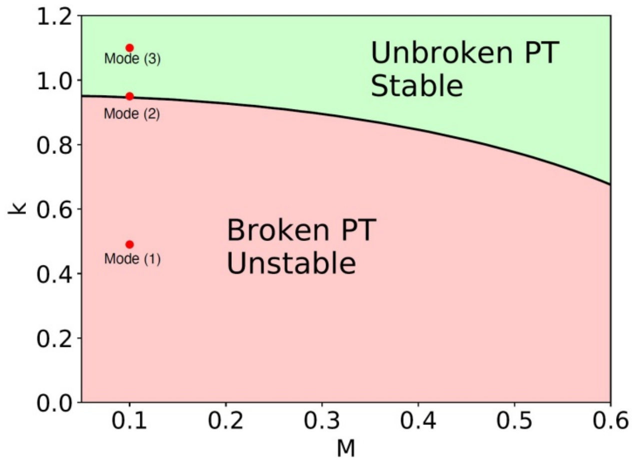
Parity-Time Symmetry Breaking Triggers Kelvin-Helmholtz instabilities



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Stability diagram in the parameter space. Unstable modes, e.g., Modes (1) and (2), are found in the region with spontaneously broken PT symmetry. All modes, e.g., Mode (3), in the unbroken PT-symmetry region are stable.

The Science

Flows occur naturally in fluids, and in plasmas, which are often well approximated as a “fluid” of charged particles. Flows can form eddies, which break into smaller eddies and then into turbulence. For optimal performance of future fusion reactors, it is important to know when plasma flows become unstable. An important instability, the Kelvin Helmholtz instability, arises in “sheared flows”, flows for which the flow speed changes in the direction perpendicular to the flow. (A common example is wind blowing across water: when the speed of the air flow is large enough, the surface becomes unstable and breaks into waves.) Using an analogy with quantum mechanics, scientists at PPPL have shown that this is associated with breaking a fundamental symmetry, the so-called Parity-Time (PT) symmetry.

The Impact

This opens new insights for understanding instabilities in fusion plasmas. Symmetries impose constraints on dynamical motions. Dynamical systems that have PT-symmetry display a restricted distribution of possible oscillations and instabilities. The oscillation frequencies allowed by the system must be symmetric with respect to the real axis, and instabilities are formed only through the resonances between stable oscillations. The new theory predicts how new dynamical motions can arise when critical parameters such as the flow shear vary, and how a previously stable system can become unstable. The analysis is being applied to study, for example, the onset of the drift wave instability in magnetized fusion plasmas. The drift wave instability can be driven by the ion temperature gradient that naturally exists in a fusion device.

Summary

The theoretical discovery was to recognize that the equations governing perturbed sheared flows are analogous to the famous Schrodinger equation that governs quantum mechanics. In quantum mechanics, physical “observables” are associated with a so-called Hermitian symmetry. PT-symmetry is a generalized version of Hermitian symmetry, and so the mathematical theory needed to be generalized.

The theoretical result extends beyond plasma physics. The new understanding explains why, for example, the oscillations of a sheared inviscid (infinitely slippery) fluid always come in stable and unstable pairs. The Kelvin-Helmholtz instability is triggered when the PT symmetry is spontaneously broken. It is expected that all non-dissipative dynamical systems admit PT symmetry, and instabilities result from spontaneous PT-symmetry breaking. This probably won't help surfers catch the perfect wave, but it does help scientists understand how to suppress the instability, and thereby better obtain optimal fusion performance in future reactors.

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Publications

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