The core MHD events in thousand-second discharge on EAST Tokamak

by

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Outline

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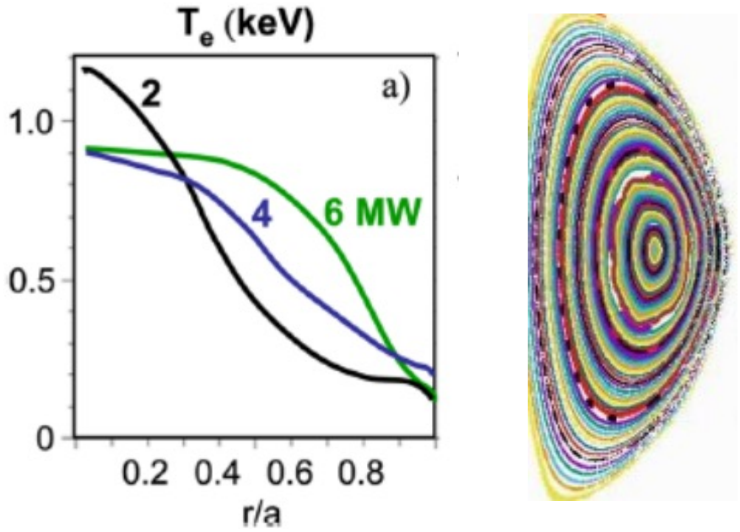
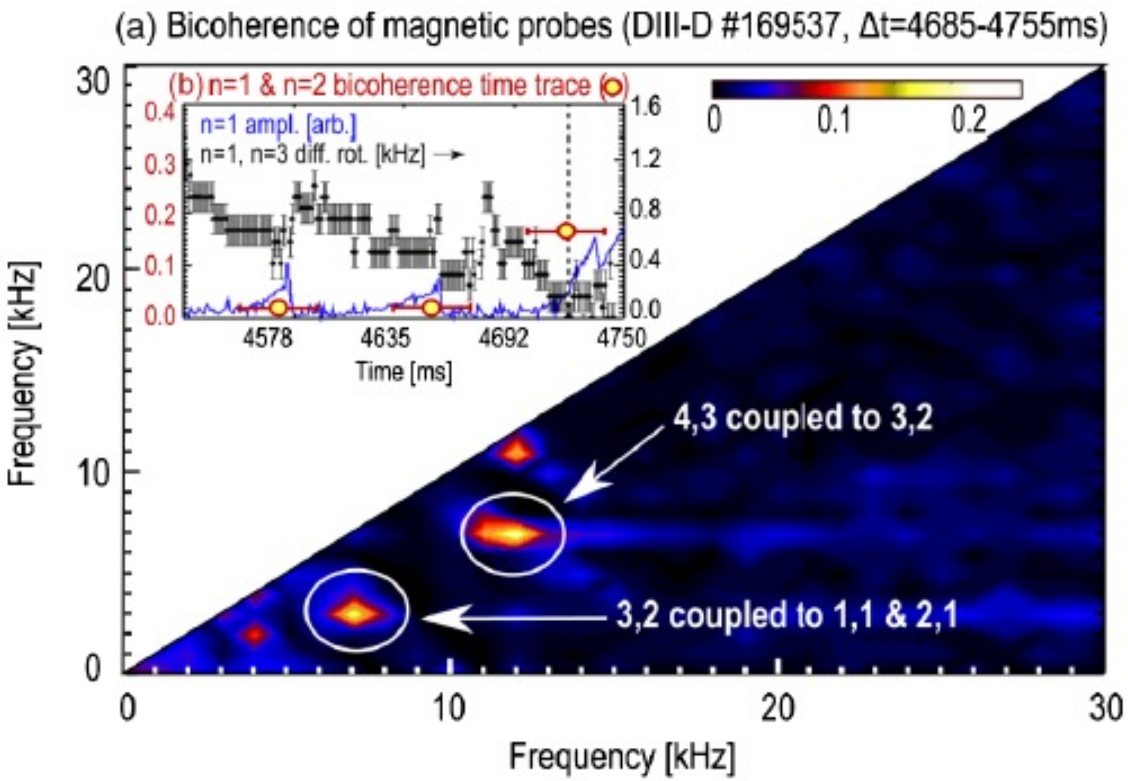
The core MHD is double-edged sword in LPO

❑ Negative:

- TM/NTM: nonlinear **three-wave coupling** or forced magnetic reconnection
- Multi-ideal: Limit the plasma performance: **change of magnetic topology**



- Te flatten due to high n ideal MHD
  S. Jardin PRL 128, 245001 (2022)



- Seed island due to three-wave coupling
  L. Bardóczi PRL 127, 055002 (2021)

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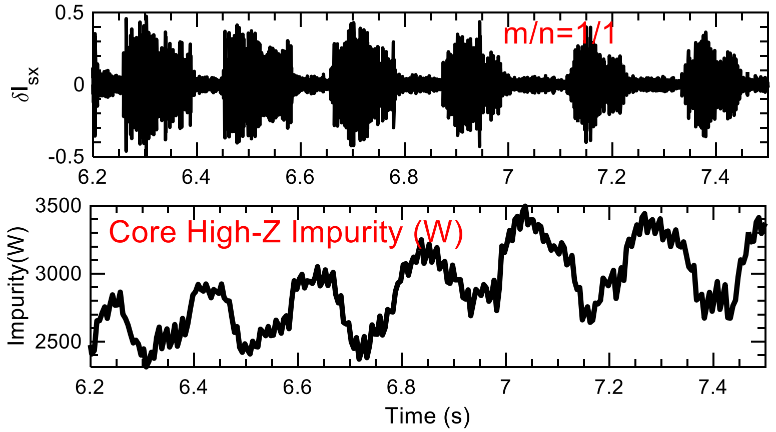
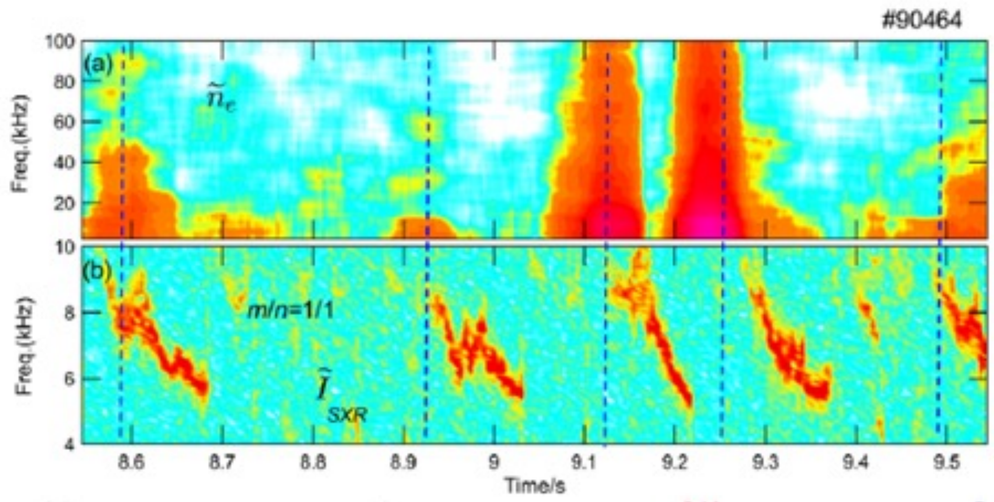
The core MHD is double-edged sword in LPO

- **Positive (Steady MHD):**
  - **Impurity accumulation avoidance**
  - Maintenance of flat q: **magnetic flux pumping**
  - Lower turbulence transport: multiscale interaction



- High-Z impurity expel from core due to MHD



- Turbulence reduced due to internal kink

E. Li PRL 128, 085003 (2022)

Active control of core MHD is needed in LPO!

