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New Paradigms for Topological Matter

Theory group of Tomáš Bzdušek

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learn more:

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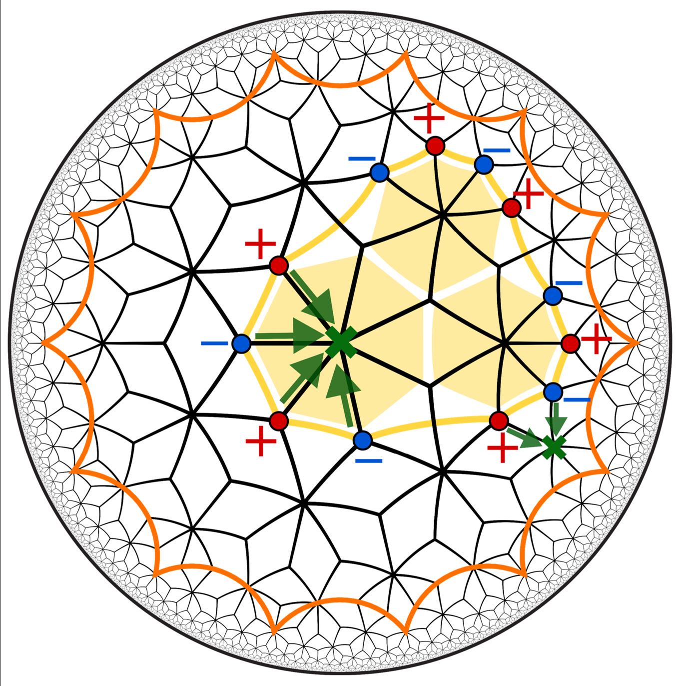
What we do

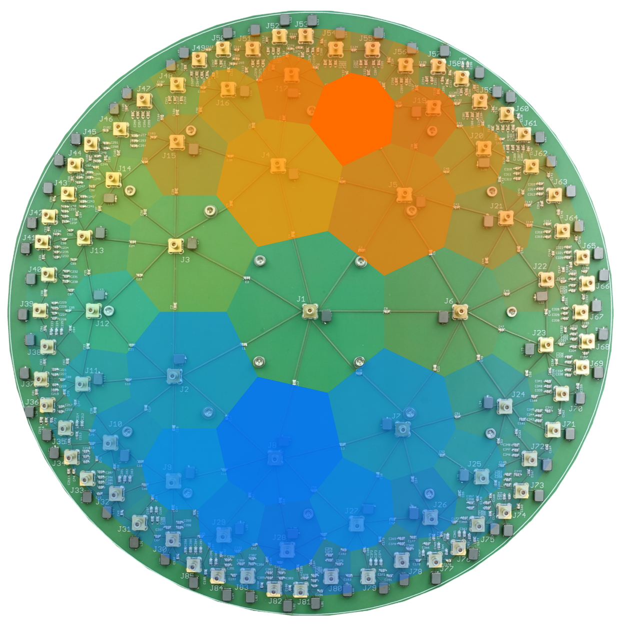
We study the mathematical characterization and physical manifestations of **topological phases of matter**. This includes topological aspects of electron energy bands in crystalline solids, notably in topological insulators, (semi)metals, and superconductors. In addition, we consider artificial (e.g. hyperbolic) lattices and also non-equlibrium (driven and dissipative) systems. The research group will fully launch in the fall of 2023, but we can already take on bachelor and master students!

Flat bands and correlations



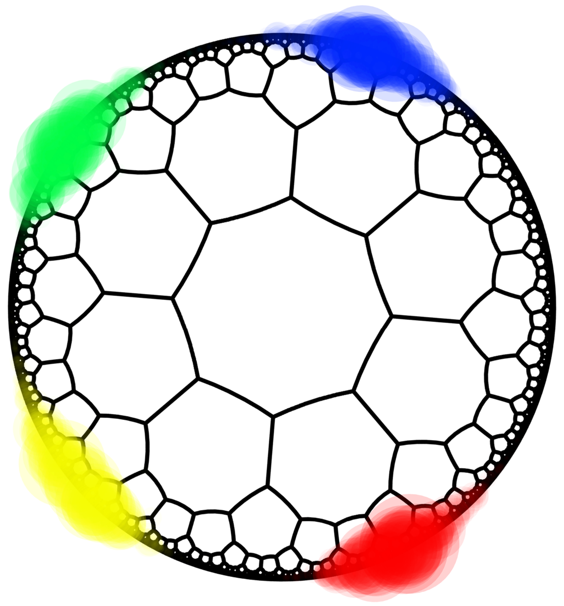
In models with **dispersionless (flat) bands**, the kinetic energy is small, and the physics is **dominated by particle interactions**. We aim to study correlated phases in hyperbolic lattices (with and without flat bands).

