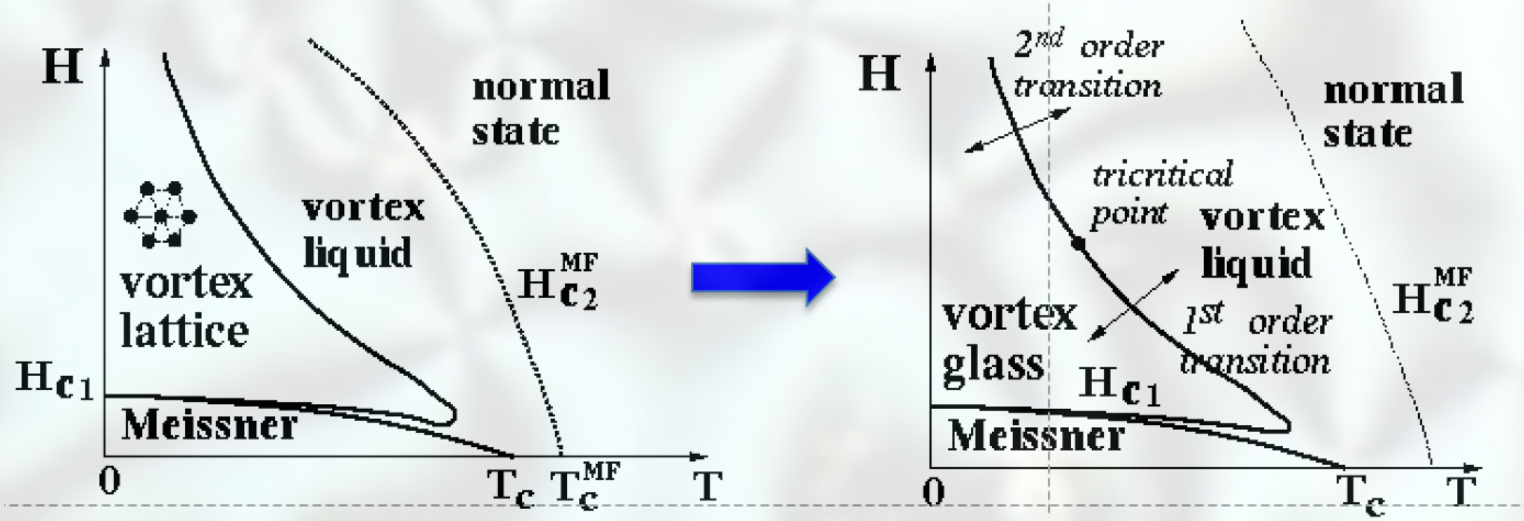
(Received 28 February 1990)



cited: *3000*

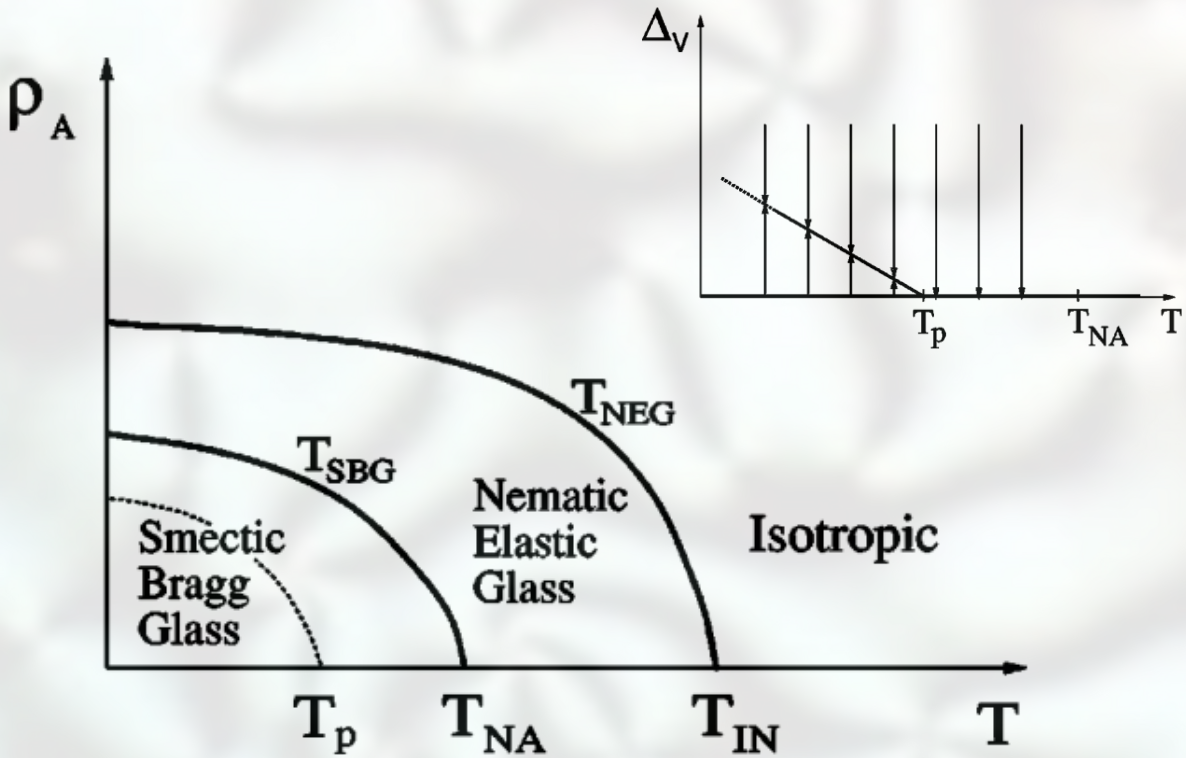
- vortex lattice pinning by point and columnar defects

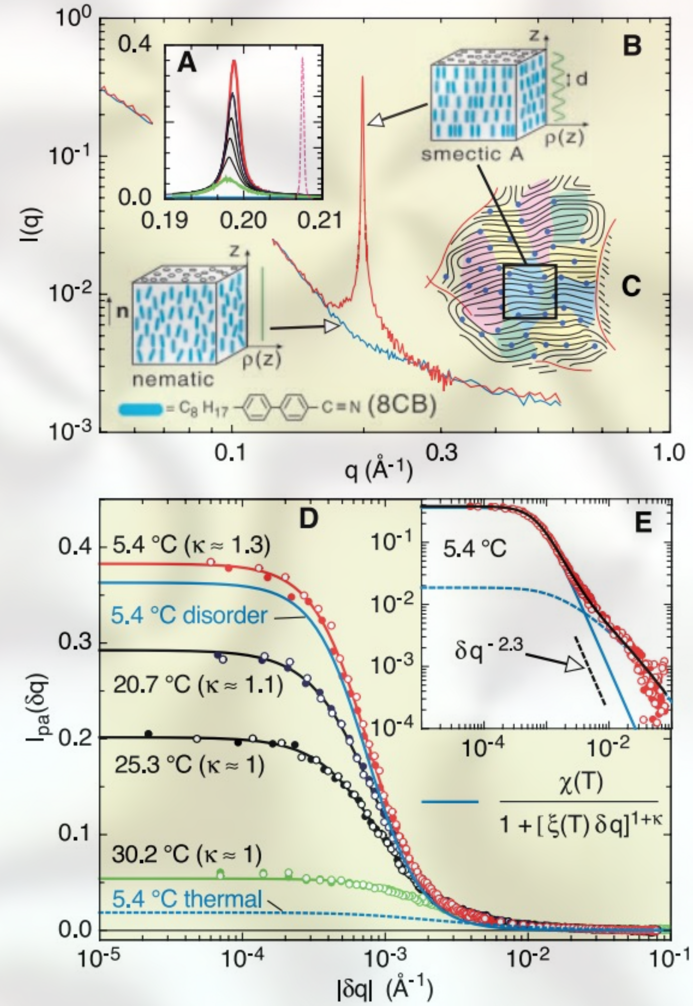


Nematic, smectic, discotic glasses in aerogel

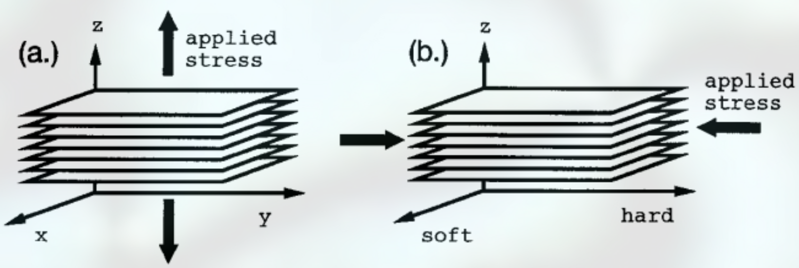
LR and Toner w/ Clark, Bellini -- *"dirt softens soap" + … (1995-2000)*

