Rotation effects in MGI rapid shutdown simulations

V.A. Izzo, P.B. Parks, D. Shiraki, N. Eidietis, E. Hollmann, N. Commaux

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Outline

1. Overview of MHD, radiation asymmetry, and impurity spreading results from non-rotating NIMROD MGI simulations

2. DIII-D observations regarding the role of toroidal rotation in MGI experiments

3. Results from NIMROD simulations with rotation

   → Evolution of the rotation profile

   → Effect on impurity spreading

   → Effect on radiation peaking

4. Summary and Future Work

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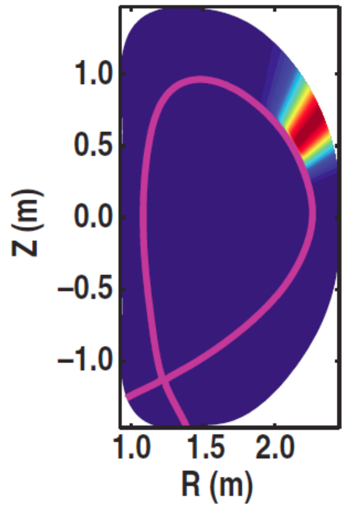
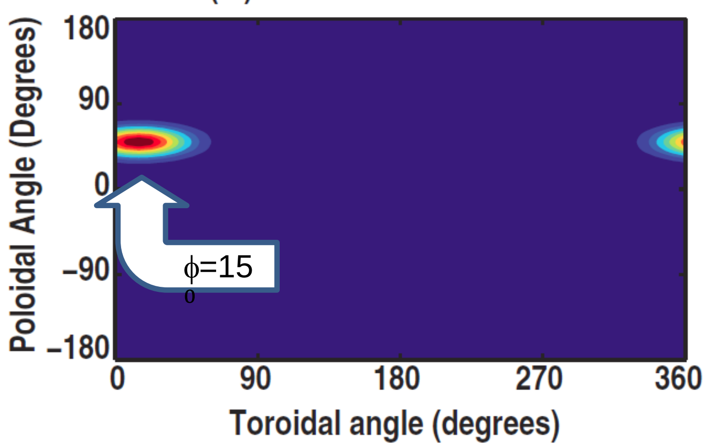
Sequence of events for a (non-rotating) NIMROD MGI simulation: 1) Neutral impurity source turned on



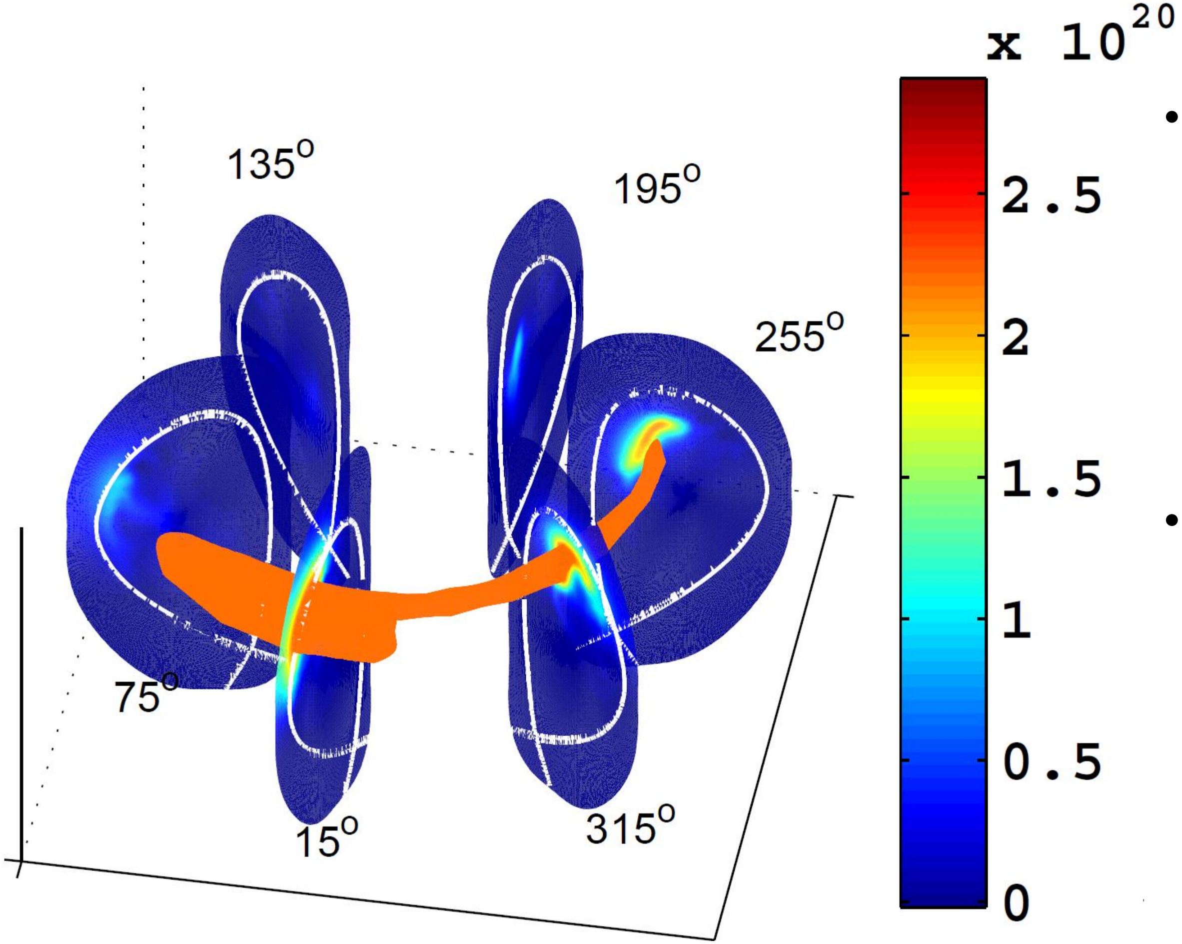
- Impurities are injected as a volumetric source into the region outside the separatrix. They penetrate into the plasma region by diffusion and any radial flows generated during the simulation.

