Impurity transport in HSX: Recent experimental results and neoclassical calculations

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Impurity transport study is a major element in HSX program

Available tools: Laser Blow-Off system, CXRS and passive fast spectrometers.

Experimental goals:

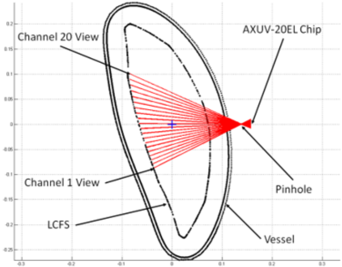
- Obtain power and density scaling of impurity confinement in quasi-symmetric and symmetry degraded configurations.
- Compare D & v profiles in both configurations.
- Identify regimes of core/edge impurity screening (peaked/hollow profiles) : biased electrode, edge islands.

This talk: Preliminary results from Laser Blow-Off

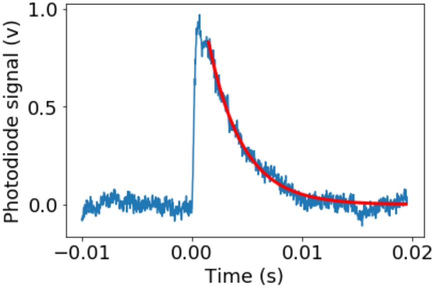
Global confinement time is obtained using Laser Blow-Off

- 850 mJ Nd:YAG laser
- Currently used for Aluminum injection
- Photodiode detectors. 5 arrays consisting of 20 channels each
- Broadband emission measurements

One of the photodiode arrays

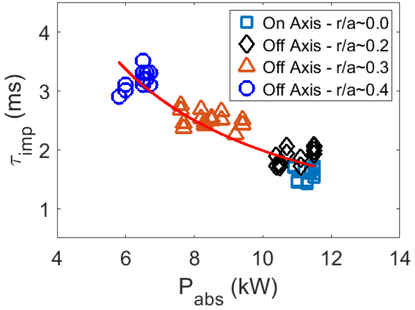


τ from central channel exponential fitting

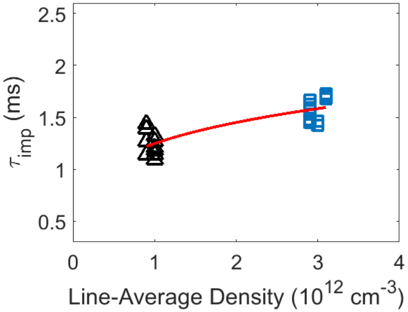


Initial studies focus on scaling of impurity confinement time with ECH power and electron density †

$\tau \propto P^{-1.0}$



$\tau \propto n_e^{0.2}$

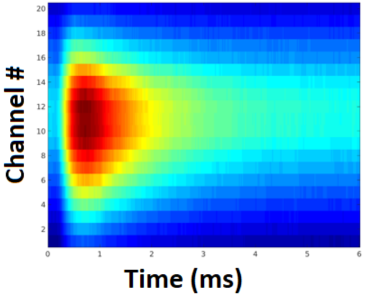


- Heating location varied to change absorbed power for same injected power, keeping density fixed.
- HSX scaling similar to W7-X ($\tau \propto n_e^{0.2}$) and W7-AS ($\tau \propto P^{-0.8}$) results

† J. F. Castillo, HSX

Near-term plans

- Get more data for power and density scaling
- Measurements of specific charge states ($Al^{+8,9,10}$) instead of broadband



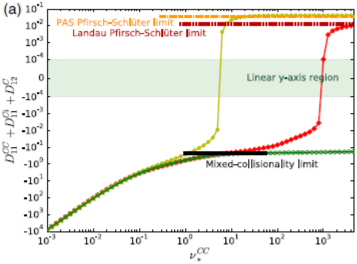
- Get D & v from STRAHL. STRAHL & optimization model are being improved (B. Geiger *et al.*)
- Comparison with other experiments (N. Tamura)

