January 2019

Nonlinear Wave Interactions Lead to Damaging Bursts of Energy at the Edge of Tokamaks

Direct sighting of a nonlinear 3-wave interaction that leads up to edge-localized instabilities in tokamaks.

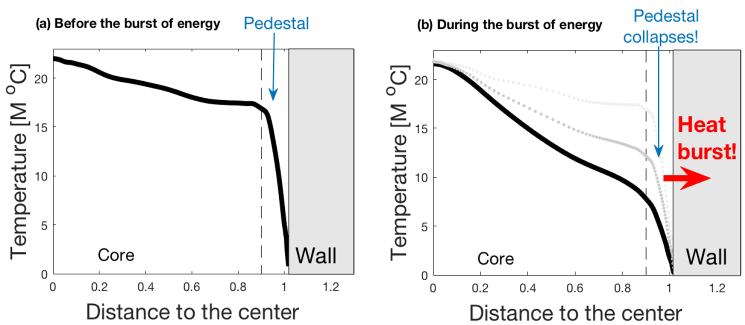

Image courtesy of J. Dominski

Cartoon illustrating the sudden collapse of temperature in the pedestal of a tokamak. This collapse causes a sudden burst of energy against the wall as pictured with red arrow at right.

The Science

Capturing the energy from the fusion of light atoms, the same energy that powers the sun, could provide a clean and sustainable source of electric power on Earth. Fusion experiments confine ionized gas, called “plasma”, at extreme temperatures of millions of degrees in device called “tokamaks”. Near the wall, the plasma temperature abruptly decreases to a few thousand degrees in a narrow region called the “pedestal” (see left figure). A steep pedestal enables tokamaks to achieve high-performance. Problematically, the pedestal rapidly collapses after its formation, by releasing a burst of energy against the wall (right figure). Scientists have discovered that the pedestal collapses when distorted by nonlinear wave mechanisms, just as a cliff collapses when eroded by ocean waves.

The Impact

Avoiding these sudden bursts of energy against the wall is necessary for the performance of a fusion reactor, because such powerful bursts may lead to significant and even permanent damage. These bursts are predicted to occur in ITER, the advanced international fusion reactor now under construction in France. The discovery that nonlinear wave interactions can cause these bursts of energy opens new possibilities for controlling them and protecting ITER and future machines.

Summary

The leading model for predicting the sudden collapse of the pedestal is based on a linear theory which predicts that an edge instability occurs when a critical limit is reached. However, in some cases, the critical condition is reached but nothing happens during an unexplained lengthy period before the pedestal finally collapses. Direct observation of the nonlinear mechanisms that lead to the sudden burst of energy elucidates this physics.

The discovery showed that two low-frequency waves combine and amplify a third wave of higher frequency located close to the wall. This well-known basic physical mechanism, called “nonlinear 3-waves interaction,” has been observed to distort the pedestal just before its collapse in a sudden burst of energy.

Identifying this nonlinear mechanism has required complex theoretical analyses. The first evidence was that the sum of the two lowest frequencies equals the frequency of the third. This matching condition is an indication that the phenomenon can occur. The second evidence was to measure the high intensity with which the energy is transferred to the third wave. By piecing this evidence together, the scientists discovered that the amplification of the third wave distorts the pedestal just before it collapses.

Contact

Julien Dominski
Princeton Plasma Physics Laboratory
jdominsk@pppl.gov

Publications

A. Diallo, J. Dominski, K. Barada, M. Knolker, G. J. Kramer, and G. McKee, “Direct observation of nonlinear coupling between pedestal modes leading to the onset of edge localized modes.”, *Physical Review Letters* **121**, 235001 (2018), [DOI:10.1103/PhysRevLett.121.235001.]