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ELM suppression and flow damping with n=1 RMP fields in tokamak plasmas

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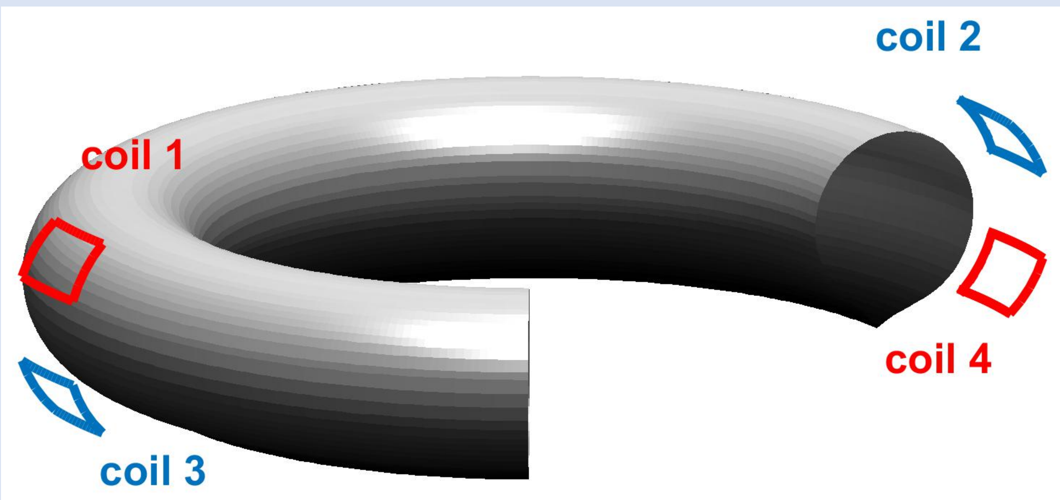
ABSTRACT

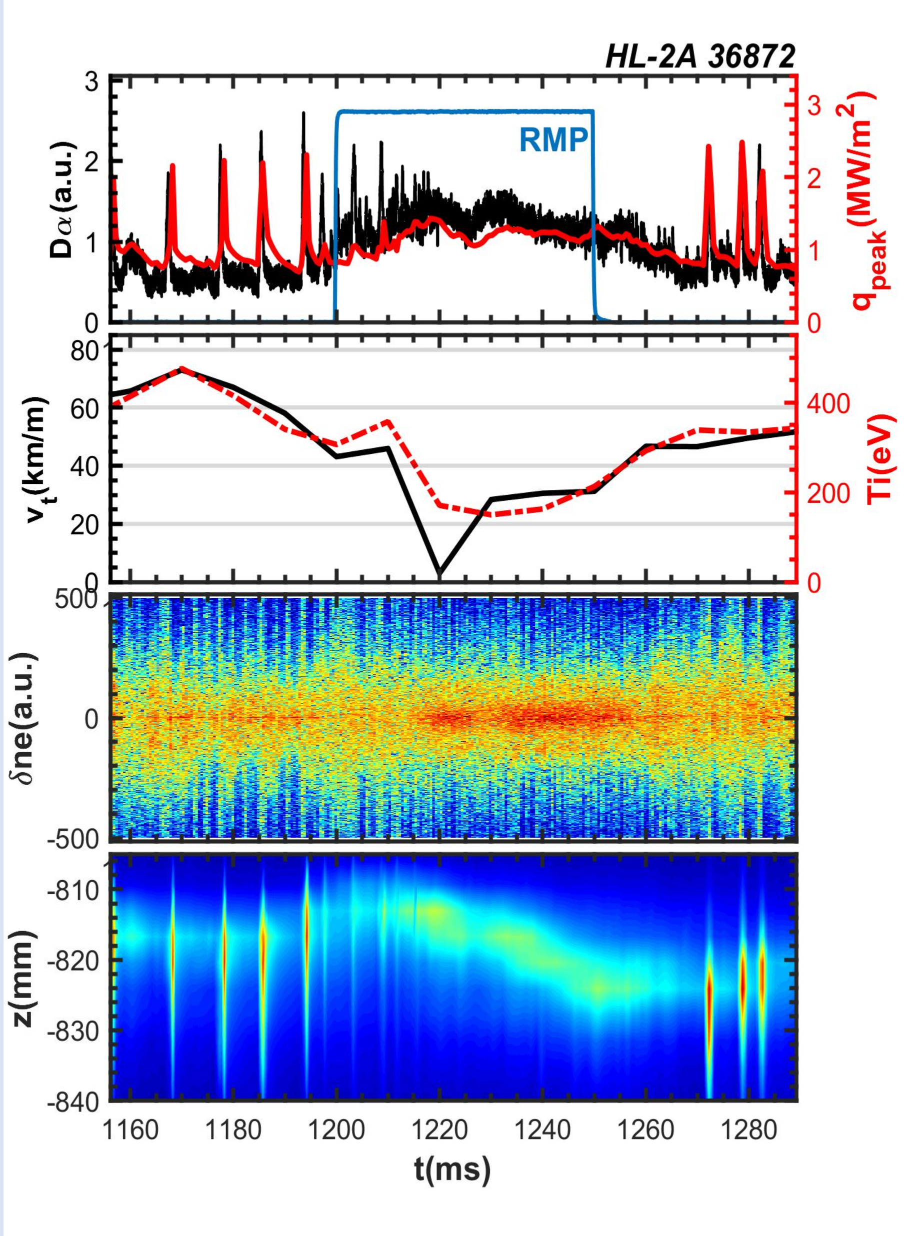
•Controling large edge localized modes (ELMs) is critical for tokamaks operating in H-mode, due to potentially severe consequences on material damages caused by ELM bursts in future large scale devices such as ITER. Resonant magnetic perturbation (RMP) has been extensively applied to mitigate or suppress ELMs. In this work, we report two new recent results on the effect of the n=1 (n is the toroidal mode number) RMP fields on ELMs and the associated plasma transport. One is the experimental result on the HL-2A tokamak, where large type-I ELMs were for the first time on this device suppressed by the applied n=1 RMP. The other is the toroidal modeling study on the plasma core flow damping by the applied n=1 RMP, with computational results quantitatively agreeing with experiments in ASDEX Upgrade.

