Effects of Toroidal Flow Direction and Plasma Density on Edge Localized Modes in Tokamaks

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(Presented by Carl R. Sovinec)

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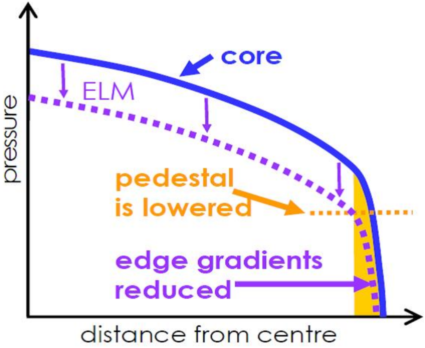
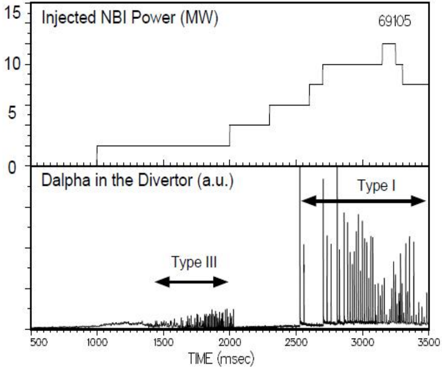
Outline

1. Background and motivation
2. Simulation results
    - Flow and plasma density effects on ELMs in limiter-typed tokamak
    - Flow and plasma density effects on ELMs in diverter-typed tokamak
3. Summary

Edge Localized Mode (ELM) can cause potential damage to wall material of tokamak



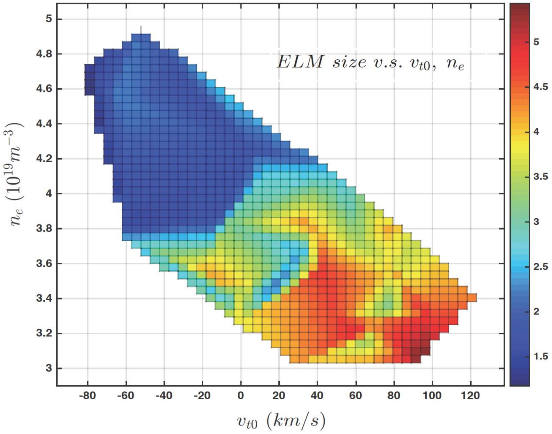


- During H-mode discharge, steep pressure gradient will lead to ELMs.
- Type-I ELM can deposite large amount of particles and heats on the divertor target plates, potentially causing damage in devices.

Large toroidal rotation can be induced by neutral beam injection in H-mode discharge

1. Plasma rotation may have stabilizing effect on ELMs;
2. Experiments suggest flow stabilization of type-I ELMs more effective in higher collisionality regime;
3. Recent experiments find ELM mitigation and suppression are more favourably achieved in the higher plasma density regime in presence of negative toroidal rotation;
4. The negative direction rotation is defined as the opposite direction of plasma current.

In the presence of negative flow, higher plasma density gives smaller ELM size in EAST experiment (#56364)



In this work, we study toroidal flow and plasma density effects on ELMs using NIMROD code

1. We first study the toroidal flow direction and plasma density effects on ELMs in a circular-shaped limiter tokamak.
2. We then verify the flow direction and plasma density effects on ELMs in divertor-typed (EAST) tokamaks.

Full extended MHD equations are solved in NIMROD code [C. R. Sovinec et al 2004]

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = -\rho\nabla\cdot\mathrm{u} + \mathrm{D}\nabla^2\rho \tag{1}$$

$$\rho\frac{\mathrm{du}}{\mathrm{d}t} = -\nabla\mathrm{p} + \mathrm{J}\times\mathrm{B} - \nabla\cdot\pi \tag{2}$$

$$\frac{\mathrm{n}}{\gamma-1}\frac{\mathrm{dT}}{\mathrm{d}t} = -\frac{\mathrm{p}}{2}\nabla\cdot\mathrm{u} - \pi:\nabla\mathrm{u} - \nabla\cdot\mathrm{q} + \mathrm{Q} \tag{3}$$

$$\frac{\partial\mathrm{B}}{\partial t} = -\nabla\times\mathrm{E} \tag{4}$$

$$\mu_0\mathrm{J} = \nabla\times\mathrm{B} \tag{5}$$

$$\mathrm{E} = -\mathrm{u}\times\mathrm{B} + \eta\mathrm{J} + \frac{\lambda}{\mathrm{ne}}(\mathrm{J}\times\mathrm{B} - \nabla\mathrm{P_e}) \tag{6}$$

