On transport characteristics of the edge ergodic layer of LHD

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Implication of impurity screening at high density operation

Even at very high density operation with more than

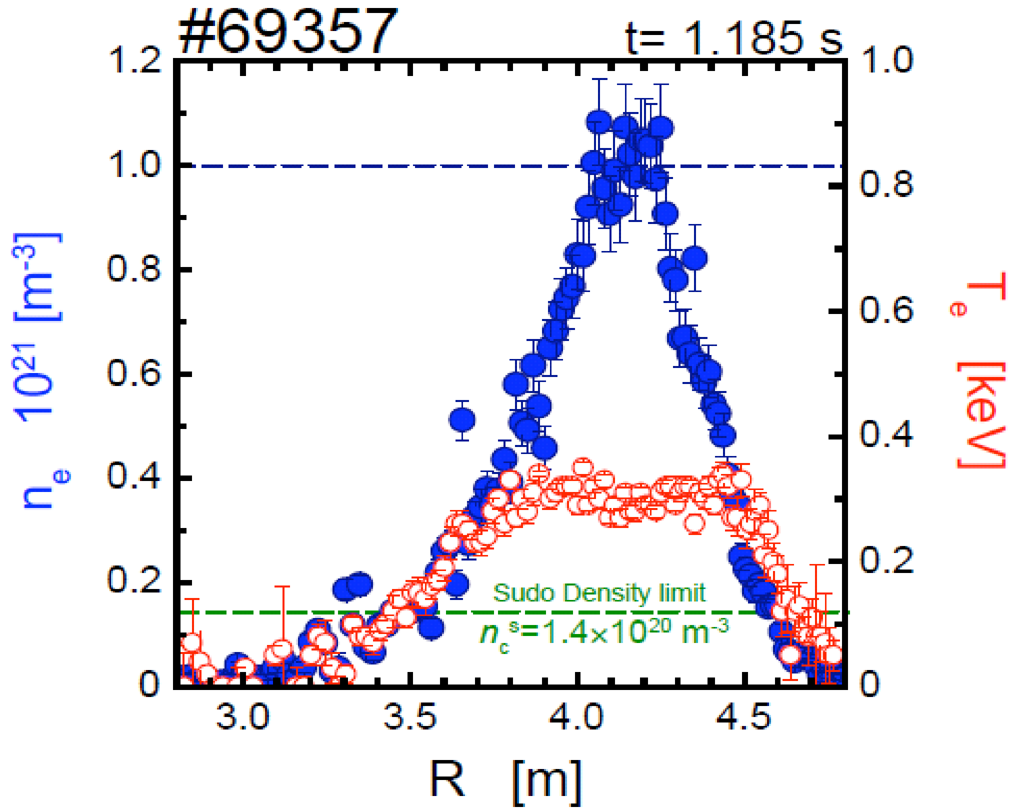
10^{20} m^{-3}

& peaked density profile,

⇩

no significant impurity accumulation

$Z_{eff} < 2$



In this paper, a possible mechanism of impurity retention (screening) is discussed in terms of edge transport.

<u>Outline of the talk</u>

- **Condition for impurity retention in SOL**
- **Impurity transport analysis in ergodic layer**
  - **3D impurity transport analysis**
  - **Comparison with experiments**
- **Implication for high Z impurity**
- **Summary**

Condition for impurity retention in SOL

1D impurity transport model along B field lines

dominant terms

$$m_z \frac{\partial V_z}{\partial t} = -\frac{1}{n_z}\frac{\partial T_i n_z}{\partial s} + m_z \frac{V_i - V_z}{\tau_s} + ZeE_{//} + 0.71Z^2 \frac{\partial T_e}{\partial s} + 2.6Z^2 \frac{\partial T_i}{\partial s} + ...$$

friction — ion thermal force

In force balance, impurity velocity becomes,

$$\boldsymbol{V_{z//} \approx V_{i//} + C_i \frac{\tau_s}{m_z} Z^2 \nabla_{//} T_i}$$