RMP ON HL-2A

The in-vessel coil with small scale of 450 × 260mm² and toroidal mode number of 1 are equip with the consider of diagnostic or heating windows and graphite tiles.



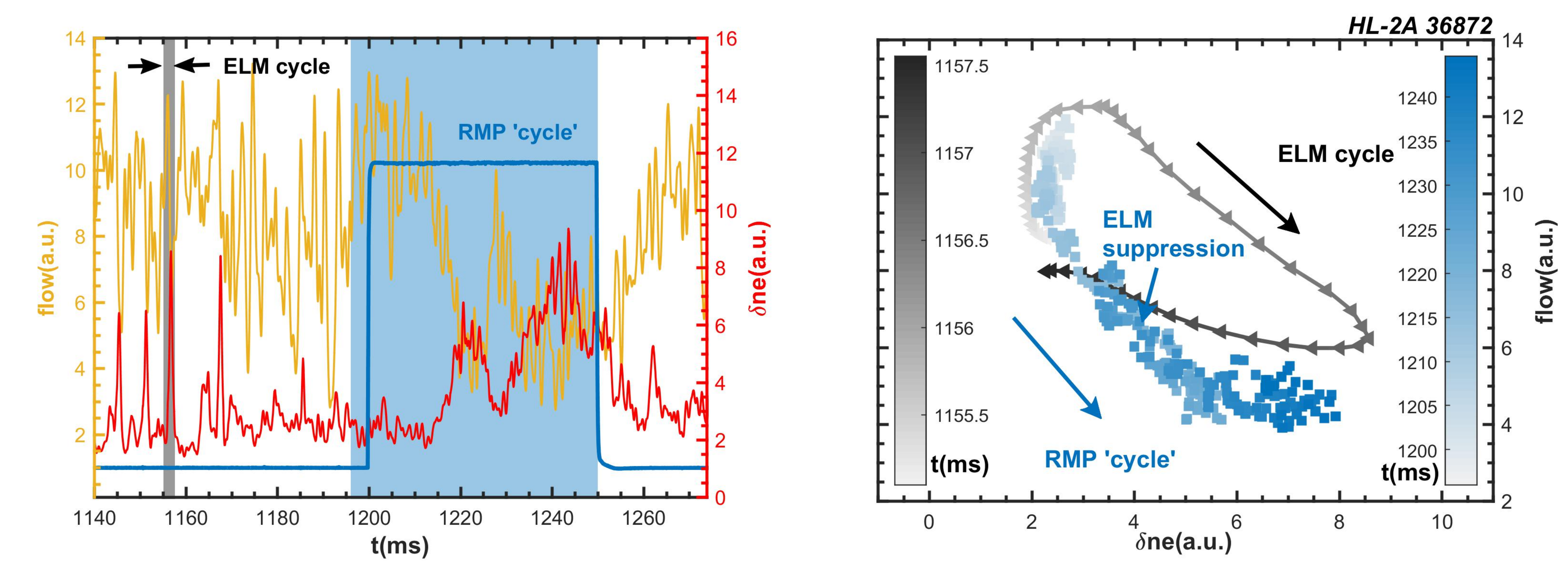
ELM SUPPRESSION ON HL-2A BY THE APPLIED RMP



