Rapporteur

Toward holistic understanding of the ITER-like resonant magnetic perturbation (RMP) ELM control on KSTAR

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Rapporteured

Edge Fluctuation Dynamics in RMP-Driven ELM Suppression and ELM-free H-mode Plasma in KSTAR

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RMP-driven ELM-crash-control needs to be holistically understood, clarifying the corresponding divertor thermal loading issues

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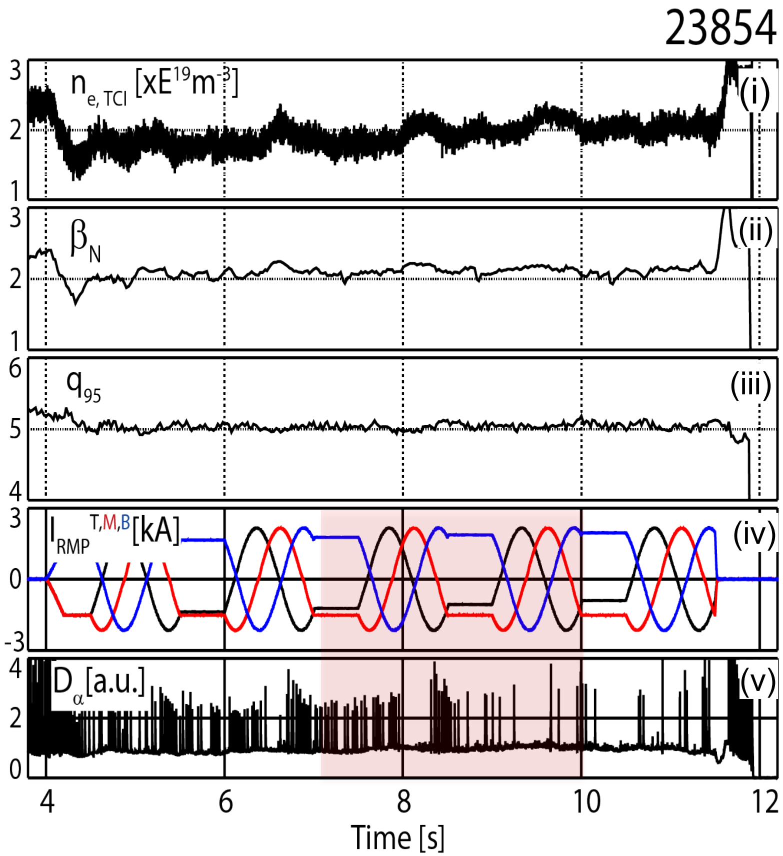
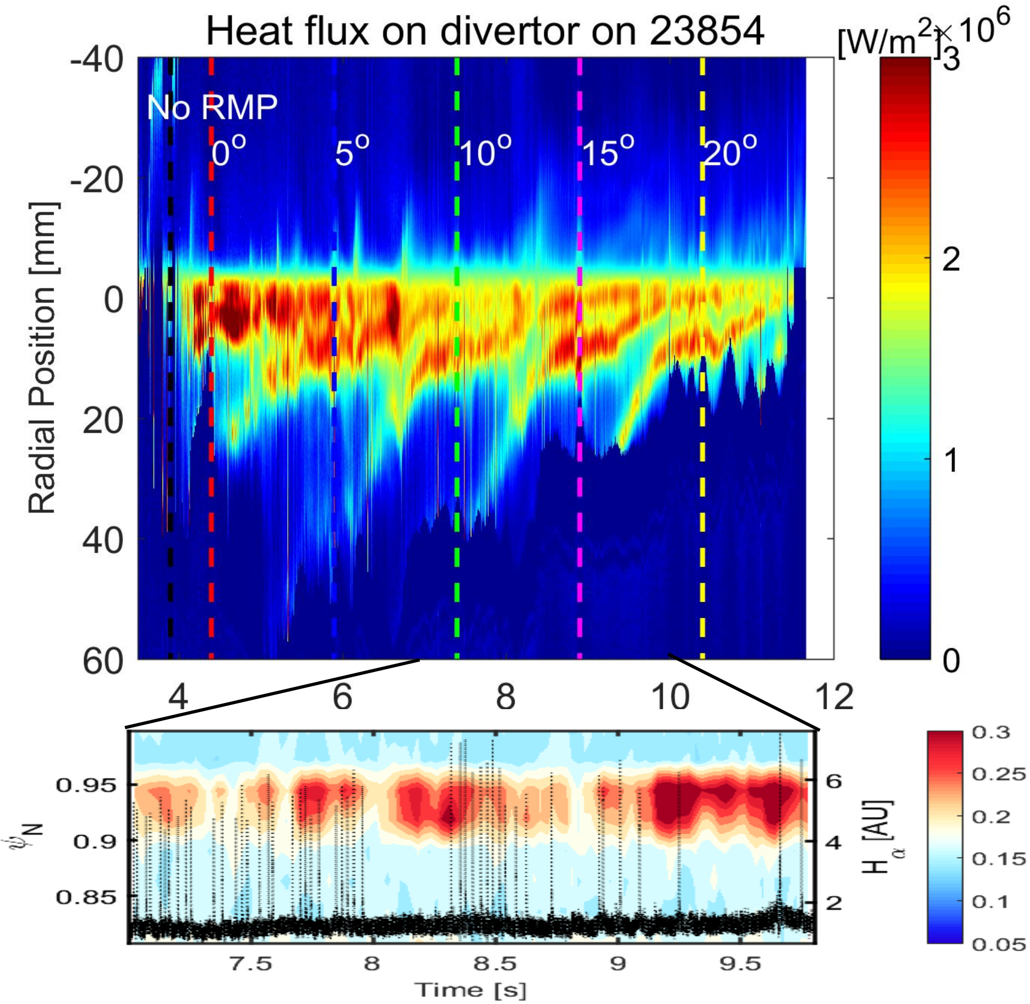
- **Articulated the synergistic benefit of kink influence on RMP-driven, ELM-crash-suppression at sub-marginal RMP strength, consistent with theory**
- **With 2-row (Mid/Bot) RMPs, both kink and anti-kink phasings are confirmed effective in suppressing ELMs, as predicted in theory**
- **The divertor 'wet' area of RMP-driven, ELM-crash-mitigation is broader than that of RMP-driven, ELM-crash-suppression**
- **Even when the mid-row is energized, the divertor heat flux broadening identified in 3-row IMCs has NOT been observed in 2-row IMCs**
- **Evidence of up/down asymmetric coupling difference for RMP-driven, ELM-crash-suppression, showing a meritorious use of Mid/Bot, instead of Top/Mid**