Neoclassical Calculations

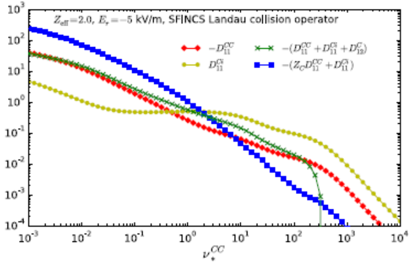
Effect of E_r and ∇T_i in a quasi-symmetric stellarator

In a mixed collisionality regime, E_r effect gets weaker, temperature screening is possible in stellarators†

∇T_i coefficient



E_r coefficient (blue) is larger at low collisionality

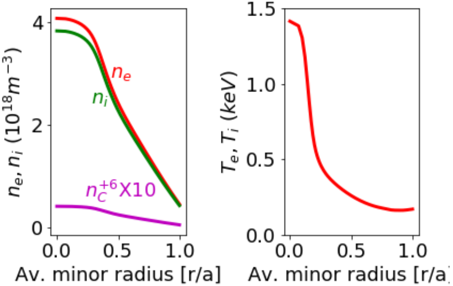


- Mixed collisionality analytical calculation agrees with SFINCS results (left figure).
- At lower ν^*, even though ∇T_i coefficient is negative, E_r effect is expected to dominate (right figure).

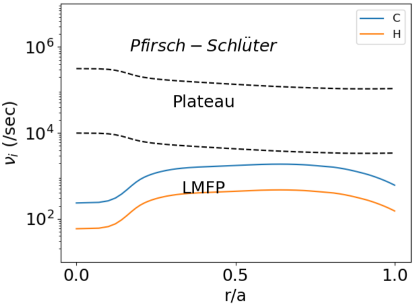
† Helander *et al.*, PRL [2017], A. Mollén, POP [2015]

Similar calculations are done for HSX configurations using PENTA†. Experimental profiles, except $T_i = T_e$

Plasma profiles used



Collisionality

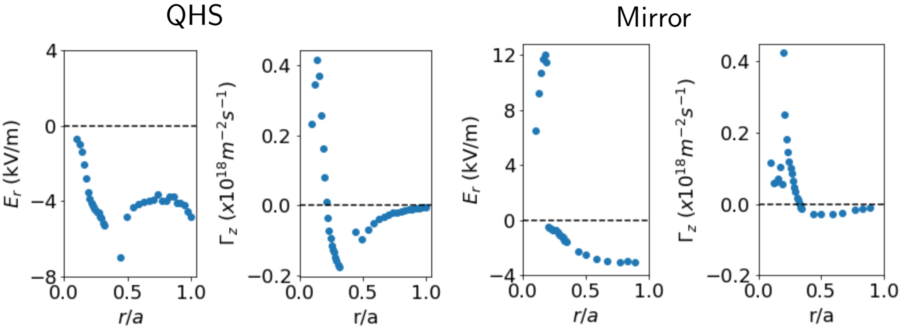


$n_{C^{+6}} = 1\%$ of n_e

Both main and impurity ions are in LMFP throughout the plasma.

†D. A. Spong [2005], J. Lore [2010]

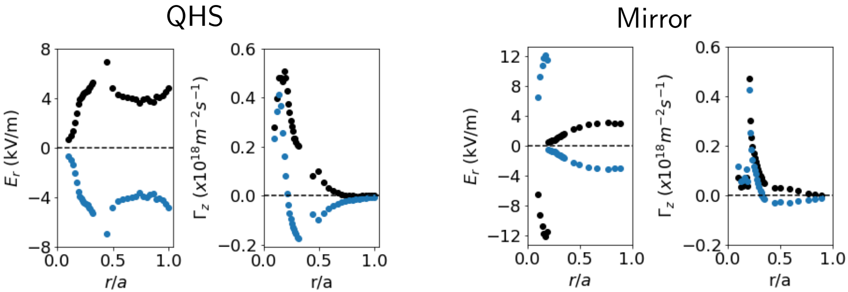
Outward impurity flux is calculated in the core region for both configurations, even though E_r is negative.



QHS - standard quasihelically symmetric configuration
Mirror - Symmetry degraded configuration.