A typical ELM suppression discharge with 4.9kA current in the RMP coils

- The amplitude of D_α and q_{peak} signal increases to a high level though the large ELMy bursts riding on it disappeared
- Both ion density and toroidal rotation near the pedestal top (ρ=0.95,R=1.9) drop sharply
- The DBS channels show enhanced broadband fluctuations ($k_\perp$=4.6-6.8 cm^{-1}) along with the ELM suppression
- The heat load region is expanded during the ELM suppression

E×B FLOW CHANGES AT THE ONSET OF RMP



Time evolution of the E × B flow and density fluctuation near ρ = 0.94

- The flow and fluctuation are negatively correlated
- The ELM crash-recovery cycle (e.g. 1155 to 1157.5 ms) is clockwise, which means the turbulence leads flow
- The ELM suppression half cycle (form 1220 to 1250 ms) is anti-clockwise, which indicates the flow leads turbulence

PLASMA RESPONSE MODEL

Linear response model

Single fluid+resistive MHD+plasma toroidal rotation+toroidal geometry

$$i(\Omega_{RMP}+n\Omega)\xi = \mathbf{v} + (\xi\cdot\nabla\Omega)R^2\nabla\phi$$

$$i\rho(\Omega_{RMP}+n\Omega)\mathbf{v} = -\nabla p + \mathbf{j}\times\mathbf{B} + \mathbf{J}\times\mathbf{b} - \rho\left[2\Omega\nabla Z\times\mathbf{v} + (\mathbf{v}\cdot\nabla\Omega)R^2\nabla\phi\right] - \rho\kappa_\parallel|k_\parallel v_{th,i}|[\mathbf{v}+(\xi\cdot\nabla)\mathbf{V}_0]_\parallel$$

$$i(\Omega_{RMP}+n\Omega)\mathbf{b} = \nabla\times(\mathbf{v}\times\mathbf{B}) + (\mathbf{b}\cdot\nabla\Omega)R^2\nabla\varphi - \nabla\times(\eta\mathbf{j}) \qquad \mathbf{j}=\nabla\times\mathbf{b}$$

$$i(\Omega_{RMP}+n\Omega)p = -\mathbf{v}\cdot\nabla P - \Gamma P\nabla\cdot\mathbf{v}$$

Equation for RMP coils: $\nabla\times\mathbf{b} = \mathbf{j}_{RMP}$

Equation in vaccum region: $\nabla\times\mathbf{b} = 0, \quad \nabla\cdot\mathbf{b} = 0$

Quasi-linear plasma response model

n≠0 MHD equations coupled to *n*=0 toroidal momentum balance equation

$$\frac{\partial L}{\partial t} = D(L) + T_{NTV} + T_{JXB} + T_{REY} + T_{source}$$

