OV/P-5: Overview of the Recent Experimental Research on the J-TEXT Tokamak

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1. Summary

Over the last 2 years, the J-TEXT researches has contributed to the impacts of 3D MP fields on magnetic topology, plasma disruptions, MHD instabilities, and plasma turbulence transport.

- The locked mode is avoided by the feedback application of RRMP and the TM can be suppressed by negatively biased electrode. A new control strategy for TM control is proposed based on modulated static RMP and proved numerically.
- The fluctuations of electron density, electron temperature, and plasma potential are observed to be significantly modulated by the island structure.
- The RE generation and suppression has been studied, especially on their relationship with the magnetic perturbations. The MGI can cause MHD activities before disruptions, while the strong magnetic fluctuations during the CQ can suppress the RE generation. The RE generation can be actively suppressed by applying SMBI and RMP induced locked island.
- The SPI has been successfully applied to dissipate the MGI-induced runaway current for the first time on J-TEXT.

2. Introduction

A. J-TEXT tokamak

- Main parameters

Ohmic plasma in limiter conf.

R = 1.05 m, a = 0.255 m (limiter)

I_p < 240 kA, B_T = 1.2 ~ 2.5 T

n_e = 0.5~7 x10^{19} m^{-3}

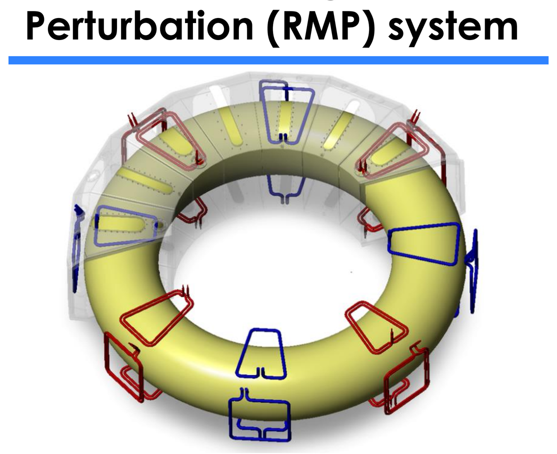
T_{e0} ~ 1 keV, T_{i0} ~ 0.5 keV

- Auxiliary Systems

RMP, EB, SMBI

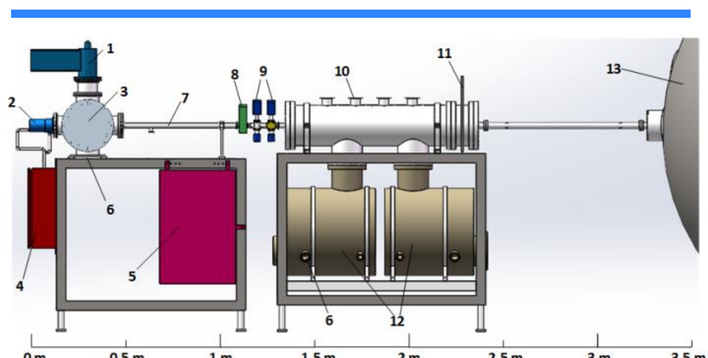
MGI, SPI

B. Resonant Magnetic Perturbation (RMP) system



- In-vessel RMP coils
  - 12 coils (2012) + 12 coils (2017);
  - DC or AC (1 – 6 kHz)
  - Maximum current: 6 kA
  - 2/1 RMP @ 5.6 G/kA (DC)
  - n = 1 to 4, m = 2 or 3&1

C. Shattered Pellet Injection (SPI) system



- Argon pellet
  - Φ ~ 5 mm, length 1.5-10 mm @ 64 K
  - 0.07-5×10^{21} atoms
  - 150-300 m/s
- shattered by impacting on a strike plate

