NSTX

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Expected Scaling of Particle Transport from 3D Fields (For XP1125)

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For informal discussion
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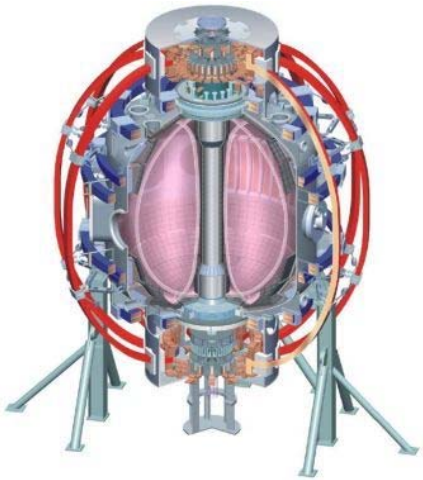

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3D fields can produce non-ambipolar particle transport

- 3D fields can deform flux surfaces and produce Non-Ambipolar (NA) particle transport
  - Radial ion transport dominates and accompanies momentum transport
  - NTV theory can be used for prediction

- 3D fields can destroy flux surfaces and produce stochastic particle transport
  - Parallel electron transport may be significant
  - Yet hard to predict

- Ion particle transport in 2D is also largely neoclassical in NSTX and can be compared with 3D transport

NTV theory gives prediction for particle transport by 3D fields

- NTV theory for a species gives

$$D_{NA,s} \cong \frac{q^2 T_s}{\varepsilon^2 (Z_s e)^2 R_0 B_0^2 N_s} \frac{\left\langle \hat{\phi} \cdot \vec{\nabla} \cdot \overleftrightarrow{\Pi} \right\rangle_s}{\omega_{\phi,s} - \omega_{Neo,s}}$$

$$\frac{\left\langle \hat{\phi} \cdot \vec{\nabla} \cdot \overleftrightarrow{\Pi} \right\rangle_s}{\omega_{\phi,s} - \omega_{Neo,s}} \cong \frac{\varepsilon^{-1/2} N_s T_s}{\sqrt{2}\pi^{3/2} R_0} \sum_{nmm'l} \left\{ \frac{n\delta B_{nml}}{B_0} \right\} \left\{ \frac{n\delta B_{nm'l}}{B_0} \right\} \left\{ \frac{v_s}{\left\{ n\omega_{ps} \right\}^2 + v_s^2} \right\}$$

- Rotation damping rate can be used if measured

$$D_{NA,s} \cong \frac{M_s q^2 T_s}{\varepsilon^2 (Z_s e)^2 B_0^2} v_{damp,s}$$

If $M_s >> M_D$ and $v_s \approx v_{sD} >> n\omega_{ps}$, then $v_{damp,s} \propto \frac{T_s}{v_{sD}} \propto \frac{M_s T_s^{5/2}}{N_D Z_s^{\ 2}}$, so

$$D_{NA,s} \propto \frac{M_s^2 T_s^{7/2}}{N_D Z_s^4}$$

3D NA transport differs from 2D transport due to opposite collisional dependency

- 3D NA transport differs from 2D transport

$$D_{NA,s} \cong \frac{M_s q^2 T_s}{\varepsilon^2 (Z_s e)^2 B_0^2} \nu_{damp,s} \qquad D_{PS,s} \cong \frac{2 M_s q^2 T_s}{(Z_s e)^2 B_0^2} \nu_s$$

- 3D NA transport becomes comparable to 2D when roughly

$$\nu_{damp,s} \approx 2\varepsilon^2 \nu_s$$

→ ***Low collisionality, high aspect ratio, and high NTV are all needed to produce dominant 3D particle transport***

- One can largely increase ratio of 3D to 2D transport depending on the regimes

$$\frac{D_{NA,s,1/\nu}}{D_{PS,s}} \propto \frac{M_s^2 T_s^4 I_{EF}^2}{N_D^2 Z_s^4} \quad \text{or} \quad \frac{D_{NA,s,\nu}}{D_{PS,s}} \propto T_s I_{EF}^2$$

→ ***High temperature, low density, high mass but low charge, and high field will be all helpful to increase ratio of 3D to 2D transport***

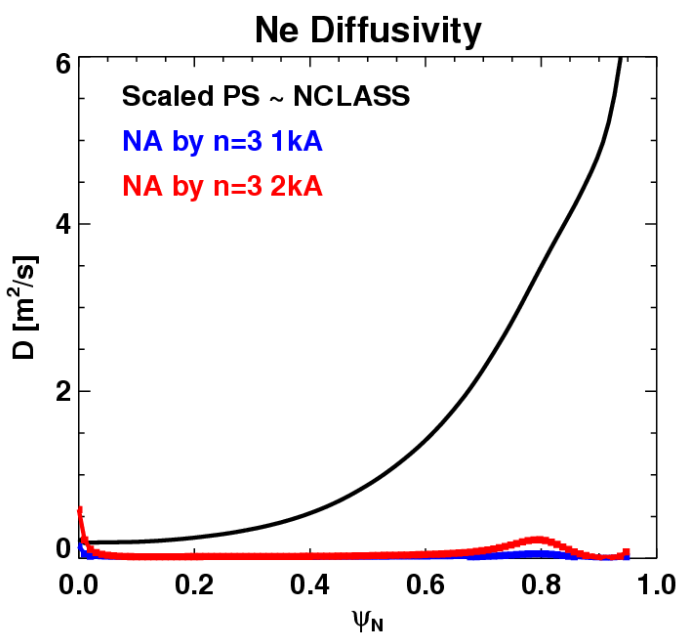
3D NA transport for impurity ions is very weak

