Impurity Transport Studies at the HSX Stellarator Using Active and Passive CVI Spectroscopy

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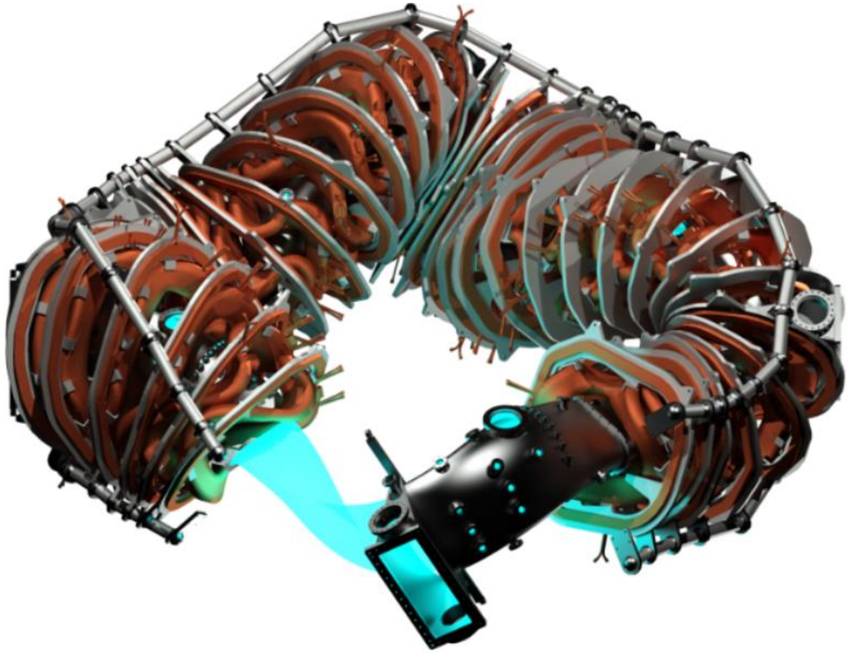


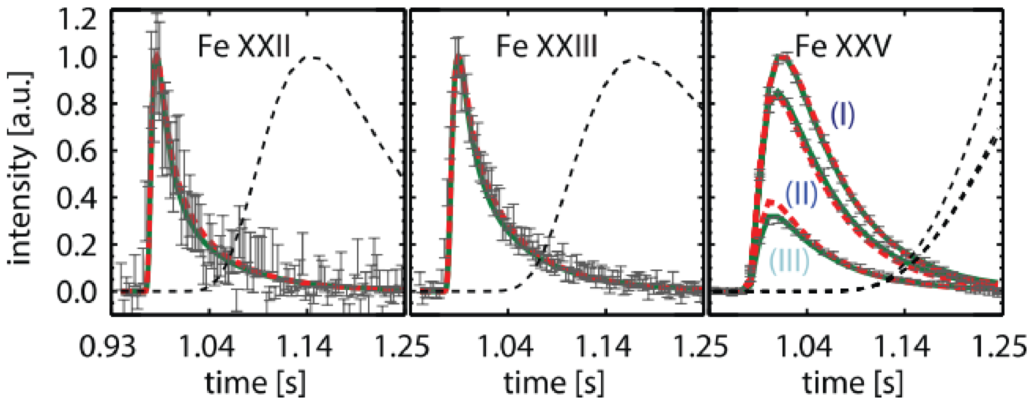
- Introduction to impurity transport efforts
- Charge exchange measurements at HSX
- pystrahl and pyfidasim
- Optimization transport profiles to fit active and passive signals
- Conclusion and outlook

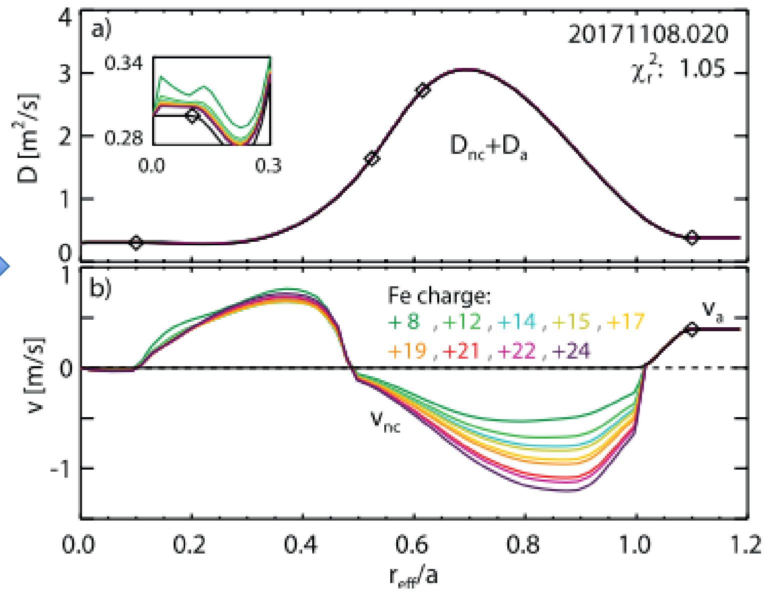
Impurity Transport Studies in Stellarators

- Non-ambipolar fluxes lead to charge separation & $\boldsymbol{E_r}$ field
  - Impurity accumulation & excessive radiative losses
- Impurity influx characterized by Diffusive and Convective components
- Many efforts to try to infer impurity transport profiles by forward modeling of spectrometry data
- Here we present a strategy for inferring D and V profiles at HSX using charge exchange measurements

Diffusion Convection

$$\Gamma = -\nabla n \cdot D_{11} + n \cdot (D_{11}\, q\, E_r/T - D_{12} \nabla T/T)$$

