Divertor detachment in the Pre-Fusion Power operation Phase in ITER during application of resonant magnetic perturbations for ELM suppression

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ABSTRACT

- Key challenges for successful operation of ITER: access to 1) a (partially) detached divertor plasma and 2) mitigation/suppression of edge localized modes (ELMs).
- The design of the ITER divertor is based on extensive modeling (SOLPS), but under the assumption of axisymmetry.
- Application of resonant magnetic perturbations (RMPs) is anticipated for ELM control, but compatibility with a detached divertor state remains an open issue.

PLASMA BOUNDARY MODELLING

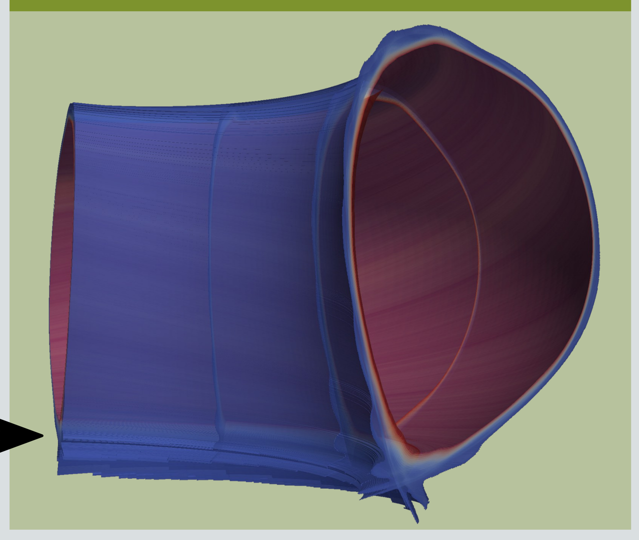
Magnetic Geometry: $B_{equi} + B_{RMP}$

Model parameters: Γ_{gas}, P_{SOL}, $D_\perp$, $\chi_\perp$

3D Plasma boundary model (EMC3-EIRENE)

$$\nabla \cdot \mathbf{\Gamma} = S_p$$
$$\nabla \cdot \left(m u_\parallel \mathbf{\Gamma} - \boldsymbol{\tau}\right) = -\nabla_\parallel p + S_m$$
$$\nabla \cdot \mathbf{q}_e = S_{ee} \qquad \nabla \cdot \mathbf{q}_i = S_{ei}$$

