3rd IAEA TM on Divertor Concepts (Austria, 4th ~ 7th Nov 2019)

Recent progress in understanding the outer divertor heat flux dynamics during the ELM-crash-suppression by RMP on KSTAR

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of divertor heat flux by RMPs on KSTAR

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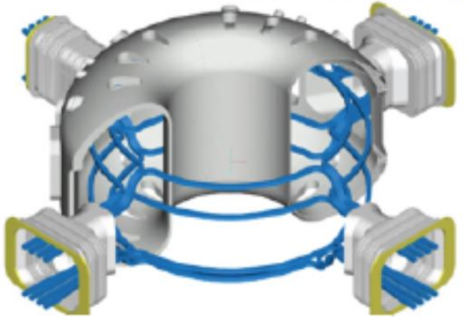
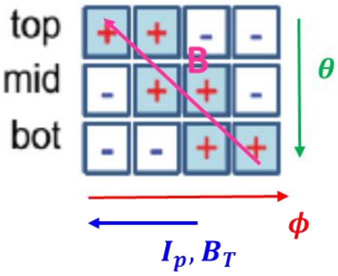
Introduction – RMPs & Div. IRTV

KSTAR In-vessel Control Coils (IVCC): Top/Mid/Bot

H.K. Kim *et al*, FED (2009)

