The role of MHD in the asymmetry of P_{rad} during mitigated disruptions

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APS-DPP
Denver
2013/11/13

Introduction and background

Disruption mitigation experiments with massive gas injection on C-Mod and elsewhere have observed asymmetries of the radiated power which is of concern for ITER

- motivated ITER to propose multiple toroidally-spaced gas injectors

A 2nd MGI valve was installed on the opposite side of the C-Mod torus, and experiments were performed to characterize the ability of two valves to control the P_{rad} asymmetry

Previously reported results:

- Two valves provide good control of P_{rad} symmetry ***during the pre-thermal quench phase*** (when impurity gas is penetrating into the plasma)
- However, during thermal quench (TQ) phase, P_{rad} symmetry was not well-controlled by two valves

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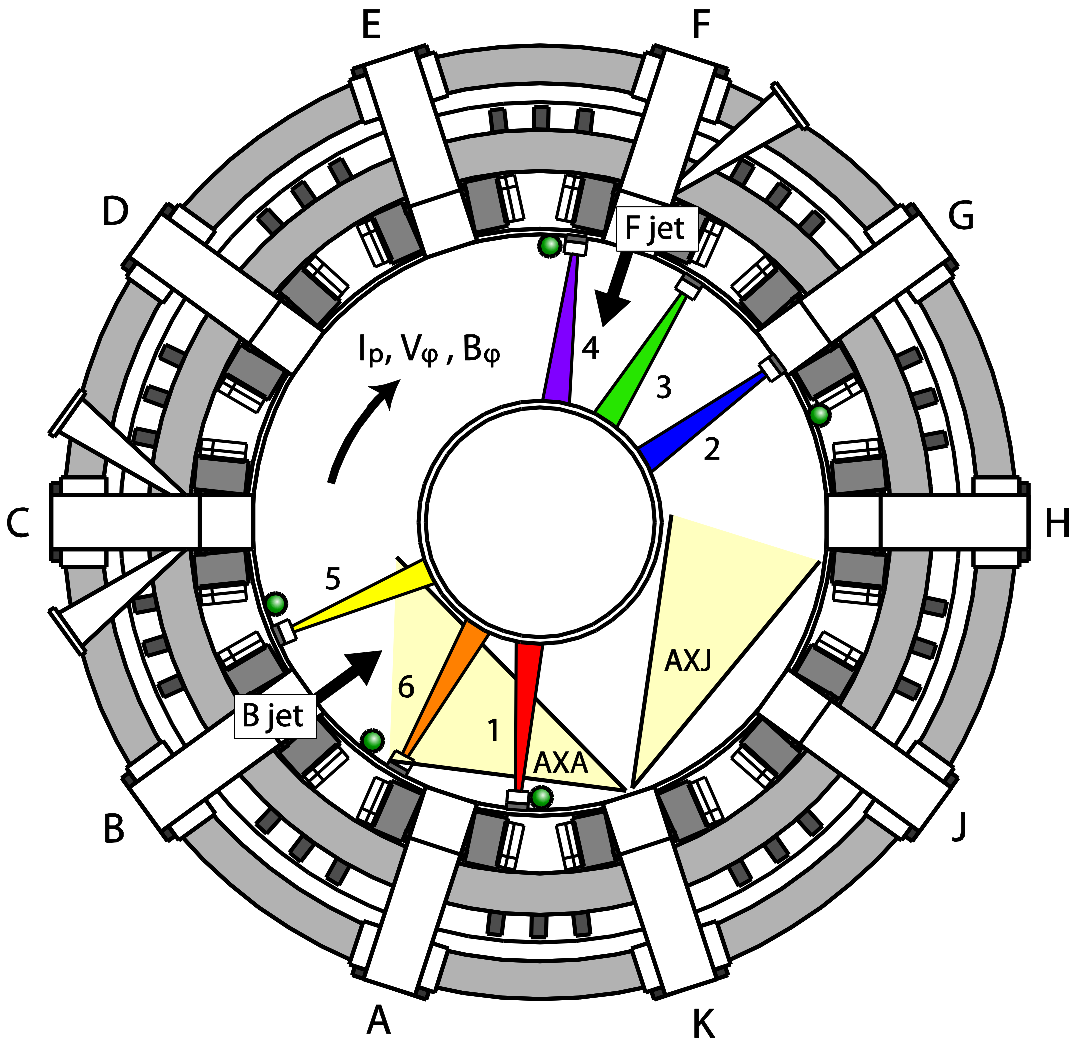
C-Mod has optimal diagnostics to study toroidal asymmetry of P_{rad} during mitigated disruptions



