Proseminar FS '14 – Topological Insulators and Superconductors

General Remarks

Topic of this Proseminar (abstract of Qi and Zhang review QZ1]: "Topological insulators are new states of quantum matter which cannot be adiabatically connected to conventional insulators and semiconductors. They are characterized by a full insulating gap in the bulk and gapless edge or surface states which are protected by time-reversal symmetry. These topological materials have been theoretically predicted and experimentally observed in a variety of systems, including HgTe quantum wells, BiSb alloys, and Bi2Te3 and Bi2Se3 crystals. Theoretical models, materials properties, and experimental results on two-dimensional and three-dimensional topological insulators are reviewed, and both the topological band theory and the topological field theory are discussed. Topological superconductors have a full pairing gap in the bulk and gapless surface states consisting of Majorana fermions. The theory of topological superconductors is reviewed, in close analogy to the theory of topological insulators."

The students give a 40–50 minutes presentation (see Wilkin's rules,

`http://www.physics.ohio-state.edu/~wilkins/`

and select the 'one-pagers' for hints on giving good talks), plus a 20–10 minute chalk-talk presentation (on the blackboard) of some specific (hard) calculation. Take into account that people will ask questions during the talk. Students are supposed to work in collaborative groups of 2–4 members depending on the specific topic. After the presentation, the candidate should answer questions from the audience. The talk should be in English (German only as a special exception)—students are supposed to explain clearly all the physics concepts associated with the problem, including experiments. The talk should show that the topic has been properly understood; during the 10–20 minutes chalk-talk, students are supposed to demonstrate their abilities to perform a difficult calculation and *explain* it properly (intimidation is not a substitute for clarity)—again, students have to prove that they understand what is being done. The time limits will be handled strictly. Each candidate should present either an experiment or a numerical analysis associated with the topic.

The references BAB, HK, QZ1, QZ2, and KM give a basic introduction/overview to the topic. The original literature (papers) should be studied. Criteria for obtaining the Credit Points: i) participate in the Python crash course and work out yourself a basic example of the bandstructure of a topological insulator, ii) give a presentation, iii) all students, but particularly group members, are expected to ask questions and participate in discussions, iv) be present in at least 80 % of all the sessions, v) hand in a written documentation of your talk, both the transparency part and the chalk-talk part. The documentation has to be written with LaTeX (RevTeX) in a usual paper style (about 6–8 PRB style pages), see Wilkins' rules and ask your assistant. The transparencies and the written reports will be collected in a book and handed out to all the students.

Supervisors

Evert van Nieuwenburg, Adel Benlagra (AdB), Oded Zilberberg (OZ), Andrei Lebedev (AL), Adrien Bouhon (AB), Alexey Soluyanov (AS), Lei Wang (LW), Volkher Scholz (VS), Sebastian Schmidt (SS).

Place HIT F12, Dates and Time (8:45-ca 11:30)

17.02. Evert van Nieuwenburg, Numerical Methods I, bring along a laptop, get a working Python distribution with the necessary packages; these can be found (works for Windows/Linux/Mac) under: https://www.enthought.com/products/canopy/academic/ (the academic version is free)

24.02. Evert van Nieuwenburg, Numerical Methods II

03.03. Band Structures (Roland Meier, meierola@student.ethz.ch)

10.03. Quantum Hall I (Patrick Haughian, phgh92@gmail.com; Ludovic Scyboz, scybozl@student.ethz.ch)

17.03. Quantum Hall II (PH; LS)

24.03. Graphene I (Marlon Azinovic, amarlon@student.ethz.ch; Tobias Wolf, wolft@student.ethz.ch)

31.03. Graphene II (MA; TW)

07.04. Topological Insulators I (Erik Cheah, echeah@student.ethz.ch; Johan Andberger, ajohan@student.ethz.ch)

14.04. Topological Insulators II (EC; JA)

05.05. Topological field theory (Florian Johne, fjohne@student.ethz.ch)

12.05. Topological Superconductors I (Poalo Molignini, paolomo@student.ethz.ch; Lennart Schmidt, schmidtl@student.ethz.ch)

