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INTRODUCTION

It is well known that fluctuations are responsible for a significant portion of the particle loss rate in tokamaks and may account for a large part of the anomalous energy losses observed. For a complete estimate of the particle and heat transport, knowledge of the fluctuations in density, temperature and electric field are needed. However, temperature fluctuations are in general difficult to measure and then often ignored.

Fluctuations in the Langmuir probe collected current result from fluctuations in plasma quantities (density, n, electron temperature, T_e, and floating potential, V_f). Therefore, the probe characteristic may be used to obtain information from fluctuation in the plasma parameters. One method that in principle can resolve all the quantities of interest, has been used successfully by D.Robinson[1] for a double probe. It involves studying the variation of the probe current fluctuation as a function of the applied voltage.

The aim of this work is to apply that method to the single probe characteristic in order to obtain information on $\tilde{n}$, $\tilde{T}$, $\tilde{V}_f$ and their cross-correlations. The method consists of fitting the experimentally determined probe current fluctuation level to a theoretical curve as a function of the bias; the required fluctuation levels are the coefficients, which are returned by the curve-fitting routine.

1. PROBE CHARACTERISTIC FLUCTUATIONS

Expanding the probe current to 1st order in the fluctuating quantities, squaring and averaging in time gives

$$\langle I^2\rangle = f_1^{\,2}\langle\tilde{n}^2\rangle + f_2^{\,2}\langle\tilde{T}^2\rangle + f_3^{\,2}\langle\tilde{V}^2\rangle + f_1 f_2\langle\tilde{n}\tilde{T}\rangle + f_1 f_3\langle\tilde{n}\tilde{V}\rangle + f_2 f_3\langle\tilde{T}\tilde{V}\rangle \qquad [1]$$

where, for the single probe case

$$\tilde{f}_1 = \left(\frac{\partial I}{\partial n}\right) = 1\text{-}e^x,\ f_2 = \left(\frac{\partial I}{\partial T}\right) = \frac{1-e^x}{2} + xe^x \text{ and } f_3 = \left(\frac{\partial I}{\partial V}\right) = e^x$$

Here normalised variables have been used: $\tilde{I} \equiv \dfrac{\tilde{I}}{I_{sat}}$, $\tilde{n} \equiv \dfrac{\tilde{n}}{n}$, $\tilde{T} \equiv \dfrac{\tilde{Te}}{Te}$, $\tilde{V} \equiv \dfrac{e\tilde{V}f}{kTe}$, $x = \dfrac{eV_a - Vf}{T}$.

It follows from Eq. [1] that it should be possible to resolve fluctuations in n, T and V and their cross-correlations, provided that the functions f's are sufficiently distinguishable.

A routine was written to analyse the single probe current fluctuations consisting of the following steps: (i) characteristics are fitted to extract the average values of n, T, V_f, that are used to normalise the data (ii) data is grouped into bins, as function of applied voltage, and the current fluctuation level calculated (iii) the experimentally determined current fluctuation level, $\tilde{I}$, is fit to the Eq. 1 using a non-linear least squares fitting routine and the plasma parameters fluctuation levels and their correlation are obtained.

2. EXPERIMENTAL RESULTS

This method has been applied to JET reciprocating probe data (acquisition frequency 500kHz). Figure 1 shows a typical curve of the probe characteristic, the current fluctuation level in linear and logarithmic scale and the calculated fit. Data from six characteristics were used.

The curve fitting technique is able to resolve all plasma quantities; the six fitting parameters are also shown in Fig. 1. Results are in good agreement with the fluctuations levels obtained from probes measuring floating potential and ion saturation current at same radial position. Error bars are in general less than 10%, apart from $\tilde{T}$, which often has an error larger than 20%, depending on the quality of the data. In L-mode plasmas, we found that fluctuations in temperature are lower than in density which are themselves smaller than potential fluctuations. The correlation between density and temperature, γ_{nT}, is in general high (>0.4) and γ_{TV} negative, (<-0.2).

In order to have a robust fit, it is very important to use several characteristics. However, for the reciprocating probe this can be problematic because the probe moves during the discharge and we do not want to average between regions of the plasma that may have different fluctuations properties. The best results are obtained when the probe is at the inner most position, where the probe moves slowly. When only one characteristic is used, the curve of the current fluctuation level may not be smooth and results may vary with the number of points used in the fit. This is illustrated in Fig. 2, where the two curves correspond to the fit to data with x<2 (red line) and x<2.3 (blue line). Results show that $\tilde{n}$ and $\tilde{V}$ are very robust; they do not vary significantly with the number of points. On the contrary, $\tilde{T}$ and the cross-correlations do vary. When the statistics are poor, the data supports temperature fluctua-tions with large variations. However, in spite of the large error bars in $\tilde{T}$, we can conclude again that fluctuations in temperature are clearly smaller than in density, often around $\tilde{n}/2$.

