TOPOLOGICAL META-FLUIDS

Topological Acoustics. Zhaoju Yang, Fei Gao, Xihang Shi, Xiao Lin, Zhen Gao, Yidong Chong, and Baile Zhang, Phys. Rev. Lett. **114**, 114301 (2015).

Topological sound in active-liquid metamaterials. Anton Souslov, Benjamin C. van Zuiden, Denis Bartolo, and Vincenzo Vitelli. ArXiv: 1610.06873

Recommended with a commentary by M. Cristina Marchetti, Syracuse University

Insulators - materials that do not conduct electrical current - are characterized by a gap in their electronic states separating the highest filled band from the lowest empty band. Topological insulators are materials that conduct electricity on the surface, but not in the bulk. This remarkable behavior arises from the nontrivial topological nature of the electronic band structure which has a bulk energy gap and surface or edge conducting states within the gap that can propagate in a single direction on the surface of the sample [1]. Such states are referred to as "topologically protected" because they possess a nonvanishing topological integer (a kind of "conserved charge") that cannot be changed by continuous deformation, which makes them robust against scattering from certain type of disorder. The propagating edge modes additionally become unidirectional when time reversal symmetry (TRS) is broken. Such topological insulating electronic phases have been observed in real materials. Similar phenomena have been shown to arise in photonic crystals [2] and in lattices of coupled gyroscopes [3].

The work by Yang *et al.* and by Souslov *et al.* demonstrates the feasibility of engineering topological "meta-fluids", fluid-based structures that support topologically protected acoustic waves capable of propagating along the sample edges without being affected by defects or disorder. To obtain such topologically protected edge states one needs to engineer a unit or meta-atom endowed with a dynamics that breaks TRS and arrange such units into a structure with a band gap. The meta-atom used by Yang *et al.* is a ring of circulating fluid obtained by confining a fluid to the annular region between an inner rotating solid cylinder and an outer thin sheet of solid material permeable to sound. Requiring no slip boundary condition at the rotating cylinder and vanishing of the flow velocity at the outer ring yields circulating Couette flow of the fluid ring at an angular speed that can be tuned by changing the angular frequency Ω of the rotating cylinder (inset of Fig. 1). The imposed circulation breaks TRS by selecting a preferred direction of flow. A triangular lattice of such meta-atoms immersed in a stationary fluid that allows acoustic wave propagation has a band structure that is gapped at all finite values of the angular frequency Ω, with a gap size that increases with Ω. In a finite strip of such a lattice there are additional edge modes within the gap representing localized excitations traveling in one direction at the

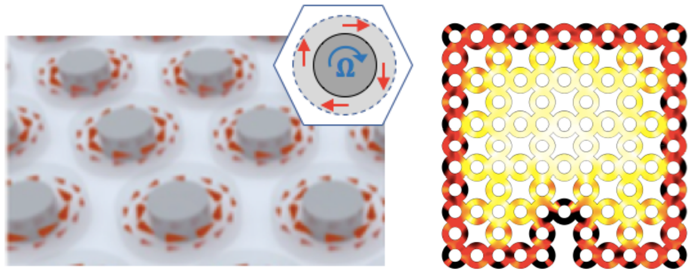

FIGURE 1. Left: The lattice of externally driven circulating currents designed by Yang *et al.* Right: The Lieb lattice of active current rings from Souslov *et al.* supports an acoustic edge state that goes around a defect.

top and bottom of the long sides of the strip. The one-way nature of such modes protects them from backscattering from impurities, providing a robust shielding mechanism that the authors suggest may have application to soundproofing technologies.

Souslov *et al.* go one step further by designing TRS-breaking meta-atoms out of active fluids. Active systems are collections of interacting self-propelled entities, such as birds, bacteria or engineered microswimmers. Such "active particles" are intrinsically out of equilibrium and the resulting active materials exhibit striking behavior not possible in passive matter [4]. For instance, active fluids, such as bacterial suspensions, flow spontaneously with no externally applied forces. An active fluid confined to a ring exhibits circulating flows that break rotational symmetry spontaneously, hence right-handed and left-handed flows are equally likely. A lattice of such rings connected by channels that allow the active fluid to flow between neighboring rings leads a stable steady state consisting of a lattice of flowing circular currents that can acquire ferromagnetic or antiferromagnitc order upon tuning the width of the connecting channels. These remarkable self-sustained steady states have been demonstrated recently in bacterial suspensions [5]. Souslov *et al.* examine the band structure of a finite lattice of such circulating current rings and demonstrate that certain lattice structures yield a gapped band structure with one-way edge modes associated with topologically protected states. In other words, the system supports sounds waves that propagate unidirectionally along the sample edges and are protected from backscattering by impurities or lattice defects. Note that the active fluids in question are overdamped, due to their interaction with a substrate. Overdamped fluids do not support truly long wavelength sound waves that arise form the interplay of elasticity and inertia, although they can support propagating waves over a finite range of wavelengths. In overdamped polar liquids sound modes originate from Goldstone modes due to the spontaneously broken orientational symmetry and hence are generic.

Both papers also show that the existence of topologically protected states can be understood by examining a generic continuum theory - the fluid Navier-Stokes equations in the case of the externally driven current rings of Yang *et al.*, and the so-called Toner-Tu equations that provide a well established continuum theory of polar active fluids in the case of the self-spinning current rings of Souslov *et al.* In both cases the continuum theory can be mapped onto the Schrödinger equation for a spinless charged quantum particle with a vector potential controlled either by the rotational frequency Ω or by the self-propulsion speed of the active fluid. The acoustic modes are then characterized by a topological invariant, the Chern number, which may be expressed in terms of the curl of a vector potential and quantifies the topological nature of the edge states.

Although the results of Souslov *et al.* seem to depend on the geometry of the lattice, the crucial ingredient for obtaining the gapped band structure with protected edge modes is that the unit cell of the lattice of circulating rings contains an odd number of rings, yielding a net circulation or chirality of the flow in each unit cell. A recent realization of *amorphous* mechanical topological insulators consisting of disordered arrangements of interacting gyroscopes [6] further suggests that the periodicity of the underlying structure may not be a necessary ingredient for such topological materials, opening up the quest for an even richer family of topological effects in liquids and soft materials.

The experimental realization of both externally driven and active topological meta-liquid structures still presents some challenges. The device proposed by Yang *et al.* requires low viscosity fluids driven at speeds that are a sizeable fraction of the speed of sound, which could therefore drive flow instabilities. Active fluids allow for these two speeds to be tuned independently, but at the same time are often subject to instabilities even at low activity. Both systems, however, promise new functionalities for sound shielding or controlled mixing in microfluidic devices.

References

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