Sau group research

(Theoretical condensed matter physics)

Condensed matter theory center and Joint quantum institute

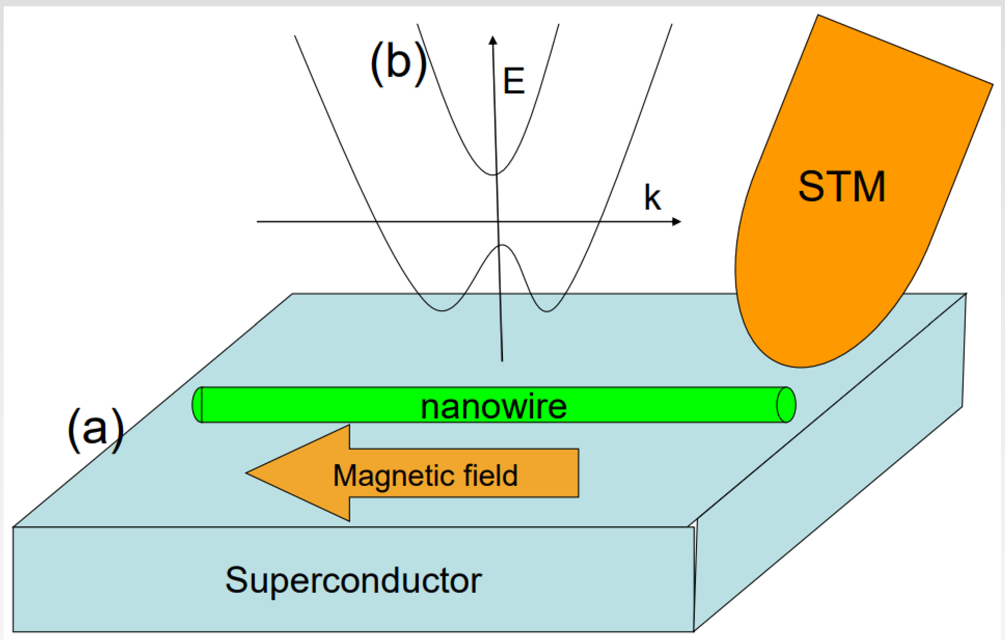
Overview of research areas

Broadly speaking we are interested in predicting and understanding manifestation of topological principles in phenomena in quantum many-body physics

- Topological superconductivity and quantum computation
  - Majorana fermions in semiconductor nanowires
  - Topological superconductors in other materials
  - Higher order topological superconductors
  - Parafermions (Maghrebi et al PRL2015; Alavirad et al PRL2017)
  - Universal quantum computation using genons in Ising topological phases (Barkeshli, Sau arxiv 2015)
- Response of topological phases
  - Chiral anomaly of Weyl materials
  - Absence of chiral magnetic effect in Weyl materials (Alavirad, Sau PRB 2016)
  - Non-topological conductance quantization in quantum anomalous Hall/SCs (Huang et al PRB 2018)
  - Chiral supercurrents of quantum Hall Josephson junctions (Alavirad et al PRB 2018)
- Topological aspects of gapless quantum systems
  - Lifshitz quantum criticality in spin-orbit Bose gases
  - Ising quantum criticality in Majorana nanowires (Cole, Sau, Das Sarma PRB 2017)
  - Instabilities on surface of Kondo topological insulators (Roy et al PRB 2015)
  - Majorana degeneracy of gapless Luttinger liquids (Sau, Halperin, Flensberg Das SarmaPRB2011)
- Topological aspects of dynamics of quantum systems
  - Soliton dynamics in Josephson junction arrays
  - Dynamical detection of Majorana phases in cold atoms (Setiawan et al PRL 2015)

Majorana fermions in semiconductor nanowires

The figure on the right illustrates the combination of spin-orbit coupling, superconductivity and magnetic field that I participated in predicting as a candidate for observation of Majorana fermions, as a postdoc at CMTC. Current experimental efforts are underway to search for Majoranas in this system.