Kink-influence increase at sub-marginal RMP drives a transition from ELM-mitigation to ELM-suppression, revealing the divertor heat flux changes





Critical transitions on edge plasma would be the primary source on the changes of divertor heat flux, as might have been expected

Articulated the synergistic benefit of kink-influence on RMP-driven, ELM-crash-suppression at sub-marginal RMP strength, consistent with theory

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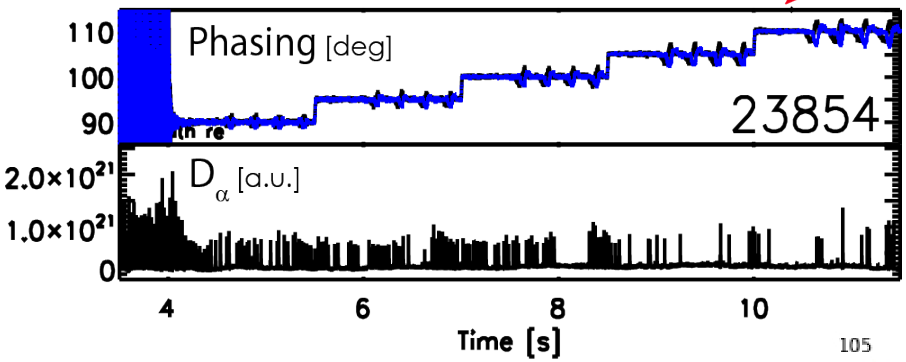
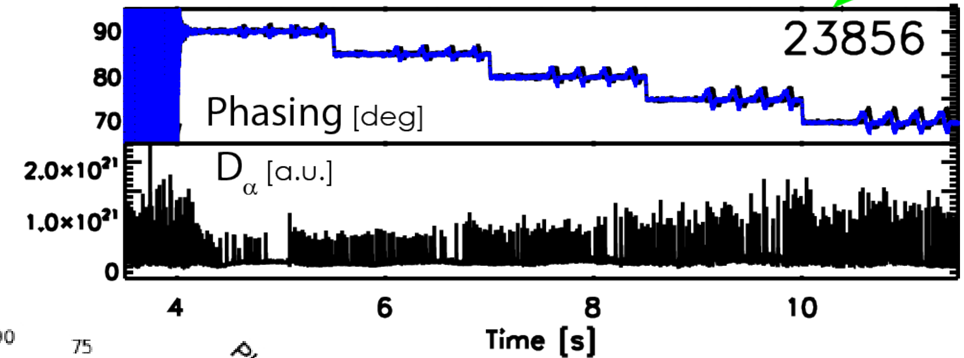
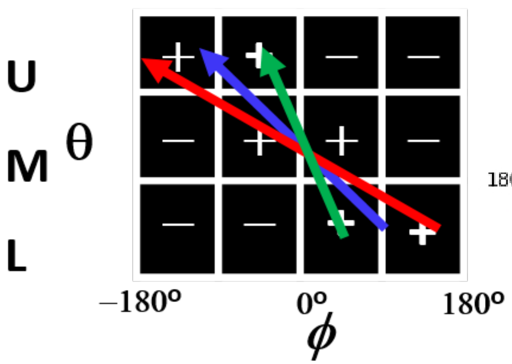
Kink phasing