- Cases presented are Ne MGI using only the upper (MEDUSA) SPI valve on DIII-D



- As Ne mixes into the plasma, ionization, recombination and radiation cooling is calculated

2) Ionized Ne spreads helically along field lines



- Spreading is driven by parallel pressure gradient—large $\chi_{||}$ equilibrates T. Pressure gradient roughly density gradient.
- Spreading is asymmetric, strongly preferring propagation toward the HFS poloidally→

2) Ionized Ne spreads helically along field lines

Nozzle equation explains preferential HFS spreading:

Continuity $$\rho AU = \text{constant}$$

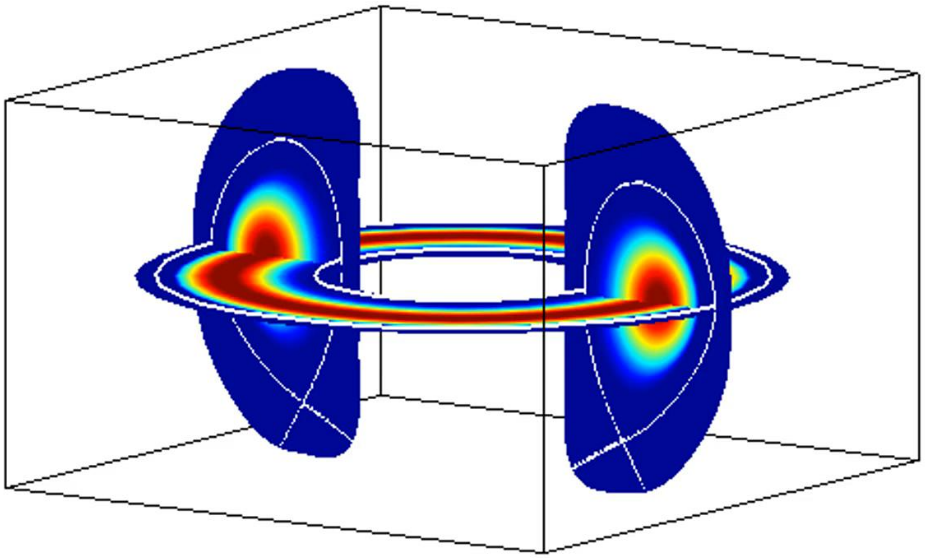
$$BA = \text{constant} \Rightarrow \frac{dr}{r} + \frac{dU}{U} - \frac{dB}{B} = 0$$

Momentum $$\rho U dU = -dp = -(dp/d\rho)d\rho = -C_s^2 d\rho$$

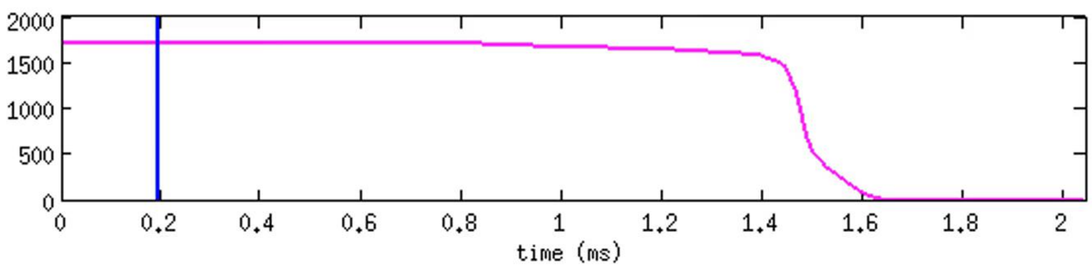
$$\Rightarrow \frac{dU}{U} = \frac{1}{(1-M^2)}\frac{dB}{B}$$

Flow starts at M<1, is thwarted where dB/B<0, accelerates where dB/B>0

3) MHD modes grow and saturate → core thermal quench



m=1/n=1 mode primarily responsible for core TQ, dumps core heat to the radiating edge asymmetrically by convection, not conduction