19.05. Topological Superconductors II (PM; LS)

26.05. Classification of topological insulators and superconductors (Stefan Huber, stefanhuber@student.ethz.ch)

Topical Reviews

- X.L. Qi, S.C. Zhang (QZ2), The quantum spin Hall effect and topological insulators, Physics Today **63**, 33-38 (2010).
- C.L. Kane and J.E. Moore (KM), Topological Insulators, Physics World **24**, 32-36 (2011).
- B. Andrei Bernevig (BAB), *Topological Insulators and Topological Superconductors* (Princeton University Press, 2013).
- M.Z. Hasan and C.L. Kane (HK), *Colloquium:* Topological Insulators, Rev. Mod. Phys. **82**, 3045 (2010).
- X.-L. Qi and S.-C. Zhang (QZ1), Topological Insulators and Superconductors, Rev. Mod. Phys. **83**, 1057 (2011).
- M. König, H. Buhmann, L.W. Molenkamp, T.L. Hughes, C.X. Liu, X.L. Qi, S.C. Zhang, The quantum spin Hall effect: theory and experiment, arXiv preprint arXiv:0801.0901.

Topics

Solving Matrix Problems Numerically with Python (all): Crash course in Python. Every participant works out a basic example of the bandstructure of a topological insulator, see also

`http://www.physics.rutgers.edu/pythtb/`

* Monday February 17, course by Evert van Nieuwenburg, 2h lecture + 1h supervised self-training, implementation of lattice setup, Hamiltonian, diagonalization.

* Monday February 24, course by Evert van Nieuwenburg, 2h lecture + 1h supervised self-training, use of package: wave functions, Brilloun Zone, Chern number, TRIMS, Z_2 index for inversion symmetric TI.

Band Structures (6 Sem): Symmetries, Translation and Point Groups, Time Reversal (without/with Spin), Symmetry Classification of Bands, Spin-Orbit Coupling, Double Groups, Band Inversion, Surface States, all with a view on Topological Insulators, i.e., tight binding with typically 4 bands in 2D, maybe 3D

- N. Ashcroft and D. Mermin, *Solid State Physics* (Holt, Reichart & Winston, 1976).
- C. Kittel, *Quantum Theory of Solids* (John Wiley, 1963).
- J.M. Ziman, *Principles of the Theory of Solids* (Cambridge, 1972).
- F. Bassani and G. Pastori-Parravicini, *Electronic States and Optical Transitions in Solids*, Pergamon, 1975.
- Landau Lifshitz, Quantum Mechanics.
- J.F. Cornwell, *Group Theory in Physics* (Academic Press, 1984).
- A.W. Joshi, *Elements of Group Theory for Physicists* (Wiley Eastern Limited, 3rd edition, 1982).
- G.F. Koster, J.O. Dimmock, R.G. Wheeler, and H. Statz, *Properties of the thirty-two point groups* (MIT Press, 1963).
- *International Table for Crystallography* (D. Reidel Publ. Comp., 1983).
- S.C. Miller and W.F. Love, *Tables of Irreducible Representations of Space Groups and Co-Representations of Magnetic Space Groups* (Pruett Press, 1967).

Specific Talks on:

* Crystal systems, Point- and Space Groups, (irreducible) Representations, Examples (rotations, SO_3, O_h, D_{4h}, D_{2h} (symmetry reduction), inversion) (VS).

* Bloch Theorem, Brillouin Zone, Spin 1/2 and Double Groups, Time Reversal and Kramer's Theorem, Symmetry Reduction in BZ, Bandstructures, Spin-Orbit interaction, Examples (free electrons in cubic crystal, diamond, GaAs, sequence C–Si–Ge–Sn–Pb with Spin-Orbit interaction) (VS).

