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How Key Stabilizing Structure in Fusion Plasma Forms and Falls Apart Revealed by Combining Data from Multiple DIII-D Diagnostics

Research at DIII-D provides the first evidence that differences in plasma coupling drive the development and failure of a structure capable of suppressing large plasma instabilities.

CHICAGO—While fusion has the potential to transform the global energy landscape as an abundant, clean energy source, challenges remain prior to commercial scaling. Recent work at the DIII-D National Fusion Facility led by Rachel Myers, a DOE FES postdoctoral fellow at General Atomics, addressed the challenge of potentially damaging bursts of energy at the plasma edge. This work developed a new understanding of how coupling between the plasma core and edge supports stable plasma operation in a fusion device, suggesting a new approach for operation to help develop fusion as a practical energy source.

The high-temperature plasma used in fusion devices can emit large amounts of energy at the plasma edge capable of damaging the interior of a fusion device, called edge-localized modes (ELMs). While not a machine safety concern, these bursts must be consistently suppressed in commercial devices to avoid downtime for device repairs.

Previous work has used a steady edge fluctuation called the edge harmonic oscillation (EHO) to suppress ELMs in tokamaks, donut-shaped fusion devices that contain plasma with magnetic fields. Operation of a tokamak in a state where the plasma is well confined without ELMs is called quiescent high-confinement mode (QH-mode) operation, and this approach is being developed for future commercial use.

“The EHO is known to suppress instabilities in a fusion plasma that lead to large releases of energy and particles, but we don’t fully understand the physical mechanisms that drive the EHO,” said Myers. “Once we understand how and why the EHO forms and fails, we will be able to better incorporate this unique operational approach into designs for future devices.”

As part of her graduate student work at the University of Wisconsin-Madison and continuing as part of her postdoctoral research, Myers analyzed plasma shots run at the DIII-D National Fusion Facility, a DOE Office of Science user facility supporting fusion science and technology research. Among operating tokamaks, DIII-D has the most extensive suite of measurement instruments, known as diagnostics.

Rachel combined information from several DIII-D diagnostics, including the Radial Interferometer-Polarimeter (RIP), magnetic sensing coils, and Beam Emission

Spectroscopy (BES), to evaluate plasma fluctuations that underwent repeated transitions between ELMs and QH-mode with the EHO. Her analysis determined that the EHO arose from nonlinear interactions and coupling between multiple magnetic fluctuations in the plasma edge, matching predictions from simulations that had not yet been validated experimentally.

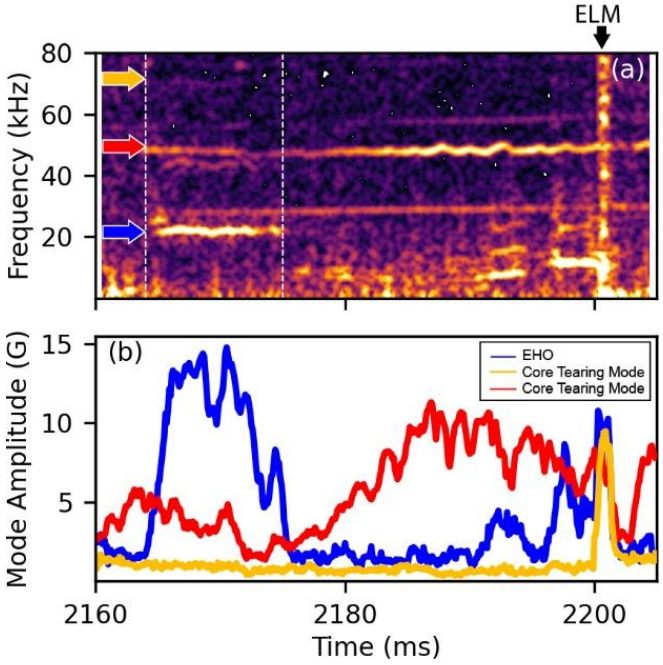


Figure 1: EHOs disappear while tearing modes grow, followed by ELM development. (a) Spectrogram showing magnetic fluctuations corresponding to an EHO (blue arrow) and tearing modes in the plasma core (red and yellow arrows) over time. (b) Corresponding strengths of the EHO and tearing modes during the same window.

Myers' work is also the first to identify an interaction that interrupted the EHO, allowing reemergence of ELMs (Figure 1). Specifically, when the EHO in the plasma edge coupled with two tearing modes, a type of instability that frequently occurs in the plasma core, the EHO was interrupted and the suppressive effect on ELMs was lost. This interaction was identified with the RIP and BES diagnostics but could not be detected with the magnetic sensing coils, illustrating how complementary use of the extensive diagnostic suite at DIII-D can discover new insights for fusion science.

"For both of these discoveries, I combined data from multiple diagnostics to determine the degree of coupling within a signal or between signals, a parameter known as bicoherence, to demonstrate that EHO arises from nonlinear coupling and is interrupted by tearing modes," said Myers. "This provides insight into how to achieve and maintain the EHO in a fusion plasma, a key step forward for QH-mode operation in future devices."

Myers' analysis of DIII-D experimental data confirms simulation predictions for QH-mode, validating their use for further development of this operational approach. Her work also implies that suppressing tearing modes in the plasma core supports the development of the EHO in the plasma edge. This could indicate that preventing coupling between the plasma core and edge would improve performance by increasing the robustness of QH-mode. The understanding developed through this study can now be applied to improve steady high-performance tokamak operation with the goal of moving toward fusion energy.

Further reading on Myers' work can be found here: https://doi.org/10.1103/z7j9-1t1m

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Abstract

NI01/1 Experimental Confirmation of Nonlinear Edge Harmonic Oscillation Coupling and Discovery of Tearing Mode-Induced QH-Mode Collapse

Session NI01: Pedestal Physics, ELM Suppression, and Edge Transitions
9:30 AM–12:30 PM, Thursday, November 5, 2026
Room: Hilton Chicago, International North, Second Floor