- Two gas injectors (B-port and F-port)
- Two midplane AXUV arrays to measure toroidal asymmetry
- Six individual AXUV detectors, collimated to measure toroidal structure of radiated power

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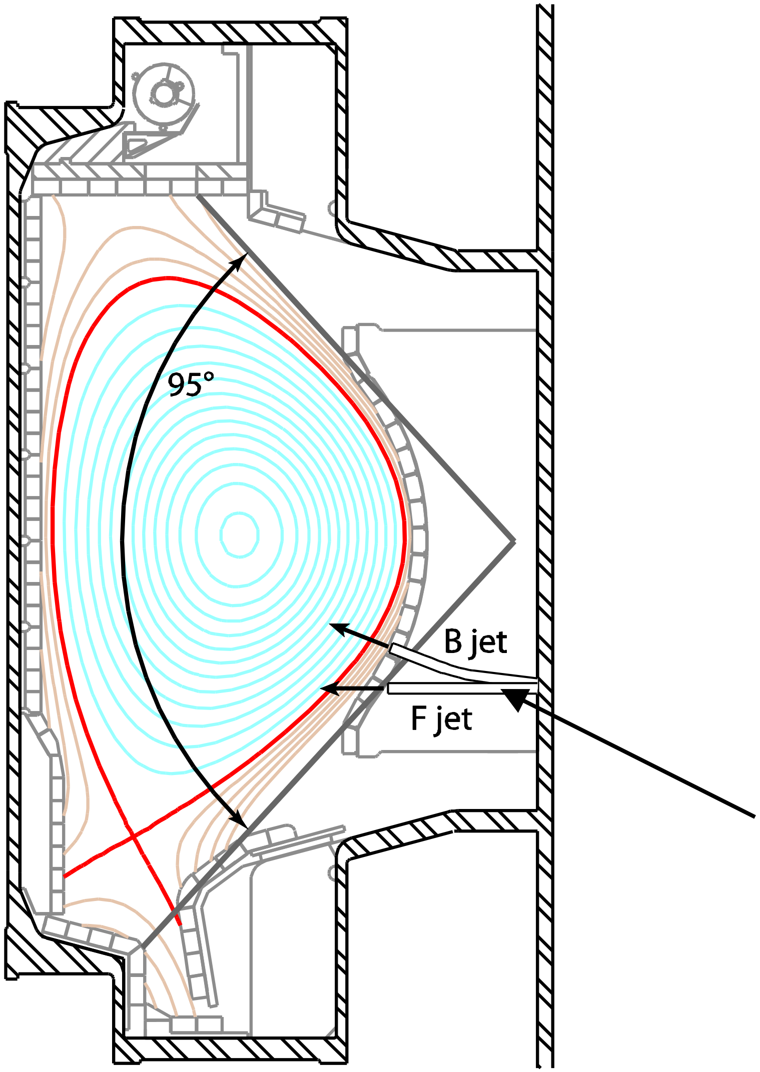
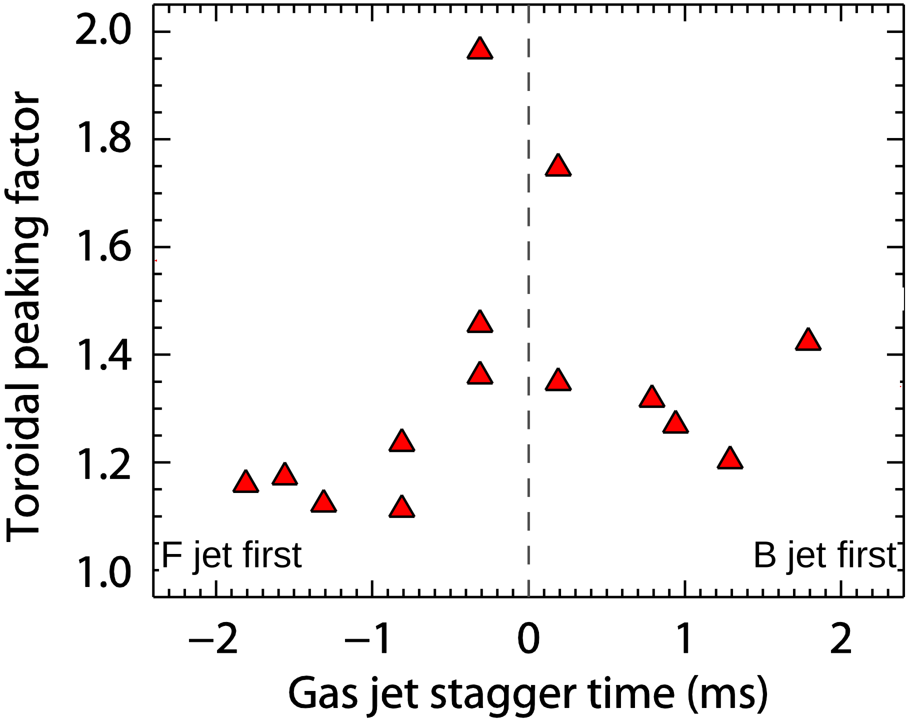


