Ciemat 706
Sp ISSN 614-087-X

EXPERIMENTAL EVIDENCE OF EDGE TURBULENCE DRIVEN BY MULTIPLE MECHANISMS IN ATF

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CENTRO DE INVESTIGACIONES
ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS

MADRID, 1993

CLASIFICACION DOE Y DESCRIPTORES

700340
STELLARATORS
TOKAMAK DEVICES
PLASMA INSTABILITY
EDGE LOCALIZED MODES
PLASMA WAVES
LANGMUIR FREQUENCY

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Este trabajo se ha recibido para su impresión en Septiembre 1992

Depósito Legal nº M-481-1993
ISBN 84-7834-177-3
ISSN 614-087-X
NIPO solicitado

IMPRIME CIEMAT

Experimental Evidence of Edge Turbulence Driven by Multiple Mechanisms in ATF

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Abstract

The scaling properties of edge fluctuations have been investigated using Langmuir probes in the edge region of the Advanced Toroidal Facility (ATF). Fluctuations in the ion saturation current ($\tilde{I}_s/I_s$) and transport inferred from the fluctuations increase with increasing density gradient, while keeping unchanged local electron temperature. The modification of the electron temperature in the range (10-50) eV, keeping constant the density profile, does not have any significant influence on $\tilde{I}_s/I_s$. In regions were $E_r/B \approx 0$, the poloidal phase velocity of the fluctuations is given by $v_{ph} \approx 2T_e/L_nB$. More than one of any so far proposed mechanisms must be invoked to explain all the experimental observations.

Much effort is being done to understand the connection between plasma turbulence and anomalous transport. There is experimental evidence showing that the induced turbulent transport can account for most of the particle transport in the edge region of the plasma in tokamaks and stellarators [1,2]. However, although our understanding of the plasma turbulence has been improved during the last few years, the dominant free energy source responsible for the turbulence (∇n, ∇T, ∇Z,...) has not been identified yet [3,4].

Studies of the scaling properties of fluctuations and transport in terms of local plasma parameters can best be done in the plasma edge because of its accessibility for diagnostic measurements. The results can then be used to test theoretical models for edge turbulence. Studies of this type have been carried out in the outer region of the plasma ($r/a_{shear} > 1$) in the TEXT tokamak [5], where a_{shear} denotes the plasma region where the phase velocity of the fluctuations reverses direction (shear layer). However, it has been shown recently that the shear layer location determines a characteristic plasma region with possibly different drives for the turbulence in the plasma edge ($r/a_{shear} < 1$) and in the scrape of layer ($r/a_{shear} > 1$) [6]. As a consequence, the scaling properties of the fluctuations are possibly different in the scrape-off layer side and in the bulk side of the shear location.

In this letter we present evidence for turbulence driven by multiple mechanisms in the plasma edge region ($r/a_{shear} = 0.9$-1.1) in the Advanced Toroidal Facility (ATF) ($l = 2$, $M = 12$ field period torsatron with $R_0 = 2.10$ m and $a = 0.27$ m). In the present experiments plasmas were achieved using electron-cyclotron heating (ECH). Discharges with $P_{ECH} \approx$ (200-400) kW, $\bar{n}_e \approx$ (4-6) x 10^{12} cm^{-3}, stored energy (S_E) $\approx$ (1-2) kJ, and magnetic field (B) = 1 T have been studied. Plasma edge turbulence has been characterized by means of Langmuir probes using the experimental methods previously described [2,6]. Fluctuations in the ion saturation current ($I_s \approx n_e T_e^{1/2}$) have been usually interpreted in terms of local density fluctuations ($\tilde{I}_s/I_s \approx \tilde{n}/n$) (1). However, the possible existence of substantial temperature fluctuations in the plasma edge region of ATF [6] would affect the interpretation of the

Langmuir probe measurements. For the sake of precision and clarity in this paper we keep the notation $\tilde{I}_s/I_s$ instead of the $\tilde{n}/n$.

Figure 1 shows the radial profiles for density, temperature and ion saturation current ($\tilde{I}_s/I_s$) and floating potential ($\tilde{\phi}_f/T_e$) fluctuations, using the velocity shear layer as a point of reference. These measurements were done in plasmas with $P_{ECH} \approx 200$ kW, $\bar{n}_e \approx 4 \times 10^{12}$ cm^{-3} and $P_{ECH} \approx 400$ kW, $\bar{n}_e \approx 6 \times 10^{12}$ cm^{-3}. Within our experimental error, temperature gradients remain unchanged. However, the density profile is steeper in the case of plasmas with $P_{ECH} \approx 400$ kW and $\bar{n}_e \approx 6 \times 10^{12}$ cm^{-3}, implying an enhancement in the fluctuations of the ion saturation current.