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01 **Motivation of core MHD study in EAST LPO**

02 **Experimental observations and analysis**

- ✓ Features of core MHD : structure and dynamic
- ✓ Nonlinear interaction: MHD and turbulence
- ✓ Active control with novel technology : Vloop feedback with LH

03 **M3D nonlinear simulation of mode dynamics**

04 **Summary and plans**

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Saturated m/n=1/1 mode observed in EAST long pulse operation

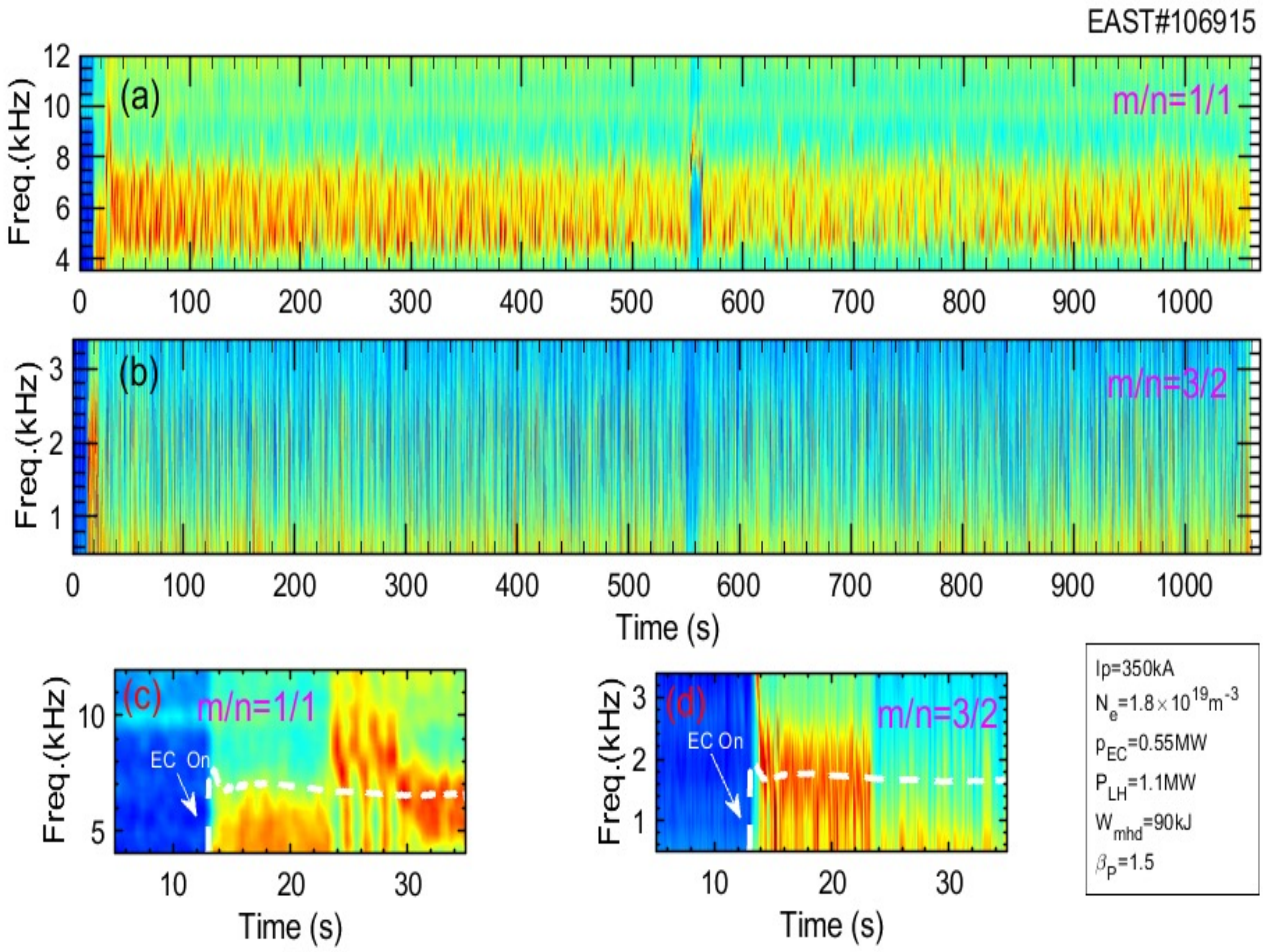
❑ > 1000s operation

- Pure RF heating with $\beta_p = 1.5$
- **Electron heating dominant**

  $T_{e0} \sim 6keV$ and $T_{i0} < 1.0keV$

❑ Core MHD

- m/n=1/1 mode dominant **from t=23s to t >1000s,** accompanying **with 1/1 to 3/2 transition**.
- $f_{3/2} \sim 2\text{kHz} < f_{1/1} \sim 7\text{kHz}$



Repetitive burst of saturated m/n=1/1, no sawtooth crash!

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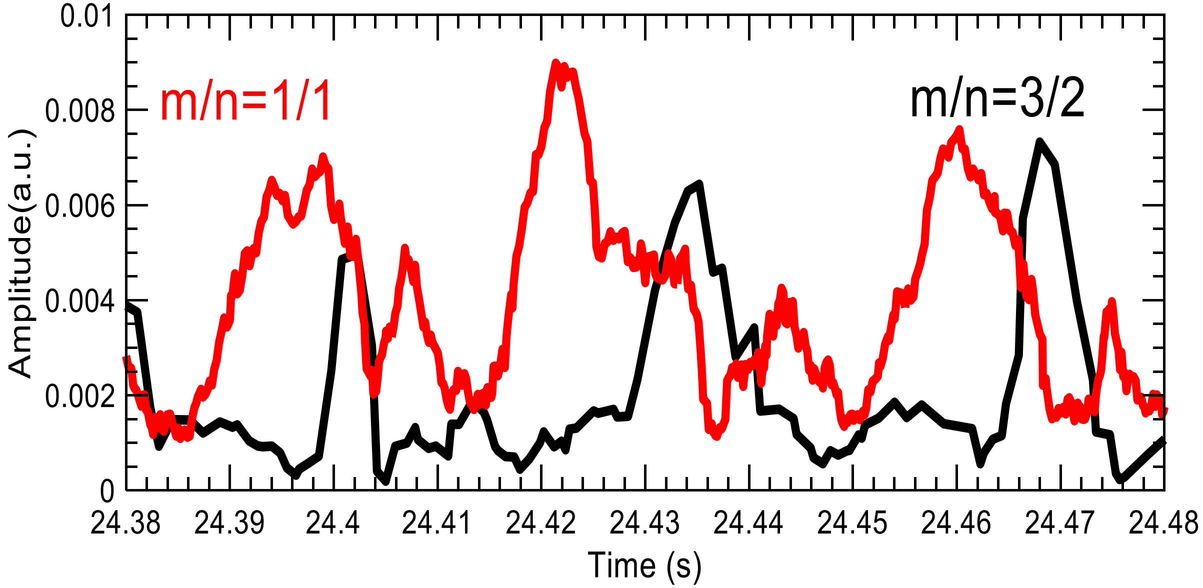
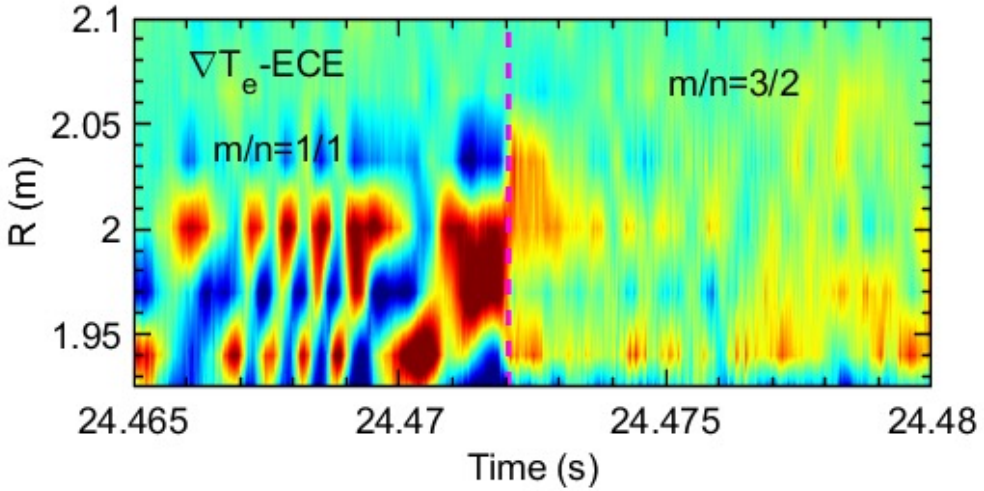
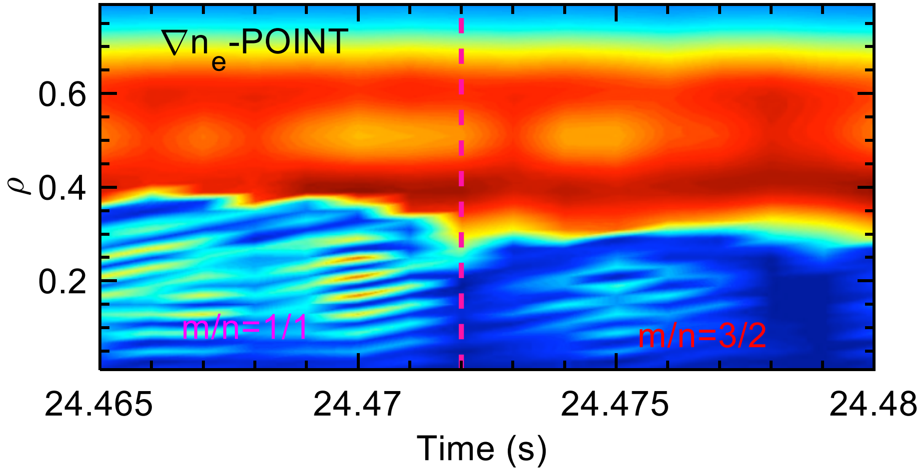
Observation of m/n=3/2 triggered by m/n=1/1