Each of the six individual detectors has identical viewing geometry:

- narrow toroidal slice
- full poloidal cross-section

Gas injection outlets are very close to plasma

Counterintuitively, toroidal radiation asymmetry in the TQ phase is *worse* for synchronous two-jet cases



Implies that P_{rad} asymmetry in the TQ phase is not set just by gas dynamics

- not good news for ITER DMS design

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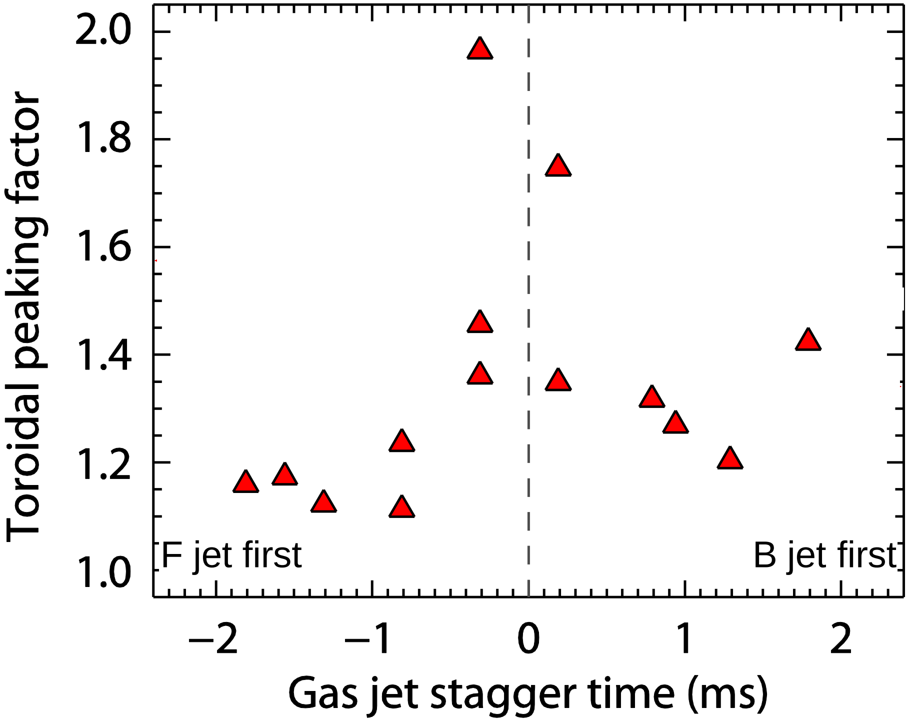