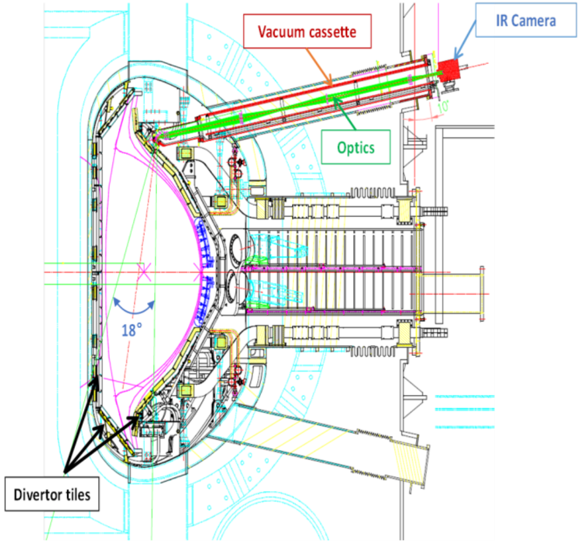


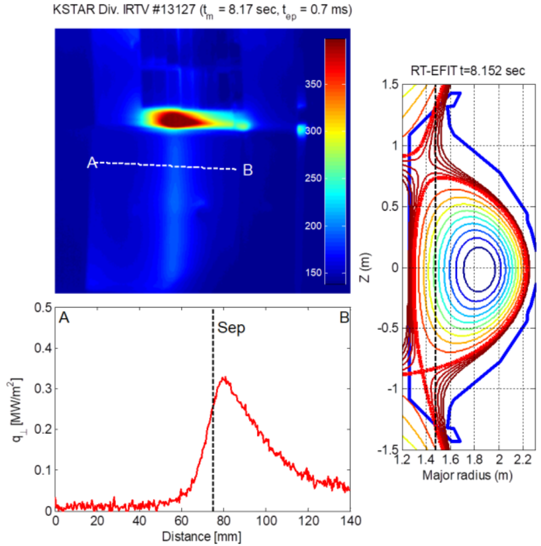
n = 1, +90 phasing



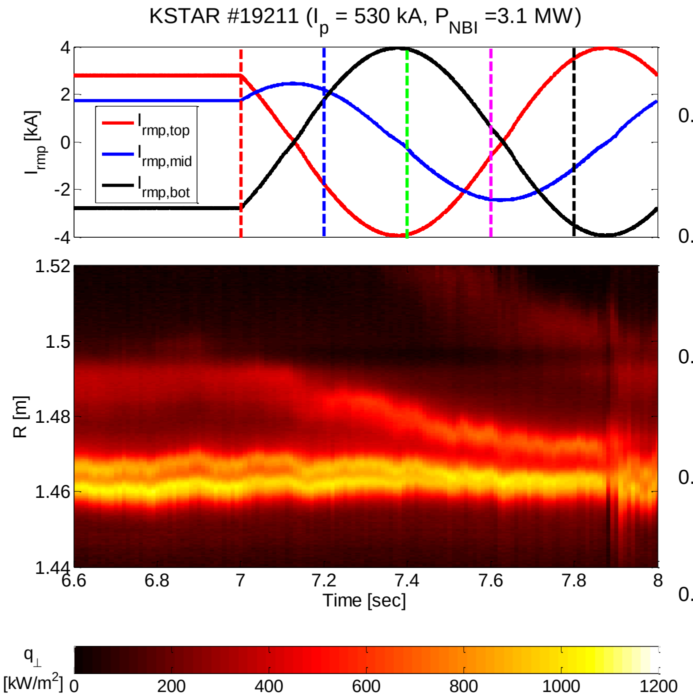
in (r, θ, ϕ) coordinates

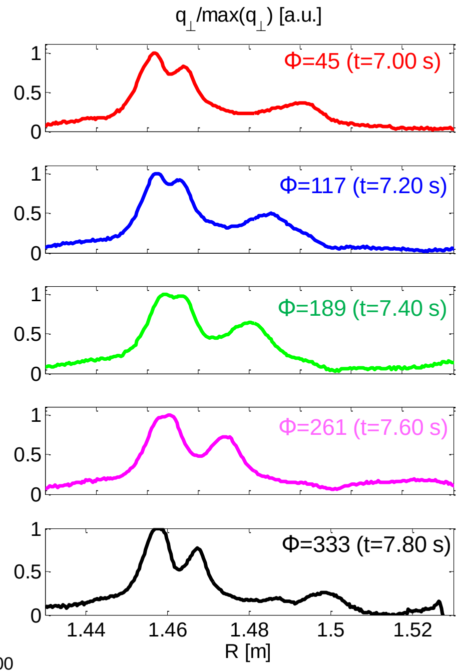
Divertor IRTV measuring the outer divertor heat flux (on the central divertor target)

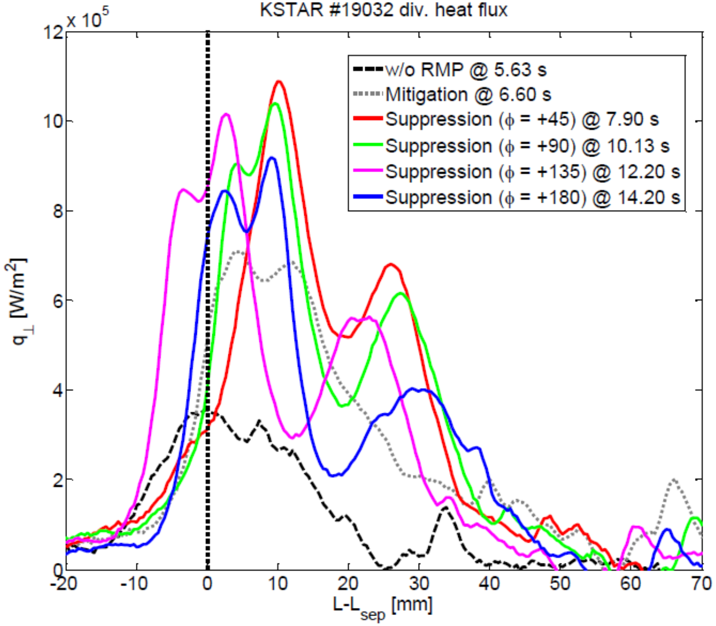




Observations



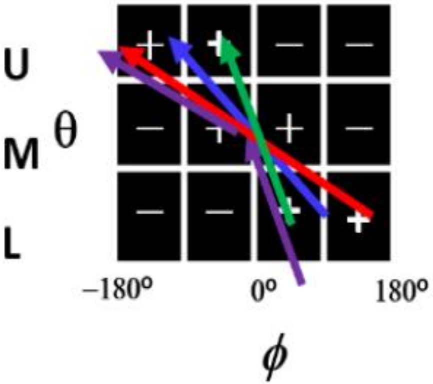




The heat flux profile measurement clearly captured the effects of 3D RMPs on the divertor heat load

Interestingly, it has been observed that *the peak heat flux is much higher in ELM-supp. Regime* than those in the w/o RMPs and ELM-mitigation regimes

Control – heat flux broadening



Phasing (= phase difference between rows)

0. Reference (default, $\phi_{UM} = \phi_{ML} = 90°$)

A. 3-rows

I. "distorted" ($\phi_{UM} \neq \phi_{ML}$)

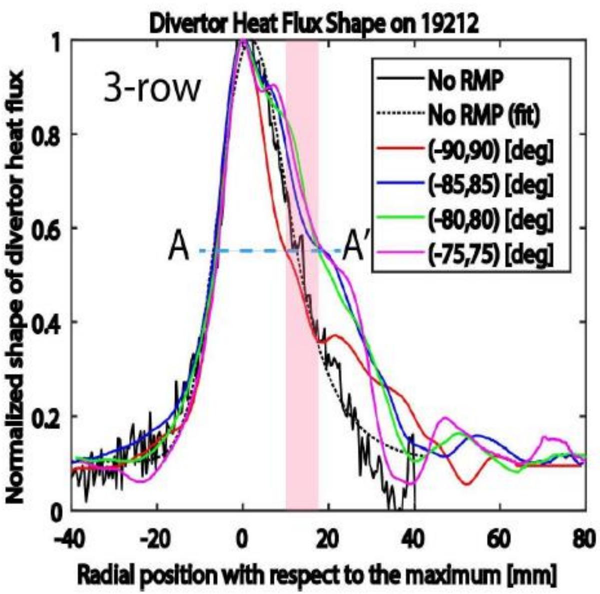
II. "away" ($\phi_{UM} = \phi_{ML} > 90°$)

