NSTX

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# Dependence of impurity transport on $\rho^*$, $\nu^*$, rotation and effects on MHD in NSTX

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*and the NSTX Research Team*

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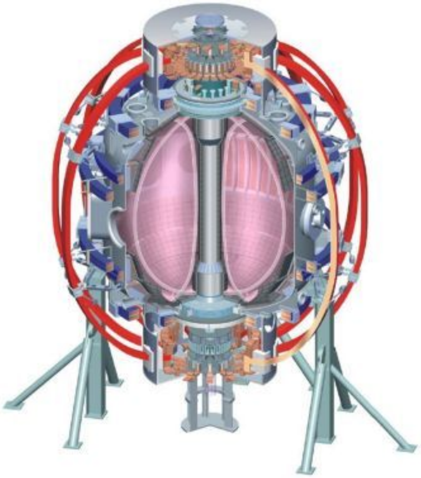

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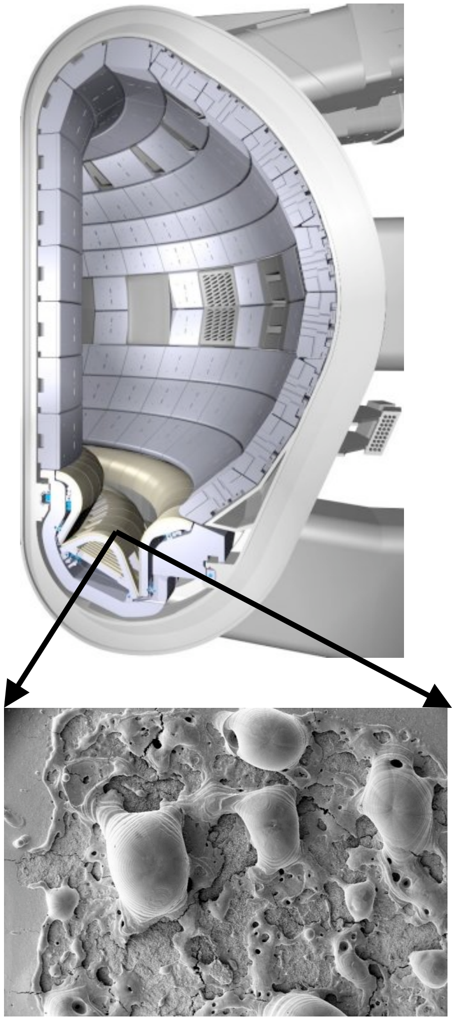
# Motivation

① The understanding of impurity transport in magnetically confined fusion plasmas is one of the challenges facing the current fusion research.

② Study the properties of impurity transport in a spherical tokamak (ST) in a variety of scenarios are important for extrapolation to the next step ST devices such as **CTF** and for comparison with the large aspect ratio tokamaks like **ITER**.

③ Develop an understanding of impurity transport at high-Mach numbers important for **NSTX**, **NSTX-Upgrade** and **NHTX**.

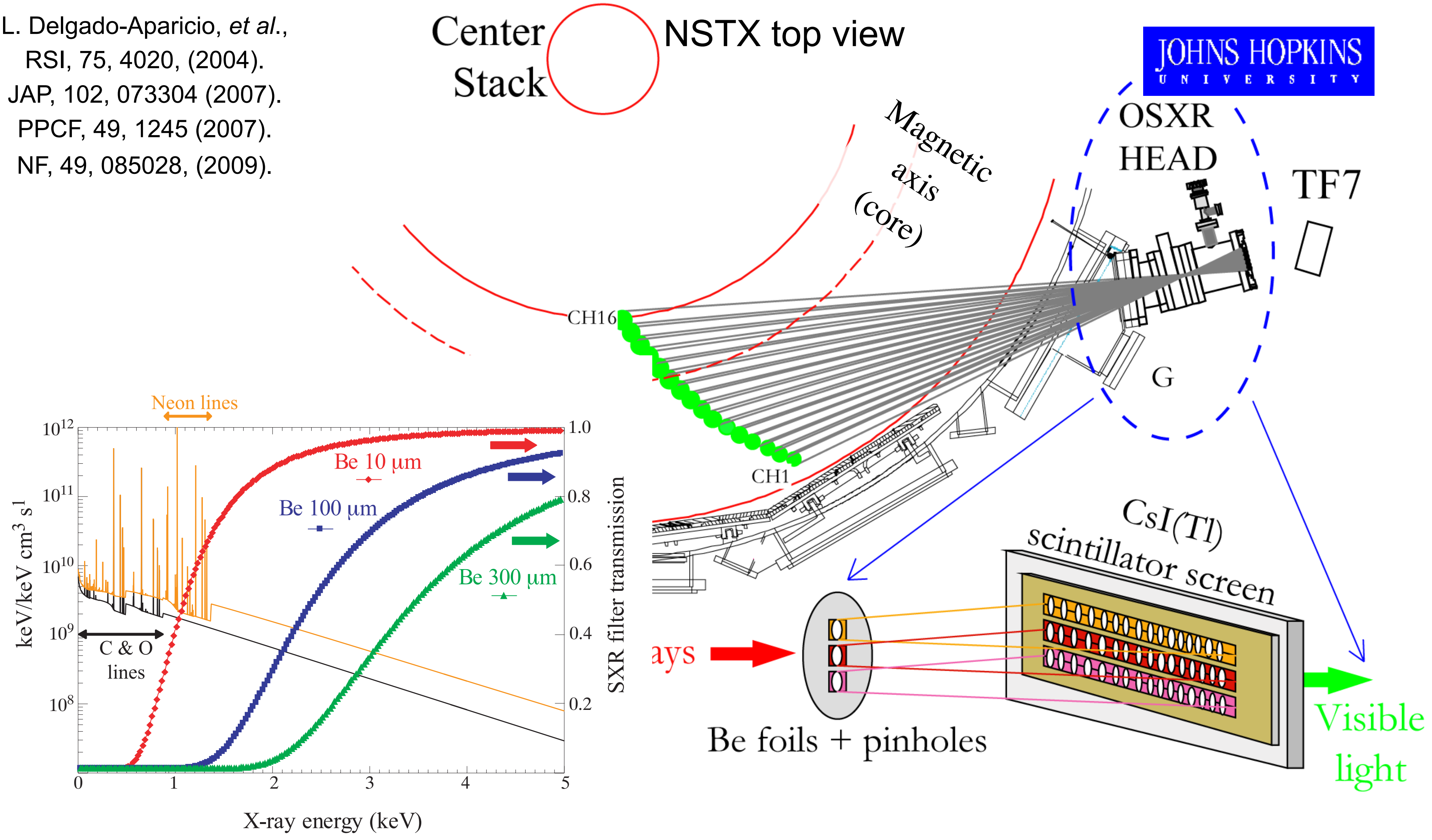
④ Asses the impact of impurity radiation as a driving mechanism for tearing mode activity in any magnetically confined plasma scheme.



Melted tungsten for the ITER-DT phase?

# The main diagnostic for impurity transport and related MHD studies is the tangential ME-SXR array

L. Delgado-Aparicio, *et al.*,
RSI, 75, 4020, (2004).
JAP, 102, 073304 (2007).
PPCF, 49, 1245 (2007).
NF, 49, 085028, (2009).



# Low-Z impurity transport experiments and modeling

The time evolution of the neon emissivity AFTER the injection is modeled using the time-dependent Multiple Ionization Stage Transport (MIST) code.