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Quantum Hall Effect (6): Free Electrons in a Magnetic Field, Gauges, Gauge invariance, Linear Response Theory, Hall Effect and Conductance (transverse and longitudinal transport), Shubnikov De Haas and Hall Quantization, Laughlin Pump, Disorder, Edge States, 2D QHE on a Lattice, Magnetic Translation Group, Hofstadter Problem, Diophantic Equation, Berry Phase, Chern Number, Gauge Obstruction, Bulk-Edge Correspondence, Chern insulator.
Play with Hofstadter problem/IQHE on a superlattice structure without/with boundaries and generate Figs. 6.3 and 6.4 in BAB. Play with model Chern Insulator 8.17 and generate Fig. 8.2 as a function of M in BAB.

- D.R. Yennie, Integral quantum Hall effect for nonspecialists, Rev. Mod. Phys. **59**, 781-824 (1987).
- R.E. Prange and S.M. Girvin, The Quantum Hall Effect, Graduate Texts in Contemporary Physics, Springer, 1990, 2nd edition.
- S.M. Girvin, Les Houches Lectures on *The Quantum Hall Effect: Novel Excitations and Broken Symmetries*, http://arxiv.org/pdf/cond-mat/9907002.pdf
- M.V. Berry, Quantal Phase Factors Accompanying Adiabatic Changes, Proceedings of the Royal Society of London A, Mathematical and Physical Sciences **392**, 45-57 (1984).
- Di Xiao, Ming-Che Chang, Qian Niu, Berry phase effects on electronic properties, Rev. Mod. Phys. **82**, 1959-2007 (2010).
- D.J. Thouless, M. Kohmoto, M.P. Nightingale, and M. den Nijs, Quantized Hall Conductance in a Two-Dimensional Periodic Potential, Phys Rev. Lett. **49**, 405-408 (1982).
- B.I. Halperin, Quantized Hall conductance, current-carrying edge states, and the existence of extended states in a two-dimensional disordered potential, Phys. Rev. B **25**, 2185 (1982).
- Yasuhiro Hatsugai, Chern number and edge states in the integer quantum Hall effect, Phys. Rev. Lett. **71**, 3697-3700 (1993).
- Takahiro Fukui, Yasuhiro Hatsugai, and Hiroshi Suzuki, Chern Numbers in Discretized Brillouin Zone: Efficient Method of Computing (Spin) Hall Conductances, J. Phys. Soc. Jap. **74**, 1674-1677 (2005).

Specific Talks on:

* Electrons in a magnetic field, transport in linear response, longitudinal and transverse, Shubnikov de Haas Oscillations at weak field, quantum Hall effect at strong fields, Laughlin pump, bulk-edge correspondence, experiments (OZ).
* Berry phase, Chern number, gauge obstruction, magnetic translation group, TKNN and band structure with chiral edge states, diophantine equation (OZ).
* implementation of TKNN and Hofstadter problems in Python, with edge states (OZ).

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Graphene (6): Bandstructure, Dirac Fermions, Quantum Hall Effect, Gap Opening Terms, Zig-Zag and Arm-Chair Boundaries, Edge States, Haldane Model.
Play with bandstructure of Graphene including edge states. Generate Figs. 7.8 to 7.14 for various edge types. Include Haldane mass and generate Figs. 7.15 to 7.18.