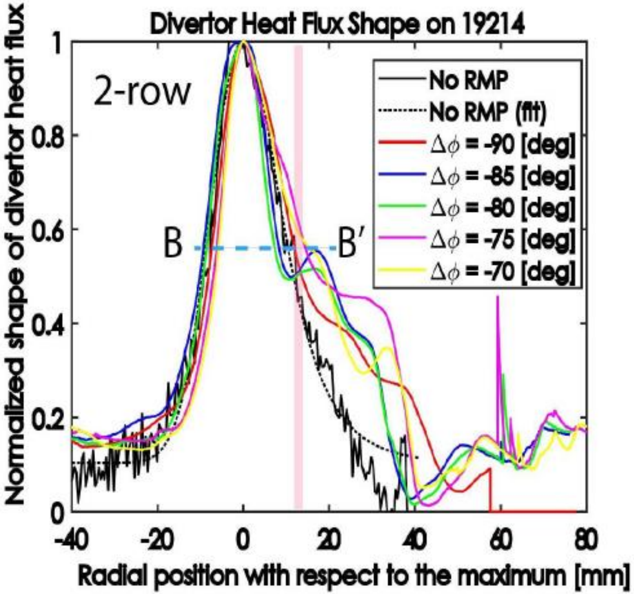
III. "toward" ($\phi_{UM} = \phi_{ML} < 90°$)

B. 2-rows

Upper/Lower only (without mid-row)

ITER-like 3-row RMPs have broadened the divertor heat flux during ELM-supp. at the near SOL, which cannot be seen with 2-rows