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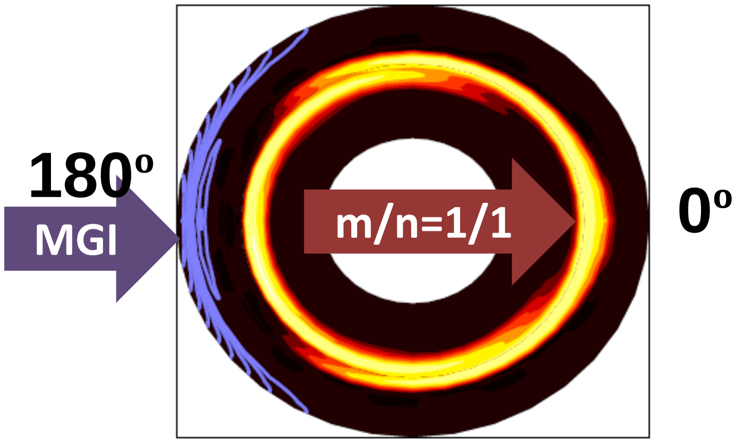
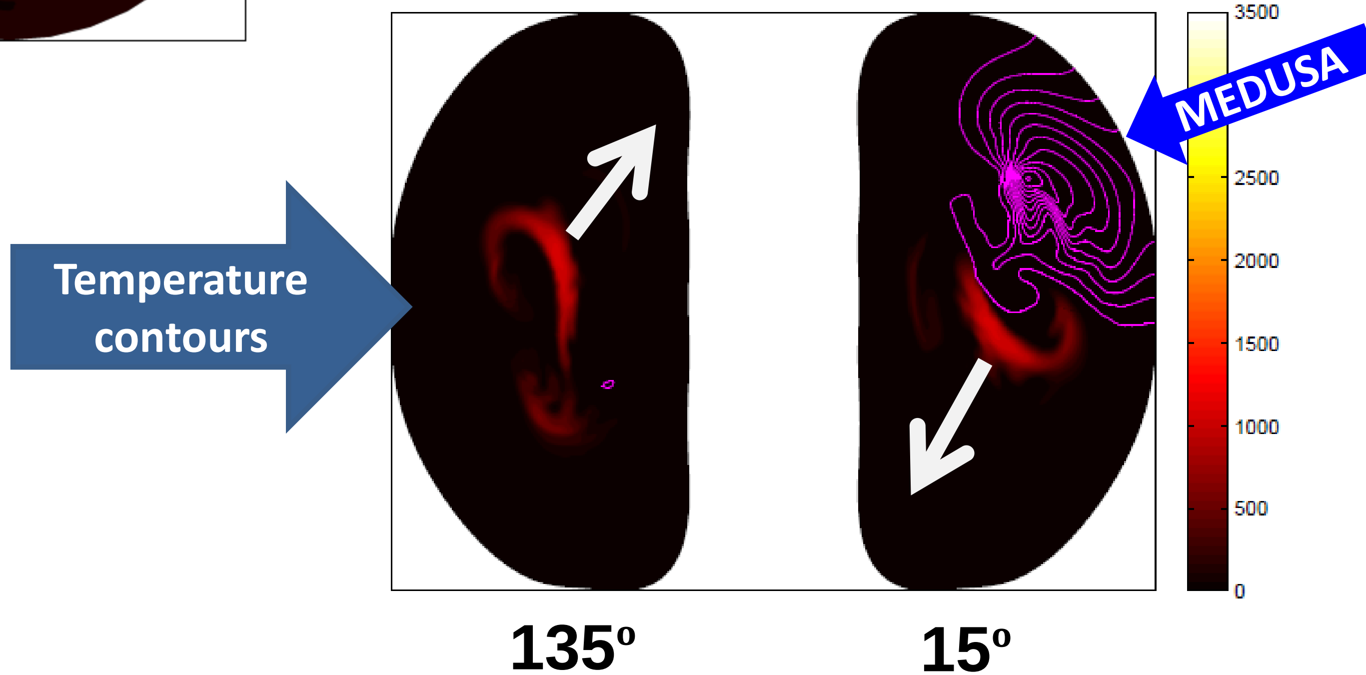
3) MHD modes grow and saturate → core thermal quench



Absent plasma rotation, 1/1 mode dumps core heat directly away from gas injection location→ counterintuitive result that radiation is peaked 180° away from gas jet



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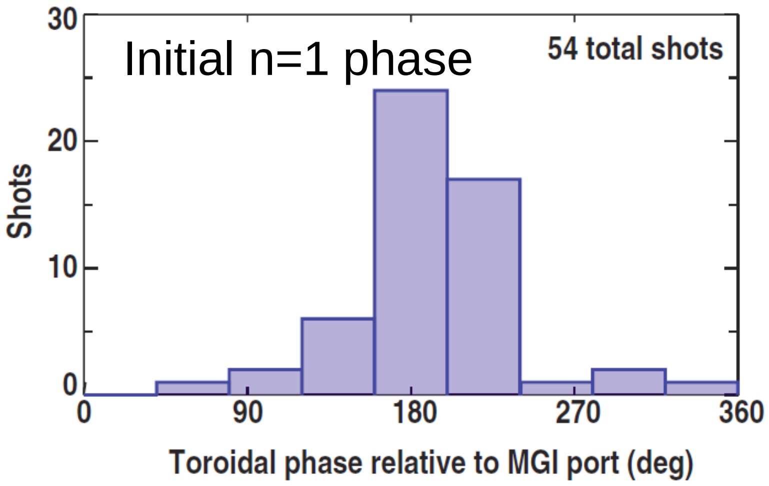
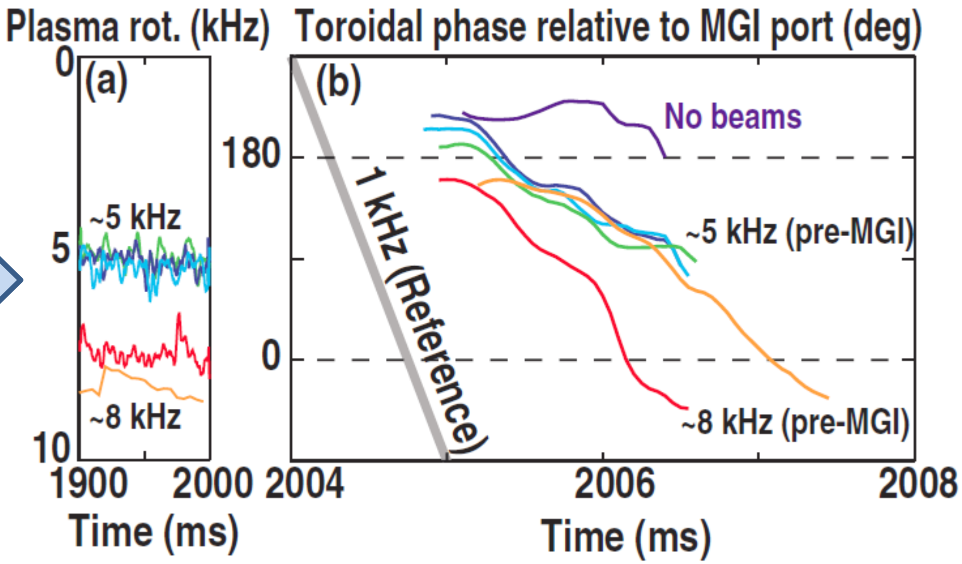
DIII-D experiments: Initial n=1 phase corresponds to NIMROD prediction, then phase rotates