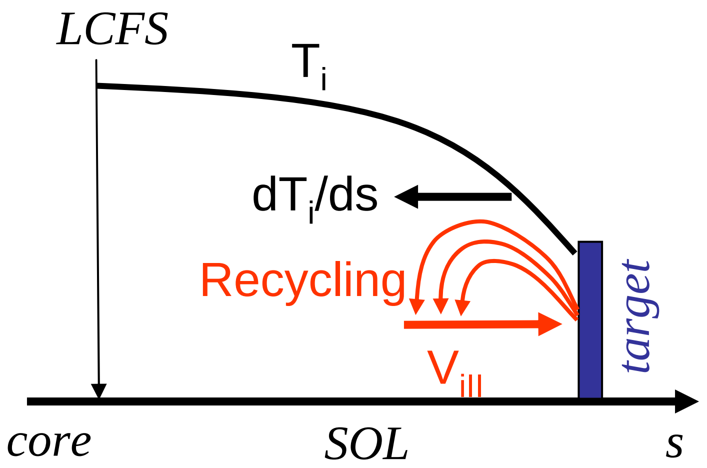
Condition for impurity retention

$$V_{i//} > C_i \frac{\tau_s}{m_z} Z^2 \nabla_{//} T_i$$

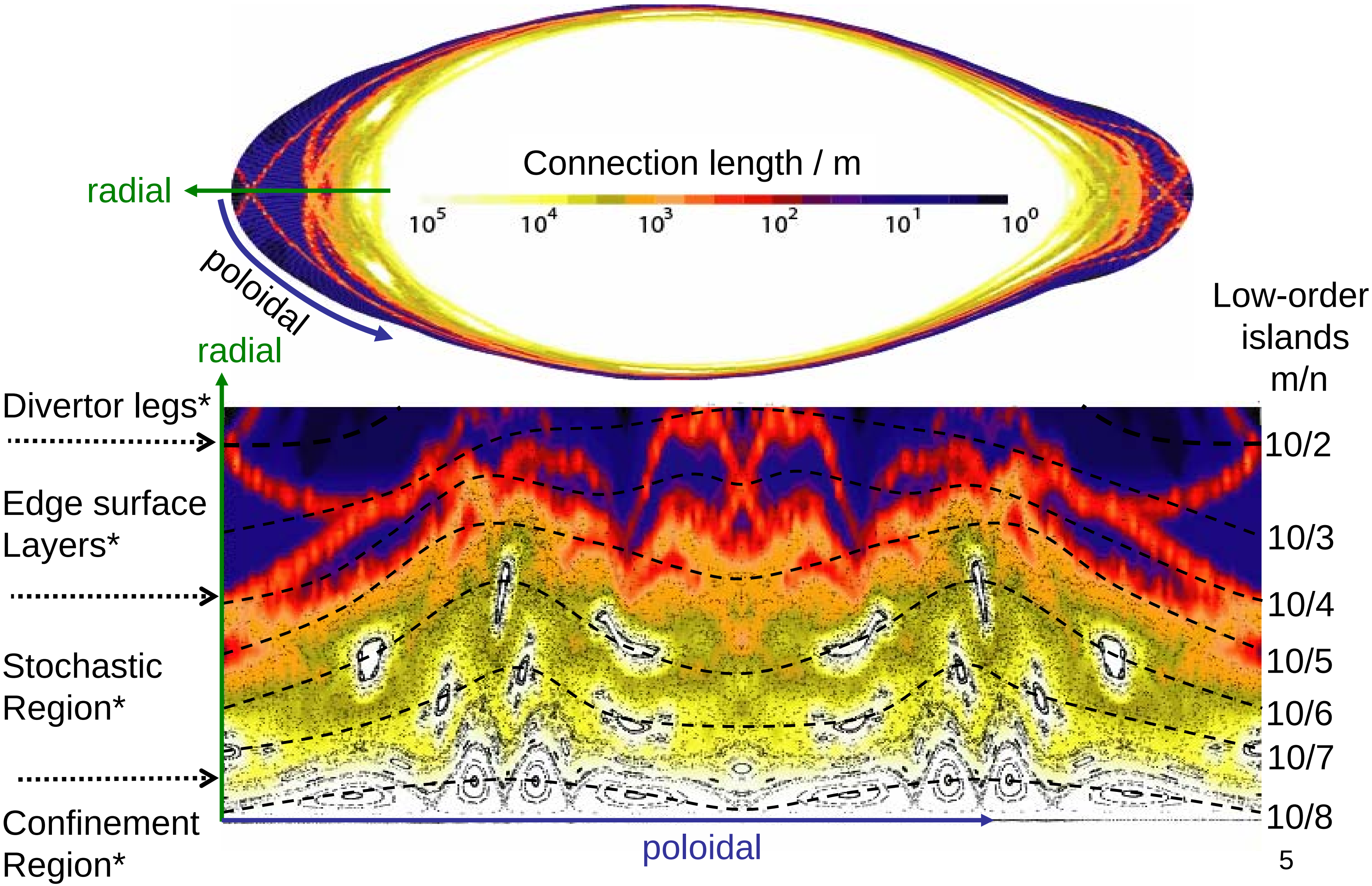
$$\frac{\textit{friction}}{\textit{thermal force}} > 1$$ ➔ impurity retention

