Perturbative transport modeling and comparison to cold-pulse and heat-pulse propagation experiments in Alcator C-Mod and DIII-D

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Past work suggested that “non-local effects” are correlated with intrinsic rotation reversals

- [Rice NF 2013], [Gao NF 2014]
- Seemingly unrelated parameters abruptly change:
  - Ohmic confinement saturation, ”Non-local” heat transport,
  - **Intrinsic Rotation**, Density profile peaking, Up/down impurity asymmetry

New experiments and analysis techniques show that plasma current and auxiliary heating decorrelate “non-local effects” and intrinsic rotation reversals.

*Figure from Rice J. E. et al., NF 2013*
Perturbative transport studies the effect of perturbations

- Perturbative transport focuses on the response of the plasma to perturbations to isolate the effect of different contributions to transport.
- Transport is modified during the perturbation state due to changes in:
  - Steady-state plasma parameters ($\Delta T_e, \Delta n_e, \Delta I_p, \ldots$)
  - Instability thresholds $\Rightarrow$ Enhance turbulent transport

*Figure from [Kissick NF 1994]*
In 1995, experiments in TEXT showed that core $T_e$ rises after injecting edge cold pulse

- In low density plasmas $\Rightarrow$ Core $T_e$ increases as a consequence of sharp edge $T_e$ drop
- Observed in many devices:
  - TEXT, TFTR, Tore Supra, RTP, ASDEX-U, JET, LHD,
  - HL-2A and Alcator C-Mod
- Reduction of transport $\Rightarrow$ Transient enhancement of confinement!

Past work on C-Mod suggested correlation with intrinsic rotation

- $T_e$ inversions are known to disappear at a given value of density
- [Rice NF 2013] suggested that, in Alcator C-Mod, $V_{tor}$ reversal was coincidental with the disappearance of $T_e$ inversions
- Unified model for multi-channel transport was suggested
- In this work, new experiments were designed to test the robustness of this “unified” result
Observed mixing effect motivates new parameterization of $T_e$ response

- LBO system at C-Mod allows multiple injections and controlled amount of impurities
- Mixing process: Inward-propagating Edge cold-pulse + Temperature Inversion

Observed mixing effect motivates new parameterization of $T_e$ response

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Extract of Figure 23 from [Rice NF 2013]
In contrast to past work, transition from "non-local" to standard transport is smooth.

Core $\pm |\Delta T_e|$ depends strongly on $I_p$ and $P_{RF}$.

At high $I_p$, inversions persist at HIGH $\langle n_e \rangle_l$.
$T_e$ inversions observed with both co-current and counter-current rotation

**a)** Shot 1120216017 1.1 MA, low density  
**b)** Shot 1120216011 1.1 MA, high density
$T_e$ inversions and standard drops observed with co-current rotation with $P_{RF}$

- **a)** Shot 1150901021
- **b)** Shot 1150901008

1.2MW, 0.8 MA, low density
1.2MW, 0.8 MA, high density
A Laser Blow-Off (LBO) system is being developed for DIII-D

• LBO in DIII-D will allow cross-machine comparison of cold-pulse experiments

• Differences between “non-local” and “standard transport” cases with suite of fluctuations diagnostics at DIII-D

• ECH heat pulses and LBO cold pulses comparison using perturbative transport analysis techniques

*Routine operation of LBO on DIII-D expected for FY18
Summary and Future Work

New interpretation of $T_e$ inversions and mixing phenomena was needed:

- $I_p$ and $P_{ICRF}$ decorrelate “non-local effects” and intrinsic rotation reversals
- At high plasma current, temperature inversions persist at high density
- Transition to standard transport behavior is not abrupt

In progress – *Can a local turbulence model reproduce quantitatively temperature inversions?*

- Investigate ion channel $\Rightarrow$ Importance of $v_{ie}$ and $\frac{T_i}{T_e}$ stabilization terms
- Examine changes in stiffness, $\chi_e^{inc}$, in transitions to standard behavior
- Use of reduced models for turbulent transport (TGLF)

Near future

- Cross-machine comparison (DIII-D & C-Mod)
- Heat pulse – cold pulse comparison $\Rightarrow$ perturbative transport techniques