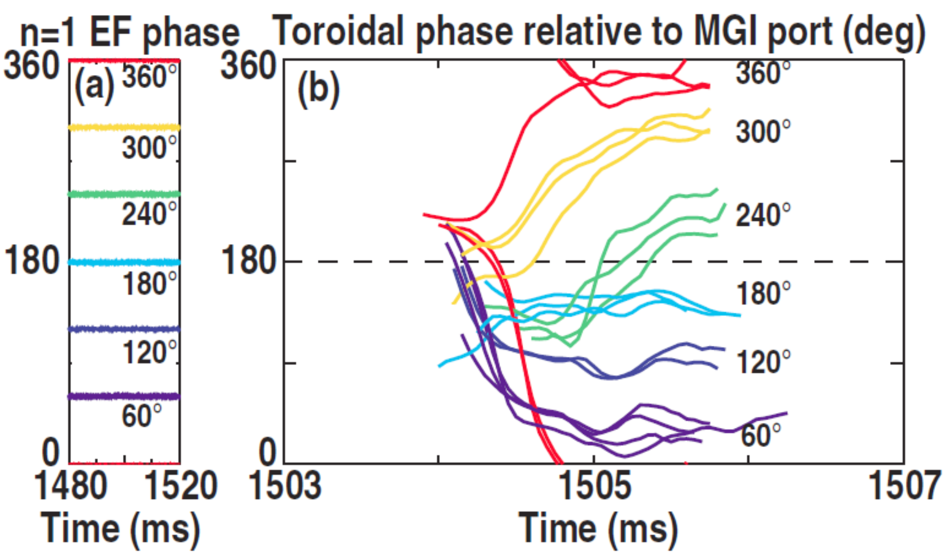
Phase of n=1 mode when it first appears (prior to the TQ) is 180 degrees from gas jet location, in agreement with NIMROD prediction

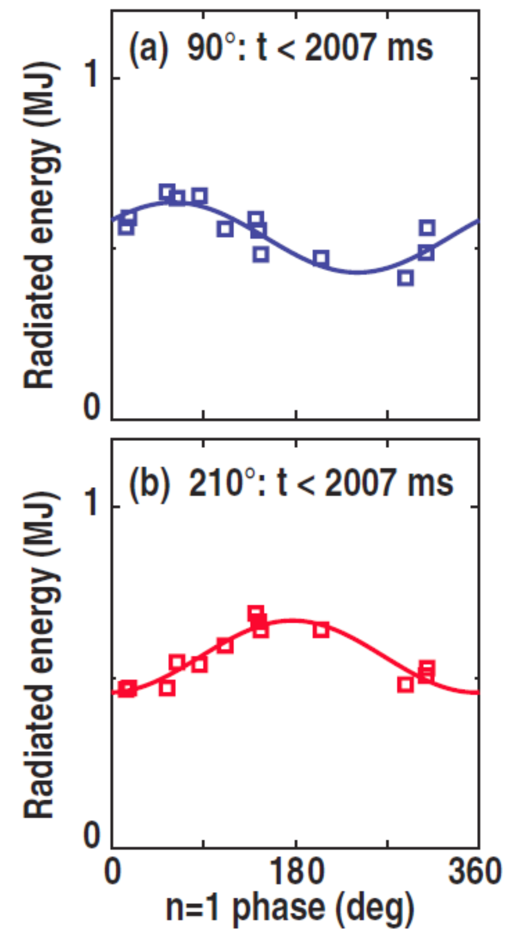
Between initial appearance and TQ, n=1 phase rotates. Higher pre-MGI plasma rotation → more pre-TQ mode rotation



DIII-D experiments: n=1 phase at TQ can be controlled with error fields (particularly at low rotation)

Use of error fields to control final phase of mode is useful to measure radiation toroidal peaking factor with limited diagnostic set. Same TPF found at 90 and 210 degrees suggests impurity distribution not a large factor in TPF (uniform?)





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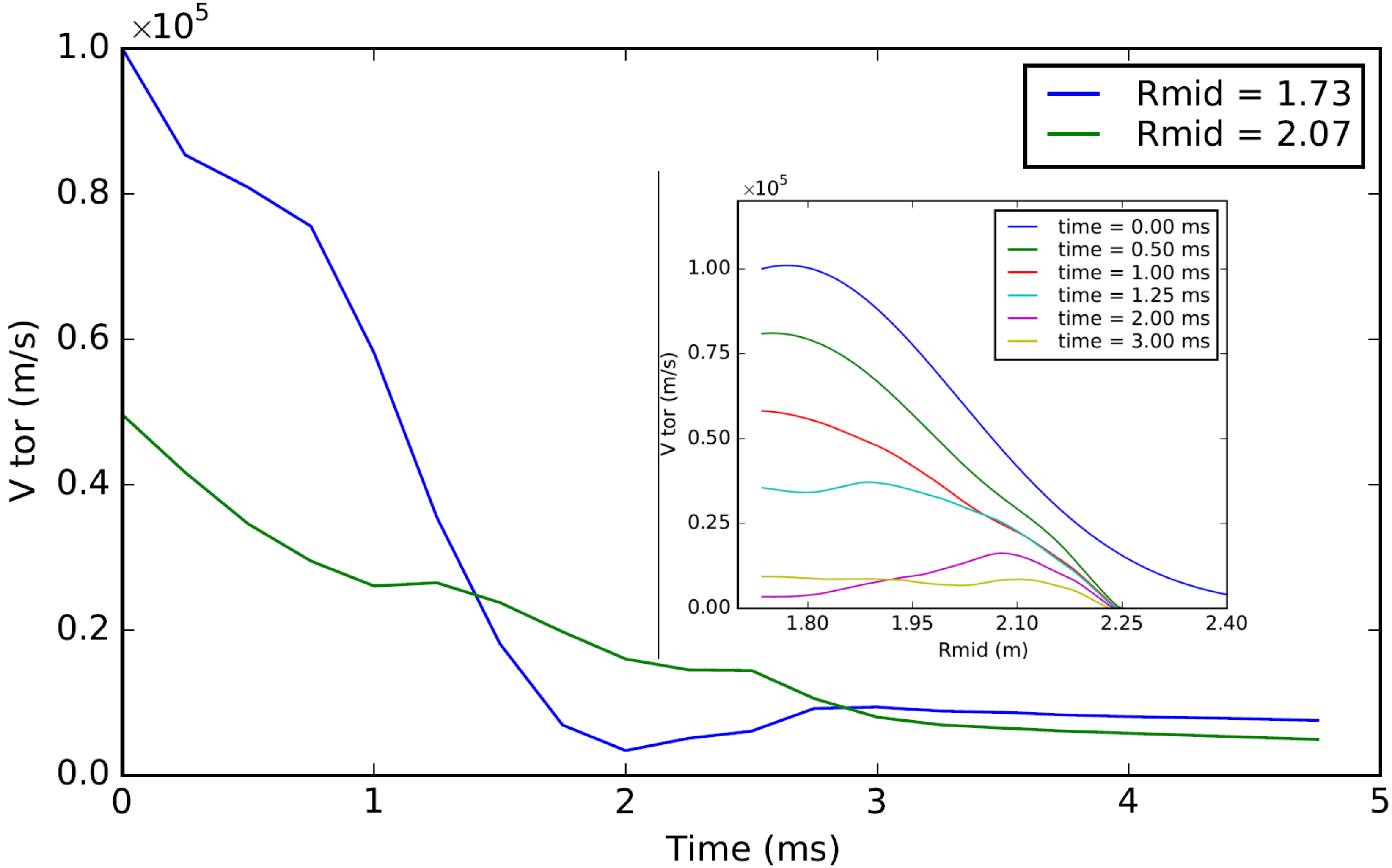
Sharp drop in core rotation, slight uptick in edge



