ICRF induced edge plasma convection in ASDEX Upgrade

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Motivation

- Edge Ion Cyclotron Range of Frequency (ICRF) fields ➔ large inhomogeneous sheath rectified potentials in front of the antennas ➔ Significant E×B convective transport, hot spots, impurity generation and power dissipation [1] .
- The convective transport can modify the edge density and influence the coupling of the ICRF power. The hot spots may damage the antennas and surrounding structures.
- Thus it is critical important to investigate these drifts induced by the edge ICRF fields. Theory and numerical studies are needed to understand and predict the SOL modifications caused by these drifts.

Benchmark of prescribed drifts

The EMC3 equations [2] including the particle, momentum, electron and ion energy transport equations.

Prescribed drift terms added to the emc3 equations.

$$\nabla\cdot\left(n_iV_{i\|}\vec{b}+n_iV_{drift}\vec{b}_\perp-D_i\vec{b}_\perp\vec{b}_\perp\cdot\nabla n_i\right)=S_p$$

$$\nabla\cdot\left(m_in_iV_{i\|}V_{i\|}\vec{b}+m_in_iV_{drift}V_{drift}\vec{b}_\perp-\eta_\|\vec{b}\vec{b}\cdot\nabla V_{i\|}-D_i\vec{b}_\perp\vec{b}_\perp\cdot\nabla m_in_iV_{i\|}\right)=-\vec{b}\cdot\nabla p+S_m$$

$$\nabla\cdot\left(\frac{5}{2}n_eT_eV_{i\|}\vec{b}+\frac{5}{2}n_eT_eV_{drift}\vec{b}_\perp-\kappa_e\vec{b}\vec{b}\cdot\nabla T_e-\frac{5}{2}T_eD_i\vec{b}_\perp\vec{b}_\perp\cdot\nabla n_e-\chi_en_e\vec{b}_\perp\vec{b}_\perp\cdot\nabla T_e\right)$$
$$=-k\left(T_e-T_i\right)+S_{ee}$$

$$\nabla\cdot\left(\frac{5}{2}n_iT_iV_{i\|}\vec{b}+\frac{5}{2}n_iT_iV_{drift}\vec{b}_\perp-\kappa_i\vec{b}\vec{b}\cdot\nabla T_i-\frac{5}{2}T_iD_i\vec{b}_\perp\vec{b}_\perp\cdot\nabla n_i-\chi_in_i\vec{b}_\perp\vec{b}_\perp\cdot\nabla T_i\right)$$
$$=+k\left(T_e-T_i\right)+S_{ei}$$

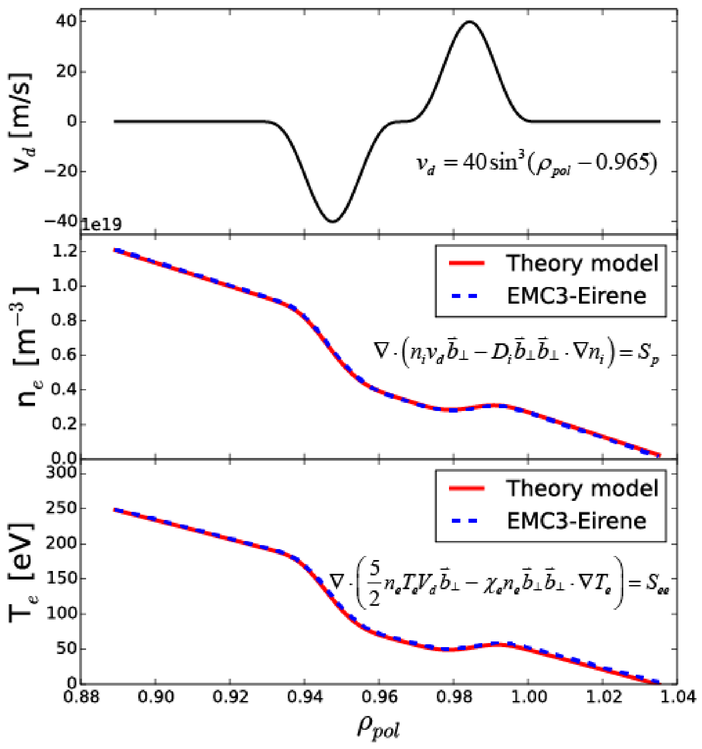


Figure 1. Benchmark of the 3D code results against the analytical ones in a cylindrical geometry.

