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Thermal Quench Dynamics and Heat Flux Distribution during Massive-Impurity-Injection Triggered Disruption in EAST

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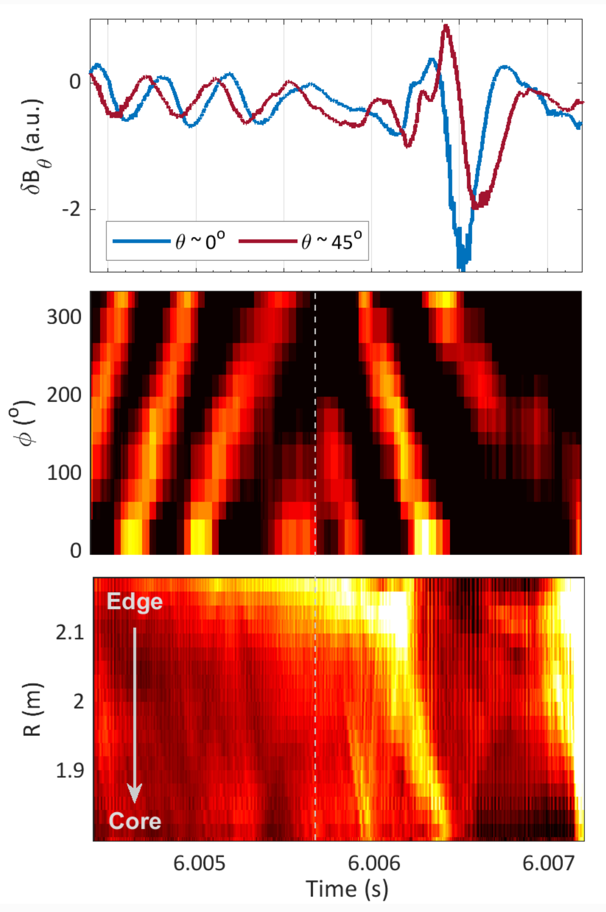
Summary

- **Thermal quench dynamics in massive-impurity-injection triggered EAST disruptions have been demonstrated in experiments and simulations.**
- **Sudden change in mode frequency**: A sudden change of the radial electric field (Er), caused by collisionality transition from the banana to the P–S regime, can drive the poloidal rotation and enhance impurity influx.
- **Double-stage TQ**: The 3/1 mode couples with the 4/1 and 5/1 modes, contributing to edge stochasticity. The non-linear interaction between the 3/1 and 2/1 modes primarily leads to global stochastic.
- **3D splitting of heat flux**: The parallel convective particle flux at the upper-outer target, combined with the strike-point splitting, exhibits an n = 1 structure.

Impurity Transport during the pre-TQ Phase

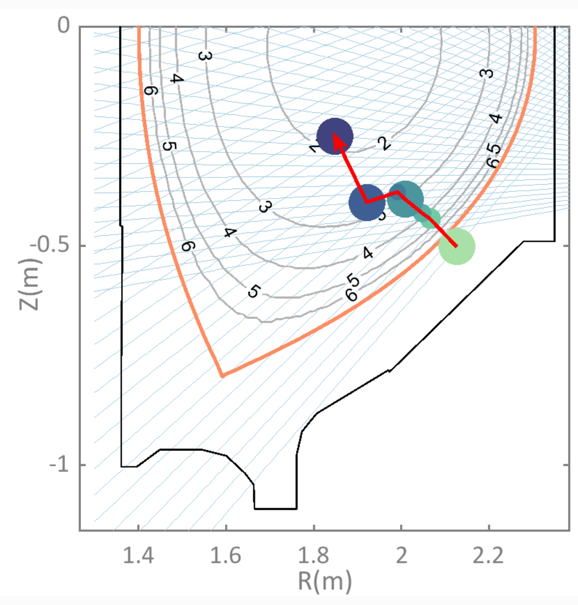


- The intrinsic 2/1 mode's rotation slows down and then reverses from the ion diamagnetic to the electron diamagnetic direction after neon injection into co-current NBI-heating plasmas.
  - ***The mode frequency changes from 2 kHz to −3 kHz in < 0.5 ms.***
  - *The radiation in the core region significantly increases following the rotation direction of the mode reversed.*