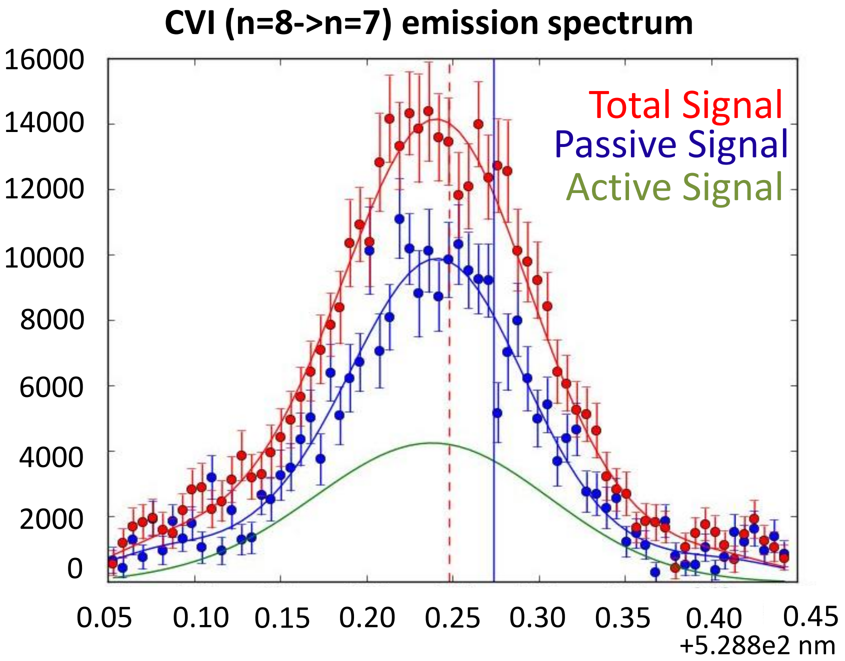


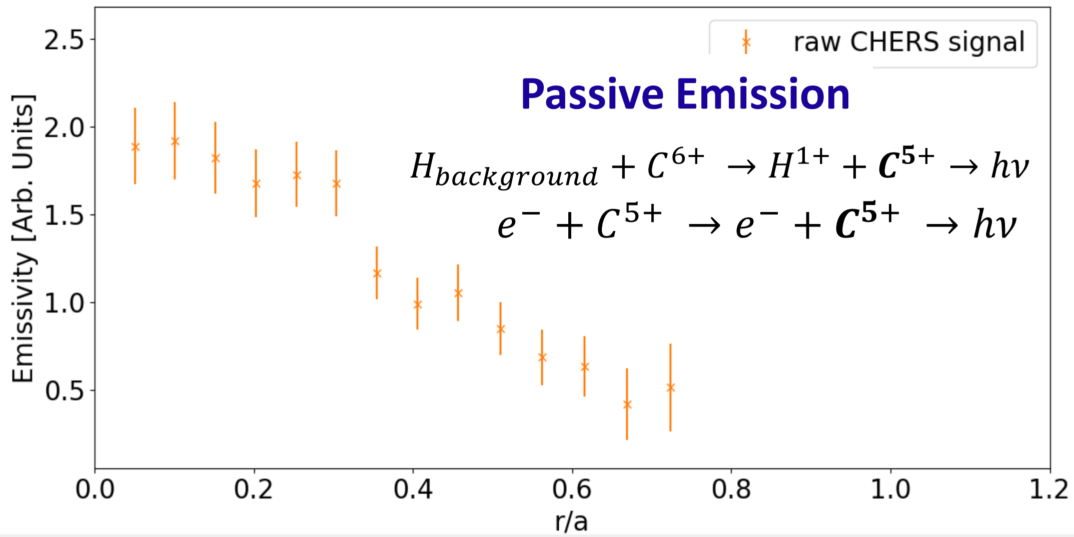


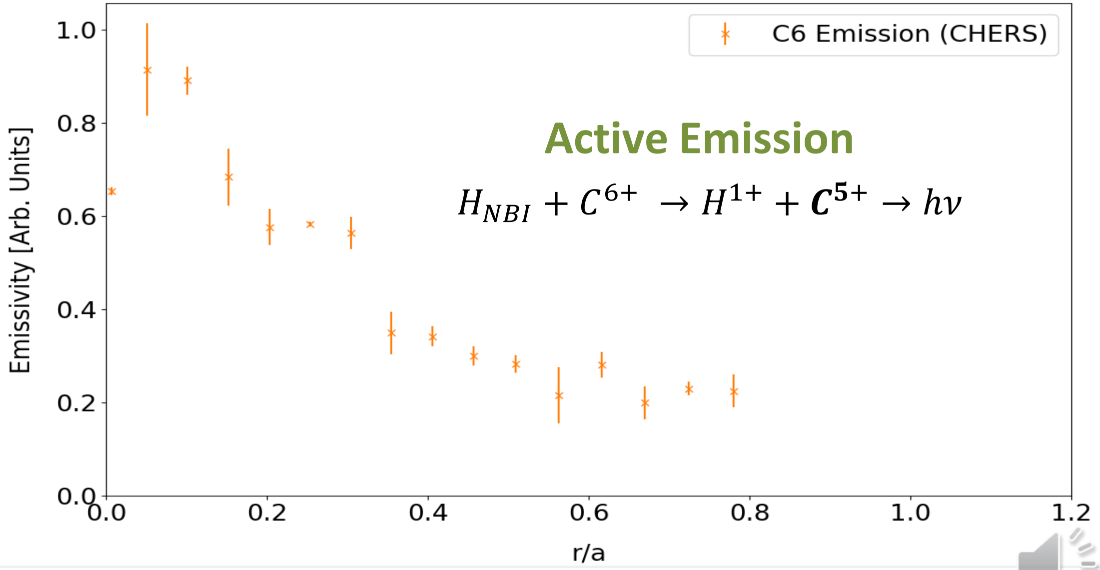
B. Geiger et al, 2019

CHERS Diagnostic at HSX

- NBI injection at 28 keV, 4A particle current
- Czerny-Turner spectrometers view 20 lines of sight intersecting NBI
- Observation of characteristic radiation from C^{5+} relaxation via charge exchange (average 12 shots)

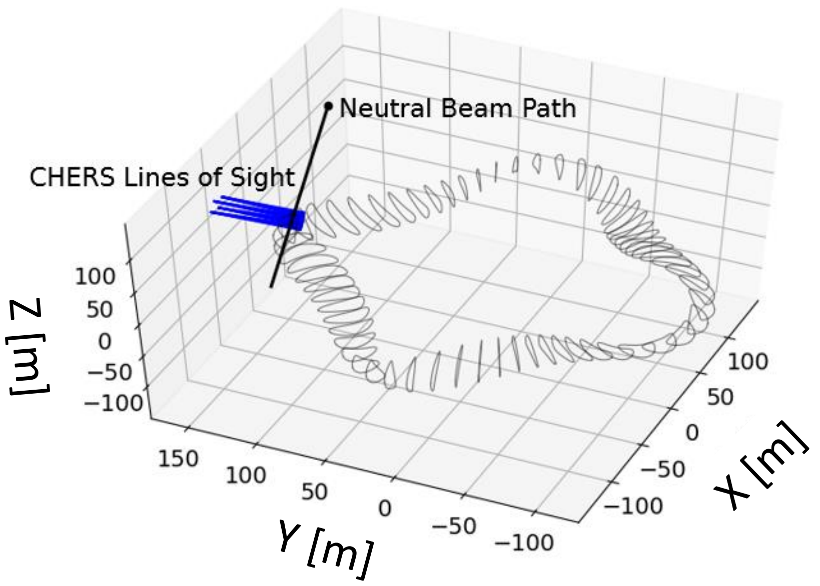


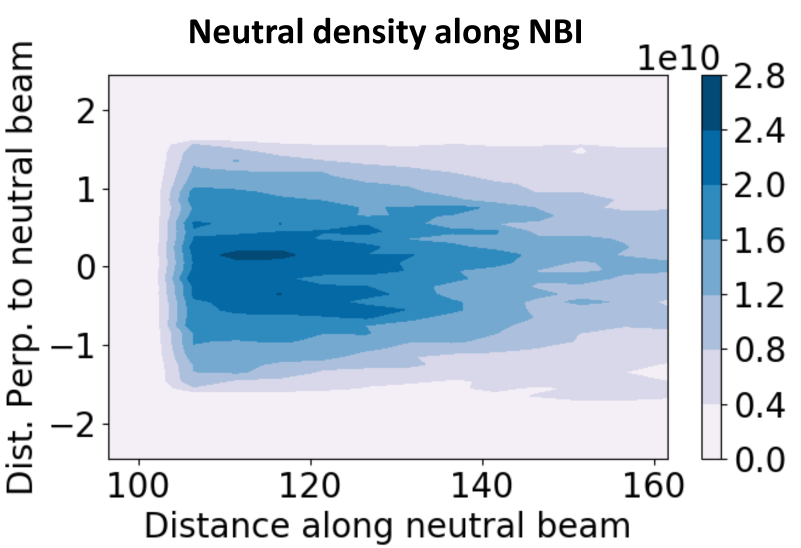




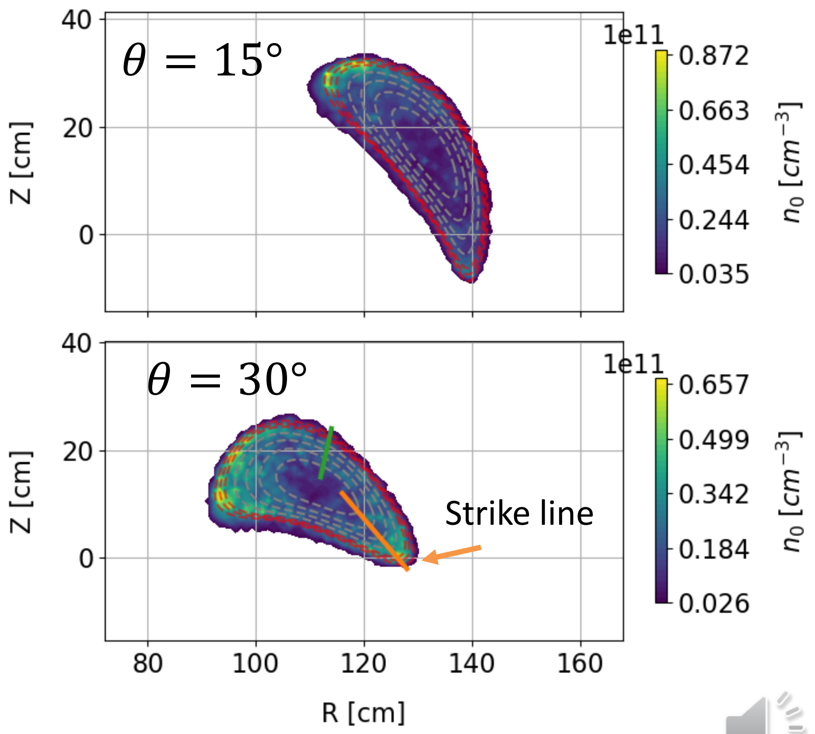
pyFIDASIM can Calculate Neutral Beam Emission and Background Neutral Densities

- PyFIDASIM is a 3D Monte Carlo Code which follows neutrals as they traverse the plasma
- Contains information on 3D geometry of diagnostic lines of sight
  - Calculates charge exchange radiation along diagnostics
- Defining a source function for neutrals at the LCFS allows for calculation of background neutrals



