Separation of L- and H-mode density fluctuations in dithering Wendelstein 7-AS plasmas

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1. Introduction

Density fluctuations were measured with the CO_2 laser based LOcalised TUrbulence Scattering (LOTUS) diagnostic [1] in a series of similar discharges in the Wendelstein 7-AS (W7-AS) stellarator. The discharges displayed dithering between L- and H-mode states. The H_α-signal monitoring an inner limiter was used to select L- and H-mode time windows. The measurements comprised a wavenumber scan; the probed wavenumber was changed between each discharge, so that $k_\perp \in [14, 62]$ cm^{-1} was covered in 8 discharges.
The left-hand time traces of figure 1 show correlations between density fluctuations for a wavenumber of 14 cm^{-1} at 700 kHz, H_α-light and magnetic fluctuations. The stored energy is shown for reference at the bottom. The dithering observed is clearly long-time (ms) correlated (the H_α signal and the RMS value of the magnetic fluctuations shown are both about 70 % correlated to the density fluctuations). The right-hand side of figure 1 displays how we construct a series of L- and H-mode time windows from a time interval of 50 ms. A horizontal line delineates L-mode (plusses) and H-mode (asterisks) time points.

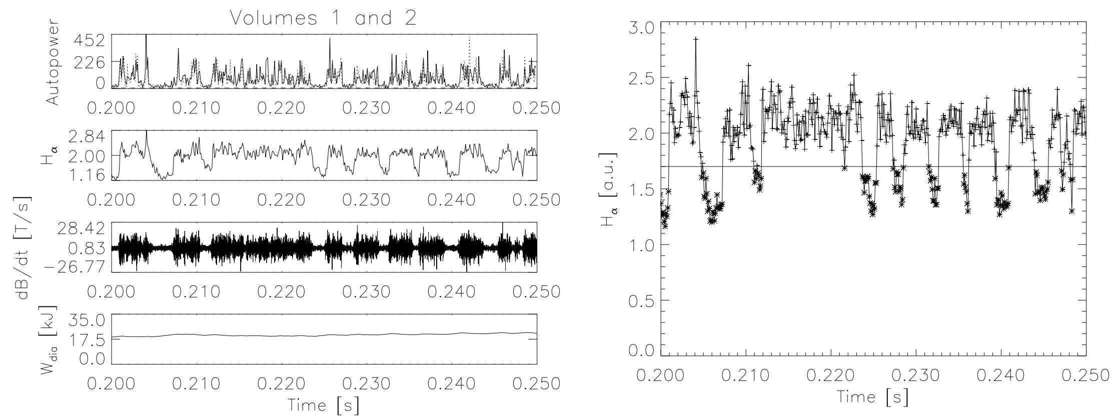

Figure 1: Left, top to bottom: Density fluctuations at 700 kHz, $k_\perp = 14$ cm^{-1} in volume 1 (solid) and 2 (dotted), H_α-light, magnetic fluctuations and the stored energy, right: H_α trace for the same 50 ms time window. The horizontal threshold line selects L-mode (plusses) and H-mode (asterisks) time windows.

2. L- and H-mode separated autopower spectra

Constructing a series of L- and H-mode time windows as shown in figure 1 enables us to calculate autopower spectra of the density fluctuations for L- and H-mode plasmas separately or the average of these. This is illustrated in figure 2, where the spectra are plotted for a single volume (LOTUS is a dual volume diagnostic). Fluctuations having an opposite frequency sign are poloidally counterpropagating.
Our initial observation is that the spectra all have a tent-like profile, which indicates that they obey a

$$P(k_\perp, \nu) = c_1(k_\perp) \times e^{c_2(k_\perp)\nu} \qquad \text{where} \qquad \frac{1}{c_2(k_\perp)} = c_3 + c_4 \times k_\perp^2 \tag{1}$$

type scaling [2], where P is autopower and c_3 and c_4 are constants. Further, the H-mode spectra (dotted) are limited to lower frequencies than the L-mode spectra (solid) and are steeper as a function of frequency.