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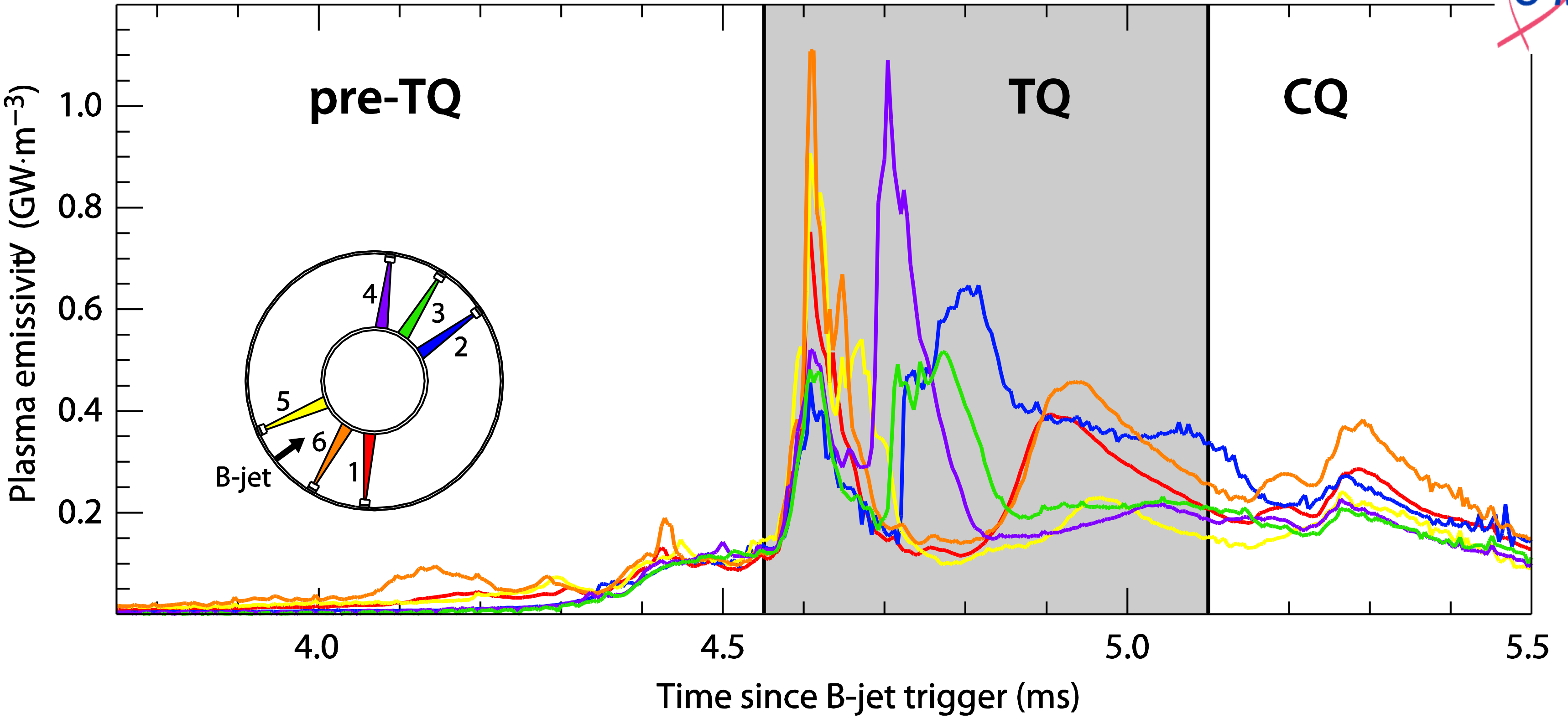
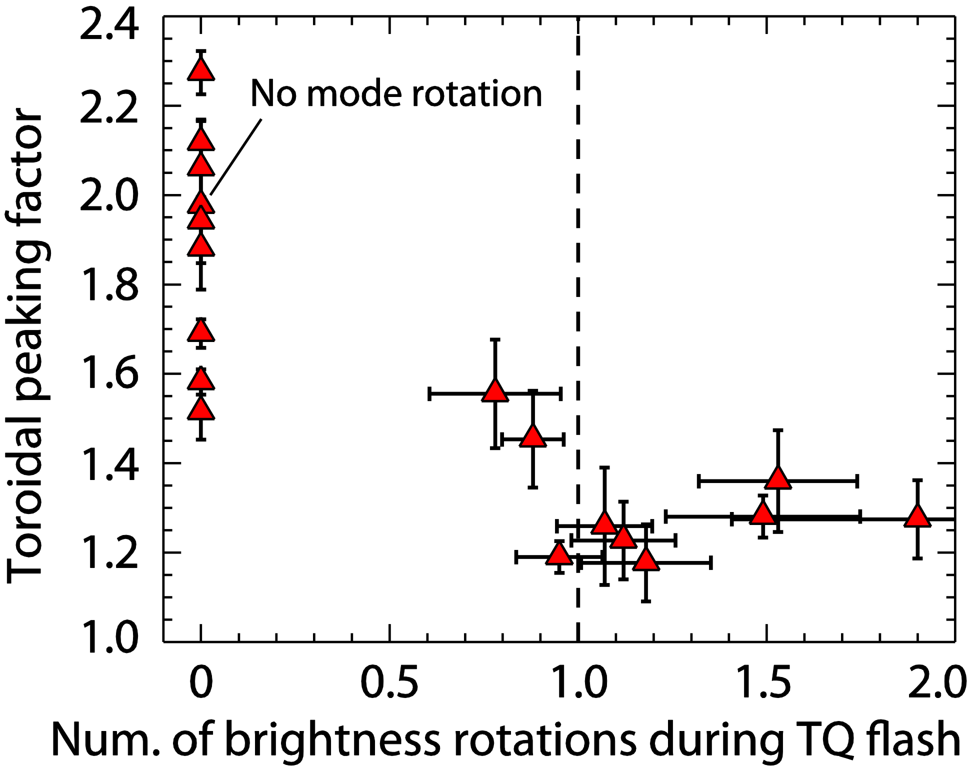
➢ Might the *n* =1 MHD mode be affecting P_{rad} in the TQ phase?

