



**HAL**  
open science

## Electrostatic Fluctuations Measured in Low Temperature Helical Plasmas with Low Collisionality

Masaki Takeuchi, Ryosuke Ikeda, Takafumi Ito, Kazuo Toi, Chihiro Suzuki,  
Go Matsunaga, Chs Group

► **To cite this version:**

Masaki Takeuchi, Ryosuke Ikeda, Takafumi Ito, Kazuo Toi, Chihiro Suzuki, et al.. Electrostatic Fluctuations Measured in Low Temperature Helical Plasmas with Low Collisionality. 2004. hal-00002011

**HAL Id: hal-00002011**

**<https://hal.science/hal-00002011>**

Preprint submitted on 22 Oct 2004

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Electrostatic Fluctuations Measured in Low Temperature

### Helical Plasmas with Low Collisionality

M. Takeuchi<sup>a</sup>, R. Ikeda<sup>a</sup>, T. Ito<sup>a</sup>, K. Toi<sup>b</sup>, C. Suzuki<sup>b</sup>, G. Matsunaga<sup>c</sup>, and CHS Group<sup>b</sup>

<sup>a</sup> *Department of Energy Engineering and Science, Nagoya University, Nagoya, Japan*

<sup>b</sup> *National Institute for Fusion Science, Toki, Japan*

<sup>c</sup> *Japan Atomic Energy Research Institute, Naka, Japan*

#### Abstract

Electrostatic fluctuations have been measured by Langmuir probes from edge to core plasma region in low temperature helical plasmas which are produced by 2.45 GHz microwaves at very low field less than 0.1T. The principal dimensionless parameters of the plasmas, that is, the normalized electron-ion collision frequency  $\nu_{ei}^*$ , and averaged plasma beta  $\beta_\phi$  and others are in the same range of them in high temperature plasmas, except the normalized gyro radius  $\rho_s^*$ . The data on fluctuation characteristics from the dimensionally similar low temperature plasmas may give an important insight into understanding of turbulent transport in high temperature plasmas. Dependences of fluctuation amplitudes on the radial electric field shear,  $\rho_s^*$  and  $\nu_{ei}^*$  are investigated. Electrostatic fluctuations propagate in electron-diamagnetic drift direction have been observed in the plasma edge region and in ion-diamagnetic drift direction in the plasma core region.

#### I. Introduction

Understanding of turbulent transport is one of the key issues for magnetic confinement fusion. There is broad consensus that turbulent transport in tokamak and stellarator plasmas is caused by the correlation among electrostatic fluctuations of electron density ( $\tilde{n}_e$ ), electron temperature ( $\tilde{T}_e$ ) and space potential ( $\tilde{V}_s$ ). In high temperature plasmas, simultaneous measurements of these fluctuations and correlations are extremely difficult. Considering this difficulty, we are attempting a new simulation experiment of high temperature plasma transport using low temperature one in the Compact Helical System (CHS) [1, 2], where principal dimensionless parameters such as normalized electron-ion collision frequency ( $\nu_{ei}^*$ ), plasma beta ( $\beta_\phi$ ) and others are adjusted to be almost the same, except normalized gyro-radius ( $\rho_s^*$ ). Between these “dimensionally similar plasmas”, characteristics of plasma transport are expected to be similar [3]. In low temperature and low density plasma where the collisionality is fairly low, Langmuir probes (LPs) can be applied to the edge to the plasma core region.

In this paper, we present the characteristics of electrostatic fluctuations measured by LPs in low temperature plasmas of the CHS stellarator.

## II. Experimental set-up

The experiments have been performed in CHS. Radial profiles of electron density  $n_e$ , temperature  $T_e$  and space potential  $V_s$  and their fluctuations have been measured with a triple-type LPs from the edge to the plasma core region with high time (2 $\mu$ s) and spatial resolutions (a few mm). The local electron density  $n_e$  measured with LPs is calibrated by the line average density  $n_{e\_2mm}$  measured by 2mm microwave interferometer. The plasmas are produced by 2.45GHz microwave up to  $P_{ecr}=20$ kW at very low toroidal field  $B_\phi=0.06-0.1$ T [4]. The fuel gas is hydrogen and the filling pressure is  $\sim 7.0 \times 10^{-5}$ Torr.

