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# Local Improvement Confinement in the Ion Bernstein (IBW) Experiment on FTU (Frascati Tokamak Upgrade)

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**Abstract.** New experiments with the ion Bernstein waves (IBW) has been performed on FTU both in Hydrogen (H) and Deuterium (D) majority plasmas, at higher radio-frequency power level, plasma density, current, lower effective ion charge than in previous campaign of 1999. Also in these conditions, no role is played by non-linear edge physics, which prevented, instead, the RF penetration in the plasma bulk of DIII-D. With resonant toroidal magnetic field (□8T), improved confinement occurs inside a radial region of 1/3 of the minor radius operating in H-plasma, and 2/3 of the minor radius operating in D-majority plasma. Such behavior is consistent with the model of turbulence suppression by locally-induced-IBW-sheared flow expected to occur close the resonant layer. The FTU results provide support for active control of the pressure profile by IBW which is of relevance for advanced tokamaks.

## Introduction

The first IBW experiment on FTU supported the IBW scheme [1,2] by a simultaneous increase of the electron density and temperature with profile peaking [3]. Such behaviour was found for the first time in an IBW experiment. The present paper shows that: i) the IBW-FTU experiment is not dominated by edge physics as occurred in previous experiments ii) the recent progress in improving local plasma confinement is found, consistently with the IBW model. Operations both in Hydrogen and Deuterium majority plasma were performed at resonant (7.9T) and non-resonant (6T) toroidal magnetic field (f=433MHz). The modelling relevant for the IBW experiment on FTU is shown in Ref. [4]. At the present time, the coupled routinely power by the two IBW launchers is about 0.5 MW limited by arcing at the antenna mouth (0.6 MW is the maximum coupled power allowed by the RF generator).

## Role of the edge physics

The antenna coupling behaviour with plasma density during the experiment is in agreement with the LHW launch [5] (see Figure 1).

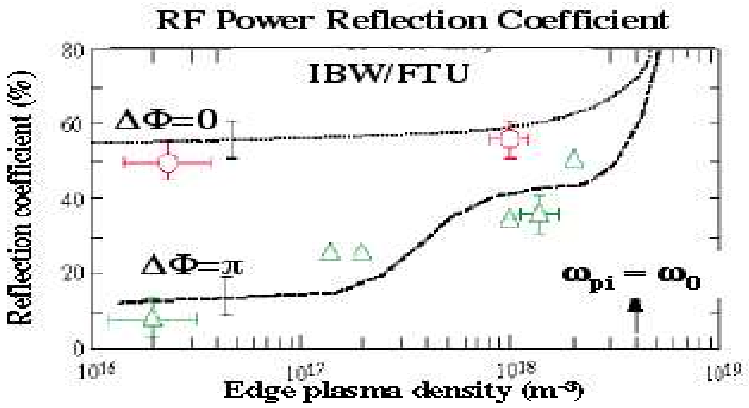


Fig. 1 - Modeling and experiment of the IBW antenna-plasma coupling of FTU. Modelling (dotted line) and experiment (circles) for phasing $\Delta\Phi=0$, modelling (dashed)/experiment (triangles) for $\Delta\Phi=\pi$.

Two waveguide phasing $\Delta\Phi=0$ and $\Delta\Phi=\pi$ are considered corresponding to launching a power spectrum in parallel refractive index ($n_{//}$) peaked around $n_{//}\approx1$ and $n_{//}\approx5$, respectively. In FTU, no significant change of the edge density due to ponderomotive effect are found in the experiment, as expected. Conversely, an undesired non-linear behaviour of the antenna coupling with the coupled RF power was found in D-IIID [6]. In FTU, the reflected power rate is independent of RF power and depends on plasma density at the antenna mouth, which is determined only by the antenna position in the plasma. The IBW-FTU experiment naturally meets the condition of strong convective loss which is suitable for avoiding strong parametric instability (PI) activity [7], as was not the case of DIII-D [8,9]. In FTU, only small pump broadening (<1MHz @10 dB below the pump power level) and low sidebands (>30 dB below the pump power level). Such result indicates that in FTU the LHW is proper launched by the antenna, and the low PI level does not inhibit IBW mode conversion and RF power penetration in the bulk. The impurity influx in not significant in FTU During injection of high IBW power the concentration of Oxygen, the main light impurity, (0.3%) does not change during the IBW phase. Some reduction of the heavy impurity concentration is observed. In FTU, the low impurity influx is consistent with the negligible effect which are expected by the RF sheaths in producing gas desorbtion from metallic walls [10].