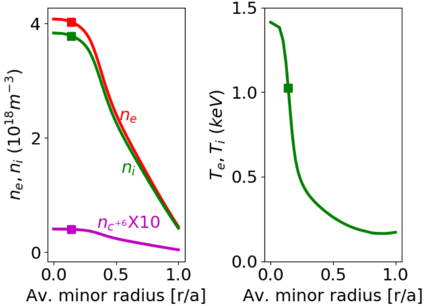
Flux near the core is largly unaffected by E_r direction

To check the effect of E_r, repeated calculations with E_r direction reversed.

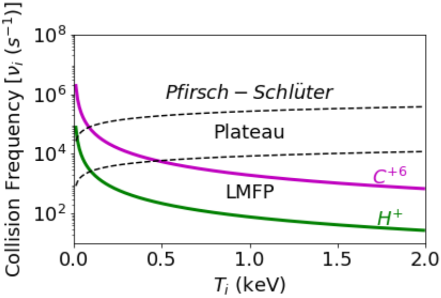


Transport coefficients are calculated at r/a$\sim$ 0.14 for a range of impurity collisionality

Plasma Parameters

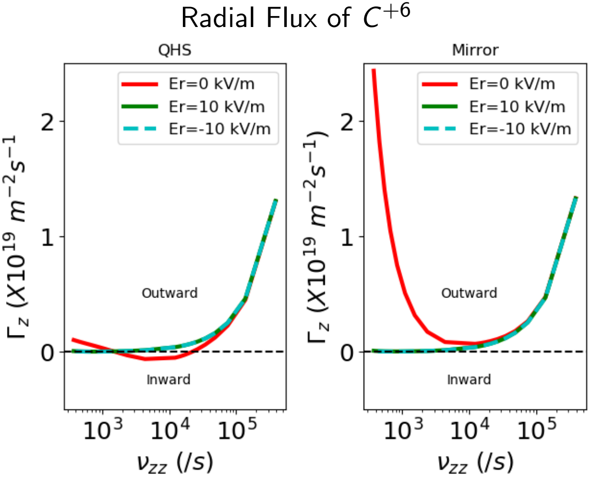


Collisionality Regimes



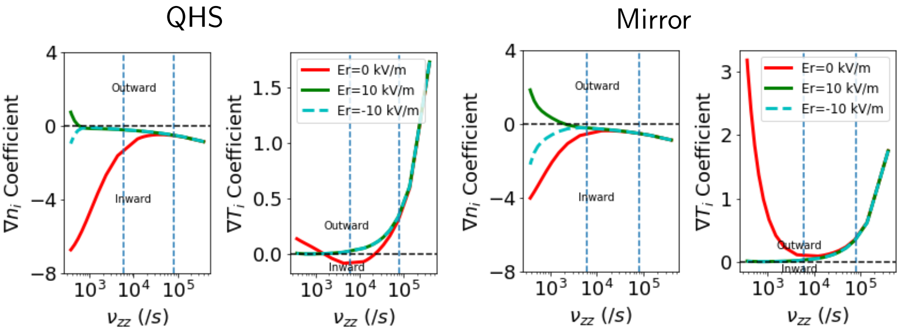
- Experimental values n_e & T_e are used, $T_i = T_z = T_e$ is assumed, impurity density $= 1\%$ of n_e is used.
- T_i is varied to scan the collisionality regimes, keeping all other parameters the same in the calculation.

Outward impurity flux is calculated for both configurations



- Impurity expulsion, except for a narrow range of collisionality when E_r=0 in QHS.

Outward directed convection velocity is due to temperature screening (∇T_i effect)



Sign of E_r has no effect except in the very low collisionality.

Summary

- HSX neoclassical calculations for $T_i = T_e$ case show outward convection of impurities for ion-root electric field.

- Outward convection is due to temperature screening (∇T_i)

- E_r effect is negligible in presence of relatively strong ∇T_i, even at low collisionality.

Both HSX and W7-X (mixed collisionality) results contradict conventional thinking about temperature screening in stellarators.

Similar calculations in other devices will be useful.