Finite element meshes used in NIMROD computation

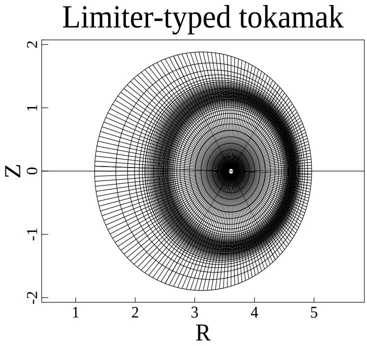
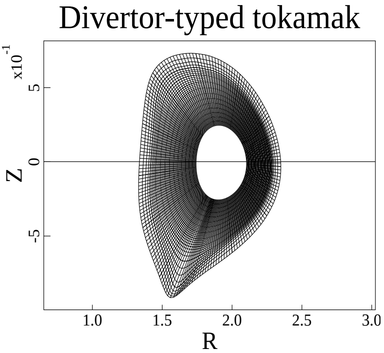

Limiter-typed tokamak

Figure: mx=72,my=180


Divertor-typed tokamak

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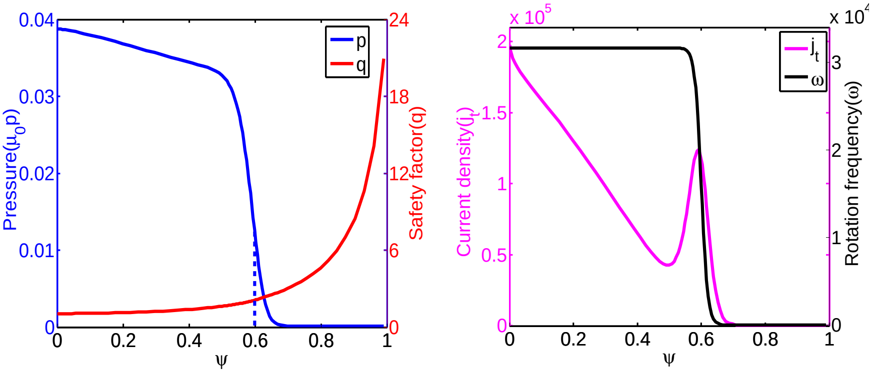
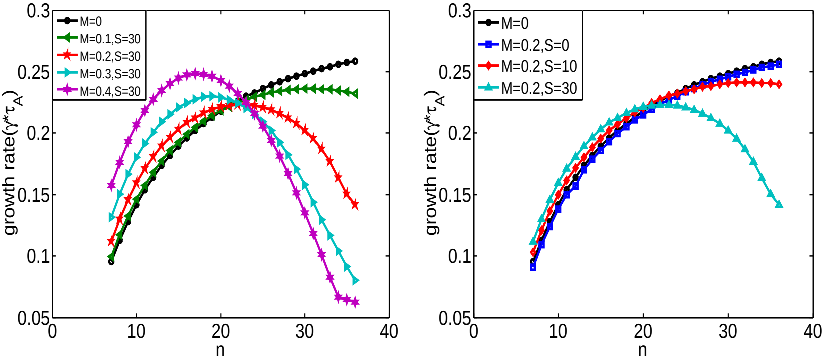
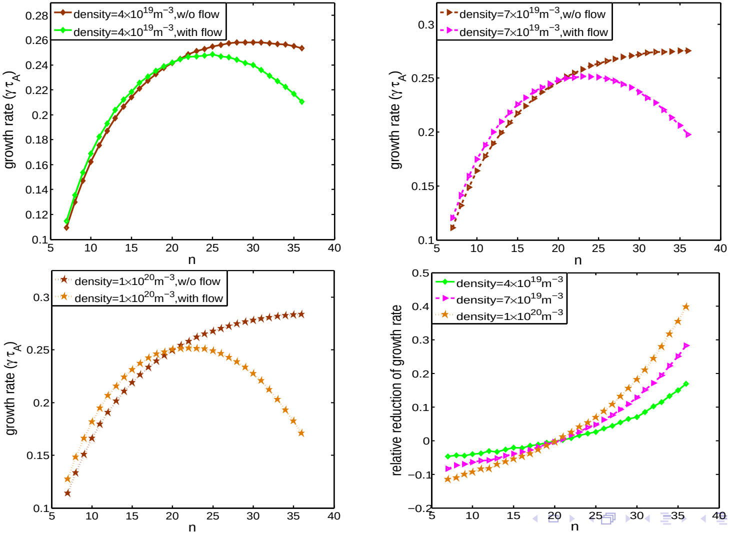
Circular-shaped limiter tokamak H-mode equilibrium profiles