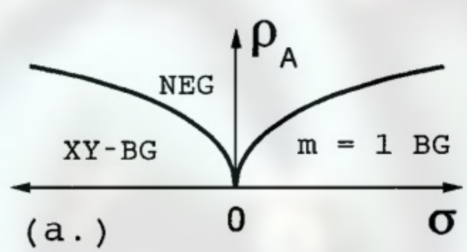
- Liquid crystals in aerogel





- Strained aerogel

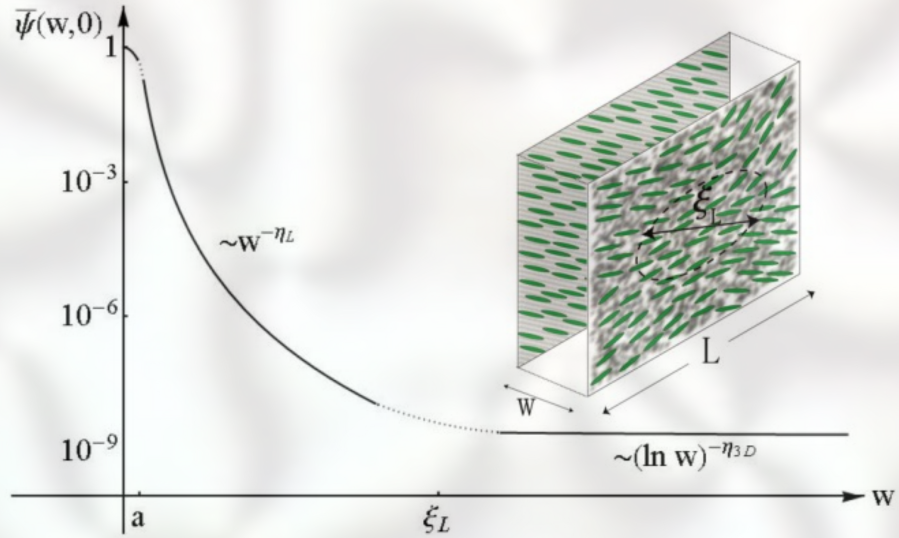




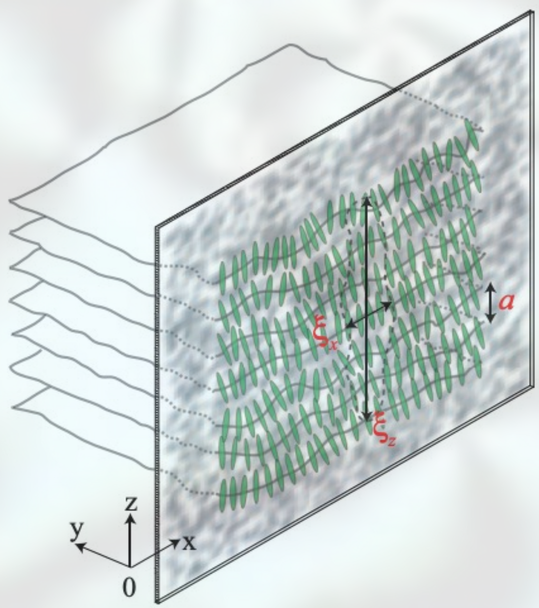
Zhang, L.R. 2009, 2010

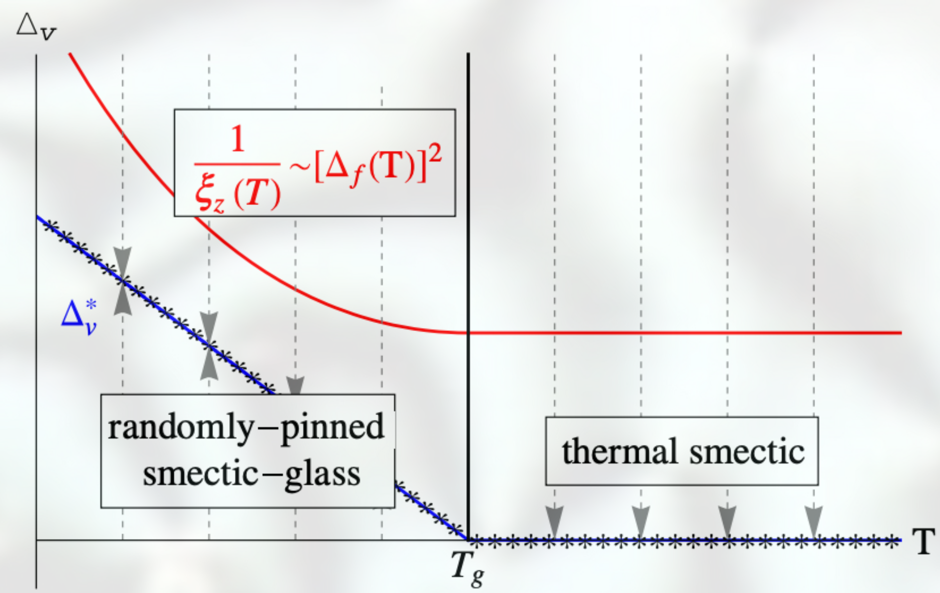
Dirty surface glasses

- Nematic glass



- Smectic glass





Bose-glass to columnar vortex glass duality

(cf, Nelson+Vinokur)

PHYSICAL REVIEW B VOLUME 39, NUMBER 4 1 FEBRUARY 1989

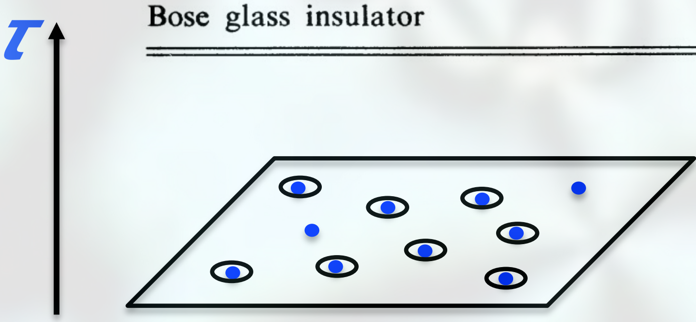
Correspondence between two-dimensional bosons and a bulk superconductor in a magnetic field

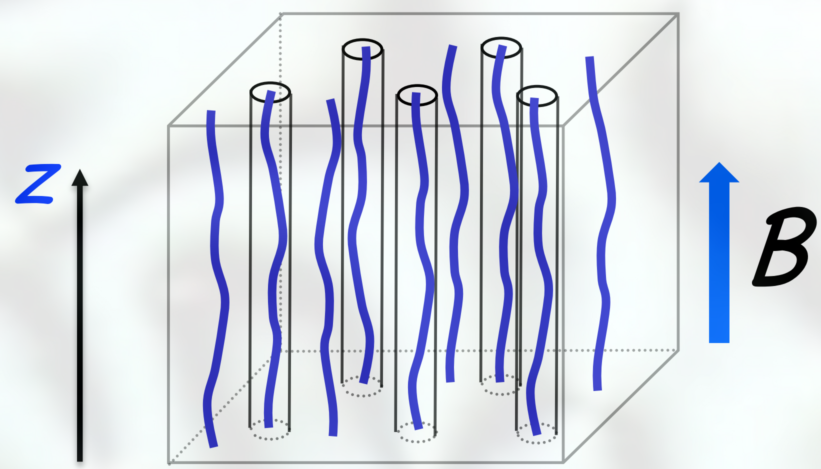
Matthew P. A. Fisher and D. H. Lee
IBM Research Division, Thomas J. Watson Research Center, Yorktown Heights, New York 10598
(Received 24 October 1988)

We study the partition function of two-dimensional lattice bosons at $T=0$ and derive a dual representation which is isomorphic to a bulk superconductor with fluctuating-gauge field in an applied magnetic field. This allows us to relate boson ground states to thermodynamic phases of the superconductor. A density-wave Bose insulator corresponds to an Abrikosov flux-lattice phase, whereas boson superfluidity implies a nonsuperconducting flux-line liquid phase. By analogy with a boson supersolid, we suggest the possibility of an exotic Abrikosov flux-lattice phase with no superconducting long-ranged order.