**Progress in Improved Confinement in the IBW-FTU Experiment**

For testing the effects produced by different locations of the IBW resonant layer, operation both in pure Hydrogen (with about 1% of Deuterium) and D-majority plasmas

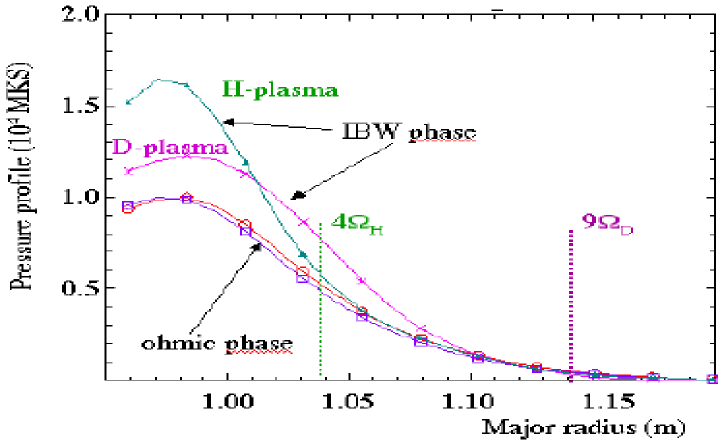


Fig. 2 - Pressure profile peaking in H and D plasmas with toroidal magnetic field of 7.9T.

(with 10% of H-minority) have been performed. The ion cyclotron harmonic layer $4\Omega_H$ is located at $r_{abs}/a\approx 0.3$, and $9\Omega_D$ at $r_{abs}/a\approx 0.65$ (a indicates the minor radius of plasma). The IBW power is fully absorbed at the first pass at about one third of the minor radius in H-plasma, and at two third of the minor radius in D-plasma [4]. At these layers, plasma flows are expected in FTU to be ponderomotively generated near the resonant layer [4]. The shearing rate produced by about 0.3MW of IBW power is expected to be sufficient for suppressing the electrostatic turbulence in FTU. Operating at mid/low averaged plasma density (□ 5 $10^{19}$ $m^{-3}$). Higher densities require higher IBW power (roughly: 8 $10^{19}$ $m^{-3}$ / 0.5MW). The experimental electron pressure profiles of the ohmic and the IBW phases operating in H and D-majority plasmas are shown in Fig. 2. The plasma current is 0.4 MA, toroidal magnetic field 7.9T (resonant), plasma density 4 $10^{19}$ $m^{-3}$, and about 0.35 MW of IBW power is coupled. In D-majority plasma (10%), the pressure profile has a wider radial foot (located in the outer half of plasma) than in pure H-plasma (in the inner half of plasma). No comparable peaking of the pressure profile is found when operating in similar conditions, but with non-resonant field ($B_T$=6T), corresponding to IBW deposition at the very periphery. Both in D and in H operations, the central ion temperature increases (of about 0.25 keV), and the effective ion charge decreases (from 3 to 2.4 during the IBW phase). The transport analysis was performed with the JETTO code [11]. Operating at high plasma current (0.8 MA) and higher density (6 $10^{19}$ $m^{-3}$) a reduction of 40 % of the electron thermal conductivity and a significant confinement improvement (of a factor 2) are found, in the plasma region interior to the resonant layer. The confinement improvement is well outside the error bar of the analysis, which is mainly due to the uncertainties of the inputted kinetic profiles. When operating at lower plasma current (0.4 MA), a significant confinement improvement is found only in H-plasma. It is attributed to the narrower radial region characterising the ITB, which is sustained by the relatively low ohmic input [12].

## Conclusions

The IBW-FTU experimental scenario is free of non-linear edge plasma physics and can achieve the full assessing the IBW scheme. Operation in Deuterium plasma (at $I_P$=0.8 MA, $n_e$□0.5 $10^{20}$ $m^{-3}$) with resonant field of 7.9 T, shows a peaking of the pressure profile (20%). Transport analysis shows a uniform decrease of the electron thermal conductivity by 40% over the region inside the absorption radius. The radial foot point of the ITB obtained in D plasma occurs in the outer half of plasma, than in the inner half as in H-plasma, consistently with the models of IBW deposition and local generation of plasma flows, useful for turbulence stabilisation.

## References

1 Ono, M., Phys. Fluids B**2** 241 (1993)
2 Biglari, H., et al., Phys. Fluids **B 2**, 1 (1990)
3 Cesario, R., et al. Phys. Plasmas **8**, 11, 4721 (2001)
4 Cardinali, A., Castaldo, C., Cesario, et al., Nucl. Fusion, **42**, 427 (2002)
5 Cesario, R., De Marco, F., Sauter, O., Nucl. Fusion **38**, 31 (1998)
6 Mayberry, M.J., et al. Nucl. Fusion **33**, 4, 627 (1993)
7 Cesario, R., et al., Nucl. Fusion, **11**, 261 (1994)
8 Pinsker, R., et al., in Proceedings of the 8th Top. Conf. on Radio Frequency Power in Plasmas, Irvine, CA 1989 (American Inst. of Physics, NY 1990) p. 314
9 Pinsker, R., et al., Nucl. Fusion **33**, 5, 777 (1993)
10 Cesario, R., et al., Nucl. Fusion **34**, 1527 (1994)
11 Cenacchi, G., Taroni, A., in Proc. 8th Computational Physics, Computing in Plasma Physics, Eibsee 1986, (EPS 1986), Vol. 10D, 57
12 Cesario, R., et al., to be published in Nucl. Fusion