Edge Turbulence Measurements
during the L- to H-Mode Transition
by Phase Contrast Imaging on DIII-D[†]

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Edge Turbulence Measurements During the L– to H–Mode Transition by Phase Contrast Imaging on DIII–D*

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1. Introduction

A CO_2-laser imaging diagnostic measures the vertical line integrals of the density fluctuations at 16 radial locations within a 7.6-cm-wide region at the outer edge of the DIII–D tokamak [1]. The phase-contrast technique [2] provides a flat response to wave numbers in the range 1–16 cm^{-1} [3] and is mostly sensitive to radial wave vectors [4]. This last property ensures that fluctuations are detected essentially in the plasma frame, since the $\mathbf{E} \times \mathbf{B}$ drift associated with the radial electric field is mainly in the poloidal direction. The radial resolution is 0.5 cm, the data acquisition bandwidth is 1 MHz, and the density sensitivity is on the order of 10^9 cm^{-3}.

The DIII–D Phase Contrast Imaging (PCI) diagnostic has been employed in the study of plasma turbulence, particularly at the transition from L– to H–mode. Past work has shown that the average amplitude of the line-integrated fluctuations in the plasma is reduced at the onset of the H–mode, in agreement with measurements by other diagnostics in DIII–D and elsewhere [5]. In the frequency domain, two distinct spectral regions were identified: a low-frequency ($\lesssim 20$ kHz) band, which is generally unaffected by the transition, and a broad high-frequency region, which is strongly suppressed in H–mode. In addition, it was determined through spatial analysis that the L–mode fluctuations have a nonzero average group velocity in the inward direction [4].

In this paper we report on measurements of turbulence carried out during a study of low-power L– to H–mode transitions [6]. As the input power approaches the threshold for H–mode, the transition occurs on a progressively slower time scale. The new results are consistent with past observations in L–mode and in the fully developed H–mode; novel features emerge, however, in the transient phase immediately following the transition. The phenomenology of these events, which lack a theoretical explanation at present, will be discussed in the next section.

2. Slow L– to H–mode transitions

This experiment was carried out in lower-single-null diverted plasmas with a toroidal magnetic field of 2.1 T, a plasma current of 1.37 MA, and a line-averaged density of 3.2×10^{13} cm^{-3}. The neutral-beam power was 2 MW, approximately 30% higher than the threshold for obtaining H–mode [6]. Data from 8 PCI chords were acquired at a rate of 500 ksamples/s; the intersections of the PCI chords with the midplane scanned the region from 2.5 cm inside to 2.5 cm outside the separatrix.