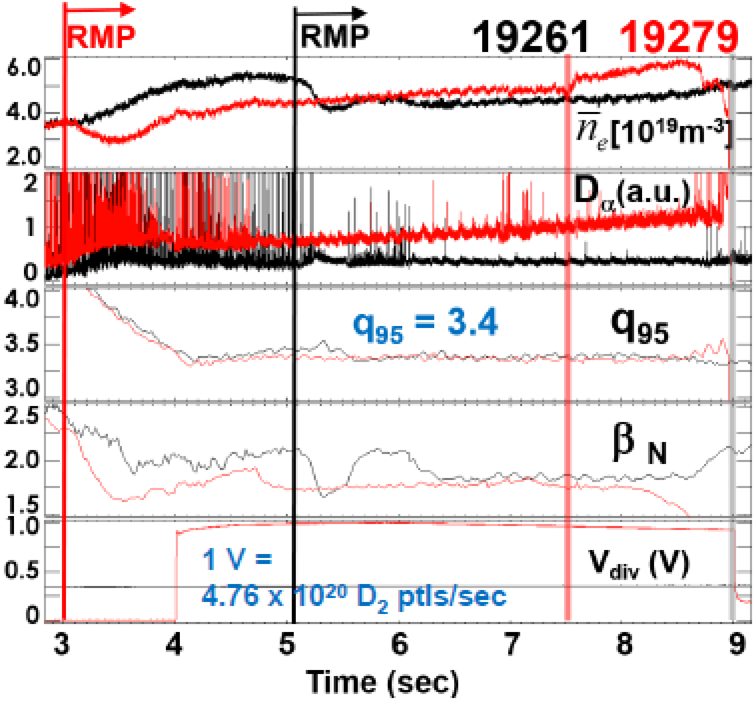


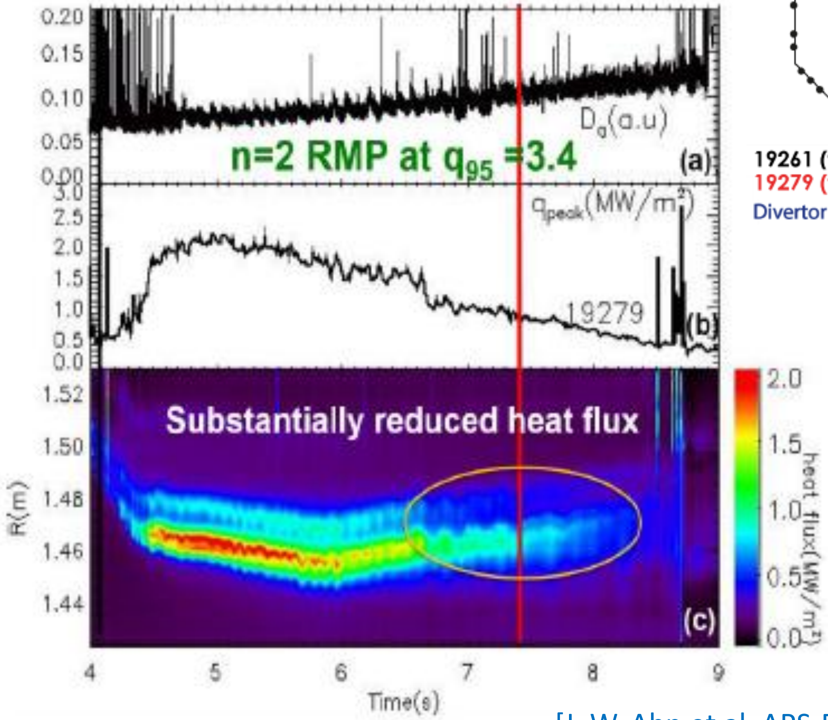


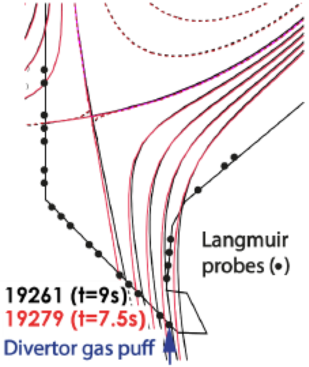
[Y. In et al, 2019 NF]

Control – ELM suppression + detachment

High density ELM-crash-suppression has been accomplished for n=2 RMPs with substantial reduction of divertor heat flux, despite no detachment yet (#19279)







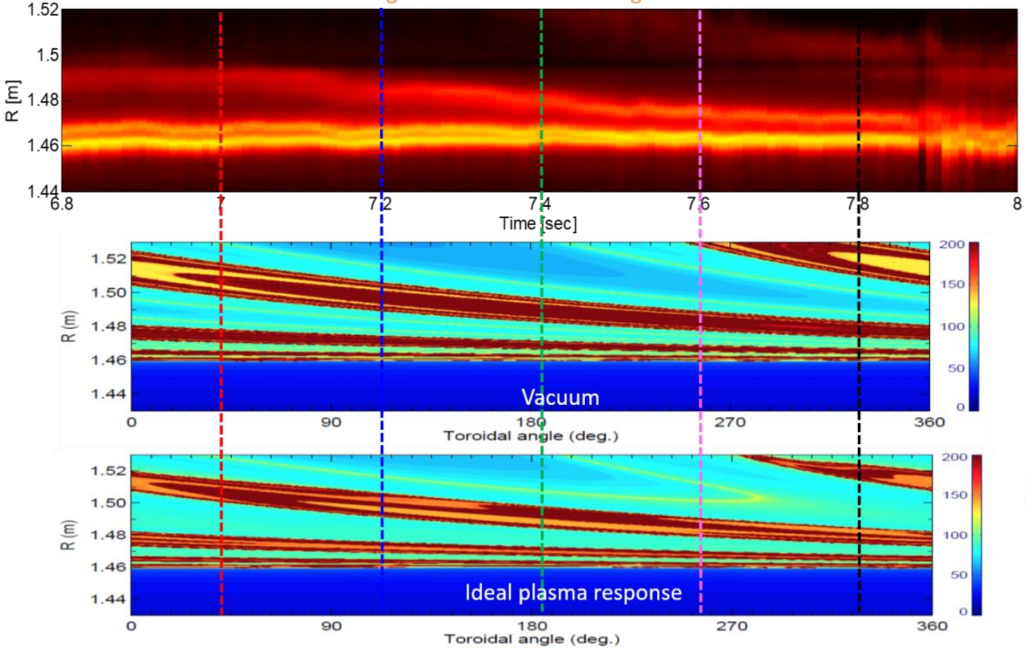
[J. W. Ahn et al, APS-DPP (2017)]

Understanding – striation pattern

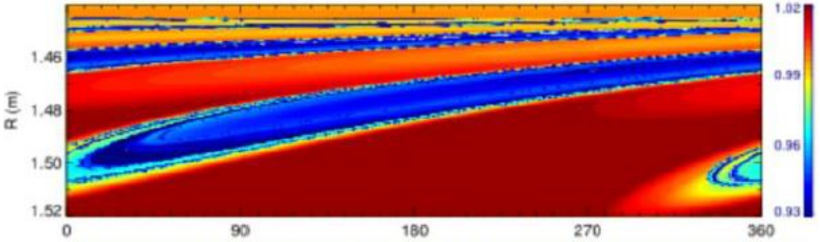
It has been realized that the main 3D sturucture feature follows the field line tracing calculation† although details of the calculation can be slightly different according to plasma response models