- P.R. Wallace, The Band Theory of Graphite, Phys. Rev. **71**, 622 (1947).
- D.P. DiVincenzo and E.J. Mele, Self-consistent effective-mass theory for intralayer screening in graphite intercalation compounds, Phys. Rev. B **29**, 1685 (1984).
- A.K. Geim and K.S. Novoselov, The rise of graphene, Nature Materials **6**, 185 (2007).
- Y. Yao, F. Ye, X.L. Qi, S.C. Zhang, Z. Fang, Spin-orbit gap of graphene: First-principles calculations, Phys. Rev. B **75**, 041401 (2007).
- Wang Yao, Shengyuan A. Yang, and Qian Niu, Edge States in Graphene: From Gapped Flat-Band to Gapless Chiral Modes, Phys. Rev. Lett. **102**, 096801 (2009).
- V.P. Gusynin and S.G. Sharapov, Unconventional Integer Quantum Hall Effect in Graphene, Phys. Rev. Lett. **95**, 146801 (2005).
- F.D.M. Haldane, Model for a Quantum Hall Effect without Landau Levels: Condensed-Matter Realization of the "Parity Anomaly", Phys. Rev. Lett. **61**, 2015 (1988).
- C.L. Kane and E.J. Mele, Z_2 Topological Order and the Quantum Spin Hall Effect, Phys. Rev. Lett. **95**, 146802 (2005).
- C.L. Kane and E.J. Mele, Quantum Spin Hall Effect in Graphene, Phys. Rev. Lett. **95**, 226801 (2005).
- J. Li, I. Martin, M. Büttiker, and A.F. Morpurgo, Marginal topological properties of graphene: a comparison with topological insulators, Phys. Scr. **T146**, 014021 (2012).
- J. Li, I. Martin, M. Büttiker, and A.F. Morpurgo, Topological origin of subgap conductance in insulating bilayer graphene, Nature Physics **7**, 38 (2011).
- J. Li, A.F. Morpurgo, M. Büttiker, and I. Martin, Marginality of bulk-edge correspondence for single-valley Hamiltonians, Phys. Rev. B **82**, 245404 (2010).
- Conan Weeks, Jun Hu, Jason Alicea, Marcel Franz, and Ruqian Wu, Engineering a Robust Quantum Spin Hall State in Graphene via Adatom Deposition, Phys. Rev. X **1**, 021001 (2011).

Specific Talks on:

* Graphene, Bandstructure, Quantum Hall Effect, Edge states for different edge types, bandstructures with edge states (LW).
* Graphene as a topological insulator (Kane Mele), induced spin-orbit effect (LW).
* Chern insulator, Haldane model (LW).

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Topological Insulators (6,8): Model Topological Insulator, HgTe Quantum Wells, 2D and 3D Generic Material and Properties, Experiments, Classification via Z_2 Invariants: Z_2 Invariant defined by Pfaffian for 1D, 2D, and 3D TR ti, Zero of Pfaffian versus Product Formula, Concept of Charge Polarization, Bulk-Edge Correspondence, Gauge Obstruction (including relation to charge polarization/TR polarization), Inversion Symmetry (IS).
Play with Haldane model versus TR top-insulator (show that 2 * HM = TR ti, 9.15) in BAB. Play with generic 4 by 4 Hamiltonian 9.35. Generate something like Fig. 9.1 on page 116. Play with HgTe quantum wells, pages 118 to 121. Try to understand and illustrate the appearance of the TR ti phase as a function of width of the well. Illustrate with an example the structure of the Pfaffian of a TR ti. Illustrate the role of TRIMs and the TRIM product formula. Show with an example how the Pfaffian zeros move through the BZ and how the product fomula changes. Illustrate the connection to Gauge choice obstruction with an example. Show change of bandstructure when including IS and illustrate new Pfaffian with product over inversion eigenvalues with specific examples, including parametric evolution between different phases. Definition of charge polarization/time reversal polarization and edge states/currents, if possible give a specific example how the charges evolve under parameter tuning for a topologically trivial and non-trivial material.