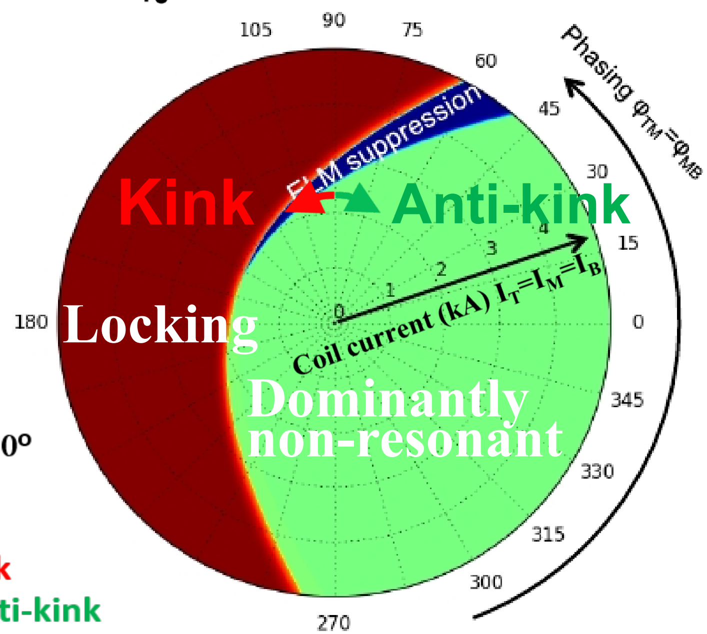


Anti-kink phasing



I_{RMP} =2.2 kA





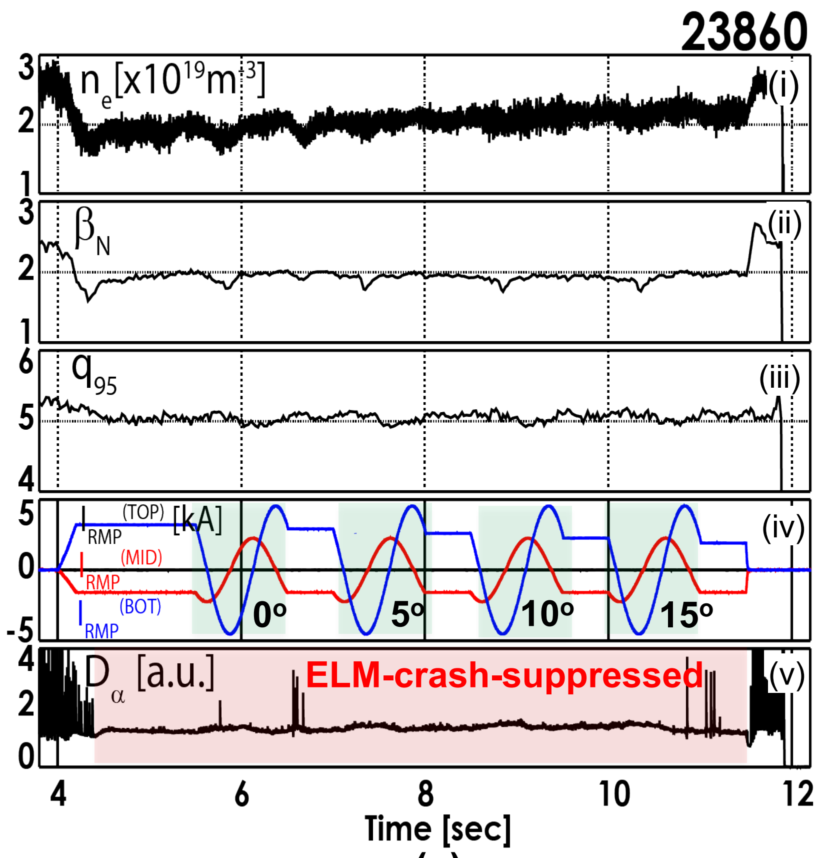
I_{RMP} =2.3 kA

n=1 RMP

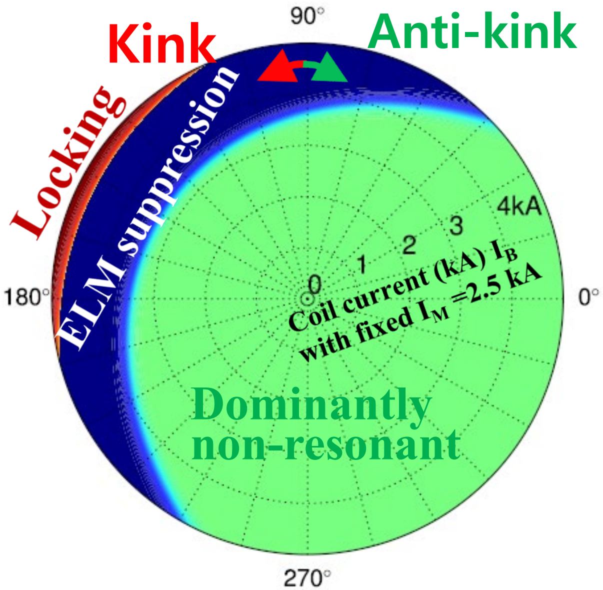
$\beta_N = 2$, q_{95}=5

Reference ($\phi_{UM} = \phi_{ML}$ =90 °)
"away" ($\phi_{UM} = \phi_{ML}$> 90 °):kink
"toward" ($\phi_{UM} = \phi_{ML}$< 90 °): anti-kink

With 2-row (Mid/Bot) RMPs, both kink and anti-kink phasings are confirmed effective in suppressing ELMs, as predicted in theory

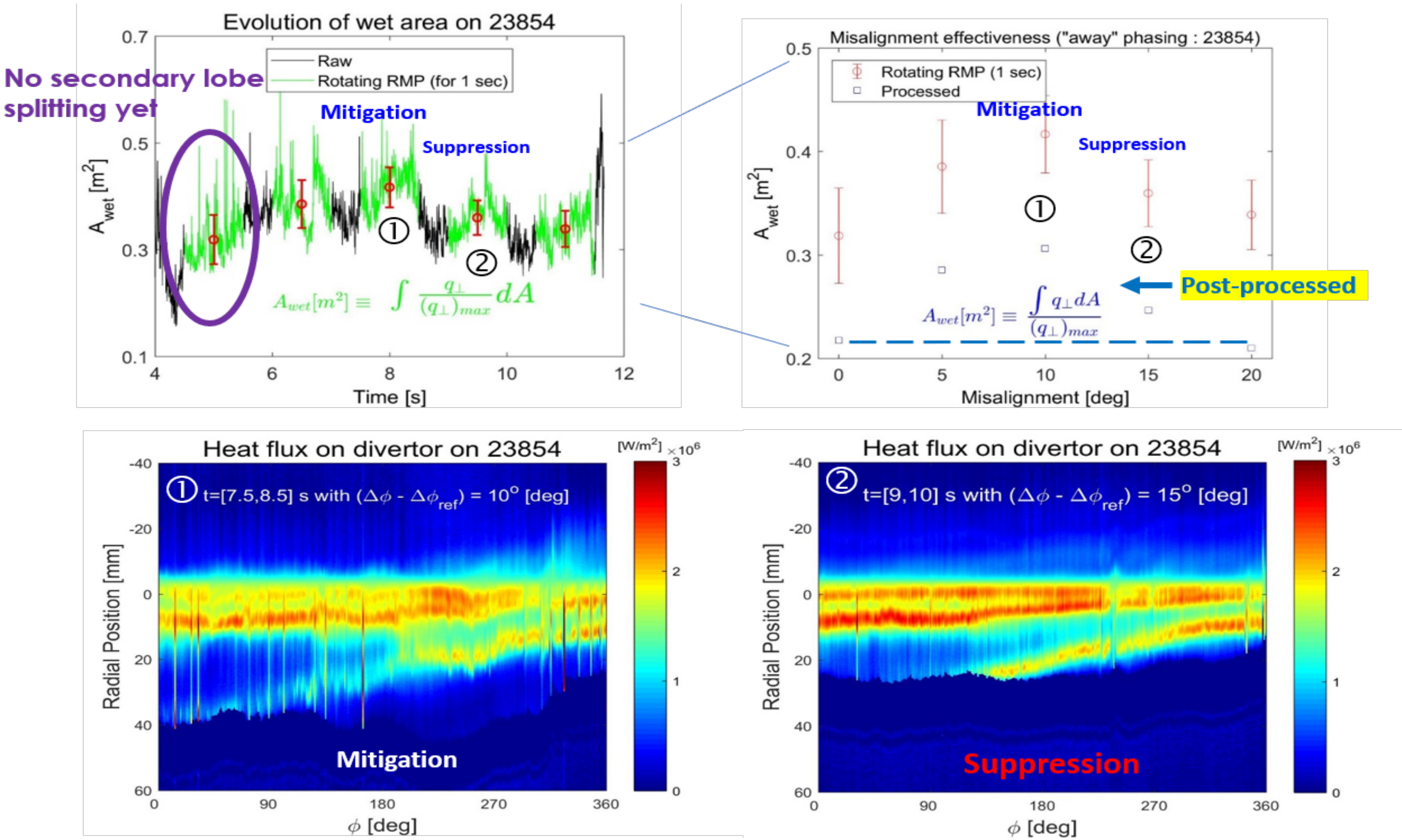


(a)