Atomic processes included in the model:
i) Electron ionization ii) excitation iii) recombination

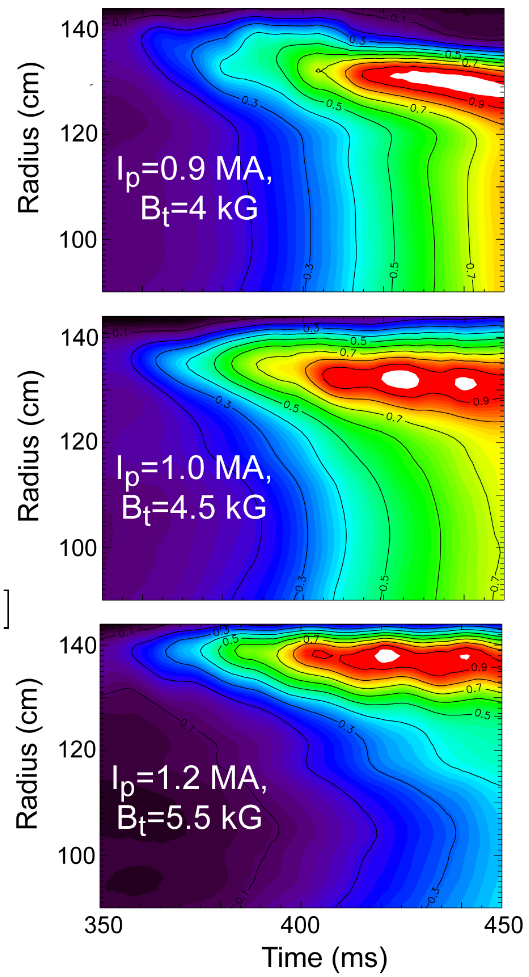
MIST computes the evolution of all charge states through the experimental $n_e(R,t)$ & $T_e(R,t)$ assuming external profiles of diffusivity (D) and convective velocity (V).

$$\frac{\partial n_Z}{\partial t} = -\nabla \cdot \Gamma_Z + \left[n_{Z-1} S_{Z-1\rightarrow Z} + n_{Z+1} S_{Z+1\rightarrow Z}\right] - n_Z \left[S_{Z\rightarrow Z-1} + S_{Z\rightarrow Z+1}\right]$$

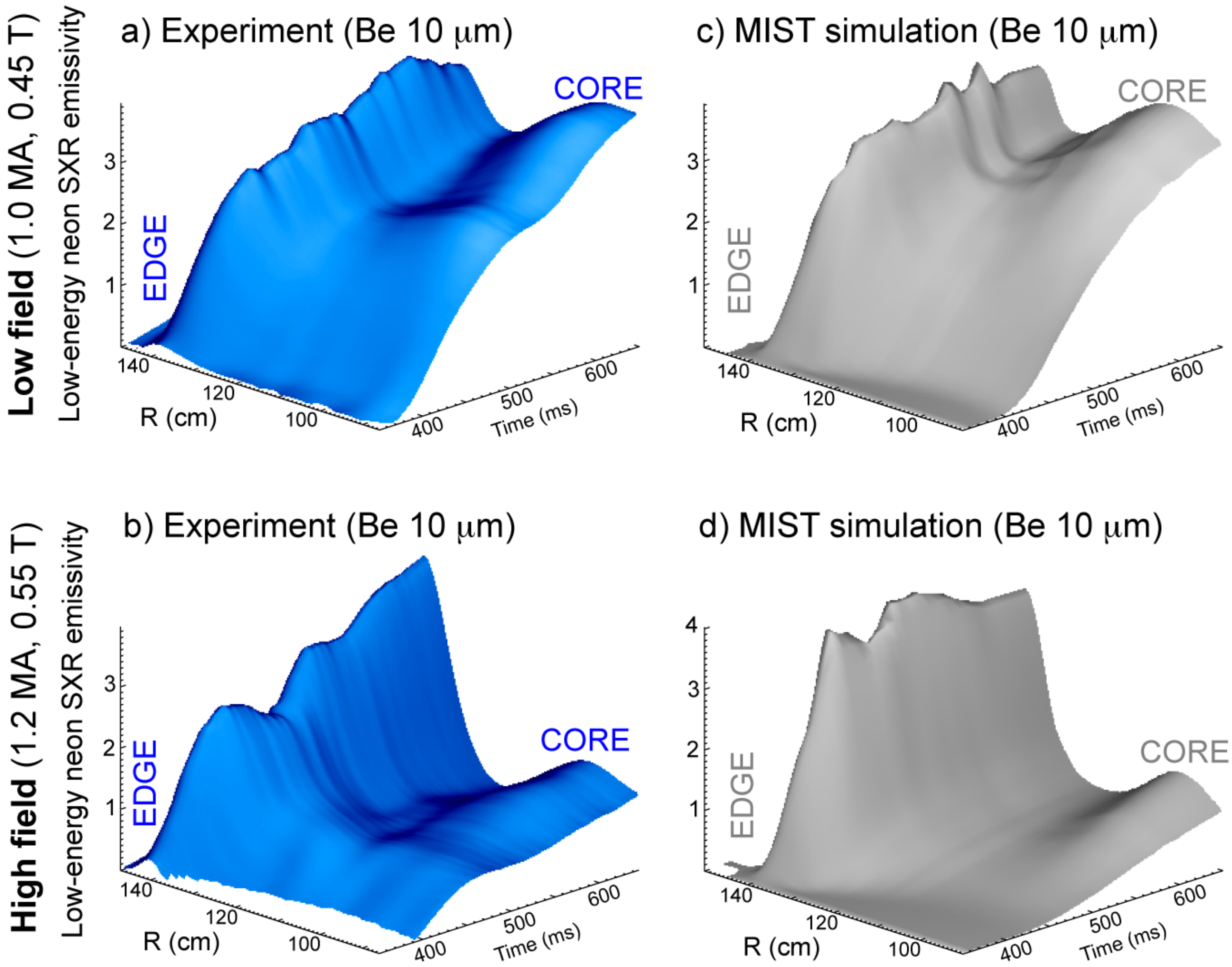
$$\Gamma_Z(r,t) = -D_Z(r,t)\frac{\partial n_Z(r,t)}{\partial r} + n_Z(r,t)V_Z(r,t)$$

