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Fast Ion Transport in DIII-D Fusion Plasmas Clarified by Massively Parallel Simulations

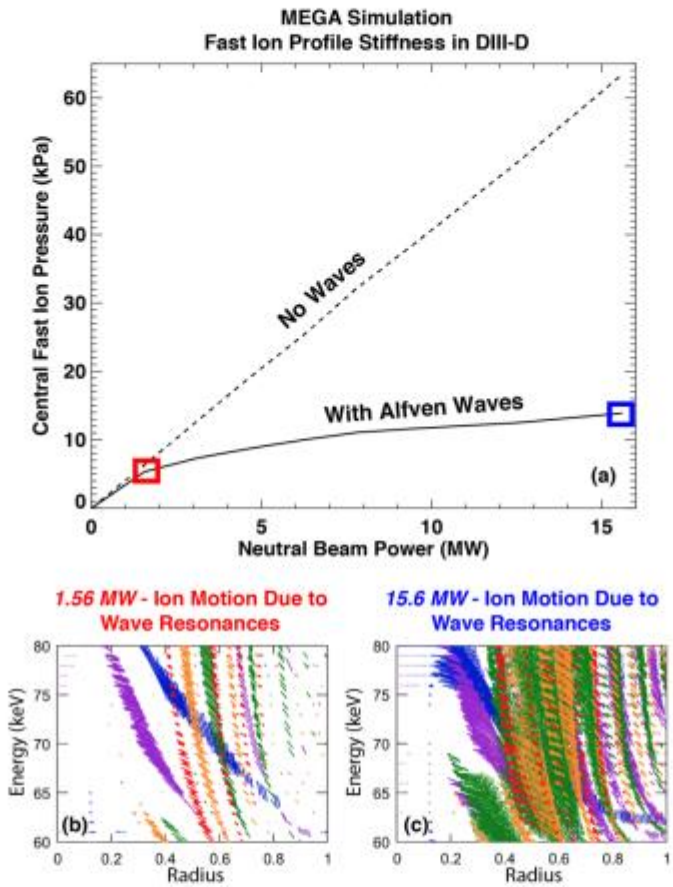
MEGA simulations show resonance overlap of multiple Alfvén waves leads to fast ion profile stiffness

The Science

Recent DIII-D experiments show fast-ion transport increases rapidly above a threshold in injected neutral beam power leading to fast ion profile stiffness. These results are explained by MEGA simulations which, for the first time, are able to self-consistently calculate the injection of high energy heating beams, the spectrum of waves in the plasma and the self-consistent interplay between the two as the waves grow up and transport the very beam ions responsible for driving them. When beam power / drive for the waves becomes sufficiently large, multiple overlapping modes grow up and very effectively kick the beam ions from the center, reducing heating and performance.

The Impact

The confinement of fast ions is essential for the realization of burning plasmas and fusion energy. This work shows that above a certain power threshold, multiple Alfvén eigenmodes can grow up and cause a large increase in fast ion transport reducing fusion performance and potentially causing damage to the device. This threshold power is substantially higher than the point at which modes first become unstable. The simulations carried out as part of this research offer a deep insight into the underlying physical processes causing the transport and also give confidence in our ability to predict this effect in future devices.



MEGA simulations of DIII-D plasmas showing: (a) Central fast ion density resulting from a range of injected neutral beam powers with (solid) and without (dashed) Alfvén wave physics included. As beam power is increased, Alfvén eigenmode amplitudes and induced transport increases rapidly, effectively clamping the fast ion profile. At the highest injected power, the central fast ion density is only 22% of the ideal case with no waves. Panels (b) and (c) show ion orbit perturbations due to individual wave-particle resonances in the 1.56MW and 15.6MW cases. The higher power case clearly has far more overlapping resonances which can cause chaotic orbits and transport.

Summary

A collaboration between researchers at the Japanese National Institute for Fusion Science (NIFS), General Atomics and University of California Irvine has led to an explanation for the large observed transport and reduction in performance due to Alfvén eigenmodes in DIII-D plasmas. The understanding comes from massively parallel simulations with the MEGA code, which employ a novel approach called a multi-phase simulation for energetic particles interacting with a magnetohydrodynamic fluid. As in experiment, monotonic degradation of fast ion confinement and fast ion profile stiffness is found with increasing beam deposition power. The confinement degradation and profile stiffness are caused by a large increase in fast ion transport brought about by resonance overlap of multiple Alfvén waves for fast ion pressure gradients above a critical value. Analysis of the time evolution of the fast ion energy flux profiles reveals that intermittent avalanches take place with contributions from the multiple eigenmodes. The critical gradient and critical beam power at which profile stiffness sets in are substantially higher than the point at which modes first become unstable. These simulations and new understanding will be fundamental to making reliable and efficient predictions for the confinement of fast ions in future burning plasma experiments.

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Publications

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