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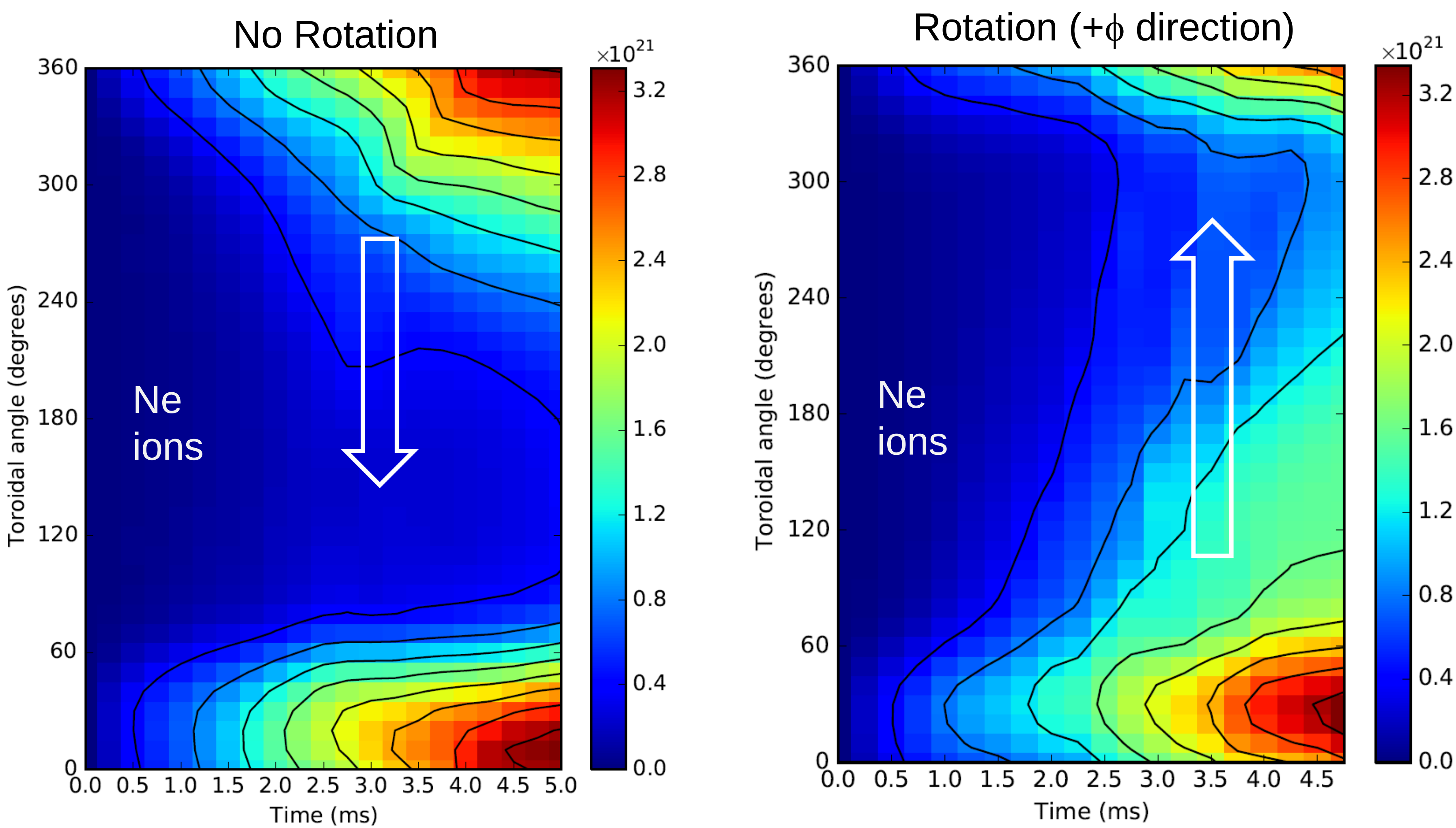
Impurity spreading follows rotation direction (reverse of stationary case)