† K. Kim PoP **24** 052506 (2017)

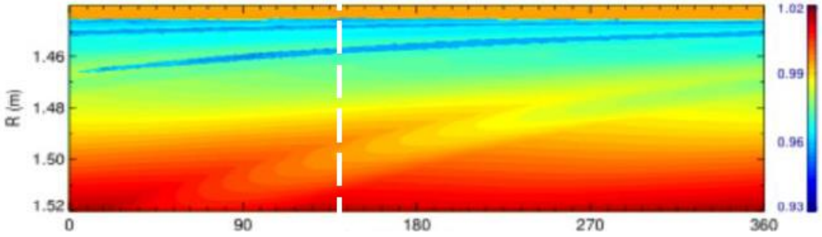
The measurement time can be regarded as the toroidal angle



Ideal plasma response



MARS (incluling rotation effect)

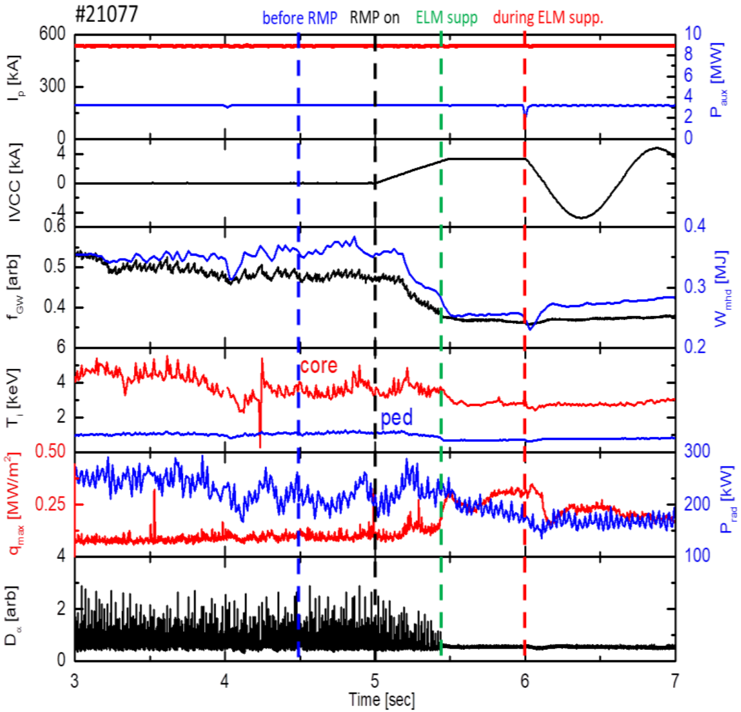


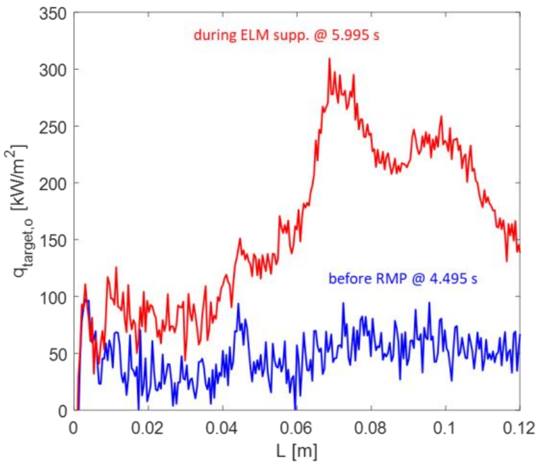
[Y. In et al, APS-DPP (2019)]

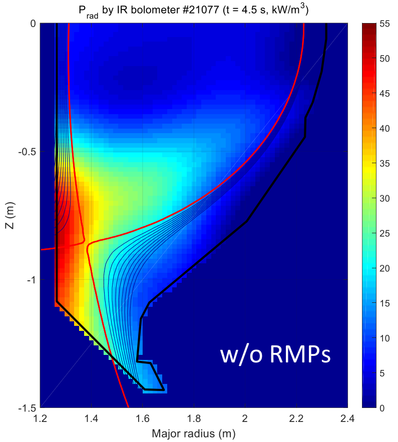
Understanding – heat flux increase by RMPs