Artificial lattices (metamaterials)



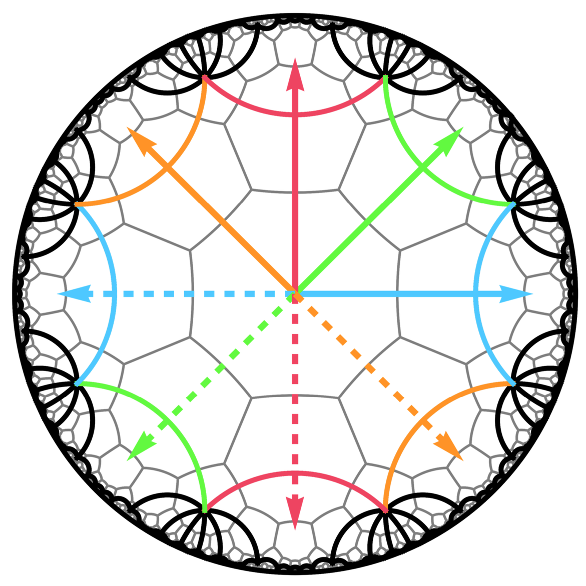
Metamaterials (such as electric-circuit networks, or coupled photon resonators) allow for **controlled experimental realizations** of designed systems on **arbitrary lattices**. Even lattices in negatively curved space, which can't be realized with crystalline solids, can be emulated.

