Images of Edge Turbulence in NSTX

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***Abstract*—The two-dimensional structure of edge plasma turbulence has been measured in the National Spherical Torus Experiment (NSTX) by viewing the emission of the D_α spectral line of deuterium. Images have been made at framing rates of up to 250 000 frames/s using an ultra-high speed charged coupled device camera developed by Princeton Scientific Instruments. A sequence of images showing the transition between L-mode and H-mode states is shown.**

***Index Terms*—Edge plasma, imaging, National Spherical Torus Experiment (NSTX), turbulence.**

EDGE plasma turbulence is important for tokamak research since it controls the edge plasma temperature and can significantly affect global plasma confinement. Edge turbulence also strongly affects the plasma-wall interaction since it controls the radial flow of particles and heat through the scrape-off layer. This paper describes high-resolution images of edge turbulence recently obtained in NSTX.

The basic structure of edge turbulence is clear from previous studies [1]: it consists of perturbations which has a small spatial scale in the direction perpendicular to the magnetic field B (i.e., a few cm), a very long scale in the direction along B (i.e., many meters), and a short autocorrelation time (typically $\approx$10 μs). Most previous imaging of edge turbulence has used the D_α spectral line of neutral hydrogen (656 nm), which responds (not quite linearly) to electron density fluctuations. More recently, localized sources of neutral atoms have been used to image the two-dimensional (2-D) radial versus poloidal structure by viewing the turbulence along a sightline parallel to the magnetic field line direction [2]–[5].

The images shown in Fig. 1 were made in D_α light in NSTX using the gas puff imaging (GPI) diagnostic [2]–[4]. The view here is directed along a magnetic field line near the outer midplane magnetic separatrix, and extends about 20 cm in the radial direction (left/right, with outward toward the right) and 20 cm in the poloidal direction (up/down). A deuterium gas puff manifold located just outside this field of view provides a local source of deuterium atoms within this region. The D_α light is emitted in the region where roughly $5\ \text{eV} \leq \text{T}_\text{e} \leq 50\ \text{eV}$, within which the neutrals are excited but not completely ionized. These images have a spatial resolution of $\approx$1 cm.

The new feature of Fig. 1 is the combination of high spatial and time resolution, which is made possible using the Princeton Scientific Instruments PSI-5 ultra-high speed camera. This camera has a custom CCD chip which stores 300 frames with a spatial resolution of 64×64 pixels at speeds of up to 500 000 frames/sec. This CCD has a light sensitive pixel size of 100 μm, a net quantum efficiency of $\geq$15%, a readout noise of $<$32 electrons/pixel, and a saturation level of $>$24 000 electrons/pixel. The camera was used with an image intensifier for this experiment. A low noise 14 bit analog-to-digital converter (ADC) is used to read out the data after the image capture.

The sequence of images in Fig. 1 shows an NSTX discharge in which the neutral beam power level was marginally above that required to sustain a high-confinement H-mode plasma (shot #113 075 at 208 ms). The first set of frames (#1–#12) shows a typical H-mode pattern in which the D_α light forms a nearly quiescent uniform band in the poloidal direction, i.e., lying along a flux surface. The middle frames (#17–44) show the development of a typical L-mode pattern, in which localized coherent structures called "blobs" form and then move either radially or poloidally [2]–[4]. The final frames (#49–#64) again show a typical H-mode pattern, in this case with a small blob breaking off. This switch from H-mode to L-mode and back again at marginal power is sometimes called "dithering," and can occur on a timescale short compared with the energy confinement time ($\approx$30 msec).

The most interesting parts of Fig. 1 are the transitions from H-L and L-H. During the H-L transition (frames #15–#21), it looks as if an initial disturbance propagates poloidally from the bottom of the frame to the top within $\approx$25 μs, i.e., at a speed of nearly 10 km/s. Shortly afterward the image breaks up into 3 distinct blobs (frames #24–#25), which then begin to propagate outward at a speed of 1–2 km/s (frames #25–#30). In normal L-mode discharges, this pattern of blob formation, mutation and motion persists continuously, but in the "dithering" discharge of Fig. 1 the plasma then makes another transition from L- to H-mode (frames #41–#45). Here, there seems to be no clear signature of the L-H transition; the blobs just seem to disappear and the quiescent H-mode pattern reforms again. The motion can be seen in movies of these images.[1]

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[1] See http://www.pppl.gov/~szweben/NSTX04/NSTX_04.html.