Conclusions

1. For the first time we have added the prescribed drift terms to the particle, momentum and energy transport equations in the EMC3-Eirene code and benchmarked the 3D code results against the analytical ones in a cylindrical geometry.
2. For the first time we have calculated the RF sheath rectified potentials, the electric fields and the drift velocities in 3D geometry, and simulated the ICRF induced SOL modifications in ASDEX Upgrade.
3. The ExB drifts caused by the rapid variation of the potential across the magnetic field will result in edge plasma convections. The RF convection tends to drive the edge plasma outward and flatten the SOL profiles through the formation of pump-out structures.
4. Further simulations and experiments in AUG will give more accurate characterisation of the ICRF induced SOL modifications.

[1] D. A. D'Ippolito et al., PHYSICS OF PLASMAS 13, 102508 (2006)
[2] Y. Feng et al., Contrib. Plasma Phys. 44, No. 1-3, 57-69 (2004)
[3] L. Colas et al., AIP Proceedings, Vol. 1580, p259 (2014)

Experimental Results

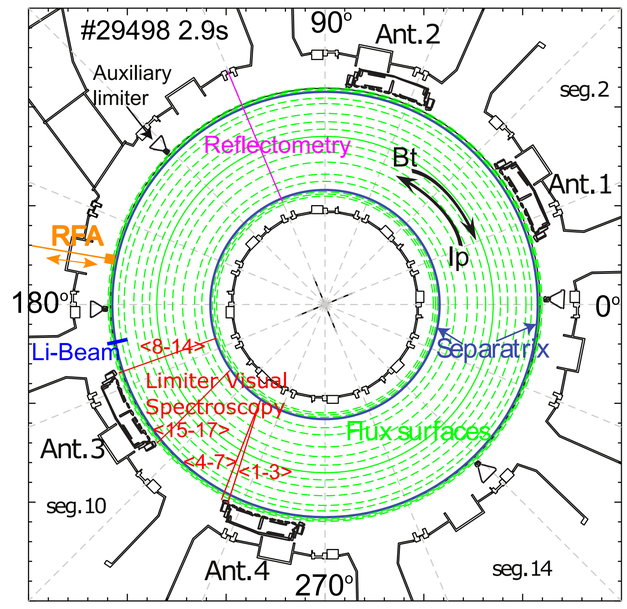


Figure 2. AUG top view

Discharge: #29498(L mode), standard D(H) minority scenario. Only ohmic and ICRF heating. $P_{ICRF2}=P_{ICRF4}=0.9$MW, $f_{RF}=30$MHz.