Theory (topological band theory)

- B.A. Bernevig and S.C. Zhang, Quantum Spin Hall Effect, Phys. Rev. Lett. **96**, 106802 (2006).
- B.A. Bernevig, T.L. Hughes, S.C. Cheng Zhang, Quantum Spin Hall Effect and Topological Phase Transition in HgTe Quantum Wells, Science **314**, 1757-1761 (2006).
- C.L. Kane and E.J. Mele, Z2 Topological Order and the Quantum Spin Hall Effect, Rev. Lett. **95**, 146802 (2005).
- C.L. Kane and E.J. Mele, Quantum Spin Hall Effect in Graphene, Phys. Rev. Lett. **95**, 226801 (2005).
- Liang Fu and C.L. Kane, Topological Insulators with Inversion Symmetry, Phys. Rev. B **76**, 045302 (2007).
- Liang Fu, C.L. Kane and E.J. Mele, Topological Insulators in Three Dimensions, Phys. Rev. Lett. **98**, 106803 (2007).
- C.X. Liu, X.L. Qi, H.J. Zhang, X. Dai, Z. Fang, S.C. Zhang, Model Hamiltonian for topological insulators, Phys. Rev. B **82**, 045122 (2010).
- Takahiro Fukui, Yasuhiro Hatsugai, and Hiroshi Suzuki, Chern Numbers in Discretized Brillouin Zone: Efficient Method of Computing (Spin) Hall Conductances, J. Phys. Soc. Jap. **74**, 1674-1677 (2005).
- Takahiro Fukui and Yasuhiro Hatsugai, Quantum Spin Hall Effect in Three Dimensional Materials: Lattice Computation of Z2 Topological Invariants and Its Application to Bi and Sb, J. Phys. Soc. Jpn. **76**, 053702 (2007).

- J.E. Moore and L. Balents, Topological invariants of time-reversal-invariant band structures, Phys. Rev. B 75, 121306(R) (2007).
- Rahul Roy, Topological phases and the quantum spin Hall effect in three dimensions, Phys. Rev. B **79**, 195322 (2009).
- Xiao-Liang Qi, Yong-Shi Wu, and Shou-Cheng Zhang, Topological quantization of the spin Hall effect in two-dimensional paramagnetic semiconductors, Phys. Rev. B **74**, 085308 (2006).
- R.D. King-Smith and David Vanderbilt, Theory of polarization of crystalline solids, Phys. Rev. B **47**, 1651-1654 (1993).
- R. Resta, Macroscopic polarization in crystalline dielectrics: the geometric phase approach, Rev. Mod. Phys. **66**, 899 (1994).
- Liang Fu and C.L. Kane, Time reversal polarization and a Z2 adiabatic spin pump, Phys. Rev. B **74**, 195312 (2006).
- A.A. Soluyanov and D. Vanderbilt, Computing topological invariants without inversion symmetry, Phys. Rev. B **83**, 235401 (2011).
- Rui Yu, Xiao Liang Qi, Andrei Bernevig, Zhong Fang, and Xi Dai, Equivalent expression of Z2 topological invariant for band insulators using the non-Abelian Berry connection, Phys. Rev. B **84**, 075119 (2011).
- Emil Prodan, Manifestly gauge-independent formulations of the Z2 invariants, Phys. Rev. B **83**, 235115 (2011).
- Congjun Wu, B. Andrei Bernevig, and Shou-Cheng Zhang, Helical Liquid and the Edge of Quantum Spin Hall Systems, Phys. Rev. Lett. **96**, 106401 (2006).
- Cenke Xu and J.E. Moore, Stability of the quantum spin Hall effect: Effects of interactions, disorder, and Z2 topology, Phys. Rev. B **73**, 045322 (2006).

2D Materials

- B.A. Bernevig, T.L. Hughes, S.C. Cheng Zhang, Quantum Spin Hall Effect and Topological Phase Transition in HgTe Quantum Wells, Science **314**, 1757-1761 (2006).
- M. König, S. Wiedmann, C. Brüne, A. Roth, H. Buhmann, L.W. Molenkamp, X.L. Qi, S.C. Zhang, Quantum spin Hall insulator state in HgTe quantum wells, Science **318**, 766-770 (2007).
- C. Liu, T.L. Hughes, X.L. Qi, K. Wang, S.C. Zhang, Quantum spin Hall effect in inverted type-II semiconductors, Phys. Rev. Lett. **100**, 236601 (2008). (InAs/GaSb/AlSb quantum wells)
- A. Roth, C. Brüne, H. Buhmann, L.W. Molenkamp, J. Maciejko, X.L. Qi, S.C. Zhang, Nonlocal transport in the quantum spin Hall state, Science **325**, 294-297 (2009).
- Seongshik Oh, The Complete Quantum Hall Trio, Science **340**, 153 (2013) (Quantum anomalous Hall effect).