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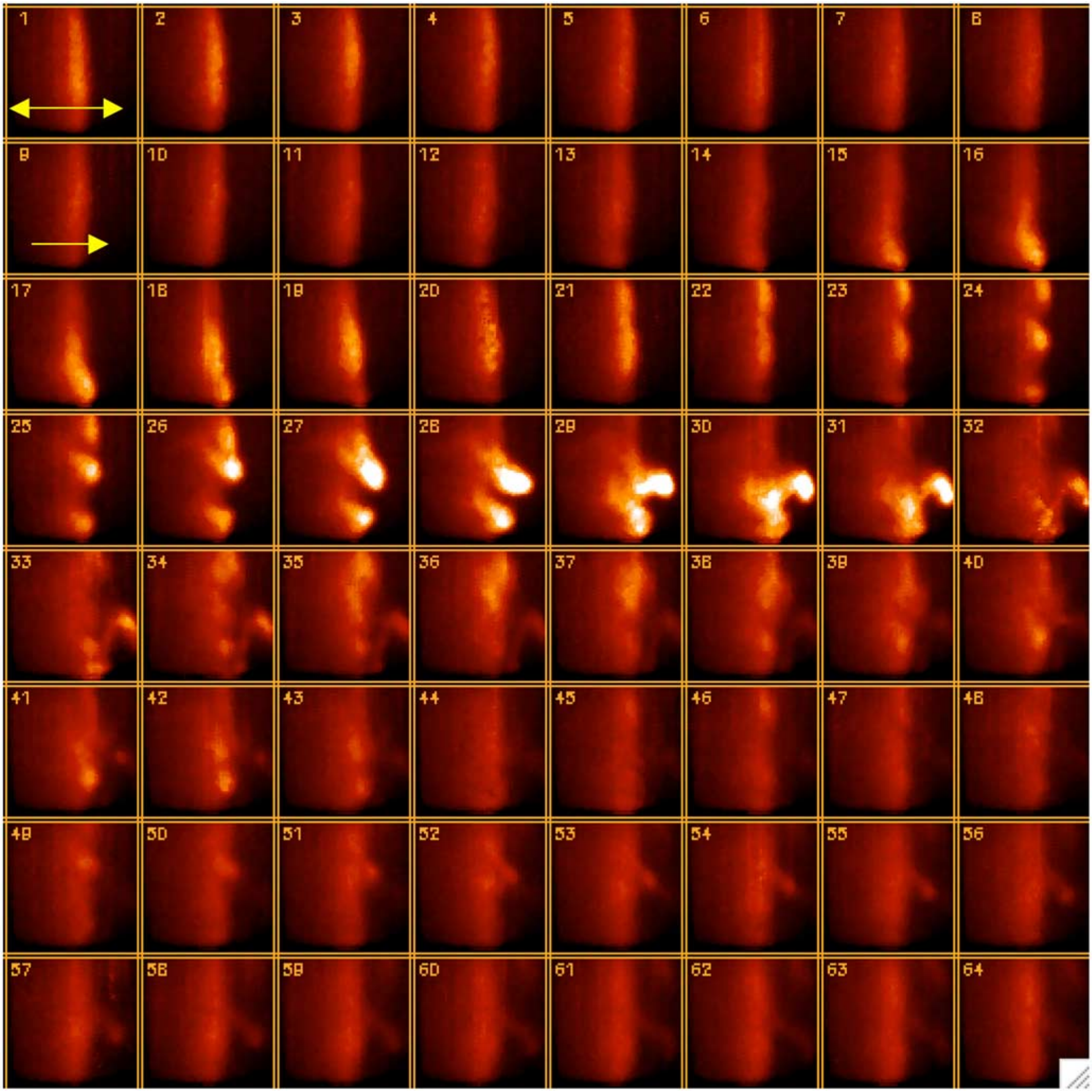

Fig. 1. Images of D_α light from the NSTX edge plasma recorded at a framing rate of 250 000 frames/sec and an exposure time of 4 μs per frame. Each frame views a region $\approx 20\ \mathrm{cm} \times 20$ cm centered just above the outer midplane separatrix, with radially outward to the right. This sequence covering 256 μs shows a "dithering" transition from a quiescent H-mode to an unstable L-mode pattern and then back again to an H-mode. These frames are displayed using a linear false-color "red temperature" scale.

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