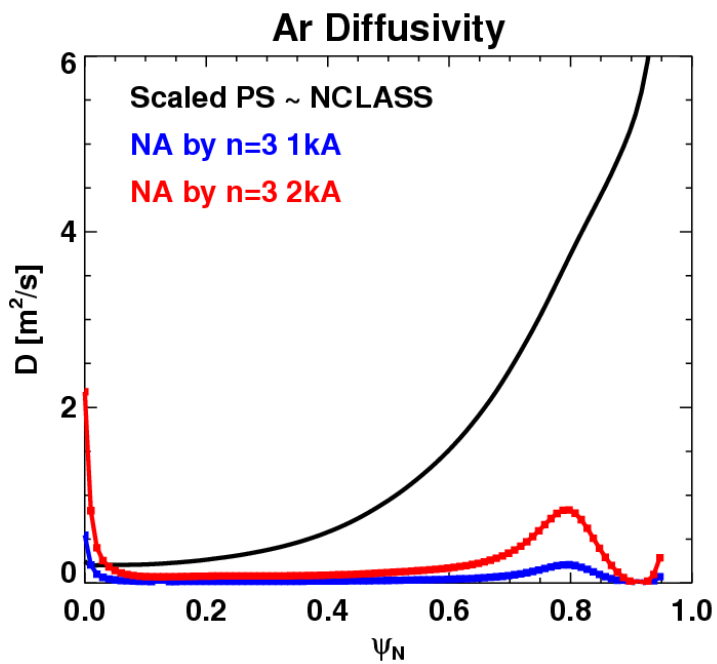
- Preliminary analysis is done with
  - Very rough approximation based on measured Carbon damping (#124439)

$$\nu_{damp,Neon} \approx \nu_{damp,CHERS}$$

  - Predicted scaling in 1/ν-regime, assuming Z_s=8, T_s=T_D
  - For 2D, PS transport is calculated and scaled to NCLASS results
- Expected 3D NA transport is very weak

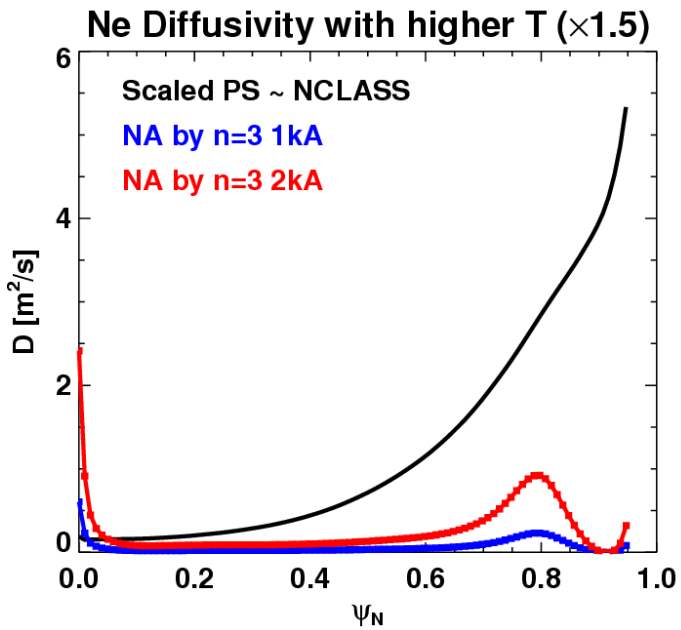
[Delgado-Aparicio, NF 49 085028 (2009)]

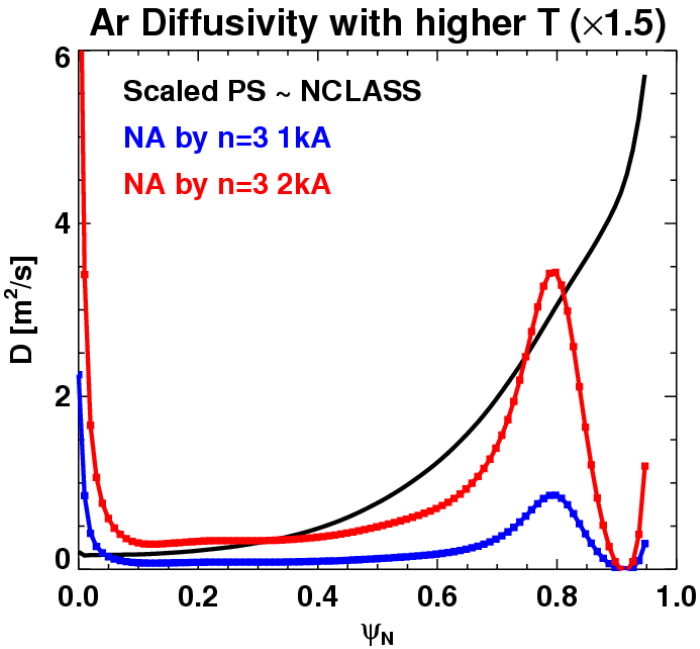




3D NA transport may be measurable if higher temperature is achieved

- Higher temperature by a factor of 1~2 can greatly enhance 3D NA transport





- Impurity species with higher mass and lower charge will be helpful

Summary

- NTV theory gives
  - Very strong scaling with temperature and mass for 3D NA transport
  - However, high charge makes 3D NA transport very weak

- 3D NA transport may be measurable if
  - n=3 EF currents are increased up to 1~2kA
  - Higher temperature and lower density is achieved by1~2 factors
  - Impurity ions with higher mass and lower charge are used
  - Higher field coupling by targeting low q_{95}

- Future work :
  - Analytic NTV calculations with upgrade for passing impurity ions
  - Actual orbit calculations (Kim, Kramer)