

Jason Alicea, Caltech

David Mross, Andrew Essin, & JA, Physical Review X 5, 011011 (2015)









BURKE





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B ↑ ↑

electron











co-propagating Majorana + charge edge modes

Pairing instability of composite Fermi sea yields **non-Abelian** "Moore-Read" fractional quantum Hall state!





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Moral: emergent "metals" are interesting and provide efficient way of capturing exotic topologically ordered gapped phases.



3D topological insulator: protected by time-reversal, U(1) particle conservation symmetries



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Impossible band structure in strict 2D systems with time-reversal, where only **even** # of Dirac cones can appear.

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Impossible in strict 2D, since would imply fractionalization, topological order.

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Impossible in strict 2D, since superconductor would always break T.

Without interactions, this is the full story:

-Symmetry implies massless electron Dirac cone -broken symmetry implies anomalous gapped phases.

Does symmetry imply surface metallicity more generally?

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Does symmetry imply surface metallicity more generally? No!

A Time-Reversal Invariant Topological Phase at the Surface of a 3D Topological Insulator

Parsa Bonderson,¹ Chetan Nayak,^{1,2} and Xiao-Liang Qi^{3,1}

Symmetry Enforced Non-Abelian Topological Order at the Surface of a Topological Insulator

Xie Chen,¹ Lukasz Fidkowski,² and Ashvin Vishwanath^{1,3}

A symmetry-respecting topologically-ordered surface phase of 3d electron topological insulators

Max A. Metlitski,¹ C. L. Kane,² and Matthew P. A. Fisher³

Gapped Symmetry Preserving Surface-State for the Electron Topological Insulator

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Clearly break time reversal symmetry in 2D, but **not** on surface!



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"Composite Dirac liquids" = new correlated gapless surface states that unify these works.





-Wild deviation from Weidemann-Franz law!



Composite
Dirac liquid

Instead, will "cheat" and follow route with virtues of physical transparency, analytical control.

Key technical idea: relax time-reversal to weaker "antiferromagnetic" symmetry (states *still* impossible in 2D)

Quasi-1D deformation allows rigorous analytical progress a la Teo & Kane.

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...but heat transport is chiral, so must have neutral modes left over!

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Nested Composite Dirac Liquids

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Outlook

Interplay between interactions, symmetry-protected topological phases rich topic.

Provide unifying view on lots of physics, including quantum Hall; <u>accessible</u> <u>via controlled analytical</u> <u>methods that deal with</u> <u>physical electrons.</u>

Naturally extends to "weak topological insulators". (D. Mross, A. Essin, JA, A. Stern, arXiv:1507.01587)

Extension to 3D topological superconductors?

Isotropic implementations?

Quasi-realistic Hamiltonians for such states?

Is the composite fermion a Dirac particle?

Dam Thanh Son

Kadanoff Center for Theoretical Physics, University of Chicago, Chicago, Illinois 60637, USA (Dated: February 2015, revised July 2015)

Dual Dirac liquid on the surface of the electron topological insulator

Chong Wang and T. Senthil

Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (Dated: May 21, 2015)

Particle-vortex duality of 2D Dirac fermion from electric-magnetic duality of 3D topological insulators

See Ashvin's talk!

Max A. Metlitski¹ and Ashvin Vishwanath^{2,3}

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³Materials Science Division, Lawrence Berkeley National Laboratories, Berkeley, CA 94720, USA.

Half-filled Landau level, topological insulator surfaces, and three dimensional quantum spin liquids

Chong Wang and T. Senthil Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (Dated: July 31, 2015)