3. Control of Tearing Modes (Ding Y H, EX/P3-13, *Wed. 08:30*)

A. Interaction between RMP and TMs

- EM torque

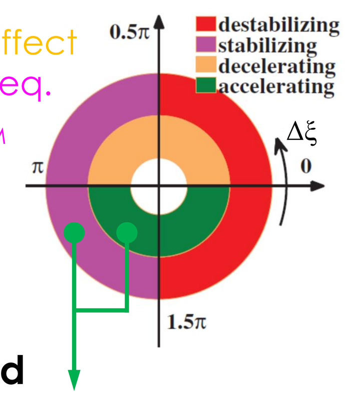
$$T_{REMs} = -4\pi^2 R_0 \frac{m^2}{\mu_0}|\Psi_{vac}||\Psi|\sin(\Delta\xi)$$
$$T_{pEMs} = -\frac{n}{m}T_{REMs}$$

Net braking effect → Reduce slip freq. $f_s = f_{RMP} - f_{TM}$

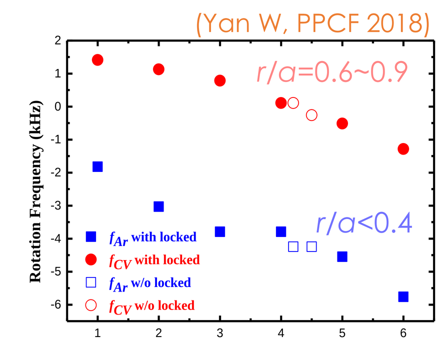
- Tearing stability index

$$\Delta'_{RMP} = \frac{2m}{r_s}\left(\frac{W_{vac}}{W}\right)^2\cos(\Delta\xi)$$
$$\Delta\xi(t) = \int_0^t \omega(t)\,dt + \arg(\Psi_{vac}) - \arg(\Psi)$$

→ Net stabilizing effect



- Control f_{TM} and plasma rotation by rotating RMPs

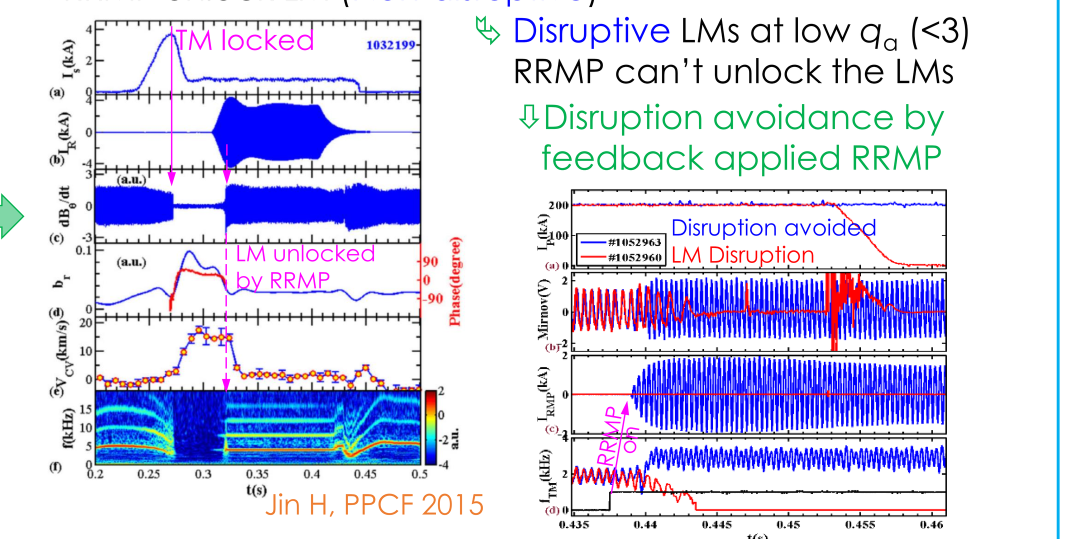


B. Control of the locked modes by RRMP

⇩RRMP unlock LM (Non-disruptive)

Disruptive LMs at low q_a (<3) RRMP can't unlock the LMs

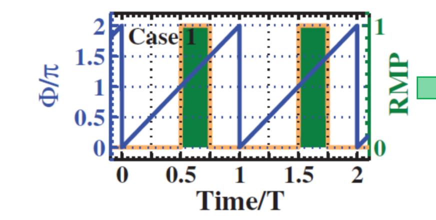
⇩Disruption avoidance by feedback applied RRMP