L. Delgado-Aparicio, et al., PPCF, 49, 1245 (2007), NF, 49, 085028, (2009).

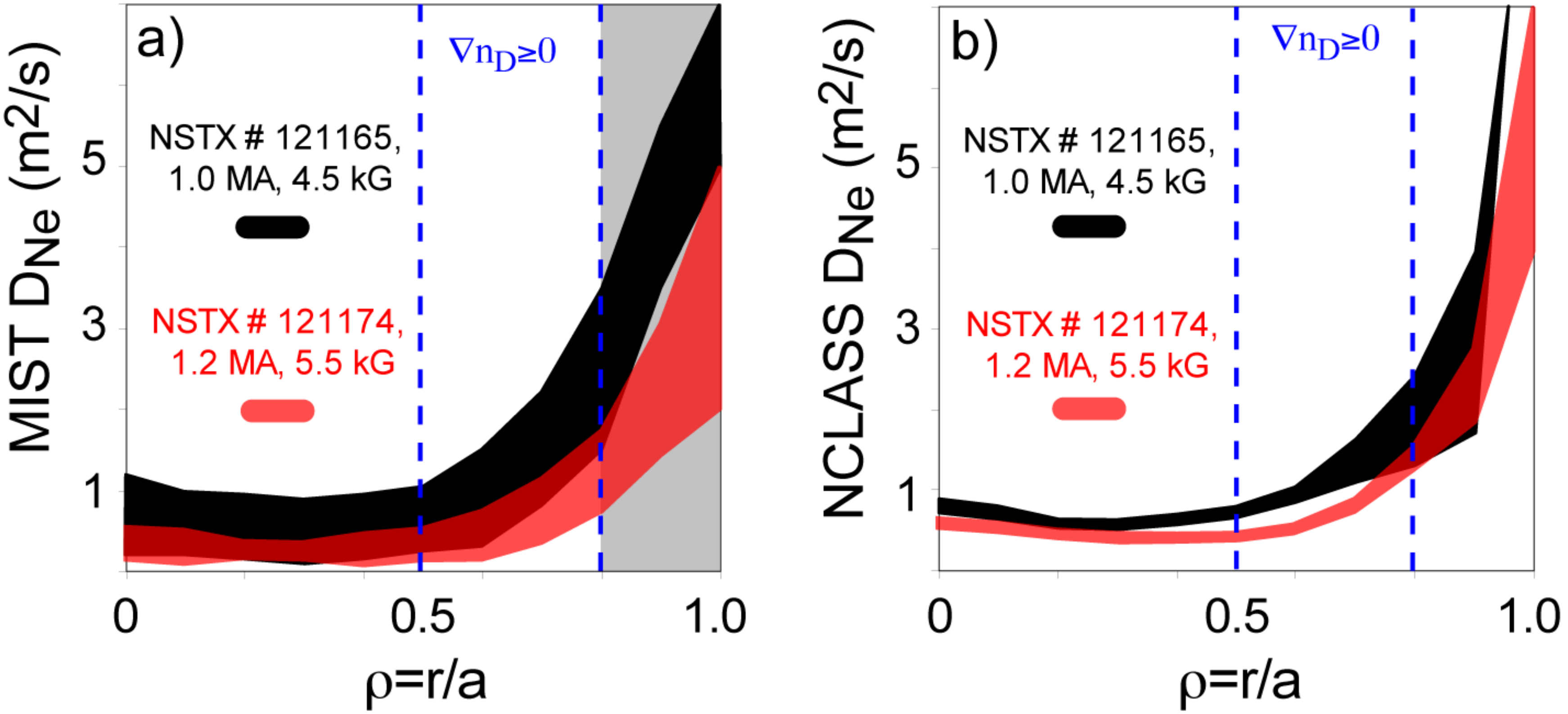
SXR emissivity profiles during neon injection in ρ*-scan at fixed q-profile



# Impurity build-up and penetration to the core changed substantially in the $\rho^*$-scan at fixed *q*-profile



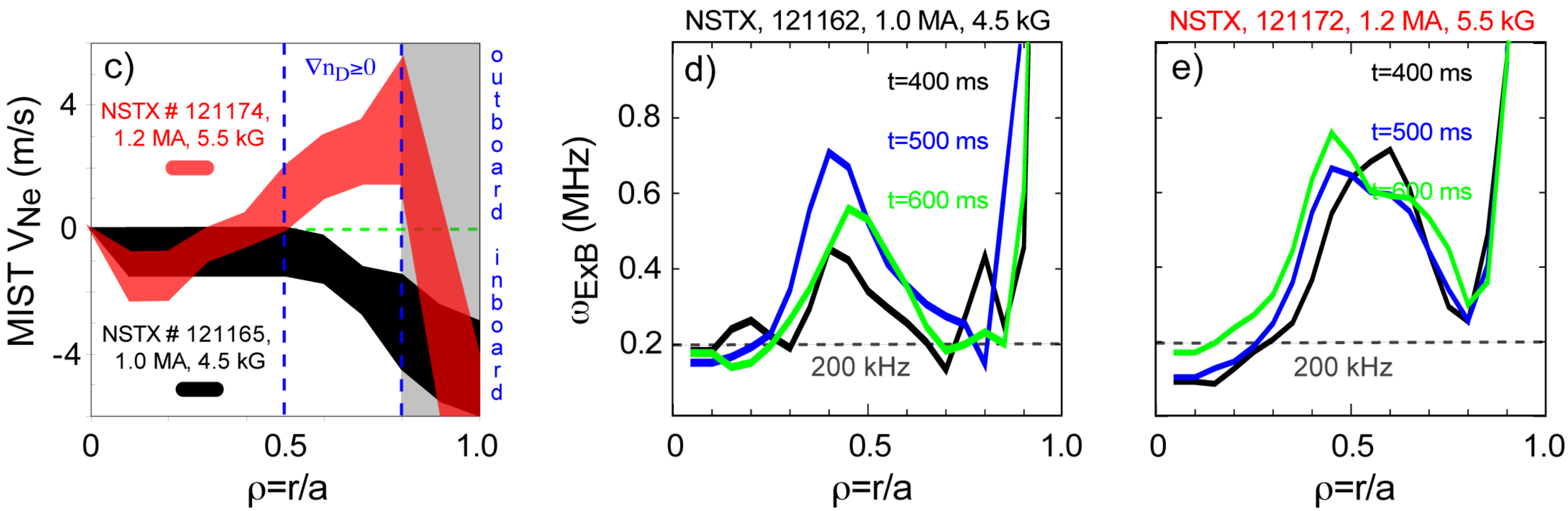
# Experimental neon diffusivity in agreement with theoretical models



- Note large increase in $D_{neo}$ and $D_{exp}$ at $r/a>0.8$
- Neoclassical ordering in the core is ~ $1 m^2/s$