- **m/n=3/2 mode triggered by m/n=1/1 mode**
  - Multi-MHD mode coupling and competitive

- **Heat/particle outward with m/n=1/1**
  - ∇n_e is dominant with m/n=3/2 tearing

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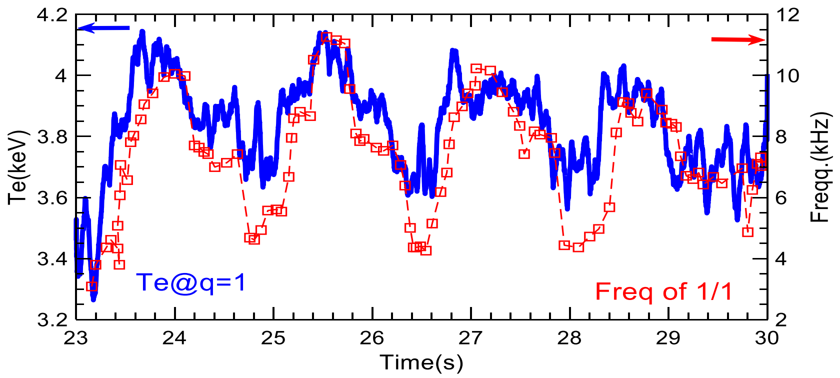
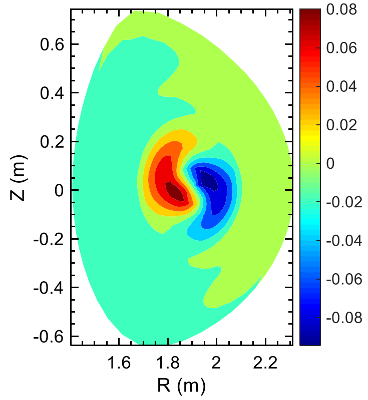
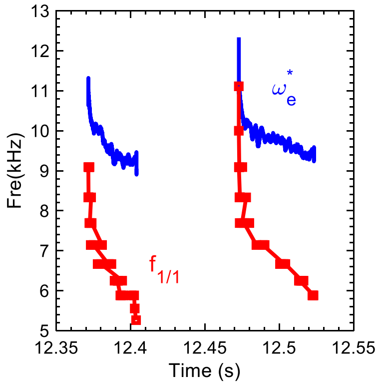
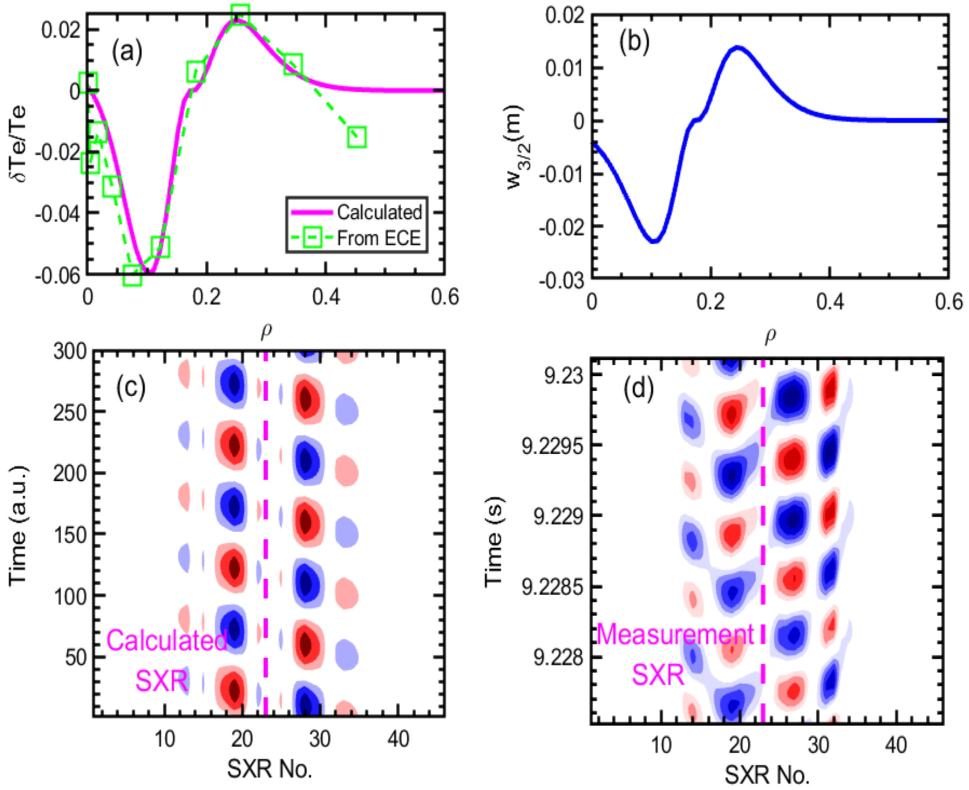
Features of core MHD: dynamics and spatial structure









❑ m/n=1/1

- twisted structure, no clear island formation
- $f_0 \propto T_{e,q=1}$; $f_t \propto \omega_e^*$

❑ m/n=3/2

- Clear island identified by ECE with a size of ~2cm

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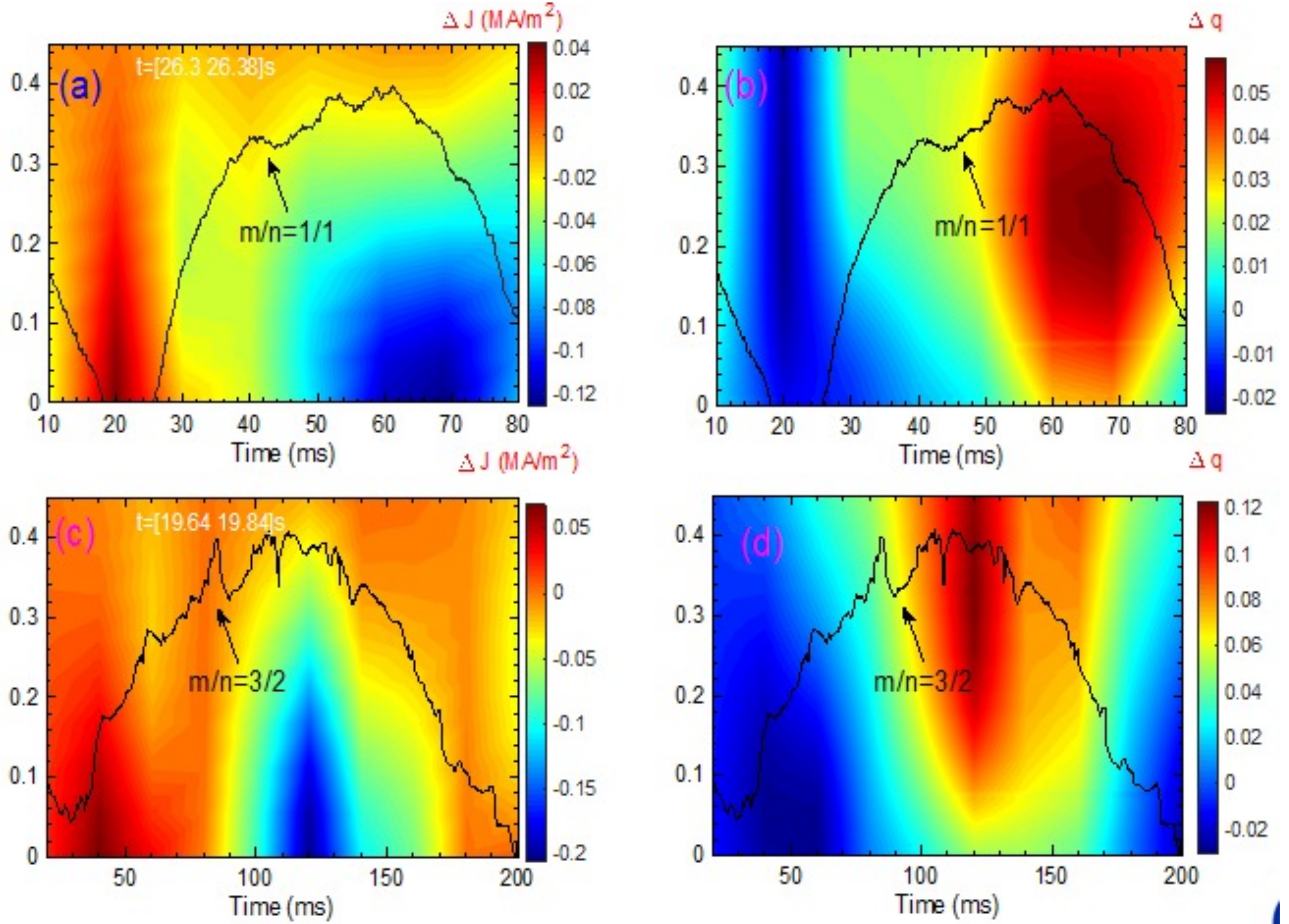
A negative equilibrium current generated with saturated MHD