Jay D. Sau, Sumanta Tewari, Roman Lutchyn, Tudor Stanescu, S. Das Sarma

Phys.Rev.B82:214509,2010

One of the research activities often in collaboration with the Das Sarma group is to predict and understand signatures of topological superconductivity in these systems. Some of the results are analytical (see right) and sometimes they are numerical comparison of theory simulations and experiments.

$$Z=\sum_W Z_W=\sum_W Z_W^{\mathrm{BdG}}\int_W \mathcal{D}\phi e^{-S_W[\phi]}$$

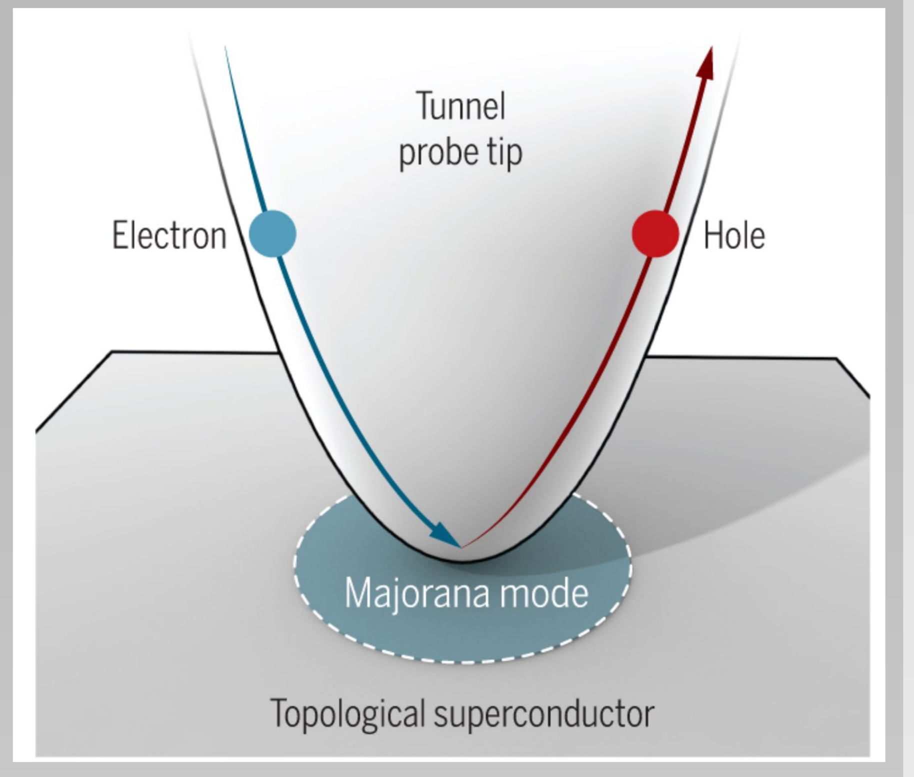
$$Z_{\pm1}/Z_0\approx(\mathrm{sgn}\ \mathrm{Pf}\ H_{\mathrm{BdG}})\prod_{\varepsilon>0}2\tanh\left(\frac{\beta\varepsilon}{2}\right)\times$$
$$\exp\left(\pm i\pi N_{\mathrm{g}}\right)\exp\left(-\frac{\pi^2}{\beta E_C}-2g_0\right)$$

Chun-Xiao Liu, William S. Cole, Jay D. Sau

Phys. Rev. Lett. 122, 117001 (2019)

Topological superconductivity in other materials

We are also interested in manifestation of topological superconductivity in other systems. One example is the possibility of topological superconductivity with surface Majorana arcs Jay D. Sau, Sumanta Tewari Physical Review B 86, 104509 (2012) for which evidence was found by the Paglione group at UMD.



Jay Sau Science 10 Jan 2020:

Another recent exciting example is the possibility of vortex Majorana modes in iron-based superconductors. Evidence for quantized conductance, which is a signature of perfect Andreev reflection off of Majorana modes was recently seen in these materials. I was fortunate to write a perspective on this observation.

More seriously, we are collaborating with experimentalists (Jenny Hoffman and Jimmy Williams) to estimate the possibility of measuring the Majorana qubits (something not done till date) from the vortex currents

Benjamin H. November, Jay D. Sau, James R. Williams, Jennifer E. Hoffman arXiv:1905.09792

$$H=[-iv\{(\sigma_x\cos\theta+\sigma_y\sin\theta)\partial_r+\frac{1}{r}(\sigma_y\cos\theta-\sigma_x\sin\theta)\partial_\theta\}]\tau_z$$
$$-\mu\tau_z+\Delta(r)\{\cos n\theta\tau_x+\sin n\theta\tau_y\}.\qquad(2)$$

$$j_a(r)=\tfrac{v_F}{2}\Psi^\dagger\sigma_a\Psi+j_{S,a}(r)\qquad \nabla\cdot j_{S,a}=|\Delta|[\cos\phi\tau_y-\sin\phi\tau_x]$$

