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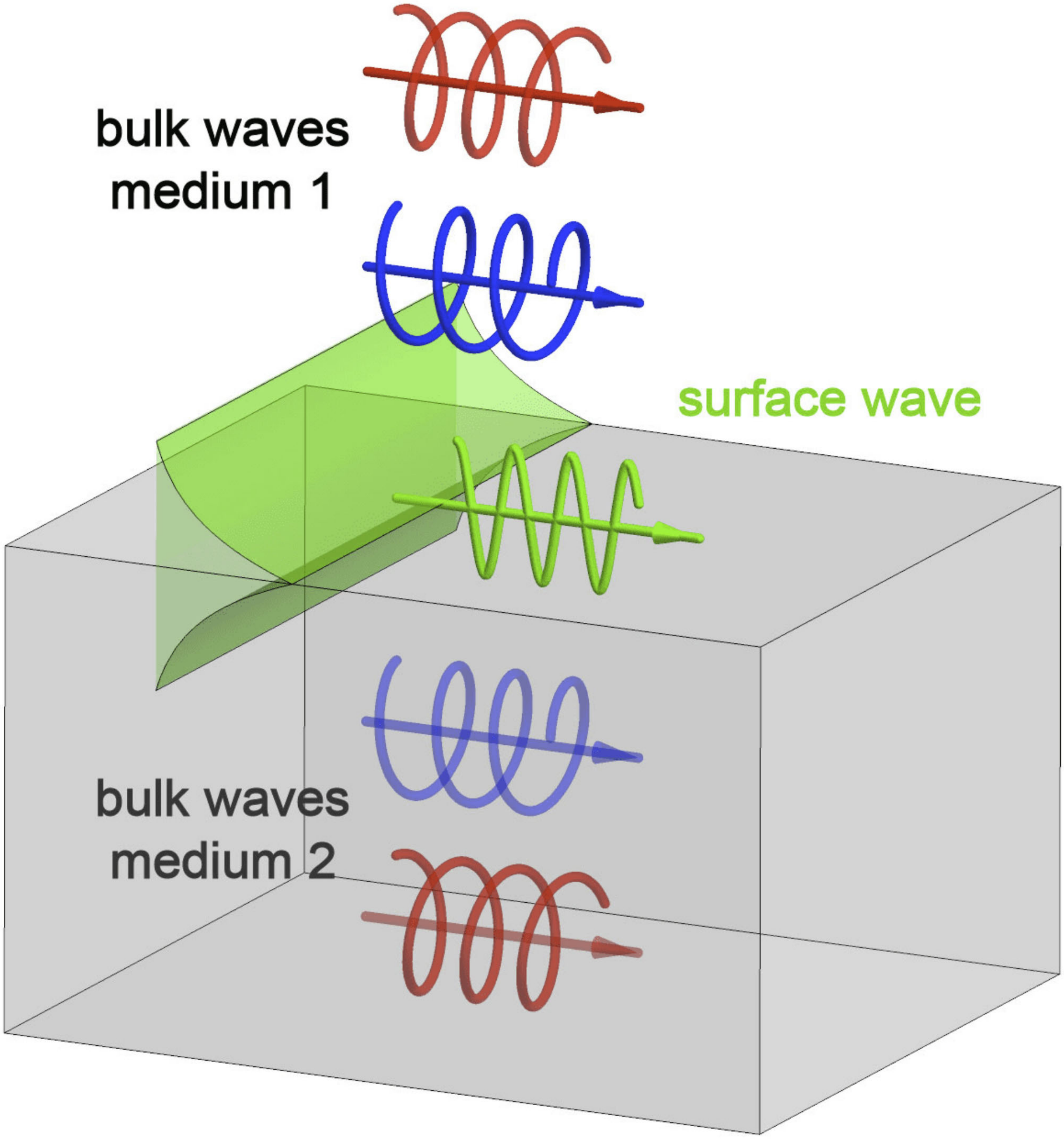
Unveiling the topological nature of electromagnetic surface waves

