Plasma Physics Seminar

UCLA College | Physical Sciences Physics & Astronomy

Physics & Astronomy Building (PAB) Room 4-330
Via Zoom: https://ucla.zoom.us/s/96507503189
Meeting ID: 965 0750 3189 l Passcode: 105058
Friday May 16th at 12:30 PM
Lunch will be served at 12:00 PM

Metastable dynamics and nonlinear relaxation in plasmas

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In myriad physical settings, sudden, dramatic events punctuate the behavior of otherwise slowly evolving systems. Prominent terrestrial examples include earthquakes, structural failures, severe weather events and climate “tipping points". The violent nature of these phenomena is a consequence of their being relaxations of metastable states — local, but not global, minima of the energy landscape. In the realm of plasma physics, a phenomenon of this kind presents a significant obstacle to energy production from magnetic-confinement fusion. Sudden eruptions — edge-localized modes (ELMs) — can expel a significant fraction of plasma from tokamaks operating in high-confinement mode (H-mode). While ELMs can be tolerated in existing machines, a single ELM burst would produce intolerable levels of degradation in planned power-plant-scale devices.

Although substantial progress in phenomenological modeling of ELMs has been achieved in the past few decades, theoretical understanding remains in its infancy. We do not, for example, understand how the H-mode plasma self-organizes to become unstable first gradually and then suddenly, how the sudden eruption is triggered, the proportion of the thermal energy and mass expelled during the ELM burst, nor how ELMs saturate and transfer their energy to plasma-facing components. The principal barrier to theoretical progress is that ELMs are not linear instabilities, but rather nonlinear (subcritical) instabilities of the metastable plasma state. Moreover, the fact that ELMs are fundamentally 3D (because erupting field lines must twist to overcome magnetic shear) is a significant obstacle to both modeling and theory.

In this talk, I present a minimal, physically realizable case of plasma equilibrium with ELM-like metastable eruptions. Specifically, I show analytically that curved field lines hosting a transonic field-aligned flow can support well-confined states below the linear threshold of the ballooning instability, but erupt nonlinearly when pushed close to that threshold. Remarkably, this is true even in equilibria without magnetic shear, as I confirm with direct numerical simulations in Z-pinch geometry. This raises the possibility of formulating an understanding of the fundamental physics underpinning ELMs in a simplified system. As illustration of this, I show that a key problem for ELMs — calculating the amount of plasma energy ejected by the eruption — can be solved accurately as a function of the flow-shear rate for the minimal model, by combinatorial optimization of flux-tube interchanges.