- **Negative current generation**
  - Axis-symmetry **equilibrium** current generated by 3D **asymmetry** perturbation helical modes
  - Intrinsic current
- **Increase of q_0**
  - Eliminate of q=1 and **sawtooth free**
  - Helping formation of **weak magnetic shear** in the core, and improve performance



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- ✓ Features of core MHDs: structure and dynamic
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03 **M3D nonlinear simulation of mode dynamics**

04 **Summary and plans**

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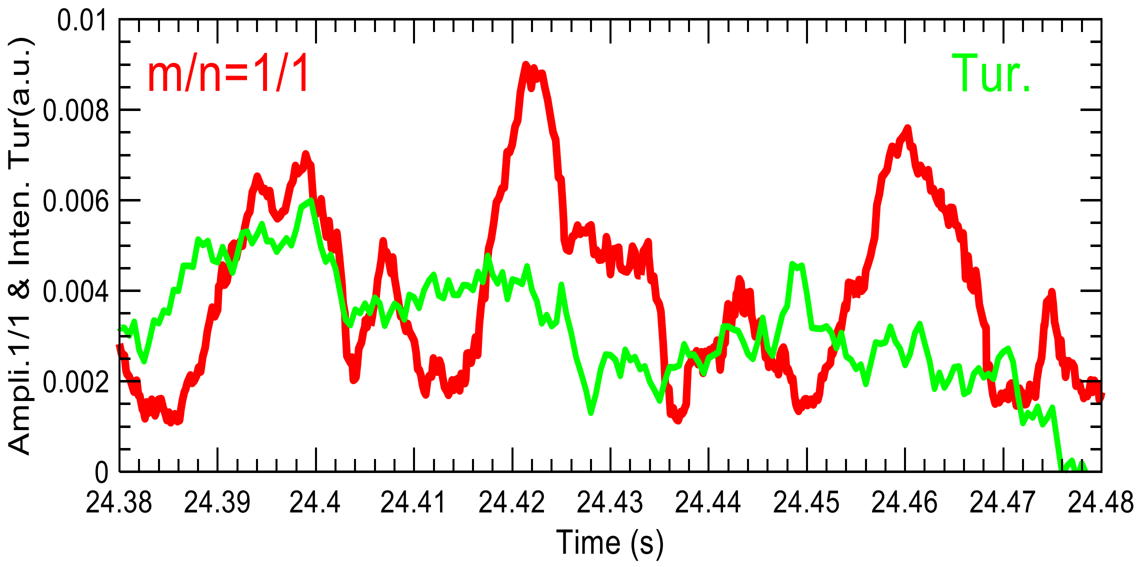
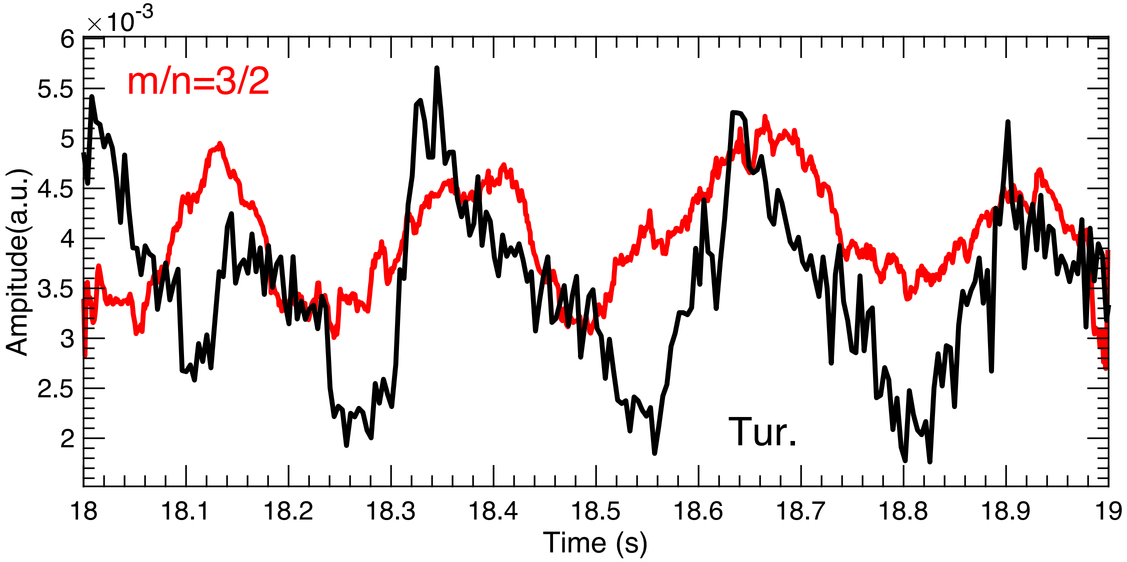
Nonlinear interaction: MHD (kink and tearing) and turbulence





- **m/n=1/1 internal kink & turbulence**
  - Intrinsic current generated by turbulence could be a medium to multiscale interaction

- **m/n=3/2 island & turbulence**
  - Turbulence modulated by m/n=3/2 island
  - Magnetic reconnection at X point of island play a key role

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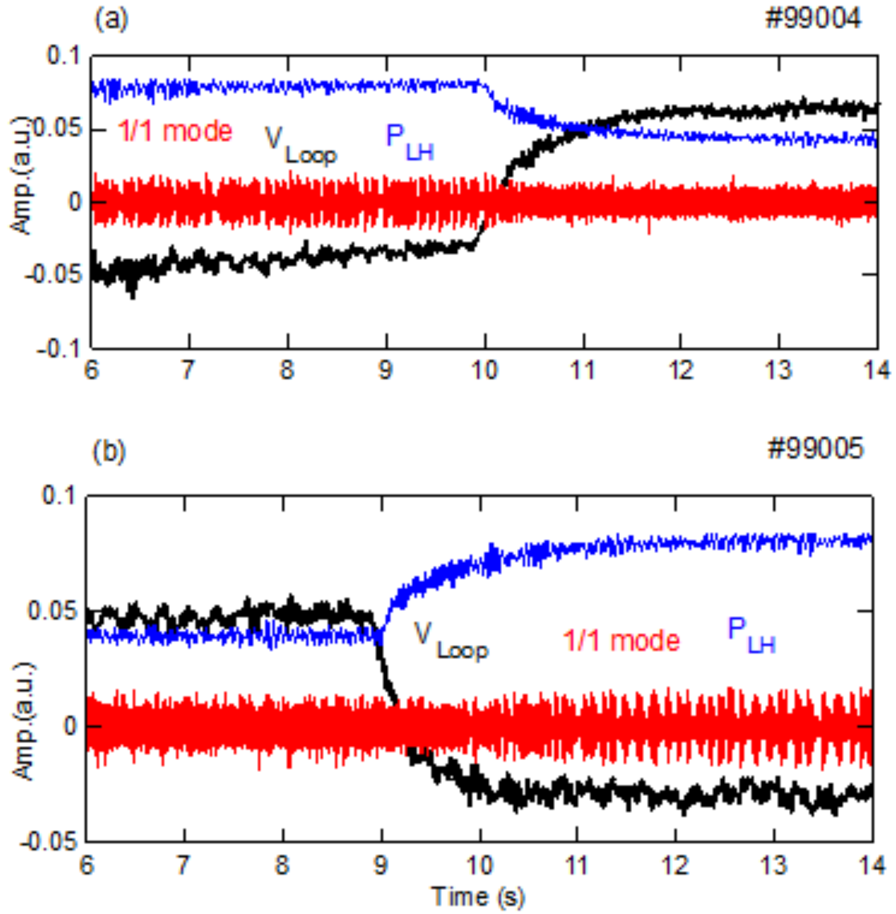
Vloop feedback control with LH waves is used for MHD control

- **MHD control**
  - RF waves(ECCD , ICRF or LH): modification of local **current density**
  - Magnetic configuration
  - NBI or ICRF: generation of **fast ions or plasma rotation**
  - RMP: non-axis-symmetry **3D magnetic perturbation** via non-resonant effect
- **Novel Vloop feedback method**
  - 4.6GHz LH waves is applied



A robust technology for core MHD control is required for ITER, where magnetic island will form via three wave coupling.