Hyperbolic topological insulators

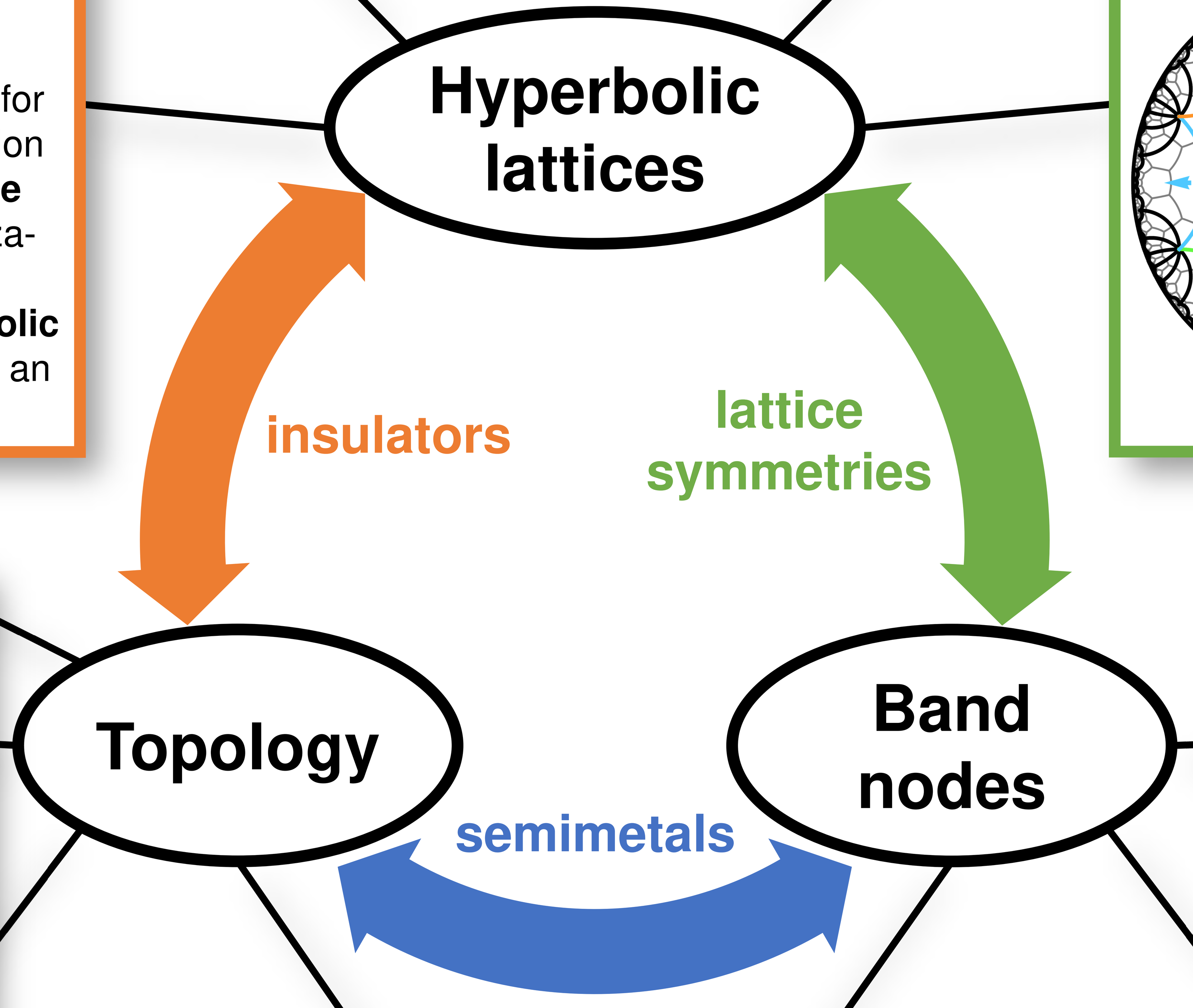


Hyperbolic lattices have an **extensive boundary**, which might be favorable for an efficient realization of **topological edge states**. Characterization of topological states with **hyperbolic band theory** is still an open problem.

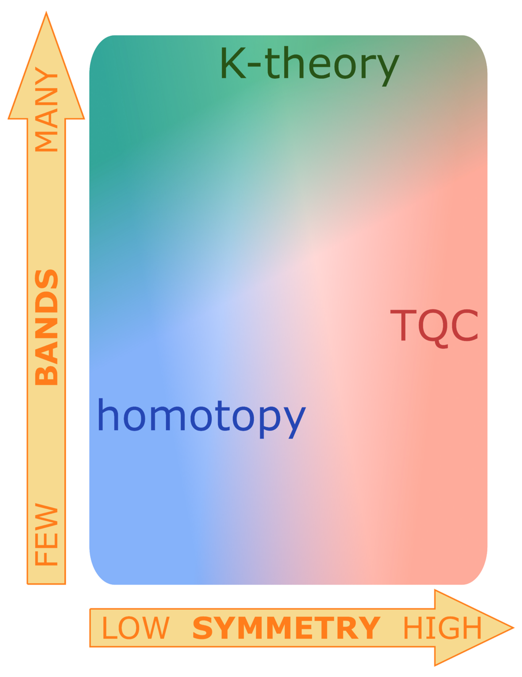
Translation symmetry



Translations in hyperbolic lattices **do not commute**. This has important consequences for the hyperbolic extension of the (Bloch) band theory; for example, the **Brillouin zone** becomes **higher-dimensional**.