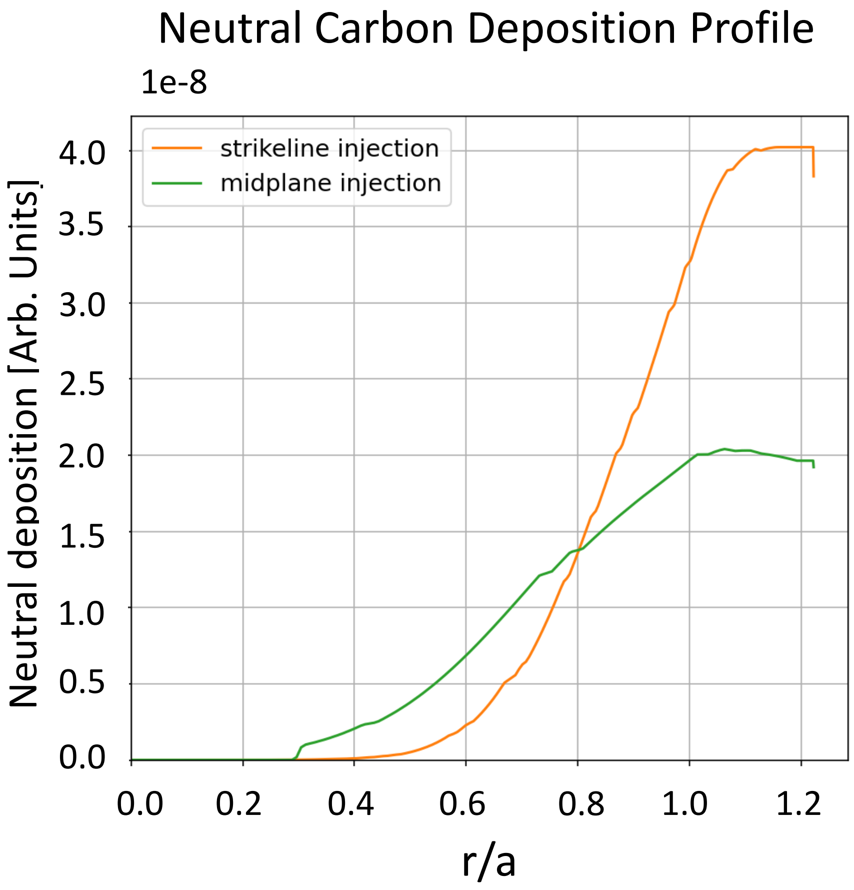


3D Neutral Density Calculated by pyfidasim



Pystrahl for Stellarator Configurations

- Pystrahl (python translation of STRAHL code) solves the impurity transport equation on a 1D radial grid
- **Inputs:** T_e, n_e, n_0, impurity source, D, v; **Output:** $n_{i,z}(r,t)$
- To accommodate 3D effects of stellarator geometry:
  - Edge Profiles: EMC3-EIRENE simulation mapped to extrapolated surfaces $(\frac{r}{a} > 1)$
  - Neutral Impurity Deposition profile calculated for injection from strike line

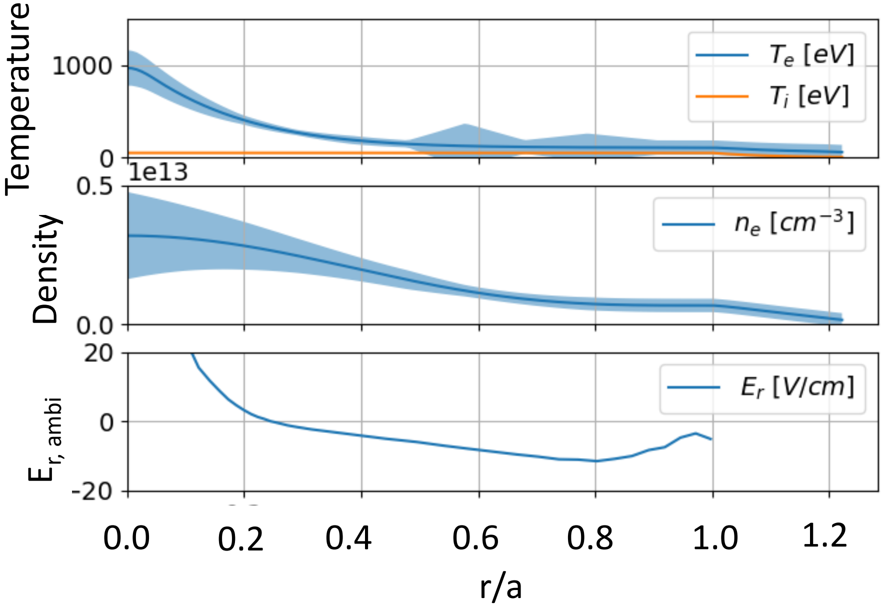


1D Impurity Transport Equation

$$\frac{\partial n_{I,Z}}{\partial t} = -\nabla \vec{\Gamma}_{I,Z} + Q_{I,Z}$$

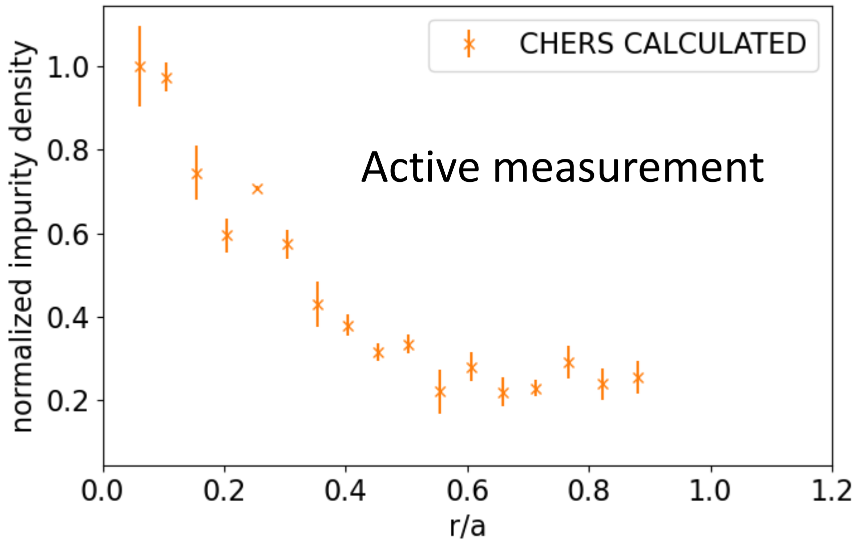
Transport of impurity I (charge state Z)

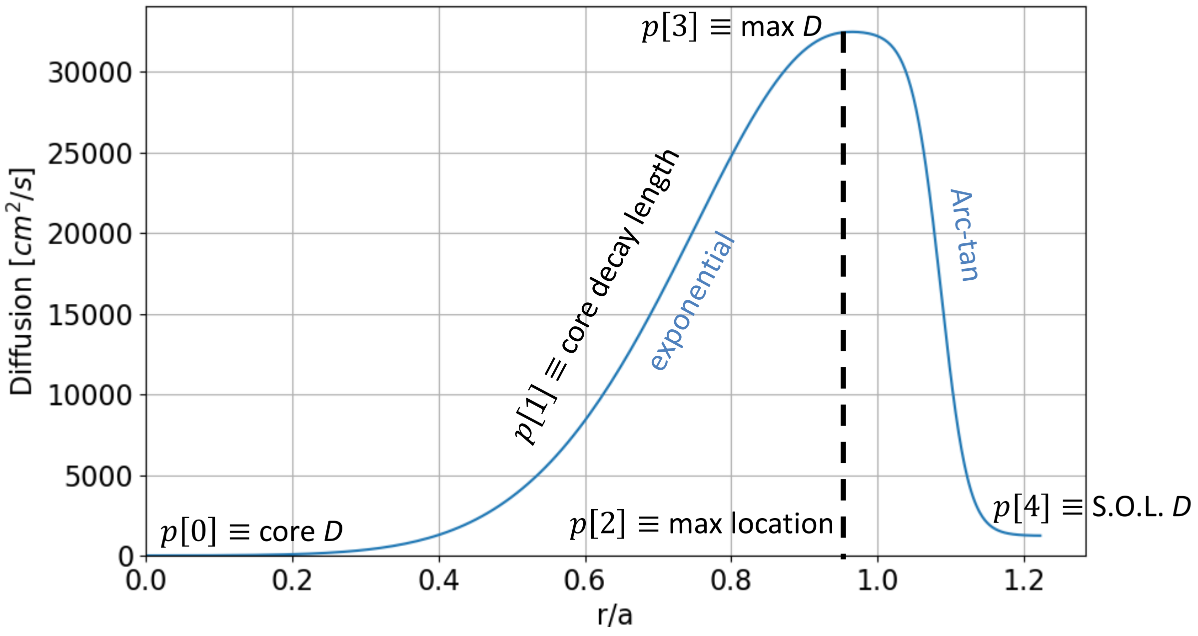
Sources/sinks (ionization, recombination)