The particle flux due to the correlation between density and potential fluctuations (Γ) has been computed with the assumption that the effect of temperature fluctuations on probe current fluctuations is negligible and that the floating potential is a good estimate of the plasma potential fluctuations [2]. Particle fluxes also increase with increasing ∇n. This enhancement in the particle fluxes is mainly due to $\tilde{I}_s$ effects.

The scaling of the ion saturation current and floating potential fluctuation levels with ∇n is different, as shown in Fig. 1. Additionally, the probe current fluctuation levels are well described by the mixing length level, $\tilde{I}_s/I_s \approx (0.5\text{-}1)/(kL_n)$, where k is the poloidal wave number, whereas the floating potential fluctuations do not show a mixing length scaling. These results can be a consequence of a non-Boltzmann relationship of the fluctuations (i.e. $\tilde{I}_s/I_s \approx \tilde{n}/n \neq \tilde{\phi}_p/T_e$), but may also be evidence of non-negligible temperature fluctuations (i.e. $\tilde{\phi}_{fl} \neq \tilde{\phi}_p$). Actually evidence of substantial temperature fluctuations in the plasma edge region in ATF has been recently reported [3,6] which can be an indication of radiation drives for the turbulence.

The influence of local electron temperature on probe current fluctuations has been studied in plasmas with different line average density. Figure 2 shows density, temperature and current probe fluctuation profiles measured in plasmas with $\bar{n}_e \approx 4 \times 10^{12}$ cm^{-3} and $\bar{n}_e \approx 6 \times 10^{12}$ cm^{-3} and plasma heating power $P_{ECH} \approx 200$ kW; electron temperature profiles are sensitive to the average electron density while radial density profiles remain basically constant. It is clear that a modification in the local temperature in the range (10 - 50) eV, keeping unchanged the density profile, does not have any significant influence on $\tilde{I}_s/I_s$ ($\tilde{I}_s/I_s \propto T_e^{0.0\pm0.2}$).

Density gradient driven turbulence models developed by Terry-Diamond and Waltz-Dominguez [7,8] predicts $\tilde{n}/n \propto T_e^{0.5}$. The model proposed by Hasegawa-Wakatani gives $\tilde{n}/n \propto T_e^{0.25}$[9]. Turbulence driven by resistive interchange modes predicts $\tilde{p}/p \propto T_e^{-0.50}$ assuming Spitzer's resistivity [10].

Interchange modes are expected to be one of the dominant mechanism in the edge region of stellarator devices. Furthermore, the theoretical expectations of resistive interchanged turbulence levels ($\tilde{p}/p$) [11] are consistent with the measured probe current fluctuations $\tilde{I}_s/I_s$ ($I_s \propto n\, T_e^{1/2}$) for $r/a_{shear} < 1.0$ (Figure 3). In the scrape-off layer side of the velocity shear layer ($r/a_{shear} > 1$) the level of current fluctuations is much higher than that calculated for resistive interchange instabilities. Interchange modes are candidates to partially explain edge fluctuations in the plasma bulk side of the velocity shear layer.

With nitrogen and methane puffing a substantial cooling of the plasma edge has been observed in the TEXT tokamak, while probe current fluctuations remain essentially unchanged (i.e. $\tilde{I}_s/I_s \propto T_e^0$) [12]. The similarity of the edge density fluctuation levels in ATF (stellarator) and TEXT (tokamak) ($0.9 < r/a_{shear} < 1.2$) [3], as well as the similar scaling $\tilde{I}_s/I_s \propto T_e^0$ ($r/a_{shear} < 1$), suggest a common and dominant drive for the edge turbulence in both devices. Atomic physic processes, such as radiation, ionization and charge-exchanged, work in both tokamak and stellarator devices and should be considered as candidates to account for edge fluctuation levels [3]. Actually, turbulence driven by radiative instabilities has been already considered as a possible candidate to partially account for the observed edge turbulence [12,13].