2D bosons ($T=0$)	Bulk superconductor
Chemical potential μ	Applied field H
Bose density n	Total field B
Mott insulating phase	Meissner phase
Density-wave insulator	Abrikosov flux lattice
Superfluid	Nonsuperconducting flux-line liquid
Supersolid	Nonsuperconducting flux lattice
Bose glass insulator	Superconducting glass

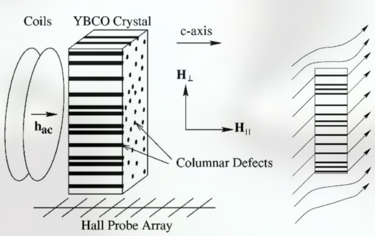
cited: 500

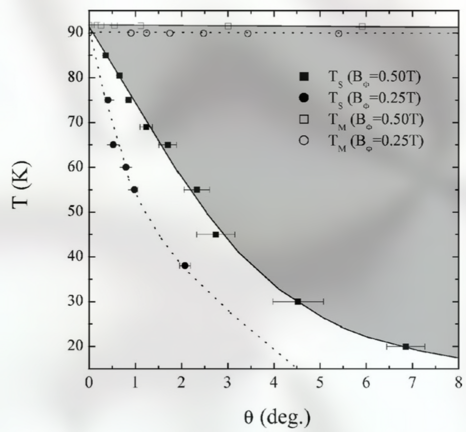


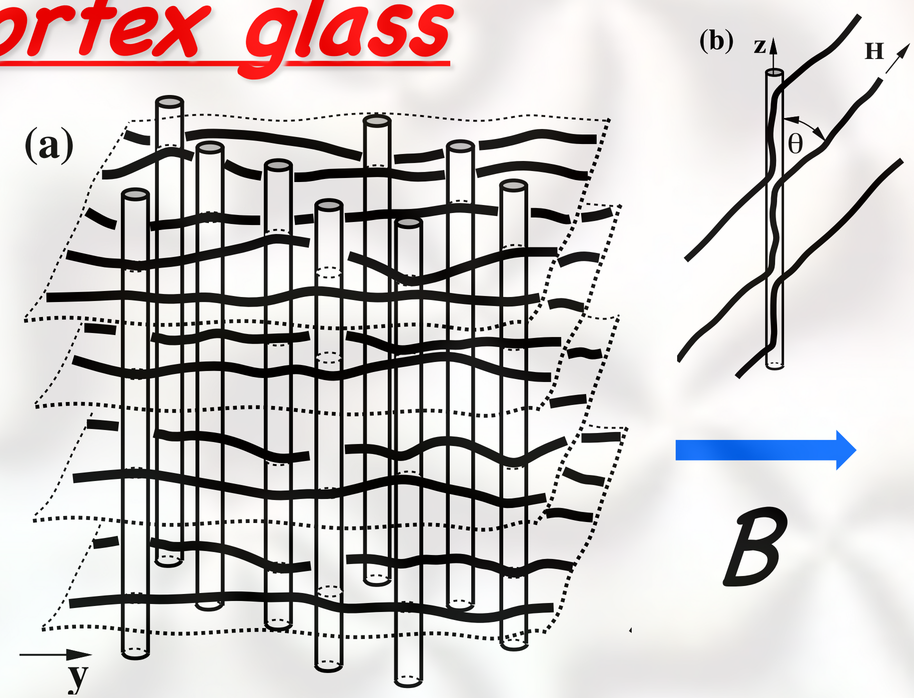


L.R., PRB 2021

Smectic vortex glass





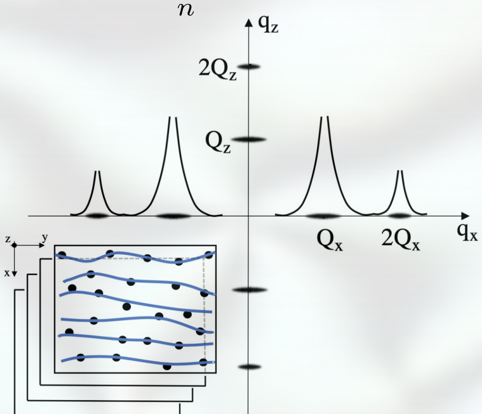


$$S(0,q_z) \sim \sum_n I_{nQ_z}\,\delta(q_z - nQ_z)$$

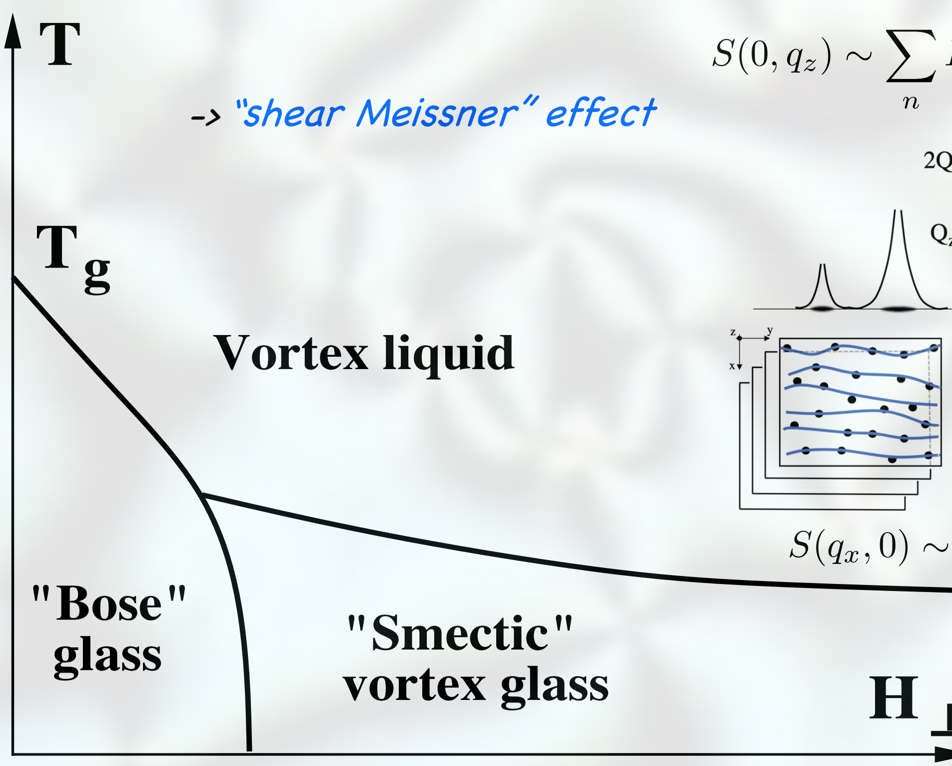
-> *"shear Meissner" effect*

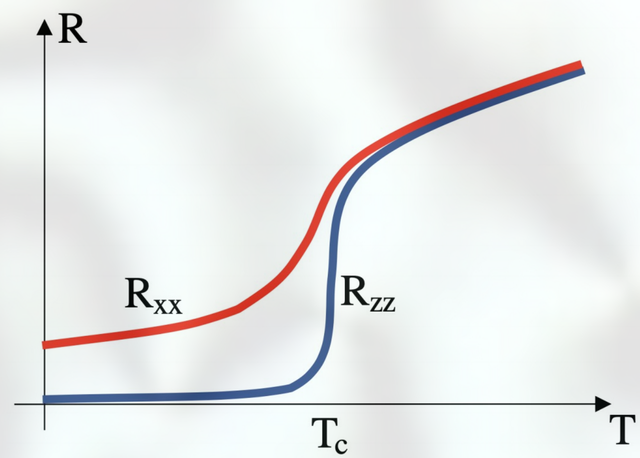
divergent anisotropy:

ρ_{xx} / ρ_{zz} -> ∞



$$S(q_x,0) \sim \sum_n \frac{1}{|q_x - nQ_x|^{1-n^2\eta}}$$





Sliding CDW

Temporal Order in Dirty Driven Periodic Media

Leon Balents and Matthew P. A. Fisher
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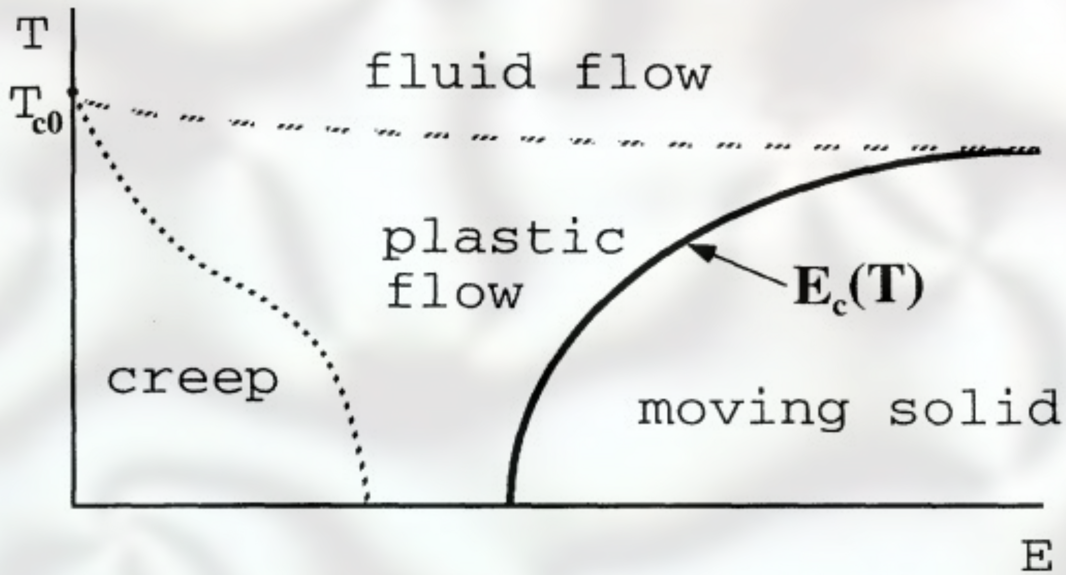
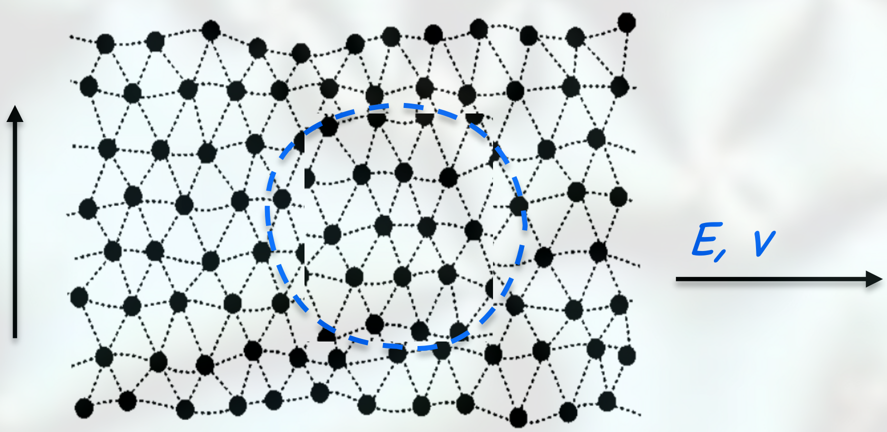
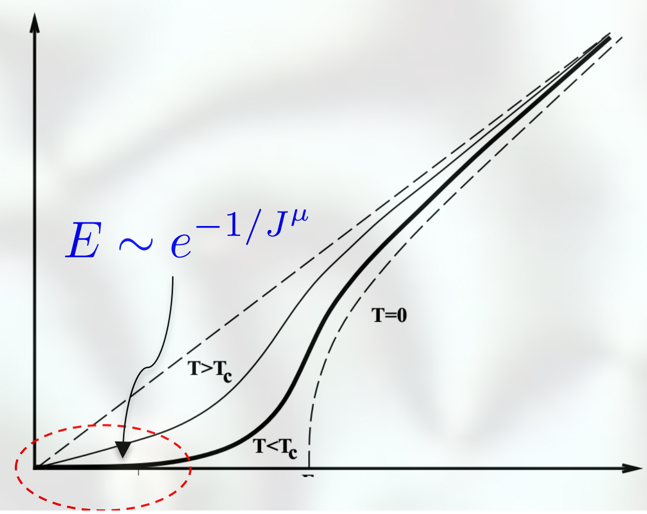
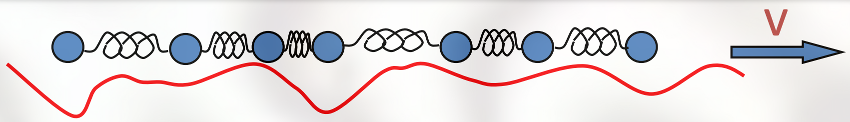
(Received 21 April 1995)





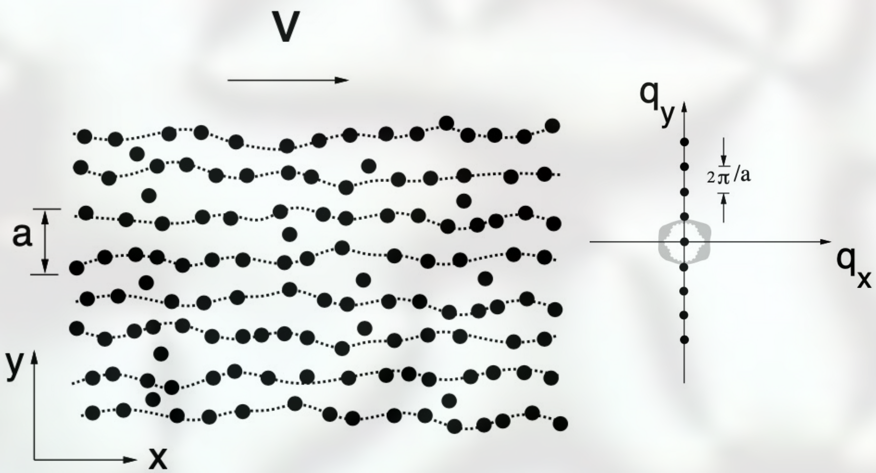


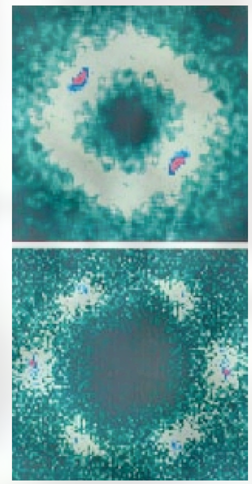
Moving elastic media over random substrate

