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ICRF Mode Conversion Flow Drive in JET D(³He) Plasmas and Comparison with Results from Alcator C-Mod

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** See annex of F. Romanelli et al, "Overview of JET Results",
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ABSTRACT.

Following a recent Alcator C-Mod experiment on ICRF mode conversion flow drive [1,2,3], we have carried out a similar experiments in JET D(^3He) plasmas (Fig.1): $B_{t0} = 3.45\text{T}$ at $R_0 = 2.97\text{m}$, $I_p = 2.8$ and 1.8MA , central density $n_{e0} \sim 3 \times 10^{19} \text{ m}^{-3}$ during flat top, and in L-mode confinement. The plasma current was in the same direction as the toroidal B field. All the plasmas were in D majority with external ^3He puffing. The ^3He concentration $X(^3\text{He}) \equiv n_{\text{He}3}/n_e$, was feedback controlled in real-time (Fig.1(c)), and scanned pulse by pulse. $X(^3\text{He})$ was estimated from visible spectroscopy light in the divertor, linking relative light intensities to relative concentrations. The ICRF power was at 33MHz . At $B_{t0} = 3.45\text{T}$, the ^3He ion cyclotron resonance layer was about 20cm to the low field side of the magnetic axis. For $X(^3\text{He}) \sim 13\%$, the D- ^3He hybrid layer was about 10cm to the high-field-side of the magnetic axis. The ICRF antennas were at -900 phasing, i.e., the launched fast waves were toroidally asymmetric predominantly in the counter- I_p direction. The toroidal angular velocity ω_ϕ of C^{6+} is measured by the core CXRS system during beam blips. As shown (Fig.1(e)) for Pulse No: 78845, counter- I_p rotation ($\omega_\phi < 0$) was observed during all the blips for $t < 11$ sec, and the rotation only became co- I_p later in the pulse with continuous neutral beam injection. A scintillator probe measured the energy and pitch angle of lost fast ions. As shown in (Fig.1(h)), the detection of 3.7MeV α -particles, born from the nuclear reaction between D and ^3He , indicates a hot ^3He ion population near the plasma centre.

INTRODUCTION

The observed rotation profiles are sensitive to $X(^3\text{He})$. For $X(^3\text{He}) \leq 5\%$, the rotation is in the co- I_p direction, $\omega_\phi \sim 1\text{-}4$ krad/sec, with a nearly flat profile, similar to those previously reported in minority heated plasmas that have high I_p and near-axis heating [5,6]. The result for $X(^3\text{He}) \geq 25\%$ is similar. For $X(^3\text{He}) \sim 10\% - 17\%$, the rotation is ~ 0 for the outer half of the plasma, but is in the counter I_p direction for $r/a < 0.4$ and peaked near the plasma centre. In Fig. 2, the central rotation ($R = 3.04\text{m}$) is plotted versus $X(^3\text{He})$. On Alcator C-Mod, the flow drive is also sensitive to $X(^3\text{He})$, largest flow drive at $X(^3\text{He}) \sim 10\text{-}12\%$, but the driven flow is in the co- I_p direction [3].

In Figure 3(a), we show the central rotation from all the beam blips in this experiment vs. RF power level. There is no PRF dependence for $X(^3\text{He}) \leq 5\%$, but for $X(^3\text{He}) \sim 6\% - 18\%$, we have larger counter- I_p rotation at higher RF power. The rotation change at ~ 2 krad/sec per MW ICRF power is about a factor of 4 larger than the observed rotation difference in a previous study on direct momentum input from the directional fast waves in the ICRF minority heating scenario [7]. A pulse at 1.8MA indicates a larger counter- I_p rotation. Note $\omega_\phi \sim -10$ krad/s corresponds to thermal Mach number $M_{\text{th}}(0) \sim -0.07$ and Alfvén Mach number $M_A(0) \sim -0.003$. The approximately linear RF power dependence is similar to the result from Alcator C-Mod as shown in Fig.3(b), which also shows an I_p dependence (details discussed in Ref. [3]).

At low $X(^3\text{He})$, the ICRF power is in the minority heating regime, and fast waves directly interact with the ^3He ions. At large $X(^3\text{He})$, e.g., $\geq 25\%$ in this JET experiment, almost all the RF power is

deposited on electrons via mode converted waves, and wave ^3He ion interaction is weak. In the intermediary regime where we observed large flow drive effect on both JET and Alcator C-Mod, the launched fast waves from the antenna undergo mode conversion, and the resulted MC ion cyclotron waves also interact with the ^3He ions. The 2-D power deposition contours from TORIC simulation [8] are shown in Fig.4 (a) for JET and 4(b) for Alcator C-Mod, with the wave branches labelled. This mode conversion scenario and interaction between the MC waves with the ^3He ions and associated transport may be key for flow drive, but the detailed physical mechanism is not yet understood.

