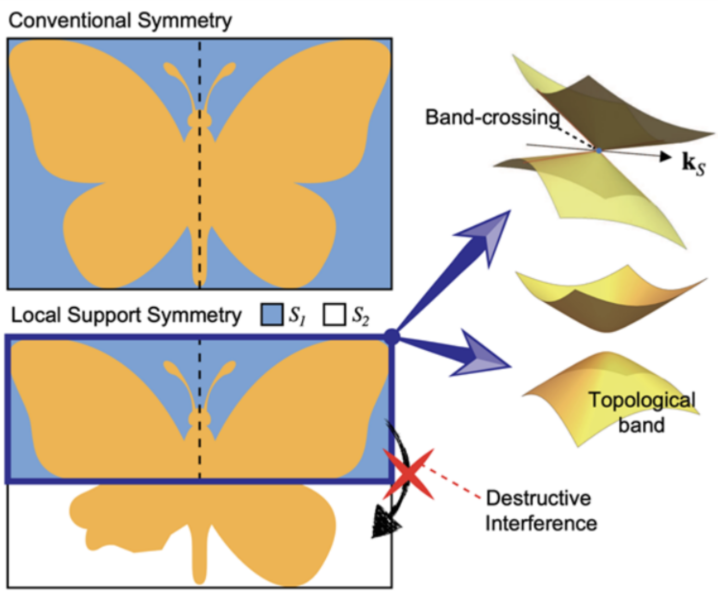
Topological states protected by local support symmetry and destructive interference

Jun Won Rhim[1], Jaeuk Seo[2], Seongjun Mo[3], Hoonkyung Lee[3], Sejoong Kim[4], B. Andrei Bernevig[5]

[1]Ajou University, Suwon, South Korea, [2]Korea Advanced Institute of Science and Technology, Daejeon, South Korea, [3]Konkuk University, Seoul, South Korea, [4]Hongik University, Sejong, South Korea, [5]Princeton University, Princeton, USA



Symmetry has played a central role in the classification and protection of topological phases over the past two decades. In conventional understanding, symmetry-protected topological (SPT) phases and symmetry-enforced band crossings require that the protecting symmetry acts globally on the entire system. This assumption has underpinned the theoretical framework of topological insulators, topological crystalline insulators, and various Dirac and nodal semimetals. In this work, we demonstrate that this long-standing premise is not a necessary condition. We introduce a generalized protection mechanism based on local support symmetry (LSS), whereby a symmetry preserved only within a subregion of a system can protect topological features of the full system, even in the presence of symmetry-breaking couplings, if it is assisted by the destructive interference, which is the key mechanism for the stabilization of flat bands.

We consider systems partitioned into two subsystems, S1 and S2, where the protecting symmetry is respected in S1 but explicitly broken in S2. We derive explicit algebraic conditions under which topological invariants and band crossings remain robust despite inter-part coupling. In insulating phases, we show that if the inter-part coupling satisfies an orthogonality condition with respect to the occupied eigenstates of S1, the topological invariant of the full system remains identical to that of the symmetric subsystem. In semimetallic phases, we establish momentum-space compatibility conditions under which band crossings along symmetry-invariant lines are preserved. In both cases, destructive interference of Bloch wave functions plays a crucial role: compactly supported states confined to S1 prevent symmetry-breaking perturbations from hybridizing with the protected states.

We illustrate the general theory using representative tight-binding models. First, we construct a topological insulator model protected by a local support time-reversal symmetry, where helical edge modes persist even though global time-reversal symmetry is broken. Second, we demonstrate Dirac band crossings protected by local support crystalline C2 symmetry. Third, we show symmetry-enforced crossings stabilized by a local support nonsymmorphic screw symmetry. In each example, the robustness of the band features is quantitatively analyzed via a fragility parameter measuring gap opening under perturbations.

Finally, we present a realistic material realization based on density functional theory calculations for a fluorinated biphenylene network. Although global C2y symmetry is broken by fluorination, massive Dirac dispersions exhibit anomalously small gaps. We show that these originate from approximate local support symmetry combined with destructive interference, consistent with our theoretical framework.

Our results redefine the minimal conditions for symmetry protection and extend the conceptual foundations of topological matter beyond global symmetry requirements.