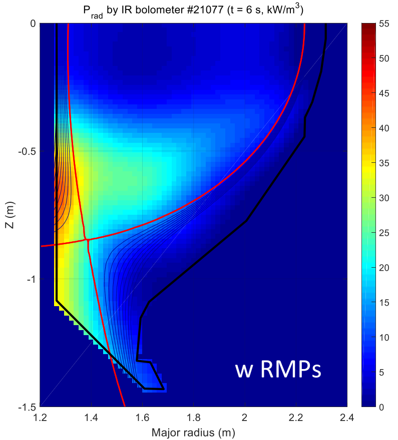
It seems that divertor heat flux is increased when the plasma goes to the attached regime from the (partially) detached regime by the significant density reduction due to the application of RMPs

?? partial detachment → RMPs → density ↓ → attachment + SOL radiation ↑ → q_{target} ↑ ??

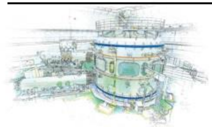








IR bolometer measurement indicates that the radiation power at lower divertor region **decreases** during RMP-ELM suppressed regime



Understanding – heat flux braodening

It seems that Ideal MHD + field line tracing is not sufficient to explain the broadened heat flux profiles, based on a simple modeling

- **Sheath-limited heat flux**

$$q_{div}(R) = \frac{n(R)\quad T(R)^{3/2}}{n_{sep}\quad T_{sep}^{3/2}}$$

- **Conduction-limited heat flux**

$$q_{div}(R) = \frac{T(R)^{7/2}}{T_{sep}^{7/2}}$$

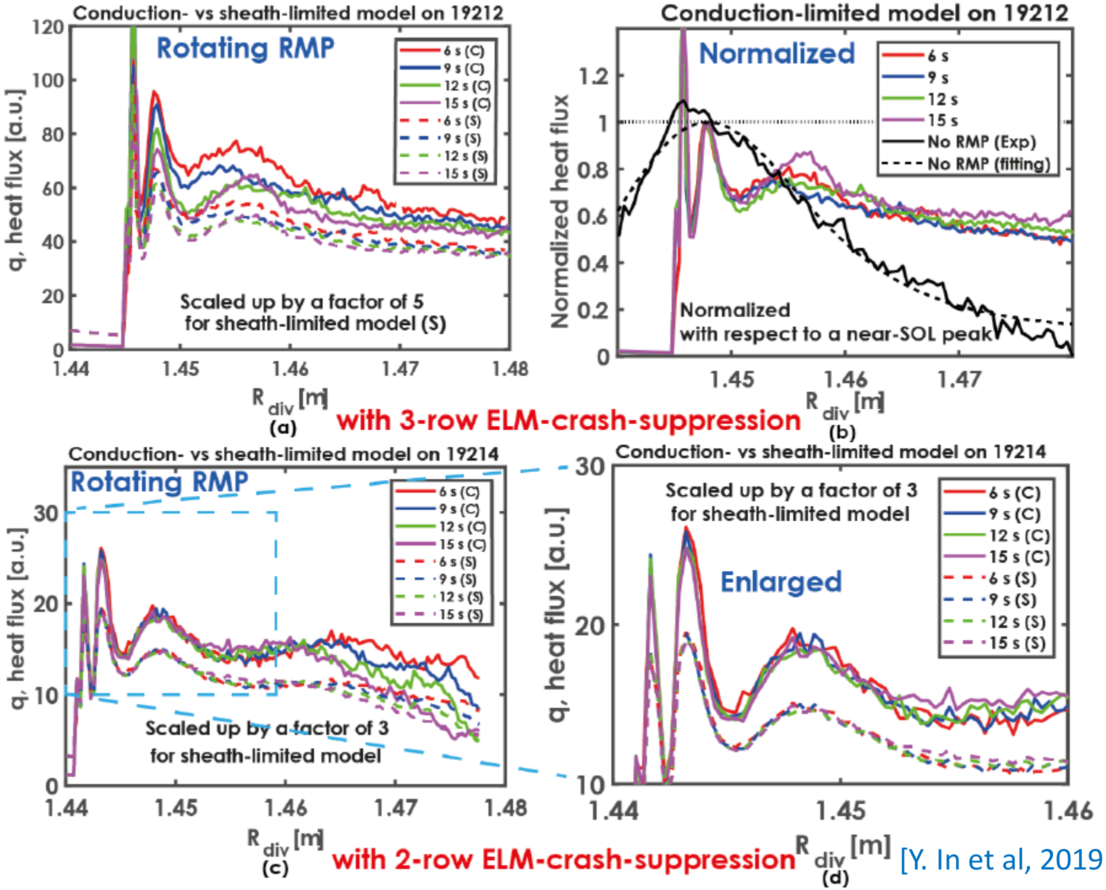
where

$$T(R) = T_{sep} + \frac{T_{ped} - T_{sep}}{\Delta}(R_{sep} - R)$$

$$n(R) = n_{sep} + \frac{n_{ped} - n_{sep}}{\Delta}(R_{sep} - R)$$

Although conduction-limited heat flux model appears better than sheath model, no feature of broadening has been properly modeled