## III. Experimental Results

The dimensionless parameters of the low temperature plasma produced in CHS are  $v_{ei}^*=0.05-0.5$ ,  $\beta_\phi=0.005-0.02\%$  and  $\rho_s^*=0.02-0.04$ . The parameters  $v_{ei}^*$  and  $\beta_\phi$  are almost the same as those in high temperature plasmas of CHS, but  $\rho_s^*$  is about three to five times larger than that in high temperature one.

The radial profiles of  $n_e$ ,  $T_e$ ,  $V_s$  and their normalized fluctuation amplitudes in a typical low-temperature plasma with low collisionality are shown in Fig.1, where the plasma is produced by electron cyclotron wave power of  $P_{ecr}=9$ kW at  $B_\phi=0.06$ T. As seen from Fig.1, the normalized fluctuation amplitudes become large toward the edge and  $\tilde{V}_s/T_e > \tilde{n}_e/n_e > \tilde{T}_e/T_e$  is realized in a whole plasma radius. These features are the same as those observed in high temperature plasma [5, 6]. We have tested whether the Mixing Length Theory [7] could explain the experimental data or not. That is, the relationship between the density fluctuations and the scale length of the density gradient  $\tilde{n}_e/n_e \approx \rho_s/L_n$  is investigated for these low temperature plasmas obtained in CHS. This result is shown in Fig.2 including other tokamaks and stellarators [8]. The electron density fluctuation amplitude fits for the Mixing Length Theory in the cases that the density gradient is appreciably large.

Effect of the radial electric field shear  $dE_r/dr$  on plasma fluctuations attracts much attention in toroidal plasma confinement. In these low temperature plasmas, LPs can provide the information of  $E_r$  and  $dE_r/dr$ . Figure 3 shows the dependence of the normalized fluctuation amplitude on  $dE_r/dr$  in the particular regions of  $\rho=0.3-0.4$  (the

core region) and  $\rho=0.7-0.8$  (the edge region), where  $B_\phi=0.06\text{T}$ , and microwave power  $P_{ecr}$  through a launching port is scanned from 6, 8, 9 and 11kW. This figure clearly shows that the fluctuation amplitude is almost independent of  $dE_r/dr$ . This may be a reason why the plasma is produced by dominant electron heating and ion temperature is inferred to be much lower than  $T_e$ . This is an interesting and important research target of this new research project.

We also investigated the dependence of the normalized fluctuation amplitude on principal dimensionless parameters  $v_{ei}^*$  and  $\rho_s^*$  for the core and edge plasma regions, as shown in Fig.4. These amplitudes are almost unchanged for the change of  $v_{ei}^*$  in the plateau regime ( $v_{ei}^*=0.1-1$ ). On the other hand, the fluctuation amplitudes decrease with the decrease of  $\rho_s^*$ . This  $\rho_s^*$  is scanned by the change of the toroidal field from 0.06 – 0.09 T. In other words, the fluctuation amplitude is decreased by the increase in  $B_\phi$ .

For the evaluation of turbulent particle and heat fluxes, it is necessary to know the frequency range of fluctuation power and cross phase between  $\tilde{n}_e$  or  $\tilde{T}_e$  and  $\tilde{V}_s$ . The Power spectra, coherence and phase between  $\tilde{n}_e$  and  $\tilde{V}_s$  are shown in Fig.5 for several radial locations. The power spectrum of  $\tilde{n}_e$  in edge region extends to relatively high frequency range, while the power spectrum of  $\tilde{V}_s$  has a similar shape from the edge to the plasma core. Toward the plasma core from the edge, the coherence between density and potential fluctuations obviously decreases and the phase approaches zero radian. In the core region the phase between density and potential fluctuations is fairly small, which suggests that the fluctuations have a character of drift mode. On the other hand, the magnitude of the phase is close to  $\pi/2$  radians, of which phase suggests a character of resistive interchange mode.