L. Delgado-Aparicio, et al., Nucl. Fusion, 49, 085028, (2009).

# Convective velocity changes sign with $B_T$ is consistent with weaker E×B shear suppression at low fields

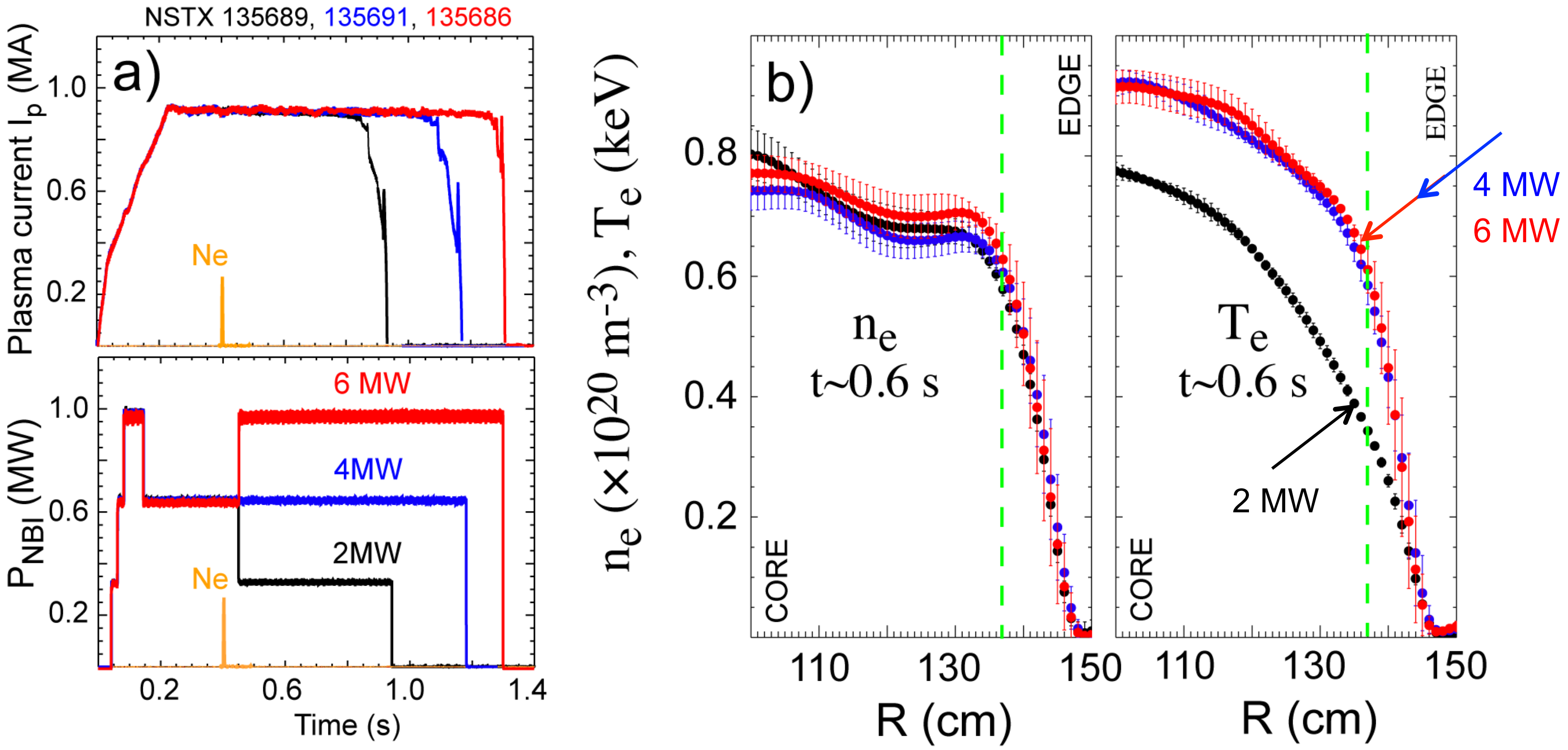


- A reversal of the $V_{Ne}$ in the low field case indicates some anomalous effect to be at play at the gradient region.

- We attribute the negative pinch velocity to the incomplete shear suppression of drift-wave-like instabilities at an outer radii (r/a~0.7-0.8).

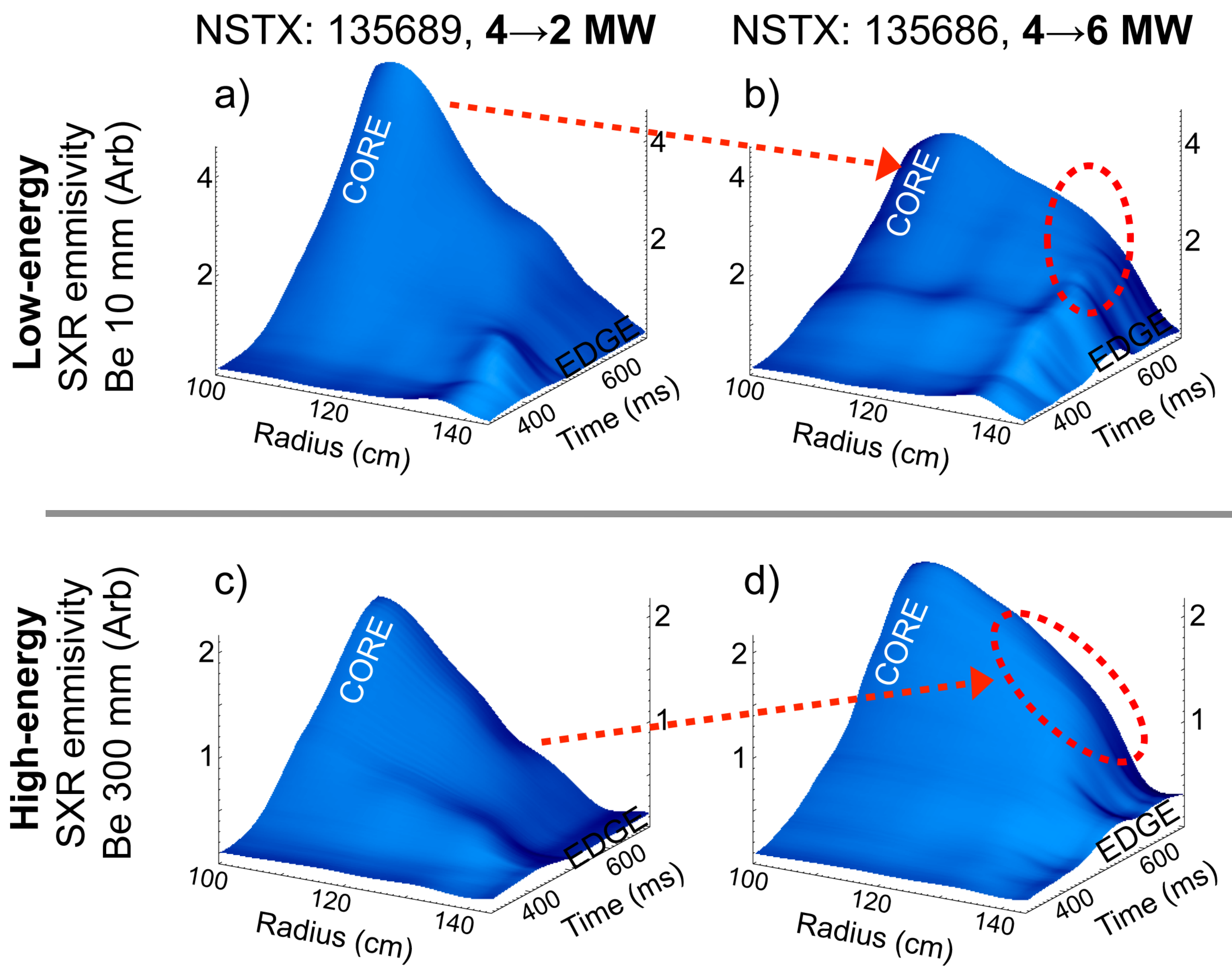
L. Delgado-Aparicio, et al., Nucl. Fusion, 49, 085028, (2009).

# New experiments tested the ν* dependence at the gradient region



- ν* scan of NBI heated H-mode plasmas with $n$, $I_p$ and $B_\phi$ held constant.
- The high-power discharges have as much as twice the $T_{i,e}$ in the gradient region.
- ν* vary up to a factor of four with nearly identical density profiles.

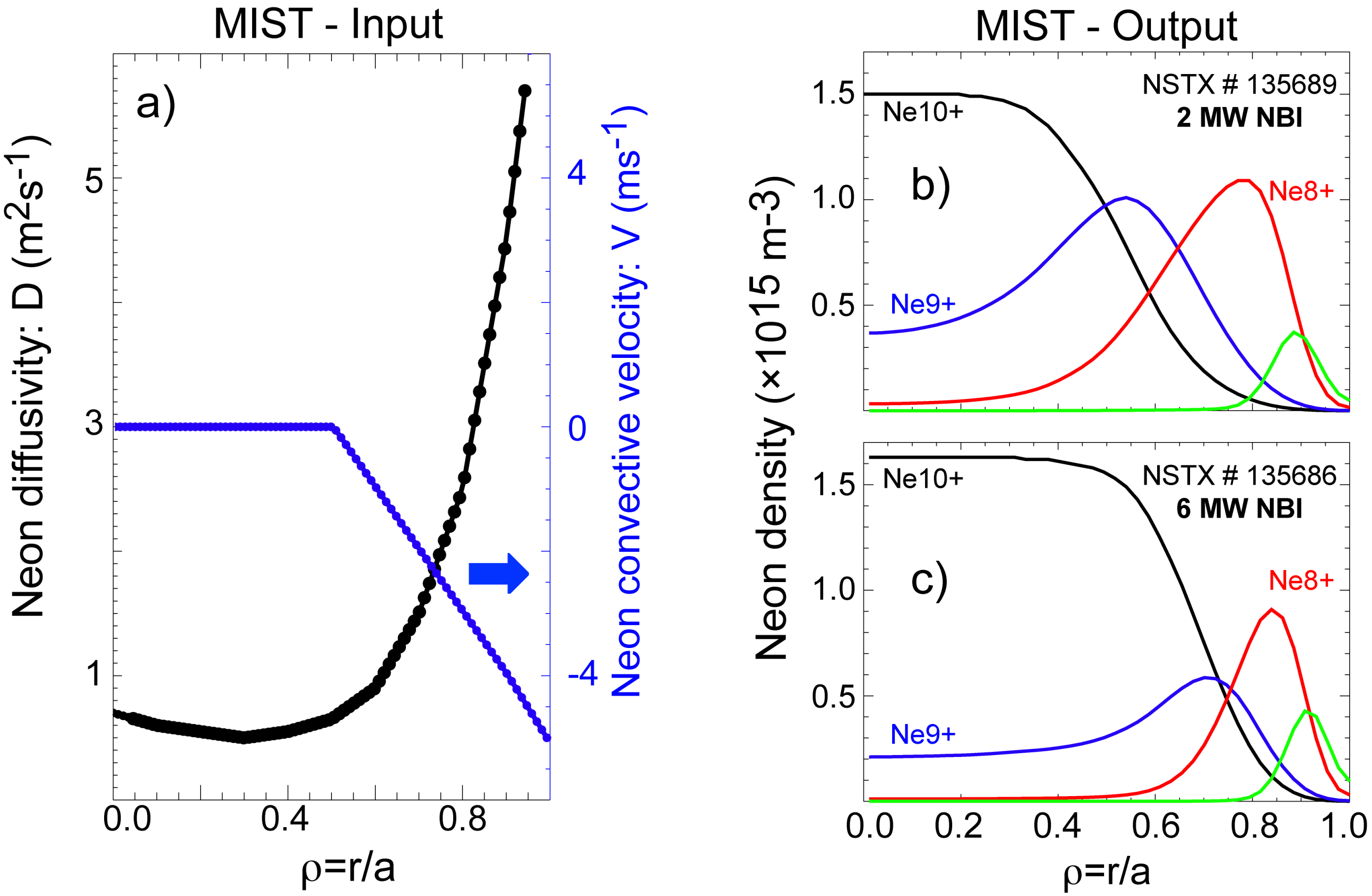
# Reconstructions show differences in the core and gradient region suggesting a possible change in impurity transport



