*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.023 (2005)*

Anomalous transport events in the core plasma of the Wendelstein 7-AS stellarator

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Introduction

Over the past years data from several diagnostics of the Wendelstein 7-AS stellarator showed transients with some hundred microsecond characteristic lifetime. This timescale is an intermediate one between the energy confinement time ($\approx 10ms$) and the timescale of the turbulence in various regions in the plasma (1-50 μs). This ordering indicates that these events neither belong to the basic turbulence nor they are associated with global changes in the plasma. Although generally present, these transients showed high sensitivity to the magnetic configuration, therefore the question arises to what extent they can be responsible for anomalous transport, which is also known to be strongly dependent on the magnetic configuration[1]. A remarkable feature of these phenomena is that their statistical properties are very well reproducible and steerable by external parameters.

This paper is devoted to a systematic study of these transient phenomena. We analyze exclusively 140 GHz ECRH heated discharges at 2.5 T toroidal magnetic field. The rotational transform was taken to be close (but not at) to either 1/3 or 1/2 and in some cases it was fine tuned by external fields or by an internal current[2] to study differences in the phenomena when the confinement changes nearly a factor of two in response to a minute rotational transform change. We collect all the information obtained from various diagnostics, and analyze correlations among them. Finally we investigate the transport relevance of these events.

Transients in various plasma parameters

Transients are analyzed in edge poloidal magnetic field (Mirnov coil signals), electron temperature profile (from ECE), small scale ($k = 15cm^{-1}$) density fluctuations from collective laser scattering and the edge density profile measured with Li-beam emission spectroscopy (Li-BES). Transients in the Mirnov coil signals and collective scattering manifests themself in a change of fluctuation power in a certain frequency band. Consequently these diagnostic signals are analyzed by constructing a signal describing the change in power as a function of time. Of course the time resolution of these calculated signals will be less than the original signal, but still better than the time resolution of profile diagnostics. Details of this technique were described elsewhere[3,7].

The *magnetic field* fluctuations show characteristic frequencies in the 10-100 kHz range, often more than one frequency at a time. Detailed analysis of the power modulation and spatial structures is presented in Ref. [4]. The results show that the fluctuations are composed of bursts with some hundred microsecond length (couple of oscillations) and they result from transiently present low-m MHD modes in the plasma, with poloidal mode numbers (m) mostly equal to the reciprocal of the rotational transform (m=2 or m=3). (W7-AS has a flat rotational transform profile.) At some frequencies the phase distribution cannot be fitted by a mode. From *density fluctuations* measured by Li-beam diagnostics[5] and correlated with the magnetic fluctuations the mode is found to be located *always* inside the Last Closed Flux Surface. Due to the limited measurement depth of the Li-beam diagnostics the radial location of the modes cannot always be determined.

Measurements with a double-volume CO_2 laser scattering diagnostic[6] revealed that the power of *mm-scale* $(k = 15cm^{-1})$ *density fluctuations* is also modulated in otherwise quiescent plasmas[7]. The autocorrelation time is about $100\mu s$ and changes are correlated with the modulation of magnetic field fluctuations described above. Although the laser scattering diagnostic measures line integrals of the density fluctuations, some localization can be achieved[6], and detailed investigations revealed[7] that the modulation of the amplitude occurs completely correlated at the bottom and top of the plasma. (In both cases inside the LCFS.) An earlier analysis of the laser scattering diagnostic showed[6], that the cross-field correlation length of the density turbulence is in the order of some cm, that is the turbulence structures cannot cover the distance between the top and bottom of the plasma. This means that the correlated amplitude modulation at the top and bottom of the plasma should be caused by a correlated modulation of the fluctuation drive, most probably along a whole magnetic flux surface.

