Examination of Current Profiles in Magnetic Islands During RF Current Condensation

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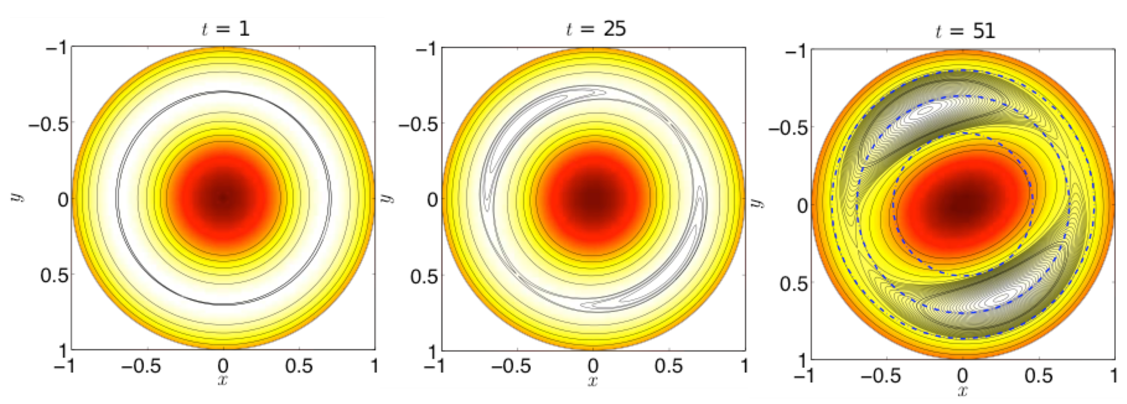
Magnetic islands degrade confinement in fusion devices

- Magnetic islands are formed by the tearing of toroidally nested flux surfaces



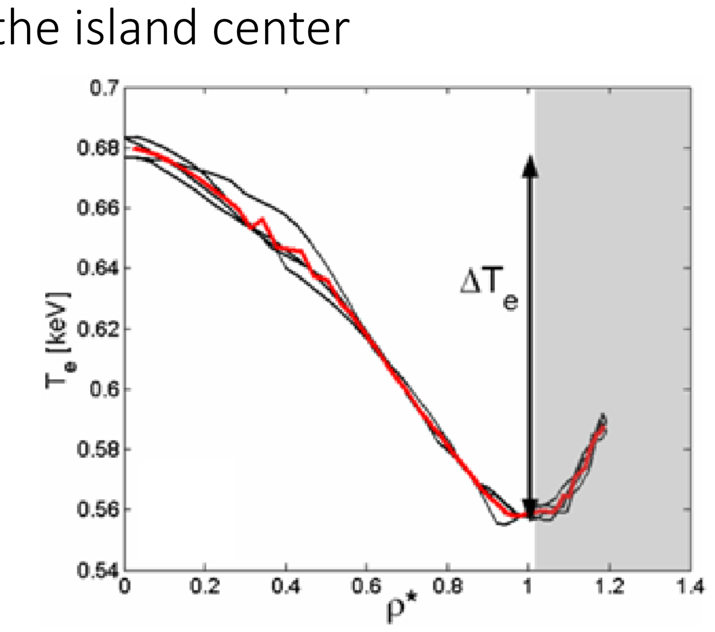
Formation of magnetic islands in a tokamak.
Image credit: Qian Teng

- Magnetic islands are thought to be destabilized by a loss of bootstrap current
- Islands can be stabilized by driving current directly into their centers
- Typically, electron cyclotron current drive (ECCD) and lower hybrid current drive (LHCD) are used
- However, radio frequency (RF) driven current needs to be constantly readjusted to accommodate island formation and movement

The *RF current condensation effect* could stabilize magnetic islands without the need for precise steering of waves

- Both electron cyclotron and lower hybrid waves deposit the most power where electron temperature is greatest
- In a magnetic island, electron temperature is greatest at the island center

Temperature in a magnetic island as a function of normalized island radius.
Image credit: I. G. J. Classen