The trend in the wave particle interactions versus $X(^3\text{He})$ is also confirmed by the Scintillator Probe (SP) measurement of fast α -particle (3.7MeV) losses and gamma-ray spectrometry. For $X(^3\text{He}) < 0.5\%$, SP shows a large amount of fast α -particle loss, suggesting high energy ^3He ions generated by the fast wave minority heating on the IC resonance with effective temperature $\sim 200\text{keV}$. For $X(^3\text{He}) \sim 13\%$, the fast α -particle loss becomes much smaller but is still significant. Together with gamma-ray observations and the temperature dependence of the $\text{D } ^3\text{He}$ reaction rate, the result indicates a population of hot ^3He ions (effective temperature $\sim 20\text{--}40\text{ keV}$) near the plasma centre, created by the interaction between the MC ICW and ^3He ions. In our experiment, the pulses with larger counter- I_p rotation have less ^3He ion loss than those in the minority heating regime, where no flow drive effect is observed. As a result, we can reasonably exclude the contribution of fast ion losses to the observed counter- I_p rotation.

Similar rotation in the counter- I_p direction has also been observed in a (H)- ^3He inverted mode conversion plasmas (with dipole phasing) [9]. Counter- I_p rotation has been observed in low I_p minority heating [5], ripple experiment [10], and low I_p 2nd harmonic ^3He heating [9], thus mode conversion is not the only effective method to drive counter rotation on JET. Further experiments on JET and other tokamaks are needed in order to understand the direction and magnitude of the rotation in these mode conversion flow drive experiments.

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REFERENCES

- [1]. Y. Lin *et al*, Physical Review Letters **101**, 235002 (2008).
- [2]. Y. Lin *et al*, Physics of Plasmas **16**, 056102 (2009).
- [3]. J. Rice *et al*, Parameter scalings of ICRF MC flow drive in Alcator C-Mod plasmas, this conference, P5.181.
- [4]. V. Kiptily *et al*, Nuclear Fusion **49**, 065030 (2009).
- [5]. L.-G. Eriksson *et al*, Plasma Physics and Controlled Fusion **51**, 044008 (2009).

- [6]. J.M. Noterdaeme *et al*, Nuclear Fusion **43**, 274 (2003).
- [7]. L.-G. Eriksson *et al*, Physics Review Letters, **92**, 235001(2004).
- [8]. J.C. Wright *et al*, Plasma of Physics **11**, 2473 (2004).
- [9]. T. Hellsten *et al*, submitted to Plasma Physics and Controlled Fusion.
- [10]. M.F.F. Nave, *et al*, Toroidal rotation in ICRF heated H-mode plasmas, this conference, O4.122.

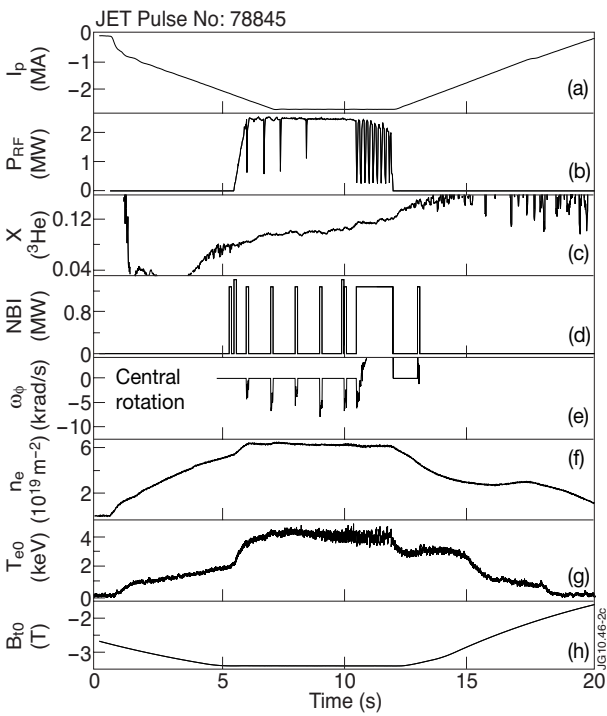


Figure 1: Data traces for JET Pulse No: 78845. Rotation in the counter- I_p direction ($\omega_\phi < 0$) shown in panel (e).

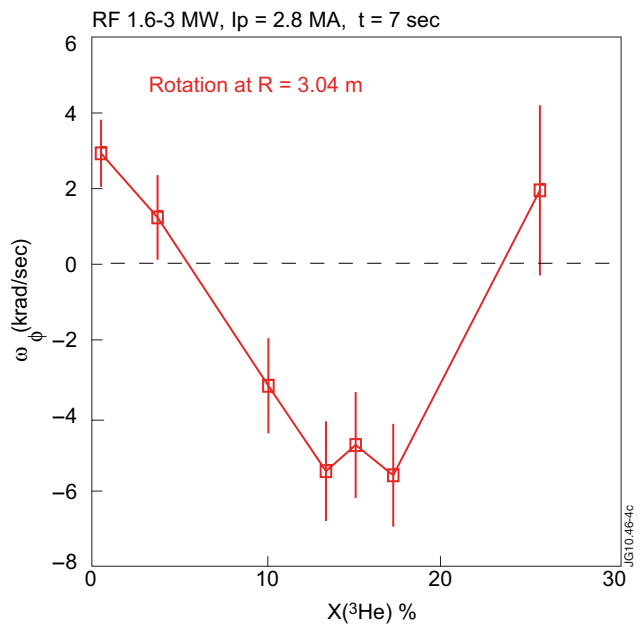


Figure 2: Central rotation versus $X(^3\text{He})$.