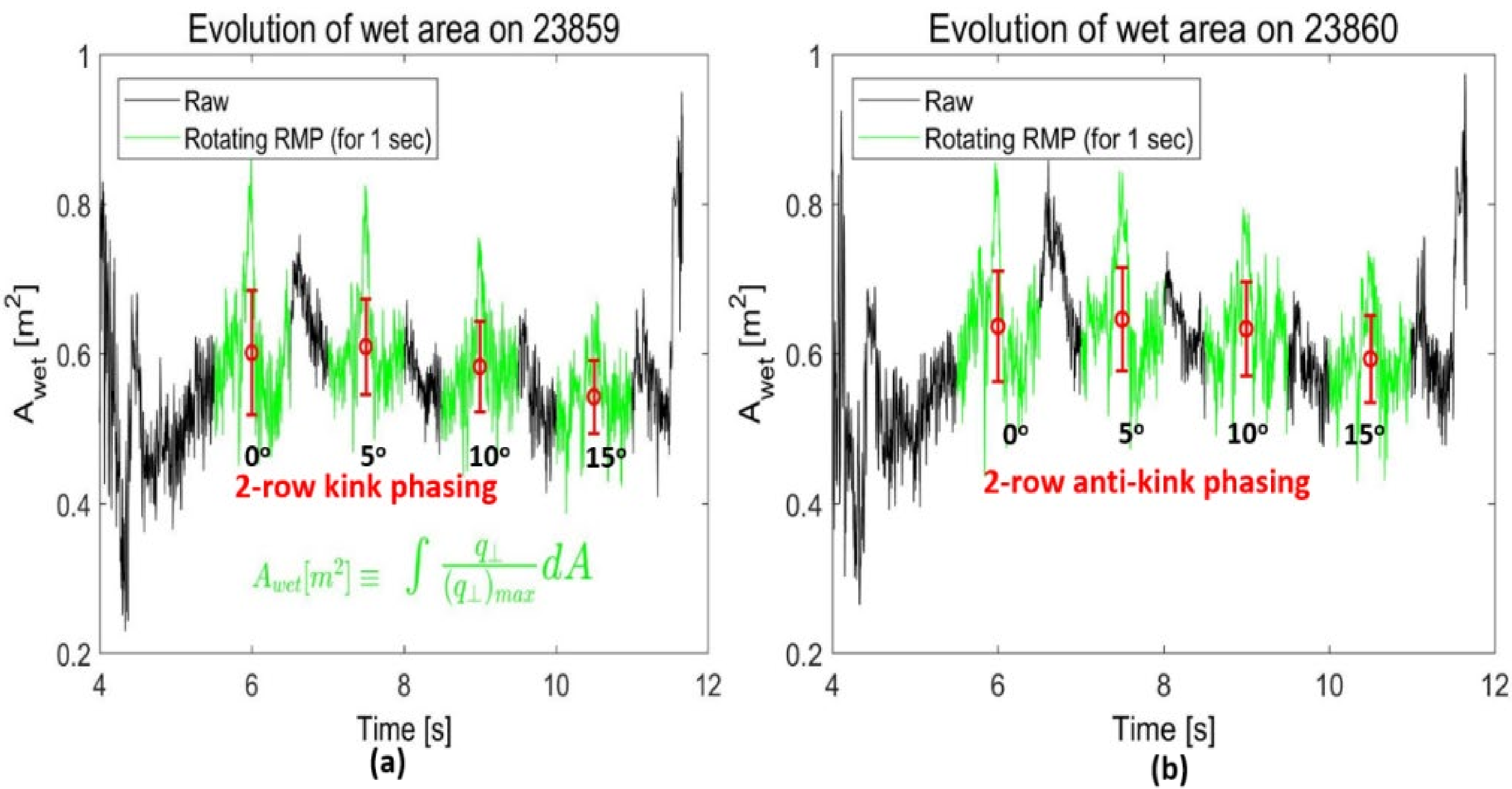
Note that the RMP amplitude of bottom-row is double that of mid-row

The divertor 'wet' area of RMP-driven, ELM-crash-mitigation is broader than that of RMP-driven, ELM-crash-suppression



NOTE that the measured heat flux during RMP-driven, ELM-crash-mitigation represents an averaged thermal loading, including multiple spikes

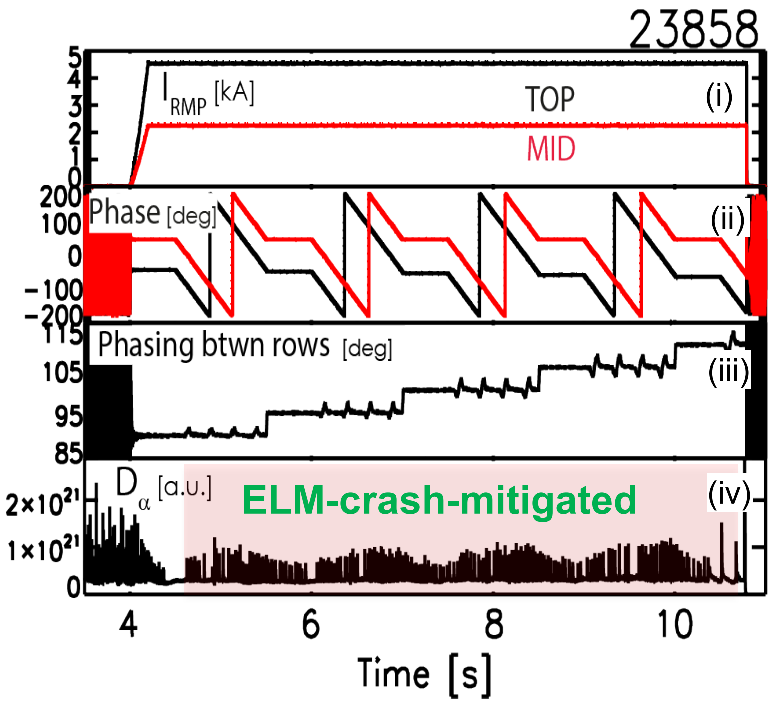
Even when the mid-row is energized, the divertor heat flux broadening identified in 3-row IMCs was NOT seen in 2-row IMCs