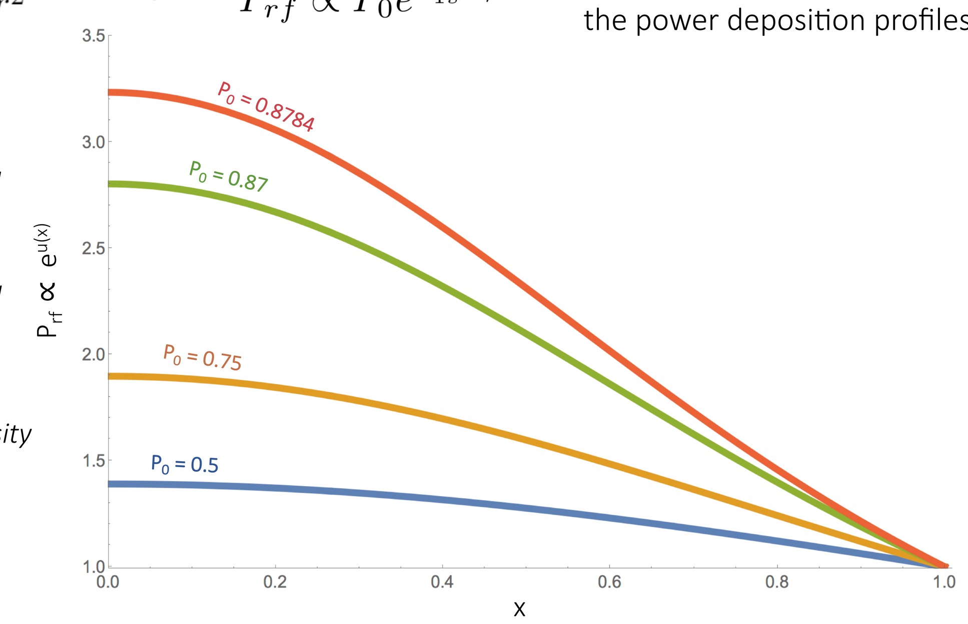


- As a result, ECCD and LHCD should naturally deposit more power at the island center
- This should cause electron temperature to increase further, resulting in a positive feedback loop and the *RF current condensation effect*

Constant power density results in noticeable current condensation at the island center

- Assume that the power density available for absorption by the island is constant
  - Steady-state diffusion equation in 1D slab island: $$n\kappa_\perp \frac{\partial^2 T}{\partial r^2} = -P_{rf}$$
  - Power dissipated in the island for constant power density: $$P_{rf} \propto P_0 e^{\omega_{1s}^2 \tilde{T}/T_s}$$
  - Setting $u \equiv \omega_{1s}^2 \tilde{T}/T_s$ and normalizing other variables, can solve the diffusion equation for u(x) to obtain the power deposition profiles

Normalized power deposition profiles in a magnetic island for constant power density

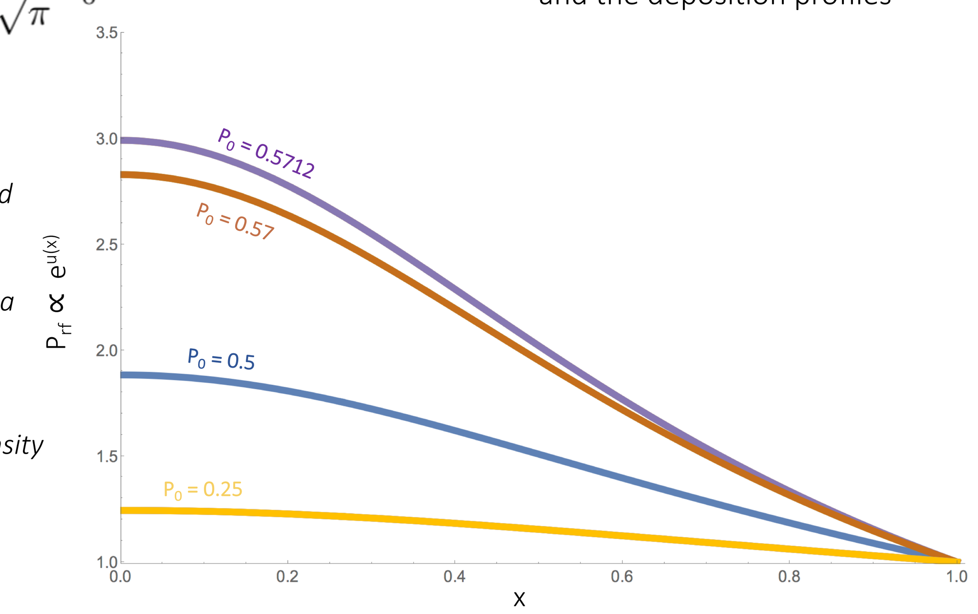


- Constant power density demonstrates notable current condensation at the island center