Chiral anomaly of Weyl materials

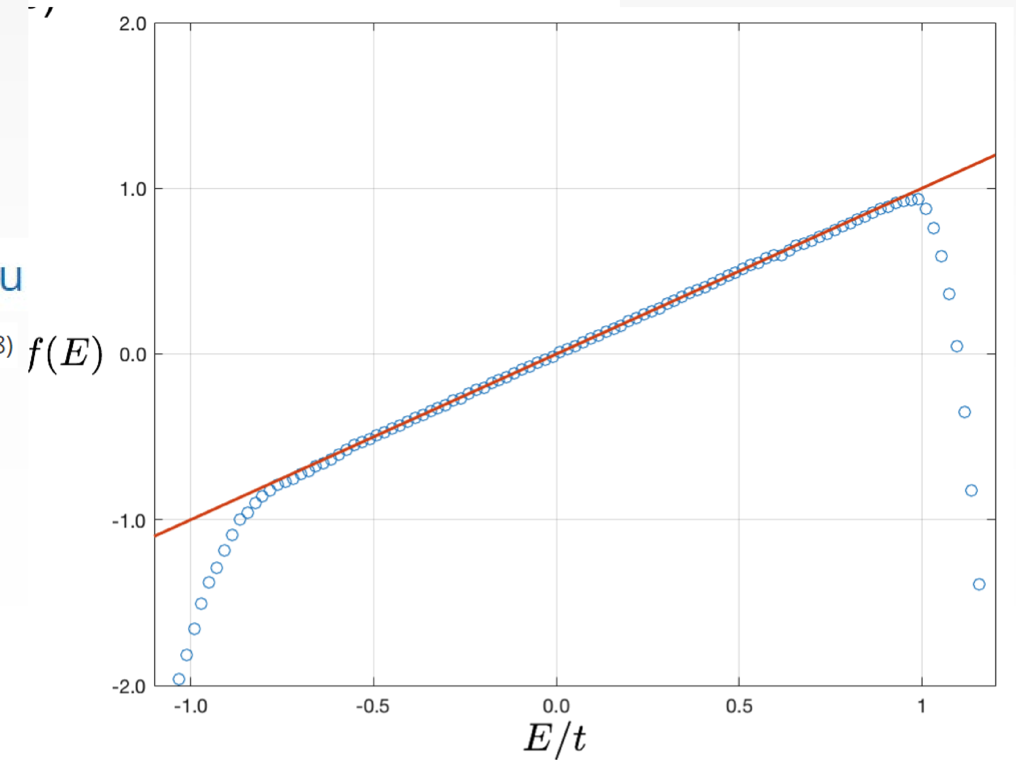
Weyl materials provide an example of a manifestation of the chiral anomaly from high energy physics. We asked the question of how to describe this important phenomena in a diffusive system where disorder killed the Landau levels completely. Such a system is described by a supersymmetric sigma model F[Q]. We showed analytically that such a field theory leads to a quantized level velocity that we were able to verify in numerical simulations providing a fully quantum description of the anomaly in the presence of strong disorder.

$$F[Q]=\frac{\pi\nu}{8}\int d\mathbf{r}\,\mathrm{str}\left[D\left(\nabla Q-\frac{ie}{c}[Q,\mathbf{A}\tau_3]\right)^2+2i\omega\Lambda Q\right]$$

$$f(E)=\sum_{E_i\le E}\int_0^{2\pi}d\phi\ v_{E_i}(\phi)$$
$$=\frac{\Phi}{h/e}(E-E_0).$$

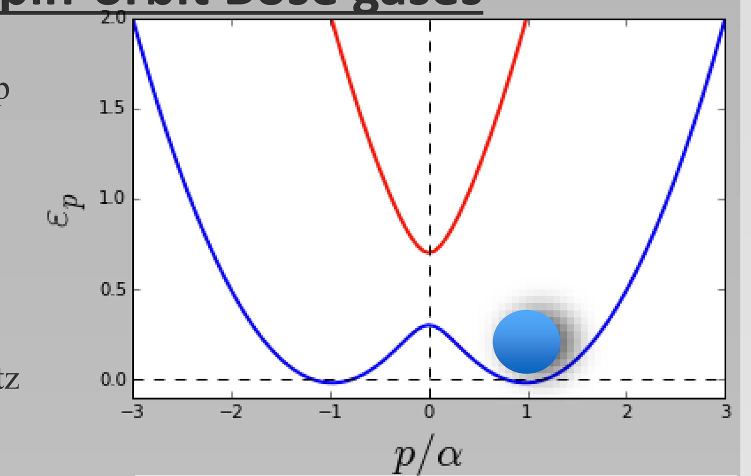
: Junhyun Lee, J. H. Pixley, Jay D. Sau

Phys. Rev. B 98, 245109 (2018)