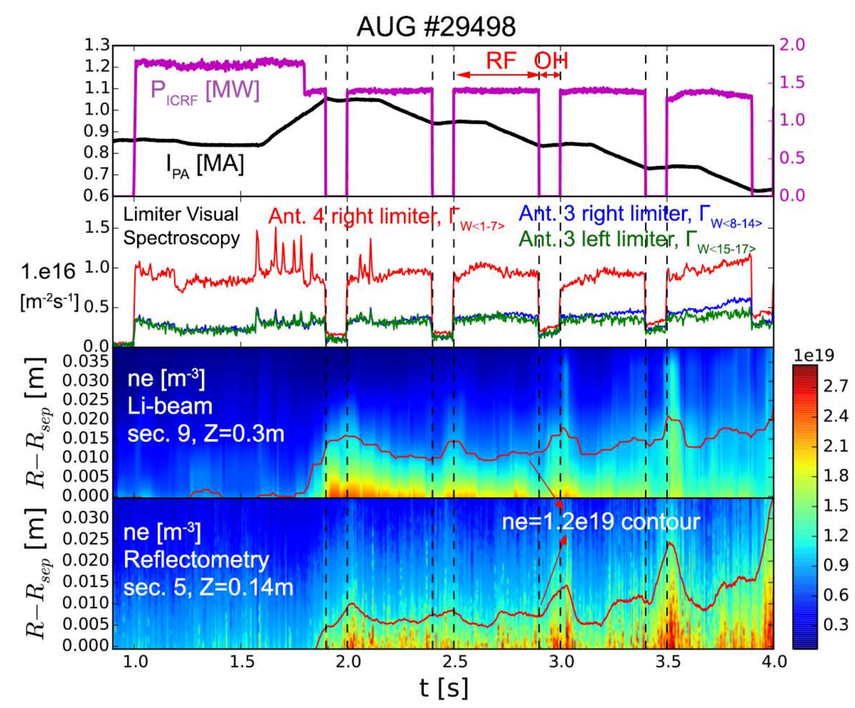
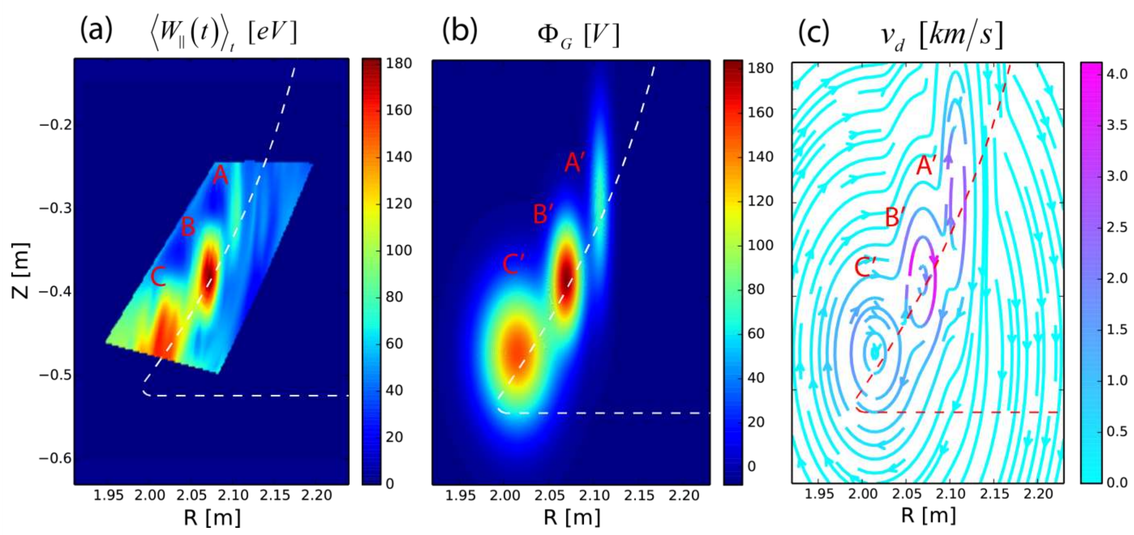


Figure 3. Experimental evidences of RF induced convection.

Simulation Results

1. RF induced Potential



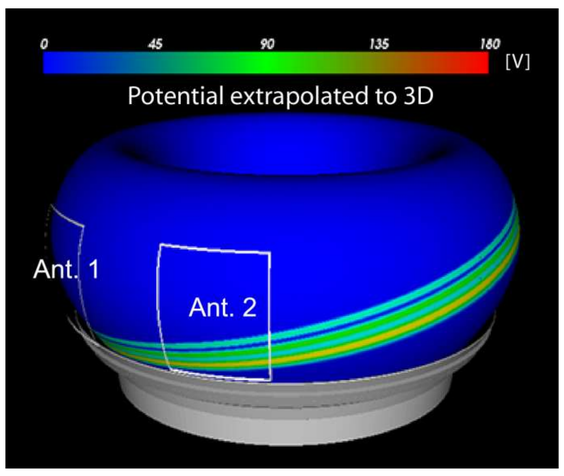
$W_\|$: The average collected ion parallel energy by RFA probe, data from [3].

$$\overrightarrow{v_{drift}}=\left(\vec{E}\times\vec{B}\right)/B^2$$
$$\approx(E_zB_\phi\vec{R}-E_RB_\phi\vec{z})/B^2$$
$$=(-\nabla_z\Phi\cdot B_\phi\vec{R}+\nabla_R\Phi\cdot B_\phi\vec{z})/B^2$$

Figure 4. (a) Measured parallel energy with RFA.

(b) Gaussian mapping.

(c) Drift velocity.



The potential is nearly constant along the magnetic field in the plasma region. Much of the full voltage drop occurs in the sheaths. The edge plasma convection is caused by the rapid variation of the potential across the field lines.

A Gaussian function is used to map the experimental potential.

$$\Phi_G=\Phi_0\cdot\exp\left\{-\left[\frac{(R-R_0)^2}{2\sigma_R^2}+\frac{(Z-Z_0)^2}{2\sigma_Z^2}\right]\right\}$$

The 2D potential is extrapolated to a 3D one based on the assumption that the potential is constant along the magnetic field.

Figure 5. Potential extrapolated to 3D.