Further investigation of the details is under way

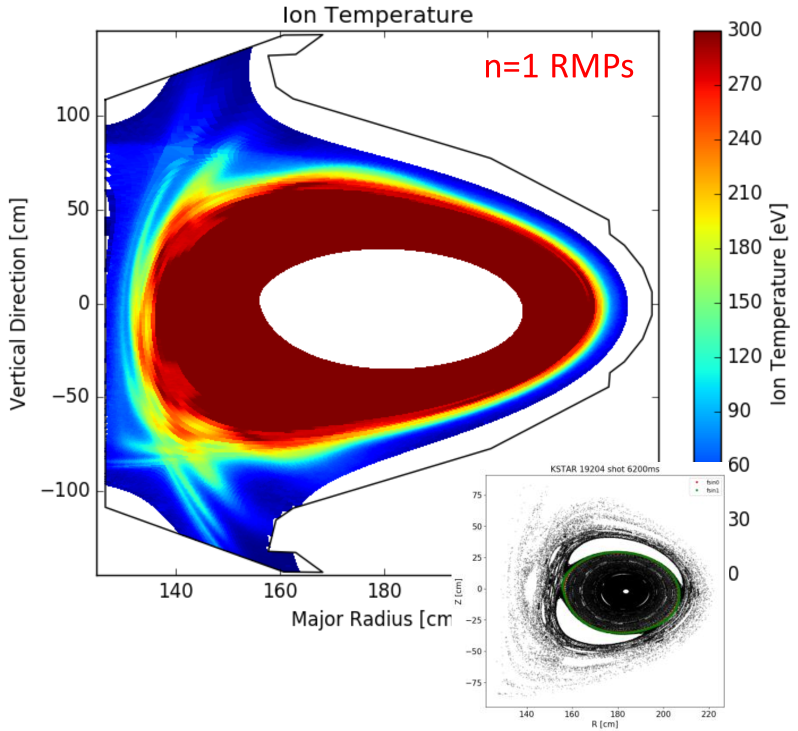


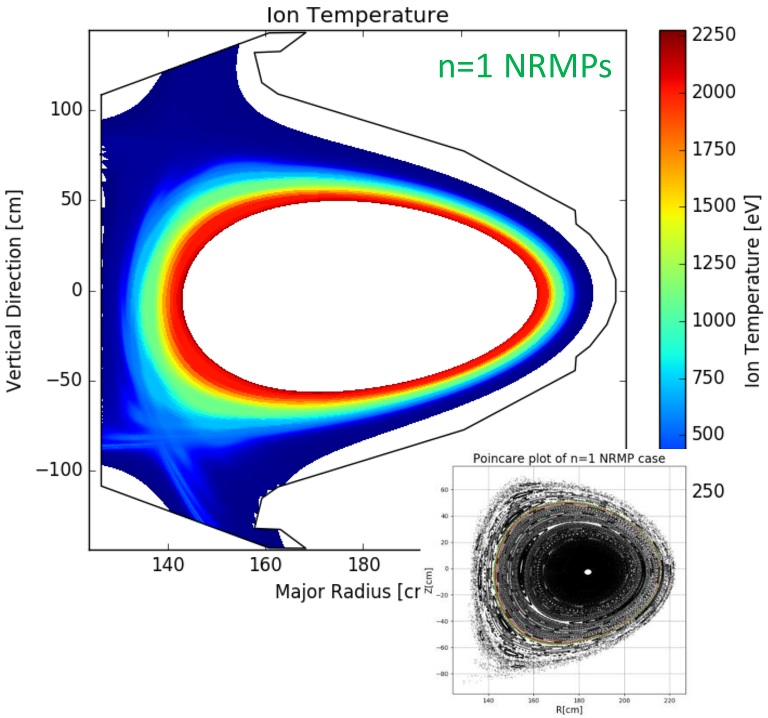
[Y. In et al, 2019 NF]

Understanding – numerical modeling

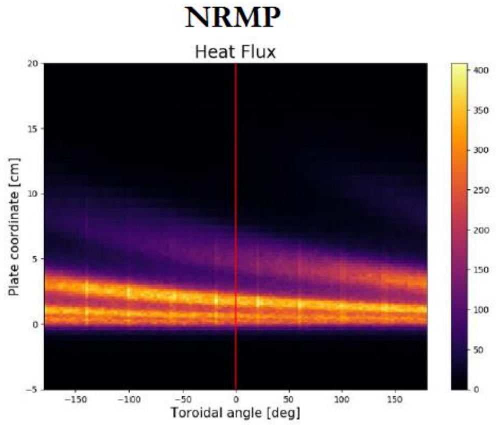
EMC3-EIRENE is being implanted and optimized for KSTAR