① The low-energy emissivities ($\varepsilon_{LE\text{-}SXR} \sim n_{Ne8+,\ Ne9+}$) indicate that the core emissivity decreases with NBI power while increasing at the gradient region.

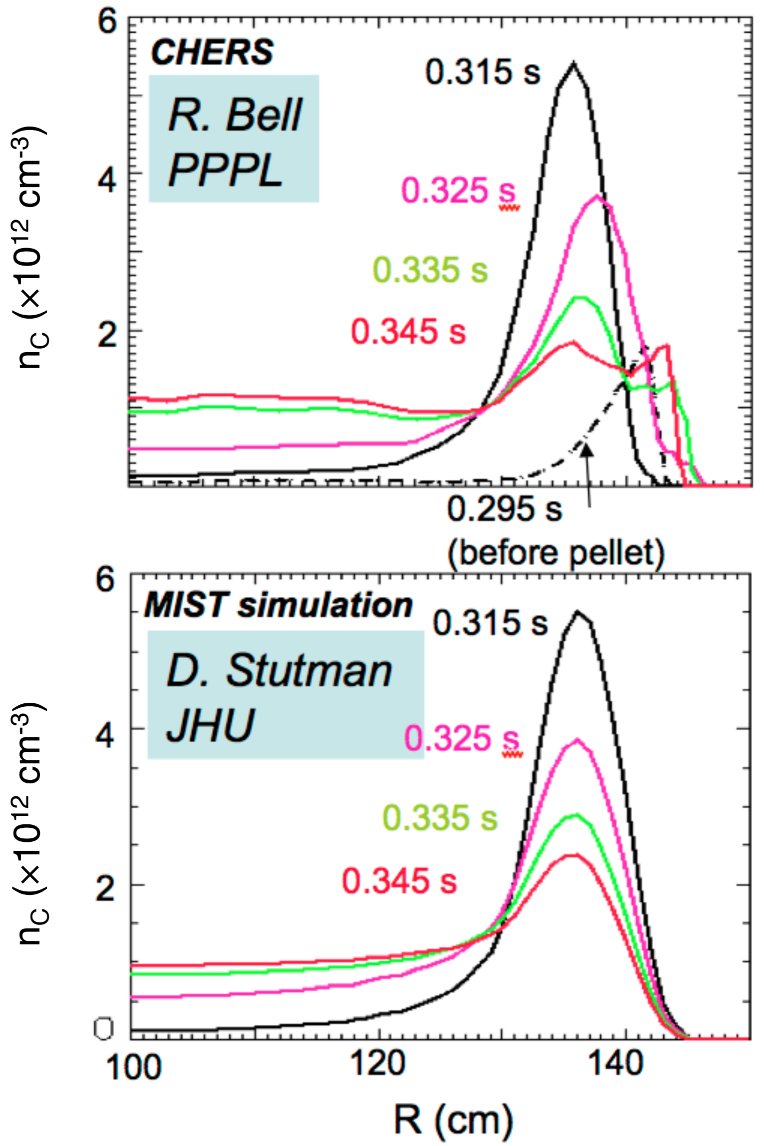
② However, the high-energy emissivity ($\varepsilon_{HE\text{-}SXR} \sim n_{Ne10+}$) indicate that both the core and gradient region emissivity increases with NBI power.

# Charge state distribution can explain the differences in emissivity without the need of changing the transport



Results from MIST simulations indicate that a factor of two increases of $T_e$ (0.6<r/a<0.8) could be solely responsible for modifying the Ne charge state distribution and thus the SXR emissivity, without the need of changing the underlying transport properties.

# Pellet injection can probe time-dependent transport: first results indicate enhanced core impurity transport

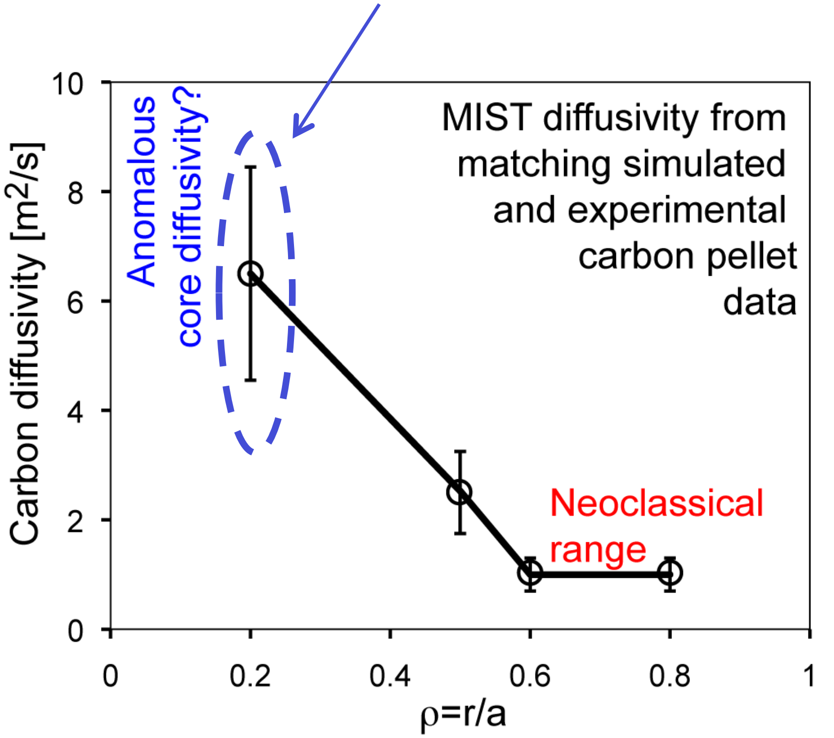


① Ablation resistant, vitreous C pellets deposits impurity deep in the plasma.

