Disruption Avoidance via RF Current Condensation

ID: xxx

A. Reiman[1], N. Bertelli[1], N. Fisch[1], S. Frank[2], S. Jin[1], R. Niess[1], E. Rodriguez[1]

[1]*Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ*

[2]*MIT, Cambridge, MA*

reiman@pppl.gov

To discuss this poster, please contact me via zoom at https://pppl.zoom.us/j/99835999288 between 12PM and 4PM ECT

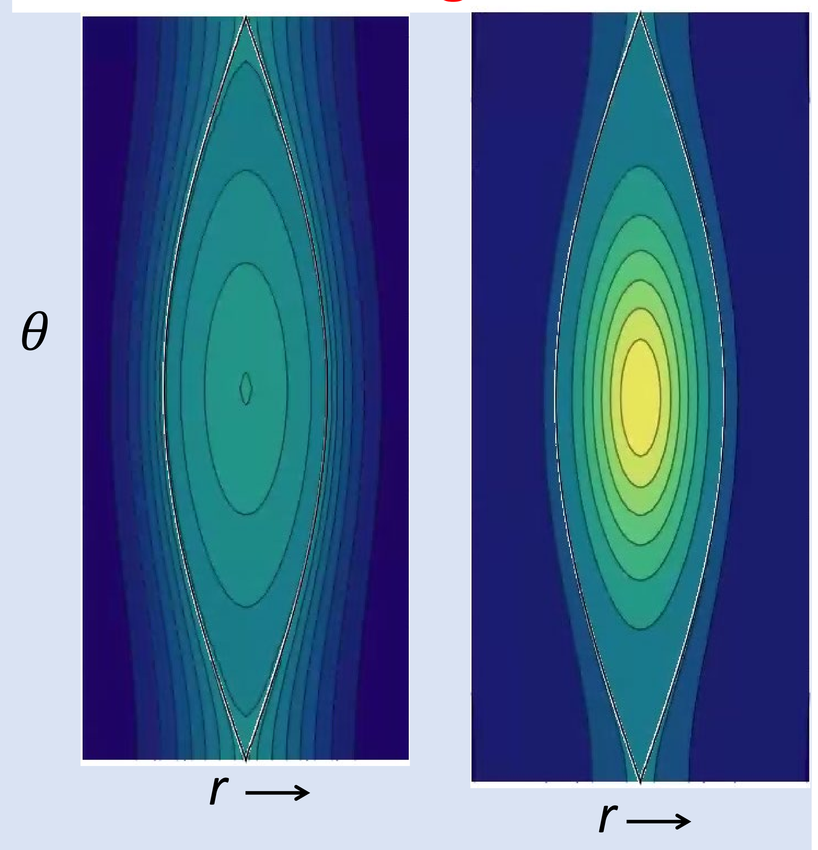
ABSTRACT

- ITER will tolerate a limited number of mitigated disruptions.
- We are interested in developing a capability to stabilize large islands via RF driven currents to avoid the need for mitigation to the extent possible.
- Nonlinear effects come into play when stabilizing large islands:
  - A nonlinear "RF current condensation" effect can concentrate current near magnetic island O-point and aid stabilization.
  - A nonlinear "shadowing" effect can hinder stabilization if aiming of ray trajectories does not account for nonlinear effects.

BACKGROUND

- 95% of the disruptions in JET are preceded by appearance of large islands (Gerasimov et al, IAEA FEC 2018) .
- Statistical analysis of 250 disruptions on JET found distinct locked mode amplitude at which plasma disrupted (de Vries et al, Nucl. Fusion, 2016).
  - Further analysis concluded that W/a ≈ 0.3 is threshold.
  - Suggests that there is time to stabilize them.
  - Suggests that islands are playing key role in triggering disruptions.
- An important example: In disruptions triggered by impurity accumulation and radiation in plasma core, growth of large island is typically the direct trigger for the disruption.
- ECCD stabilization studies for ITER have focused on routine stabilization of small islands produced by NTMs.
- We should be prepared to deal with large islands in ITER.
- When large islands are stabilized by significant levels of EC power, nonlinear effects can come into play.

Sensitivity of current drive and power deposition to small change in temperature can give rise to "RF current condensation".



- Temperature perturbation in island increases power deposition there.
- Gives nonlinearly enhanced temperature perturbation.
- Sensitivity of current to temperature perturbation concentrates it near center of island.
- **Increases contribution to resonant component of field, providing more efficient stabilization.**

