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T. Munsat, E. Mazzucato, H. Park, C.W. Domier, M. Johnson,
N.C. Luhmann, Jr., J. Wang, Z. Xia, I.G.J. Classen,
A.J.H. Donné, and M.J. van de Pol

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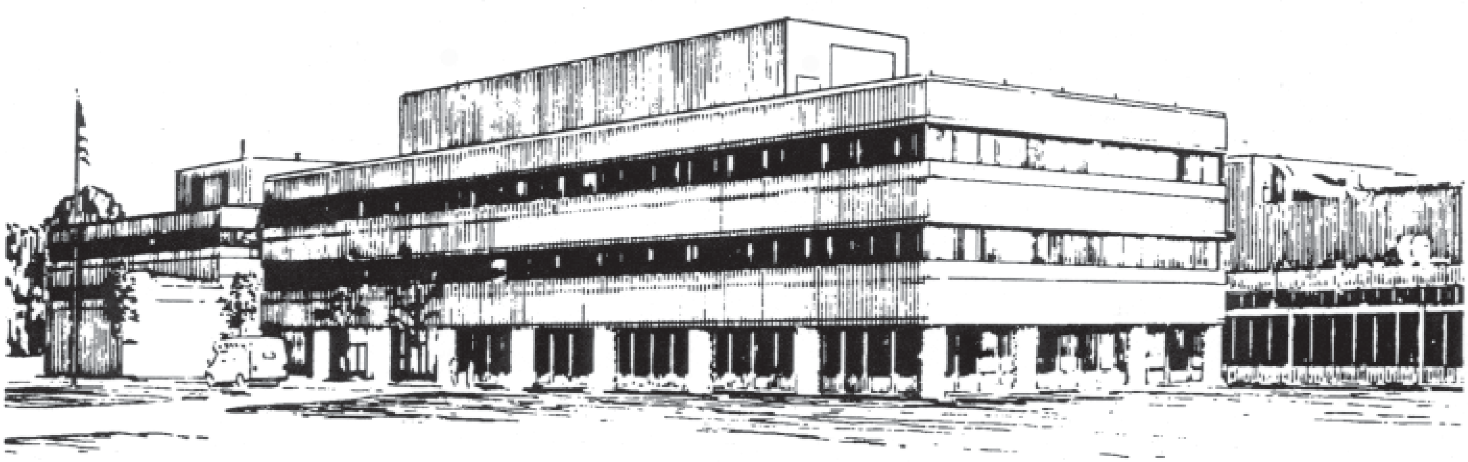

PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

2-D Imaging of Electron Temperature in Tokamak Plasmas

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Abstract - By taking advantage of recent developments in millimeter wave imaging technology, an Electron Cyclotron Emission Imaging (ECEI) instrument, capable of simultaneously measuring 128 channels of localized electron temperature over a 2-D map in the poloidal plane, has been developed for the TEXTOR tokamak. Data from the new instrument, detailing the MHD activity associated with a sawtooth crash, is presented.

Electron cyclotron emission (ECE) measurements have been used for several decades to measure electron temperature (T_e) profiles and fluctuations in magnetized toroidal plasmas. In a conventional ECE radiometer, a horn antenna receives the ECE radiation emitted over a wide range of frequencies, which is separated into different frequency bands corresponding to different horizontal plasma locations. Previous efforts to obtain 2-D T_e profiles from ECE measurements have most often invoked the “rigid body” rotation assumption, allowing time variations measured by a 1-D ECE system near the plasma mid-plane to be projected as poloidal variation [1,2]. Additionally, soft X-ray arrays have been used to create 2-D tomographic reconstructions from line-integrated measurements [3]. In this article, data from a new instrument is used to provide directly-measured 2-D T_e maps of MHD behavior resulting from a sawtooth crash at the q~1 surface in the TEXTOR tokamak.

In the ECE Imaging (ECEI) technique, the single antenna of a conventional heterodyne ECE radiometer is replaced by a vertically distributed array of antennas/mixers, using large diameter optics to image the ECE emission layer onto the array, thus transforming the 1-D radiometer into a 2-D imaging instrument. The TEXTOR instrument uses a wide-band intermediate frequency scheme for each of 16 antennas, enabling simultaneous detection of 8 frequencies distributed over ~4 GHz for a total of 128 channels. The spatial resolution of the instrument is ~1 cm in both the radial and vertical directions. Further details of the ECEI approach and the TEXTOR instrument in particular can be found in Refs. [4,5].

