The Dependence of Impurity Transport and Turbulence on Heating Mix in Low Collisionality, ELM-y H-mode Discharges

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Motivation

- **Goal: Experimental validation of particle transport**
  - Gyrokinetic TGLF-SAT0  [G.M. Staebler NF 2017]
  - Gyrokinetic CGYRO  [J. Candy JCP 2016]
  - Drift kinetic code NEO  [E. Belly et al PPCF 2008]

- **Method: Investigate propagation of trace impurity**
  - Laser blow off injection of Aluminum and Tungsten

- **Experimental scenario:**
  - Compare dominantly ion and electron heated plasma
  - Designed via predict first approach

- **Predictive TRANSP+TGLF/NEO**
  - Up to 5-fold increase in impurity diffusion
  - Well above experimental uncertainties
Target Experimental Scenario

- Discharge designed to maximize variation in impurity turbulent flux
  - ELMy H-mode, 10-20Hz ELM frequency
  - $I_p = 0.9\text{MA}$, $B_T = -2.0\text{T}$, $\langle n_e \rangle = 4 \cdot 10^{19}\text{m}^{-2}$, $q_{95} = 5.8$
  - Weak MHD activity, without sawtooth

- NBI and ECH power scan, ECH resonance at $\rho = 0.25$ and 0.4
  - Constant torque of 2 Nm by applying counter-current beam

- Low collisionality to increase variation in $T_e/T_i$ by reducing $Q_{ei}$
  - Modify turbulent regime from TEM/ITG mixture to dominant ITG
Electron mode dominates outside of ECH position both low and high-k.

Decrease in ECH power correlates with a grow of ITG mode and drop in medium and high-k amplitude of electron mode.
- **Al** injections are monitored by SXR, CER and SPRED
- Impurity after LBO propagates swiftly up to ECH resonance
  - Shown by a background subtracted SXR emissivity
- Localized increase of diffusion outside of ECH heating radius
  - Order of magnitude larger change than in existing published research
- Large edge localized inward pinch is necessary to match a long decay phase ($\tau_{\text{imp}} \approx 250\text{ms}$, $\tau_E \approx 120\text{ms}$)
• **Localized increase of diffusion outside of ECH heating radius**
  – Order of magnitude larger change than in existing published research

• **Large edge localized inward pinch is necessary to match a long decay phase** ($\tau_{\text{imp}} \sim 250\text{ms}$, $\tau_E \sim 120\text{ms}$)
Power balance (PB) heat flux was evaluated by TRANSP suite of codes
- Heat flux ratio $Q_e/Q_i$ varied in range 0.5-5
- $x_i$ is increased by 50% by ECH
- ECH increased $x_e$ by factor of 2

Experimental PB $x_i$ and $x_e$ are well reproduced by flux matched TGYRO model
• Centrifugal asymmetry strongly enhances neoclassical transport
  – D Mach# is between 0.15-0.25
  – Al asymmetry is 5%, W is 50%!
  – Increase neoclassical diffusion of W by order of magnitude
  – Reverse direction of the neoclassical pinch by reducing $T_i$ screening

• Only a limited variation between both phases of the discharge
• Regions dominated by neoclassical transport are excellently reproduced by NEO
  – Finite orbit width effects?

• Heat flux matched TGLF reproduces observed experimental trend
  – Diffusion overestimated in NBI only case
  – V/D is slightly negative (peaked profile)

• Ion scale nonlinear CGYRO
  – Ion heat flux matched
  – Well reproduces transport in both cases
  – V/D close to TGLF result
• Neoclassical flux exceeds experimental diffusion coefficients
  – Could be the poloidal asymmetry overestimated?
  – Effect of fast NBI ions

• D from TGLF is almost identical to aluminum profiles
  – Weak M/Z dependence
  – Difference between Al and W transport is primarily due to neoclassical transport
## Summary of the validation effort

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**Notes:**
- ✔️: Valid
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