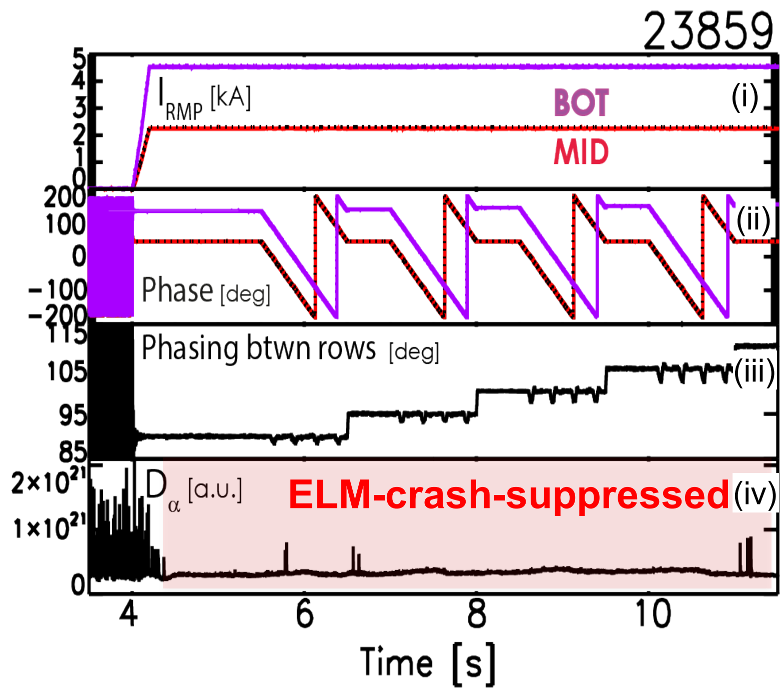
- Confirmed the uniqueness of 3-row IMC-driven, ELM-crash-suppression with broadened divertor heat flux, suggesting a need of 3rd row for IMC broadening

Y. In *et al*, NF 59 (2019) 126045 no broadening on TOP/BOT

Evidence of up/down asymmetric coupling difference for RMP-driven, ELM-crash-suppression, showing a meritorious use of Mid/Bot, instead of Top/Mid



(a)

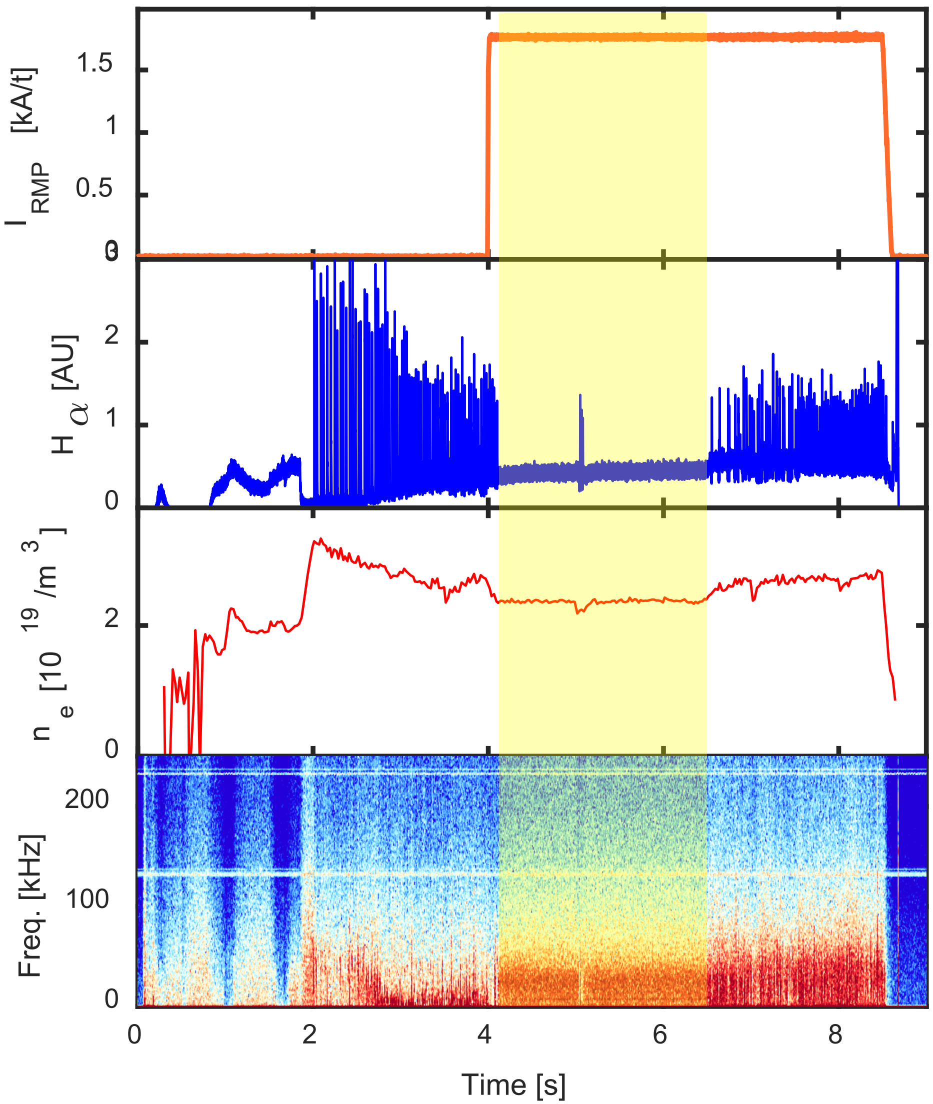


(b)