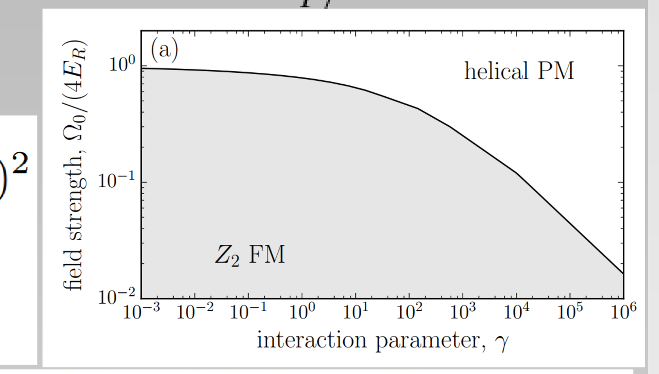


Lifshitz quantum criticality in spin-orbit Bose gases

Spin-orbit Bose gases that have been pioneered at the Spielman group at UMD, in one dimension, show a double minimum bandstructure, which leads to a Z_2 symmetry breaking Bose condensate into one or the other minimum. We showed that adding strong interactions can drive the system into a paramagnet phase as a result of strong phase fluctuations of the Bose condensate. Further more we were able to write the effective field theory for the quantum critical point to show that it was of the Lifshitz variety, which would have quite non-Lorentz invariant dynamics, which is unusual for critical points, that we are currently exploring.



$$\frac{\mathcal{L}}{\rho_0E_R}=(\partial_t\phi)^2-f(\partial_x^2\phi)^2+f\left(\frac{v_C}{v_S}\right)^2(\partial_t\partial_x\phi)^2$$
$$-(\zeta-f)(\partial_x\phi)^2-\frac{\zeta}{4}(\partial_x\phi)^4$$

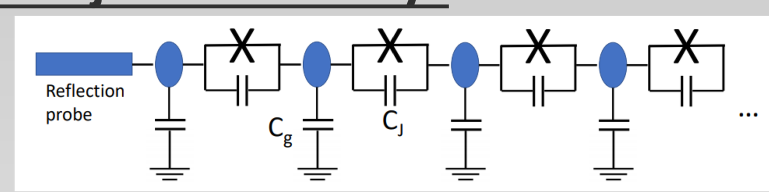


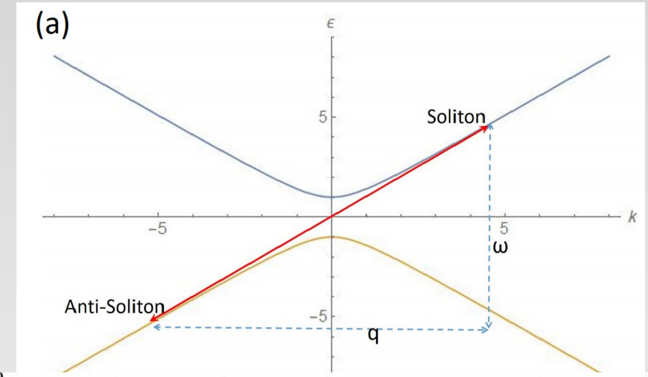
William S. Cole, Junhyun Lee, Khan W. Mahmud, Yahya Alavirad, I. B. Spielman, Jay D. Sau

Scientific Reports 9, Article number: 7471 (2019)