Observed in both SPI and MGI triggered disruptions

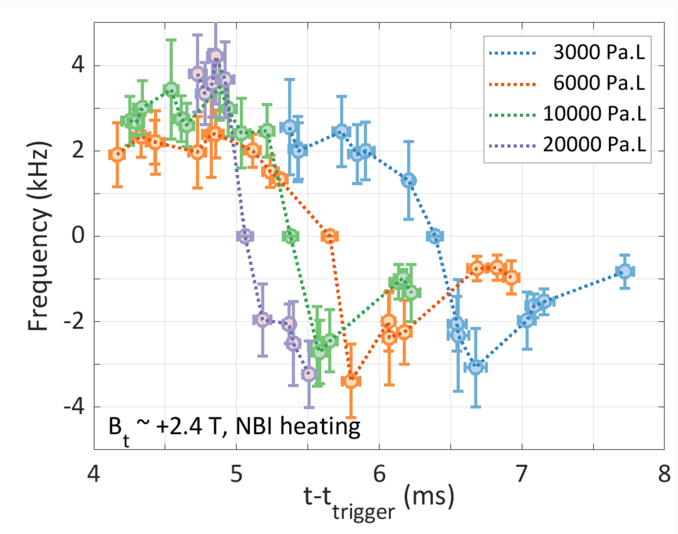
Two stages for impurity transport

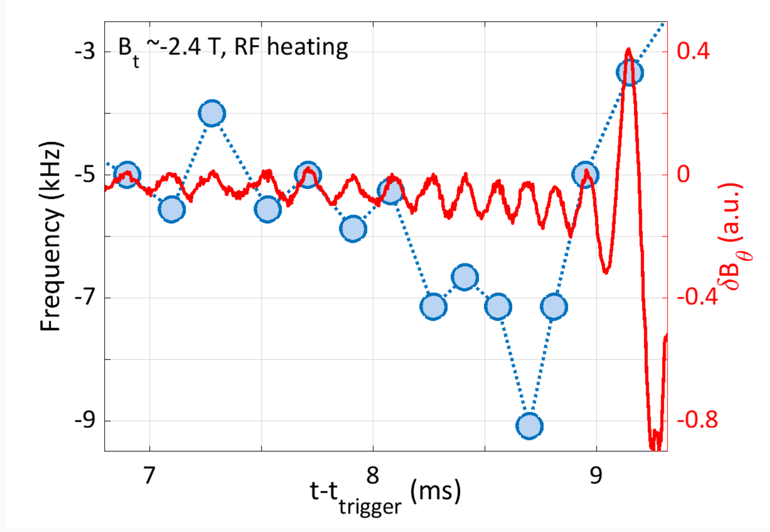
- ***STAGE 1:*** *impurities drift along ion diamagnetic direction; Outside of q=2 surface.* ***Inward pinch speed ~ 60 m/s.***
- ***STAGE 2:*** *impurities drift along electron diamagnetic direction; Across q=2 surface.* ***Inward pinch speed ~ 300 m/s.***



❖ Characteristics of mode-frequency change

- The phenomenon has been observed by scanning species and numbers of impurities, and heating methods.
  - *Amount scan: Earlier and faster reversion of rotation direction.*
  - *The mode frequency changes from **−5 kHz to −9 kHz in ~ 0.5 ms** after argon injection into RF-heating plasmas.*





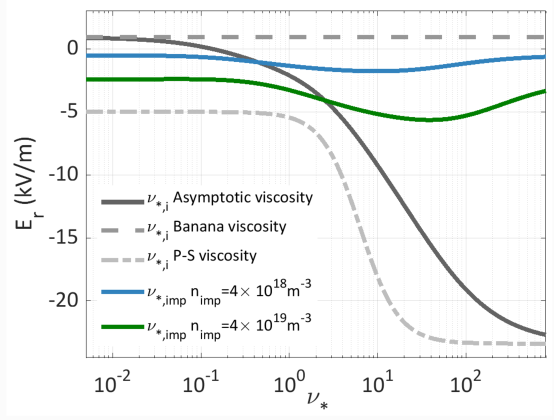
- Change of mode frequency is mainly **caused by poloidal angular frequency.**
  - *Time scale of frequency change (< 0.5 ms) is much less than τ_E (50-100 ms) on EAST.*

Poloidal rotation velocity $\delta U_\theta = -\frac{B_T}{B^2}\delta E_r$

Effect of Impurity on Poloidal Rotation

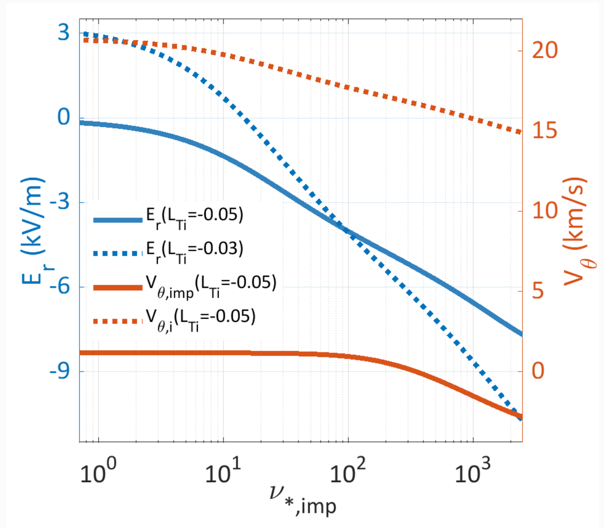
- The neoclassical theory is applied due to the short time scale.
  - *The poloidal rotation can be driven by **the viscosity associated with the collisionality and impurity.***
  - *The parallel momentum and heat flow balance equations for the impurity and ion species in the form of matrix equations are derived.*

A clear change in radial electric field is observed as collisionality transitions from the banana to the P–S regime.