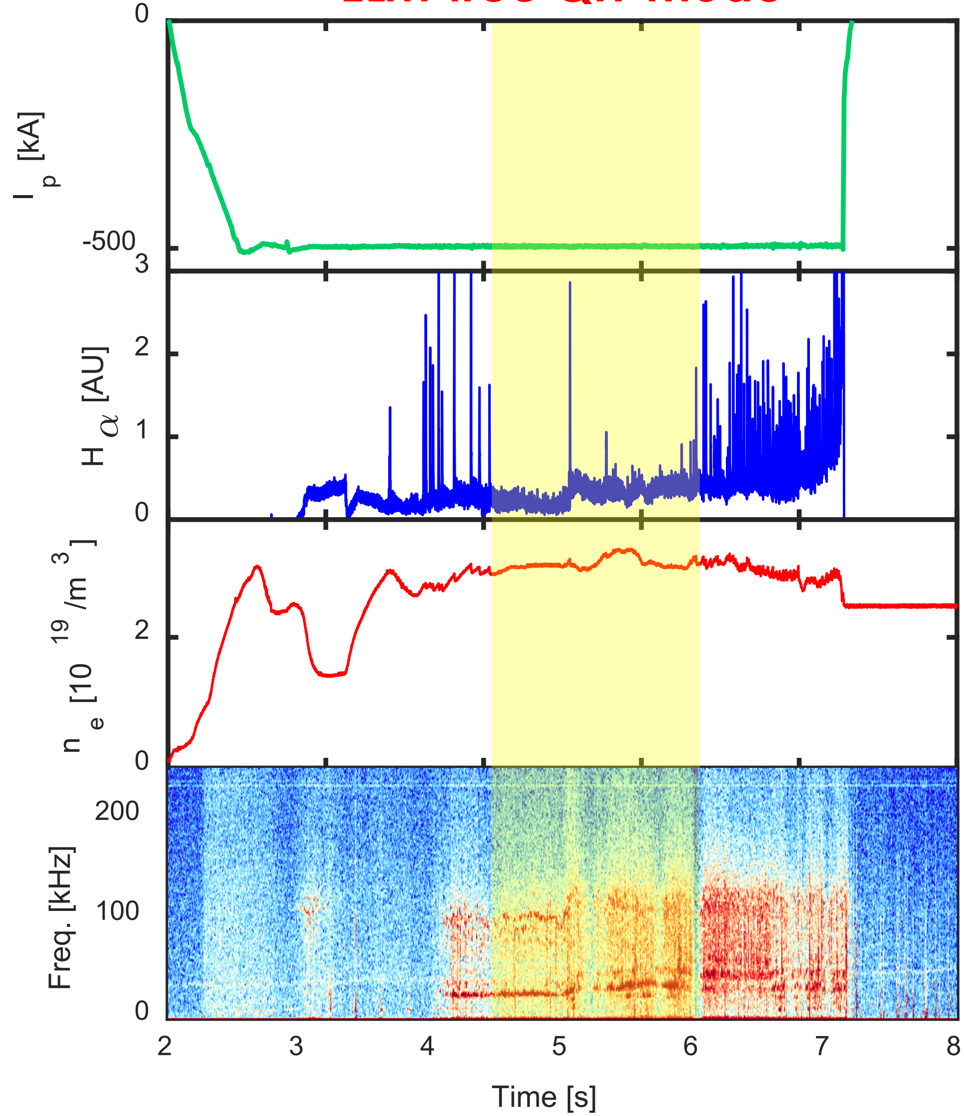
- **Potentially critical information for ITER RMP operation**
- **Much more reduced level of bottom-row RMP was found to be sufficient, suggesting a weak coupling of top-row RMP**