$$\left(\sim \frac{5/2 n_i T_i V_{i//}}{\kappa_0^i T_i^{2.5} \nabla_{//} T_i} \propto \frac{n_i V_{i//}}{T_i^{1.5} \nabla_{//} T_i} \right)$$

Impurity retention :
dense and cold plasma, flow acceleration.



Basic field structure: island overlapping → stochastic



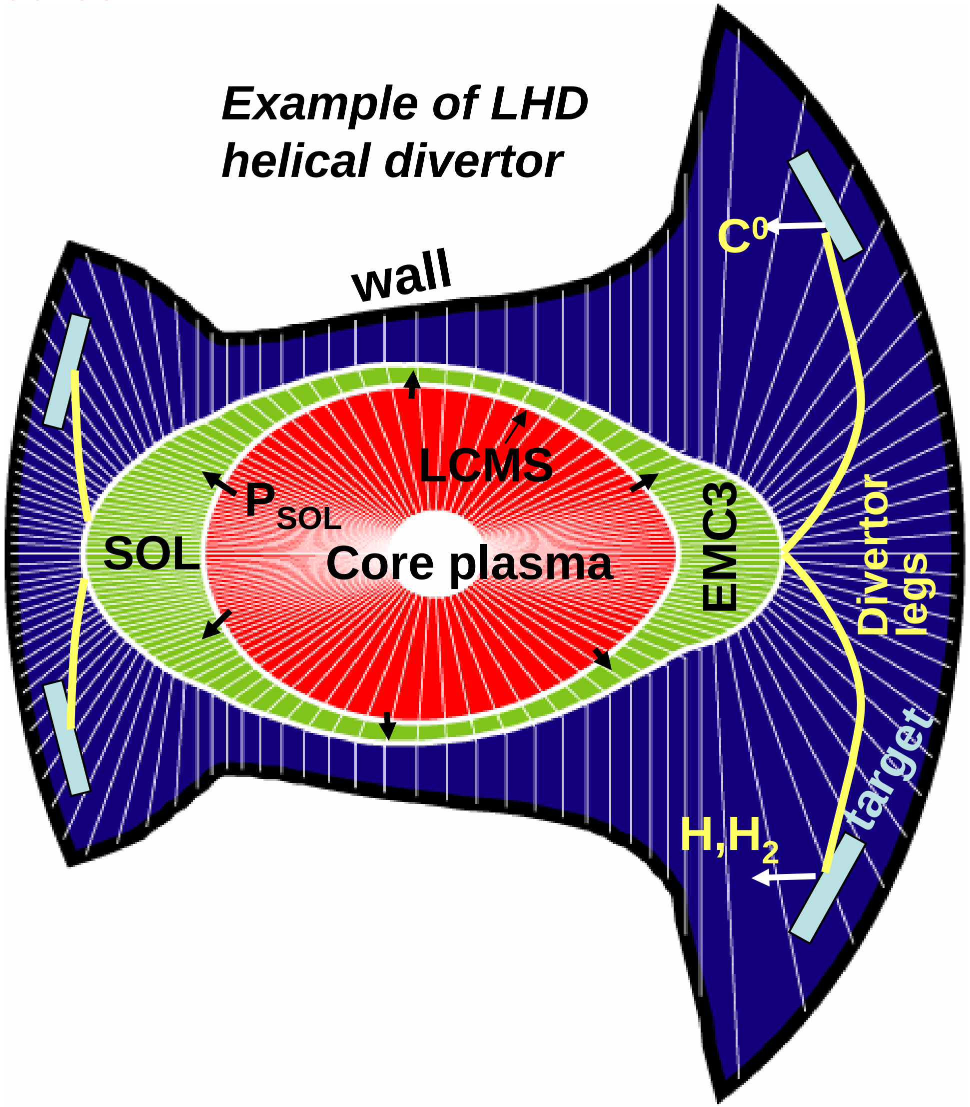
*Terminology: *N. Ohyabu et al., Nucl. Fusion, Vol. 34, No.3 (1994)*