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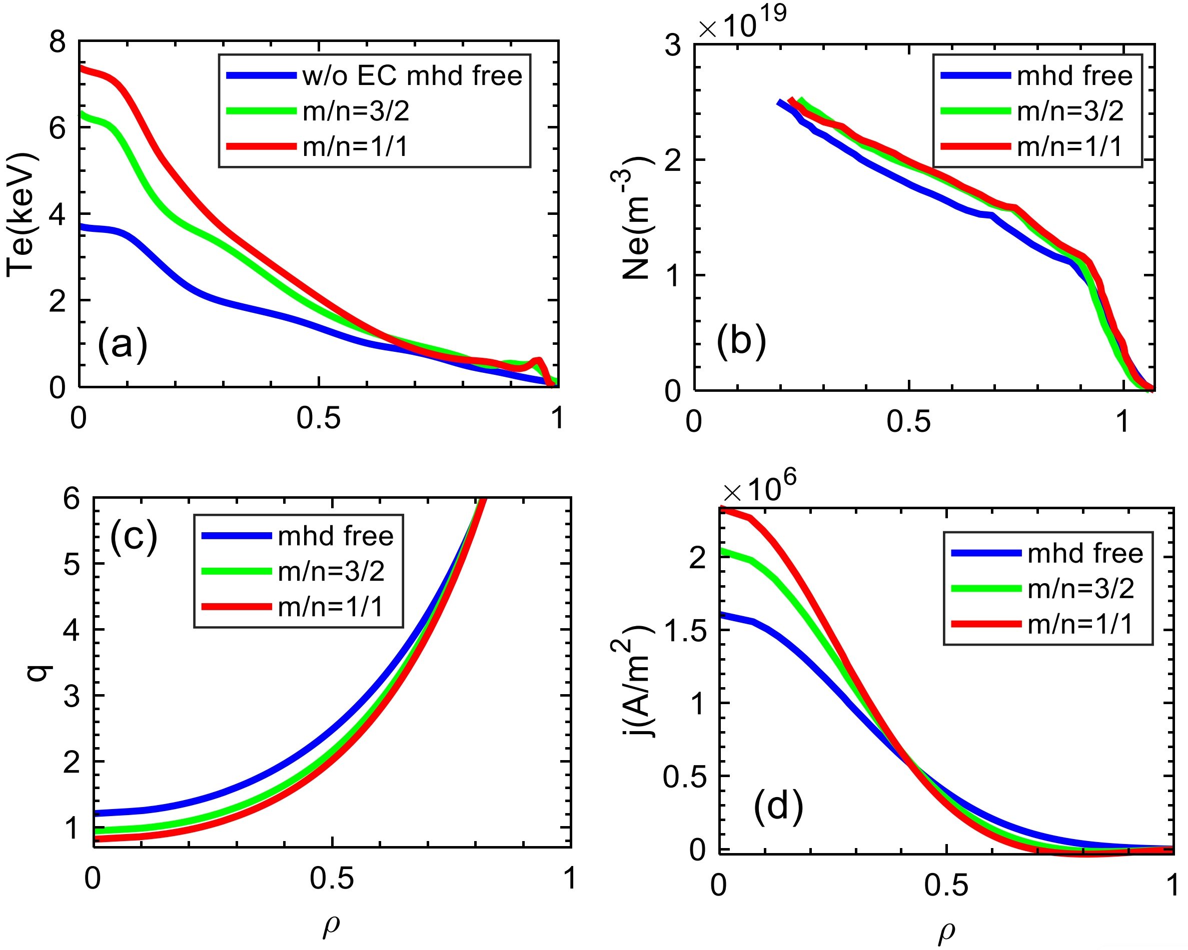
Nonlinear 3D code M3D is used to simulate m/n=1/1 steady mode

- **M3D nonlinear simulation**
  - Extend-MHD code in 3D torus, including dissipation, diffusion , viscosity and Hall effect **. Separate ne from pressure**, and including drift effect.
  - Use EAST realistic magnetic configuration and **equilibrium(Te, Ne, q and current density)**



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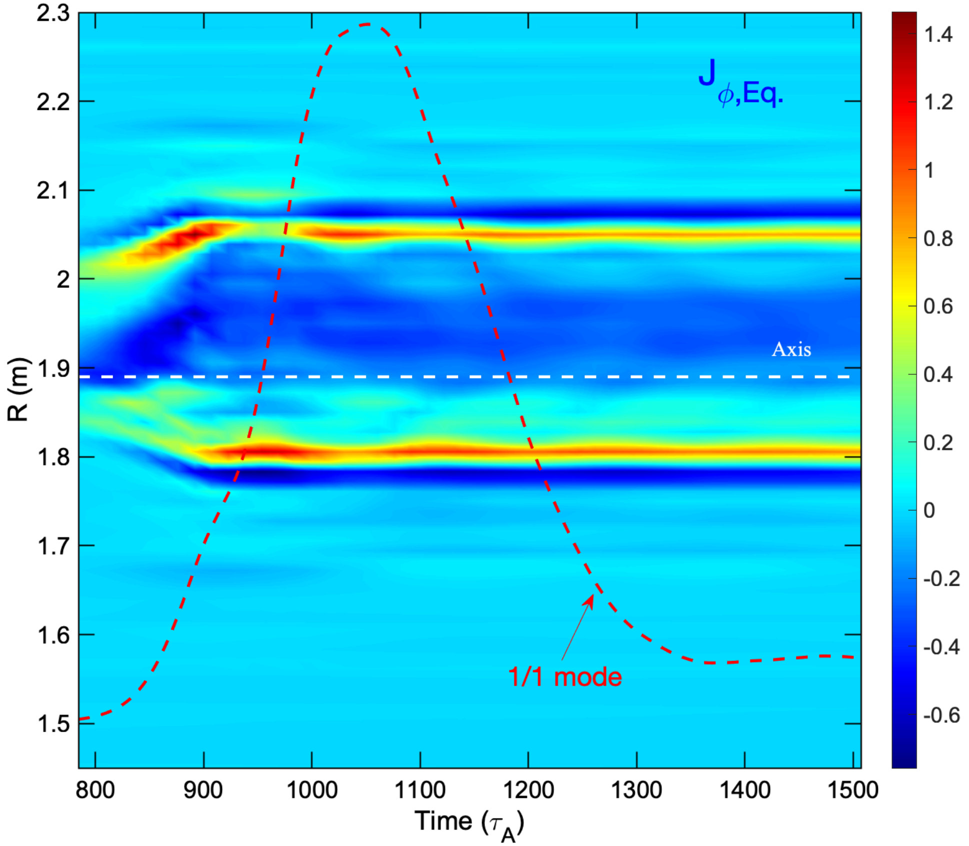
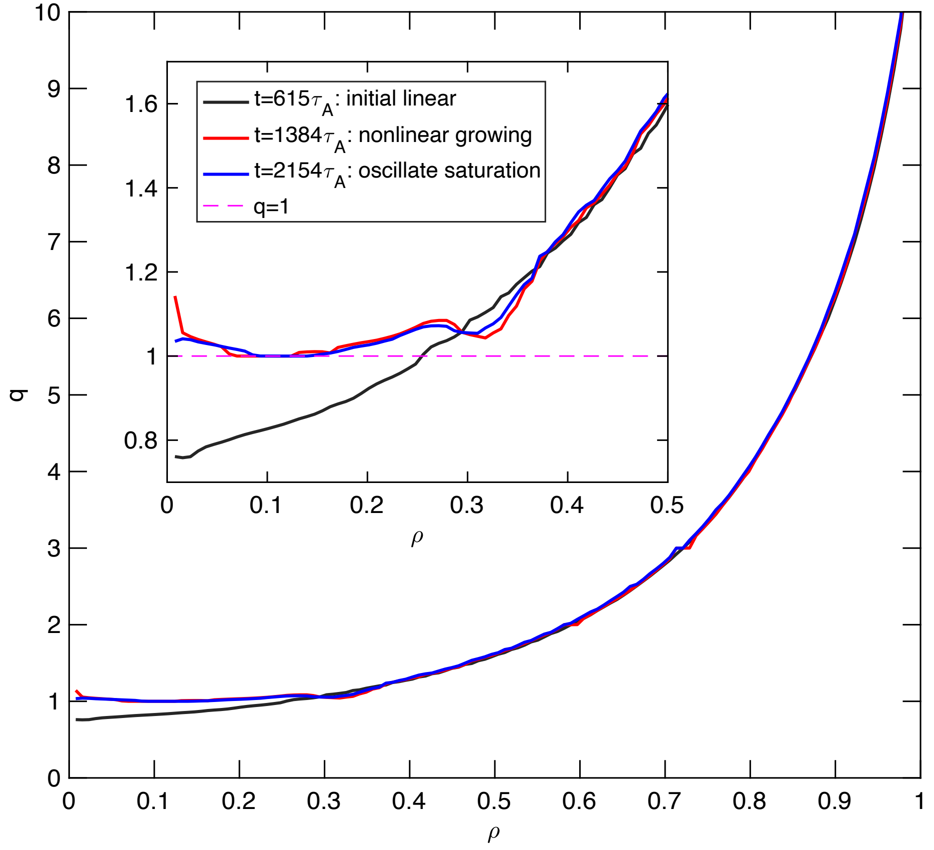
The 2-D equilibrium current modification by 3-D 1/1 mode





