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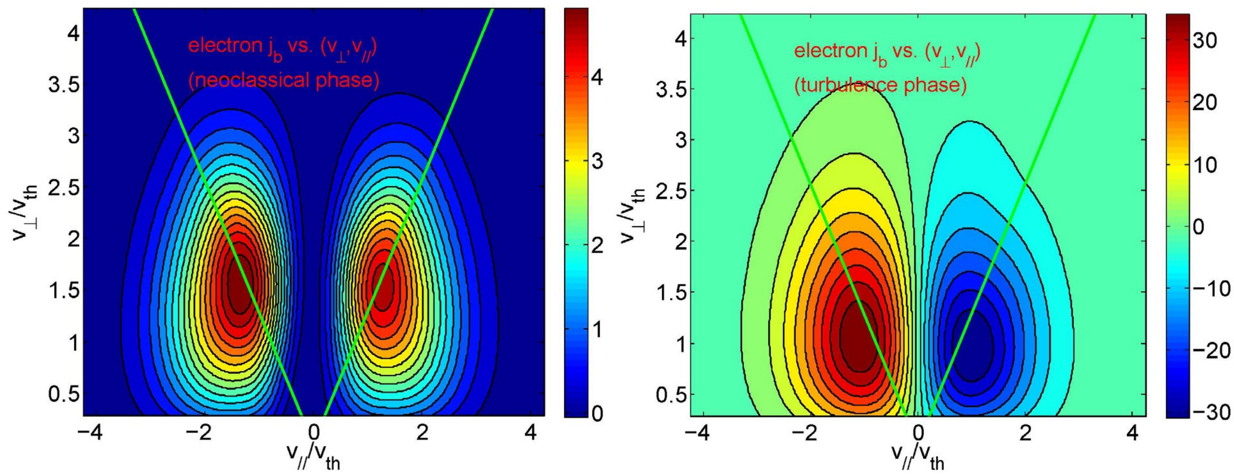
Electrical Current Generation by Turbulence Can Affect Plasma Confinement in Future Fusion Reactors

Multi-physics computer simulations uncover new mechanism of self-driven current generation in magnetically confined plasmas.



First-principles-based, multi-physics computer simulations illustrate which electrons carry electrical current and in which direction, uncovering a clear picture of how self-driven plasma current is increased or decreased by micro-turbulence. The vertical and horizontal axes are the parallel (to the magnetic field) and perpendicular velocity (in the units of thermal mean velocity) of electrons. Electrons located between the two straight lines are trapped by the well of magnetic field, and the rest electrons are untrapped.

The Science

In computer simulations of the charged particles in magnetically confined plasmas (ionized gases), the dynamics driven by the particles colliding with themselves in the presence of curved -- but static in time -- magnetic fields and that driven by turbulently fluctuating magnetic and electric fields are, for expedience, typically treated separately; however, these different physical processes can interact at certain spatial and temporal scales. This interaction can strongly affect the total plasma current, the control of which is essential for the stable operation of tokamaks, the leading design for a future fusion reactor. Using “multi-physics” simulations performed on supercomputers, physicists at the Princeton Plasma Physics Laboratory in collaboration with Seoul National University have discovered a new mechanism for self-driven plasma current generation that is driven the interaction.

The Impact

Plasma currents contribute a crucially important part of the magnetic field in tokamaks: lose control of the plasma current, and you lose control of the plasma and this can damage the machine. The newly revealed current-generation mechanism raises important questions about how much plasma current we may expect, questions that need answers if we are to predict performance in the burning plasma regime when fusion energy is being produced.

Summary

Like tiny beads, sliding, bouncing off each other, on vibrating curved elastic strings, magnetically confined plasmas are full of turbulent fluctuations in the particle density and temperature, in the flows in the plasma, and in the magnetic and electric fields. Driven by various micro-instabilities, the turbulence can give a net acceleration to the electrons and thereby drive additional plasma current, in either direction to the magnetic field. Among other effects, the interaction between the collisions and turbulence can significantly reduce the current generation when there are fewer particle collisions. The amount of extra current is substantial enough to modify crucial properties of the total current, and this can trigger instabilities in an otherwise stable plasmas.

Researchers must now consider a new paradigm: by driving self-generated plasma current, micro-turbulence can affect macro-performance in the confinement and stability of magnetically confined plasmas. The magnitude of the self-driven current may extrapolate differently than what was previously thought to the high-temperature, burning plasma regimes of future fusion reactors. The discovery opens an important, as-yet unexplored avenue of generating plasma currents that will affect the design and operation of future steady state tokamak experiments and reactors, and which can be explored on existing experiments.

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Publications

W. X. Wang, T. S. Hahm, E. A. Startsev, S. Ethier, J. Chen, M. G. Yoo and C. H. Ma, “Self-driven current generation in turbulent fusion plasmas”, *Nuclear Fusion* **59** (2019) 084002. https://dx.doi.org/10.1088/1741-4326/ab266d.