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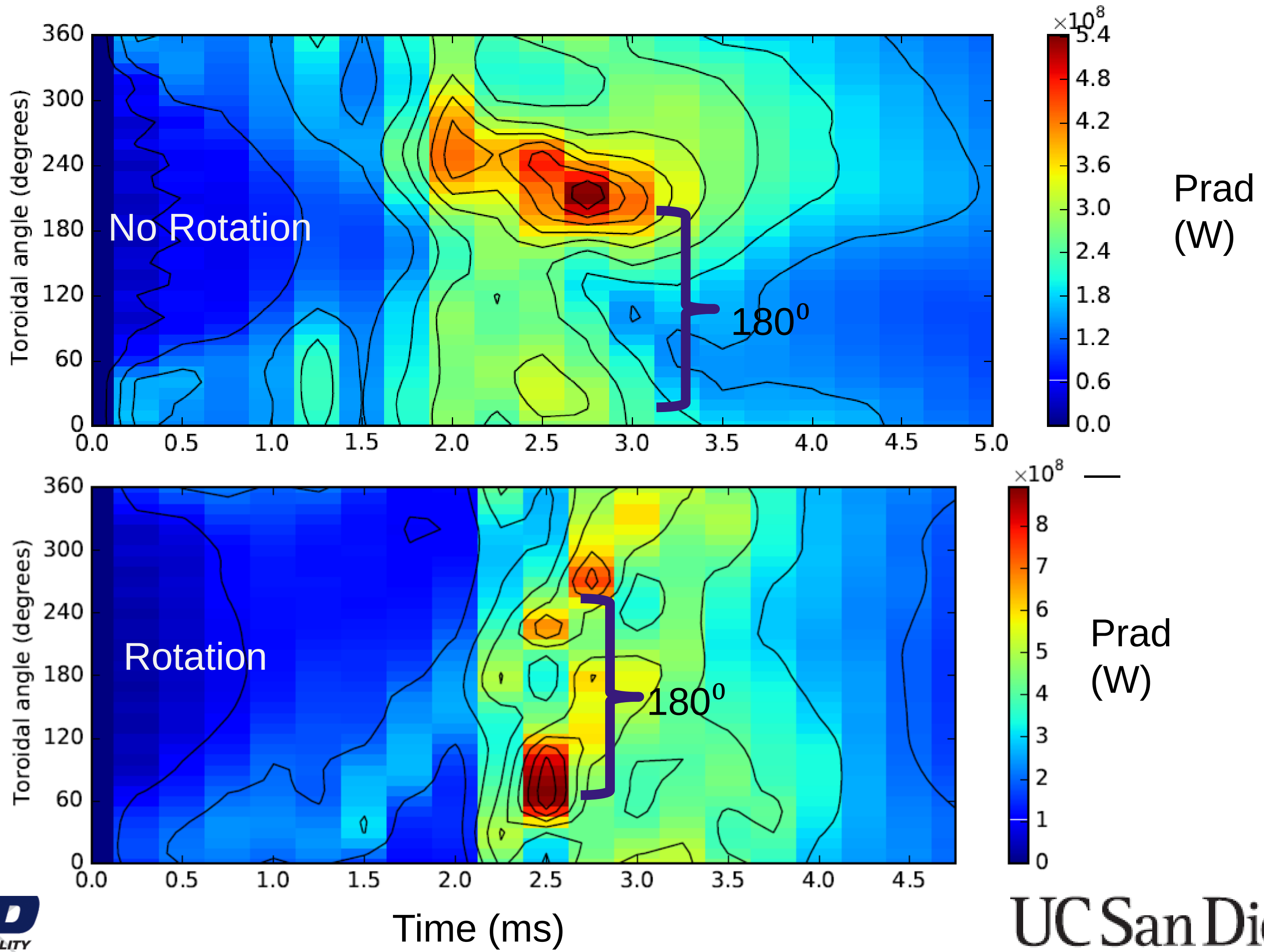
Rotating structure appears beginning at jet location, TQ flash is ~180^0 from structure phase at TQ time



