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Experimental realization of new topological phases of matter beyond topological insulators

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A three-dimensional (3D) Z_2 topological insulator (TI) is a crystalline solid, which is an insulator in the bulk but features spin-polarized Dirac electron states on its surface. In 2007, the first 3D TI was discovered in a bismuth-based compound. The discovery of the first TI tremendously accelerated research into phases of matter characterized by non-trivial topological invariants. Not only did the 3D Z_2 TI itself attract great research interest, it also inspired the prediction of a range of new topological phases of matter. The primary examples are the topological Kondo insulator, the topological 3D Dirac and Weyl semimetals, the topological crystalline insulator, topological nodal line semimetal and the topological superconductor. Each of these phases was predicted to exhibit surface states with unique properties protected by a non-trivial topological invariant. In this talk, I will discuss the experimental realization of these new phases of matter in real materials by momentum and time-resolved photoemission spectroscopy. Special attention will be given to the experimental discovery of Dirac semimetal phase in Cd_3As_2 and topological nodal-line phase in $PbTaSe_2$. The unusual properties of the protected topological surface states can lead to potential future applications in spintronics and quantum information, which hold promise to revolutionize our electronics and energy industries. *This work is supported by start-up funds from University of Central Florida (MN) and Los Alamos National Laboratory LDRD program. The work at Princeton and Princeton-led ARPES measurements are supported by the Gordon and Betty Moore Foundations EPiQS Initiative through grant GBMF4547 (Hasan) and by U.S. Department of Energy DE-FG-02-05ER46200.*