Figure 4 shows the influence of edge electron temperature on the poloidal phase velocity of the fluctuations (v_{ph}) as well as on the velocity due to the radial electric field (v_{ExB}

$= E_r/B$) in the plasma region $r/a_{shear} \approx (0.8\text{-}0.9)$. The velocity has been computed from the $S(k,\omega)$ function using two floating potential signals [6]; $v_{ph}=\Sigma_k(\omega/k)S(k,\omega)/\Sigma_k S(k,\omega)$. The plasma potential ($\phi_p$) and the radial electric field ($E_r = -d\phi_p/dr$) have been estimated from measurements of the electron temperature and the floating potential [2]. The phase velocity propagates in the electron diamagnetic drift direction with a value in the range $(0.5 - 2) \times 10^5$ cm/s and it is considerably larger than v_{ExB} ($\approx 0.2 \times 10^5$ cm/s). It has to be noted that v_{ph} increases by increasing electron temperature. Thus, in this plasma region ($r/a_{shear} \approx 0.8\text{-}0.9$) where the plasma potential is essentially constant, the phase velocity of the fluctuations is dominated by the electron diamagnetic drift velocity ($v^* \approx T_e / BL_n$) and $E_r \times B$ velocity effects are weak. However, although the scaling of v_{ph} with temperature is in agreement with the temperature dependence of the diamagnetic drift velocity, its value exceeds the diamagnetic drift velocity by a factor of about two . This may be due to the presence of non-linear effects (i.e. mode coupling [14]) that can substantially modify the frequency spectrum of the fluctuations (ω) and consequently the measured mean velocity ($v_{ph} \approx \omega/k$).

Because $v_{ExB} << v_{ph}$ in the plasma edge region ($r/a_{shear} \approx 0.9$), the two point correlation technique can be used reliably to get the poloidal wave number (k). The product $k\rho_s$, where ρ_s is the ion gyroradius at the electron temperature, is about (0.05 - 0.1) [2], and it is independent of temperature.

In conclusion, when the free energy available to drive turbulence (∇n) increases, fluctuation levels ($\tilde{I}_s/I_s$) and transport also increase in the edge plasma region of the Advanced Toroidal Facility. Fluctuations in the probe current ($\tilde{I}_s/I_s$) are independent of the local temperature in the range (10-50) eV. In the plasma region were $E_r/B \approx 0$, the poloidal phase velocity of the fluctuations is given by $v_{ph} \approx 2T_e/L_nB$. More than one of any so far proposed mechanisms must be invoked to explain all the experimental observations. Edge turbulence in ATF is consistent with interchange instabilities with additional effects due to atomic physics processes.

Acknowledgements

The authors are grateful for contributions of B.A. Carreras, P.H. Diamond and L. García. This research was sponsored in part by the Office of Fusion Energy, United States Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc. C. Hidalgo was supported by Euratom.

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Figure captions

Figure 1.

Radial profile for density (n_e), electron temperature (T_e), floating potential ($\tilde{\phi}_f/T_e$) and current probe fluctuations ($\tilde{I}_s/I_s$) measured in ECH plasmas with $P_{ECH} \approx 200$ kW, $\bar{n}_e \approx 4 \times 10^{12}$ cm^{-3} (o) and $P_{ECH} \approx 400$ kW, $\bar{n}_e \approx 6 \times 10^{12}$ cm^{-3} (•). The location of the velocity shear layer has been used as a point of reference.

Figure 2.

Radial profile for density (n_e), temperature (T_e) and current probe ($\tilde{I}_s/I_s$) fluctuation levels measured in ECH plasmas with $P_{ECH} \approx 200$ kW, $\bar{n}_e \approx 4\ 10^{12}$ cm^{-3} (o) and $P_{ECH} \approx 200$ kW, $\bar{n}_e \approx 6\ 10^{12}$ cm^{-3} (x). The location of the velocity shear layer has been used as a point of reference.

Figure 3.

Fluctuations in the probe-current ($\tilde{I}_s/I_s$) (o) and the calculated interchange turbulence levels ($\tilde{p}/p$) (x).

Figure 4

Phase velocity of the fluctuations (v_{ph}) and E x B velocity (v_{EXB}) as a function of the electron temperature. Measurements carried out at $r/a_{shear} \approx 0.85$, in ECH plasmas with $P_{ECH} \approx 200$ kW and $\bar{n}_e \approx (4\text{-}6)\ 10^{12}$ cm^{-3}.