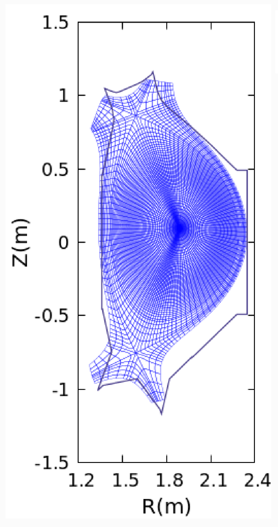


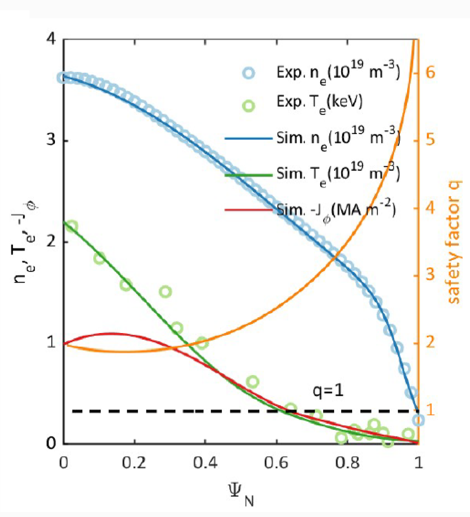
- *As ion collisionality increases, the radial electric field decrease nonlinearly.*
- *The viscosity is sensitive to impurity strength: impurity orbits perturb ion orbits and thereby alter the effective viscosity.*

- Global effects with massive impurity injection show **variations in ion poloidal flow are governed by the E×B drift.**
  - *E_r is estimated in the range from −12 kV/m to −8 kV/m according to the typical parameters, consistent with the experimental value of ~ −10 kV/m.*



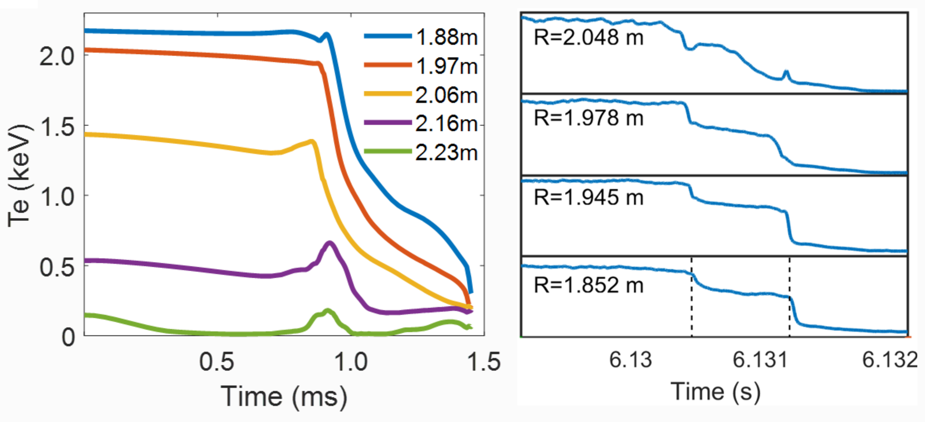
Interpretive Simulation of TQ with JOREK