Gaussian power density causes similar power deposition at center as constant power density case

- Assume that the power density takes the form of a Gaussian, centered at the island center
  - Power dissipated for Gaussian power density of e^{-4x^2}: $$P_{rf} \propto \frac{4}{\sqrt{\pi}} P_0 e^{-4x^2} e^{\omega_{1s}^2 \tilde{T}/T_s}$$
  - Employing the same diffusion equation and process as the constant case, can obtain u(x) and the deposition profiles

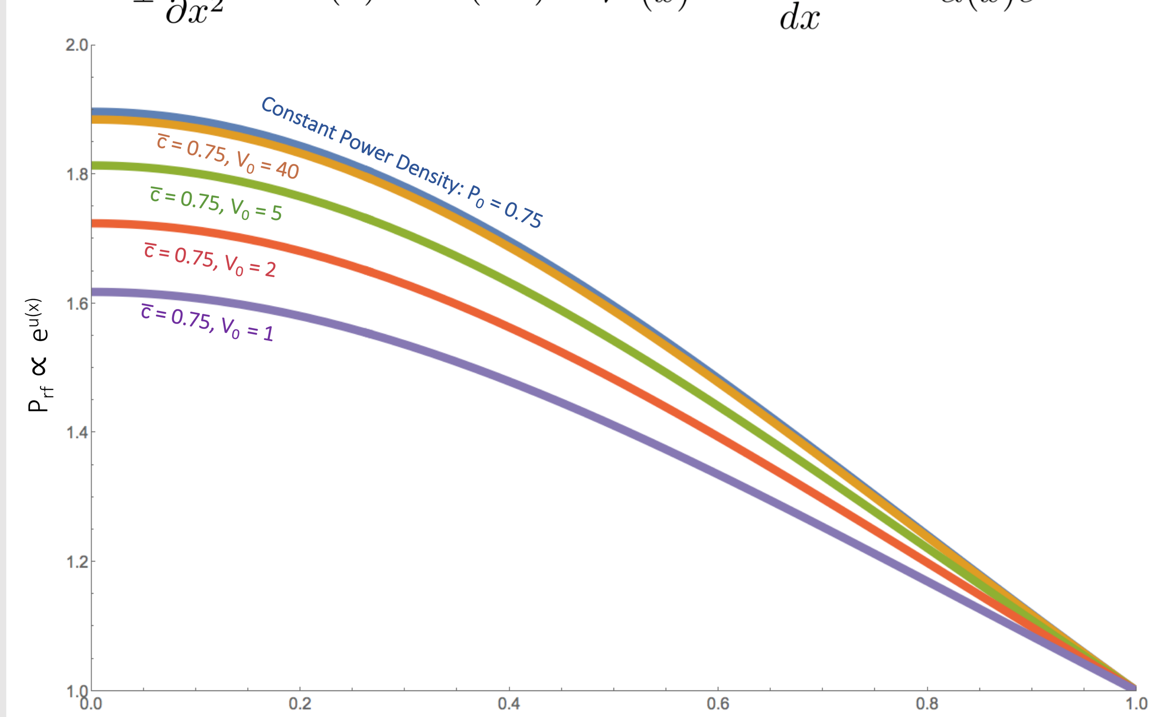
Normalized power deposition profiles in a magnetic island for Gaussian power density