3D Impurity transport analysis in ergodic layer

3D modelling of LHD edge region (EMC3-EIRENE)

Computational mesh, configuration and installations

- Core, CX-neutral transport, particle source
- SOL, EMC3 simulation domain
- Vacuum of plasma*



Physics model

- Standard fluid equations of mass, momentum, ion and electron energy
- Trace impurity fluid model (Carbon)
- Kinetic model for neutral gas (Eirene)

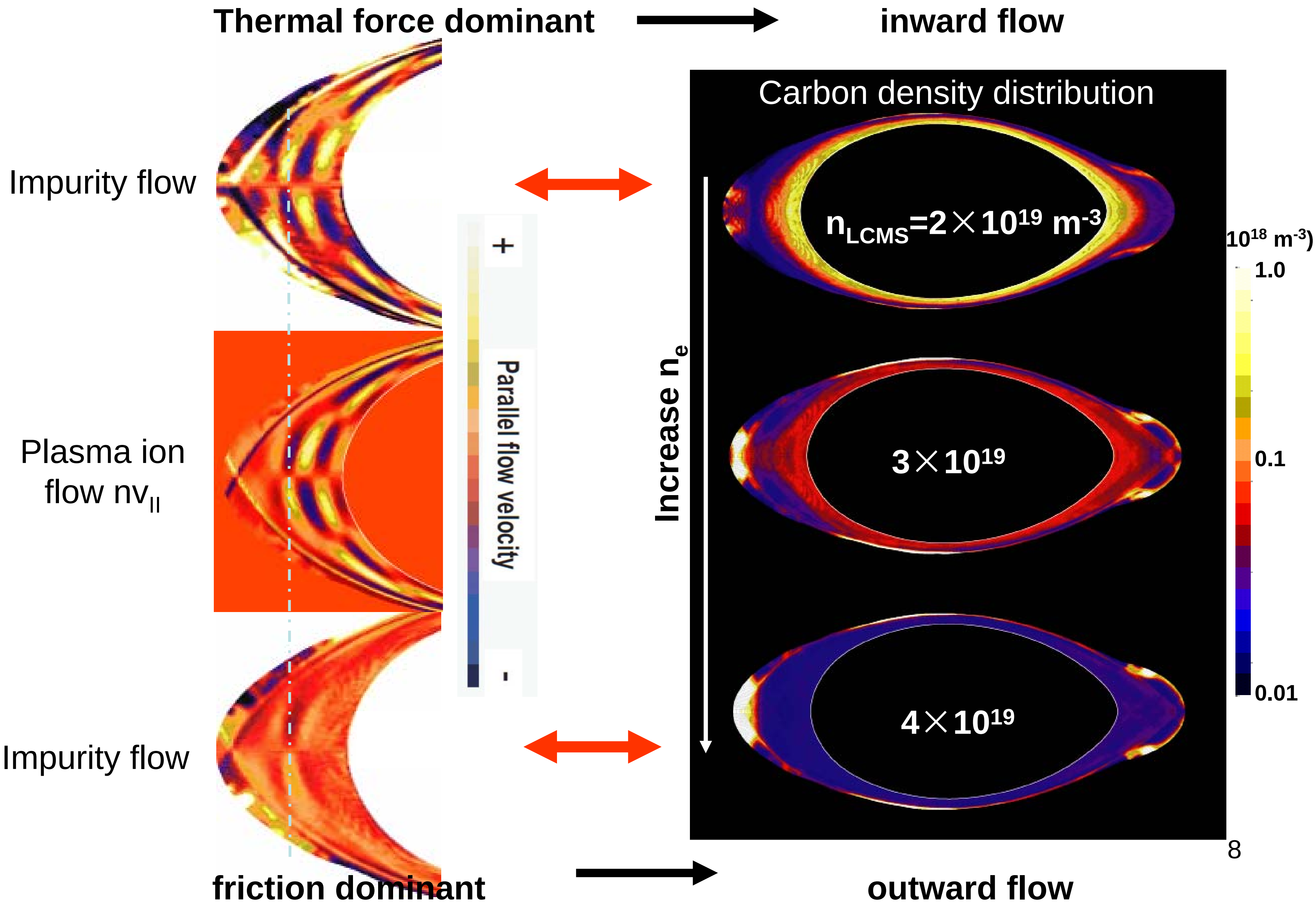
Boundary conditions

- Power entering the SOL
- Density on LCMS
- Sputtering coefficient

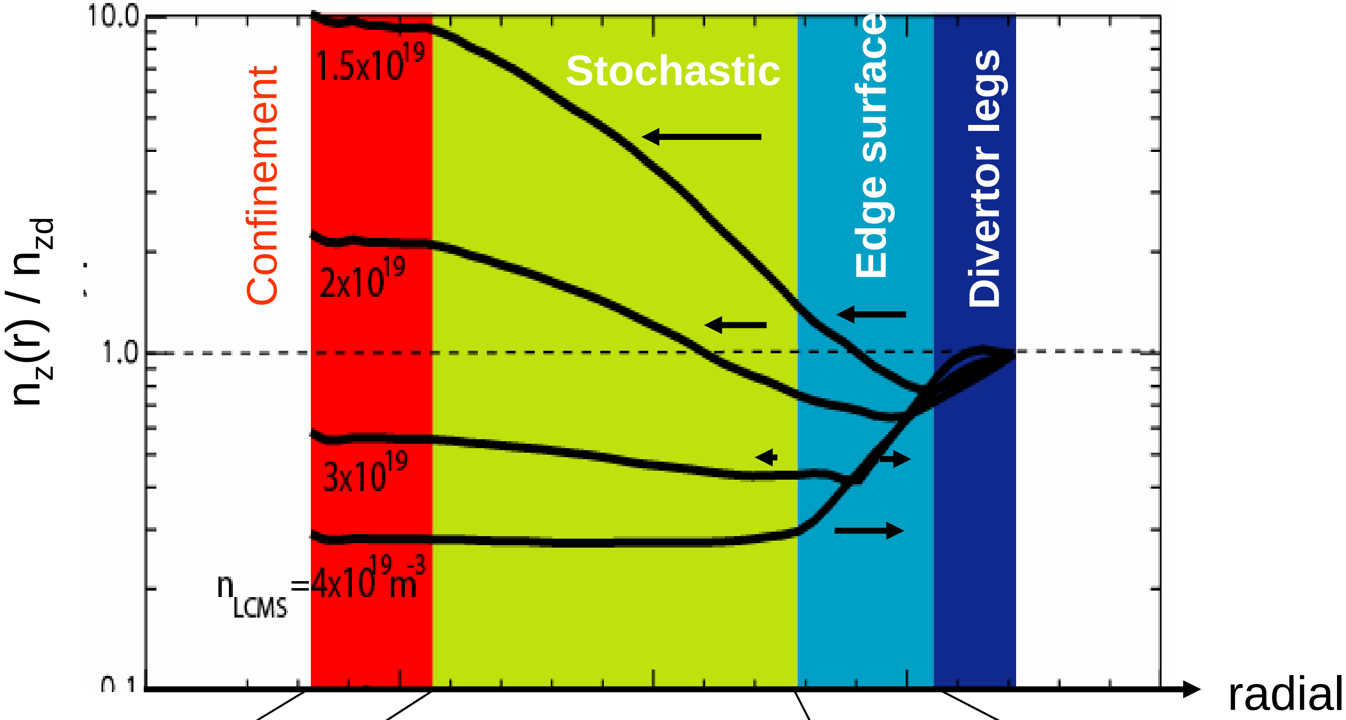
Cross-field transport coefficients

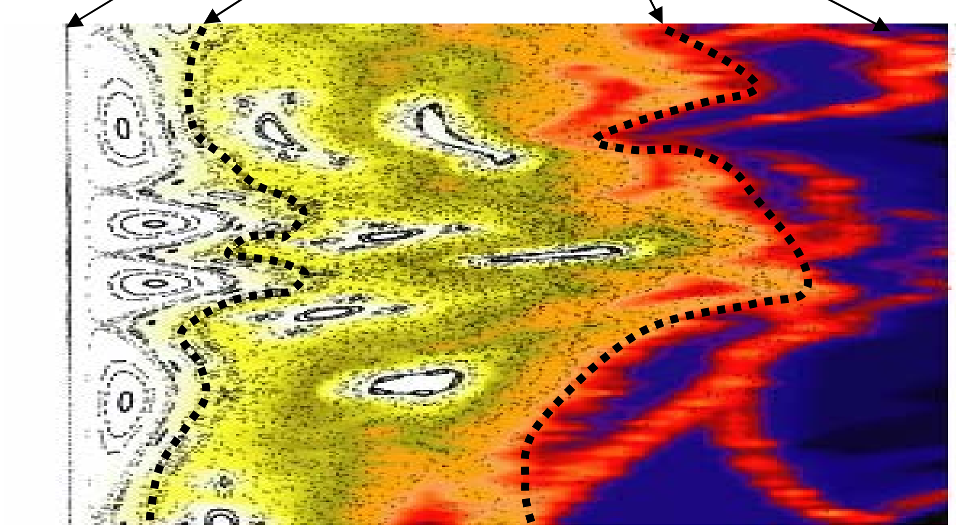
- $\chi_e = \chi_i = 3D$ roughly holds
- spatially constant (global transport)
- determined experimentally