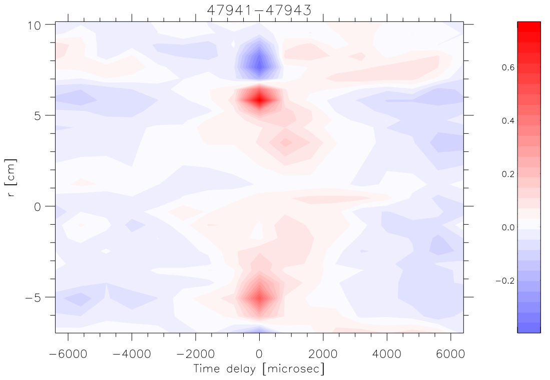

Fig. 1. Spatiotemporal correlation function of T_e *profile perturbations. The reference point is at r=6 cm on the LFS. Positive* r *values correspond to the LFS. Positive time lag means delay relative to the reference channel.*

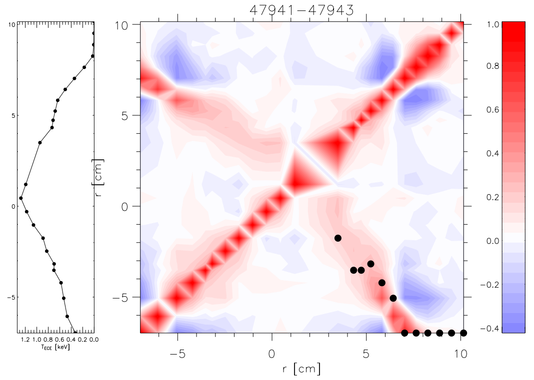

Fig. 2. Spatial correlation of T_e *profile perturbations at* $\tau = 0$ *time lag. The black dots indicate the points where the temperature on the HFS is closest to the temperature on the LFS.*

Earlier analysis with the ECE diagnostic indicated *ELM-like sudden flattenings and relaxations in the temperature profile*[8]. Although the sudden flattenings resemble ELMs, these phenomena are different in the sense, that they are not always localized to the plasma edge. In order to investigate the spatial and temporal structure of these events we have done a correlation analysis of the ECE signals. The time resolution of these is in the 0.65-2 ms range, therefore we are not looking at temperature fluctuations, but rather at profile variations. Typical correlation functions are shown in *Figs. 1-2.*

Around the point of reference one typically sees a region with positive correlation. At some point the correlation always switches to negative indicating that the profile flattens, hot plasma moves from the inside outwards. (Although the correlation analysis does not show the sign of the perturbation, we assume that a sudden change decreases the gradient.) The structure repeats itself on the other side of the plasma. The location of the maximum correlation between the LFS and HFS was compared to the locations where the electron temperatures are identical and a very good correlation was found in all cases. These observations indicate that the temperature perturbations occur along a whole flux surface. This is in agreement with expectations, as the temperature equilibration time along a flux surface should be much less ($< 10\mu s$) than the time resolution of the ECE diagnostic. The sub-ms fast profile change is limited to some radial range, which depends on the plasma configuration. This is usually followed by radial propagation of the perturbation on a ms timescale, clearly resolved by the ECE diagnostic. The RMS amplitude of the temperature modulation associated with these events is small, typically below 10%.

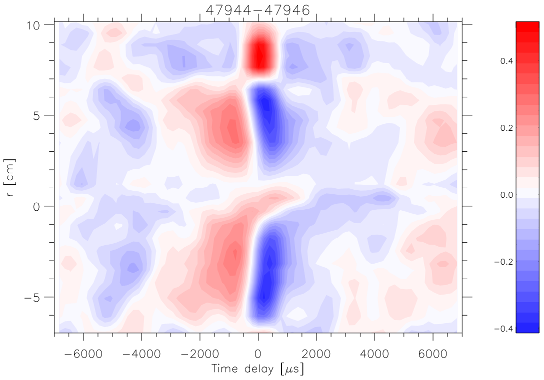

Fig. 3. Spatiotemporal correlation function of T_e profile perturbations with Mirnov RMS amplitude signal.