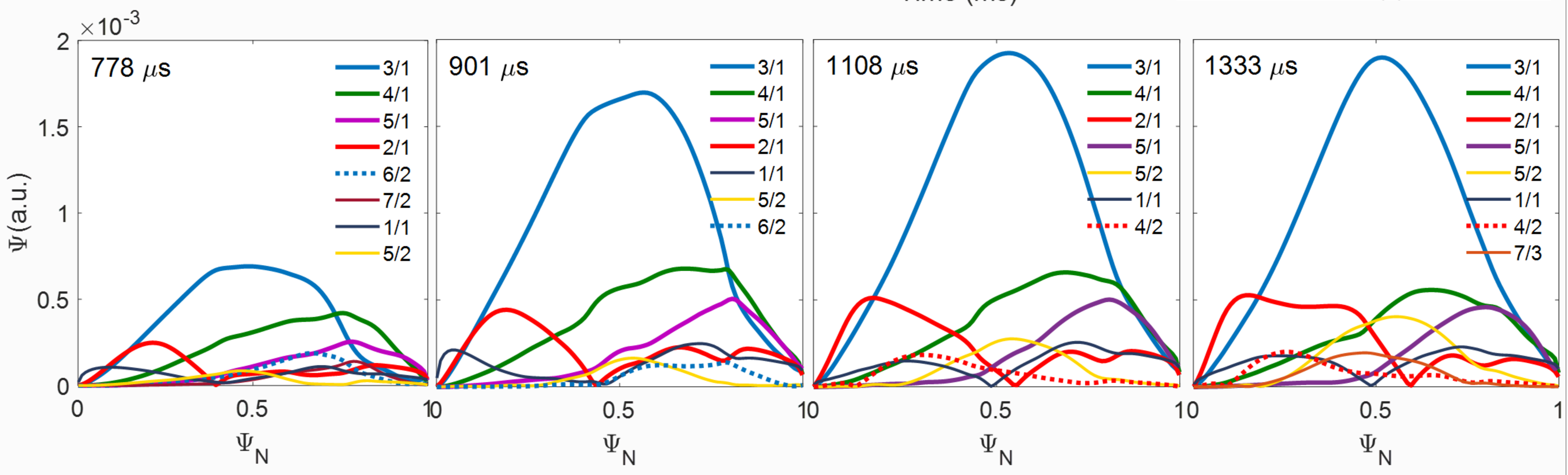




- Simulation setup: A typical L-mode plasma with I_P ~ 0.4 MA and **q_{min} ~ 1.6 in the core region**.
  - *The initial core T_e is ~2.2 keV, electron and ion temperatures are assumed to be equal, and the core n_e is ~3.6×10^{19} m^{-3}.*

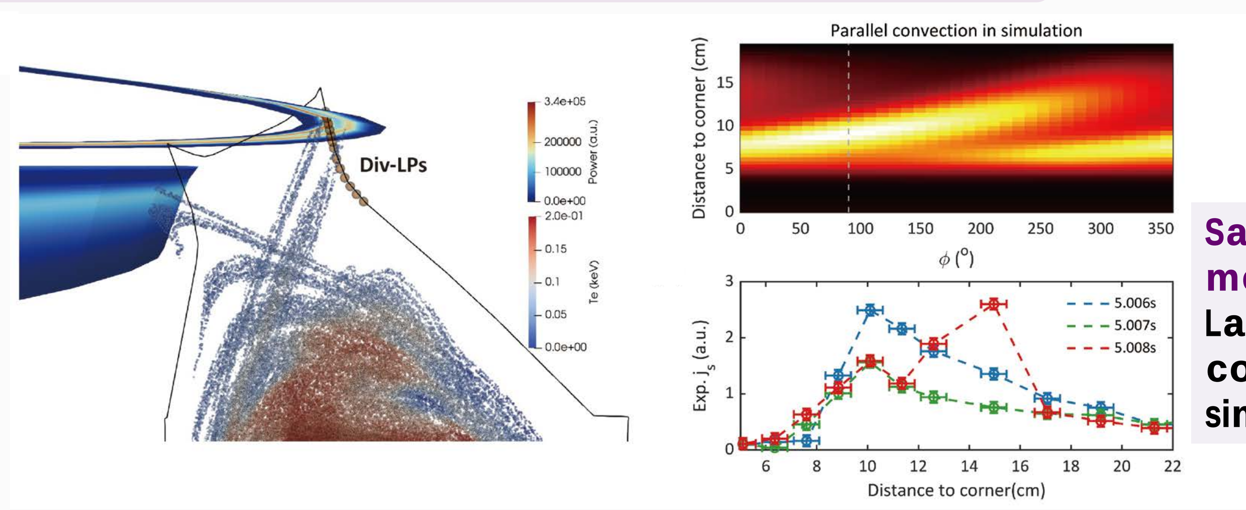
- The process of a double-stage TQ has been represented with neon MGI, consistent with the experimental observation.





- **The 3/1 mode is dominant** in the whole collapse process.
  - ***First collapse*** *is from the outer region (q>2) and the coupling between 3/1 and 4/1 is the main reason.*
  - ***Second collapse****: The coupling among 2/1, 3/1 and higher harmonic mode 4/2 is dominant in the final collapse.*

❖ Strike point splitting on the divertor



Saturated ion flux measurement by Langmuir probes consistent with simulations

- The simulated parallel convective particle flux on the divertor, combined with **the strike-point splitting, exhibits an n = 1 structure**.
  - *This result provides an explanation for the broadening of energy deposition width during the TQ in ASDEX Upgrade and JET.*