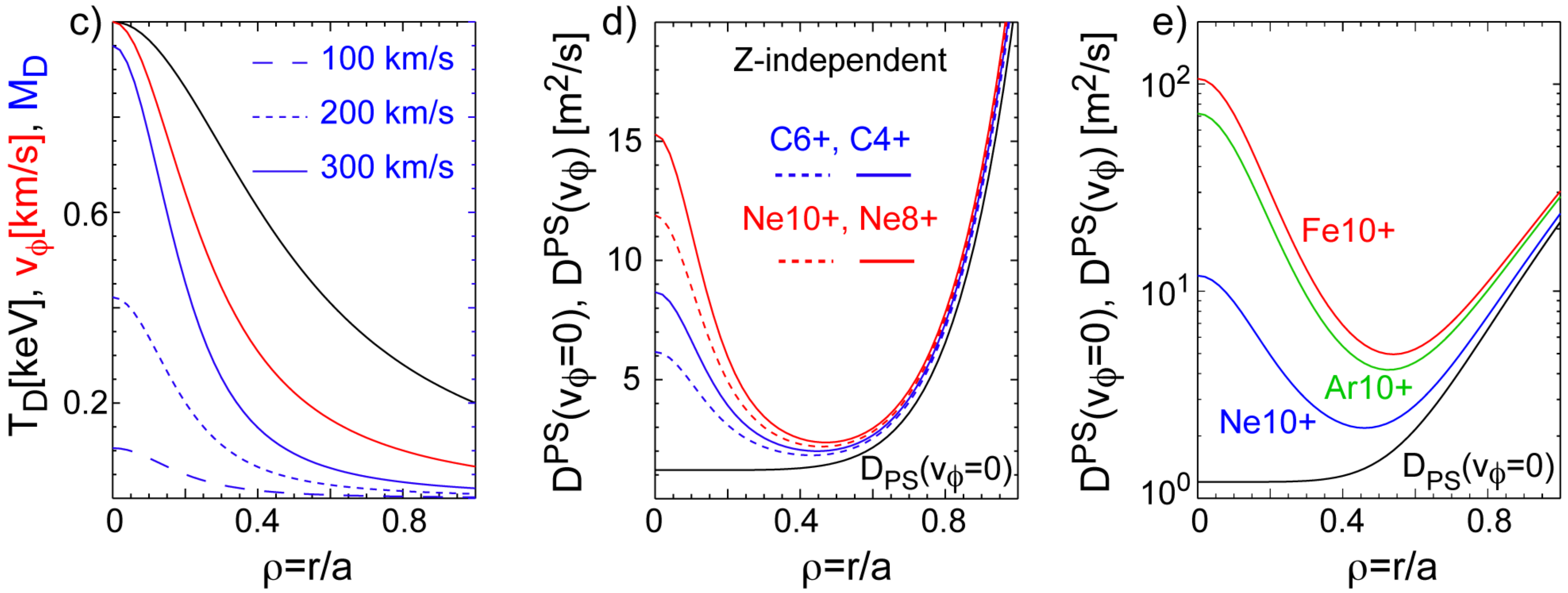
② Evolution of $\delta n_Z$ much slower than that of $\delta T_e$.

③ $D_C$ around 1 $m^2/s$ for r/a > 0.6 (Neoclass. range).

④ $D_C(r/a \rightarrow core) > 1 m^2/s$


MIST diffusivity from matching simulated and experimental carbon pellet data

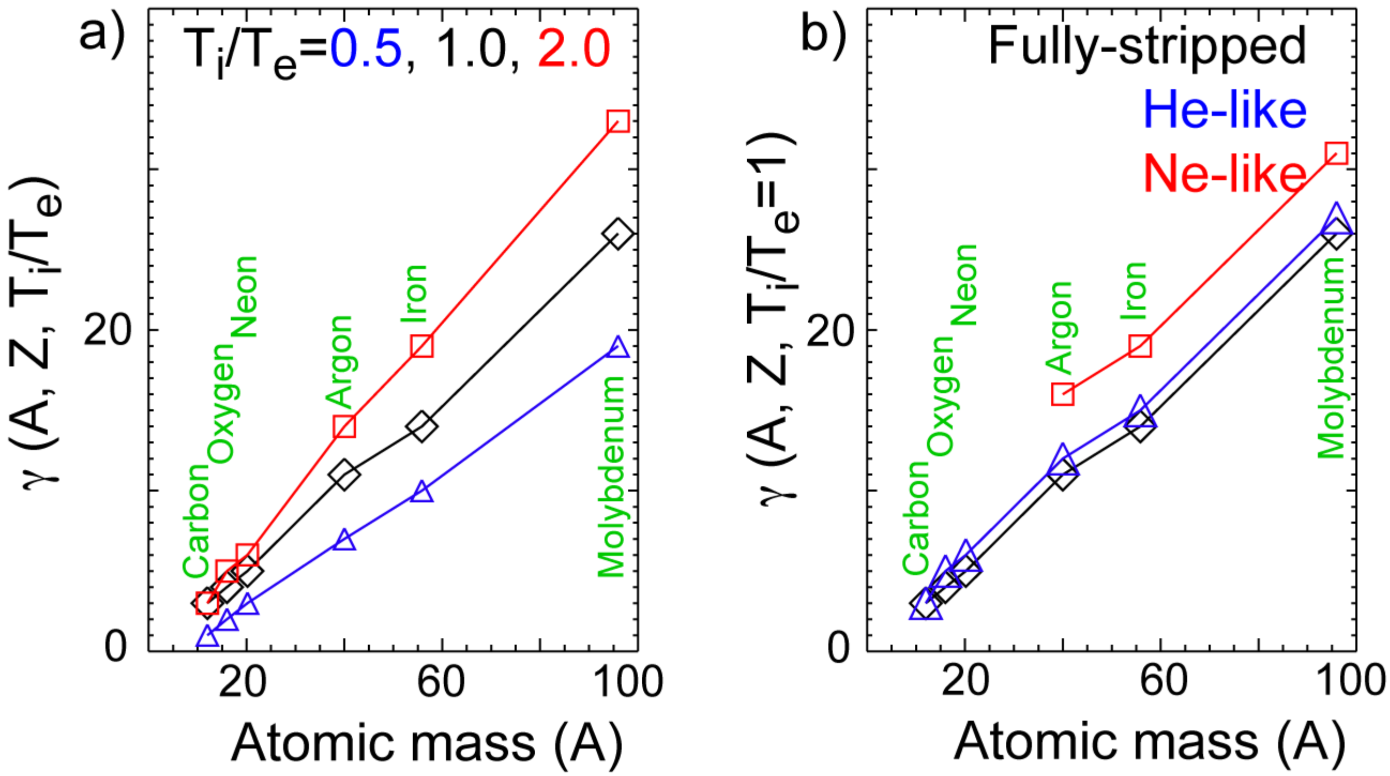
# Core impurity diffusivity can be affected by rotation in NSTX (×10-100 static $D_{Neo}$)



① Charge-states from heavy impurities can have different $D^{PS}(v_\phi)$ that can be several times larger than that of the conventional neoclassical transport.

② This mechanism explains enhanced core diffusivities without the need of invoking the presence of long wavelength electrostatic turbulence.