This method has been applied to discharges where the fluctuation levels are clearly different and a reasonable agreement was observed for most of the cases showing that this method is able to resolve fluctuations in plasma quantities.

3. IMPORTANCE OF PLASMA QUANTITIES IN THE FIT

It is of interest to vary the number of fitting parameters corresponding to different assumptions about the plasma. In Fig. 3 it is assumed that fluctuations in either n, T or V are zero and data fitted to the remaining three parameters, for the same data shown in Fig. 1. Neglecting density fluctuation results in a fit clearly not as good as with the six parameters. $\tilde{I}_{sat}$ is underestimated and χ^2 increases by a factor of 5. Assuming $\tilde{T} = 0$, the fit is reasonable good, apart from the region around x = 0, and χ^2 increases only by a factor smaller than 2. Neglecting V fluctuations we get the worst fit, only $\tilde{I}_{sat}$ is well reproduced. This indicates that temperature fluctuations are less important in the fit than fluctuations in density or potential, confirming previous results.

4. COMPARISON WITH MODIFIED TRIPLE PROBE

The relative merits of the single and triple probe methods for measuring fluctuations are as follows: The main disadvantage of the triple probe method is that measurements are not local. The triple probe method cannot distinguish between fluctuations in the plasma gradients and temperature fluctuations and therefore can only give an upper limit for $\tilde{T}$. An important disadvantage of the curve fitting technique is that results are not time-resolved (time resolution is the sweeping time) and, in spite of the high acquisition frequency of the signal, the spectral information is minimal because the fluctuation level has a weak dependence on the acquisition frequency. However, spectral information may be obtained by calculating the fluctuations levels for different frequency ranges, so that their contributions to transport can be evaluated. Data has been Fourier analysed in two frequency ranges, below and above 50kHz. Analysis shows that most of the transport occurs at frequencies below 50kHz since results can be reproduced using only that frequency range. For frequencies above 50kHz a strong reduction in γ_{nT} is observed. We have also observed that the fluctuation level for x<0 is strongly reduced in that frequency range, as expected, but not for x>0. This means that high frequencies are more important in the electron current that ion current. The spectrum of the fluctuations for negative applied voltage is steeper than for positive applied voltage.

5. CONSEQUENCES FOR PARTICLE TRANSPORT

The particle flux induced by fluctuations is given by $\Gamma_{ExB} = \langle \tilde{n}\tilde{E}_\theta \rangle /B$. Temperature fluctuations are often ignored and therefore density and plasma potential fluctuations derived respectively from the ion saturation current and floating potential fluctuations. We found that in general $\tilde{T} < \tilde{n} \le \tilde{V}$. Since $\tilde{I}_{sat}$ has a week dependence on $\tilde{T}$, $\tilde{I}_s^{\,2} \approx \tilde{n}^2 + \tilde{T}^2/4 + \langle \tilde{n}\tilde{T} \rangle$, it is a good approximation to neglect $\tilde{T}$. However, the plasma potential has a strong dependence on $\tilde{T}$, $\tilde{V}_p^{\,2} \approx \tilde{V}_f^{\,2} + 9\tilde{T}^2 + 6\langle \tilde{V}_f\tilde{T} \rangle$. Fluctuations in the plasma potential are difficult to estimate because the two last terms are large and of opposite sign. Using typical results obtained by the curve fitting technique, it was found that the floating potential is a reasonable approximation for the plasma potential. Therefore, temperature fluctuations do not appear to be responsible for the large cross-field particle flux measured in the JET edge plasma.

CONCLUSIONS.

We have shown that the method described to analyse single probe fluctuations is able to resolve plasma fluctuations. In L-mode plasma, fluctuations in temperature are smaller than in density, which are themselves smaller than potential fluctuations. Although the spectral information given by the method is very limited, we have shown that most transport occurs at frequencies below 50kHz. Results tend to support the standard estimation of cross-field particle flux which ignores temperature fluctuations.