The temporal relationship between temperature profile perturbations and magnetic field bursts were analyzed by calculating the change in RMS amplitude of Mirnov signals on the timescale of the ECE measurement. The resulting signal is taken as reference and correlation with all ECE signals is calculated. An example is shown in *Fig. 3.* for a case when a profile flattening occurs on a much larger radial range than in the case of *Figs. 1 and 2.* Such figures always show a positive correlation at the plasma edge, indicating that the amplitude of the magnetic field fluctuations increases when the temperature profile flattening occurs.

No time delay can be observed between the amplitude change of the magnetic field fluctuations and the temperature profile change, but Fig. 3. shows some inward ballistic-like radial propagation. The time delay is within the resolution of the ECE diagnostic, therefore its significance needs further analysis.

The correlation between edge density profile changes (measured with Li-BES) and amplitude modulation in the Mirnov signals showed that there is an edge density increase associated with these events. The radial location of the increase agrees with the location of the temperature rise. As the Lithium beam diagnostic measures at a completely different poloidal and toroidal location than ECE, this observation supports the idea that hot and dense plasma is moved outward across flux surfaces.

These correlation analysis shows that the temperature flattening, transient MHD mode and increase of mm-scale density fluctuation amplitude all belong to the same phenomenon. The temperature profile change indicates an enhanced radial transport during the event.

Relevance to transport and interpretation possibilities

Analysis of various discharges revealed that the above described transients are present under all investigated plasma conditions. The amplitude, radial location and extent of the temperature flattening depends on rotational transform and other plasma parameters. High amplitude and large radial extent usually correlates with a degraded energy confinement time. The amplitude of the temperature excursions also decreases at the L to H transition therefore these transients should contribute at least to some extent to the anomalous heat and particle transport. However, a clear one-to-one correspondence between confinement time and the amplitude of these events was not observed.

For the interpretation of these events several possibilities can be thought of. The key question is what triggers the sequence of observed events. One possibility would be that some kind of MHD instability occurs and causes the quick radial transport. This is unlikely as there are no obvious mechanism driving the mode unstable: no fast ions are present in the ECRH discharges, the modes occur also in low-density, low-power discharges therefore they are obviously not pressure gradient driven. In several cases different frequency modes are excited in a correlated way[4] and additionally the density perturbation associated with the mode appears to be a smooth harmonic oscillation, not some nonlinear phenomenon.

Another possibility would be that an m=0 modulation occurs in the turbulence (as seen by the laser scattering) due to a change in the poloidal flow structure (eg. damping of a zonal flow). Although this would explain the temperature and density profile change it would be difficult to understand how a poloidally symmetric modulation could trigger a transient MHD mode with $m = 1/\iota$.

Instead of the above we propose another sequence of events. The starting point is the opening of some poloidally localized radial transport channel, e.g. the one proposed in Ref.[9] for the explanation of ELMs. This would inject hot and dense plasma into a flux tube on an outer flux surface and obviously move the plasma out of force balance. This would release an MHD wave as a harmonic response of the plasma predominantly with $m = 1/\iota$. The density would be equilibrated along a flux surface after several $2\pi R/v_{th}$ ion transit times which is around 100 μs. During this time there would be a strongly varying density distribution along a flux surface causing enhanced laser scattering at the same time from the top and bottom of the plasma. Search for such poloidally localized transport events and poloidal flow modulations is underway.

References.

[1] R. Brakel *et al. Nucl. Fusion* **42**,903 (2002)
[2] S. Zoletnik *Plasma Phys.Control. Fusion* **44** 1581 (2002)
[3] G. Pokol, *et al.* IAEA C&S Papers vol. 25/CD PS-EX/P6-22 (2005)
[4] G. Pokol *et al. same conference*
[5] S. Zoletnik, *et al.*, *Phys. Plasmas* **6**, 4239 (1999)
[6] M. Saffman, *et al. Rev. Sci. Instrum.* **72** 2579 (2001)
[7] N.P. Basse, *et al. Phys. Plasmas* **12** 012507 (2005)
[8] M. Hirsch, *et al. Plasma Phys. Control. Fusion* **42**, A231 (2000)
[9] H.R. Wilson, S.C. Cowley, *Phys. Rev. Lett.* **92** 175006 (2004)