Simulation results

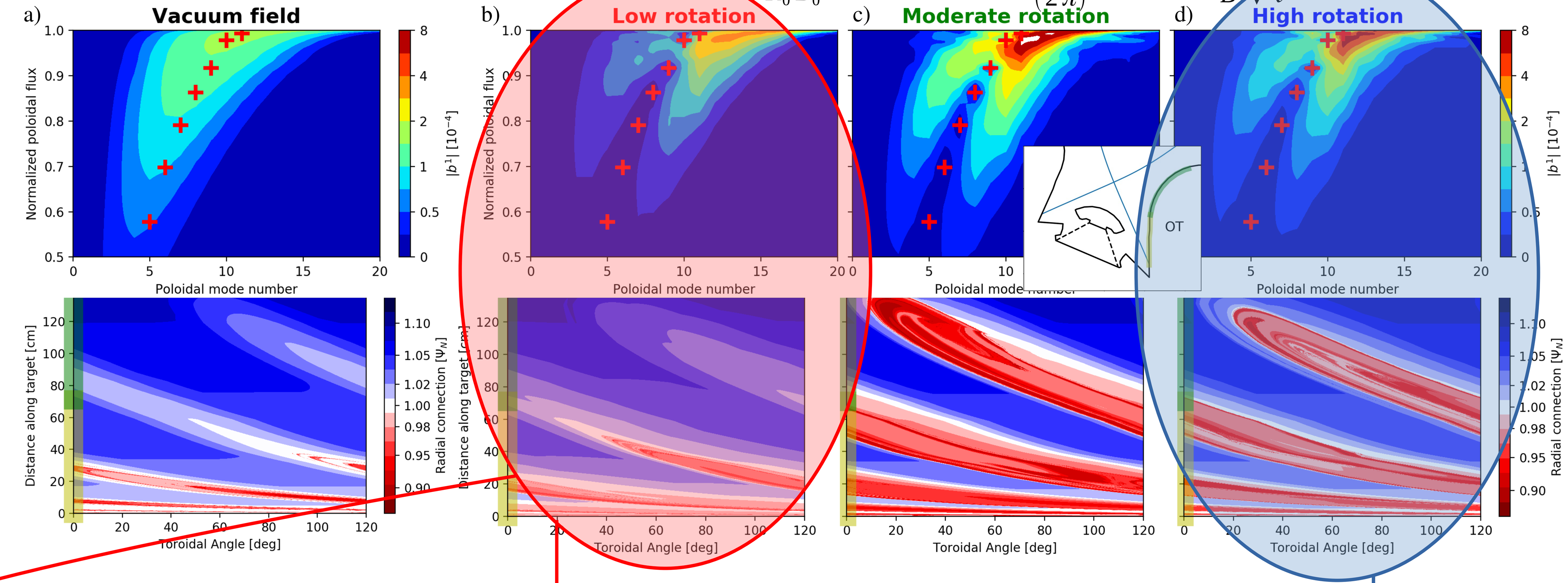


- EMC3-EIRENE: extension of "traditional" plasma boundary modelling to three dimensions.
- Magnetic geometry is input, but can include plasma response effects.

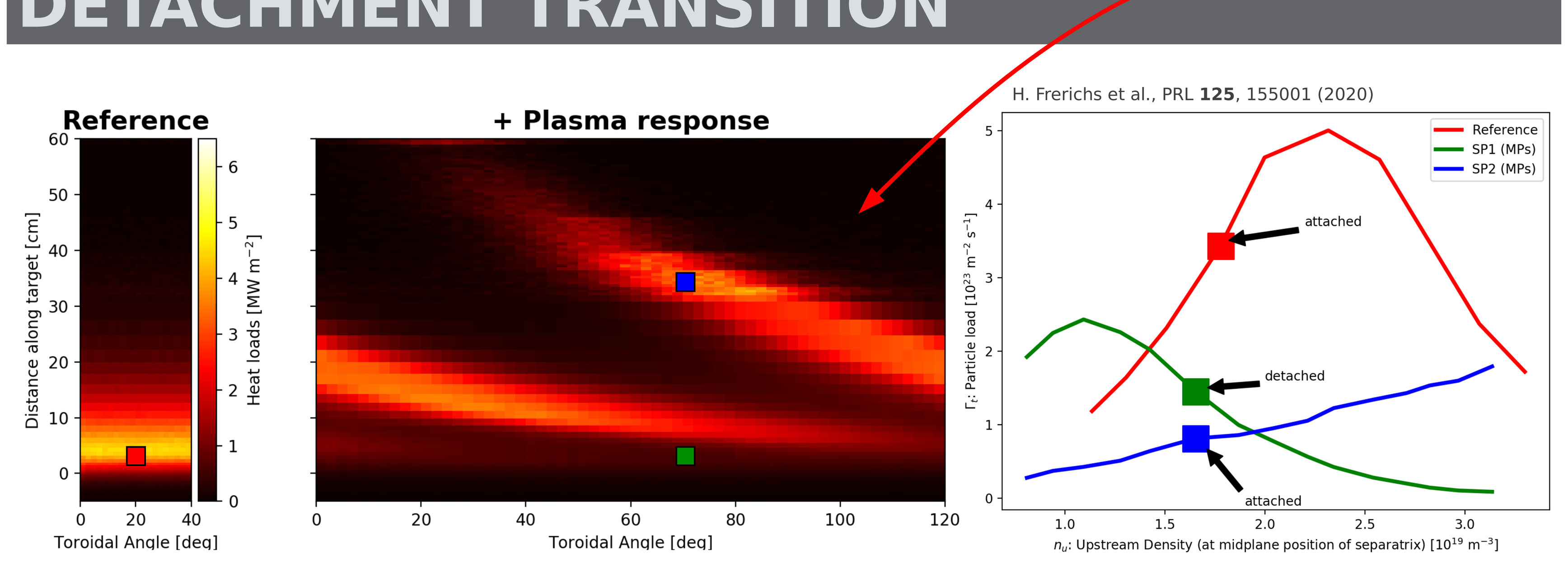
PLASMA RESPONSE EFFECTS

- Screening response: reduced radial extent of perturbed scrape-off layer.
- Plasma response (MARS-F) in resistive single fluid MHD in full toroidal geometry: field amplification near separatrix competes with screening of resonances → large magnetic footprint on divertor targets.
- "Low" rotation is expected for ITER, but sensitivity at low-moderate rotation requires further investigation.