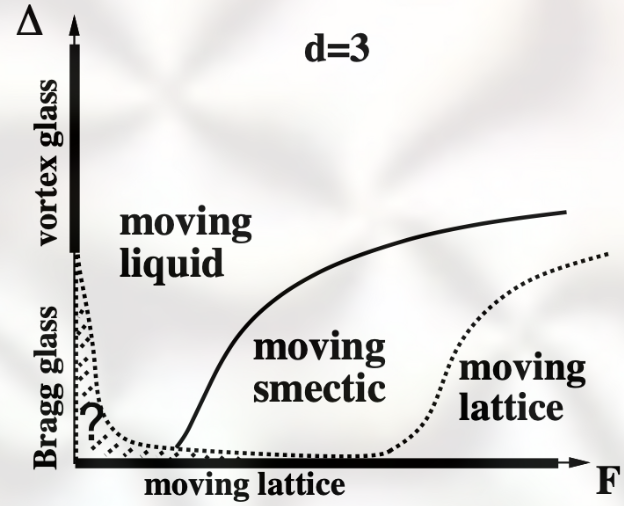


w/ Balents, Marchetti 1996-97

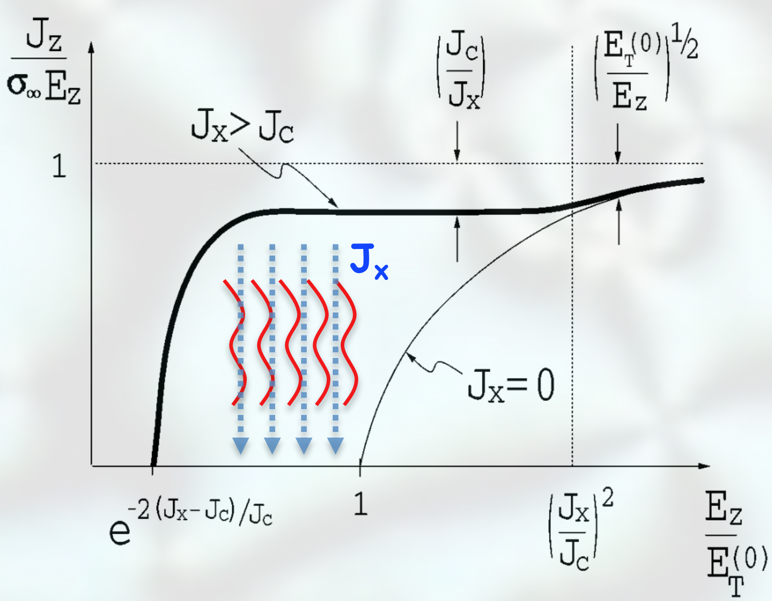
- Transverse smectic glass

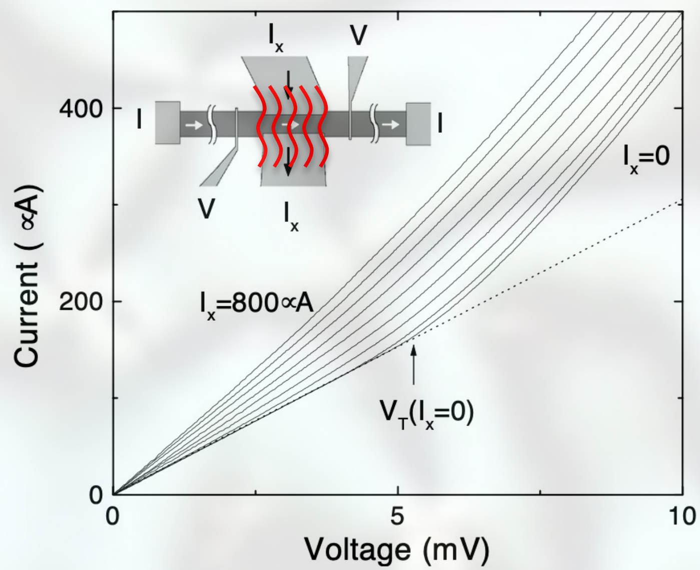


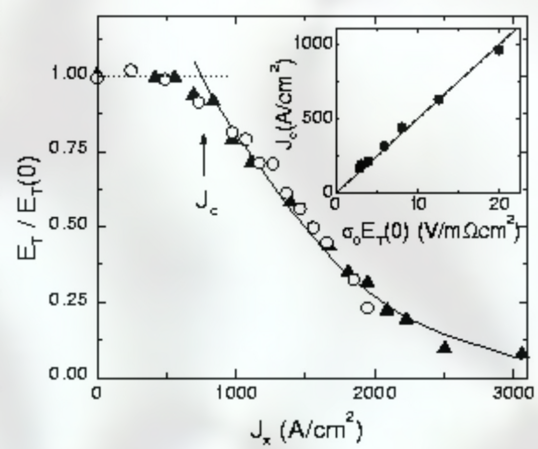




- Transversely driven CDW: current effect transistor w/ Toner 1998

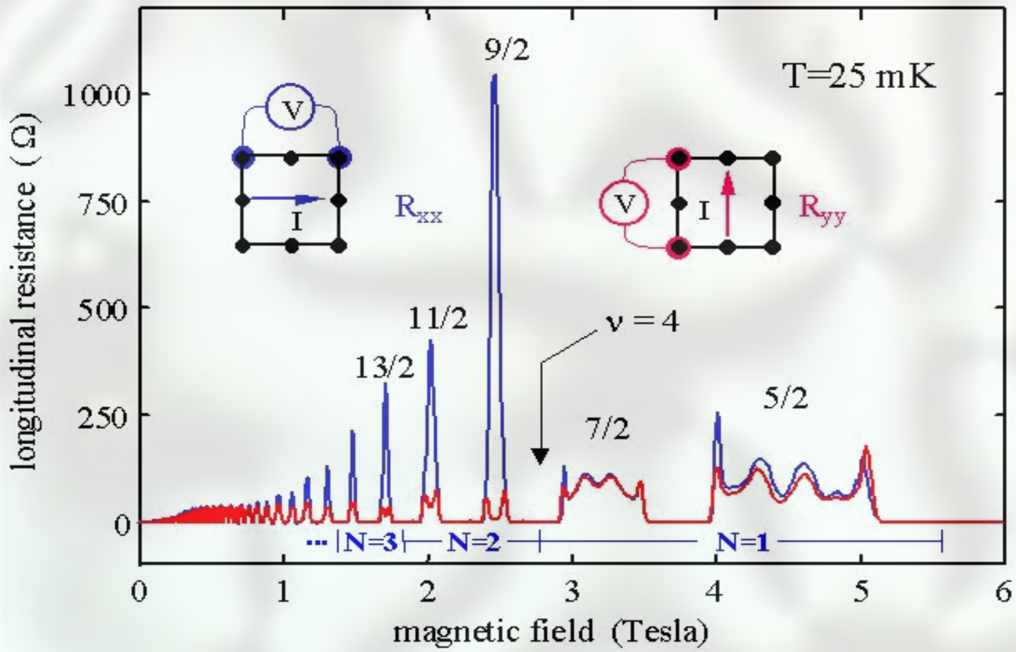






Markovic, PRL 2000

Quantum Hall smectic

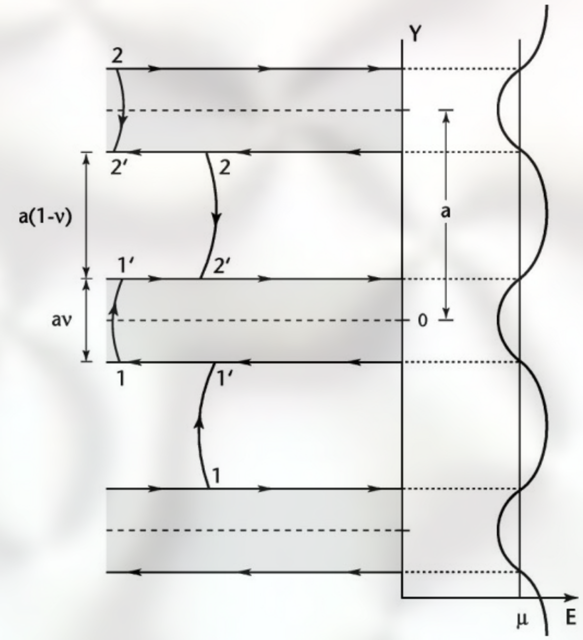


Anisotropic Transport for T<150 mK

Lilly, et al. '99

Du. et al '99

Shayegan, et al.'99



PHYSICAL REVIEW B VOLUME 61, NUMBER 8 15 FEBRUARY 2000-II

Quantum theory of quantum Hall smectics

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Matthew P. A. Fisher
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(Received 19 July 1999)

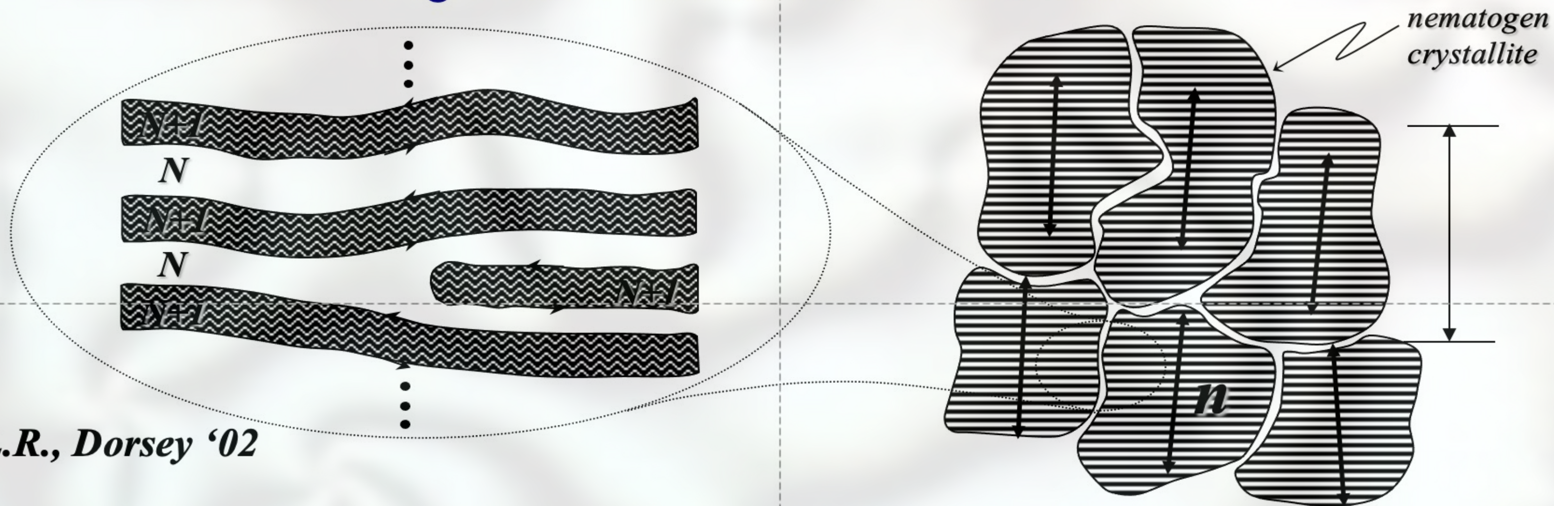
Quantum Hall nematic

VOLUME 88, NUMBER 21 PHYSICAL REVIEW LETTERS 27 MAY 2002

Theory of Quantum Hall Nematics

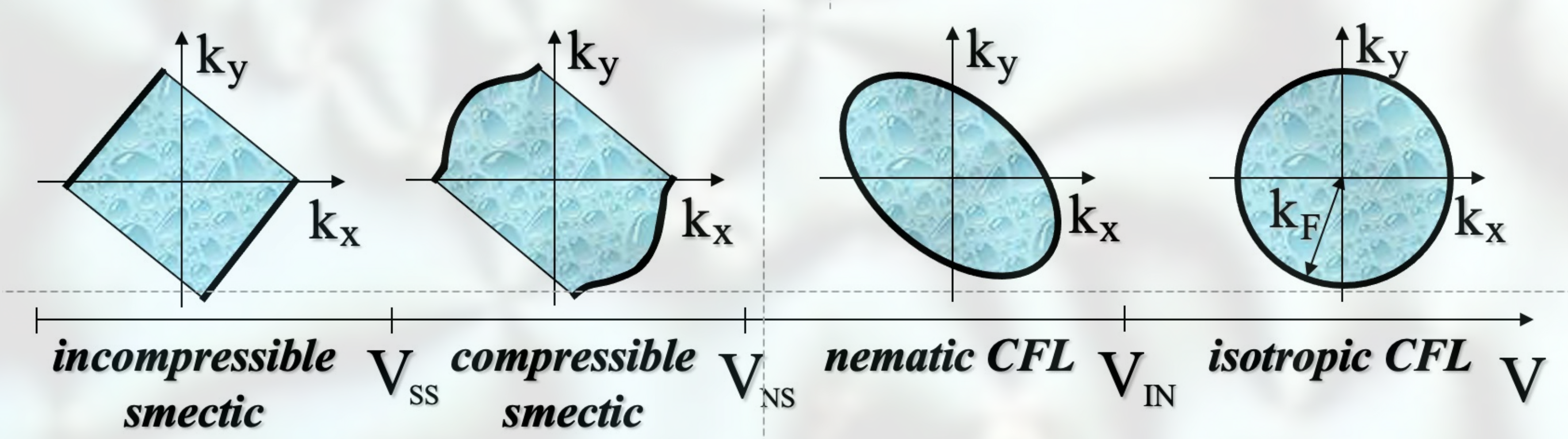
Leo Radzihovsky[1] and Alan T. Dorsey[2]