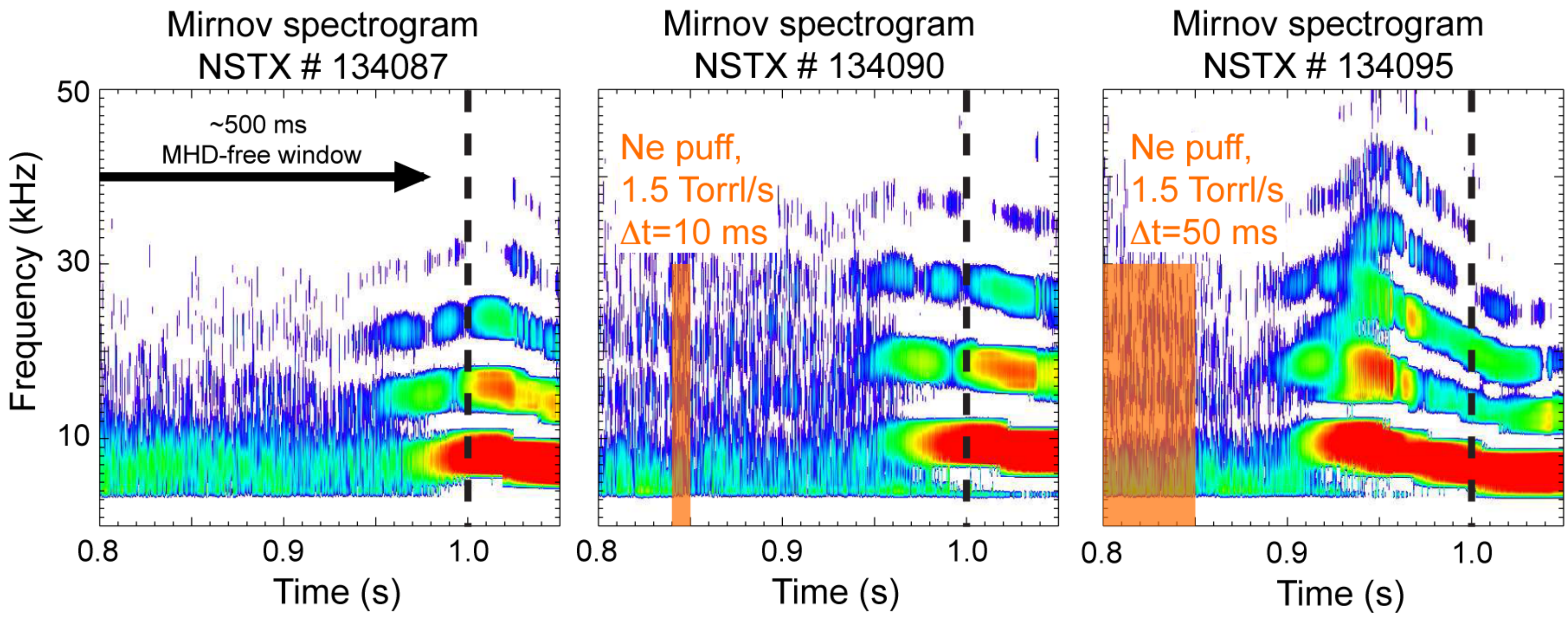
# The enhanced transport is sensitive to the impurity charge, mass, $T_i/T_e$ and the deuterium Mach number



$$D_Z^{PS}(A, Z, T_i/T_e, v_\phi) = D_Z^{PS}\left[1 + \gamma \cdot M_D\right]^2$$

$$M_D \approx 1.05 \times 10^{-5} v_\phi^2[\mathrm{km/s}]/T_D[\mathrm{keV}]$$

# The occurrence of tearing mode activity appears to be correlated also with impurity accumulation



Three mechanisms are being considered:

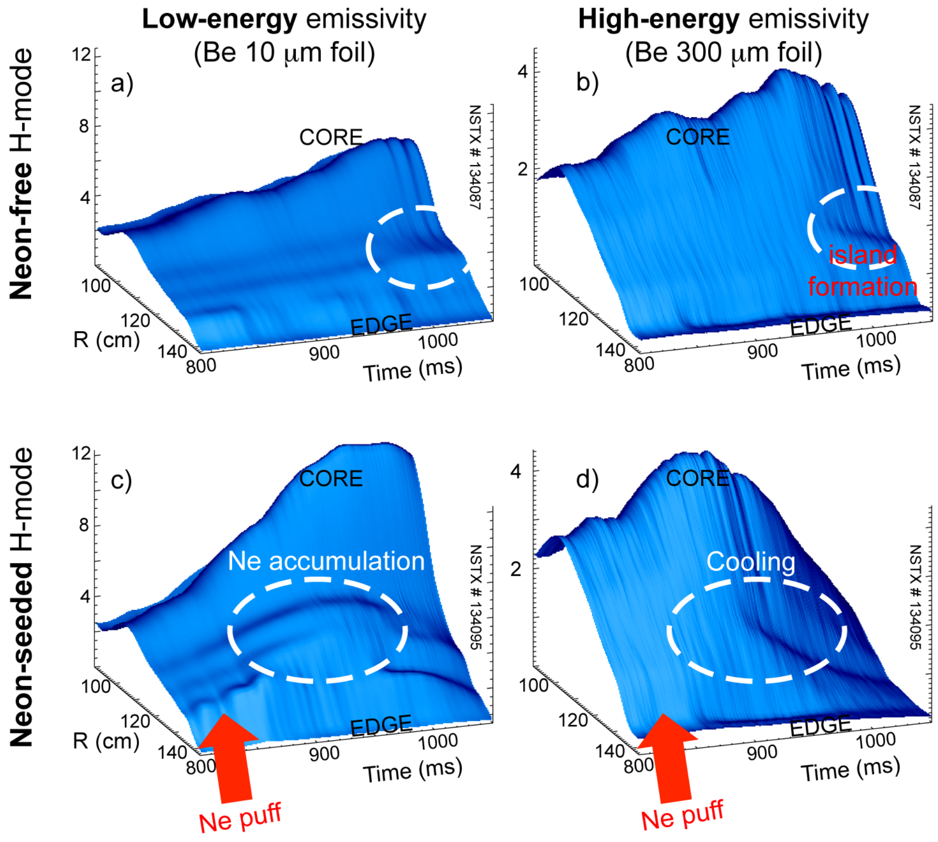
① Increasing $n_Z$ increases the NTM drive through resistivity:

$(\eta \sim \nu_{e,i}, \nu_{e,i}=\nu_{e,D}+\nu_{e,Z}, \nu_{e,Z} \sim n_Z Z^2)$

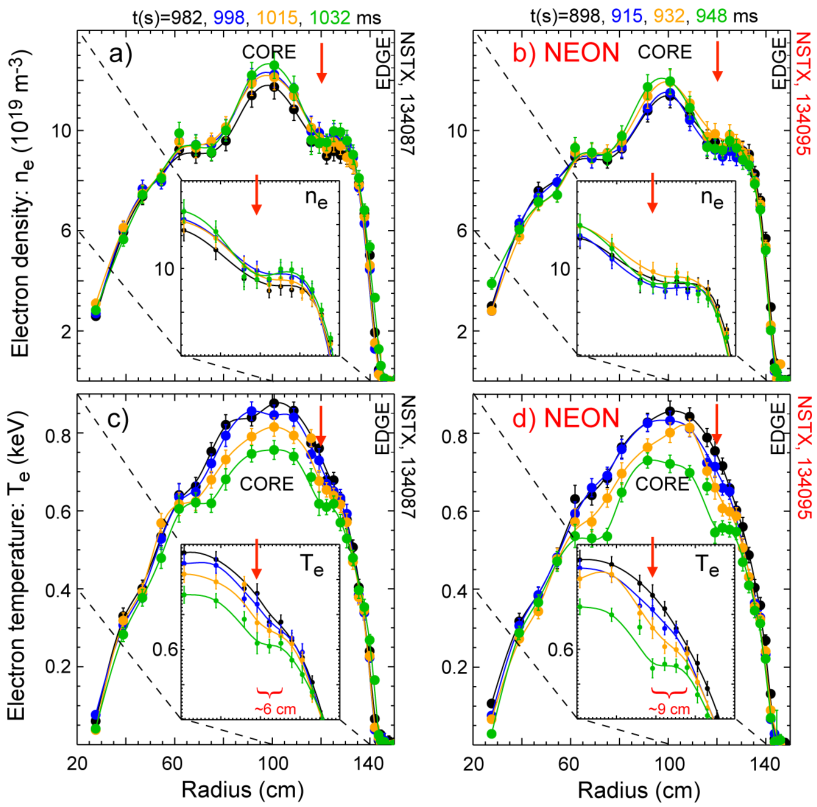
② Increasing $n_Z$ increases $P_{rad,continuum}$ also through $\sim n_Z Z^2$ dependence.