- Poloidal Fourier harmonics: $b^1_{mn} = \frac{1}{R_0^2 B_0}\Phi_{mn}$ $\quad \Phi_{mn} = \frac{1}{(2\pi)^2}\oint d\vartheta\, d\varphi \frac{B_{RMP}\cdot\nabla\psi}{B\cdot\nabla\vartheta} e^{-i(m\vartheta - n\varphi)}$

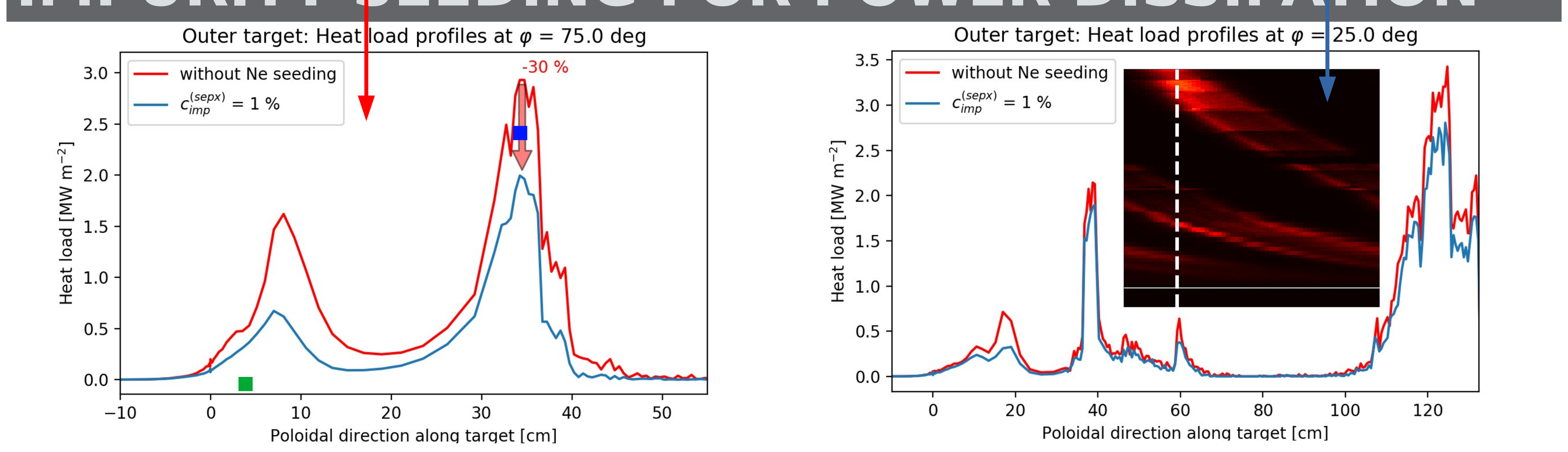


DETACHMENT TRANSITION



- Earlier onset of detachment (i.e. at lower upstream density) in original strike zone (SP1) compared to unperturbed reference.
- Non-axisymmetric strike point in far SOL (SP2) remains attached, even at higher upstream densities.

IMPURITY SEEDING FOR POWER DISSIPATION



- Moderately sized magnetic footprint (low rotation):
  → Mitigation of non-axisymmetric far SOL heat loads possible with impurity concentration of 1 % at separatrix.
- Large magnetic footprint (moderate/high rotation):
  → Impurity seeding is significantly less effective due to higher temperature and lower density at the far SOL peaks.

CONCLUSIONS

- A good understanding of the plasma response is key for reliable predictions of divertor loads.
- Rerouting upstream heat flux along perturbed field lines into the far SOL brings high temperatures to strike points which remain attached to higher upstream densities.
- Field amplification near the separatrix may result in magnetic footprints that exceed the vertical target onto the rounded baffle where tolerances are much lower.
- Dissipation from impurity seeding is less effective with large magnetic footprints.

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