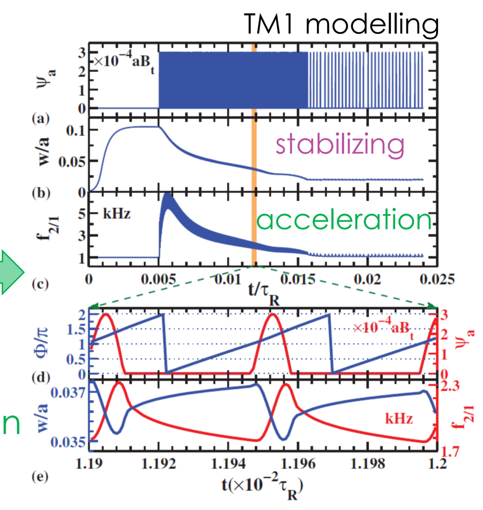
Jin H, PPCF 2015

C. Suppressing magnetic island and accelerating its rotation by modulated RMP

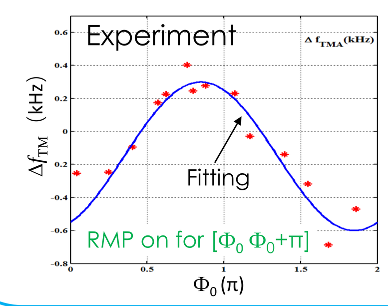
- Modulated RMP
  - RMP on only during the **good** phase region (accelerating & stabilizing).



Hu Q M, NF 2016



- TM acceleration & suppression obtained by modelling

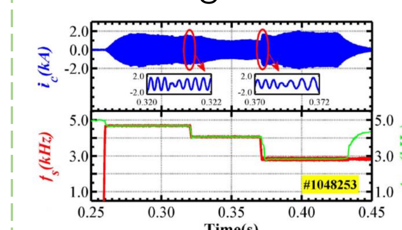


- The acceleration effect confirmed experimentally

⇦TM frequency ⇗ or ⇘ depending on the region that RMP applied.

An idea for TM control (Rao PPCF 2013)

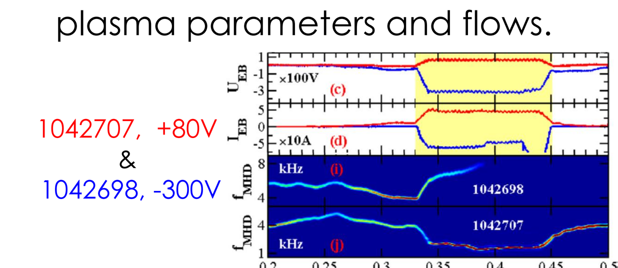
→ maintain a finite f_s to maximum the net stabilizing effect ⇘



⇘ Fast locking to hopping-frequency RRMP, hard to maintain small f_s without locking → TBC.

D. Control of the TMs by biased electrode

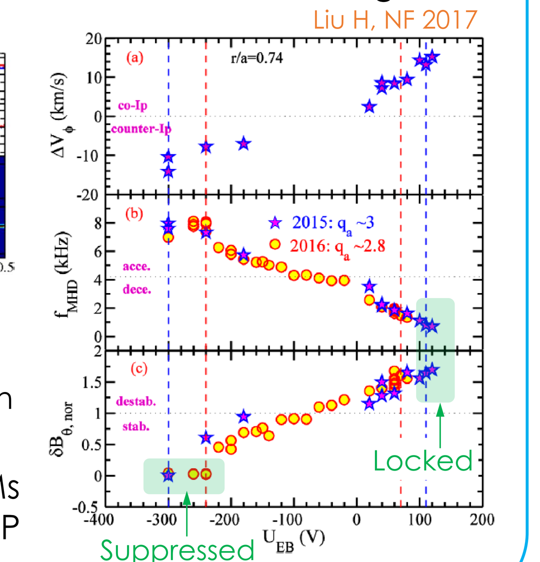
- The biased electrode is an efficient method to change the plasma parameters and flows. (Liu H, NF 2017)



I_{EB}<0 →acceleration & stabilization → Suppression

I_{EB}>0 →deceleration & destabilization → Locking

- The unlocking/acceleration of TMs locked to static or rotating RMP was achieved in 2018.