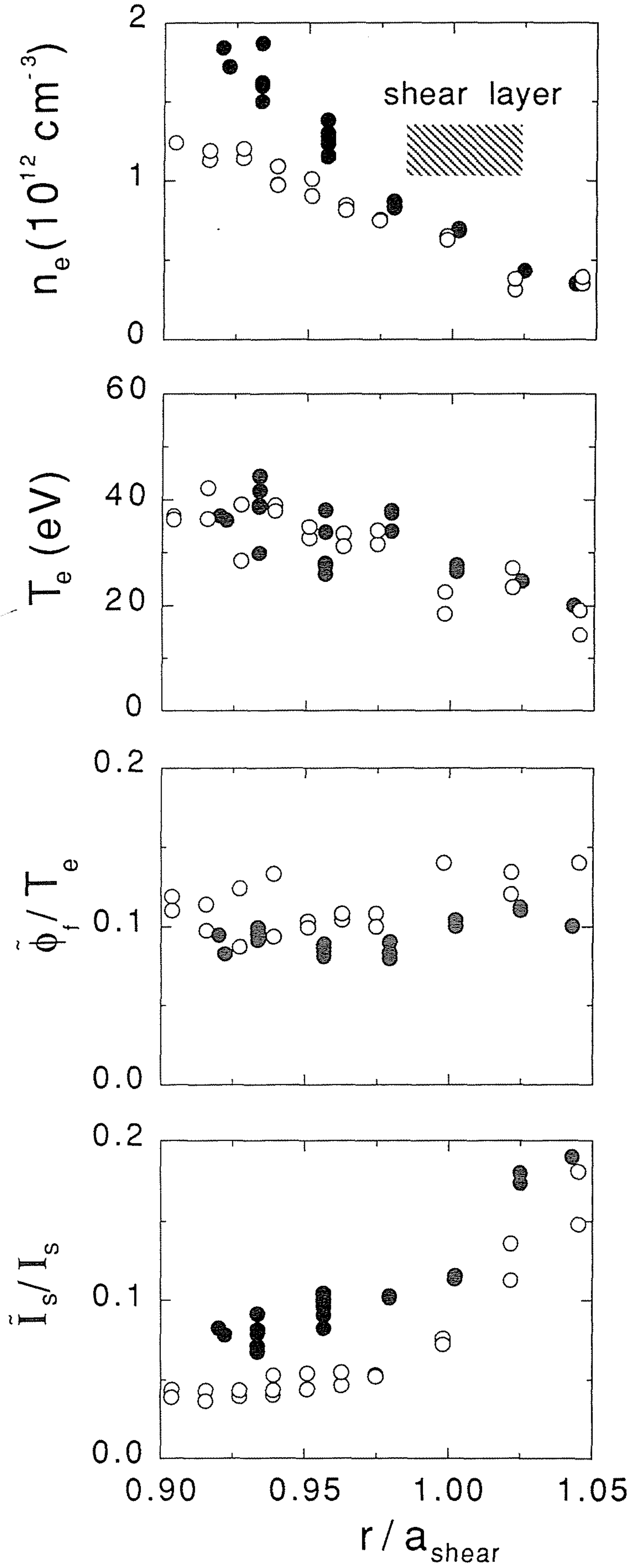
shear layer
$n_e (10^{12}\,\mathrm{cm}^{-3})$
2
1
0
T_e (eV)
60
40
20
0
$\tilde{\phi}_f / T_e$
0.2
0.1
0.0
$\tilde{I}_s / I_s$
0.2
0.1
0.0
0.90
0.95
1.00
1.05
r / a_{shear}