P_{rad} detectors reveal a rotating, toroidally-peaked radiation feature during the TQ phase



- Structure (predominantly *n* =1) and rotation (frequency, direction) of P_{rad} in TQ is very similar to *n* =1 MHD mode in pre-TQ
- Compelling evidence that **MHD is responsible for the radiation asymmetry**

P_{rad} feature does not rotate in all disruptions



- No rotation ⇒ high P_{rad} asymmetry *integrated over TQ*
- Finite rotation ⇒ low P_{rad} asymmetry *integrated over TQ*

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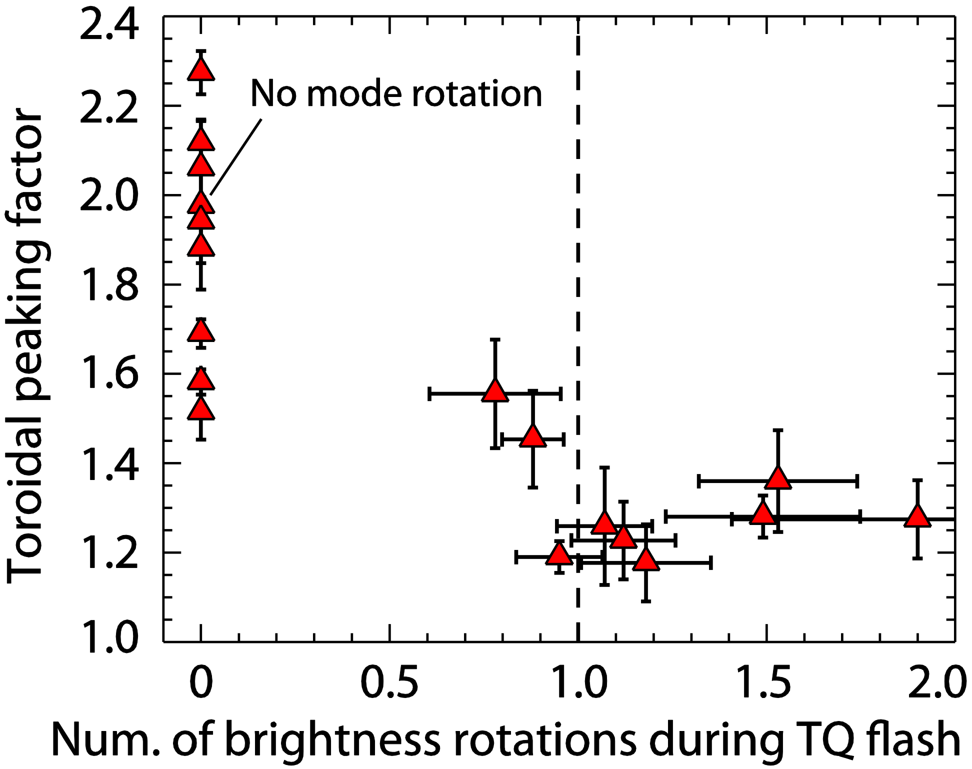