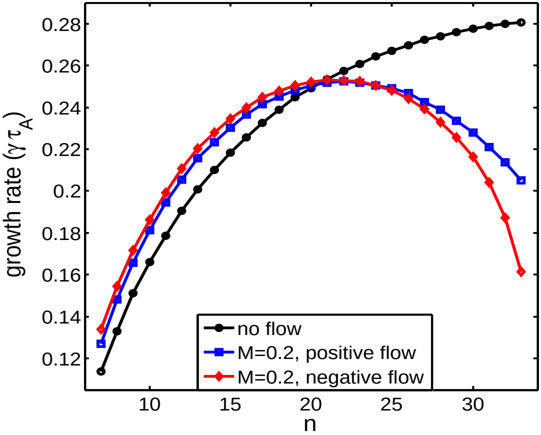
Toroidal shear flow can stabilize high-n modes and de-stabilize low-n modes [S.-K. Cheng, P. Zhu, and D. Banerjee, Phys. Plasmas 24, 092510 (2017)]



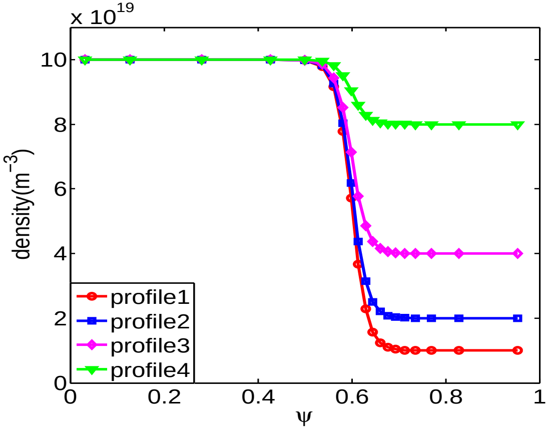
Increasing plasma density can enhance flow stabilization on high-n ELMs



Negative toroidal flow strongly suppresses high-n ELMs in limiter-typed tokamak

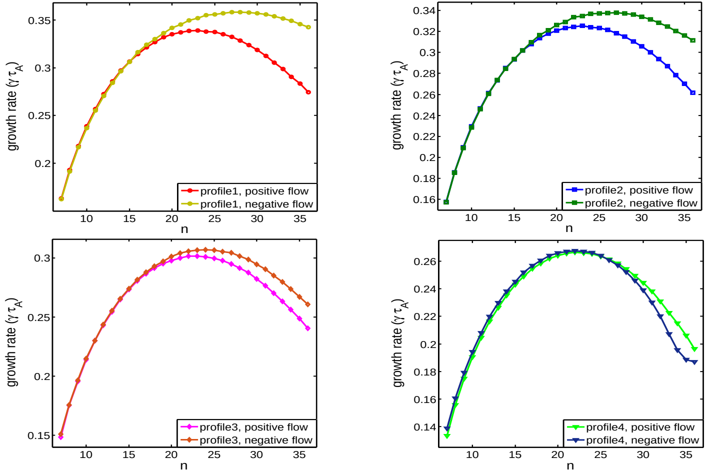


Density profiles with different edge plasma density are used in limiter-typed tokamak