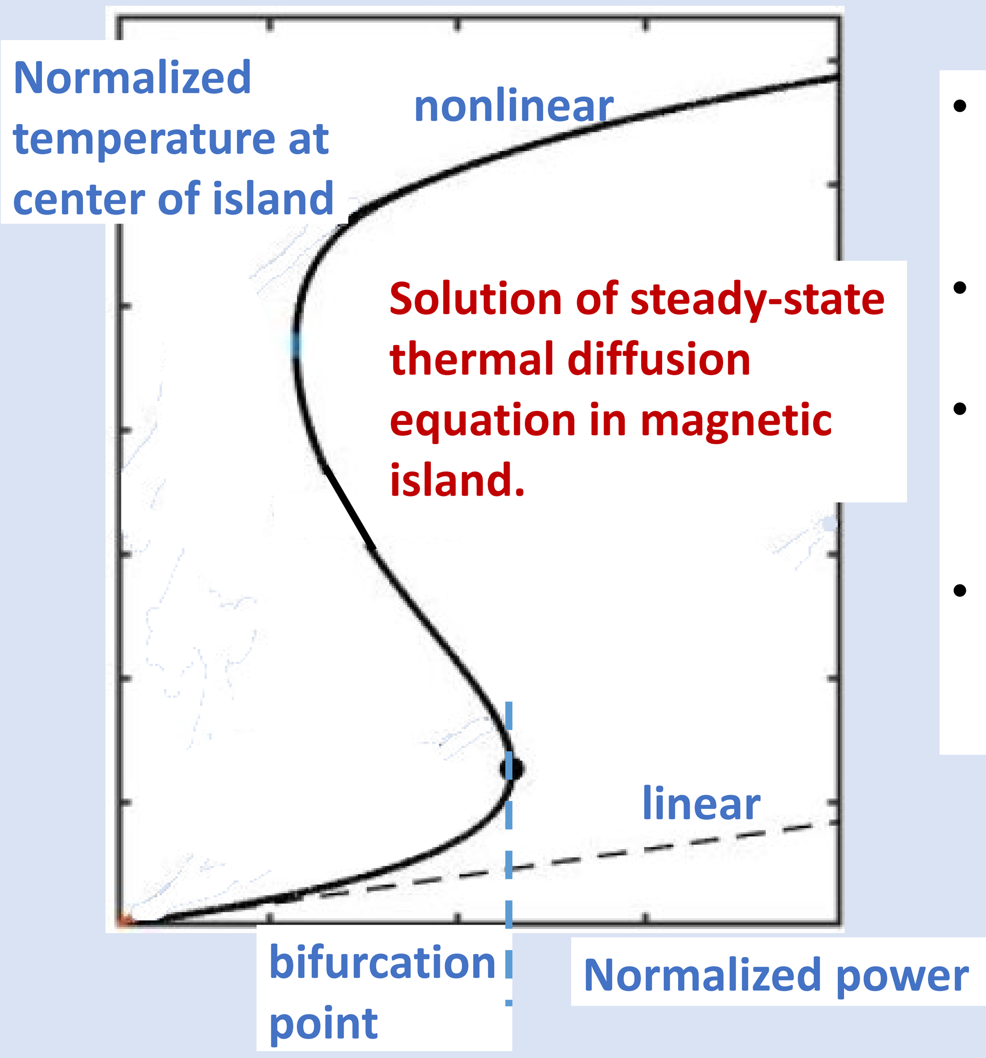
A. Reiman and N. Fisch, Phys. Rev. Lett. 121, 225001 (2018).

In electron-cyclotron current drive (ECCD) and lower hybrid current drive (LHCD), energy deposited on electron tail → deposition sensitive to temperature.

- Number of resonant electrons Maxwellian: number (and power deposition) $\propto \exp\left(-V_p^2/V_T^2\right)$, with V_T thermal velocity, V_p phase velocity.
- Let $T = T_0 + \tilde{T}$, with T_0 unperturbed temperature, and let $w \equiv V_p/V_T$. Then $P_{RF} \propto \exp(-w^2) = \exp(-w_0^2)\exp\left(w_0^2\,\tilde{T}/T_0\right)$, w_0 unperturbed w.
- Typically, $w_0^2 \gg 1$ so can get strong effect even for $\tilde{T}/T_0 \ll 1$.
- Relativistic effects complicate the picture, but exponential dependence still generally a good approximation.

We define an effective $\bar{w}_0^2$ as a diagnostic in numerical calculations.