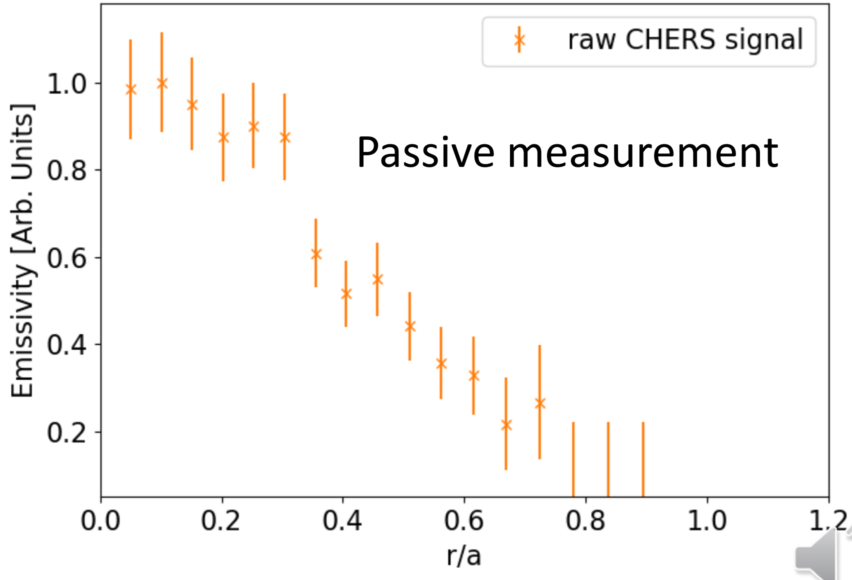


Objective Function & Global Minimization

- Active Signal can be easily inverted to get shape of C^{6+} profile
- Measured C^{6+} density and passive measurement (both normalized) can be compared to forward model
- Minimization scheme varies D profile, impurity influx, & scaling factor for neutral density, minimized reduced chi squared statistic
- D profile defined by exponential – arc-tangent piecewise function

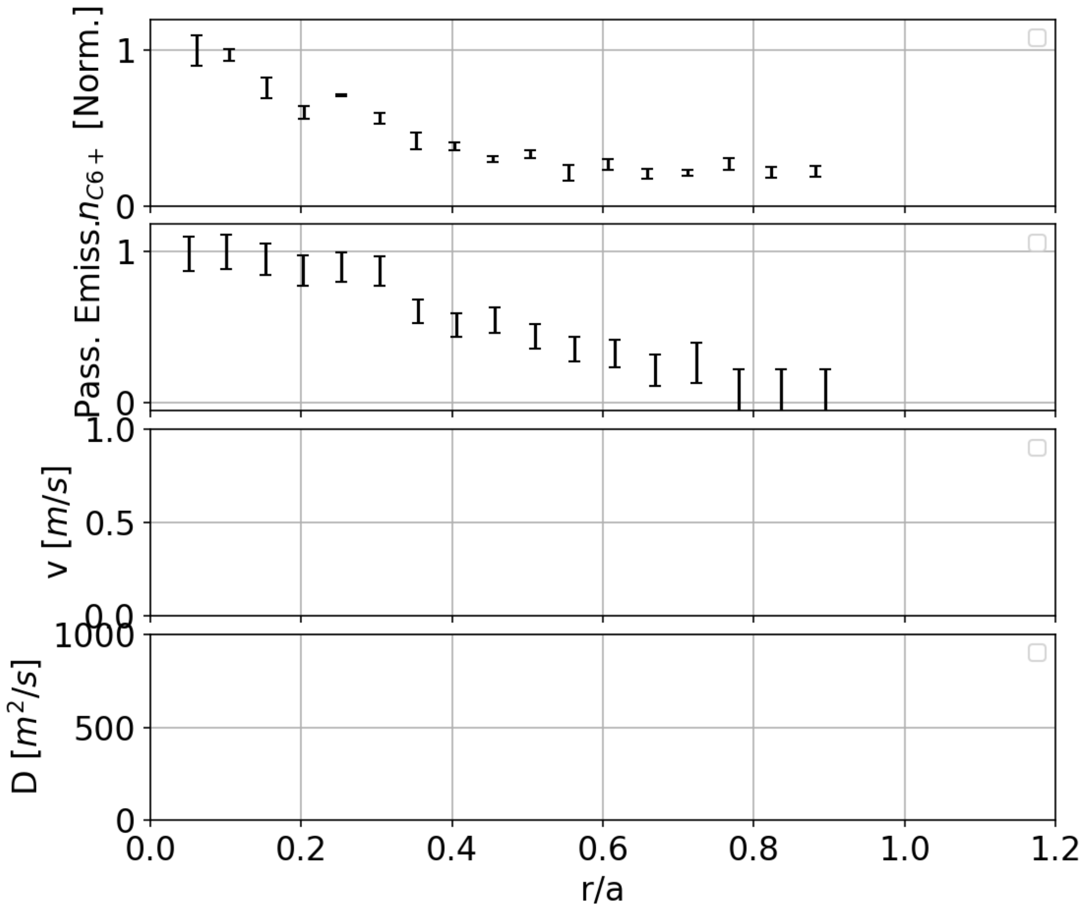






Fitting Results Indicates Anomalous Transport

- Objective function minimized using global optimizer "Basinhopping"
- Considering only neoclassical transport (calculated via PENTA code) does not explain active and passive CX measurements



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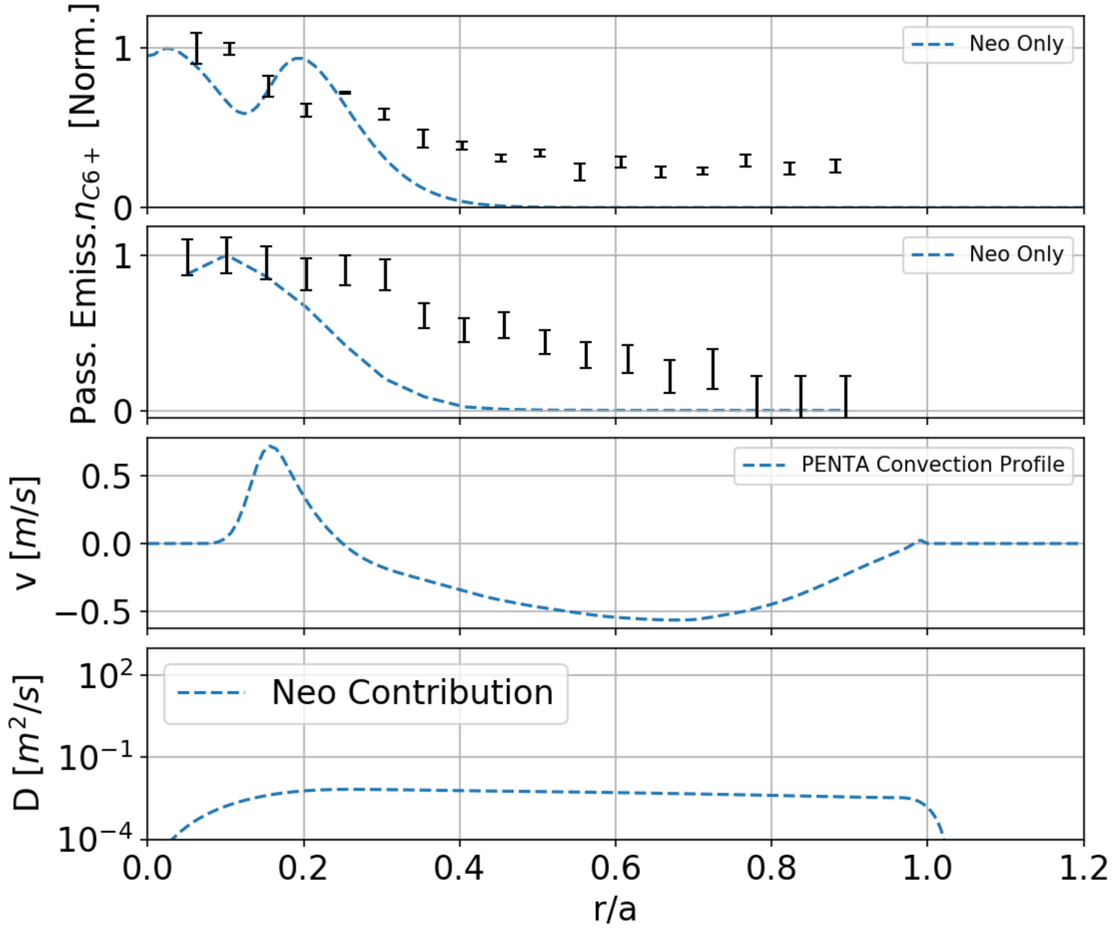