- fluctuations ⟹ smectic + dislocations ⟺ long-range orientational order and short-range translational order ⟺ nematics



L.R., Dorsey '02

-



Luttinger liquid transport – columnar pinning

VOLUME 68, NUMBER 8 PHYSICAL REVIEW LETTERS 24 FEBRUARY 1992

Transport in a One-Channel Luttinger Liquid

C. L. Kane
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104

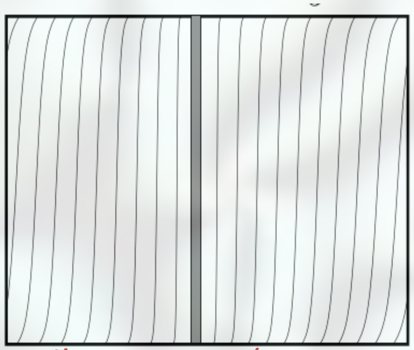
Matthew P. A. Fisher
IBM Research, T. J. Watson Research Center, P.O. Box 218, Yorktown Heights, New York 10598

(Received 15 November 1991)

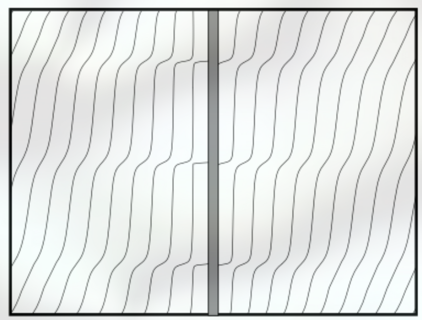
L.R. PRB 2006

Sine-Hilbert model

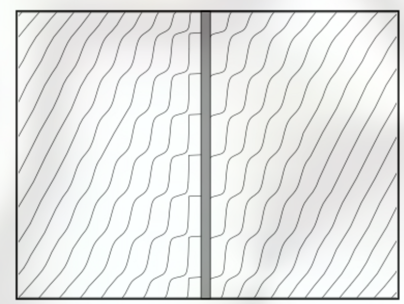
$$H_0 = \overline{K} \int_z \int_{z'} \left(\frac{u_0(z) - u_0(z') - h(z-z')}{z - z'} \right)^2 - v \int_z \cos[G u_0(z)]$$



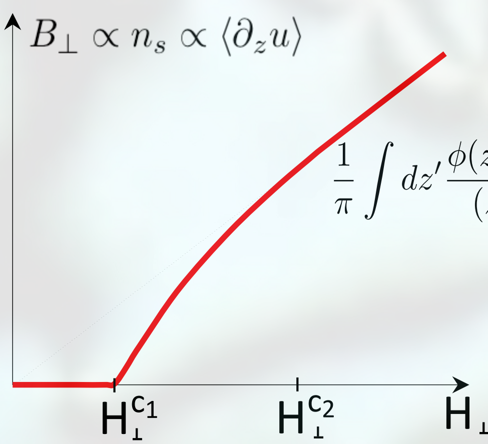
vanishing tilt response (transverse Meissner effect)



nonlinear tilt response via solitons proliferation



linear tilt response overlapping solitons

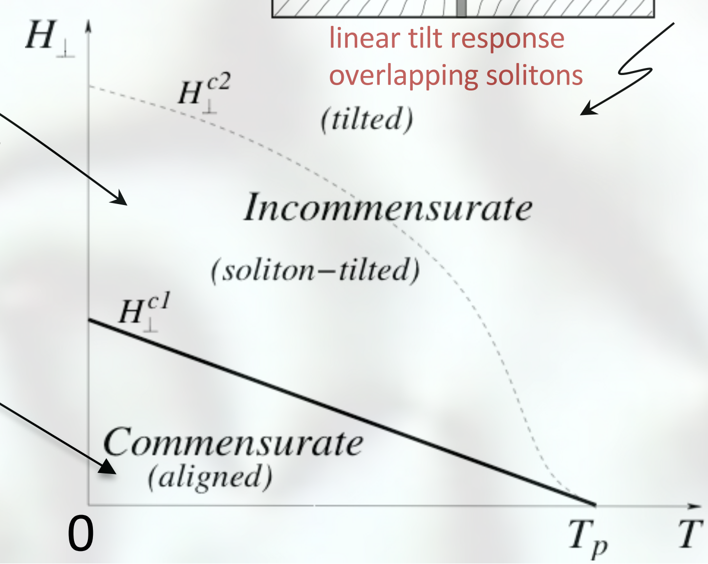


$$\frac{1}{\pi} \int dz' \frac{\phi(z) - \phi(z')}{(z - z')^2} + \sin\phi(z) = 0 \quad \partial_z \phi(z)|_{z=0,L} = h$$

soliton:

Peierls '40, Nabarro '47
Ablowitz '87

$$u_s(z) = -a/\pi \tan^{-1}(1/z)$$



Peskin
Dasgupta, Halperin
Fisher, Lee

XY-SC gauge duality

PHYSICAL REVIEW B VOLUME 39, NUMBER 4 1 FEBRUARY 1989

Correspondence between two-dimensional bosons and a bulk superconductor in a magnetic field

Matthew P. A. Fisher and D. H. Lee
IBM Research Division, Thomas J. Watson Research Center, Yorktown Heights, New York 10598
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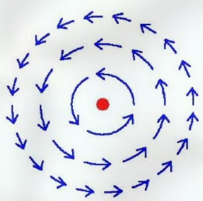
Superfluid

vortices



topological winding:

$$\nabla \times \mathbf{j} = \rho$$

$$\mathbf{j} = \nabla\phi$$

Goldstone mode

$$H = \frac{1}{2}\int d^2x \left[|\nabla\phi|^2 + n^2\right]$$

$$[n, \phi] = i$$

Maxwell Gauge Theory (with matter)

particles

Gauss's law:

$$\nabla \cdot \mathbf{E} = \rho$$

photon

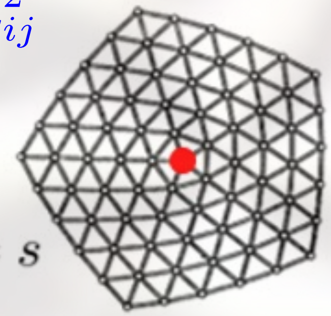
$$H = \frac{1}{2}\int d^2x \left[|\mathbf{E}|^2 + (\nabla \times \mathbf{A})^2\right]$$

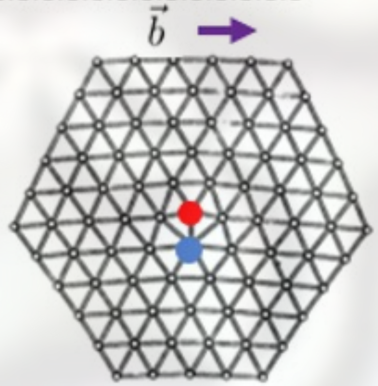
$$[A_i, E_j] = i\delta_{ij}$$

M. Pretko,
L. R.,
PRLs 2018

Fracton-elasticity duality

$\mathcal{H} = \frac{1}{2}B_i^2 + \frac{1}{2}E_{ij}^2$	$\mathcal{H} = \frac{1}{2}\pi_i^2 + \frac{1}{2}u_{ij}^2$
Fracton $\partial_i \partial_j E^{ij} = \rho$	Disclination $\epsilon^{ik}\epsilon^{j\ell}\partial_i \partial_j u_{k\ell} = s$
Dipole	Dislocation
Gauge Modes	Phonons
Electric Field E_{ij}	Strain Tensor u_{ij}
Magnetic Field B_i	Lattice Momentum π_i





$$\partial_t B^i + \epsilon_{jk}\partial^j E_\sigma^{ki} = 0. \quad \Longleftrightarrow \quad \partial_t \pi^i - \partial_j \sigma^{ij} = 0$$

Faraday <-> Newton

Quantum liquids

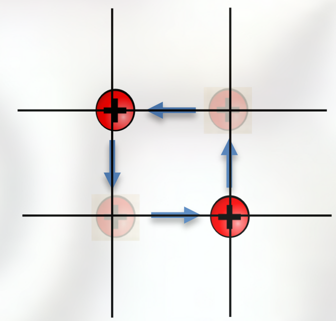
PHYSICAL REVIEW B **66**, 054526 (2002)