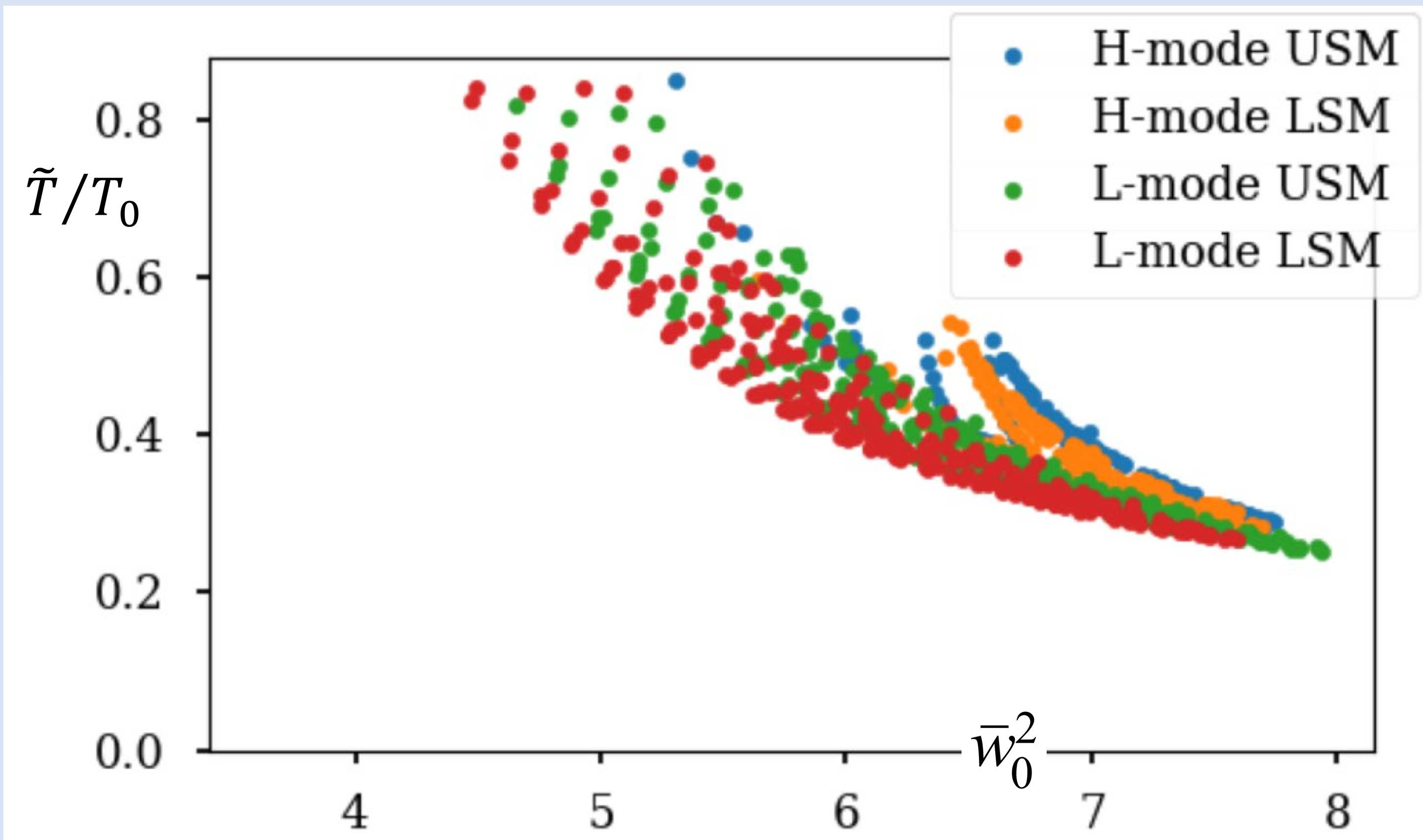
The solution of the nonlinear steady-state thermal diffusion equation in the island can display a bifurcation.



- With exponential dependence of power deposition, get nonlinear thermal diffusion equation in island.
- Solution of steady-state equation displays bifurcation.
- Above bifurcation point, time-dependent solution rises until additional physics enters.
- Rise in temperature can be saturated by depletion of energy in wave, or by stiffness encountered at microinstability threshold.

Optimal stabilization strategy must account for, and take advantage of, nonlinearity.

- Increasing toroidal launch angle will increase current drive efficiency for stabilizing larger islands.
- Can compensate for broadened deposition with RF current condensation.
- A simulation capability has been developed that couples GENRAY ray tracing and power deposition with solution of thermal diffusion equation in magnetic island.



Calculation scans toroidal and poloidal launch angles in ITER, calculating associated $\tilde{T}/T_0$ and $\bar{w}_0^2$ at bifurcation.

Nonlinear effects become important at $\tilde{T}/T_0$ about 1/3 that at bifurcation.

CONCLUSION

- To minimize (mitigated) disruptions on ITER, it will be desirable for the upper EC launcher to be steerable in the toroidal angle to increase current drive efficiency.
- RF current condensation effect can compensate for broadened deposition at larger toroidal launch angles
- Will need appropriate aiming of ray trajectories to avoid nonlinear shadowing.
- Experiments are needed to validate the nonlinear theory.
- The apparent prevalence of disruptions triggered by large islands in JET suggests that targeting large islands via ECCD stabilization could have major impact on frequency of disruptions.

REFERENCES

A. H. Reiman and N. J. Fisch, Phys. Rev. Lett. 121, 225001 (2018).

E. Rodriguez, A. H. Reiman and N. J. Fisch, Phys. Plasmas 26, 092511 (2019).

E. Rodrıguez, A. H. Reiman, and N. J. Fisch, Phys. Plasmas 27, 042306 (2020).

S.J. Frank, A.H. Reiman, N.J. Fisch and P.T. Bonoli, Nucl. Fusion 60, 096027 (2020).

S. Jin, N. J. Fisch, and A. H. Reiman, Phys. Plasmas 27, 062508 (2020).

R.Nies, A.Reiman, E.Rodriguez, N.Bertelli and N.Fisch, Phys. Plasmas 27, 092503 (2020).