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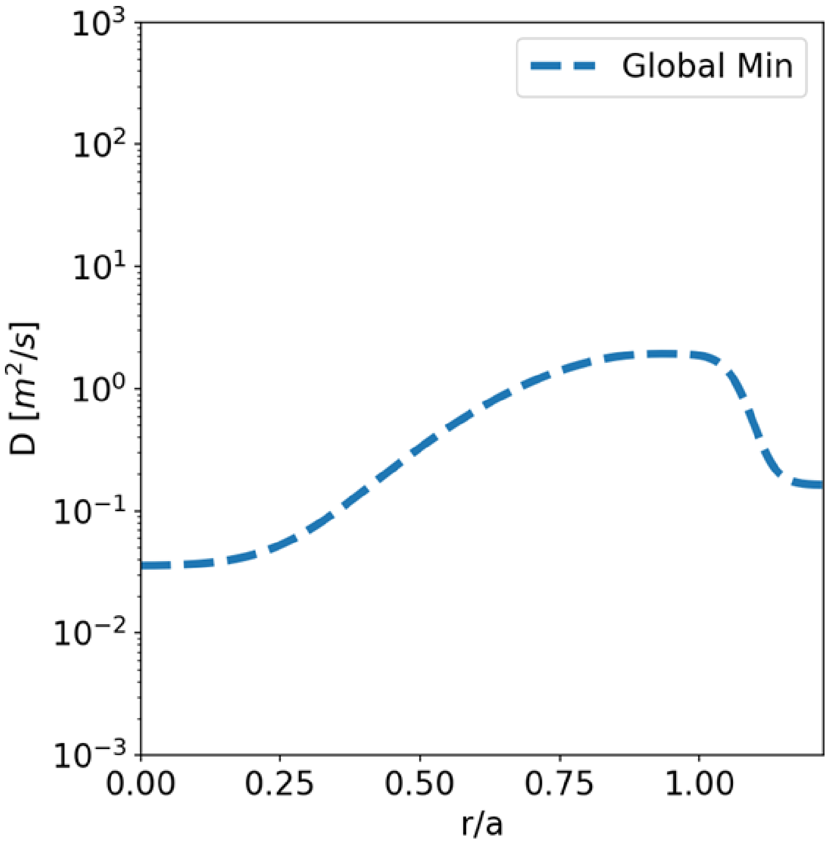

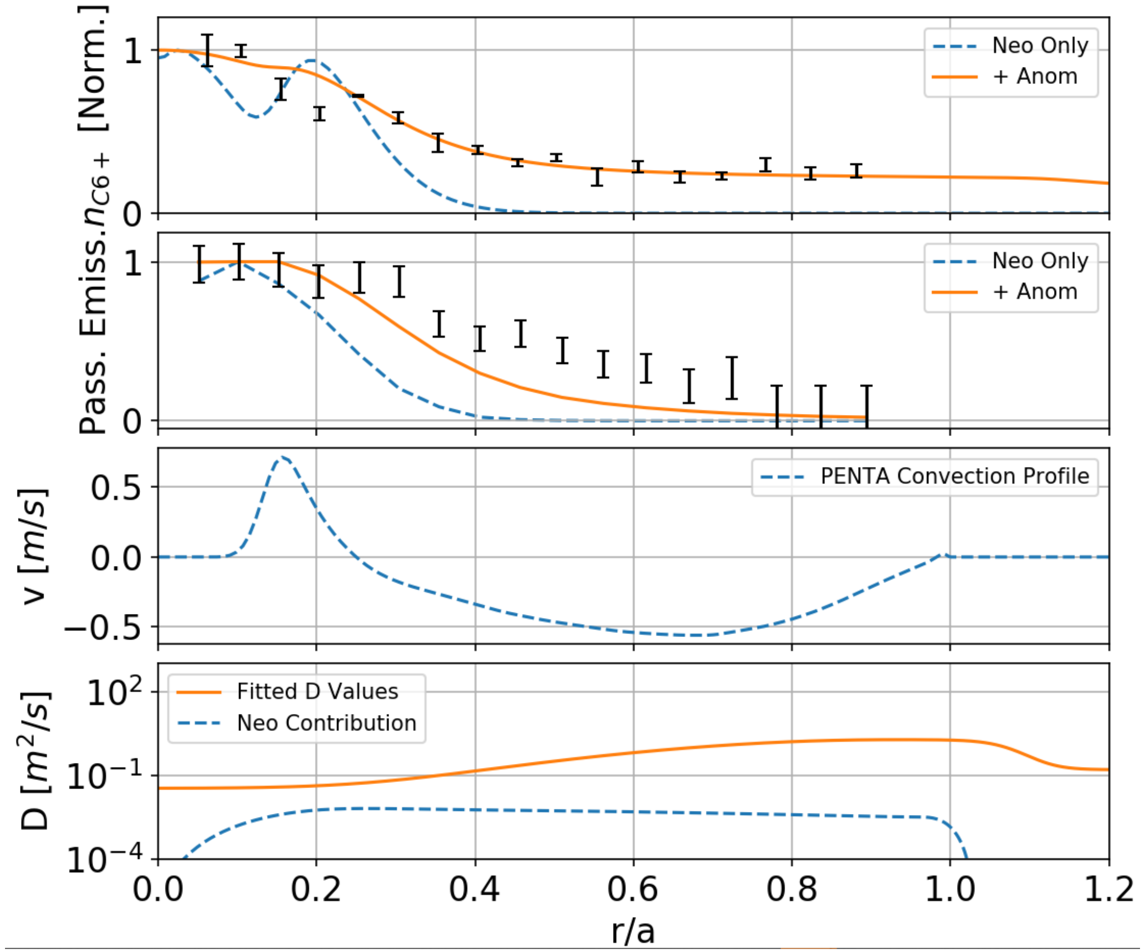

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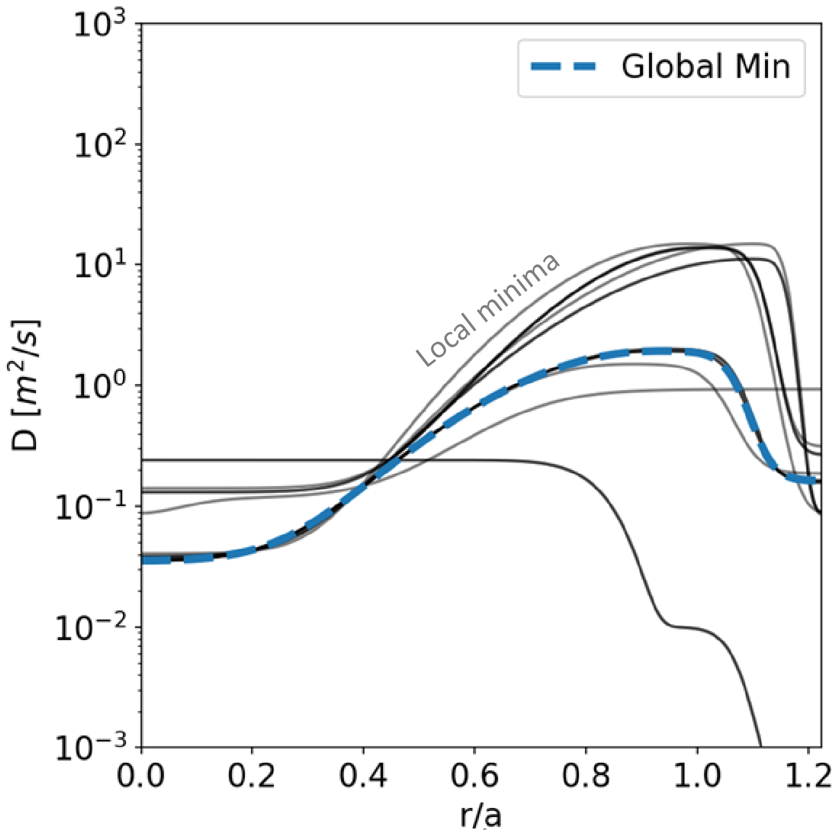