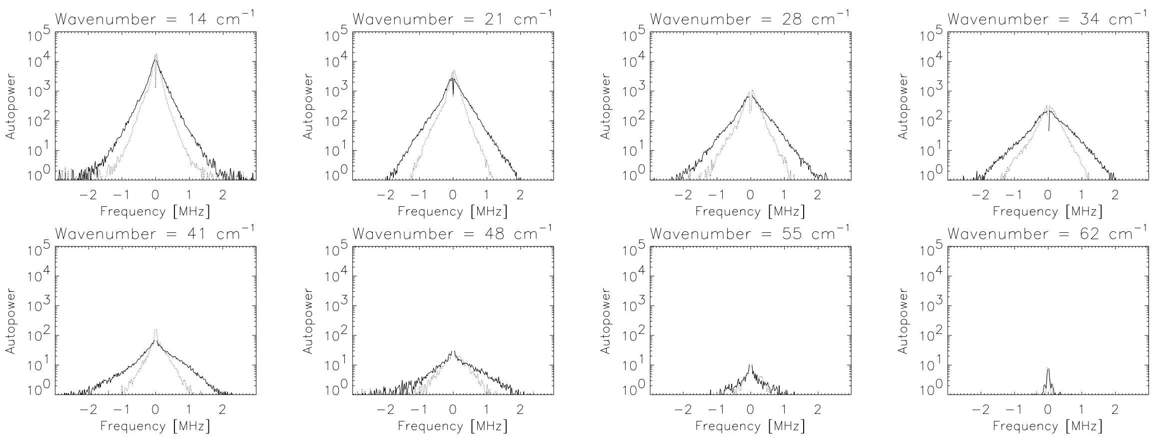

Figure 2: Separated autopower spectra. L-modes are solid and H-modes dotted lines.

To get a better impression of the differences between the spectral shapes, figure 3 shows c_1 and $1/c_2$ as determined by fits to the negative (two left columns) and positive (two right columns) frequencies of the measured spectra shown in figure 2. The solid curves on the right-hand sides are fits to the data (excluding the two largest wavenumbers) assuming the dependency of equation 1, while the dotted curves (all identical) are results presented in [2] shown for reference. The fit coefficients are shown in table 1. Since the c_4's are representing the slopes of the autopower spectra, we have directly shown that the H-mode slopes are much steeper than the corresponding L-mode ones. It is quite remarkable that the found values are not far from the Alcator C tokamak findings, although parameters such as working gas, toroidal magnetic field strength and density were entirely different (our L-mode parameters come closest to the reference values). The positive frequency slopes (fluctuations travelling inward parallel to the major radius R) are steeper than the corresponding negative frequency ones.
The characteristics of the L- and H-mode separated spectra can be further analysed by calculating ratios between these, see figure 4. Here, the H-mode divided by the L-mode autopower is shown for a single volume. Values larger than one means that H-mode power is dominating; this is observed for low frequencies, up to a few hundred kHz

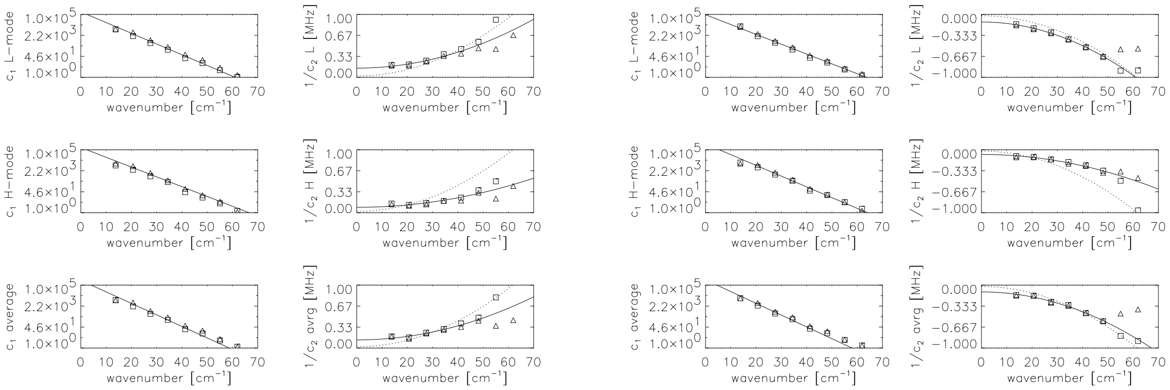

Figure 3: Autopower fit coefficients for negative (two left columns) and positive (two right columns) frequencies. For each frequency sign: Left/right, top to bottom: $c_1/(1/c_2)$ vs. $k_\perp$ for L-mode, H-mode and average spectra. The solid lines on the left-hand sides are exponential fits to c_1 (will not be discussed further), while the right-hand solid lines are fits according to equation 1 (see text). The dotted lines are reference values. Triangles are volume 1, squares volume 2.

Parameter	L_{neg}	H_{neg}	$Average_{neg}$	L_{pos}	H_{pos}	$Average_{pos}$	Reference
c_3 [kHz]	147	86	129	-121	-75	-108	22
c_4 [cm^2 kHz]	0.159	0.094	0.140	-0.235	-0.113	-0.197	0.257

Table 1: Fit coefficients c_3 and c_4. The subscripts refer to the frequency sign. Last column shows the result from [2].