The time histories of the rms fluctuation levels on two chords, one of which intersects the plasma while the other lies entirely in the scrape-off layer (SOL), are shown in Fig. 1, along with a D_α emission signal for reference. At the start of the drop in the D_α trace, which signals the onset of the H–mode, the fluctuation level on the plasma chord decreases rapidly, reaching a minimum in ~50 μs. Only a slight drop is observed on the SOL chord. After a quiescent phase of ~0.6 ms, the fluctuation level rises again, to a value similar to that of L–mode on the plasma chord, and to a substantially larger value on the SOL chord. This turbulent phase subsides slowly, on a 20–30 ms time scale. In the final H–mode phase, which begins approximately when the D_α signal completes its descent, the fluctuation amplitude is lower than in L–mode on the plasma chord and of the same order as in L–mode on the SOL chord, in accord with past measurements.
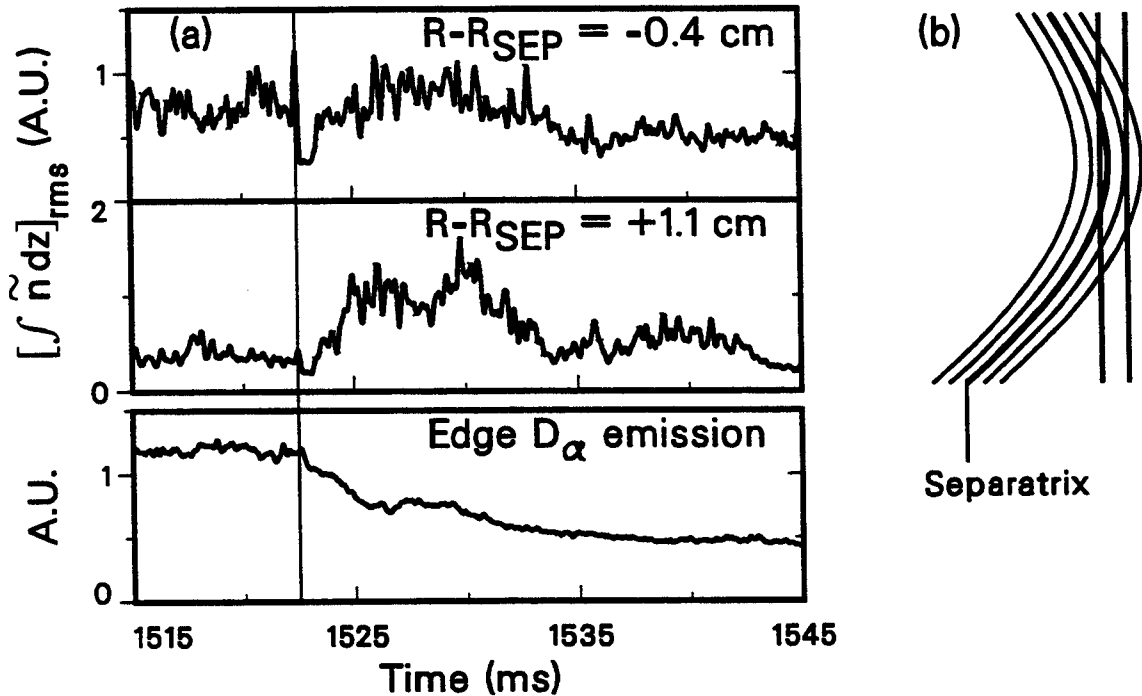

Fig. 1. (a) Rms line-integrated fluctuations on PCI chords, 0.4 cm inside (top) and 1.1 cm outside the separatrix (middle), and D_α emission signal (bottom). The vertical line denotes the time of the L–H transition. (b) Detail of field lines, with exaggerated curvature, and of the PCI chords used in left-hand plot. The uncertainty on the position of the separatrix is ±0.5 cm.

Figure 2 shows the frequency autopower spectra of the fluctuation signals in logarithmic scale on the same two chords, calculated at three different times, respectively in L–mode, in early H–mode, and in late H–mode. In L–mode, least-squares fits to inverse power functions for all 8 chords yielded exponents in the range 1.7–2.3 with reduced χ^2 values smaller than 1. The spectrum becomes more irregular in early H–mode and is also shifted toward higher frequencies. This may be partly due to residual Doppler shifts from the increased $\mathbf{E} \times \mathbf{B}$ velocity [5]. The average level is similar to that in L–mode on all plasma chords and in the deep SOL, whereas it is considerably larger at the SOL location shown in Fig. 2. It is possible in fact that the early-H–mode turbulence is limited to the SOL; by contrast, the L–mode fluctuations peak 1–2 cm inside the separatrix. This dissimilarity may account for the reduced transport in the plasma in early H–mode. Finally, the fluctuation level in late H–mode is considerably lower than that in L–mode on all plasma chords, whereas the two are of the same order on all SOL chords; these results are in agreement with past measurements.

An analysis of spatial correlations in the various phases confirms that correlations are generally weaker in late H–mode than in L–mode and that the L–mode turbulence is predominantly inward propagating. The level of correlation in early H–mode is of the same order as that in L–mode, or in some cases greater, but no net propagation is observed in H–mode. These conclusions are evidenced by Fig. 3, which shows the envelope of the correlation coefficient for two selected pairs of plasma chords.

In view of the suggested coexistence of two or more independent components in the spectrum of the turbulence, it is difficult to define simple global parameters such as correlation lengths. Indeed, the correlation coefficient is not always a decreasing function of the spatial separation. The present data will be analyzed further in the future in an effort to put these considerations on a more quantitative footing.