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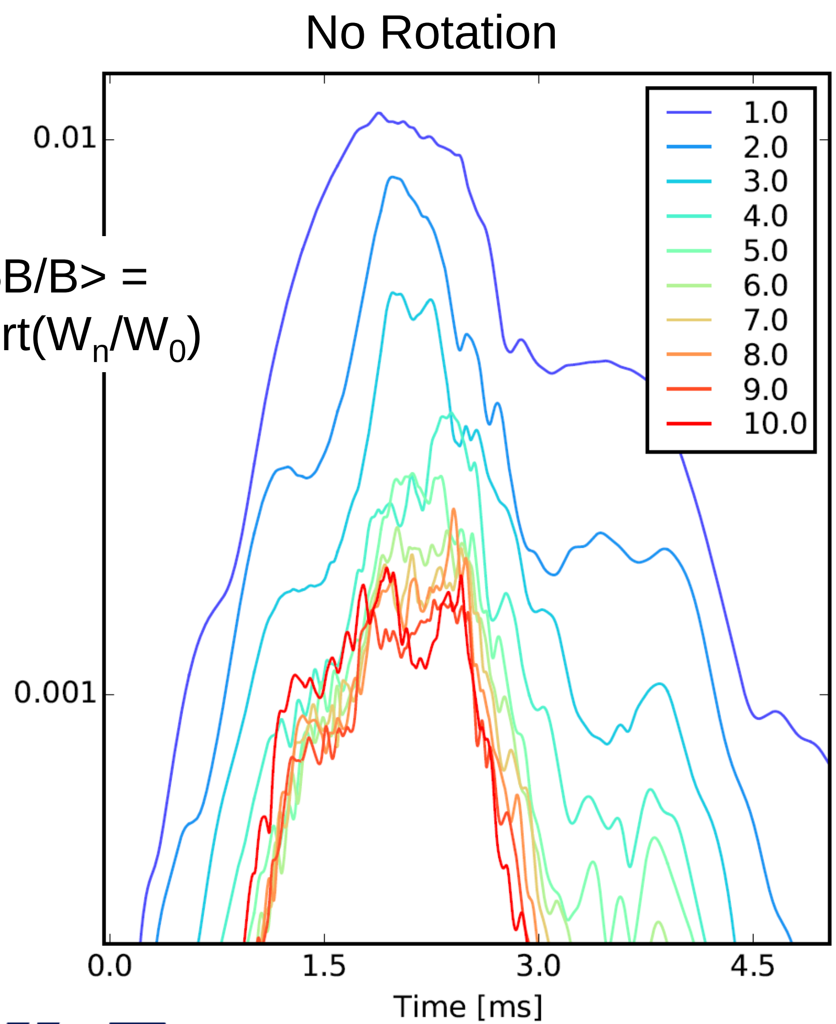
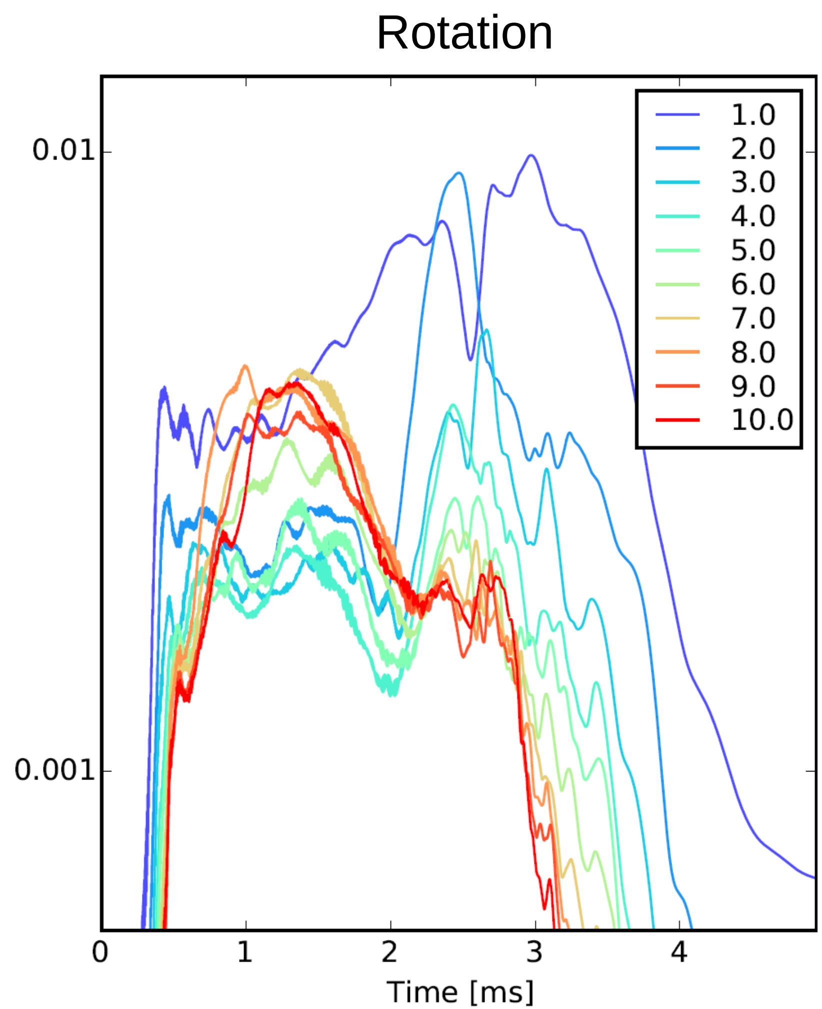
MHD activity is more complicated in the rotating case

$\langle \delta B/B \rangle = \mathrm{sqrt}(W_n/W_0)$





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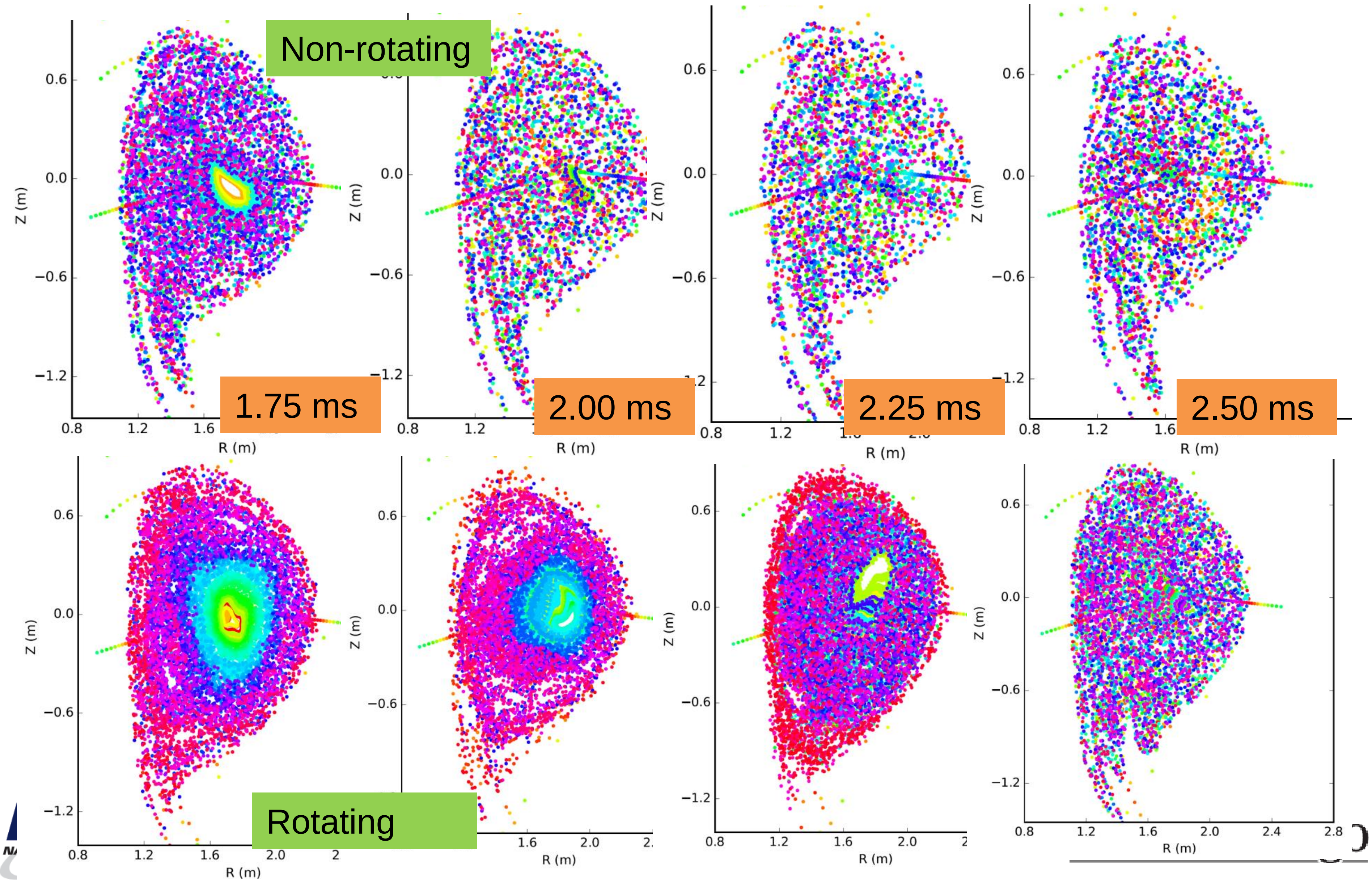
Field lines show fully stochastic fields at time of TQ- later for rotating case