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REFERENCES

[1]. D. Robinson and M Rusbridge, Plasma Phys. **11**, 73, 196

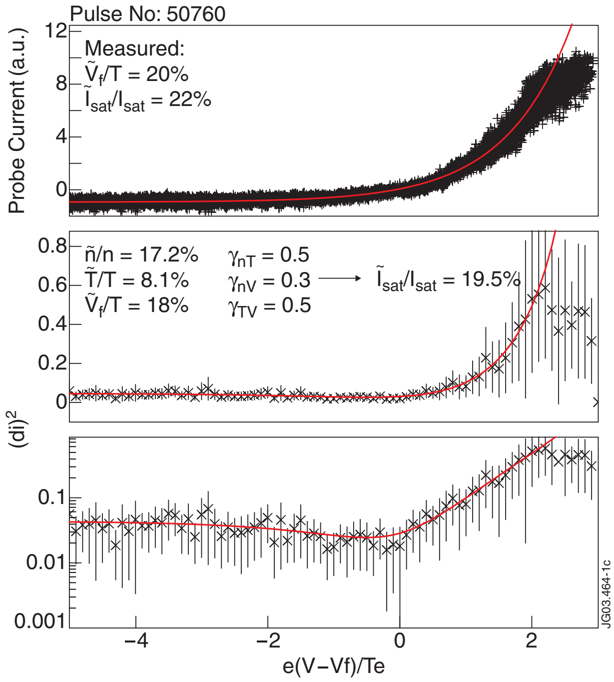

Figure 1: Example of the application of the probe fluctuations analysis and derived fluctuations levels.

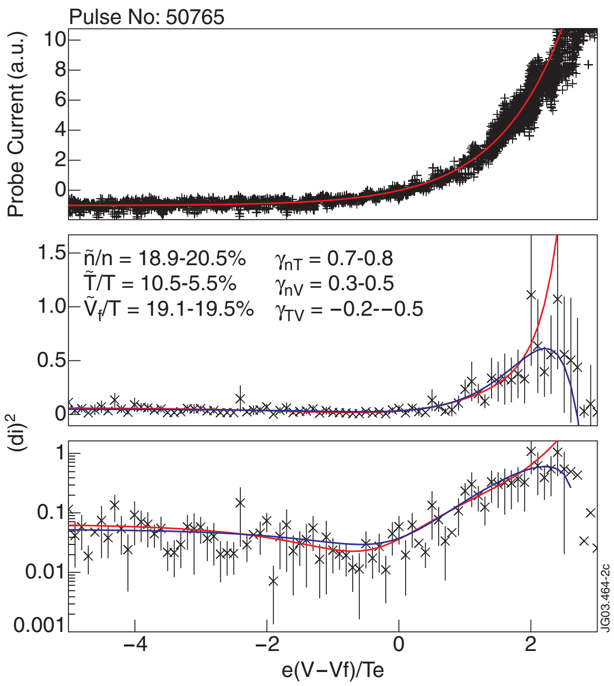

Figure 2: Fluctuation level and respective fit for a case with poor statistics.

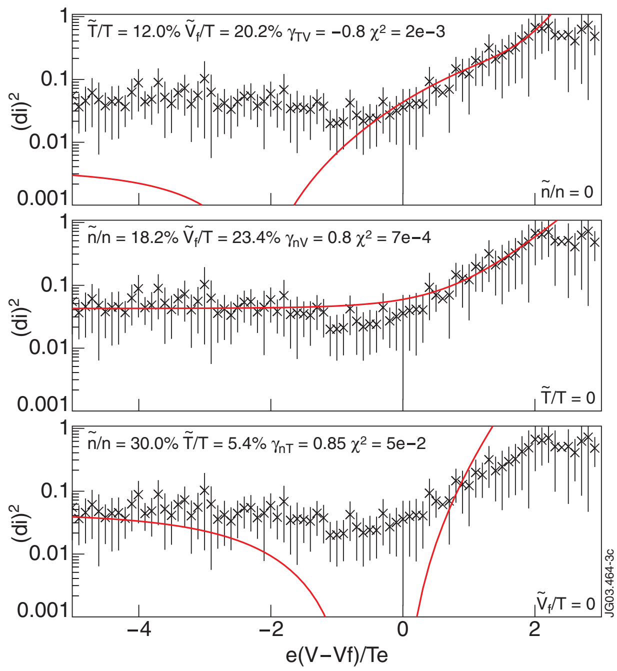

Figure 3: Fitting the probe fluctuations characteristic assuming: (a) 0 ~ =n ; (b) 0 ~ =T ; and (c) 0 ~ =V .