4. Progress on the Disruption Mitigation

A. Runaway electron generation during MGI triggered disruptions

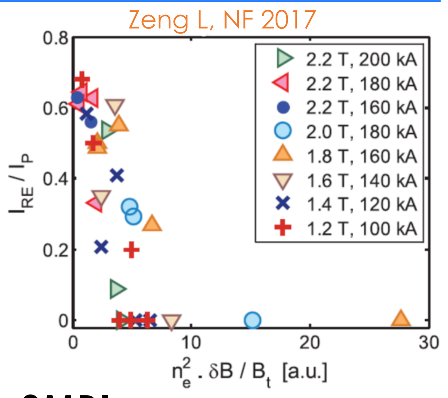
- RE currents are only obtained in the region of low electron density and low magnetic fluctuation.

⇨intended disruption by MGI of argon

$\delta B/B_t$: the maximum magnetic fluctuation amplitude during the CQ

n_e: the electron density before the disruptions

- Experimental evidence supports that the theory of hot tail RE generation might be playing a role.



Zeng L, NF 2017

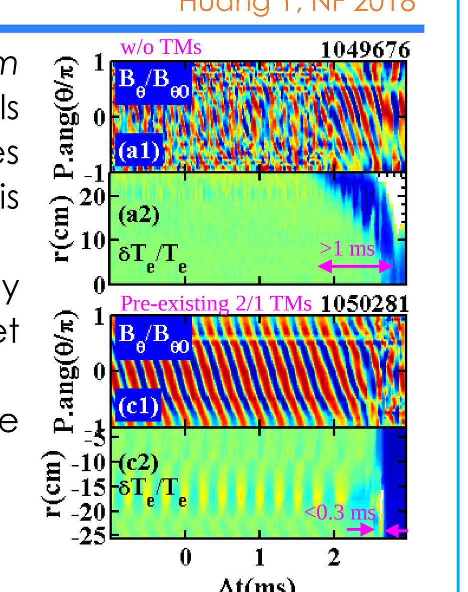
B. MHD activities and the cooling process during MGI triggered disruptions

Huang Y, NF 2018

⇨ After the argon atoms are injected, a high-*m* MHD mode is initiated. As the impurity cools the plasma deeper, the MHD mode changes to a lower-*m* mode until a 2/1 mode is initiated and a thermal quench (TQ) started.

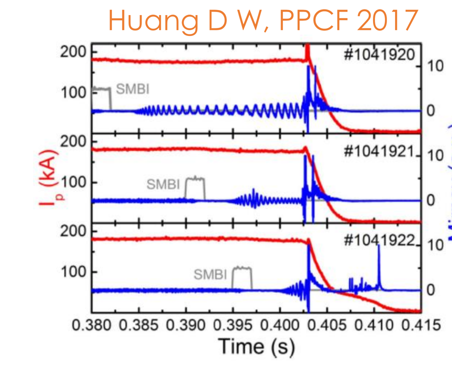
⇨ A pre-existing large 2/1 TM can significantly increase the penetration speed of a gas jet across the rational surfaces.

⇨ The 2/1 TM plays an important role in the penetration process.



C. Suppression of runaway electrons by RMP & SMBI

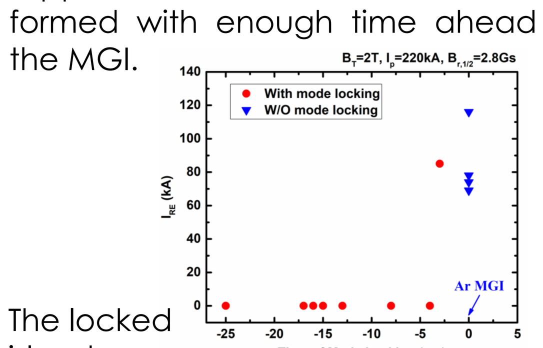
- In J-TEXT, the formation of magnetic island or even stochastic layer can be actively driven by SMBI and RMP before the disruptions triggered by MGI, and the RE can be suppressed.



