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FOR IMMEDIATE RELEASE
Nov. 12, 2008

High-speed camera reveals waves and instabilities in hot plasmas

Imaging the hot core of a tokamak plasma provides insight into the complex structure and dynamics of waves and instabilities

Researchers at the University of California at San Diego and General Atomics are using a high-speed camera, capable of recording 26,000 frames per second, to create movies of waves and instabilities in DIII-D tokamak plasmas. Tokamaks are experimental fusion reactors that use strong magnetic fields to confine hot toroidal (donut-shaped) plasmas, with temperatures reaching over 100 million degrees C. Waves and instabilities are important because they transport energy out of the plasma core and can reduce overall fusion performance. These detailed measurements of the structure of waves through direct visualization may allow the creation of more precise models to predict the behavior of future fusion reactors.

Waves and instabilities in the plasma core form when magnetic field lines bend and break due to high plasma pressure, or due to an excess or deficit of localized plasma current. One type of wave that can persist for thousands of wave periods is called a neoclassical tearing mode (NTM), and is a helical structure that is created after magnetic field lines break and reconnect, resulting in the formation of “magnetic islands.” The islands are located at special locations within the plasma where the helical winding of the magnetic field connects with itself after traveling around the torus an integer number of times. The helical island structure as a whole rotates around the torus, which gives the wave its periodicity. If the wave amplitude, characterized by the island width, grows unchecked it can cause a major disruption in the plasma, thereby stopping the fusion reaction. Thus, understanding the origin of these waves and how these waves stop growing, or saturate, is extremely important. By applying a powerful image processing technique, 2D images of mode amplitude and phase are calculated and compared to theory. A snapshot of the mode shows complex structures marked by increasing (yellow) or decreasing (blue) visible emission caused by changes in temperature and density in the plasma (Fig. 1). We observe that the saturated island width is up to 20% of the plasma minor radius, and that as expected, the mode phase reverses at the island location.

A different type of transient instability occurs when magnetic field lines suddenly break due to a concentration of electric current in the plasma core. Known as “sawtooth crashes”, these are repetitive, intense events that rapidly eject heat from the core and mix it with the surrounding plasma. The process occurs in less than 100 microseconds, and after the crash the central temperature rises on a time scale of tens of milliseconds until the process repeats itself. During the crash, the core plasma can redistribute up to 15% of its stored energy. The camera images show that the radial extent of the instability can be more than half the plasma radius, and that the dynamics of the sawtooth crash depend on the shape of the plasma.

High-speed imaging of coherent and transient fluid-like phenomena in fusion plasmas is providing exciting insights into structure and dynamics. Details of this work will be presented by Dr. J. H. Yu from the University of California at San Diego, at the APS-DPP meeting in Dallas, Nov. 17 – 21, 2008.

Work supported by the U.S. Department of Energy under DE-FG02-07ER54917 and DE-FC02-04ER54698.

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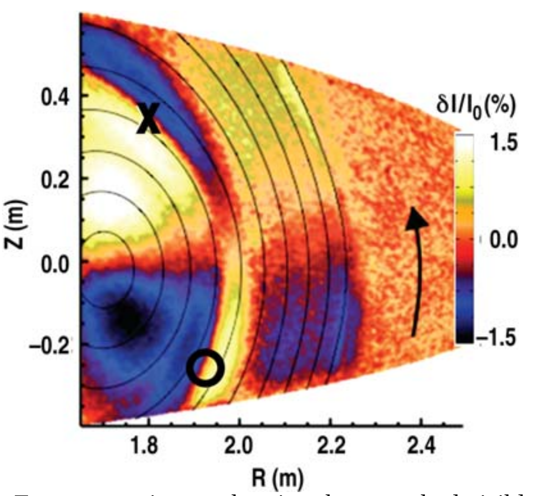

Fig. 1. Fast camera image showing the perturbed visible light due to a neoclassical tearing mode, with equilibrium magnetic surfaces shown in black. The wave distorts these magnetic surfaces, and the "O" and "X" mark the approximate locations of the magnetic island center and boundary, respectively. The arrow shows the rotation direction of the wave.

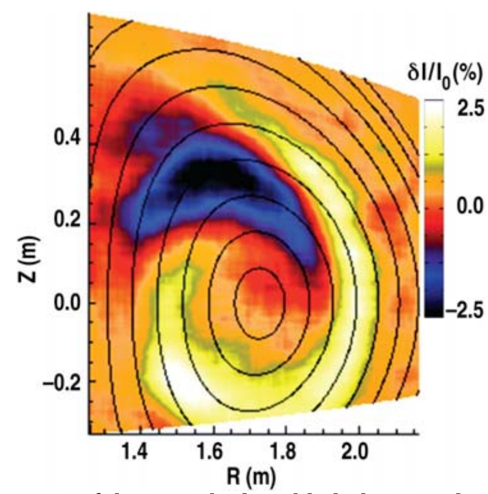

Fig. 2. Image of the perturbed visible light immediately following a sawtooth crash, showing heat being ejected from the core to the surrounding plasma. The equilibrium magnetic surfaces are shown as black contours; however, during the violent sawtooth crash, these surfaces become distorted.