- **Equilibrium current redistribution**
  - A large $J_{\phi0}$ **near q=1.5 is generated**
  - **Negative current generation in the axis**

- **Equilibrium current redistribution**
  - q(0) > 1 due to negative current generation in the axis

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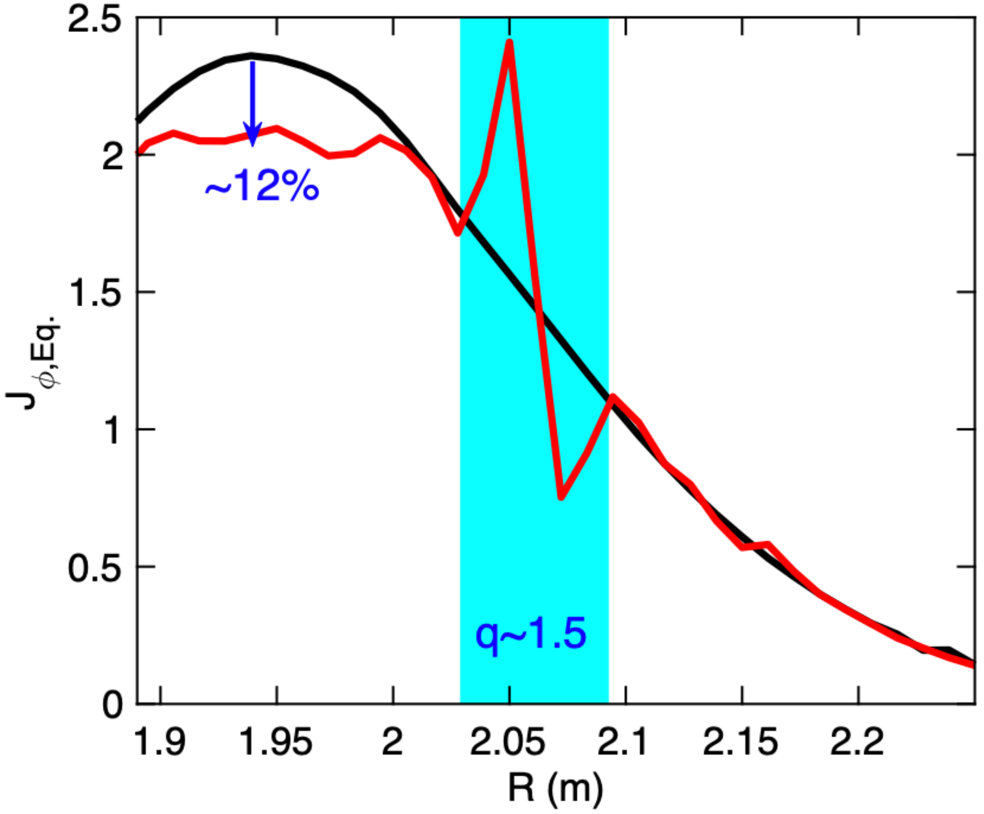
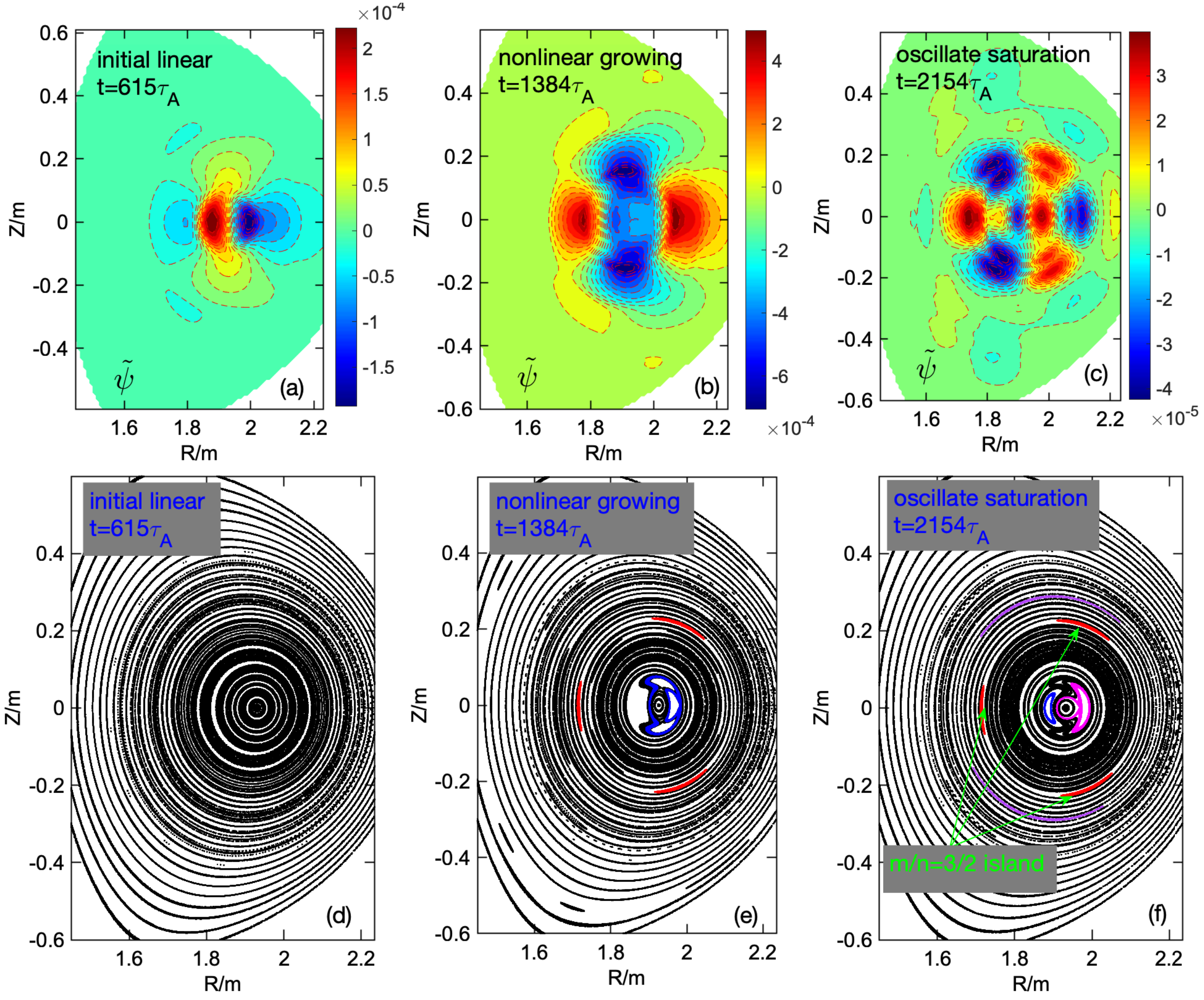
Modified equilibrium current lead to m/n=3/2 island formation





