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Toroidal rotation in ICRF only heated ASDEX Upgrade plasmas

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1. Introduction

In this paper we present the latest results on plasma rotation in ASDEX Upgrade (AUG) ICRF only heated discharges. Toroidal impurity fluid velocities from the Charge eXchange Recombination Spectroscopy (CXRS) diagnostic are compared with toroidal velocities extracted from E_r measurements obtained by Doppler reflectometry. The dependence of Alfvènic and ion thermal Mach numbers on various plasma parameters has been analyzed to provide more information on plasma rotation with low momentum input, often referred to as intrinsic rotation, whose origin is still unexplained. First comparison of AUG scaling laws with those of other machines are reported.

2. Experimental results

ICRF only heated plasmas have been performed on AUG in both L- and H-modes and with reversed B_T and I_p (compared to standard operations with $-B_T$ and $+I_p$), i.e. with the ion $B \times \nabla B$ drift pointing away from the X-point, and the short beam blips employed by the CXRS diagnostic for rotation profile measurements in the counter-I_p direction. More details can be found in our previous analysis [1]. In spite of the counter-I_p toroidal momentum imparted to the plasma by the NBI beam blip, the plasmas rotate in the co-I_p direction (see Fig.1) both in the core and at the edge (see Fig.2) similarly to most results from JET [2] and Alcator C-Mod [3]. With our convention, the sign of V_ϕ is relative to the geometry, not to the direction of I_p, which means that a negative (positive) V_ϕ corresponds to co- (counter-) I_p rotation. The quite flat rotation profiles, shown in Fig.2, suggest a momentum source at the edge. Unfortunately, the first reliable measurement of V_ϕ by the CXRS technique was rarely at the very beginning of the beam blip, which makes an accurate assessment of V_ϕ during pure ICRF heating difficult. An alternative estimation of V_ϕ can however be provided by Doppler reflectometry. The Doppler shift frequency is directly proportional to the perpendicular rotation velocity profiles of the density turbulence moving with the plasma, $u_\perp = V_{E\times B} + V_{phase}$. Generally the intrinsic phase velocity is negligible at the edge, i.e. $u_\perp \approx V_{E\times B}$, allowing the Doppler measurement to be interpreted as the $E\times B$ velocity and thus V_ϕ to be extracted using the radial force balance for the bulk ions: $E_r = \nabla P_i / Z_i e n_i - V_\phi B_\theta + V_\theta B_\phi$, where P_i and n_i are the ion pressure and the ion density. The poloidal velocity V_θ, not currently measured on AUG, was calculated using the neoclassical transport code NEOART [6]. E_r profiles are shown in Fig.3 at different times of the discharge #18951. The comparison with the component $-V_\phi B_\theta$ is shown in Fig.4. Three phases corresponding to three different types of heating power, ICRH+NBI, pure NBI and pure ICRH, have been investigated. Those with NBI allow a direct comparison between the two measurement techniques. There is a good accordance in the mid-core. With ($+B_\phi$, $-I_p$) and counter-I_p NBI, E_r is negative indicating positive rotation profile in the electron diamagnetic velocity V_{*e} direction (i.e. counter-I_p rotation with our sign convention) and $u_\perp$ matches the toroidal fluid velocity from CXRS, as expected given that the neutral beam driven toroidal rotation dominates in the core. At the edge the large plasma pressure gradient causes the diamagnetic velocity component to be the main contributor, which creates the negative well in E_r seen in Fig.3. E_r goes positive in the SOL due to the fast open flux surface connection to the divertor, i.e. $u_\perp$ is in the V_{*i} direction. When additional ICRF heating is applied, the magnitude of E_r decreases in the mid-core and changes sign in a pure ICRH phase, indicating negative rotation profile (i.e. co-I_p rotation).

3. Dependence of the Mach numbers with plasma parameters

Our previous analysis [1] showed that the co-rotation on AUG cannot be directly explained by existing theories based on arguments regarding the edge turbulence [7], or involving transport driven parallel flows in the SOL [8]. Fast ion effects cannot be either invoked to explain the significant values of V_ϕ up to 50-60 km/s (see Fig. 4) measured by Doppler reflectrometry in the core. In the absence of theoretical explanation, an inter-machine scaling study has been recently undertaken [9] for Alcator C-MOD, JET, DIII-D, Tore Supra, TCV and JT-60U to provide some hints of the parameters determining the intrinsic rotation. Following the same process as *Rice et al.* in [9], the dependence of Alfvènic and ion thermal Mach numbers on normalized plasma pressure, gyro-radius and collisionality has been investigated for AUG discharges. The comparison with the 6 other machines indicates that the intrinsic rotation is insensitive to ρ^* and ν^* and depends weakly on β_N (see Fig.5), in disagreement with results from the other tokamaks strongly depending on β_N. The weak dependence on β_N could however involve an underlying MHD mechanism on AUG, similarly to the other machines, although of a moderate significance and perhaps not via a direct route, the first analysis demonstrating no clear evidence of a direct relation with the MHD activity.