Since the first observation of sawtooth phenomena using soft x-ray emission, the general physical mechanism of sawteeth has come to be relatively well understood [6,7]. The details of the physical magnetic reconnection process are still unresolved, however, and require 2-D measurements of T_e and plasma current (I_P) to fully understand. Some of the primary outstanding issues include whether the reconnection process is partial or full, and whether the sawtooth crash is due to ballooning or kink modes.

Figures 1 and 2 show a sequence of images from the TEXTOR ECEI system, recorded near the q~1 surface, for timeslices ranging through the sawtooth crash cycle (TEXTOR shot 94568). The plasma conditions were as follows: I_P = 400 kA, B_T = 2.3 T, $n_e(0) = 4\times10^{19}$ m^{-3}, and $T_e(0)$ ~1 keV. The relative temperature oscillation for each channel was determined by normalizing to the time-averaged measured signal level (proportional to the local electron temperature). Each of the 128 waveforms was low-pass filtered at 10 kHz. In each image frame, an estimate of the inversion layer is indicated by a double black curve. This estimate is based solely on the ECEI measurements, without corroboration from a separate current profile measurement.

Typically in a TEXTOR sawtooth crash, there is a short precursor phase, exhibiting a "hot-spot" which rotates through the ECEI field of view several times before eventually breaking through the q~1 surface at the crash. The break-through of the hot region appears to be poloidally localized, in the plane-of-view of the ECEI instrument, but occurs at an arbitrary poloidal location for each sawtooth event. This includes cases where the break-through point is out of view of the ECEI system. A likely explanation for these observations is that the heat ejection occurs locally in the vicinity of a single helical field line, which has an arbitrary toroidal phase (relative to the ECEI system) at the crash time. The arbitrary toroidal phase appears as an arbitrary poloidal phase when viewed by the fixed ECEI instrument.

In the sequence shown in Fig. 1, the "hot-spot" appears to break through the inversion layer at the lower-right corner of the field of view. As can be seen in the figure, the ejection of heat through the inversion layer appears to be quite localized, until a symmetric equilibrium is restored at the end of the crash.

Figure 2 shows a similar sequence, but for a sawtooth event in which the hot spot breaks through the inversion layer slightly above the outer midplane, allowing a better observation of the heat ejection within the ECEI view.

With the addition of current-profile diagnostics and an expanded set of ECEI data from TEXTOR, these images can help to enhance our understanding of the m=1 oscillation and sawtooth crash, as well as provide data for future experiments on lower-level temperature fluctuations due to tokamak microturbulence.

T. Munsat, E. Mazzucato and H. Park are with the Princeton Plasma Physics Laboratory, PO Box 451, Princeton NJ 08543. C.W. Domier, M. Johnson, N.C. Luhmann, Jr., J. Wang, and Z. Xia are with the University of California at Davis, Department of Applied Science, Davis, CA 95616. I.G.J. Classen, A.J.H. Donné and M.J. van de Pol are with the FOM-Institute for Plasma Physics Rijnhuizen, Association EURATOM-FOM, P.O. Box 1207, 3430 BE, Nieuwegein, The Netherlands.

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REFERENCES

[1] Y. Nagayama, *et al.*, “Tomography of full sawtooth crashes on TFTR”, Phys. Plasmas 3, 1647 (1996).

[2] V.S. Udintsev, “Electron Temperature Dynamics of TEXTOR Plasmas”, Ph.D. Thesis, University of Utrecht (2003).

[3] Y. Nagayama, et al., “Soft X-ray tomography of Sawtooth Oscillations in the JIPP-T-II Tokamak”, Phys. Rev. Lett. 61, 1839 (1988).

[4] B.H. Deng, *et al.*, “ECE Imaging of Electron Temperature and Electron Temperature Fluctuations”, Rev. Sci. Instrum. 72, 301-306 (2001).

[5] H. Park, *et al.*, “Simultaneous Microwave Imaging System for Density and Temperature Fluctuation Measurements on TEXTOR”, to be publ. in Rev. Sci. Instrum. 75 (2004).

[6] S. von Goeler, *et al.*, “Studies of internal disruptions and m=1 oscillations in tokamak discharges with soft X-ray techniques”, Phys. Rev. Lett. 33, 1201 (1974).

[7] B.B. Kadomtsev, “Disruptive instability in tokamaks”, Fizika Plazmy 1, 710 (1975).