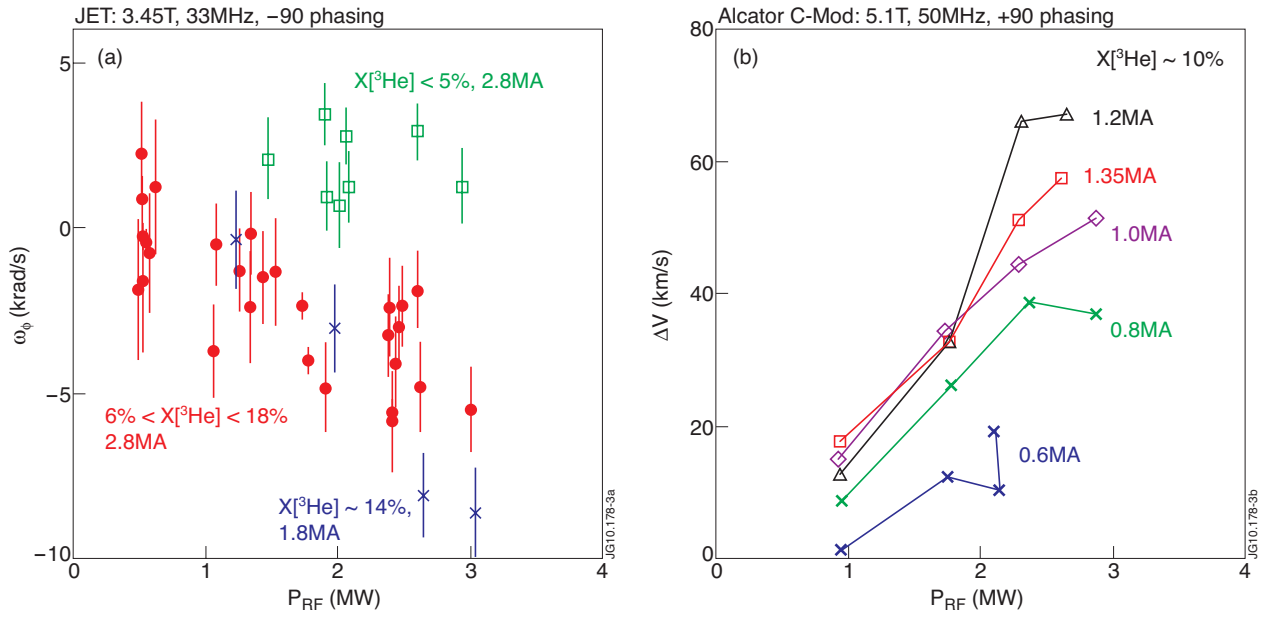


Figure 3: (a) JET rotation at different $X({}^3\text{He})$ and I_p versus ICRF power; (b):Alcator C-Mod rotation at different I_p versus ICRF power.

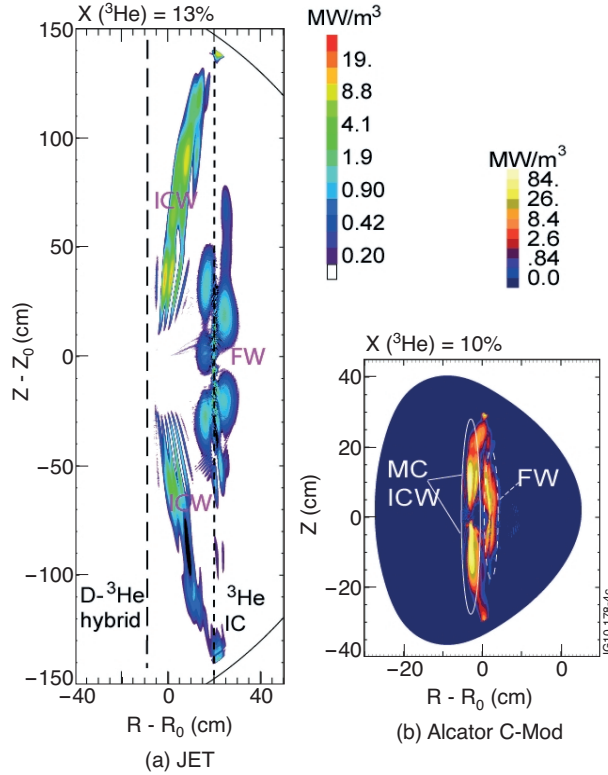


Figure 4: TORIC simulation on RF powers to ${}^3\text{He}$ ions in the cases with strong flow drive effect: (a) JET; (b) Alcator C-Mod.