Some preliminary conclusions on the effects of rotation

- Direction of impurity spreading reverses to align with rotation direction, and impurities spread more quickly overall

- Core rotation drops rapidly before significant impurities reach the core.

- Thermal quench onset is somewhat delayed, and TQ shorter in duration. Well defined spike in radiated power more consistent with measurements.

- Evolution of P_{rad} seems consistent with DIII-D magnetics analysis: mode is born aligned with gas jet and rotates, determining toroidal location of P_{rad} maximum

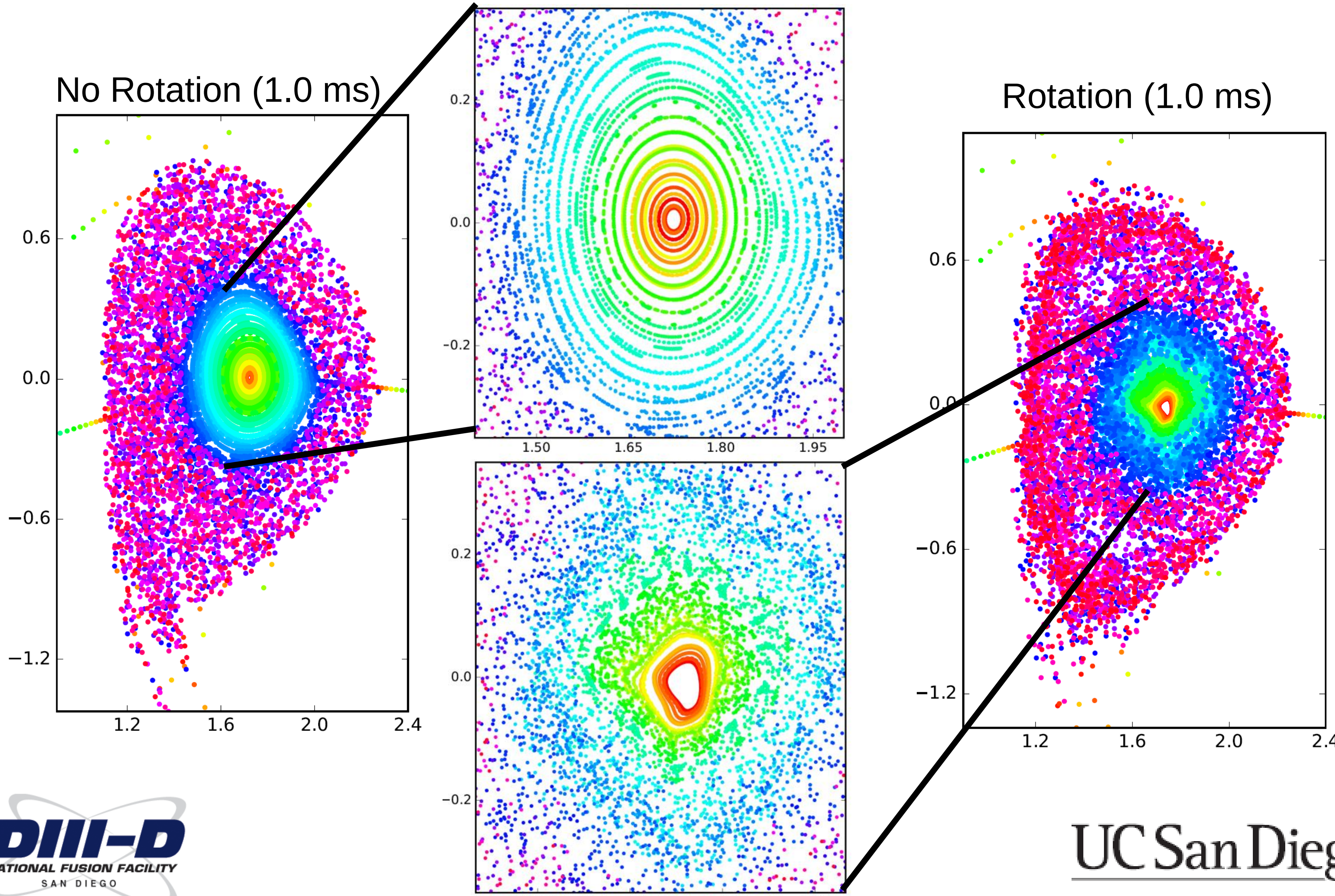
Some questions and future work

- Why does radiation pattern begin rotating at 1.5 ms?
- How does interaction of various modes effect the rotation profile?
- What is the role of the higher-n modes in the rotating case?

Future work:

- Do detailed magnetics analysis to separate m/n components
- Examine effects of viscosity in rotating simulation with no MGI

Significant effect of higher n modes in the core



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