(however, due to instrumental effects the values below ± 50 kHz should be disregarded). At higher frequencies the L-mode power clearly dominates, up to about 2 MHz where the ratio begins to fluctuate rapidly due to a very small signal (background is subtracted before ratios are calculated). There is no apparent shape variation of the ratio as the wavenumber is changed. It turns out that high frequency density fluctuation bursts are strongly correlated with bursts in H_α-light and magnetic fluctuations, even on very fast (μs) time scales (see figure 1 and [3]). Since these bursts are known to originate a few centimeters inside the Last Closed Flux Surface (LCFS) [4], it is likely that the high frequency density fluctuations are located here as well. The low frequency density fluctuations are located somewhat outside the LCFS [1]. This would also be consistent with poloidal plasma rotation due to a large negative radial electric field E_r inside the LCFS and a small positive E_r outside. So what our ratios tell us, is that low frequency fluctuations (outside LCFS) are large in H-mode, while high frequency fluctuations (inside LCFS) are large in L-mode. This would mean that high frequency fluctuations are important for the global confinement properties of the plasma.
We now discuss separated L- and H-mode wavenumber spectra, see figure 5. The left-hand plot shows the frequency integrated L-mode power vs. wavenumber and two power-law fits. The right-hand side shows the H-mode frequency integrated power vs. wavenumber, now fitted using an exponential function. Two features are especially interesting here: (i) The L- and H-mode wavenumber spectra are similar, both in amplitude and as a function of wavenumber and (ii) either spectrum can be fitted using

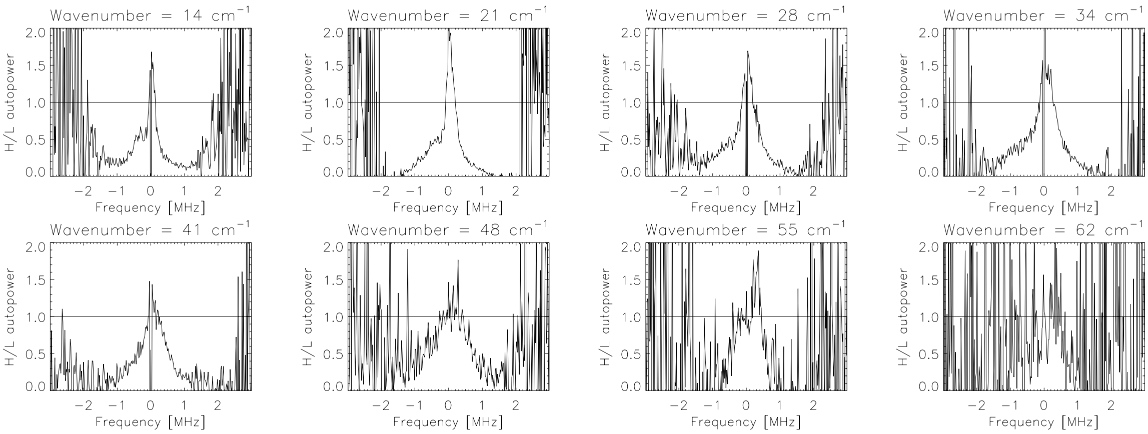

Figure 4: The H-mode/L-mode autopower ratio. Values above the horizontal line means dominance of H-mode power, values below the line dominance of L-mode power.

two power-laws or a single exponential function. Fits to power-laws $P \propto k_\perp^{-m}$ give $m \sim 2.7$ at small wavenumbers and $m \sim 7$ at large wavenumbers (see also [5]), whereas fits to exponential functions $P \propto e^{-nk_\perp}$ give $n \sim 0.15$ cm (fitting to the entire wavenumber range). We again emphasise that these numbers are valid for both L- and H-mode. The small wavenumber power-law fit is quite close to the Kolmogorov value of 8/3, while the large wavenumber exponent is completely outside this range. The fact that an exponential can fit all wavenumbers could mean that the wavenumbers observed are entering the dissipation range [6]. It is interesting to note that the found exponents apply to both L- and H-mode data, suggesting that a partial reorganisation rather than a complete suppression of the fluctuations takes place.

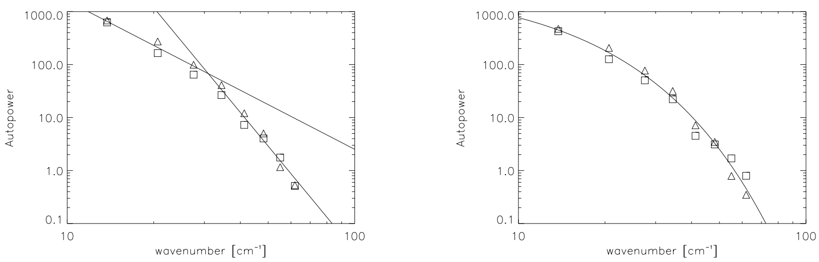

Figure 5: Left: Wavenumber spectrum of L-mode density fluctuations; power-law fits to the 3 smallest and 5 largest wavenumbers is also shown, right: H-mode wavenumber spectrum with exponential fit.

References

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