The direction of the propagation of electrostatic fluctuations is important information to identify the type of instabilities, for instance, the ion temperature gradient (ITG) drift mode usually propagates in the ion diamagnetic drift direction and the trapped electron mode (TEM) in the electron diamagnetic drift direction [9]. From the phase difference between two signals of floating potential measured at two poloidally separated position on the same magnetic surface, the poloidal wave number ( $k_\theta$ ) can be derived. In the frequency range less than 50kHz in which range the coherence is high, the averaged propagation velocity in the laboratory frame is given by  $v_{lab}=2\pi f/k_\theta$ . By subtracting E×B drift velocity ( $v_{E\times B}=E_r/B_\phi$ ) evaluated by the measured  $E_r$

from  $v_{lab}$  as  $v_{pls} = v_{lab} - v_{E \times B}$ , the propagation velocity of the fluctuations in the plasma rest frame can be obtained. Radial profiles of the propagation velocity  $v_{pls}$  is shown in Fig.6 for several time slices. This figure suggests that in the edge region the fluctuations propagating in the electron diamagnetic drift direction are observed, and in the core the fluctuations propagating in the opposite direction. It is interesting to compare the characteristics of observed fluctuations with those of ITG and TEM, moreover electron temperature gradient (ETG) mode.

#### IV. Summary

Electrostatic fluctuations were measured in dimensionally similar low temperature and low density plasmas of CHS. This experiment has a merit of the capability of utilization of LPs even in core region. Detailed fluctuation measurement by LPs in such low temperature plasmas is expected to provide important information for better understanding of turbulent transport in high temperature plasmas.

#### Acknowledgements

This research was supported in part by the Grant-in-Aid for Scientific Research from JSPS, No. 15206107.

#### Reference

- [1] K. Toi *et al.*, 29th EPS on Plasma Physics and Controlled Fusion, Montreux, paper No. P4-061 (2002)
- [2] K. Toi *et al.*, to be published in JPFR SERIES Vol.6 (2004)
- [3] B. B. Kadomtsev, Sov. J. Plasma Phys. Vol. 1, 295 (1975)
- [4] R. Ikeda *et al.*, this conference, P3-085 (2004)
- [5] B. A. Carreras, IEEE Trans. Plasma Sci. Vol. 25, 1281 (1997)
- [6] P.C. Liewer, Nuclear Fusion, Vol. 25, 543 (1985)
- [7] J. Weiland, *Collective mode in inhomogeneous plasma*, IOP, 47 (1999)
- [8] C. Lechte *et al.*, New Journal of Physics Vol. 4, 34.1 (2002)
- [9] G. Rewoldt *et al.*, Physics of Plasmas Vol. 7, 4942 (2000)

Figure

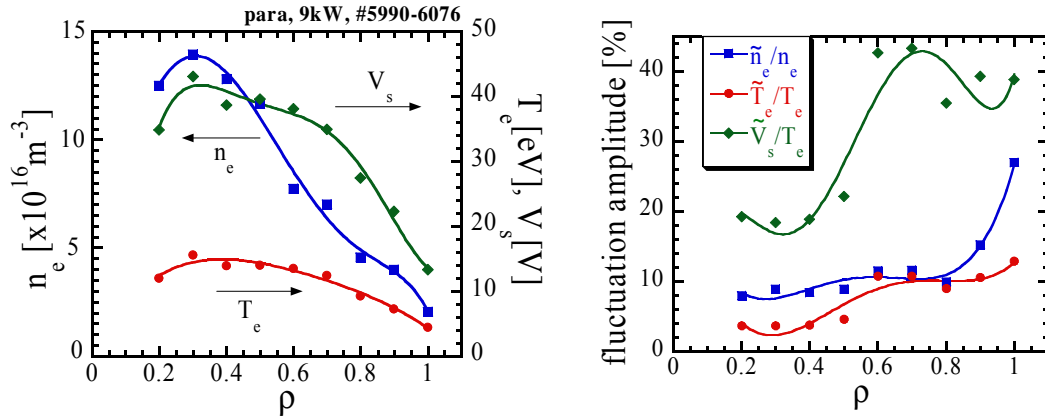


Fig.1 Radial profiles of  $n_e$ ,  $T_e$ ,  $V_s$  and their normalized fluctuation amplitudes measured in a low temperature plasma produced by 2.45 GHz microwave power  $P_{ecr}=9\text{kW}$  at  $B_\phi=0.06\text{T}$ .