13 Feb 2019 Michela Picardi



An interface between media with different helicities (red and blue curly arrows) supports zero-helicity linearly polarized surface modes (green arrow). (Credit: Konstantin Bliokh)

Maxwell's electromagnetic theory, formulated 150 years ago, was one of the greatest breakthroughs in the history of physics, and continues to yield new results today. In a recent paper published in *Nature Communications*, scientists show that surface electromagnetic waves at certain interfaces, which arise as solutions of classical Maxwell's equations, also have a purely topological origin.

Maxwell's electromagnetic theory unified electricity and magnetism, providing the ultimate description of electromagnetic waves, including light, and anticipating relativity and the field theories developed in the 20th century. About 60 years ago, scientists found that electromagnetic radiation can propagate, not only in free space, but also as surface waves at interfaces between different media, for example between metals and air or glass. This resulted in the development of plasmonics and metamaterials, where surface electromagnetic waves underpin numerous phenomena and useful applications.

Topological quantum systems are another area of modern physics, where surface waves play a crucial role. In these systems, surface modes are very robust against small perturbations and continuous deformations, which is why they are often referred to as topologically protected states. In this latest work researchers – a collaboration from Japan, Korea, Australia and the US – show that the familiar surface electromagnetic waves at interfaces between different homogeneous isotropic media have origins similar to these quantum topological states.

In their description, Konstantin Bliokh at RIKEN and the Australian National University and his colleagues show that the "helicity" of free-space (or bulk) photons plays the key role. Electromagnetic helicity is a scalar property corresponding to the projection of the photons' spin along the momentum direction. In free-space, or in a bulk medium, it can have two eigenvalues – either +1 or -1, corresponding to the two circular polarizations, left and right. When one of the medium parameters (dielectric permittivity or magnetic permeability) changes its sign, e.g., at a metal-air interface, the helicity spectra in the two media are mutually twisted in the complex-helicity plane. What Bliokh and co-authors show is that this twist results in the appearance of surface electromagnetic waves with zero helicity, such as surface plasmon-polaritons, at the interface.

Moreover, they prove that the number of surface modes is determined by the number of the bulk-medium parameters changing their signs at the interface, which is called "bulk-boundary correspondence" in the topological formalism. This means that at an interface where only the permittivity (or the permeability) changes its sign, one surface mode will exist. However at the interface between two materials with both permittivity and permeability different in sign, two surface modes will exist.

How does this change what we know of Maxwell waves?

The first author, Bliokh, says: "There is a crucial difference between the topological description of surface Maxwell waves and that of previously known topological surface modes. So far, topological properties and classification of various wave systems relied on mathematical properties of the Hamiltonian (i.e., energy) operator characterizing the system. In contrast, topological properties of Maxwell's waves are described by the so-called helicity operator, which characterizes the chirality of circularly polarized electromagnetic waves. Thus, our theory also extends the range of applicability of the topological approach to other wave systems: it shows that the topological classification can be associated not only with the Hamiltonian but also with other operators corresponding to conserved physical quantities."

Franco Nori continues: "Our work provides a new twist and insights for several areas of wave physics: Maxwell electromagnetism, topological quantum states, and plasmonics/metamaterials."

The discovery of nontrivial topological phases in condensed-matter quantum systems and the existence of topological surface modes at interfaces between topologically different materials resulted in the Nobel Prize in physics in 2016. While it was initially thought that topological properties were exclusive to complex engineered structures mimicking quantum condensed-matter systems, such as photonic crystals, this work shows that exquisite topological features are also present in the simplest continuous isotropic optical media described by the most fundamental form of Maxwell equations.

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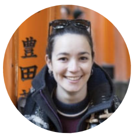

Michela Picardi is a former PhD student contributor to *Physics World.* Michela studied photonics and nanotechnology at King's College London. Find out more about our student contributor networks

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