ELM controlled plasmas in KSTAR

RMP-driven ELM suppression

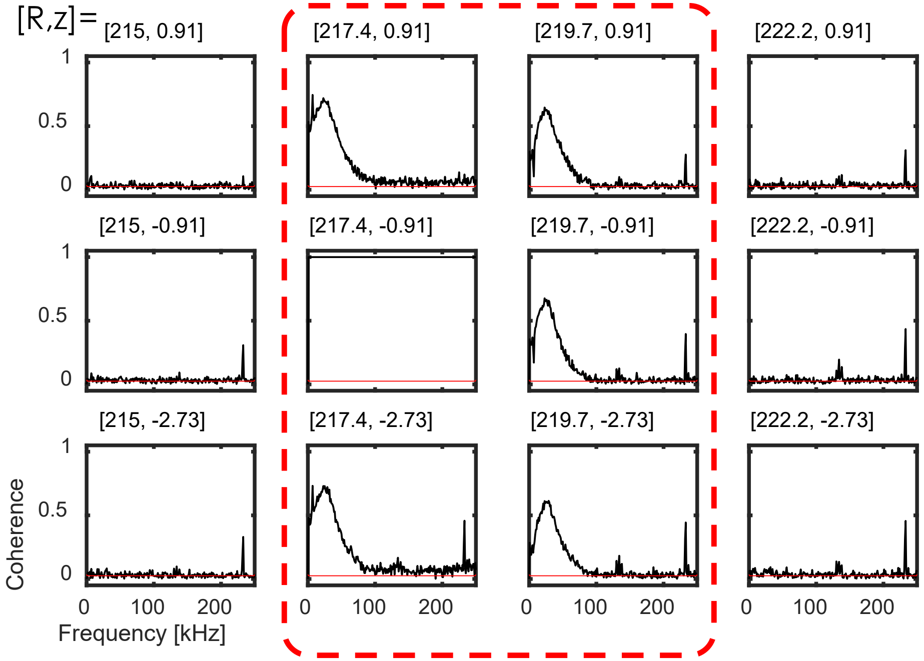


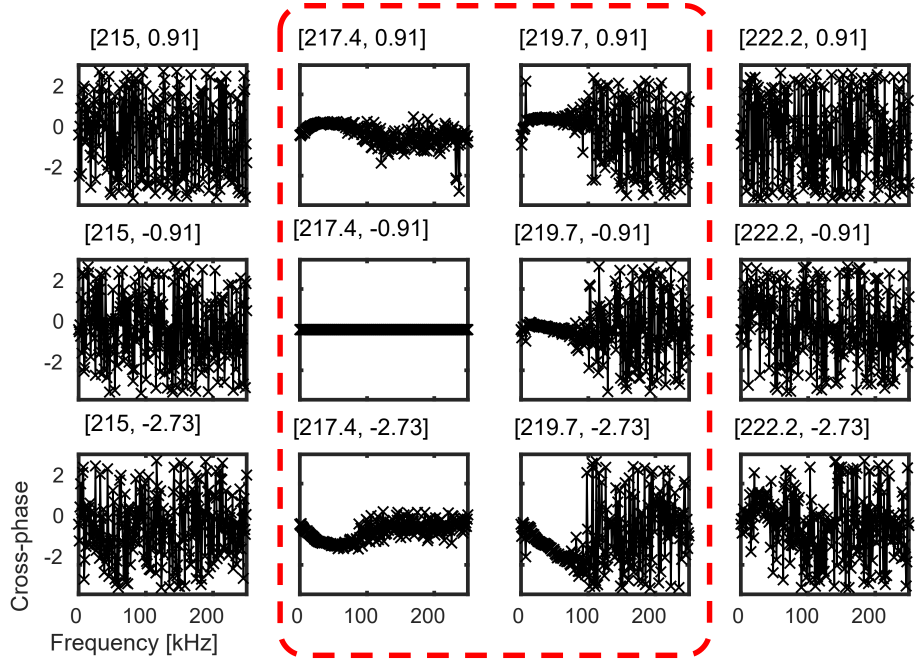
ELM-free QH-mode



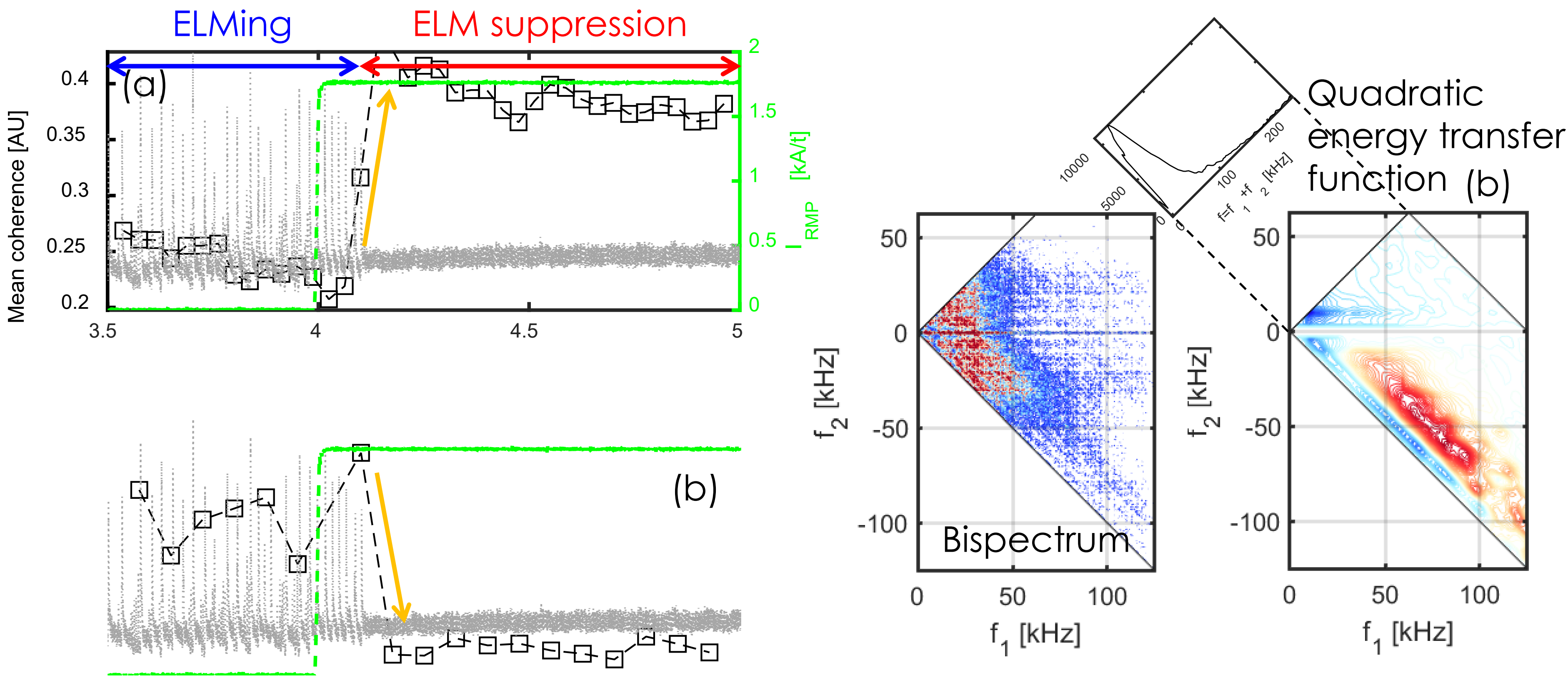
The RMP-driven ELM suppression is characterized by the coexistence of ELM filament and broadband turbulence

- The RMP induces turbulent fluctuations in the edge toward the ELM suppression phase
- The measured turbulence has long-poloidal wavelength ($k_\theta \rho_s < 0.1$) and rotates electron diamagnetic drift direction
- The possible turbulence candidates are Kinetic(or resistive) ballooning mode, micro-tearing mode, ion temperature gradient





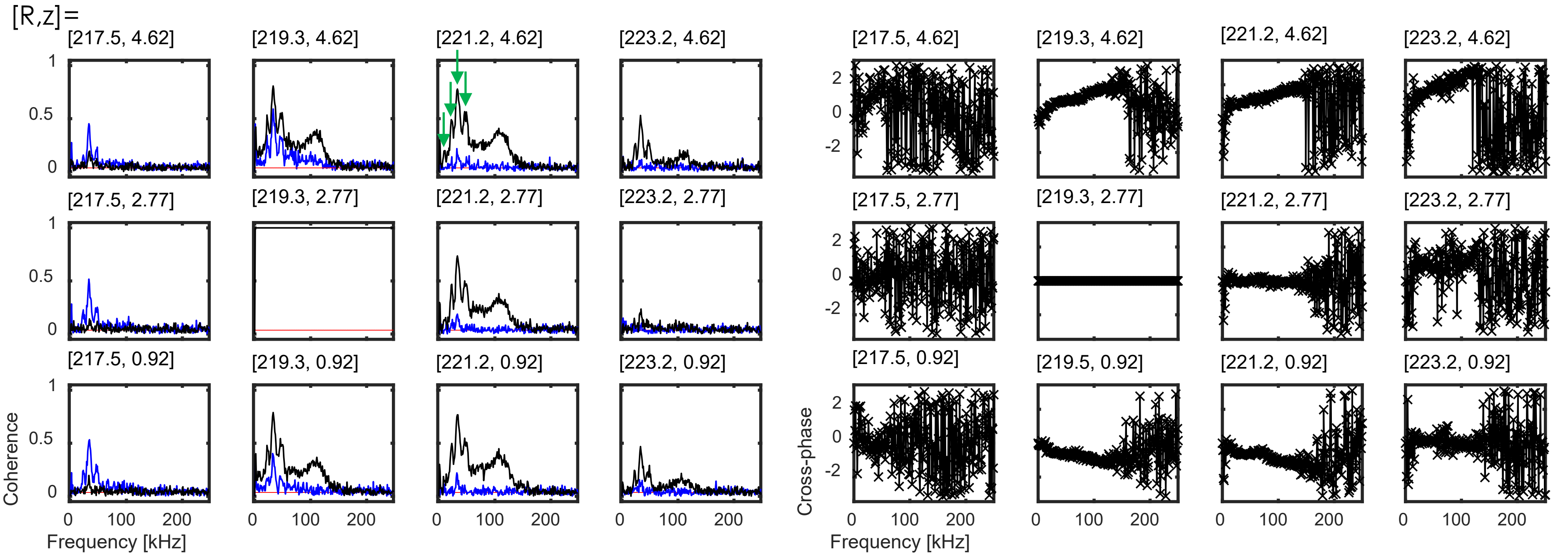
Increase of turbulence due to rapid changes in perpendicular velocity shear may be an important physical mechanism of the ELM suppression



