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FOR IMMEDIATE RELEASE
Oct. 14, 2005

High-speed images capture ripples in edge of hot plasma

Advanced imaging technology reveals mechanisms behind fusion plasma instabilities

DENVER, Colorado, Oct. 24, 2005 – Physicists have opened a new window into the complex behavior that occurs at the edge of a 100 million-degree fusion plasma. Using advanced high-speed cameras, physicists obtained very detailed, three-dimensional images of plasma instabilities known as Edge Localized Modes (ELMs). Additional images also provided researchers with their first glimpse of how particles and energy are transported during an ELM instability.

Seeking to harness the same energy source that fuels the Sun, researchers worldwide have developed a variety of techniques for confining hydrogen atoms well enough to achieve the very high temperatures (100,000,000 degrees Celsius) required for fusion. At such high temperatures, the hydrogen fuel takes the form of an electrically charged, or ionized, gas called a plasma. A promising confinement technique called a tokamak uses strong magnetic fields to confine a donut-shaped plasma, taking advantage of the fact that the charged particles closely follow the magnetic field lines, like beads on a string.

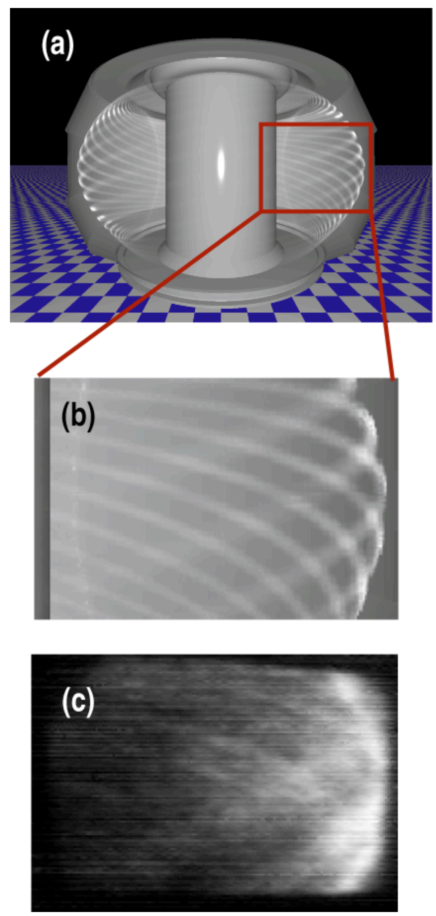

Fig. 1. Comparison of predicted ELM structure and measured light from carbon ions during an ELM: (a) calculated 3D profile of the distortion due to an ELM; (b) blow-up of the region that would be seen by the camera; (c) measured 3D profile of light emitted by carbon atoms during the ELM.

As the plasma is heated and the pressure inside the tokamak increases, there is a tendency for this plasma pressure to bend and stretch the confining magnetic field lines. If these distortions become too large or too localized, a plasma hiccup (or ELM) can occur, releasing enough plasma pressure to relieve the stress caused by this distortion.

The exact mechanisms that lead to these instabilities have been studied extensively in recent years due to the impact ELMs are expected to have in next-generation fusion devices. Yet until recently, the inability to make sufficiently high-resolution measurements has hampered efforts to fully characterize these mechanisms.

Images captured by researchers on the DIII-D tokamak at General Atomics in La Jolla, California, reveal important information on the three-dimensional structure of these instabilities and the associated transport of particles and energy. This information has led to a much better understanding of these instabilities, with several theoretical predictions verified by these measurements.

The three-dimensional structure of an ELM was captured with the use of a high-speed camera operating with a very short (10 millionths of a second) exposure time to measure the blue light emitted by carbon ions as the ELM energy and particle pulse passes through the edge plasma (Fig 1c). This image shows multiple striations during the ELM event, indicating that the ELM instability causes a helical distortion to the otherwise toroidally symmetric magnetic field. Calculations of the stability properties of this plasma indicate a class of instabilities, known as peeling-ballooning modes, localized near the plasma edge. The spatial structure of the instability calculated to be most unstable (Figs. 1a and b) is very similar to that in the image of plasma emission. This provides confidence that the present theory can predict which instability leads to the ELM event.

Additional measurements on DIII-D used advanced camera technology capable of collecting over 12,000 spectral measurements each second, each of sufficient quality to provide accurate measurements of the plasma properties. These measurements indicate that the instability-driven transport consists of two parts. The first event is a rapid (less than 300 millionths of a second) expulsion of particles (Fig. 2a). This is followed by a slower decrease (about 1 thousandth of a second) of the plasma temperature (Fig. 2b). The different time scales of these events suggest at least two different mechanisms are at play. The rapid particle loss is likely due to the instability itself, while the slower time scale of the temperature decrease suggests it is a secondary effect due to changes in the plasma properties caused by the ELM. This secondary temperature decrease appears to be due to a short-lived increase of turbulence

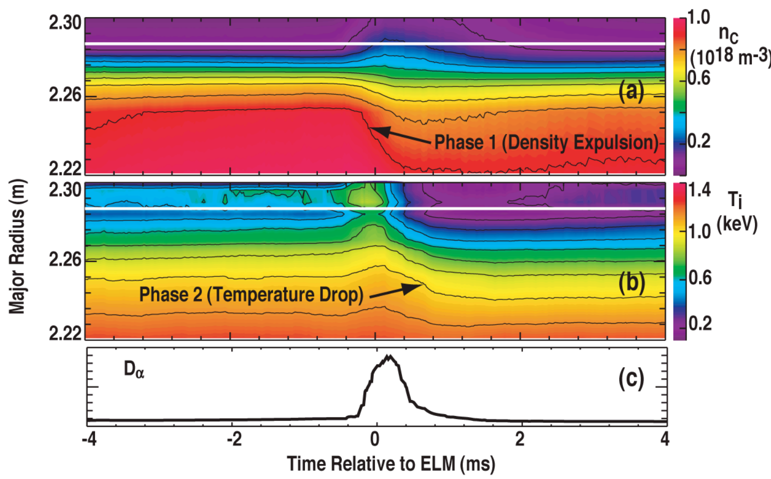

Fig. 2: Time and space evolution of (a) density of carbon ions and (b) ion temperature deduced from spectroscopic measurements on DIII-D. The white line in (a) and (b) indicates the outer boundary of the confined region. The deuterium light signal, which is indicative of the ELM timing, is shown in (c).

in the edge plasma. This is consistent with theoretical studies showing that this turbulence can efficiently transport energy out of the confined plasma.

Work supported by U.S. Department of Energy under contract DE-FC02-04ER54698.

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[CP1.00037] Comparison of ELM models with fast diagnostics in DIII-D
Abstract: **http://meetings.aps.org/Meeting/DPP05/Event/34799**
October 24, 2005
Monday, 2:00 pm
Session CP1: Poster Session II
Adam's Mark Hotel - Grand Ballroom I & II

[BO3.00009] MHD Analysis of the Tokamak Edge Pedestal in the Low Collisionality Regime
Abstract: **http://meetings.aps.org/Meeting/DPP05/Event/34518**
October 24, 2005
Monday, 11:06–11:18 am
Session BO3: DIII-D Tokamak
Adam's Mark Hotel - Governor's Square 15