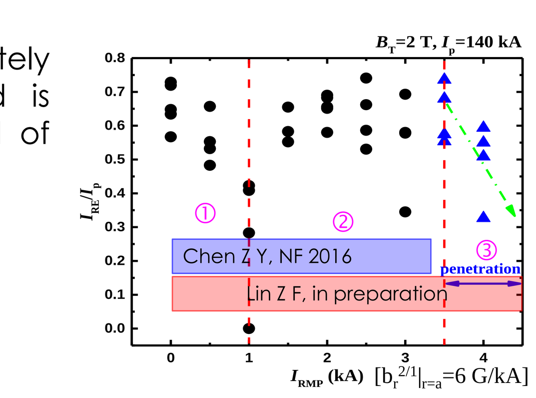
Huang D W, PPCF 2017

⇧ By applying SMBI to induce TMs with sufficient amplitude, the generation of REs is completely suppressed.

⇩The RE generation can be completely suppressed, if the locked island is formed with enough time ahead of the MGI.



The locked island appeared due to (a) the RMP penetration [Lin Z F, PPCF submitted] or (b) the locking of a pre-existing rotating island [⇧ Chen Z Y, NF 2018]



⇧ Dependence of RE on RMP amplitude

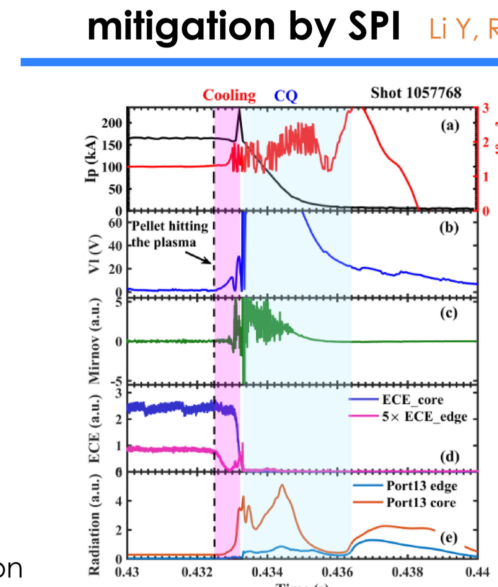
① Partial runaway suppression

② Enhancement of runaway generation

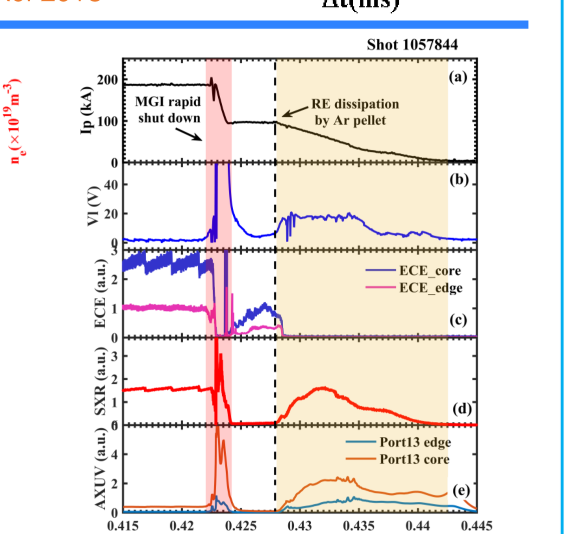
③ Partial to full runaway suppression by RMP penetration