- Poincare plots: m/n=3/2 island formation at the final state

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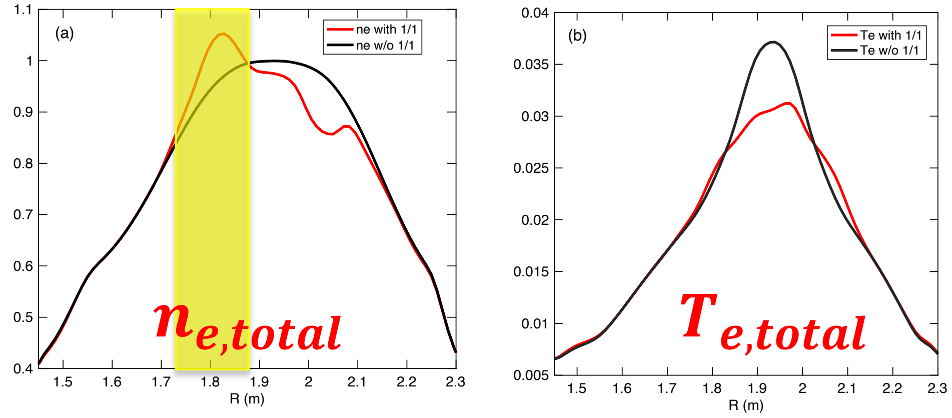
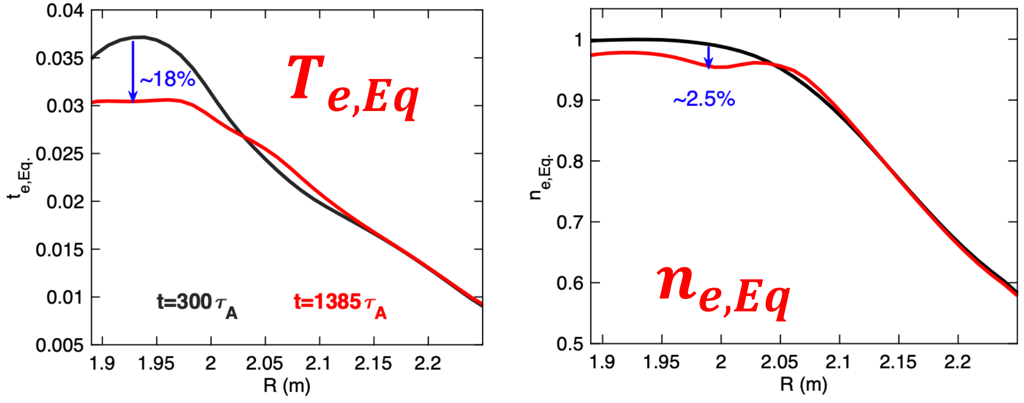
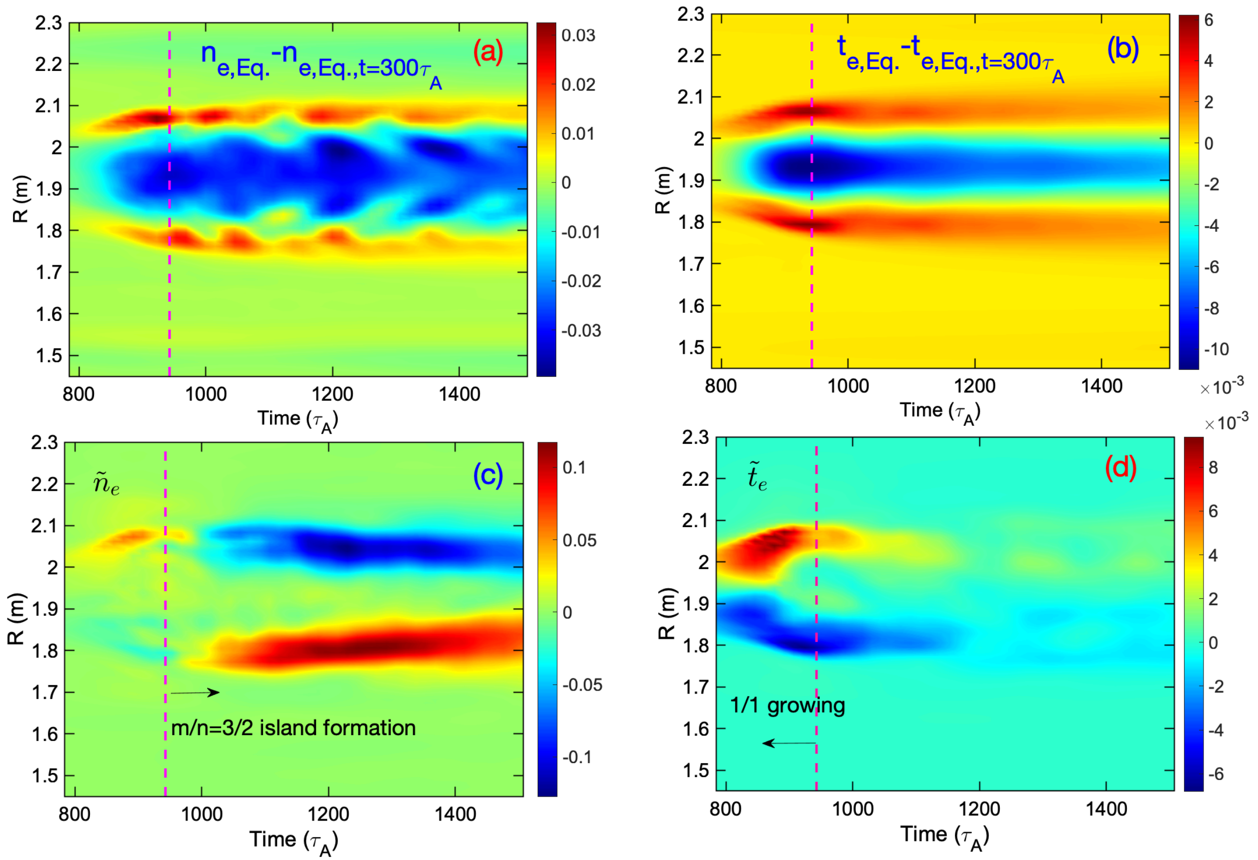
Change of equilibrium current at q=1.5 is due to local ∇n_e



- **Eq. +Pert. (3D)**
  - Δn_e is much larger than ΔT_e **at q=1.5**



- **Eq. Only (2D)**
  - ΔT_e is much larger than Δn_e **at axis**



- **Heat/particle outward of q=1**
  - Δn_e **is dominant** at q=1.5 after a transition of m/n=1/1 to m/n=3/2