③ Increasing $n_Z$ increases $P_{rad,line\text{-}emission} > P_{rad,continuum}$

# Impurity radiation can be responsible for early appearance of TM as well as increase in the island size



## Multi-point Thomson Scattering $n_e$ & $T_e$ profiles

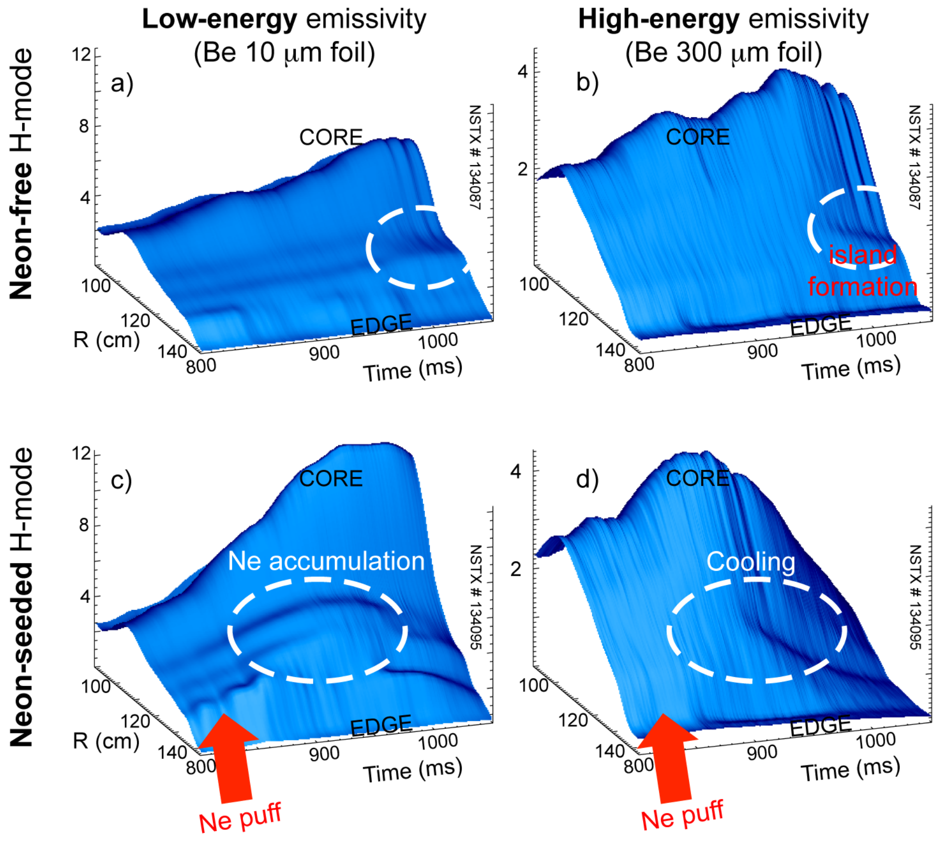


$$\frac{dw^*}{d\tau} \sim r_s\Delta' + \frac{C_1 w^*}{w^{*2}+w_\chi^{*2}} + \boxed{C_2 w^*}$$

with $C_2 \propto \tilde{P}_{rad}$

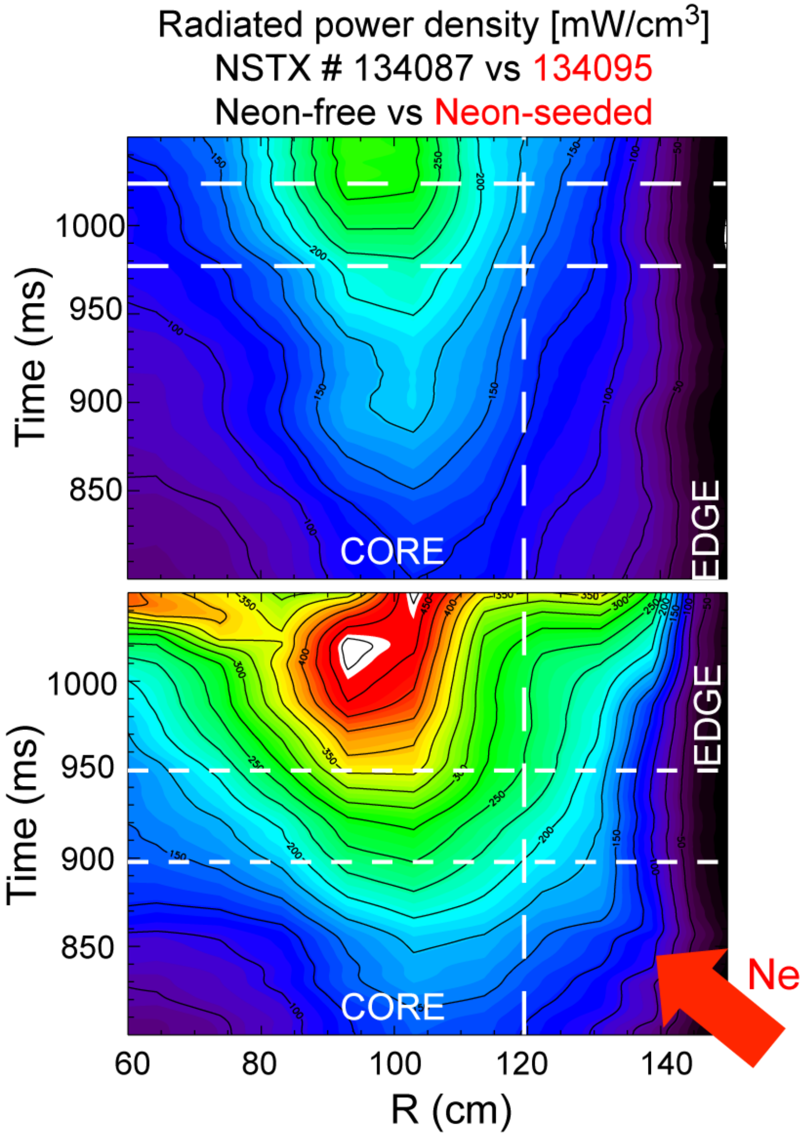
Temperature flattening increased from ~6 to ~9 cm in neon seeded H-mode

# Impurity line-emission ($P_{rad\text{-}line}$) strongly dominates over Bremsstrahlung ($P_{rad\text{-}cont}$) and $\Delta Z_{eff}$



① The enhancement of the high-energy emissivity is of about 20-30% and thus also that of $Z_{eff}$.

② The enhancement of the low-energy emissivity and thus of $P_{rad\text{-}line}$ is of ~200-300%



# Summary

① Impurity diffusivity levels consistent with the neoclassical predictions have been found, whereas a reversal of the convective velocity at low fields indicates an anomalous effect to be at play at the gradient region.

② Different charge state distributions as a consequence of different background plasma parameters have been taken into account when modeling the impurity transport and may be responsible for the change in SXR emissivity in the $\nu^*$ scan experiments, but without the need of changing the underlying transport.

③ Studies on the impact of rotation in low density H-modes (with toroidal rotation velocities of 200-300 km/s) show that heavy and not fully stripped impurities can experience diffusive and convective coefficients several times larger than that of the 'standard' neoclassical transport for stationary plasmas, without the need of invoking the presence of long wavelength core electrostatic turbulence.

④ As a by-product of a strong impurity accumulation we have also observed a correlation between the strength of the emitted radiation, the appearance of tearing modes activity, the enlarged island and associated cooling rates, all in accordance with the presence of radiatively-induced tearing modes.