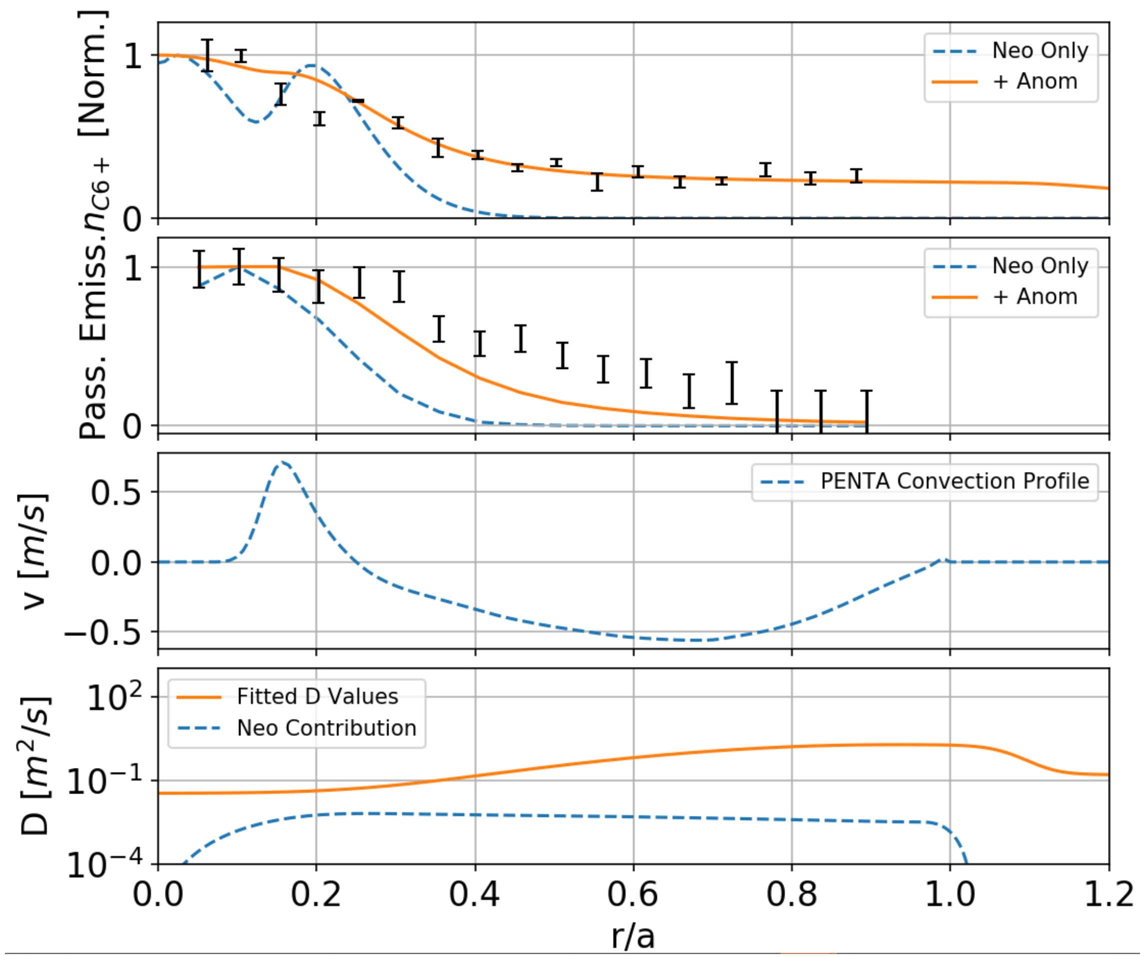

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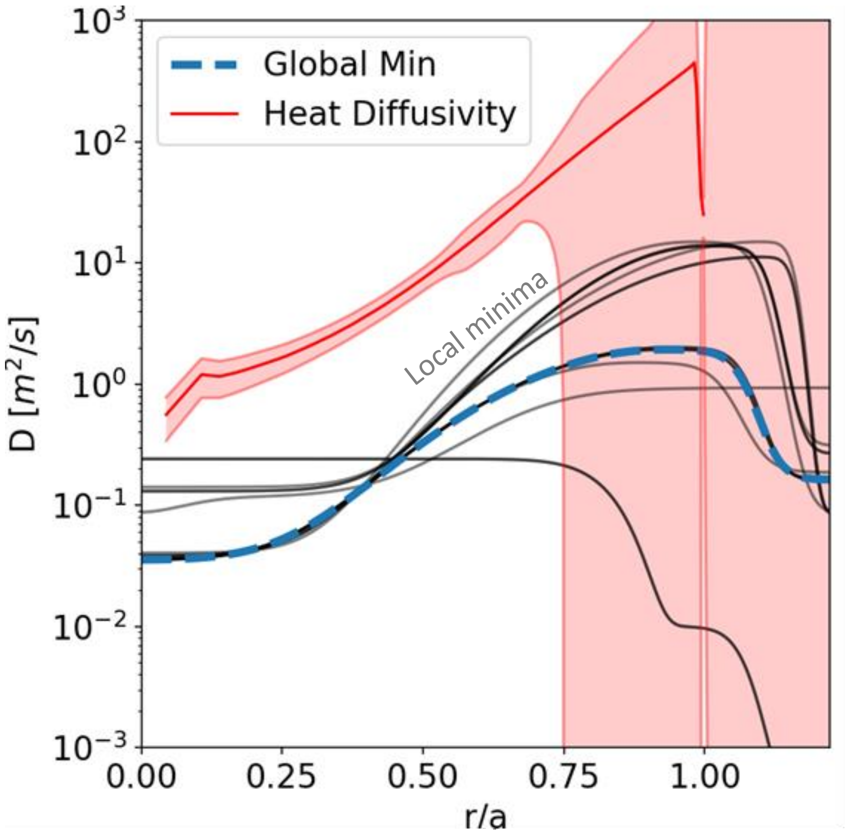
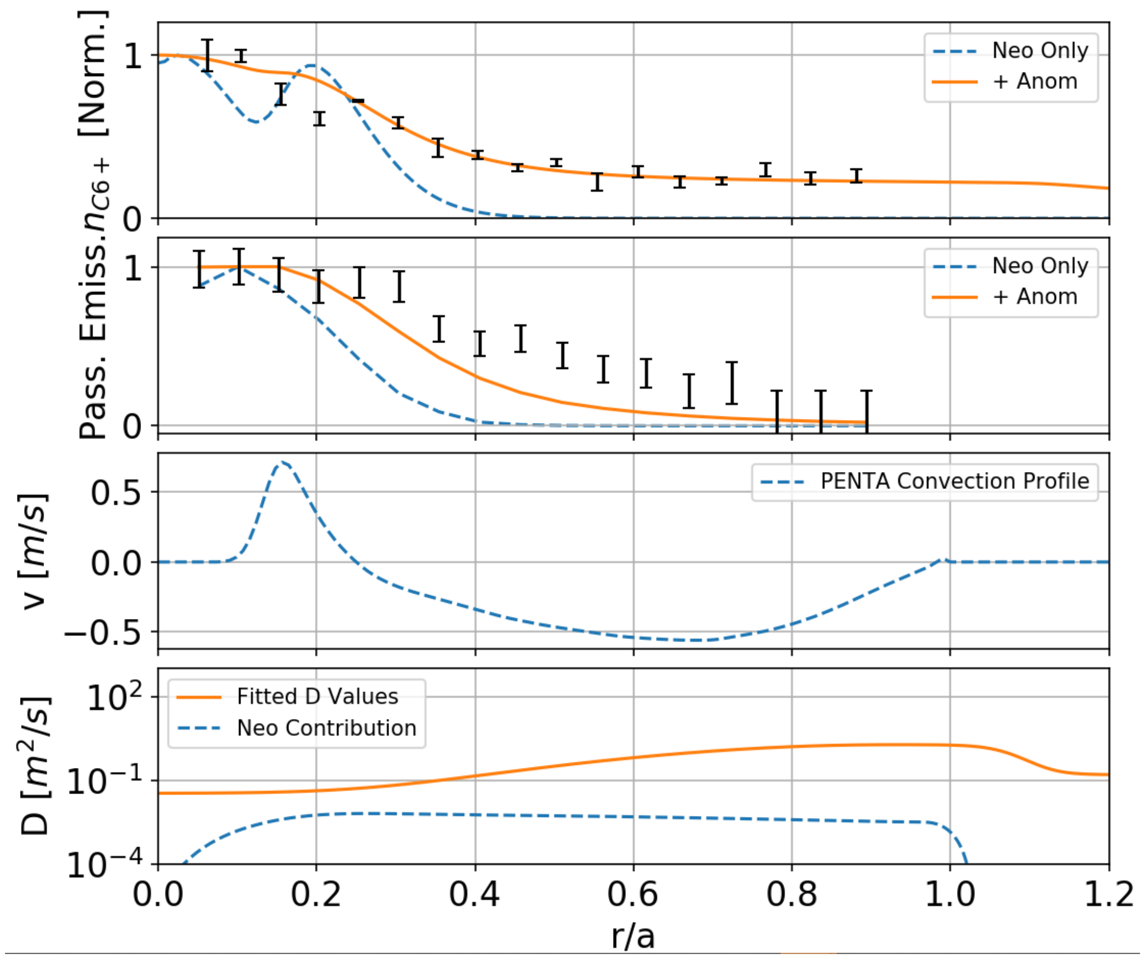
- Shape of diffusion profile matches that of electron heat diffusivity calculated using power balance calculation