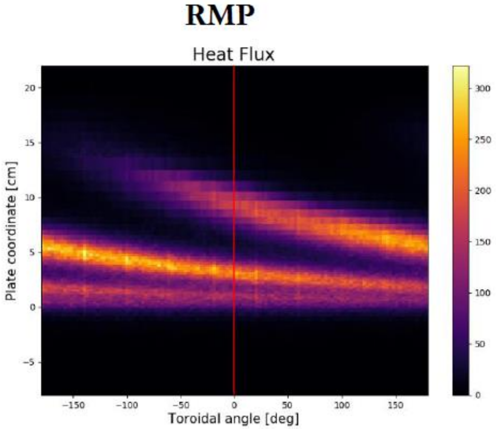
It has been realized that the expected divertor heat flux by NRMPs is much different from that by RMPs



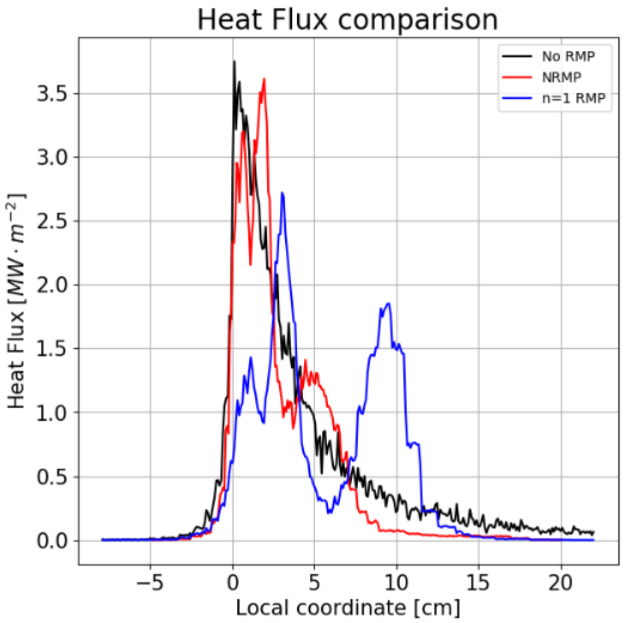


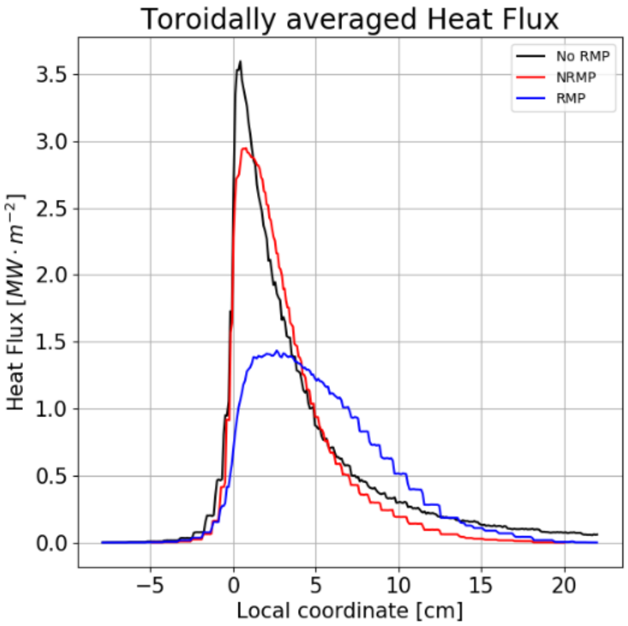
Understanding – numerical modeling





Measurement of the divertor heat flux profiles under the NRMPs is expected to be better for the validation work of the modeling result since it could avoid the complexity of the plasma response to RMPs (planned to be done in the middle of December on KSTAR)





Summary and Future works

- In KSTAR, the outer divertor heat flux dynamics is being comprehensively investigated especially during the ELM-crash-suppression regime by RMPs

- It is suspected that the radiation power decrease due to the density decrease by RMPs results in the increase in the divertor peak heat flux

- The ITER-like intentionally misaligned configuration has been successfully demonstrated to be not only compatible with ELM-crash-suppression, but also promising in broadening the divertor heat fluxes in a wider area. But, the underlying physics is still unresolved

- EMC3-EIRENE is being prepared for KSTAR. It will be actively applied to understand the divertor heat flux dynamics under the application of RMPs