D. First result on the disruption mitigation by SPI

Li Y, RSI 2018



Disruption mitigation by SPI

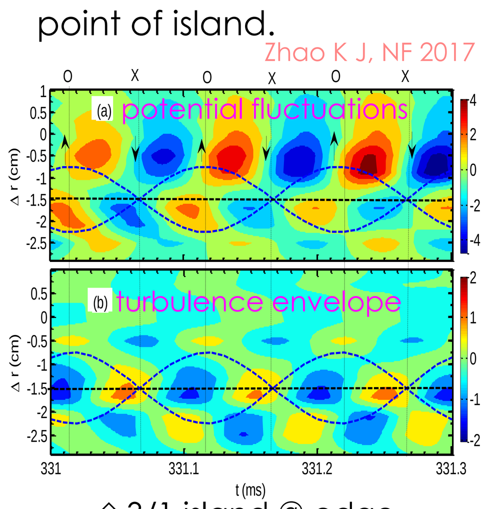


The runaway current dissipation with SPI in a MGI induced RE plateau.

5. Turbulence and Transport Study

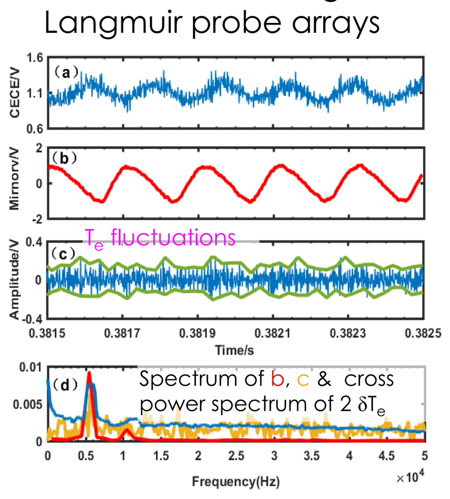
A. Impact of magnetic island on the turbulence

- The fluctuations of plasma potential, electron density and electron temperature can be significantly modulated by the island structure, and a large fluctuation level appears at the X-point of island.



Zhao K J, NF 2017

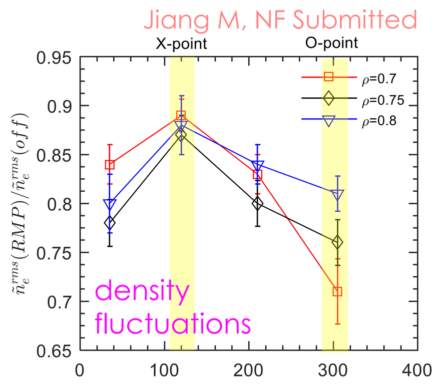
⇧ 3/1 island @ edge Langmuir probe arrays



⇦ 2/1 rotating island correlation ECE

Zhou H, RSI 2018

- The sign of the potential fluctuations for the flows inverses and the powers significantly reduce at q = 3 surface. Approaching to the islands' separatrix, the radially elongated flow structure forms. The flows are concentrated near separatrix and show quadrupole structures.

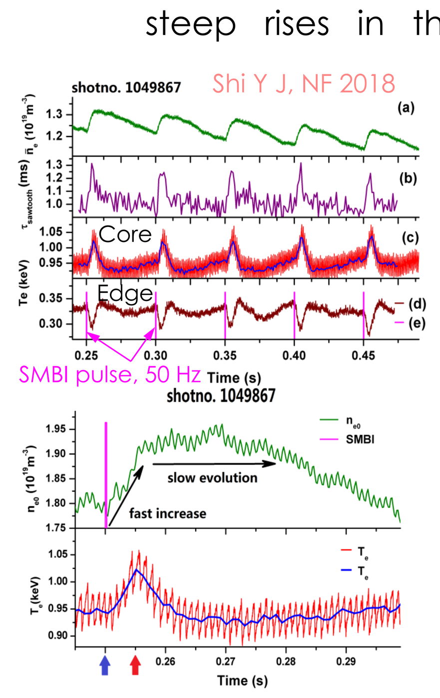


Jiang M, NF Submitted

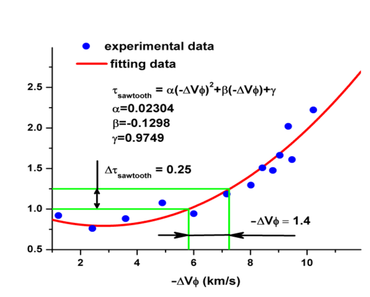
⇧ 2/1 locked island induced by RMP, Doppler backscattering reflectometer

B. Observation of multi-channel NLT

- In cold pulse experiments in J-TEXT, not only are rapid electron temperature increases in the core observed, but also steep rises in the inner density and possible acceleration of the core toroidal rotation (Indicated by sharp increase of $\tau_{Sawtooth}$).