- Cui-Zu Chang, Jinsong Zhang, Xiao Feng, Jie Shen, Zuocheng Zhang, Minghua Guo, Kang Li, Yunbo Ou, Pang Wei, Li-Li Wang, Zhong-Qing Ji, Yang Feng, Shuaihua Ji, Xi Chen, Jinfeng Jia, Xi Dai, Zhong Fang, Shou-Cheng Zhang, Ke He, Yayu Wang, Li Lu, Xu-Cun Ma, Qi-Kun Xue, Experimental Observation of the Quantum Anomalous Hall Effect in a Magnetic Topological Insulator (Chern Insulator), Science **340**, 167 (2013).

3D Materials

- D. Hsieh, D. Qian, L. Wray, Y. Xia, Y.S. Hor, R.J. Cava, and M.Z. Hasan, A topological Dirac insulator in a quantum spin Hall phase, Nature **452**, 970-974 (2008).
- H. Zhang, C.X. Liu, X.L. Qi, X. Dai, Z. Fang, S.C. Zhang, Topological insulators in Bi2Se3, Bi2Te3 and Sb2Te3 with a single Dirac cone on the surface, Nature Physics **5**, 438-442 (2009).
- D. Hsieh, D. Qian, L. Wray, Y. Xia, Y.S. Hor, R.J. Cava, and M.Z. Hasan, A topological Dirac insulator in a quantum spin Hall phase, Nature **452**, 970-974 (2008). (ARPES on Bii-0.9i Sb-0.1)
- Y.L. Chen, J.G. Analytis, J.H. Chu, Z.K. Liu, S.K. Mo, X.L. Qi, H.J. Zhang, D.H. Lu, X. Dai *et al*, Experimental realization of a three-dimensional topological insulator Bi2Te3, Science **325**, 178-181 (2009).
- Y. Zhang, K. He, C.Z. Chang, C.L. Song, L.L. Wang, X. Chen, J.F. Jia, Z. Fang, X. Dai, *et al*, Crossover of the three-dimensional topological insulator Bi2Se3 to the two-dimensional limit, Nature Physics **6**, 584-588 (2010).
- Y.L. Chen, J.H. Chu, J.G. Analytis, Z.K. Liu, K. Igarashi, H.H. Kuo, X.L. Qi, S.K. Mo, Massive Dirac fermion on the surface of a magnetically doped topological insulator, Science **329**, 659-662 (2010).
- Y. Xia, D. Qian, D. Hsieh, L. Wray, A. Pal, H. Lin, A. Bansil, D. Grauer, Y.S. Hor, R.J. Cava and M.Z. Hasan, Observation of a large-gap topological-insulator class with a single Dirac cone on the surface, Nature Physics **5**, 398 - 402 (2009).
- D. Hsieh, Y. Xia, D. Qian, L. Wray, F. Meier, J.H. Dil, J. Osterwalder, L. Patthey, A.V. Fedorov, H. Lin, A. Bansil, D. Grauer, Y.S. Hor, R.J. Cava, and M.Z. Hasan, Observation of Time-Reversal-Protected Single-Dirac-Cone Topological-Insulator States in Bi2Te3 and Sb2Te3, Phys. Rev. Lett. **103**, 146401 (2009),

Specific Talks on:

* Generic model for 2D quantum spin Hall insulators/topological insulator, experiments with HgTe quantum well, InAs/GaSb/AlSb quantum well. Generic 4-band TI for quantum spin Hall, write a package in Python (AS).
* Topological invariants for 2D topological insulators, Pfaffian, TR polarization (topological band theory). Inversion symmetric topological insulators (AS).
* Topological invariants for 2D topological insulators, TRIMs, TR polarization and comparison with Pfaffian zeros (topological band theory) (AS).