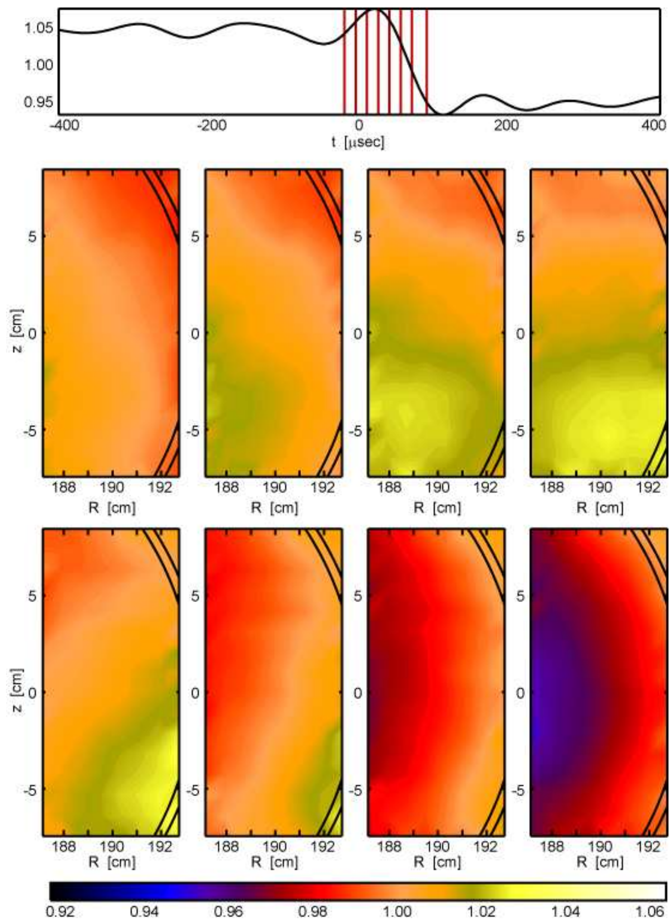

Figure 1. Progression of images of a sawtooth crash. The eight image times are indicated in the upper waveform. The inversion layer is estimated as the double black curve. The “hot spot” (yellow in the false-color scale) breaks through the inversion layer at the lower right corner of the field of view.

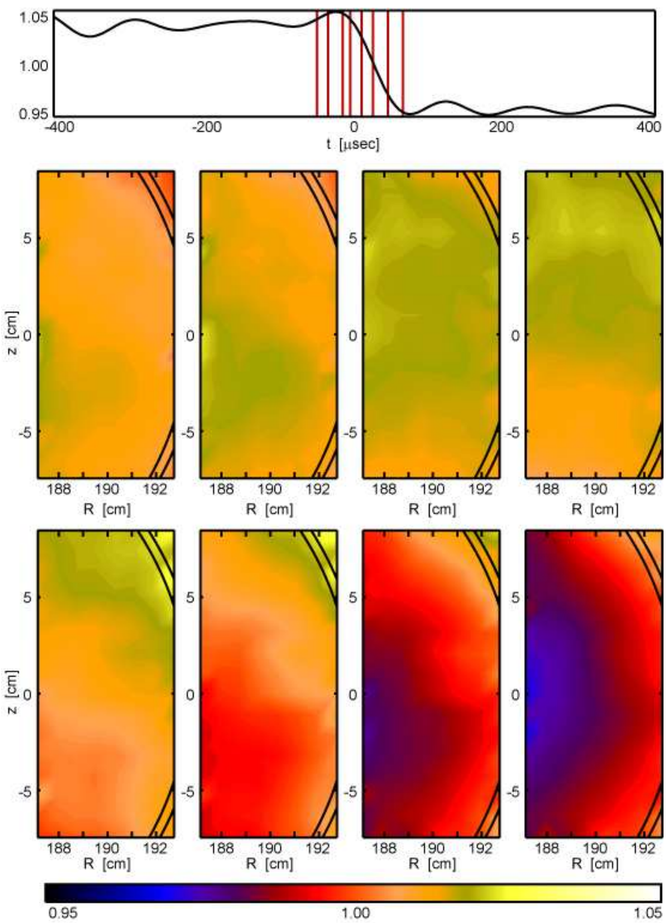

Figure 2. Progression of images taken during a sawtooth crash in which the “hot spot” breaks through the inversion layer just above the outer midplane.

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Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
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