Shi Y J, NF 2018



⇧ The scaling relation between V_ϕ v.s. $\tau_{sawtooth}$.

C. Theoretical study on the turbulence

(Wang L, TH/P6-4, *Thur. 14:00*)

- **Turbulent acceleration**, a new mechanism for intrinsic rotation is proposed. [Wang L, PRL 2013]

$$\frac{\partial}{\partial t}\langle U_\parallel\rangle + \nabla\cdot\Pi_{r,\parallel} = a_\parallel, \qquad a_\parallel \approx v_{thi}^2\left\langle \delta\tilde{n}\tilde{b}\cdot\nabla\delta\hat{P}_i\right\rangle$$

Qualitatively different { Residual stress: $\nabla\cdot\Pi_{r,\parallel}^{res}$, surface force, Turbulent acceleration: $a_\parallel$, volume force

Quantitatively comparable: $|a_\parallel| \sim |\nabla\cdot\Pi_{r,\parallel}^{res}|$ for electrostatic ITG turbulence

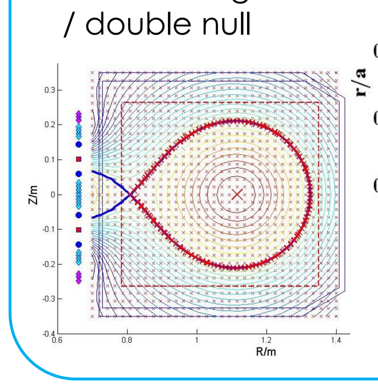
- Provide a possible explanation for the reduction of core toroidal rotation caused by ECRH via turbulence mode transition from ITG (co-current $a_\parallel > 0$) to CTEM ($a_\parallel$~0). [Wang L, PoP 2016]
- Demonstrate the **existence** of turbulent acceleration and the **consistency** between turbulent acceleration and momentum conservation! [Peng S T, PoP 2017]
- Predict **local intrinsic current density** (~80% J_{BS}) driven by ETG turbulence in the core region of ITER standard scenario, but **NO** net intrinsic current on a global scale. [He W, NF 2018]

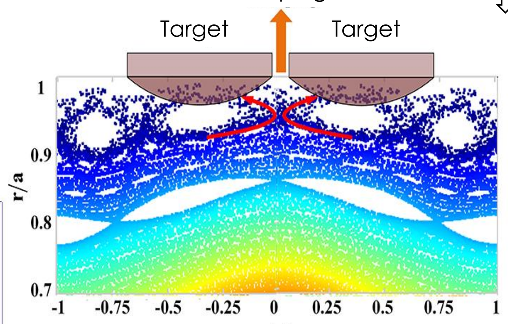
6. Outlook

In the following two years, several diagnostics and auxiliary systems will be available on J-TEXT.

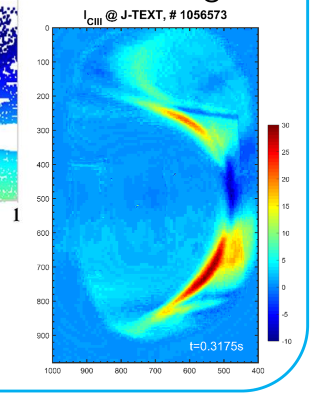
- Diagnostics: ECE-Imaging, VUV spectrometer, Doppler reflectometry…
- 105 GHz/0.5 MW/1s ECRH system coming in 2019
- The divertor configuration will be tested using the high-field side X-point configuration and the island divertor concept, respectively.

⇩ Poloidal divertor with HFS single null / double null





⇧ Island divertor: preliminary design using a 4/1 island



⇩ Formation of 3/1 boundary island using RMP

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