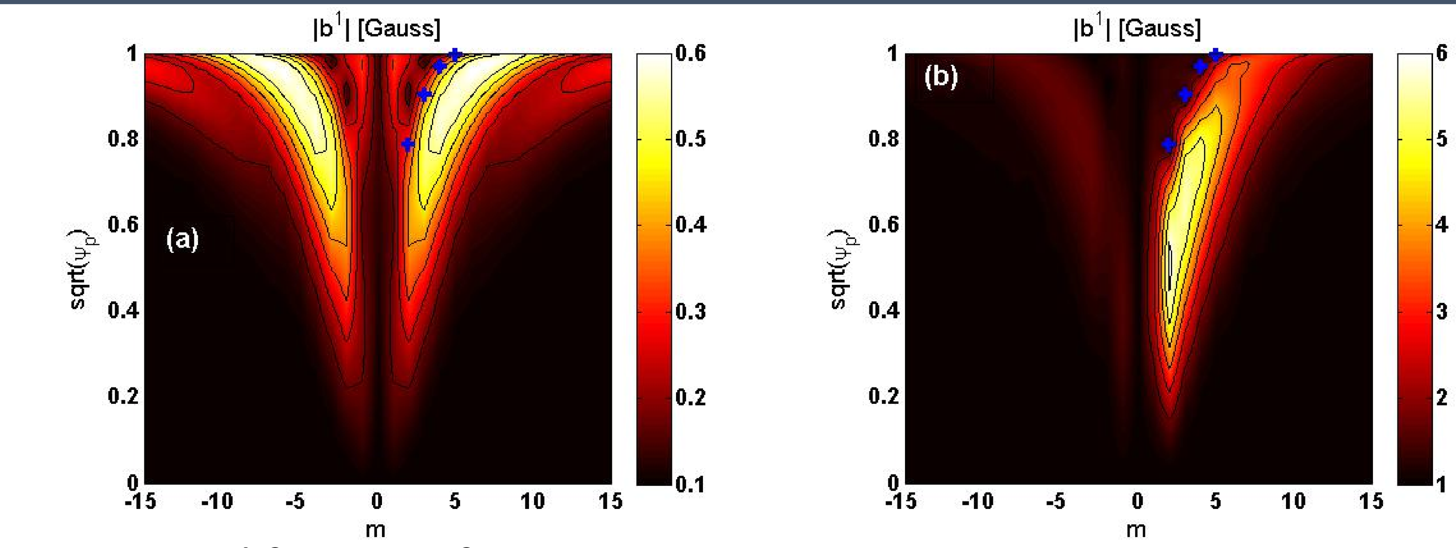
Assume torque balance (steady state flow) before applying RMP

➡ Change of momentum obeys

$$\frac{\partial \Delta L}{\partial t} = D(\Delta L) + T_{NTV} + T_{JXB} + T_{REY}$$

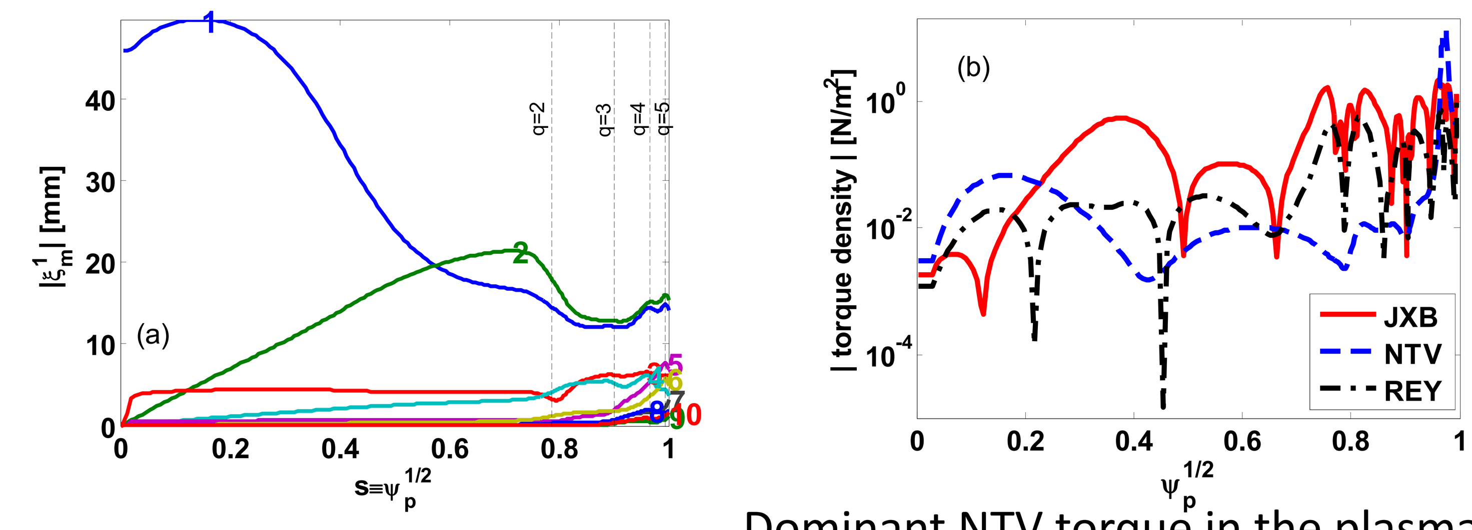
The MARS-Q is used to solve the above equations as an initial value problem.