2. Density modifications

RF sheath rectified potential can generate significant ExB drifts (in the range of 1km/s). The ExB drifts tend to drive the plasma outward through the formation of "pump-out" structures.

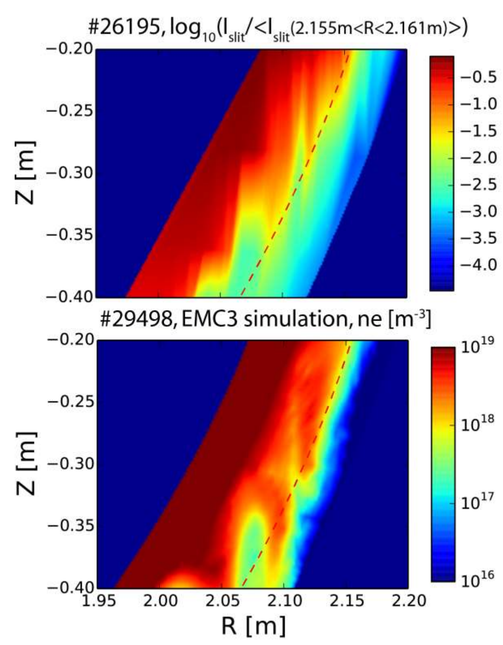


Figure 6. Comparisons of the convective structures in the middle of antenna 2 between measurements and experiments.

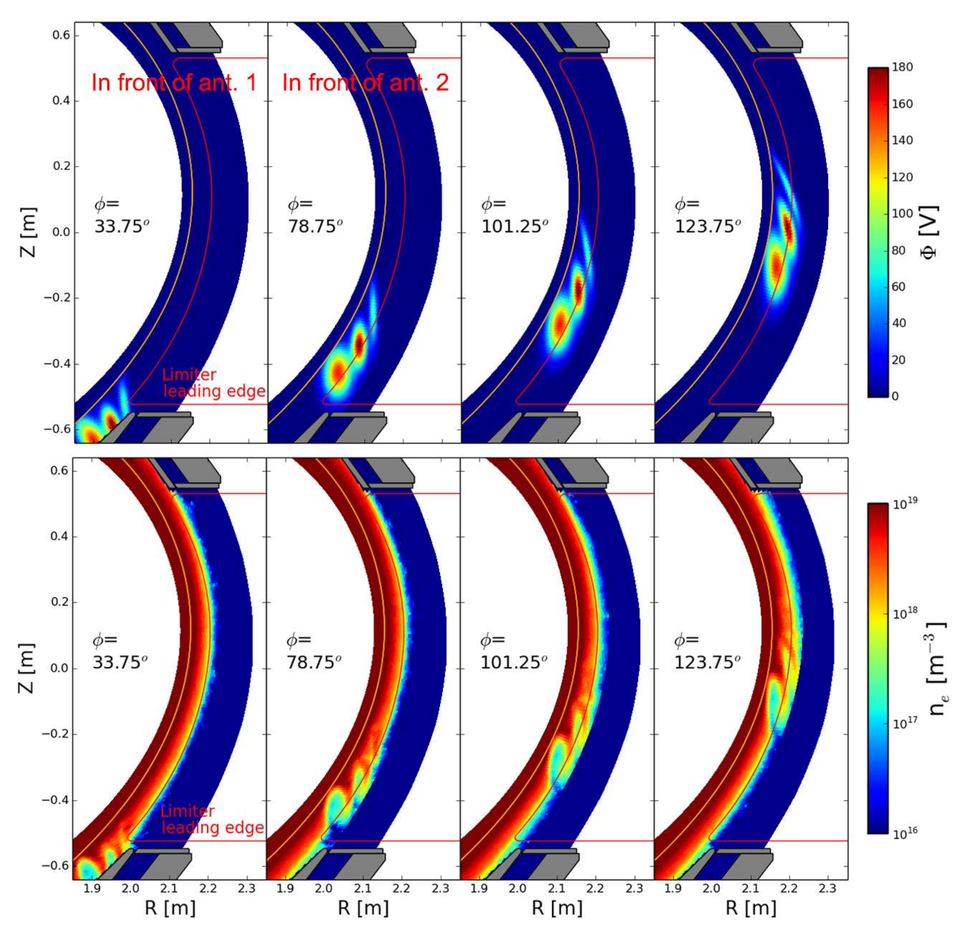


Figure 7. The implemented potential and simulated density in different toroidal positions.

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