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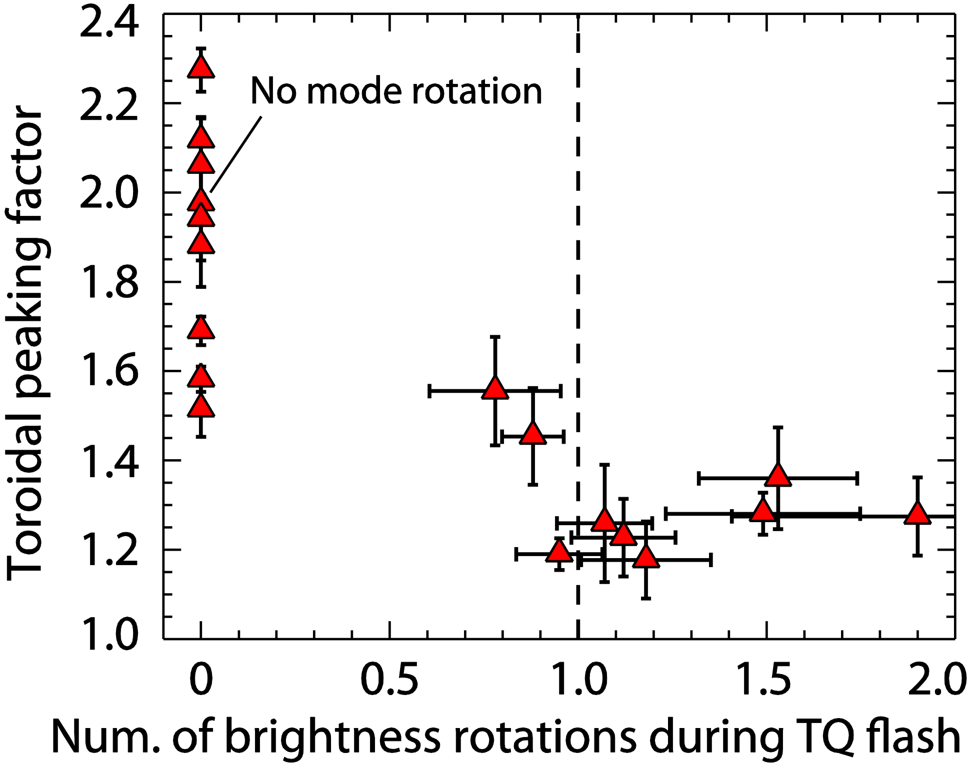