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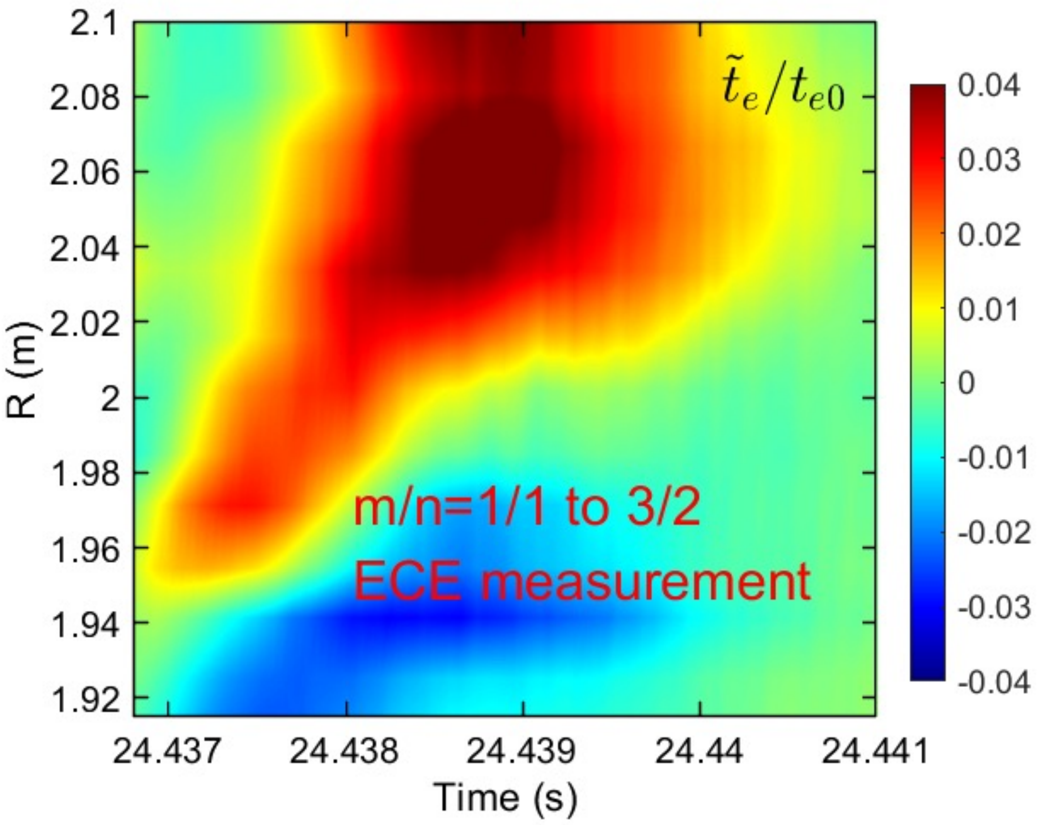
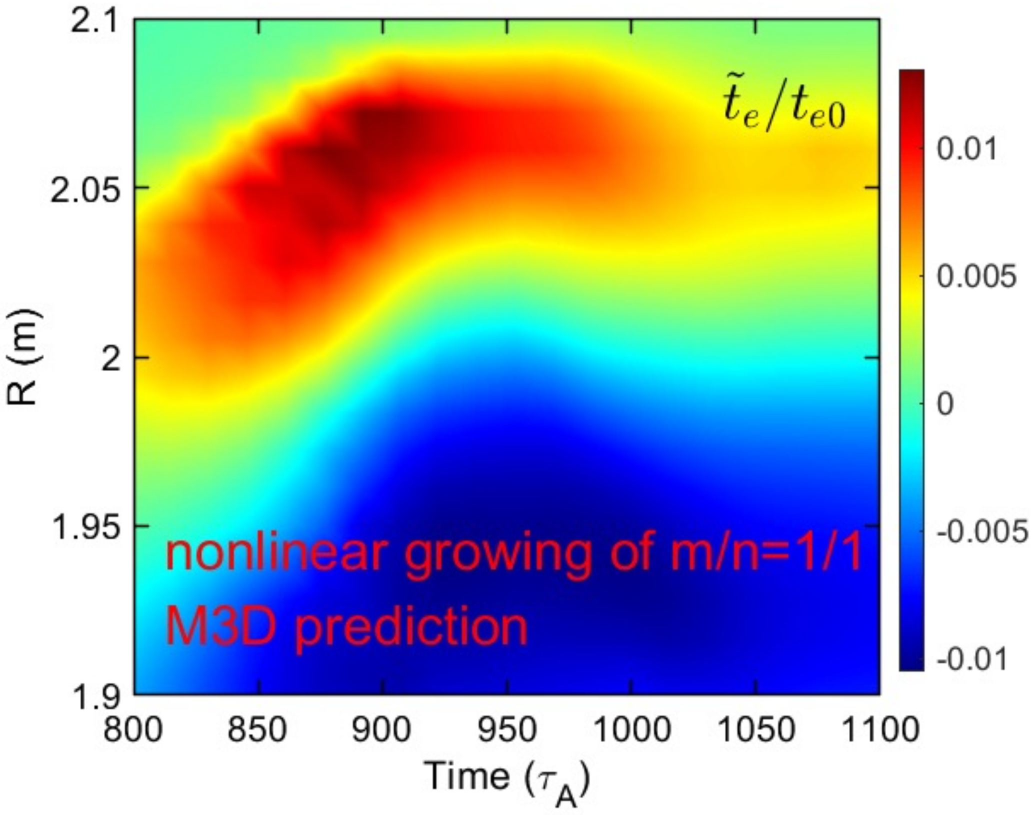
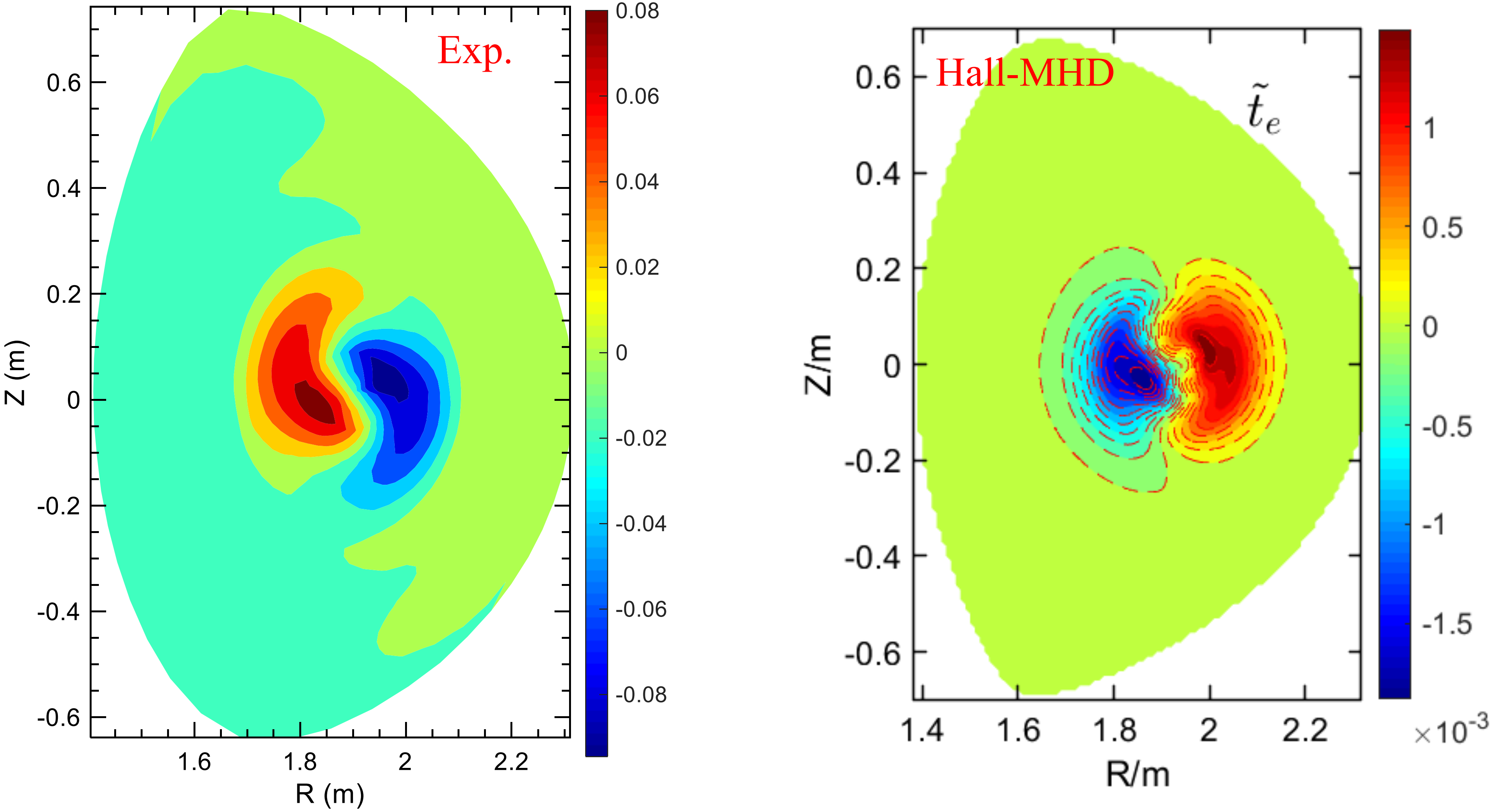
Comparison of ΔT_e during m/n=1/1 dynamics (Exp. Vs Sim.)





- **Heat outward due to m/n=1/1**
  - Good agreement between M3D simulated **Te perturbation and ECE measurement**

Prediction of 2D twisted structure with Hall effect



- The twisted mode structure is found when **Hall effect** is included.

Outline

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Summary and future plans

Summary:

- Saturated MHD modes is observed in EAST 1000s discharge. The dynamics and spatial structure have been studied.
- The presence of m/n=1/1 mode can reduce the turbulence level via multiscale interaction, which contribute to the steady state operation.
- A novel Vloop feedback control method is successfully applied to MHD control.
- Nonlinear MHD simulation indicates the twisted structure of m/n=1/1 mode is due to non-ideal effects (Hall effect).
- Nonlinear MHD simulation reproduce MHD mode transition and an equilibrium current generation at q=1.5 caused to ∇n_e is responsible for the transition.

Plans:

- The mechanism of Te ITB formation due to MHD effect.
- The mechanism of plasma dynamo: Hall dynamo or turbulence dynamo.
- Prediction of MHD modes (AI).
- The role of LH induced fast electron in m/n=1/1 saturation.

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Thanks for your attention！