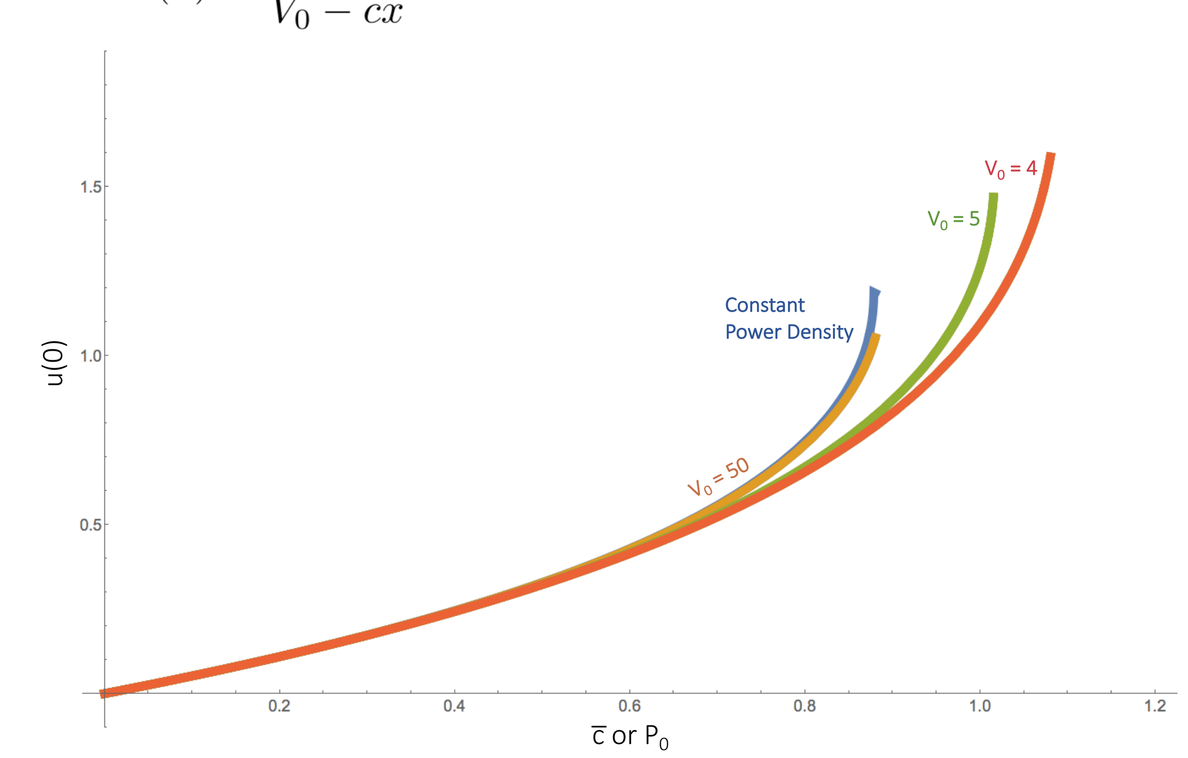
- Gaussian power density also exhibits significant current condensation at the island center

Accounting for wave depletion can result in shifting of the bifurcation point and heightened current condensation at the island center

- Wave depletion model accounts for the energy lost by the RF waves as they travel through the island
- Results in a more realistic treatment of the power deposition than the above approaches
  - Steady-state diffusion equation, with wave depletion: $$n\kappa_\perp \frac{\partial^2 T}{\partial x^2} = \overline{V}'(x) + \overline{V}'(-x)$$
  - Change in energy density of the RF wave: $$\overline{V}'(x) = \frac{d\overline{V}(x)}{dx} = -\alpha(x) e^{\omega_{1s}^2 \tilde{T}/T_s} \overline{V}$$
  - Spatial damping of the wave in the linear limit: $$\alpha(x) = \frac{\bar{c}}{V_0 - \bar{c}x}$$
  - Setting $u \equiv \omega_{1s}^2 \tilde{T}/T_s, V \equiv \omega_{1s}^2 \overline{V}/(n\kappa_\perp T_s)$, and neglecting V′(-x), can solve the diffusion equation for u(x) to obtain the power deposition profiles



Normalized power deposition profiles for both constant power density and wave depletion models



u(0) as a function of either $\bar{c}$ or P_0, where u(0) is the value of u at the island center. The curves end at their respective bifurcation points

- As V_0 increases, wave depletion profiles approach constant power density profiles
- For small V_0, wave depletion shifts the bifurcation point and can allow for greater current condensation at the island center

RF current condensation holds potential for stabilization of islands

- All three scenarios examined demonstrate noticeable current condensation at the island center
- Wave depletion for large V_0 recovers the constant power density deposition profiles
- Wave depletion for small V_0 can allow for increased current condensation
- Wave depletion above the bifurcation point could result in even greater current condensation at the island center

Future work

- Further explore the impact of V_0 on the bifurcation threshold
- Explore deposition profiles above the bifurcation threshold
- Construct profiles including the symmetrizing term, V′(-x)
- Experimentally verify the existence of the RF current condensation effect in a tokamak

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References

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