* Model 3D topological insulators, experiments. Topological invariants for 3D topological insulators, weak and strong 3D topological insulators (topological band theory) (AS).

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Topological field theory, QHE and Chern Insulators in Higher Dimension (8): Chern-Simons Theory, Effective Actions, higher Chern Nnumbers and their use TR-IS 3D ti, Charge Polarization for a Projected 4D CI → 3D TR ti, Electromagnetic Response with Topological Terms in the Action, Axion Electrodynamics.
Derive effective CS action for the electromagnetic field by integration over Fermions, derive C_2 and maybe higher Chern numbers, explain their description of winding, electrodynamics on the surface of a 3D ti. Explain the interrelation of the Z_2 index and the C_2 index for a TR-IS 3D ti. Explain electromagnetism generated by topological terms.

- S.C. Zhang, Topological field theory and the discovery of topological materials, Phys. Scr. **T146**, 014022 (2012).
- Xiao-Liang Qi, Taylor Hughes, Shou-Cheng Zhang, Topological field theory of time-reversal invariant insulators, Phys. Rev. B **78**, 195424 (2008).
- X.L. Qi, R. Li, J. Zang, S.C. Zhang, Inducing a magnetic monopole with topological surface states, Science **323**, 1184-1187 (2009).
- Andrew M. Essin, Joel E. Moore, and David Vanderbilt, Magnetoelectric Polarizability and Axion Electrodynamics in Crystalline Insulators, Phys. Rev. Lett. **102**, 146805 (2009).
- R. Li, J. Wang, X.L. Qi, S.C. Zhang, Dynamical axion field in topological magnetic insulators, Nature Physics **6**, 284-288 (2010).

Specific Talks on:

* Topological field theory (Chern Simons), effective actions for electromagnetic response, higher Chern numbers (AdB).
* Dimensional reduction to a 3D topological insulator, electromagnetism of topological insulators (AdB).

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Topological Superconductors (8): BdG formulation of mean-field superconductors, trivial non-trivial phases and transition, p-wave in 1D (Kitaev), p+ip-wave in 2D, majorana states, vortices, topological quantum computing (Ivanov), layered (QSH, Ferro, Super) systems
Play with BdG bandstrucures and illustrate topological transition as a function of μ. Discuss boundaries of non-trivial-topological superconductor to trivial ts and nt ts to insulator (vacuum), show parametric evolution of bandstructures and appearance of majorana modes at boundaries. discuss various geometries (2D), plane (strip), cylinder, disc, inclusion of flux and shift of spectrum (spectral flow of e/2 states in the gap with changing flux, installation of zero-energy majoranas at flux π), show non-abelian properties of majoranas trapped in vortices and discuss topological quantum computing (generation of full set of gates, Bonesteel).

- X.L. Qi, T.L. Hughes, S. Raghu, S.C. Zhang, Time-reversal-invariant topological superconductors and superfluids in two and three dimensions, Phys. Rev. Lett. **102** (18), 187001 (2009).
- Liang Fu and C.L. Kane, Superconducting Proximity Effect and Majorana Fermions at the Surface of a Topological Insulator, Phys. Rev. Lett. **100**, 096407 (2008).
- X.L. Qi, T.L. Hughes, S.C. Zhang, Fractional charge and quantized current in the quantum spin Hall state (on another note), Nature Physics **4**, 273-276 (2008).
- Liang Fu and Erez Berg, Odd-Parity Topological Superconductors: Theory and Application to CuxBi2Se3, Phys. Rev. Lett. **105**, 097001 (2010).
- R.M. Lutchyn, J.D. Sau, and S. Das Sarma, Majorana Fermions and a Topological Phase Transition in Semiconductor-Superconductor Heterostructures, Phys. Rev. Lett. **105**, 077001 (2010).
- Yuval Oreg, Gil Refael, and Felix von Oppen, Helical Liquids and Majorana Bound States in Quantum Wires, Phys. Rev. Lett. **105**, 177002 (2010).
- V. Mourik, K. Zuo, S.M. Frolov, S.R. Plissard, E.P.A.M. Bakkers, L.P. Kouwenhoven, Signatures of Majorana Fermions in Hybrid Superconductor-Semiconductor Nanowire Devices, Science **336**, 1003-1007 (2012).

