# **DENSITY PERTURBATION BY LARGE MHD MODES IN TEXTOR-94**

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### Introduction

Large m=2 islands in TEXTOR-94 generally exhibit a considerably peaked electron density inside the island, often together with an enhanced temperature in the island. This is an indication of improved confinement within their separatrix, and the work presented here is part of an effort to clarify this situation. The local density perturbation due to the island is diagnosed in two ways: by high-resolution Thomson scattering (two points in time) and by pulsed radar reflectometry (at high sampling rate).

#### **Pulsed radar reflectometry**

The pulsed radar reflectometer [1,2] measures the flight time of short (~ 1 ns) microwave pulses that are reflected on a layer of critical density in the plasma (where the local plasma frequency equals the microwave frequency). This flight time is a combination of the distance from the pulse-launching antenna and an extra group delay that the pulses incur while traversing regions where the local density is near the critical (reflecting) density. This extra delay is usually dominated by the region close to the reflecting layer, and strongly dependent on the density gradient just before reflection.

If the locally peaked density profile in a rotating magnetic island contains the critical density for the reflectometer, then reflection will occur alternately from the layer inside the separatrix (when the O-point of the island is in front of the antennae) and from a layer in the main plasma, probing through the X-point region (when the X-point is in front). This leads to typical "double garland" signals on the measured time-of-flight, as presented and analysed first in [3]. Simulations in [3] showed that the pulse flight time to the O-point reflection can be either shorter than the flight time to the reflection behind the X-point, or longer, depending on the internal density gradient in the island. We have now observed both cases experimentally.

### **Spectral analysis of fluctuations**

The reflectometer can launch microwave pulses at a repetition rate of up to 10 MHz, more than sufficient for studies of broadband density turbulence. Measurements typically show a fluctuation level in the pulse flight time of approx. 300 ps, compared to a total variation of the flight time over a plasma discharge of about 10 ns. Although no sound theoretical basis for the analysis of these fluctuations in pulse group delay has been established yet, first results of spectral analysis of data from the TEXTOR-94 system show good qualitative agreement with fluctuation spectra derived from a continuous-wave fluctuation reflectometer [4]. Since not for all pulses a reflection is detected, the time base for the pulsed radar data is somewhat irregular. For this reason, the spectral content of the pulsed radar data was calculated using the Lomb-Scargle periodogram [5,6], a method suitable for highly irregularly sampled data. The comparison with the continuous-wave reflectometer spectrum is shown in Fig. 1. A discharge out of a confinement experiment was chosen, because here the fluctuations show clear changes in behaviour, and the different reflectometer



channels lie close together in similar plasma regions. Qualitative agreement between the two spectrograms is good, especially considering the fact that the two reflectometers fundamentally measure different, although not unrelated quantities. The double-sided spectrum is constructed out of quadrature signals (phase and amplitude delay), whereas pulsed radar measures group delay. The agreement between the two provides a basis for applying pulsed radar

Figure 1: Overview of discharge 91082, showing (top to bottom) line integrated electron density, diamagnetic energy content, spectrogram of pulsed radar time-of-flight fluctuations, and, for comparison, a double-sided spectrogram from a non-pulsed dedicated fluctuation reflectometer. A period of Radiative Improved (RI) mode confinement is destroyed by strong  $D_2$  puffing starting from time 1700 ms. reflectometry as a fluctuation diagnostic, keeping in mind that, like for other types of reflectometry, the relationship between fluctuations in pulse flight times and the fluctuations in the electron density or its gradient is not straightforward.

### Fluctuation spectra during MHD modes

When applying the spectral analysis of the broadband fluctuations to the measurements in and around magnetic islands, some striking observations were made. The spectrogram in Fig. 2 shows the fluctuations in the time-of-flight signal from 0 to 500 kHz, as a function of time. The raw signal is superimposed on the spectrogram in white, in order to clearly show the transitions between island and background-plasma reflections. The vertical band structure in the spectrogram coincides with the transitions between the two possible reflecting layers, although the image is blurred somewhat in the phase where the island is rotating faster, due to the finite time window used for the spectral analysis.

The two time points marked O and X with arrows correspond to moments where the O-point respectively the X-point of the island was in front of the antennae. This was deduced from comparison with a (toroidally separated) ECE diagnostic, taking the (ion) rotation direction from CXRS.

Looking at the detailed spectra in Fig. 3, we see completely different spectral shapes for the island reflection and for the background-plasma reflection. The background-plasma spectrum starts off much higher in the low frequencies, falling off rapidly below the island spectrum. The change in slope at around 200 kHz occurs where the spectral power reaches the 'noise level' of a spectrum taken from back wall reflections after the plasma (shown dotted), and is therefore probably the instrumental noise floor. For comparison, also a spectrum from a



Figure 2: Spectrogram of pulsed radar reflectometer time-of-flight fluctuations; in white superimposed the time-of-flight signal from which the spectrogram was calculated (1 out of 50 points plotted). Discontinuities in the time-of-flight signal indicate a change of reflecting layer (inside or outside the island separatrix). The colours (different from Figure 1) are labelled in exponents of spectral power level (in a.u.).

Figure 3: Spectra of time-of-flight fluctuations, measured by pulsed radar reflectometry. Blue (red): during reflection from layer behind the X-point (inside the O-point) of the island in Fig. 2, at times depicted by arrows therein. Green: during an MHDstable phase in an otherwise comparable discharge; dotted: spectrum of vacuum vessel back wall reflection in the absence of plasma. (Green and dotted were averaged over a longer time interval).

discharge without MHD activity is shown. This spectrum is quite similar to the spectrum inside the island, although somewhat lower in power.

## Discussion

In this particular case the density



was only moderately peaked inside the island, which follows from the fact that the O-point reflection shows a longer time-of-flight than the X-point reflection [3], and which was also confirmed by Thomson scattering measurements. For the O-point spectrum this means that the reflecting layer was located in a very shallow density gradient. For similar density fluctuations this shallowness can be expected to enhance the level of fluctuations in the time-of-flight, which could explain why the O-point spectrum shows a somewhat higher level than the MHD-free spectrum. The low density peaking in the island also means that the reflection behind the X-point will be located very close to the island separatrix.

Further investigations will have to tell whether the strong enhancement of lowfrequency turbulence near the X-point (blue) is unique to the X-point region. It could also be a feature present everywhere just core-ward of the separatrix, only shielded from the reflectometer by the density peak in the O-points. How far the turbulence enhancement extends from the separatrix into the plasma core is also the topic of future study.

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