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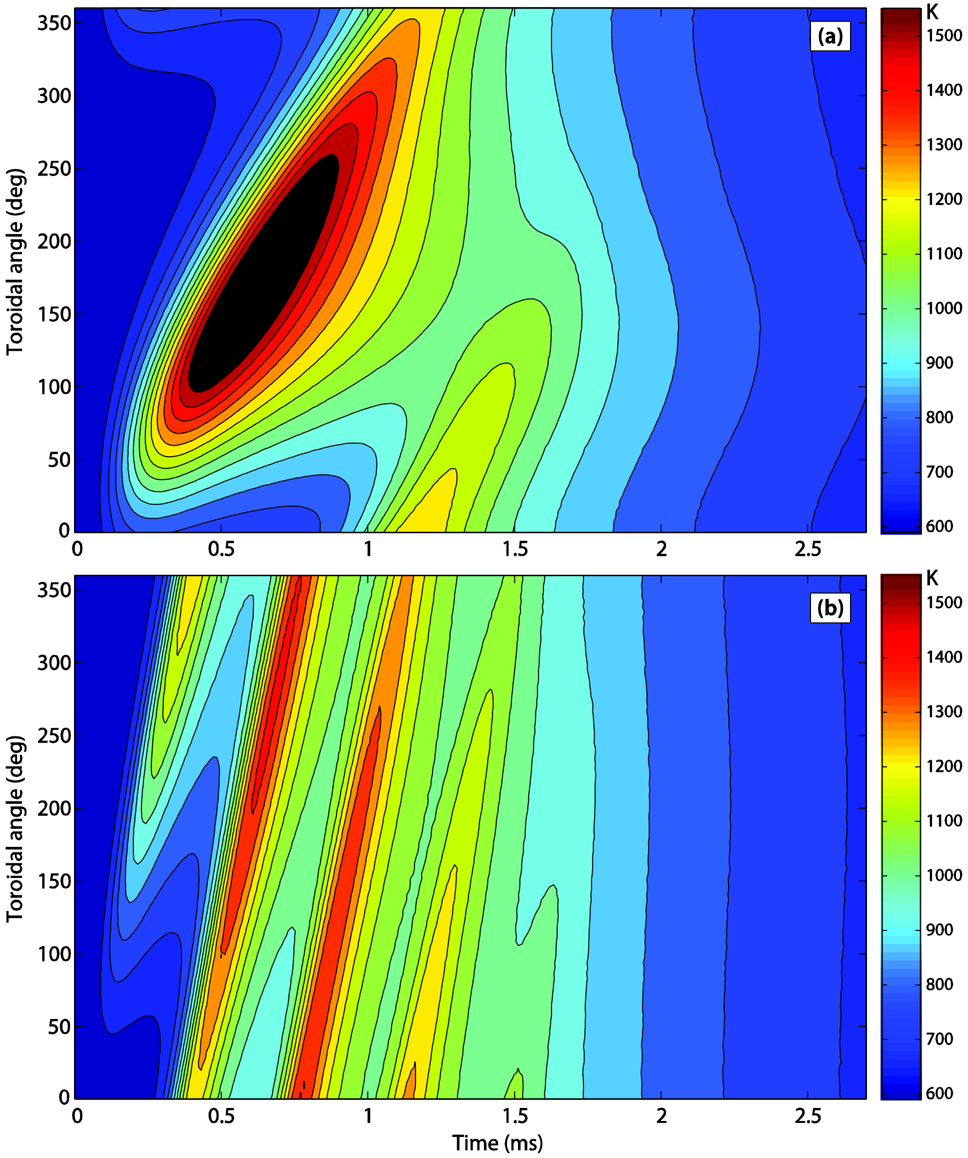
- Finite rotation ⇒ low P_{rad} asymmetry *integrated over TQ*
  - **Analogy to a lighthouse beacon**
- Simultaneous two-jet disruptions tend not to rotate

Rotation can prevent wall melt in ITER even with toroidally peaked radiation



ITER wall temperature assuming instantaneous TPF = 3.0, τ_{TQ} = 1.8 ms, wall temperature 580 K at start of TQ.

a) Slow rotation: one-third of wall melts

Mode rotation 0.9 kHz ($f\tau_{\mathrm{TQ}}$ = 1.6)