Specific Talks on:

* Mean field theory of superconductors, BdG. Unconventional superconductors (AB).

* Topological Superconductors in 1D, Majoranas and Kitaev model, 1D quantum wire realization (AB).

* Topological Superconductors in 2D, $p+ip$ superconductor, Majorana edge states, Vortices (AB).

* (Topological quantum computation with Majoranas (VS)).

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Classification of topological insulators and superconductors (8): Symmetries, dimensionalities, invariants, classification table (Schnyder)
Derive classification table, show what is behind and how to use it with specific examples.

- A.P. Schnyder, S. Ryu, A. Furusaki, A.W.W. Ludwig, Classification of topological insulators and superconductors in three spatial dimensions, Phys. Rev. B **78**, 195125 (2008).
- Alexei Kitaev, Periodic table for topological insulators and superconductors, arXiv:0901.2686 (2009).

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Specific Talks on:

* From classification of random matrices ... (Altland-Zirnbauer) (AL).
* ... to classification of topological materials (AL).

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Topological Insulators with higher symmetries (8): Point groups, generic tight-binding Hamiltonians from symmetry consideration
Illustrate parametric evolution of bandstructures generated by such high symmetry systems.

- Liang Fu, Topological Crystalline Insulators Phys. Rev. Lett. **106**, 106802 (2011).
- T.L. Hughes, E. Prodan, and B.A. Bernevig, Inversion-symmetric topological insulators, Phys. Rev. B **83**, 245132 (2011).
- A.M. Turner, Yi Zhang, R.S.K. Mong, A. Vishwanath, Quantized Response and Topology of Insulators with Inversion Symmetry, Phys. Rev. B **85**, 165120 (2012).
- T.H. Hsieh, H. Lin, J. Liu, W. Duan, A. Bansil, Liang Fu, Topological Crystalline Insulators in the SnTe Material Class, Nature Communications **3**, 982 (2012).
- P. Dziawa, B.J. Kowalski, K. Dybko, R. Buczko, A. Szczerbakow, M. Szot, E. Kusakowska, T. Balasubramanian, B.M. Wojek, M.H. Berntsen, O. Tjernberg, and T. Story, Topological crystalline insulator states in Pb1-xSnxSe, Nature Materials **11**, 1023-1027 (2012).
- Y. Tanaka, Zhi Ren, T. Sato, K. Nakayama, S. Souma, T. Takahashi, Kouji Segawa, and Yoichi Ando, Experimental realization of a topological crystalline insulator in SnTe, Nature Physics **8**, 800-803 (2012).

Specific Talks on:

* Topological Crystalline Insulators (AB)

Photonic topological insulator Implementing a topological insulator through light-matter interaction

- Netanel H. Lindner, Gil Refael and Victor Galitski, Floquet topological insulator in semiconductor quantum wells, Nature Physics **7**, 490-495 (2011).
- Mikael C. Rechtsman, Julia M. Zeuner, Yonatan Plotnik, Yaakov Lumer, Daniel Podolsky, Felix Dreisow, Stefan Nolte, Mordechai Segev, and Alexander Szameit, Photonic Floquet topological insulators, Nature **496**, 196-200 (11 April 2013).

Specific Talks on:

* Photonic Topological Insulators (SS)