Topological characterization of classical waves: The topological origin of magnetostatic surface spin waves

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A ferromagnet consists of numerous microscopic magnets called spins, and fluctuations of the individual spins can propagate as spin waves. The spin waves are a current focus of research in spintronics since they are considered a potential alternative for electrons as a carrier of information. There is a particular type of spin waves called magnetostatic surface spin waves (MSSWs), which was discovered in 1960 [1]. In contrast to the ordinary spin waves that diffuse through the three-dimensional bulk of the magnet, MSSWs propagate along the surface and only in one particular direction (Fig. 1), and are anomalously robust against back-scatterings. Because of the chiral propagation and the immunity to back-scatterings, they are almost exclusively used in fundamental studies of spin-wave transport in microstructures.

In the quantum mechanical studies of elecrtrons in solids, the recent advent of topological materials science has shown that chiral surface states robust against scatterings are a hallmark of topologically non-trivial bulk band structures. The above mentioned features of MSSWs are particularly reminescent of topological Chern insulators so that there has been peculation over their topological origin for a while, though without a proof. In this work, we have theoretically validated this claim, and revealed the precise topological nature of the spin wave band structure and its relation to the chirality and robustness of MSSWs [2]. Along the way, we have identified a mathematical structure that is absent in quantum mechanical electrons but occurs only for classical waves, whereby extending the realm of topological materials science into an unexplored new territory.

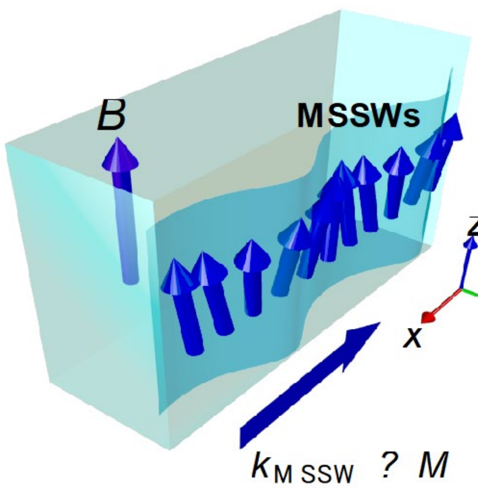

Fig.1 Unidirectional propagation of MSSWs along the surface. *B* is the magnetic field and *M* is the magnetic moment.

MSSWs arise from the dipole-dipole interactions between magnetic moments. We have carefully studied the band structure of spin waves that is determined by the linearised classical Heisenberg model including the dipole-dipole terms. The key observation was that the resulting spin-wave Hamiltonian can be written in a canonical form that allows for calculating winding numbers around any point in the Birllouin zone. The winding number around the origin of the Brillouin zone was computed to be equal to -2. This implies the presence of topologically protected vortex lines in the three-dimensional Brillouin zone of the spin waves as indicated by red and blue cylinders in Fig. 2. By appropriately generalising the bulk-edge correspondence established for electrons in solids, we successfully demonstrated that the chiral propagtion and the back-scattering immunity of MSSWs are direct consequences of the topological winding structure in the Brillouin zone.

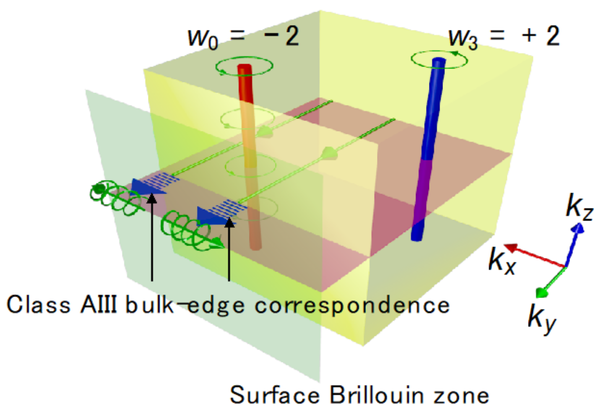

Fig.2 Schematic Brillouin zone structure for spin waves driven by dipole-dipole interactions. There exists a vortex line carrying the winding number charge -2 passing through the origin (red cylinder) and another at the Brillouin zone corner (blue cylinder) that maintain the charge neutrality.

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References

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