Summary & Outlook

Summary

- Radially resolved impurity diffusion profiles reconstructed for the first time at HSX
- Pystrahl package optimized for application in stellarator geometries
- Fitted diffusion profiles support hypothesis that particle transport in HSX dominated by anomalous contributions
- Diffusion shape follows that of heat diffusivity which is hypothesized to be driven by electrostatic turbulent fluctuations

Outlook

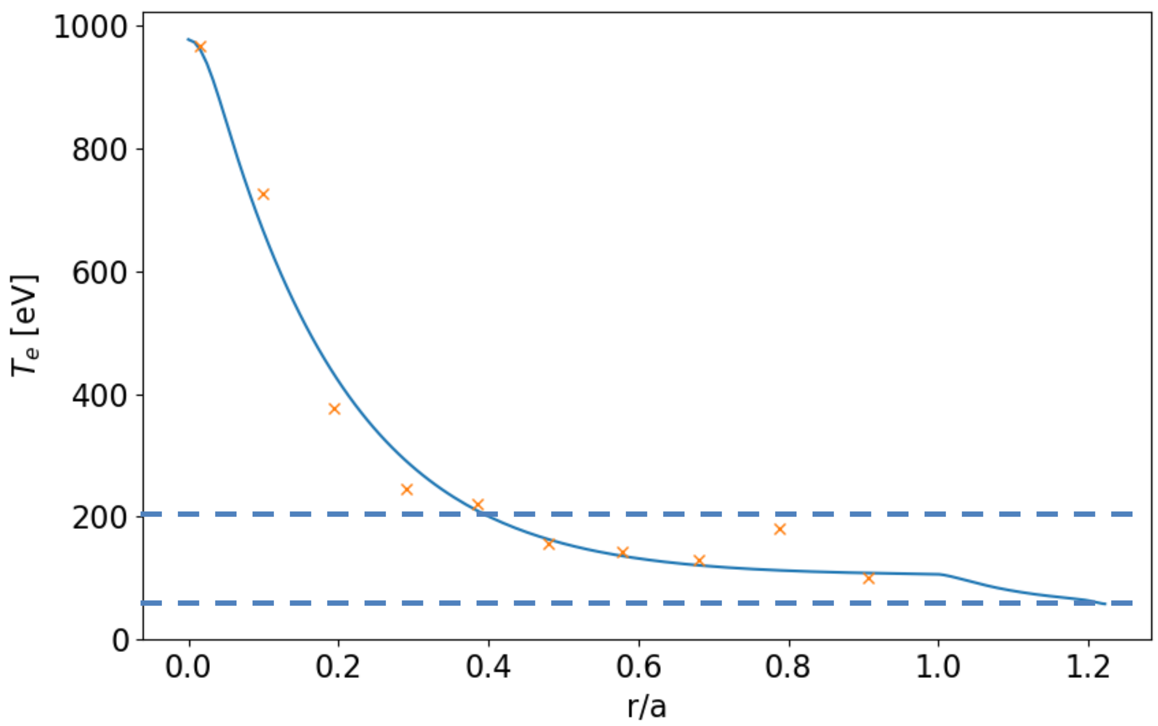
- Potential for future analysis of “mirror configuration” where quasi-symmetry is broken and higher levels of neoclassical transport are expected
- Analysis can be refined by using Bayesian approaches such as Markov Chain Monte Carlo

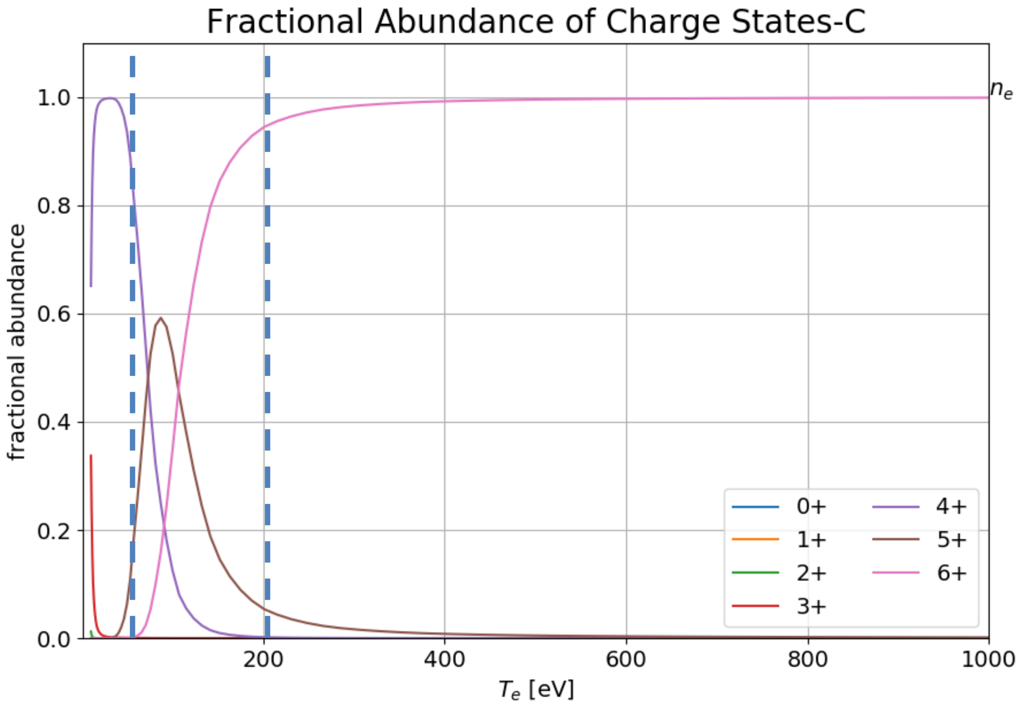
<u>Related paper under review for publication:</u>

Swee, C. (2021). *Impurity Transport Studies at the HSX Stellarator Using Active and Passive CVI Spectroscopy.* Manuscript submitted for publication

Extra Stuff – Temperature Sensitivity (1)

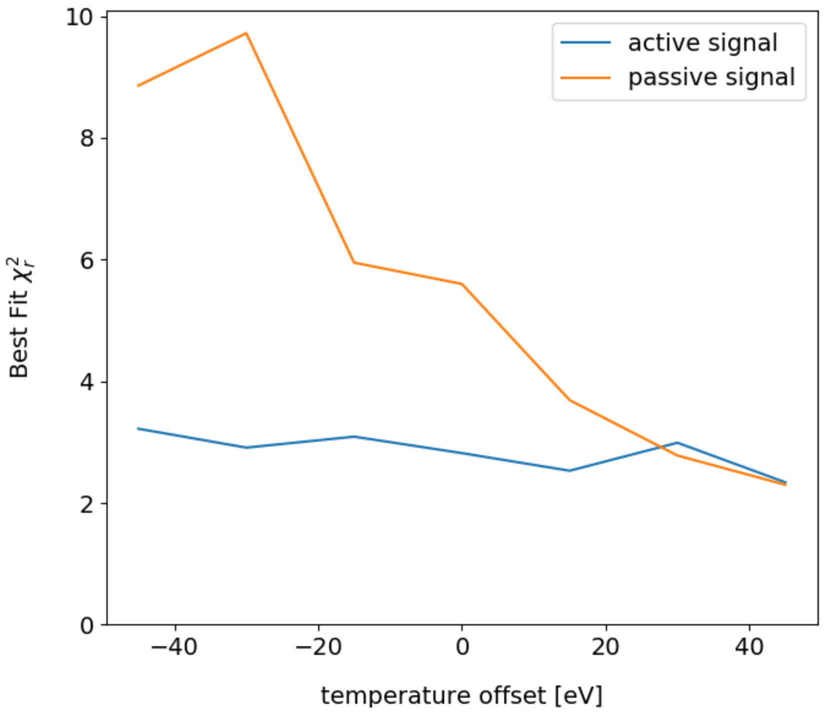
- Corona equilibrium is in absence of charge exchange and transport (balance of ionization & recombination)
- Charge distribution highly sensitive to electron temp at experimental values