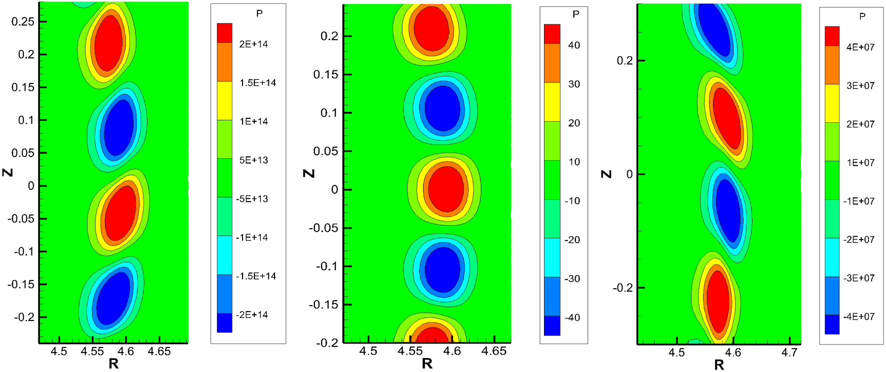
In experiments, gas puffing can increase edge plasma density while keep core plasma density the same.

Increasing edge plasma density can change flow direction effects on high-n ELMs



For low edge plasma density, the growth rates of high-n modes are: negative flow > positive flow, while for high edge plasma density are: positive flow > negative flow.

ELM elongation direction in poloidal plane changes with toroidal flow direction



Perturbed pressure in presence of positive flow (left), zero flow (middle) and negative flow (right).

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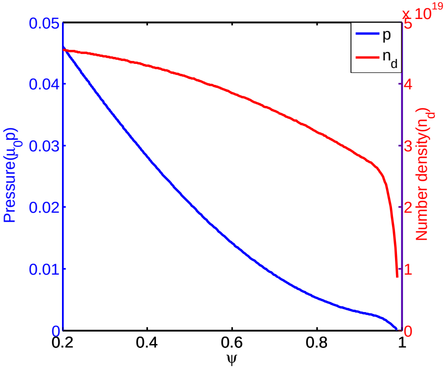
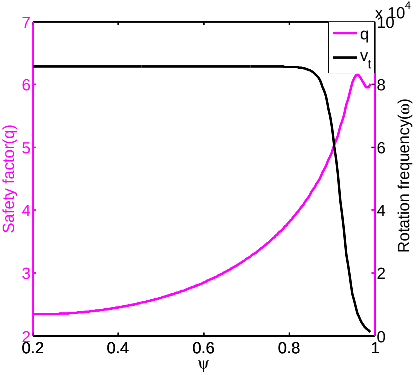
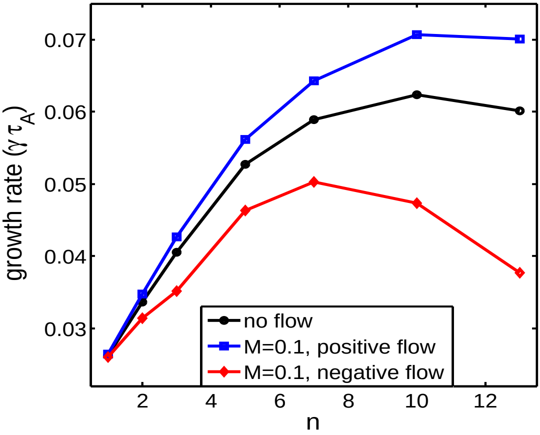
D-shaped divertor tokamak (EAST) H-mode equilibrium profiles