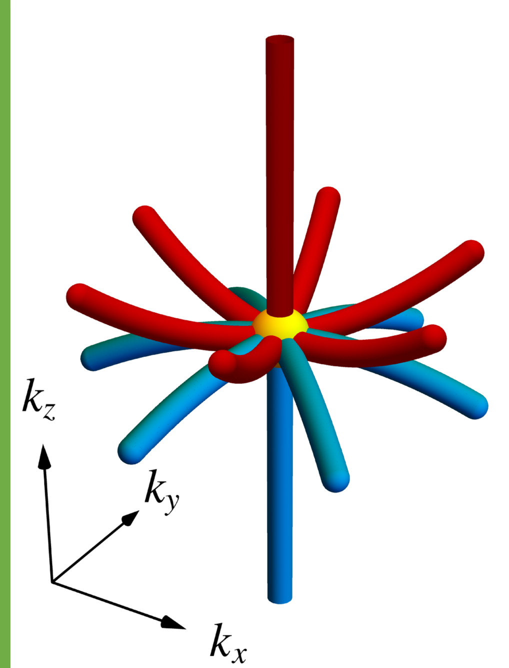


Classification of topological invariants



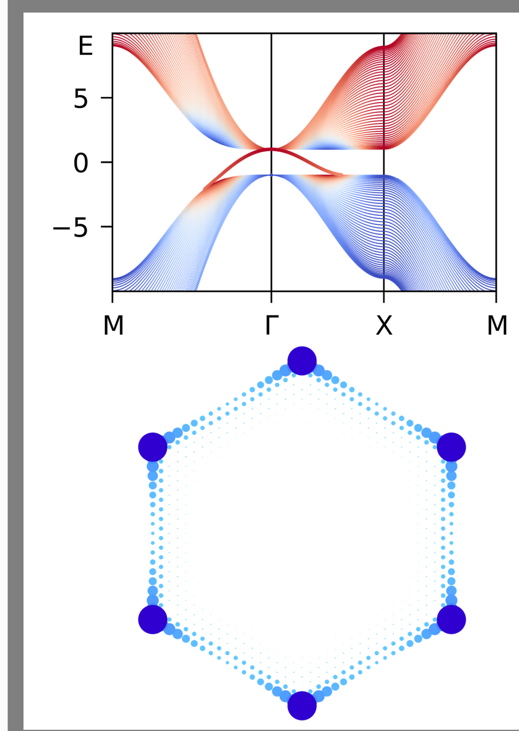
Depending on the **symmetry** and the available **degrees of freedom**, diverse mathematical techniques are useful for capturing **topological features**, coming in varying **levels of robustness**.

Characterization of band nodes



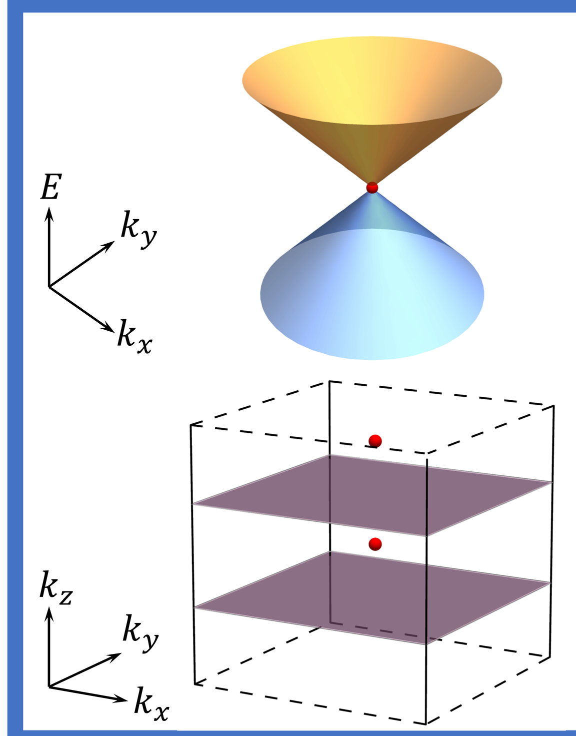
Symmetries do not only **protect** certain **band nodes**, but they also constrain the Hamiltonian in their vicinity. This allows us to **predict and classify** certain **nodal features** using symmetry.

Bulk boundary correspondence



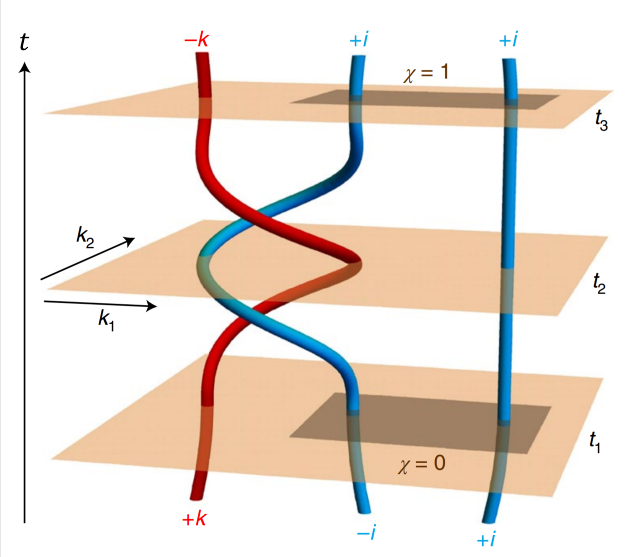
Non-trivial bulk topology in insulators and semimetals is reflected in their **boundary signatures**. Often, these are **conducting states** on the surface, but they can also be more intricate, such as a **fractional electric charge** accumulated **at corners**.

Topological semimetals



Band topology also plays a role in semimetals, where it relates to degeneracies of energy bands, known as **band nodes**. These take the role of metallic (i.e. gap-closing) transitions separating **slices of insulators** in one fewer dimensions.

Non-Abelian braiding



Usually, band nodes are characterized by additive topological "charges" (such as $\mathbb{Z}$ or $\mathbb{Z}_2$). However, sometimes, these **charges** are **non-commutative**, thus enabling their non-trivial **braiding in momentum space**.