From thermal-force to friction-dominated impurity transport

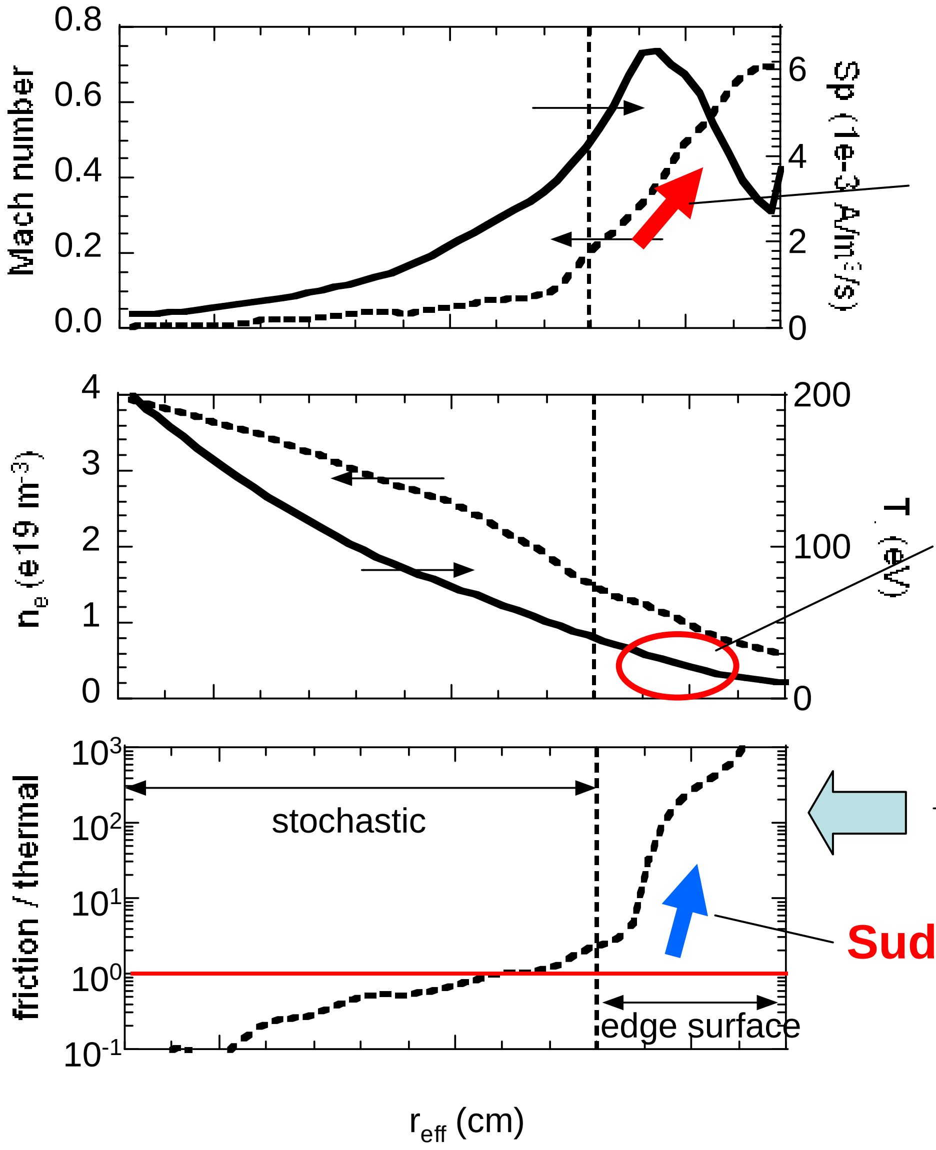


Impurity retention is effective in edge surface layer.





