Plasma heating efficiency in fusion devices boosted by metal screens

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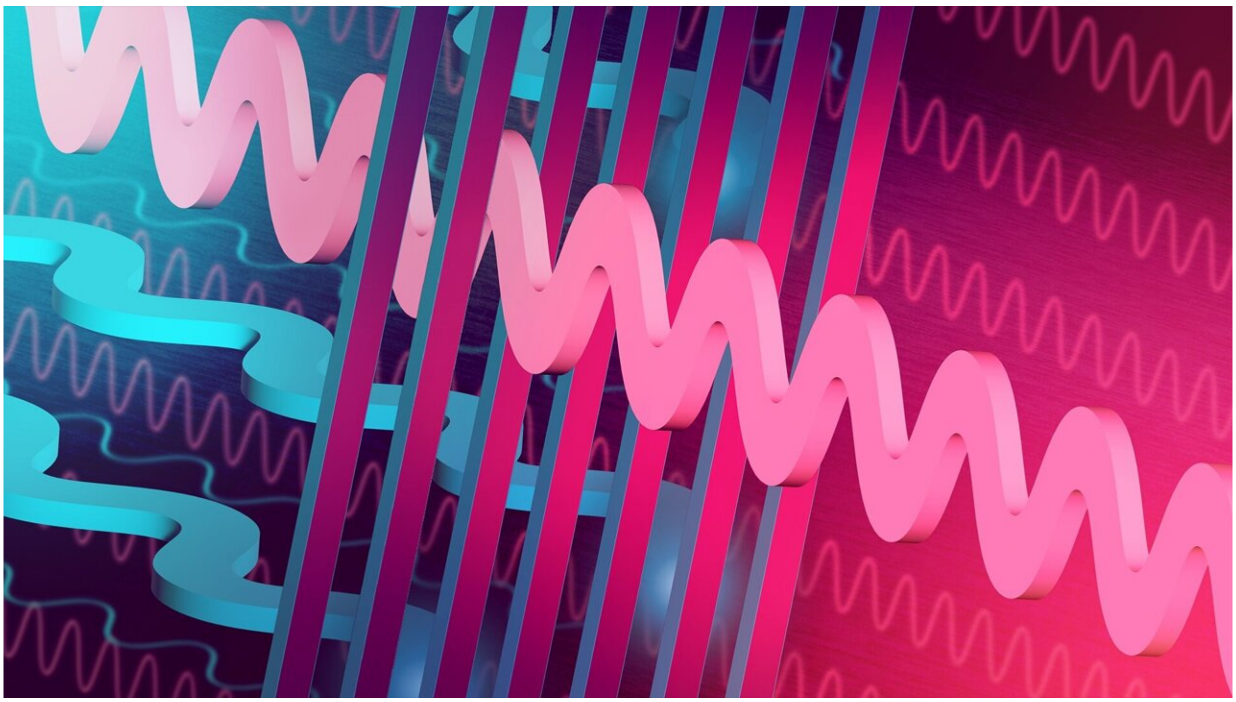

An artist's representation of a metal screen filtering electromagnetic heating waves. Credit: Kyle Palmer / PPPL Communications Department

Heating plasma to the ultra-high temperatures needed for fusion reactions requires more than turning the dial on a thermostat. Scientists consider multiple methods, one of which involves injecting electromagnetic waves into the plasma, the same process that heats food in microwave ovens. But when they produce one type of heating wave, they can sometimes simultaneously create another type of wave that does not heat the plasma, in effect wasting energy.

In response to the problem, scientists at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL) have performed computer simulations confirming a technique that prevents the production of the unhelpful waves, known as slow modes, boosting the heat put into the plasma and increasing the efficiency of the fusion reactions.

"This is the first time scientists have used 2D computer simulations to explore how to reduce slow modes," said Eun-Hwa Kim, a PPPL principal research physicist and lead author of the paper reporting the results in *Physics of Plasmas*. "The results could lead to more efficient plasma heating and possibly an easier path to fusion energy."

The team, which included researchers from General Atomics who use the DIII-D tokamak fusion facility, determined that positioning a metal grate known as a Faraday screen at a slight five-degree slant with respect to the antenna producing the heating waves, also known as helicon waves, stops the production of the slow modes. Researchers want to avoid creating slow modes, because unlike helicon waves, they cannot penetrate the magnetic field lines confining the plasma to heat the core, where most fusion reactions occur. In addition, the slow modes are easily damped or snuffed out by the plasma itself. Therefore, any energy used to create slow modes is energy that is not used to heat the plasma and foster fusion reactions.

The researchers simulated the production of helicon waves and slow modes using the Petra-M computer code, a powerful and versatile program used to model electromagnetic waves in fusion devices and space plasmas. The simulations replicated conditions in the DIII-D tokamak, a doughnut-shaped plasma device operated by General

Atomics for the DOE. The team performed a series of virtual experiments to test which of the following had the greatest effect on the production of slow modes—the antenna's alignment, the Faraday screen's alignment or the density of small particles known as electrons in front of the antenna.

The simulations confirmed suggestions made by previous researchers indicating that when the Faraday screen was aligned at an angle of five degrees or less from the orientation of the antenna, the screen—in effect—short-circuits the slow modes, making them fizzle out before they propagate into the plasma.

The suppression of slow modes depends greatly on how much the Faraday screen leans to the side.

"We found that when the screen's orientation exceeds five degrees by only a little bit, the slow modes grow by a great deal," said PPPL principal research physicist Masayuki Ono, one of the paper's authors. "We were surprised by how sensitive the development of slow modes was to the screen alignment."

Scientists could use this information to tweak the design of new fusion facilities to make their heating more powerful and efficient.

In the future, the scientists plan to increase their understanding of how to prevent slow modes by running computer simulations that consider more of the plasma's properties and factor in more information about the antenna.

More information: E.-H. Kim et al, Full-wave simulations on helicon and parasitic excitation of slow waves near the edge plasma, *Physics of Plasmas* (2024). DOI: 10.1063/5.0222413

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