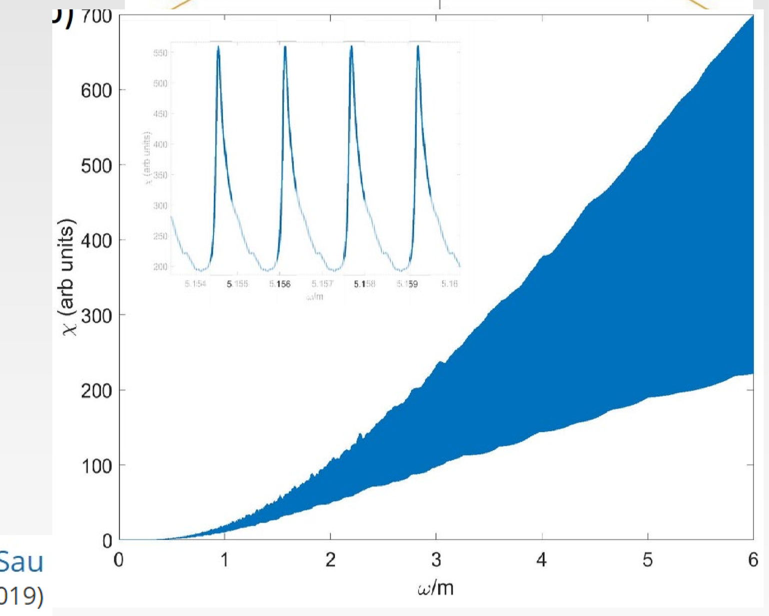
Soliton dynamics in Josephson junction arrays

Recent advances in microwave measurements at the Manucharyan group at UMD have made it possible to observe the dynamics across the superconductor-insulator transition in the Josphson junction array shown on the right. Among the perplexing observations were a sequence of broadened superfluid-like resonances in an otherwise insulating chain. We showed that these observations were qualitatively consistent with viewing the photons in these resonators as solion-antisoliton pairs in a Sine-Gordon model. Using the dispersion of solitons from previously known exact Bethe Ansatz solutions could be used to explain the dependence of the broadening on the impedance (Luttinger parameter) of the chain





$$\frac{dk}{d\omega}\sim(q^2+4m^2)^{4/3}(\omega-\sqrt{q^2+4m^2})^{-1/2}.$$
$$q=2\pi n/L$$
$$m=\Upsilon\left[g\frac{\pi\Gamma(1-K/2)}{4\Upsilon\Gamma(K/2)}\right]^{1/(2-K)}\frac{2\Gamma(\xi/2)}{\sqrt{\pi}\Gamma((1+\xi)/2)}$$

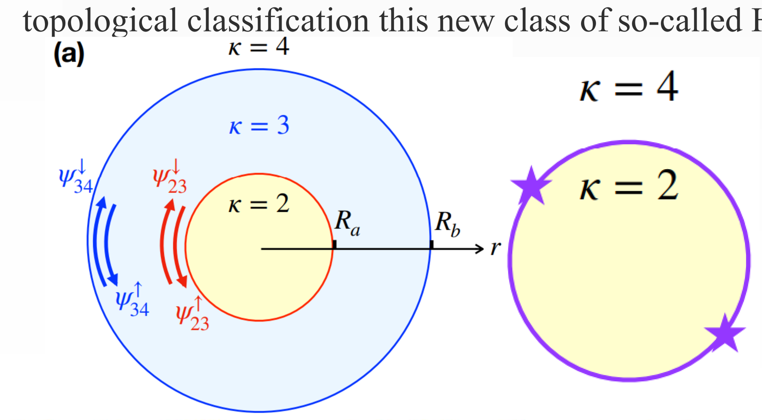


Huan-Kuang Wu, Jay D. Sau

Phys. Rev. B 99, 214509 (2019)

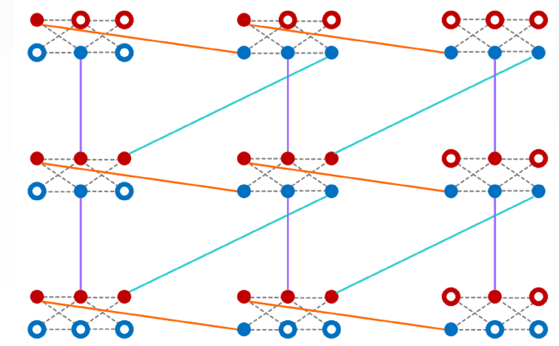
Higher order topological superconductors

Recently we proposed that a combination of quantum spin Hall and odd parity superconductivity could arise explain observed properties of WTe2, which would then support corner Majorana modes (see left panels below). Following this, we developed the topological classification this new class of so-called Higher order topological superconductors would follow (see right panels below)



Yi-Ting Hsu, William S. Cole, Rui-Xing Zhang, Jay D. Sau

arXiv:1904.06361



$$\Delta_{b,c,d}\equiv1\pmod 2$$
$$\Delta_i=n_i^{(W)}-n_i^{(A)}$$

Rui-Xing Zhang, Jay D. Sau, S. Das Sarma arXiv:2003.02559