Ring exchange, the exciton Bose liquid, and bosonization in two dimensions

Arun Paramekanti,[1,2] Leon Balents,[2] and Matthew P. A. Fisher[1]
[1]*Institute for Theoretical Physics, University of California, Santa Barbara, California 93106-4030*
[2]*Department of Physics, University of California, Santa Barbara, California 93106-4030*
(Received 7 March 2002; published 20 August 2002)

Subsystem symmetry

– *bosons conserved on every row and column*

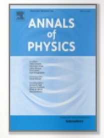


fractons -> Lifshitz renaissance

L.R. et al., '18, '20, '22
Lake, Hermele, Senthil, '22
Zechmann, et al. '22
Shao, Seiberg, et al. '21, '22
…

Quantum Brain

Annals of Physics
Volume 362, November 2015, Pages 593-602



Quantum cognition: The possibility of processing with nuclear spins in the brain

Matthew P.A. Fisher

Quantamagazine

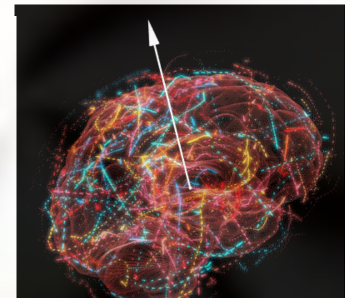
NEUROSCIENCE

A New Spin on the Quantum Brain

45

A new theory explains how fragile quantum states may be able to exist for hours or even days in our warm, wet brain. Experiments should soon test the idea.

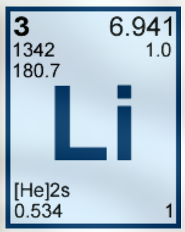
As recently as 10 years ago, Fisher's hypothesis would have been dismissed by many as nonsense. Physicists have been burned by this sort of thing before, most notably in 1989, when Roger Penrose proposed that mysterious protein structures called "microtubules" played a role in human consciousness by exploiting quantum effects. Few researchers believe such a hypothesis plausible. Patricia Churchland, a neurophilosopher at the University of California, San Diego, memorably opined that one might as well invoke "pixie dust in the synapses" to explain human cognition.



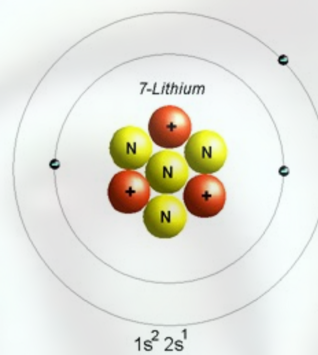
NewScientist

Is quantum physics behind your brain's ability to think?

From consciousness to long-term memories, the human brain has some peculiar computing abilities – and they could be explained by quantum fuzziness

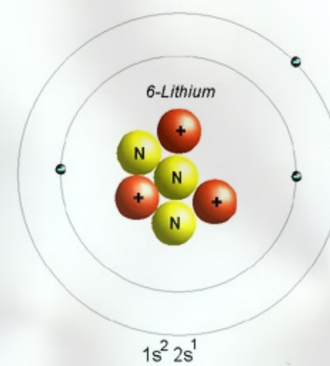


Lithium-7
3 protons, 4 neutrons



$t_{\text{Li-7}} \sim 10\,\text{sec}$

Lithium-6
3 protons, 3 neutrons

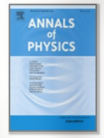


$t_{\text{Li-6}} \sim 5\,\text{min}$

- *How does lithium work?*
- *How do any psychiatric medications work ???*

Quantum Brain

Annals of Physics
Volume 362, November 2015, Pages 593-602



Quantum cognition: The possibility of processing with nuclear spins in the brain

Matthew P.A. Fisher

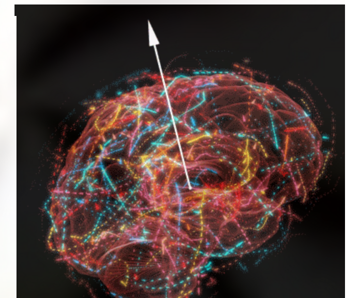
Quantamagazine

NEUROSCIENCE

A New Spin on the Quantum Brain

A new theory explains how fragile quantum states may be able to exist for hours or even days in our warm, wet brain. Experiments should soon test the idea.

As recently as 10 years ago, Fisher's hypothesis would have been dismissed by many as nonsense. Physicists have been burned by this sort of thing before, most notably in 1989, when Roger Penrose proposed that mysterious protein structures called "microtubules" played a role in human consciousness by exploiting quantum effects. Few researchers believe such a hypothesis plausible. Patricia Churchland, a neurophilosopher at the University of California, San Diego, memorably opined that one might as well invoke "pixie dust in the synapses" to explain human cognition.



NewScientist

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Biological processes are slow, too hot,...for *quantum effects*

...BUT...

Loophole: *nuclear spins* *isolated w/ seconds to minutes coherence time (e.g., NMR)*
e.g., t_{Na} ~ 1/10 sec (I=3/2), t_{Li} ~ 10 sec (I=1/2)

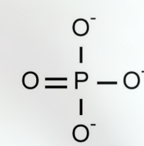
requirements:

- *biological element with **very** isolated nuclear spin 1/2 :* ***A Neural Qubit***
- *mechanism for **transporting** thru brain*
- *mechanism for **entangling pairs** of nuclear spins*
- *....*

nuclear spin S = 1/2

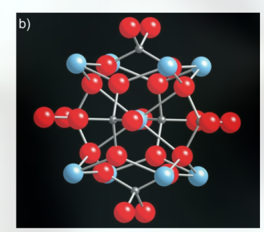
Bio-chemical elements: C H N O P S
Bio-electrical ions: Na K Ca Cl Mg

Phosphorus (P) nucleus provides *the* only possible neural Qubit $t_P \approx 10\,\text{sec}$ PO_4^{3-}



Neural qubit: ***Posner cluster*** (calcium-phosphate) transported into neuron

$$Ca_9(PO_4)_6$$



Chemical reactions

Quantum indistinguishability in chemical reactions

PNAS

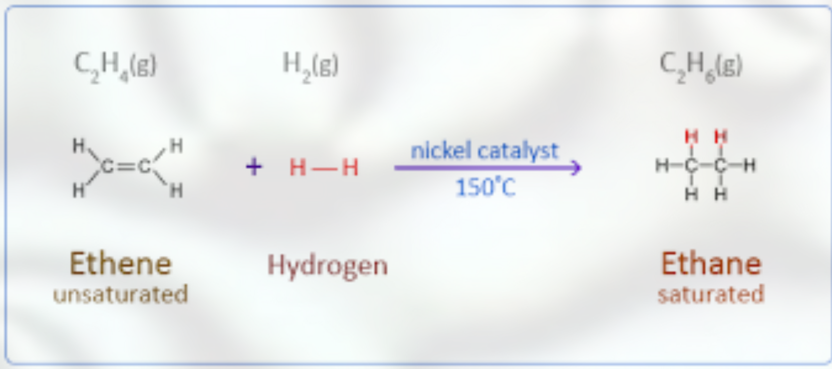
Matthew P. A. Fisher and Leo Radzihovsky Authors Info & Affiliations

April 30, 2018

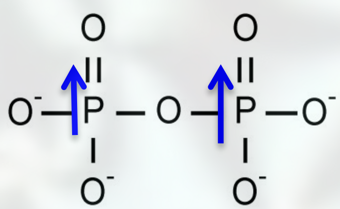
Prerequisite quantum cognition:

- *nuclear spin-dependent chemical reactivity*
- *nuclei's quantum indistinguishability crucial*

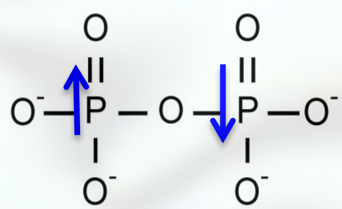
Ortho- vs Para-hydrogen reactivities?