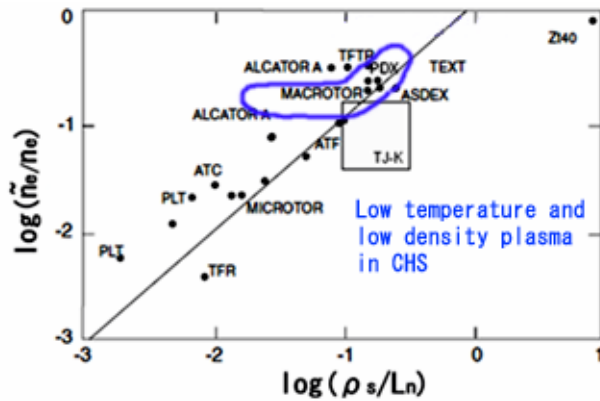


Fig.2 Comparison of the data taken in low temperature CHS plasmas with the mixing length theory, together with the data from various tokamaks, stellarators and reversed field pinches.

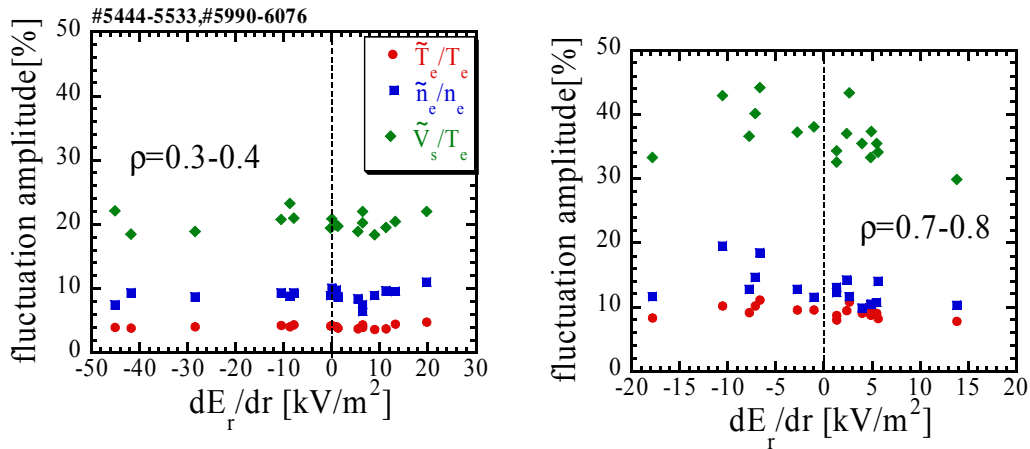


Fig.3 Dependence of the relative amplitude of  $n_e$ -,  $T_e$ - and  $V_s$ -fluctuations on the electric field shear ( $dE_r/dr$ ) in the regions of  $\rho=0.3-0.4$  (plasma core region) and of  $\rho=0.7-0.8$  (edge region), where the plasmas are produced at  $B_\phi=0.06$ T by changing microwave power as  $P_{ecr}=6, 8, 9$  and 11kW.

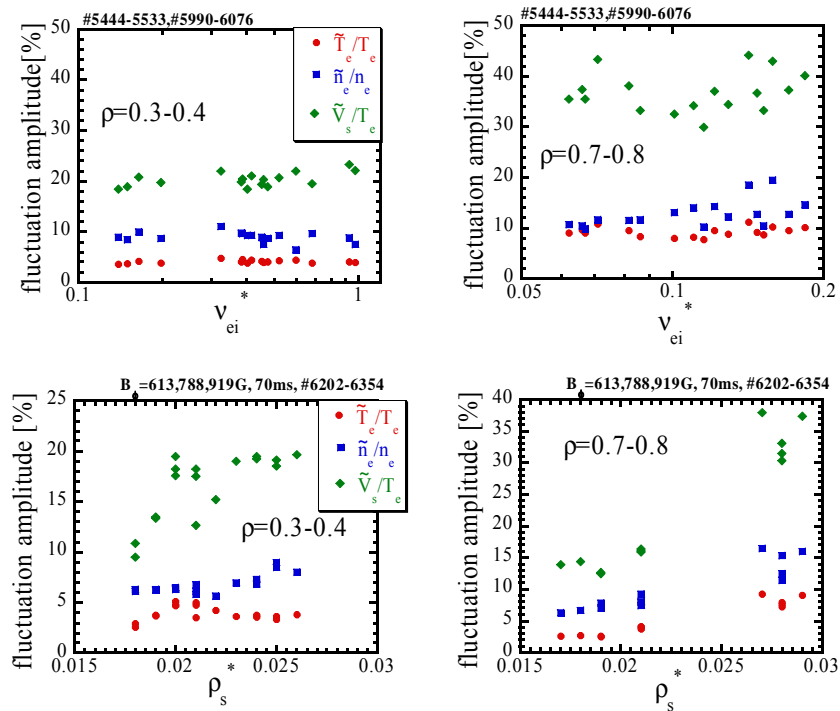


Fig.4 Dependence of fluctuation amplitude on  $v_{ei}^*$  and  $\rho_s^*$  in the core and the edge regions, where  $\rho_s^*$  is scanned by changing  $B_\phi$  from 0.06T to 0.09T.