b) Fast rotation: no melting

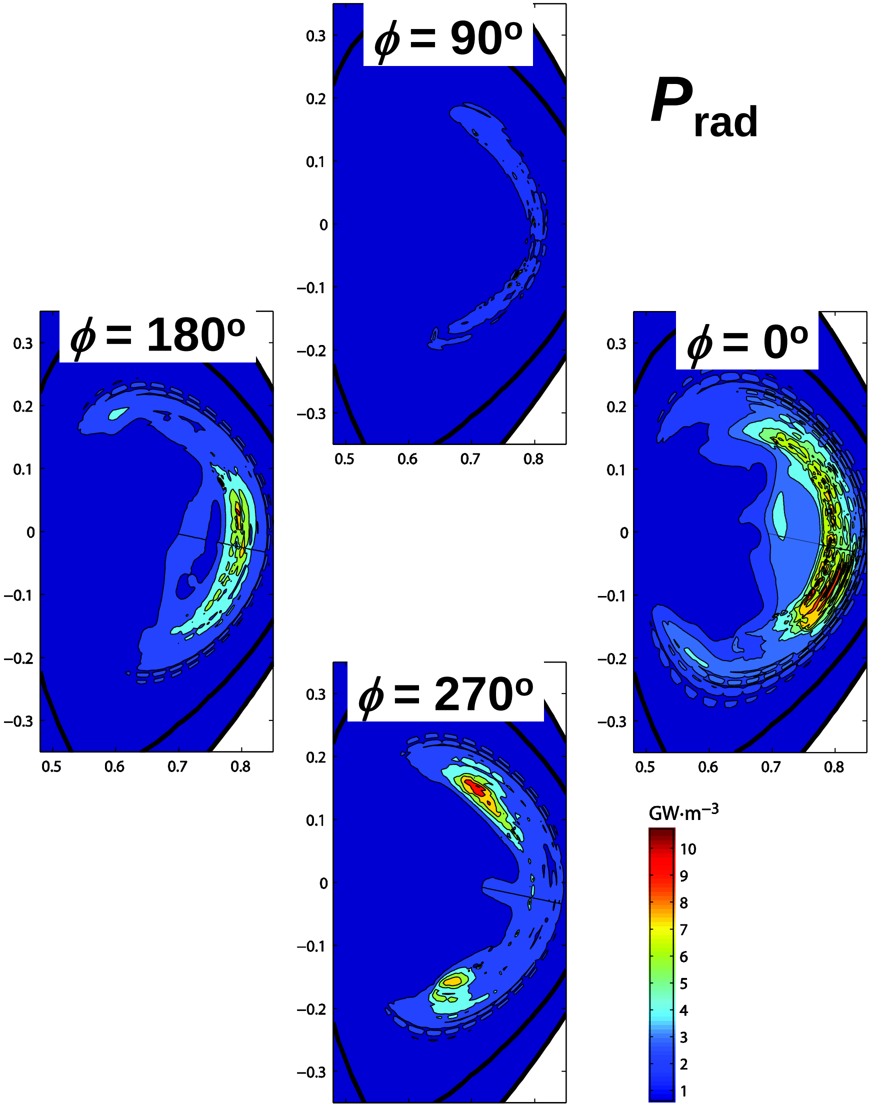
Mode rotation 2.7 kHz ($f\tau_{\mathrm{TQ}}$ = 4.9)

Use NIMROD code to investigate possible link between MHD activity and radiation asymmetry in C-Mod mitigated disruptions

NIMROD solves the extended MHD equations in 3-D toroidal geometry, with accurate impurity radiation energy loss terms. Some initial findings:

- Exponential growth of *n* =1 mode in pre-TQ;
  growth rate consistent with experimental observations
- *n* =1 mode is the dominant magnetic perturbation at the time of the thermal quench

NIMROD result: *n* = 1 MHD mode leads to toroidal asymmetry in radiated power



- Transport of thermal energy from core to impurity-laden mantle generates P_{rad}
- *n* =1 MHD mode distorts transport of W_{th} to mantle
- This results in *n* =1 radiation asymmetry ***even with toroidally symmetric injection of gas in the simulation***

NOTE: rotation is not yet included
in NIMROD simulation

C-Mod results have important implications for disruption mitigation on ITER

- MGI at multiple toroidal locations can control P_{rad} asymmetry during pre-thermal quench, ***but not during thermal quench***
- The C-Mod experimental results and NIMROD modeling show that an n =1 MHD mode is ubiquitous in MGI mitigated disruptions
- The n =1 MHD mode causes toroidal asymmetry in P_{rad}. The toroidal asymmetry may therefore be unavoidable
- BUT, sufficiently fast rotation of the MHD mode during the TQ might prevent localized overheating of the first wall

Suggested research topic:

- What causes rotation of MHD modes during disruptions? Can the rotation be controlled?