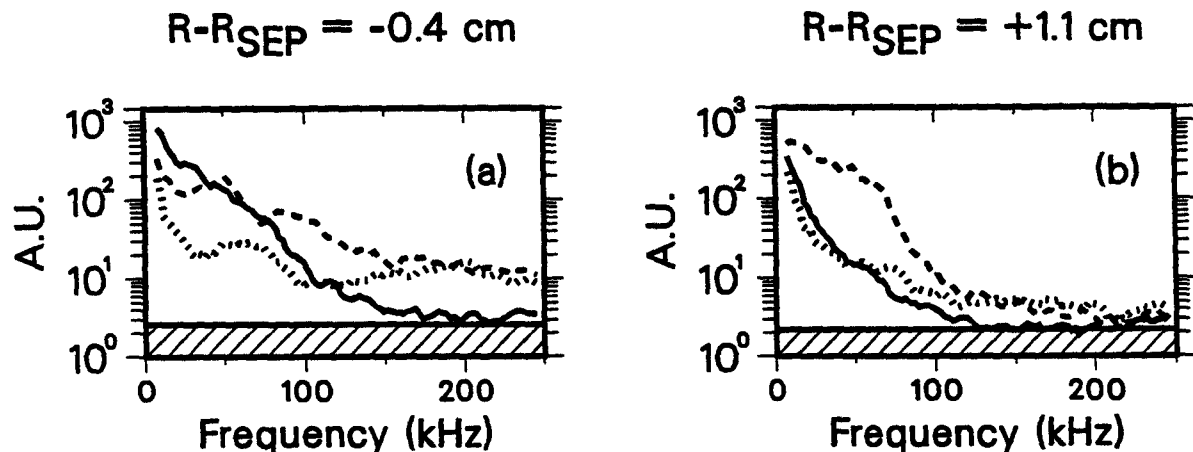$$R-R_{SEP} = -0.4 \text{ cm} \qquad R-R_{SEP} = +1.1 \text{ cm}$$

Fig. 2. Frequency autopower spectra in logarithmic scale of PCI signals from chords (a) 0.4 inside and (b) 1.1 outside the separatrix. The solid line is for L–mode, the dashed line is for early H–mode, and the dotted line is for late H–mode. Estimates were calculated on 100 realizations. The shaded area lies below the instrumental noise (signal-to-noise ratios are between 1 and 400).

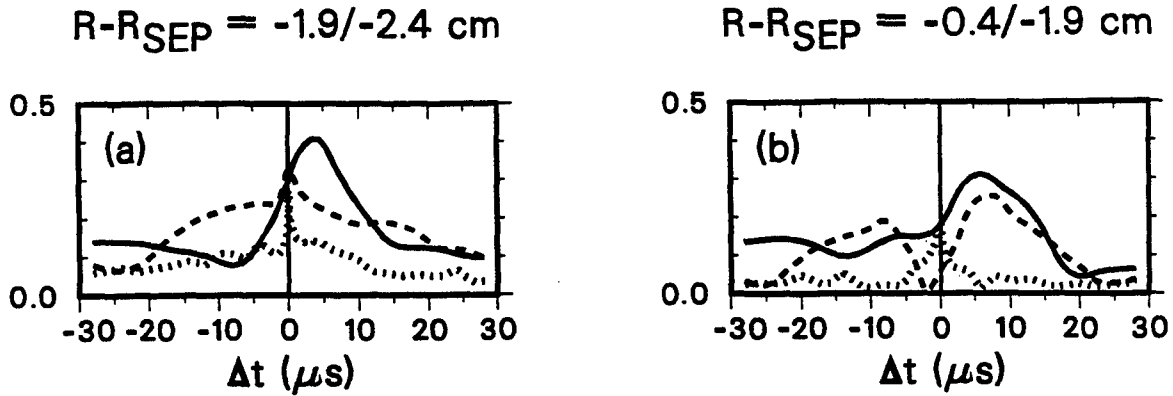R-R$_{SEP}$ = -1.9/-2.4 cm   R-R$_{SEP}$ = -0.4/-1.9 cm

Fig. 3. Envelope of the correlation coefficient between PCI chords (a) 1.9 and 2.4 cm inside the separatrix, and (b) 0.4 and 1.9 cm inside the separatrix. The solid line is for L–mode, the dashed line is for early H–mode, and the dotted line is for late H–mode. Averaging time is 10 ms. Positive skewness indicates inward group velocity.

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