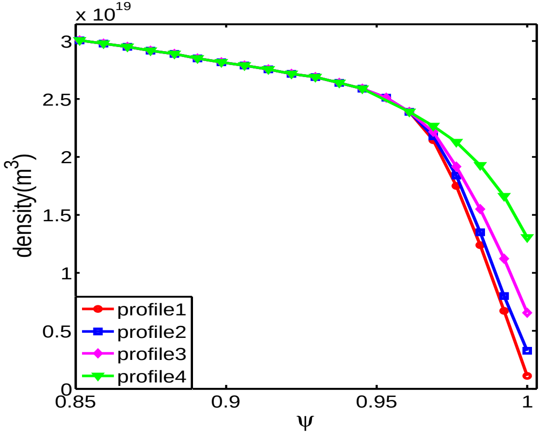




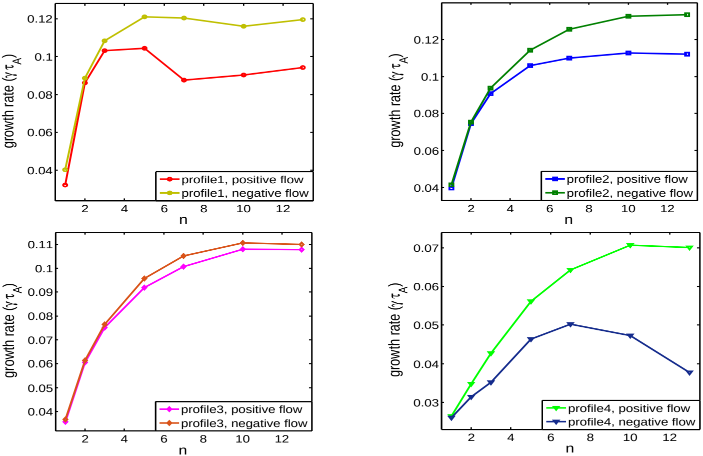
Positive flow can destabilize all-n modes while negative flow can stabilize them in divertor-typed tokamak



Density profiles with different edge plasma density are used in divertor-typed tokamak

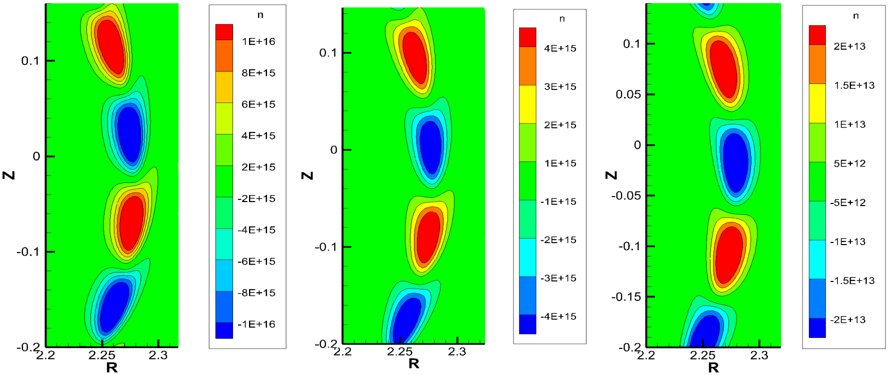


Increasing edge plasma density will change flow direction effects on high-n ELMs



For low edge plasma density, the growth rate of high-n modes are: negative flow > positive flow, while for high edge plasma density are: positive flow > negative flow.

ELM elongation direction in poloidal plane changes with toroidal flow direction in divertor-typed tokamak



Perturbed pressure in presence of positive flow (left), zero flow (middle) and negative flow (right).

Summary

1. NIMROD simulations show that, increasing plasma density can enhance flow stabilization on high-n ELMs.
2. The direction of flow play an even more significant role on ELM stabilization, in particular, negative flow can provide stronger stabilization on high-n ELMs with certain plasma density.
3. Effects of toroidal flow direction on ELMs strongly dependent on the edge plasma density, specifically, for low edge density, negative flow provide higher growth rates on ELMs, while for high edge density, this trend becomes opposite.
4. These effects may explain why ELM mitigation and suppression are more favourably achieved in the higher plasma density regime in presence of negative toroidal rotation in recent EAST experiments.

Acknowledgement

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