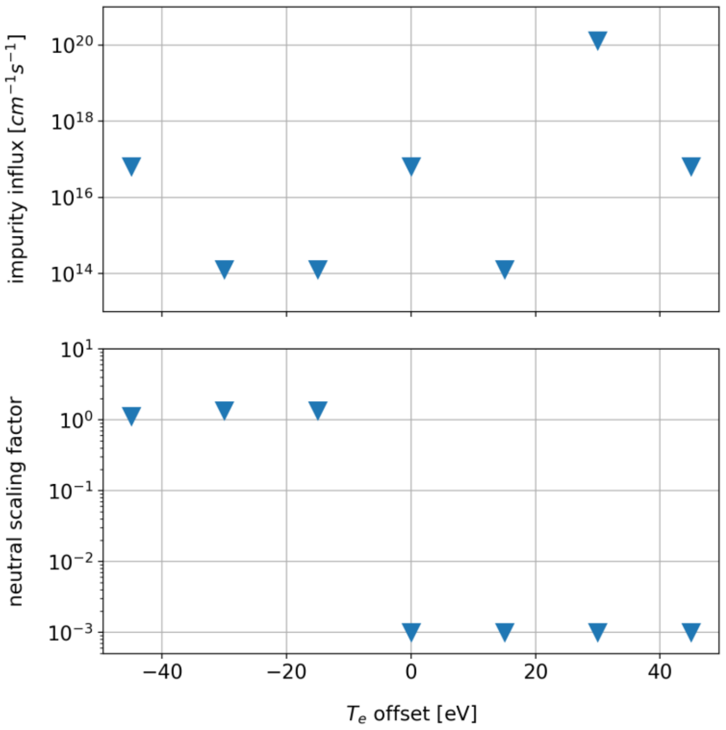


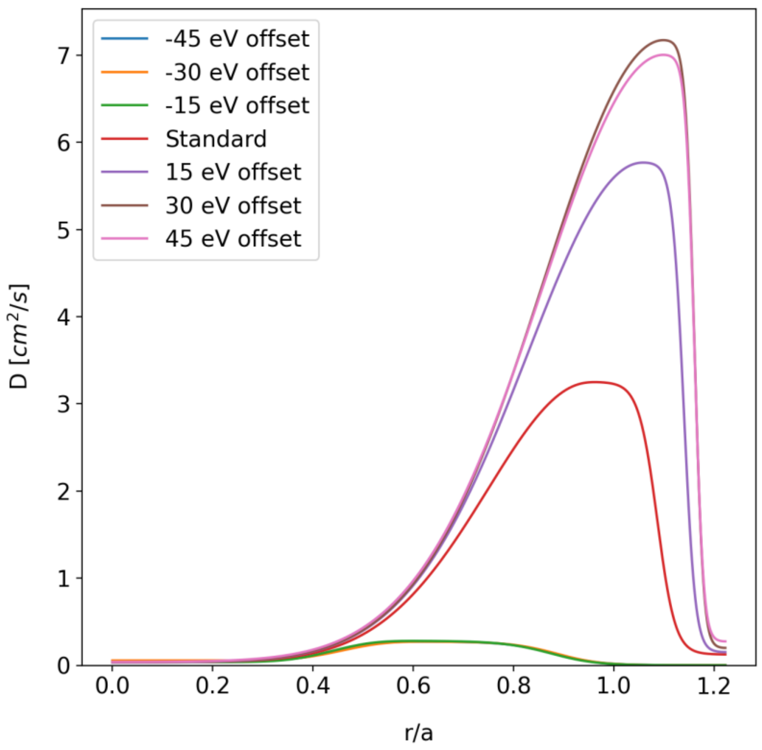


Extra Stuff – Temperature Sensitivity (2)

- Minimization carried out for various temperature offsets
- Higher temperature offsets seem to reproduce data better

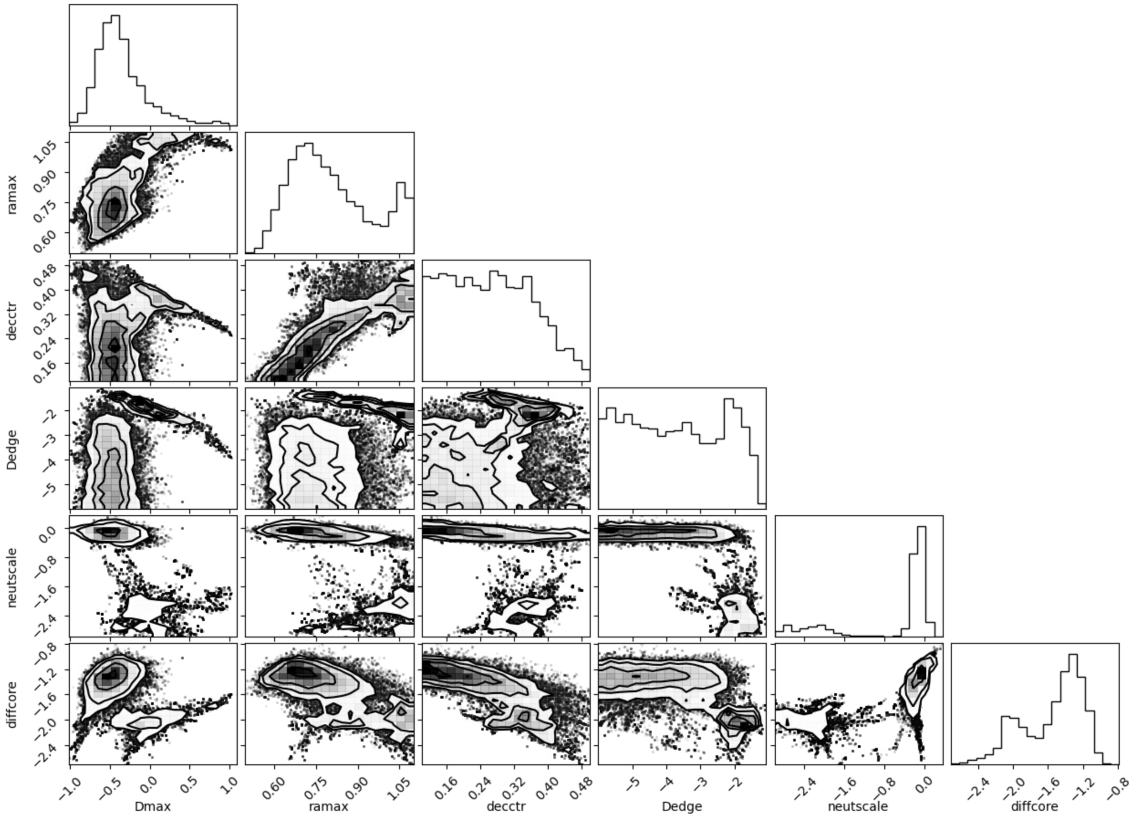


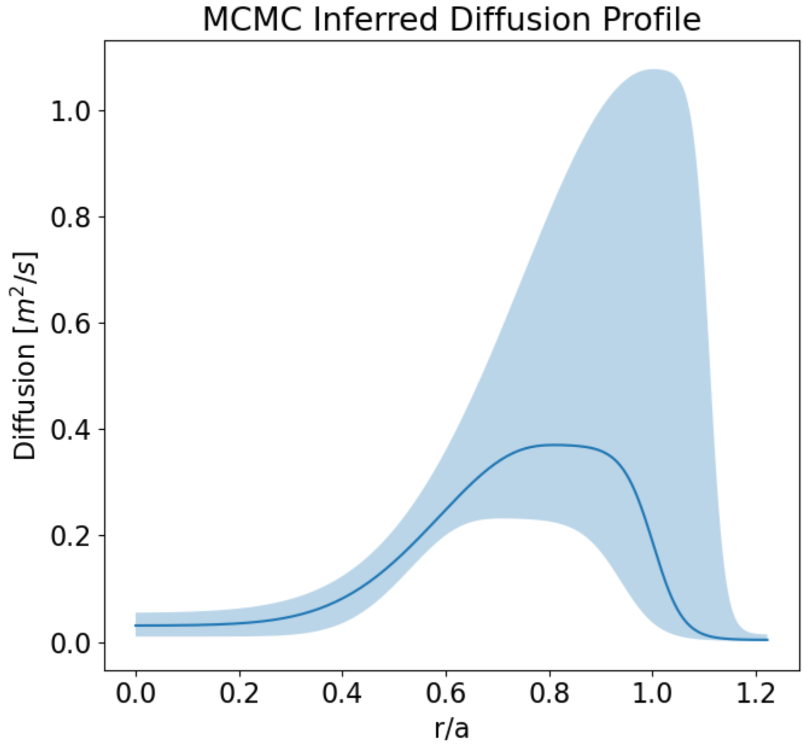




Extra Stuff – Initial MCMC Results

- Similar workflow fed into Markov Chain Monte Carlo scheme to infer diffusion profiles
- Median sample distribution agrees well with basinhopping conclusion though absolute value of diffusion profile ~1 order of magnitude lower
- Further refinement of approach needed…





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