MODELING RESULTS: LINEAR RESPONSE



Strong amplification of non-resonant components: ~10

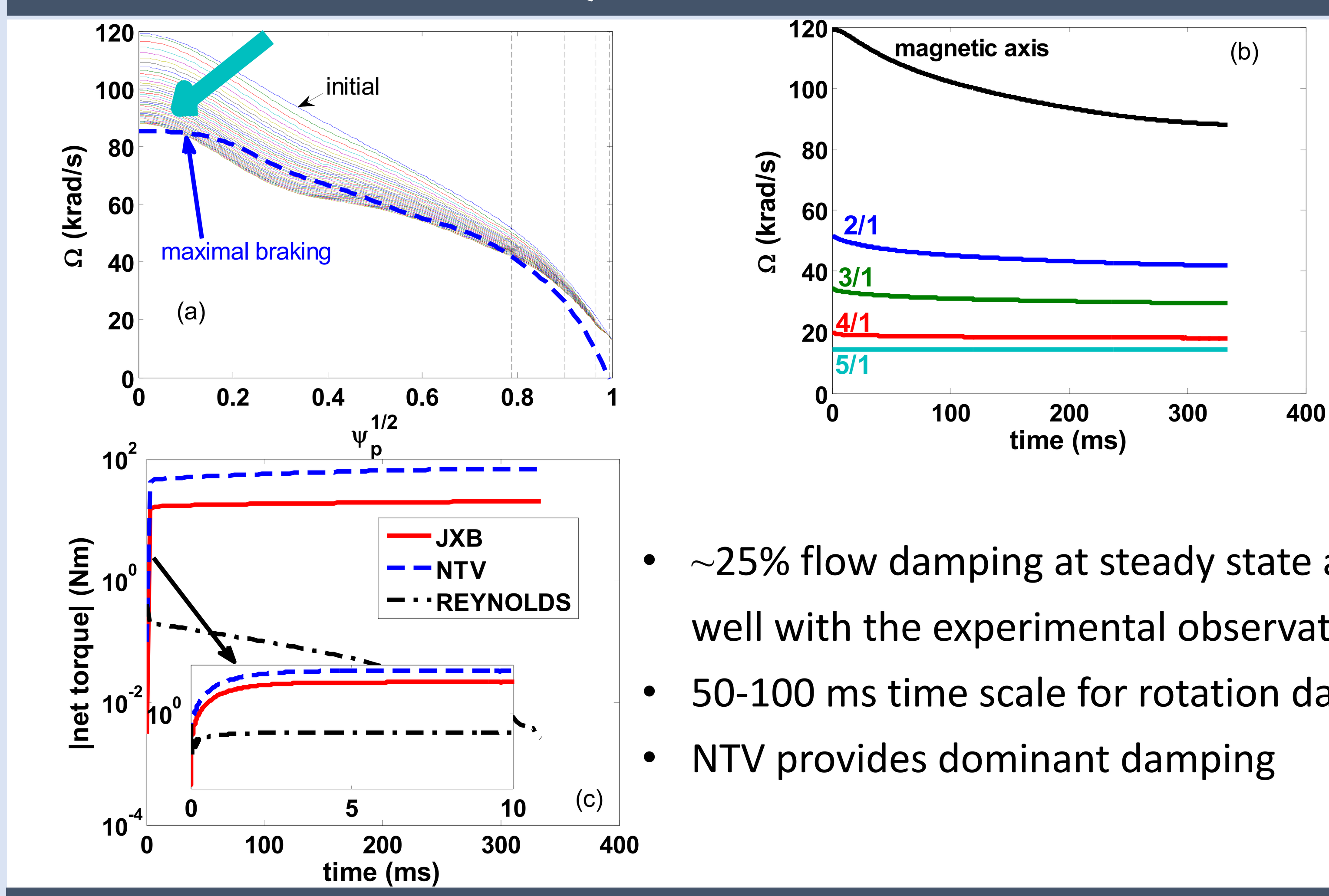
Resonant harmonics reduced by 1-2 orders of magnitude at rational surfaces



Large internal kink response

Dominant NTV torque in the plasma core region (+ a small region near edge).

MODELING RESULTS: QUASI-LINEAR RESPONSE



- ~25% flow damping at steady state and agrees well with the experimental observation
- 50-100 ms time scale for rotation damping
- NTV provides dominant damping

CONCLUSION

- The stochastic boundaries by simple n=1 RMP coils are compatible with H-mode and may be attractive for ELM control with its simple coil structure in next-step fusion tokamak.
- Internal kink response may play important role in plasma core flow damping in high-beta hybrid scenarios in future devices.