Fig. 1

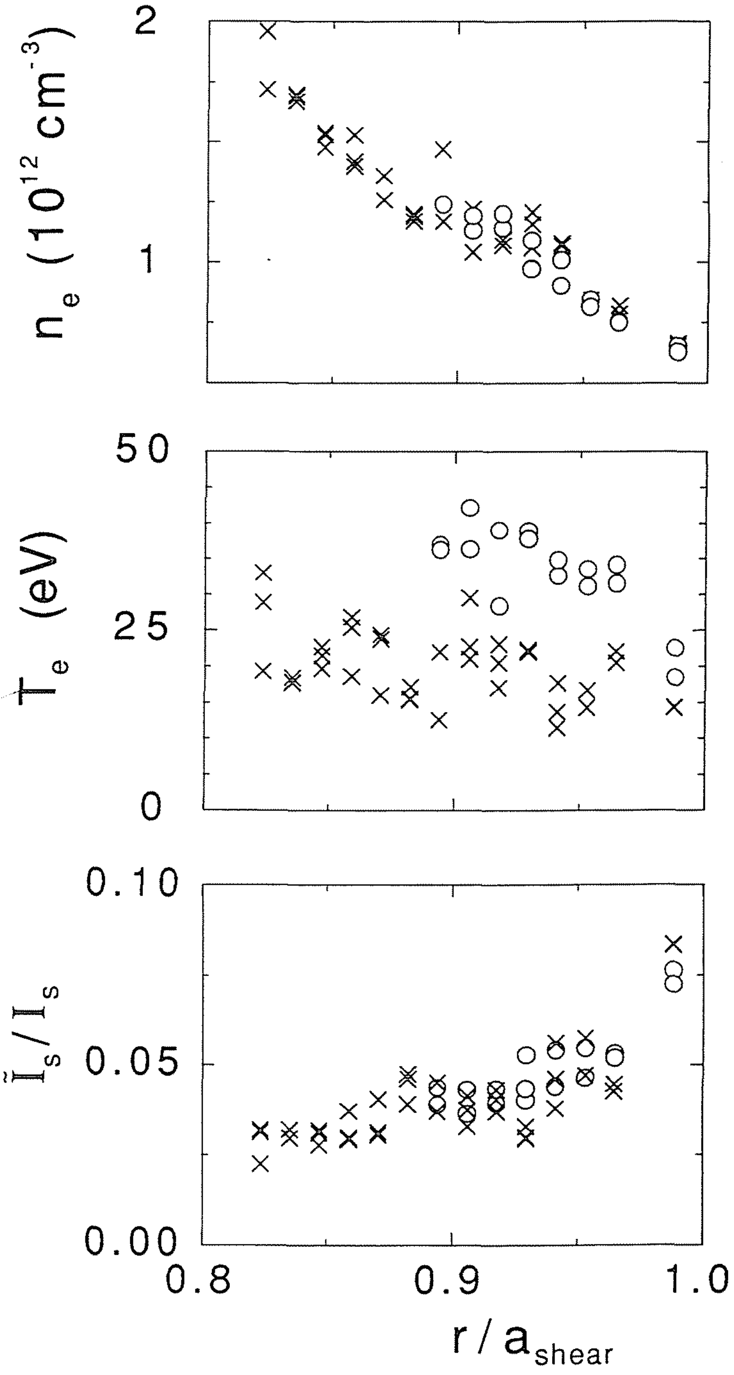
n_e (10^{12} cm^{-3})
2
1
T_e (eV)
50
25
0
$\tilde{I}_s/I_s$
0.10
0.05
0.00
0.8
0.9
1.0
r/a_{shear}