Significant increase of friction force in edge surface layers



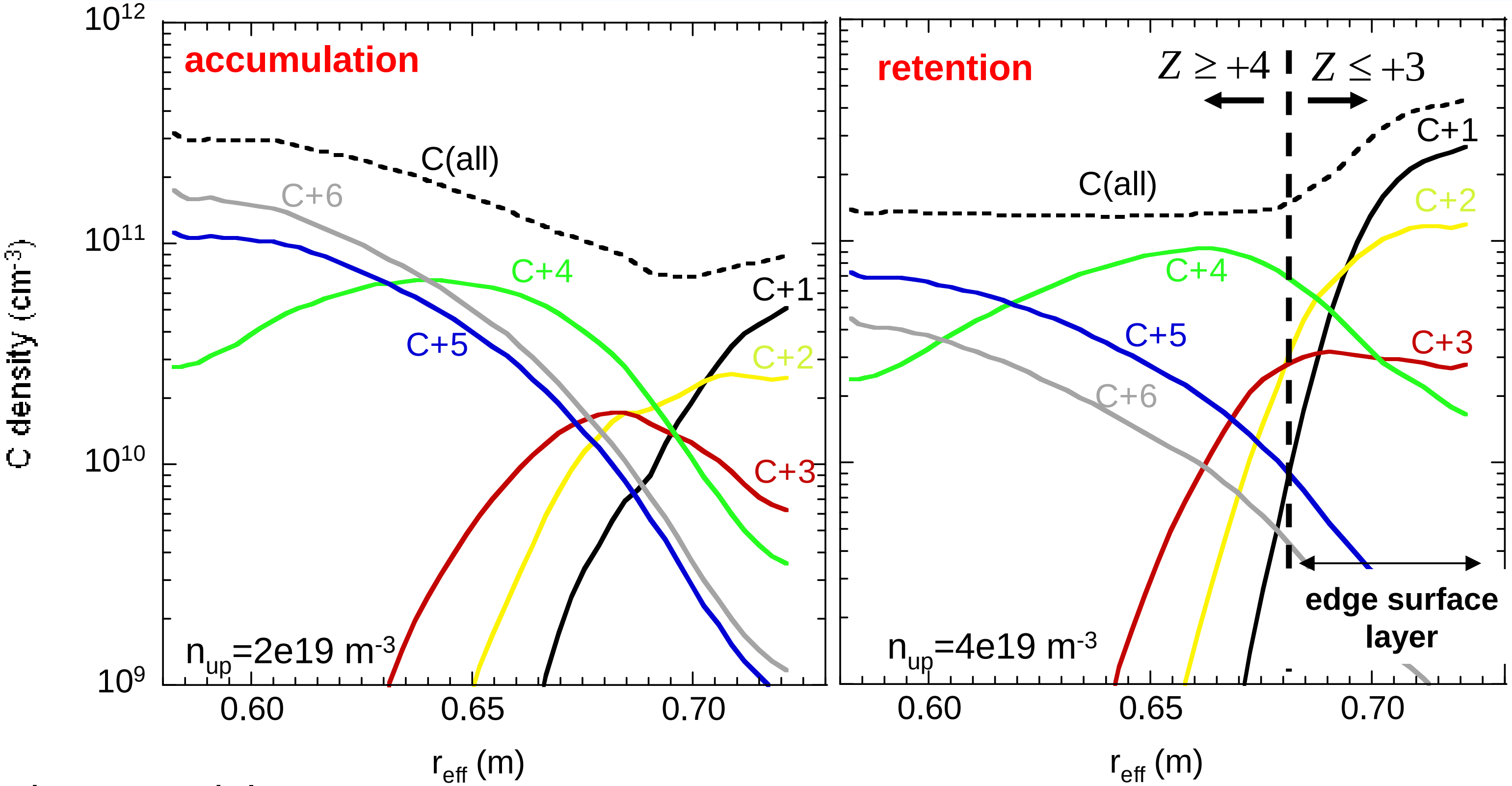
Flow acceleration in ESF due to ionization source and particle sink of short flux tubes