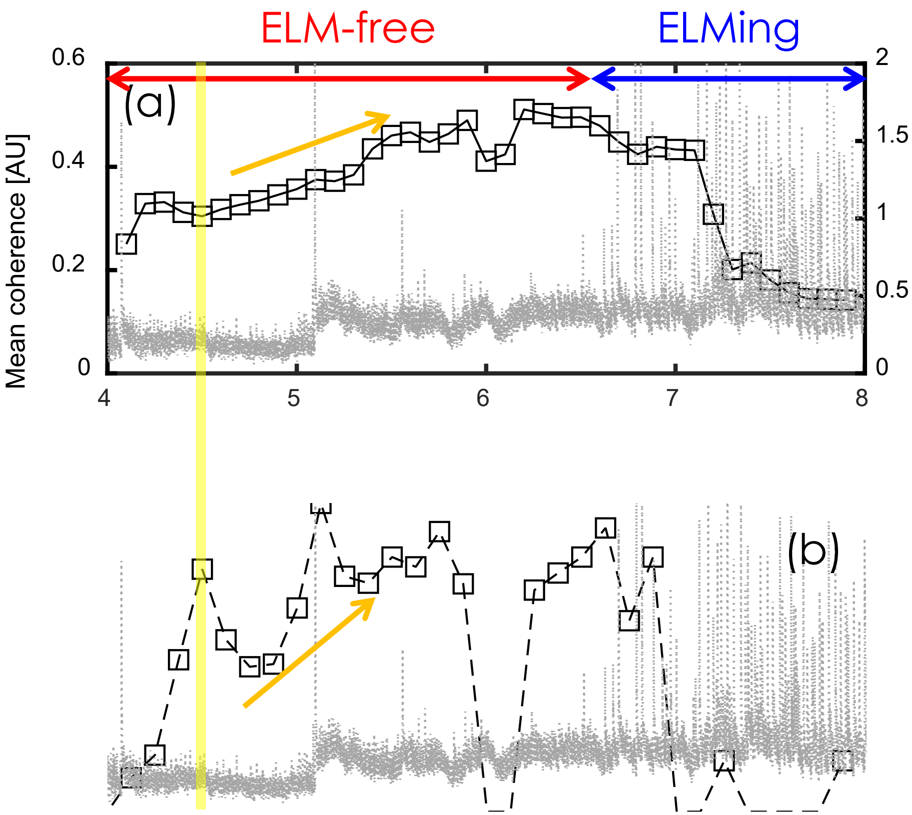
- A reduction of $v_\perp$ shear (or v_{ExB} shear) during the ELM suppression phase may lead to the increase of turbulent fluctuations at the edge
- The turbulence dissipate free energy for ELM growth in the RMP-driven ELM suppression

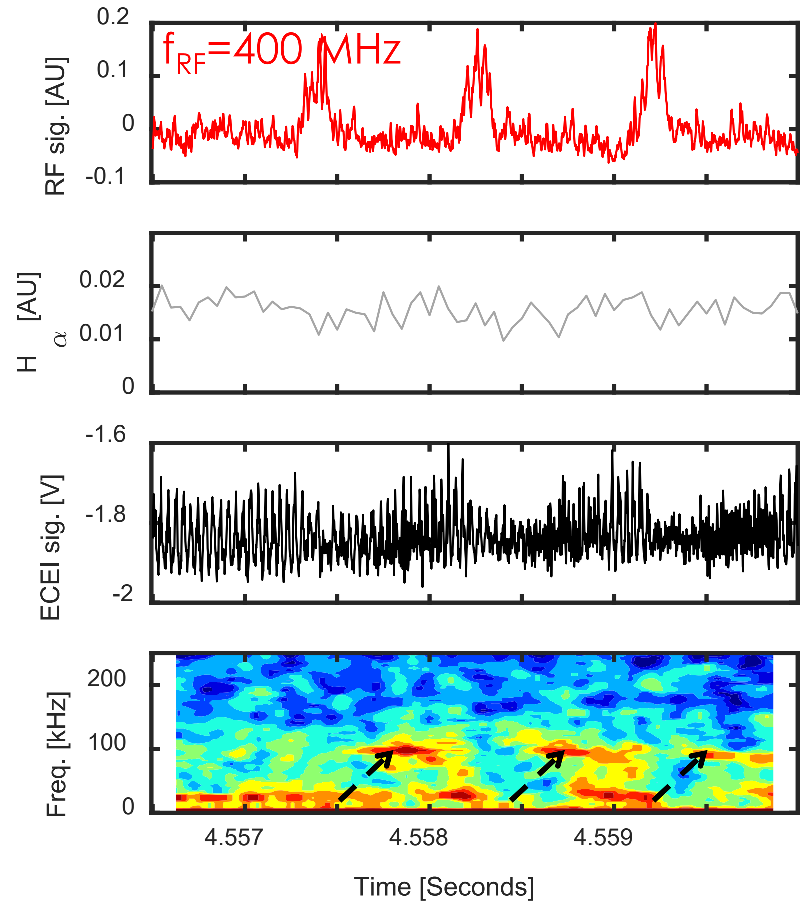
KSTAR ELM-free QH-mode is characterized by benign multiple MHD oscillations

- Strong benign MHD oscillations (maybe EHO, n=1-4) are observed at the plasma edge while the ELM-free phase is maintained
- The n=3 mode is the most powerful and seems to be a kink/peeling mode because the mode structure is also observed at the inboard side edge
- In addition to the EHO, turbulence is measured, but it didn't play a role in maintaining the ELM-free state



Increase of perpendicular flow shear and quasi-periodic RF burst may be important to sustain the ELM-free phase





- The $v_\perp$ shear remains strong while the edge harmonic oscillation is maintained
- Quasi-periodic RF burst can affect ELM-free state if the RF spikes is edge transport event rather than an ELM crash

Summary

- The ELM suppression under n=1 RMP is characterized by the coexistence of the ELM filament and smaller scale turbulent eddies in the edge
- The RMP induces turbulent fluctuations in the edge toward the ELM suppression phase
- The rapid increase in turbulence intensity is due to the reduction of perpendicular flow and its shear
- Induced turbulence interacts nonlinearly with coexisting ELM filament and dissipates free energy for ELM growth through energy exchange
- The ELM-free QH-mode is usually accompanied by a benign MHD oscillation
- Perpendicular flow shear may be important to sustain the ELM-free phase
- The ELM-free state can be correlated with lower frequency RF bursts and can affect the ELM stability by causing plasma edge transport