Fig. 2

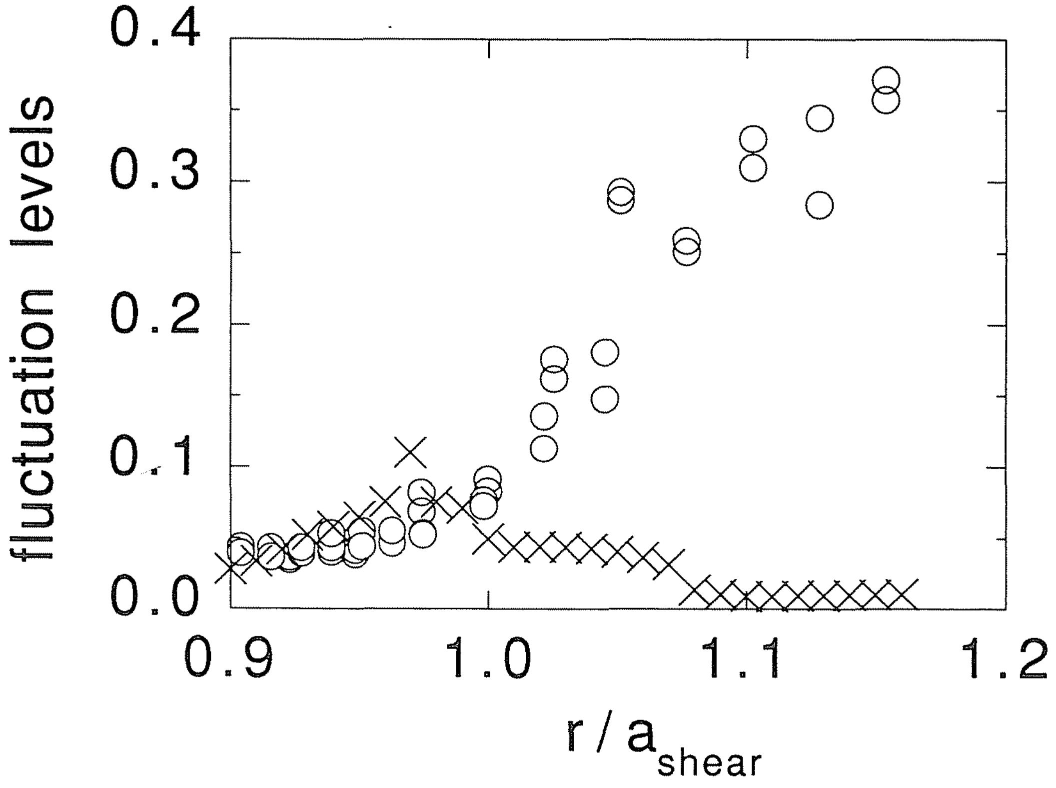

Fig. 3

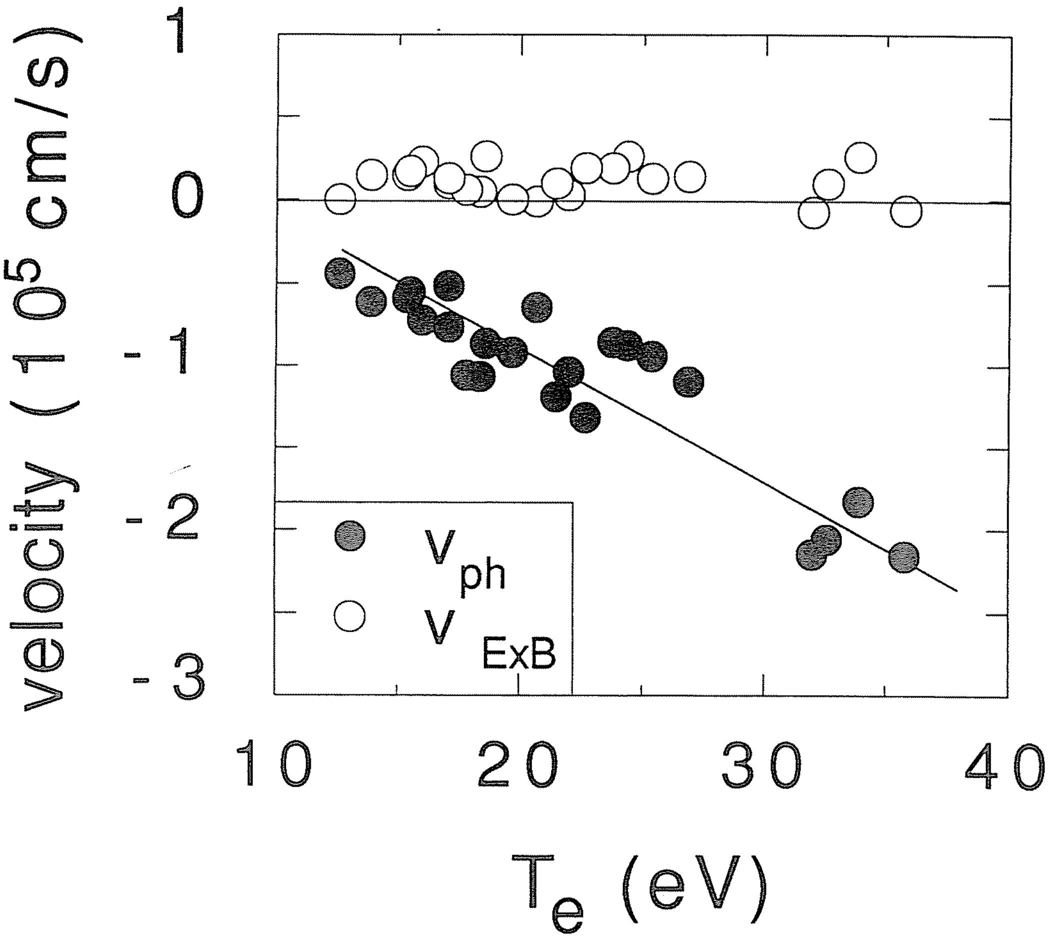

Fig. 4

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C. Hidalgo and others,16 pp., 4 fig., 14 ref.

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EVIDENCIA EXPERIMENTAL DE TURBULENCIA GENERADA POR MECANISMOS MULTIPLES EN LA REGION DEL BORDE DEL PLASMA DEL STELLARATOR ATF.

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