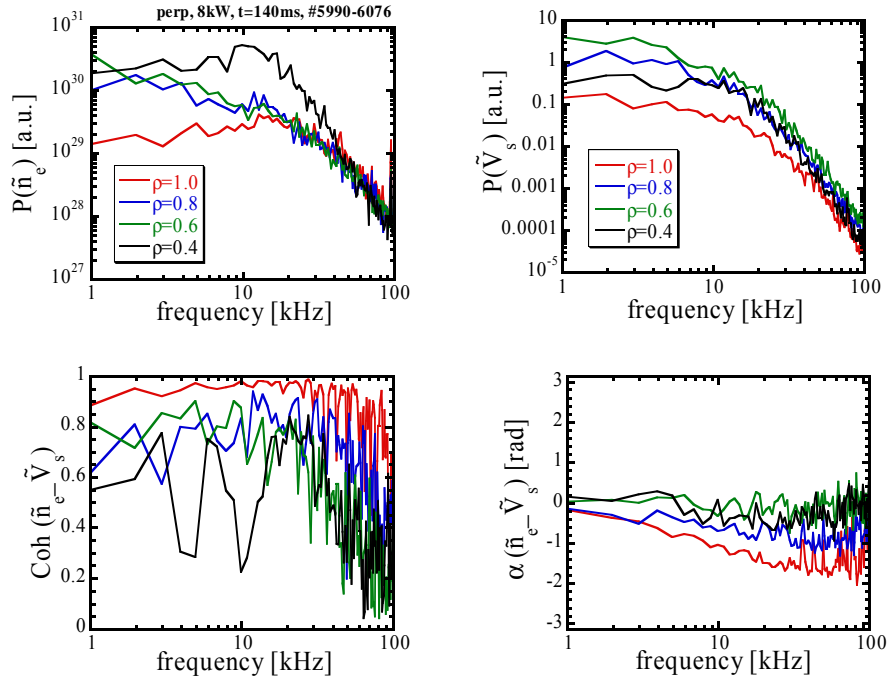


Fig.5 Frequency spectra of fluctuation power, coherence and cross phase for the fluctuations of  $\tilde{n}_e$  and  $\tilde{V}_s$  in a plasma produced by  $P_{ecr} = 8\text{kW}$  at  $B_\phi = 0.06\text{T}$ .

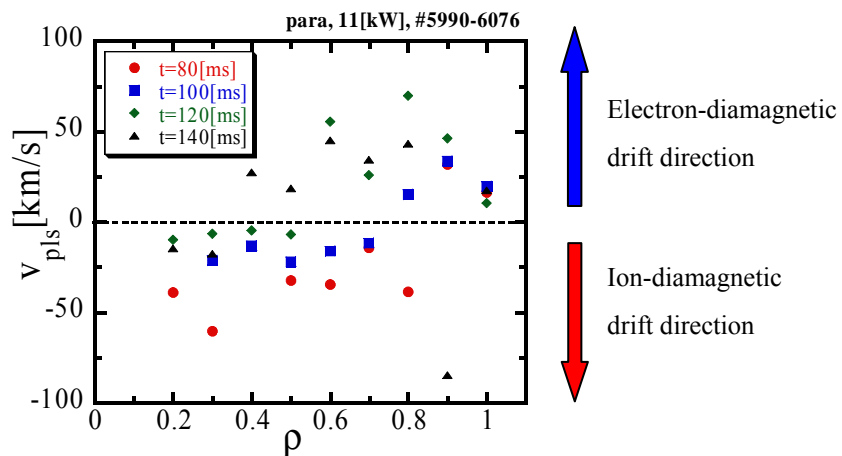


Fig.6 Radial profile of the propagation velocity in the plasma rest frame for various time slices in a plasma produced by  $P_{ecr} = 11\text{kW}$  at  $B_\phi = 0.06\text{T}$ .