4. Summary

The salient features of plasma rotation on AUG during only ICRF heating with low momentum input have been reported here. In spite of the counter-I_p beam blips used by the CXRS diagnostic for rotation profile measurements, the plasma rotates initially in the co-I_p direction both in the core and at the edge. The flat rotation profiles suggest that the rotation could be driven from the edge. Values of V_ϕ measured by the CXRS technique and extracted from E_r measurements by Doppler reflectometry are in good accordance in the mid-core. Significant values up to V_ϕ ~ 50-60 km/s have been found in pure ICRH phases from E_r measurements. The co-rotation in AUG cannot be directly explained by existing theories. Scaling laws of Alfvènic and ion thermal Mach numbers may suggest that MHD activity plays a less important role on the intrinsic rotation than for the other tokamaks.

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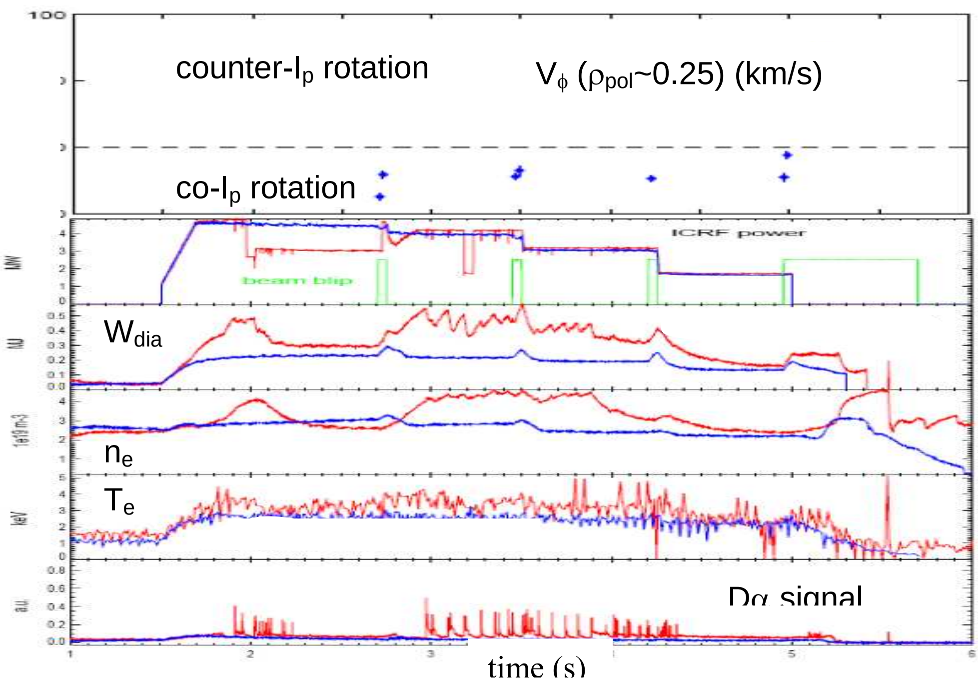
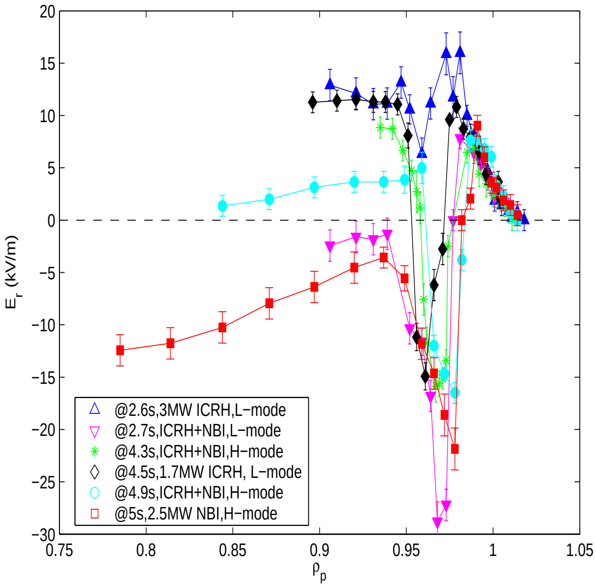


Fig.1: Time traces for the discharges #18951 mostly in H-mode (red) with (B_T=2MA, I_p=-1MA) and #18952 in L-mode (blue) with (B_T=2MA, I_p=-0.6MA). Central rotation velocity deduced from the CXRS diagnostic during each beam blips is shown for the discharge #18951.