$P_2O_7^{4-}$



Ortho (triplet) PPi



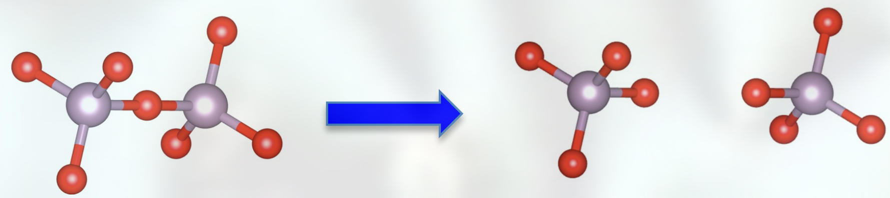
Para (singlet) PPi

Ortho/para splitting: $10^{-2}K$

$L_{\rm th} \approx 100\hbar$

$\mathrm{ATP} \rightarrow \mathrm{AMP} + \mathrm{PPi}$

$$\mathrm{PPi} \rightarrow \mathrm{Pi} + \mathrm{Pi}$$



Chemical reactions (2016)

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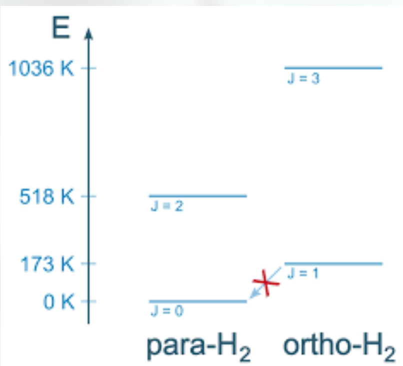
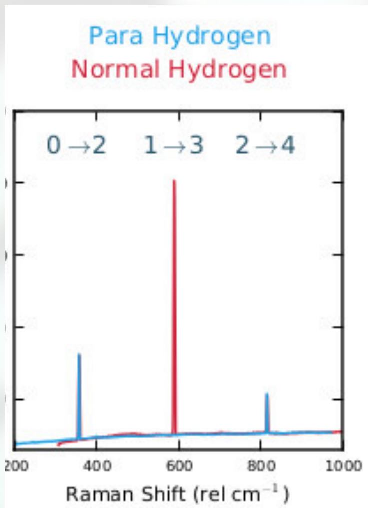
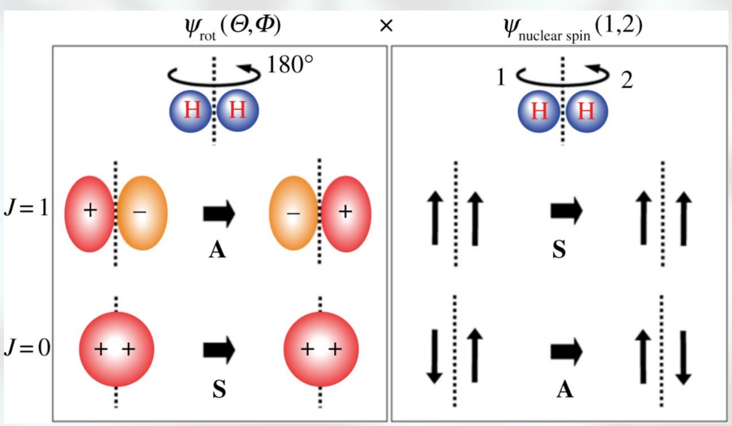
molecular spectroscopy



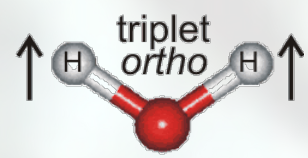


ortho H_2

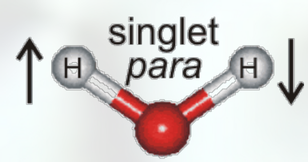
para H_2



ortho H_2O



para H_2O

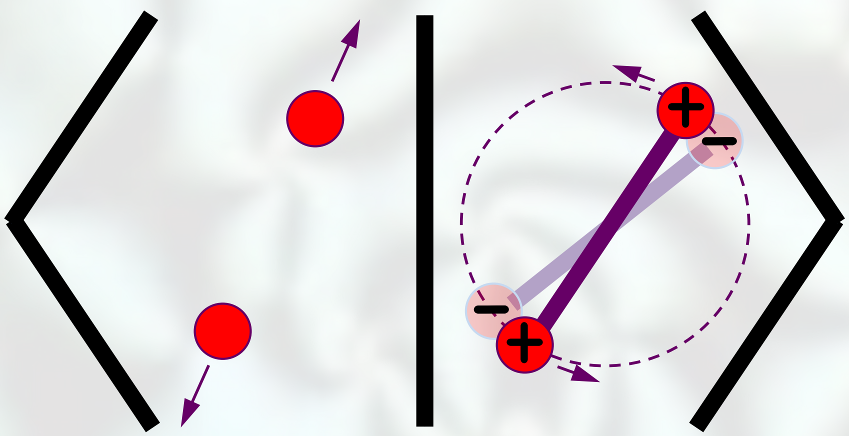


Quantum dynamical selection (QDS)

conjecture:

No direct ***bond-breaking*** transition ***from asymmetric state*** of symmetric molecules

A bond-breaking enzymatic chemical reaction on a symmetric molecule implements a projective measurement onto $\boldsymbol{L_{quasi} = 0}$



$= 0$, for $L_{quasi} \neq 0$

- Spin state-induced Berry phases -> destructive interference for $L_{quasi} \neq 0$
- "Rotating" molecule is non-reactive

Applications/Generalizations:

- *Ortho* H_2*,* H_2O *and Pyrophosphate*
- *Molecular oxygen* O_2
- *Other symmetries,* C_n *Planar and 3d* CH_4

Implications:

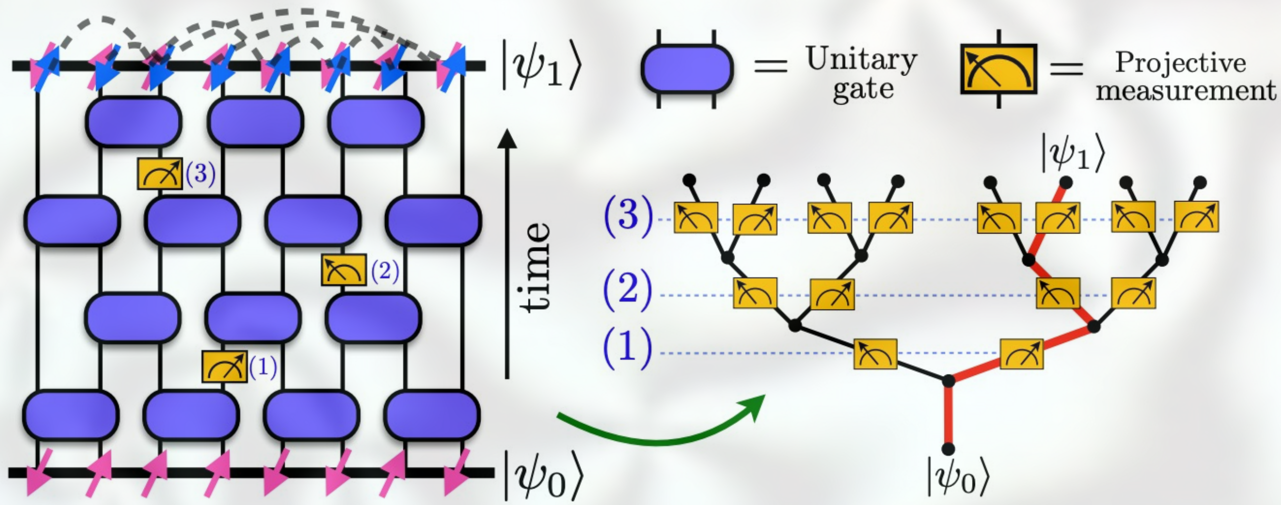
- *New isotope fractionation mechanism*
- *Nuclear spin effects on chemical reactions*
- *Oxygen and Superoxide (ROS)*
- *Hyperpolarization for zero field NMR*

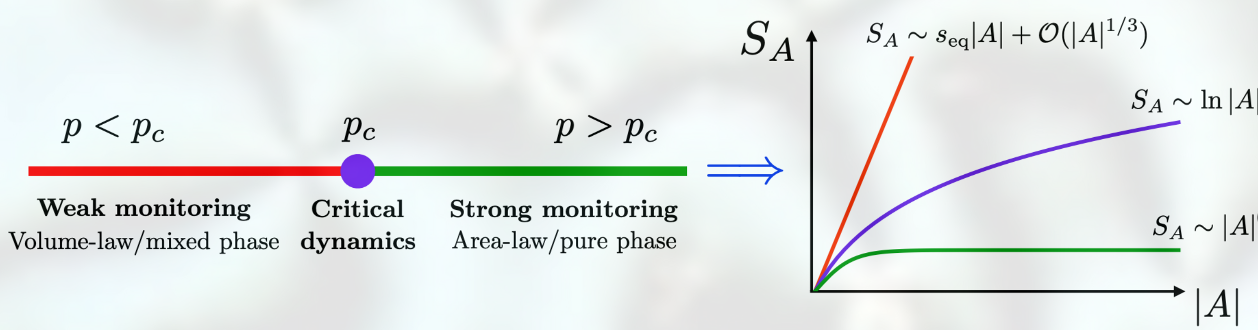
Chemical reactions -> Q-circuits w/ measurement

Quantum Zeno effect and the many-body entanglement transition

Yaodong Li,[1] Xiao Chen,[2] and Matthew P. A. Fisher[1]

PHYSICAL REVIEW B **98**, 205136 (2018)





...beyond papers -> human impact

Happy birthday, buddy!