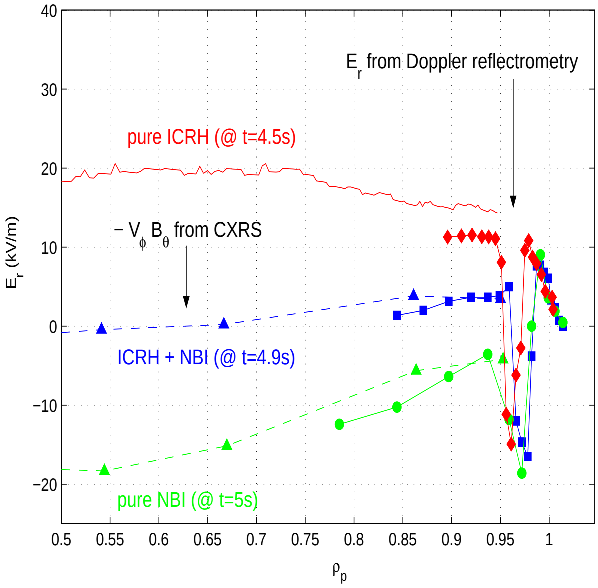
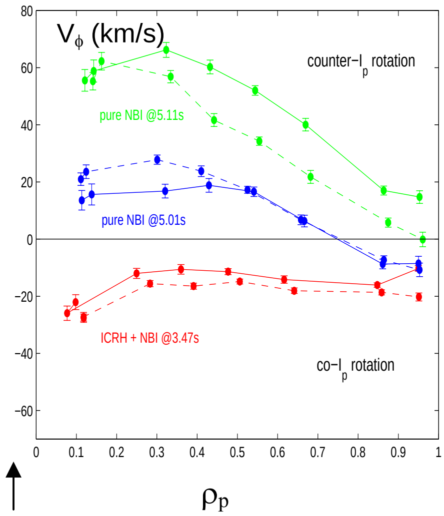


Fig.3: E_r profiles of the discharges #18951 for different types and levels of heating power.

Fig.4: Comparison between E_r profiles from Doppler reflectometry and $-V_\phi B_\theta$ from the CXRS diagnostic for the discharges #18951. The solid red line is an estimation of $-V_\phi B_\theta$ from the radial force balance for a pure ICRH phase.



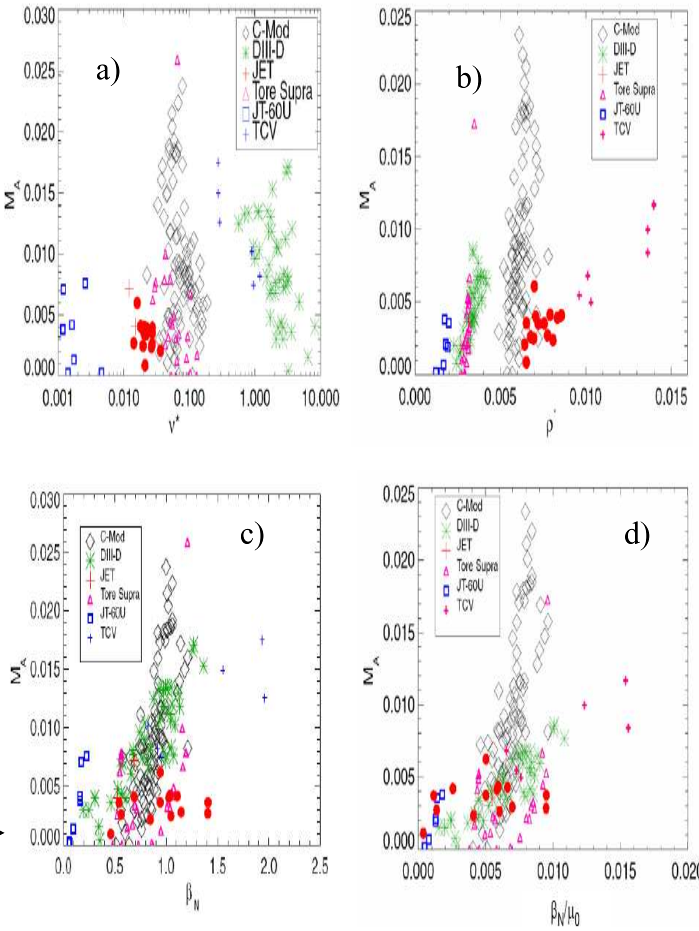


Fig.2: Rotation profiles from CXRS diagnostic for discharges #18951 (solid line) and #18952 (dashed line). The rotation direction flips when ICRH is switched-off, first in the core, later in the edge.

Fig.5: Alfvènic Mach numbers V_ϕ / C_A as a function of a) normalised collisionality, b) gyro-radius, c) plasma pressure and d) plasma pressure divided by μ_0, which is truly dimensionless, for the 6 machines studied by *Rice et al.* [9], plus AUG (red full circles).