Reduction of T in ESF

$$\frac{friction}{thermal\ \ force} \sim \frac{5/2 n_i T_i V_{i\,//}}{\kappa_0^i T_i^{2.5} \nabla_{//} T_i} \propto \frac{n_i M}{T_i\ \nabla_{//} T_i}$$

Sudden increase of friction force in ESF.

Impurity density profiles of different charge states



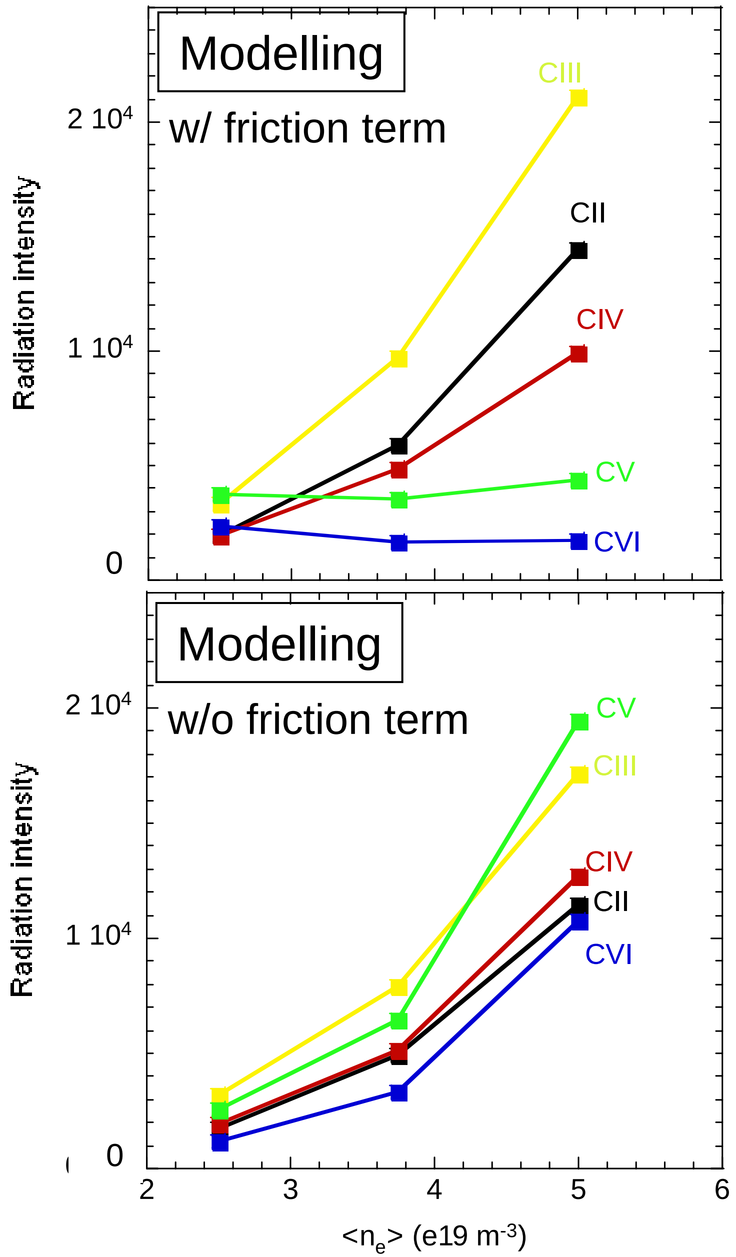
Ionization potential :
CIII (C^{+2}) : 48 eV
CIV (C^{+3}) : 65 eV
CV (C^{+4}) : 392 eV
CVI (C^{+5}) : 490 eV

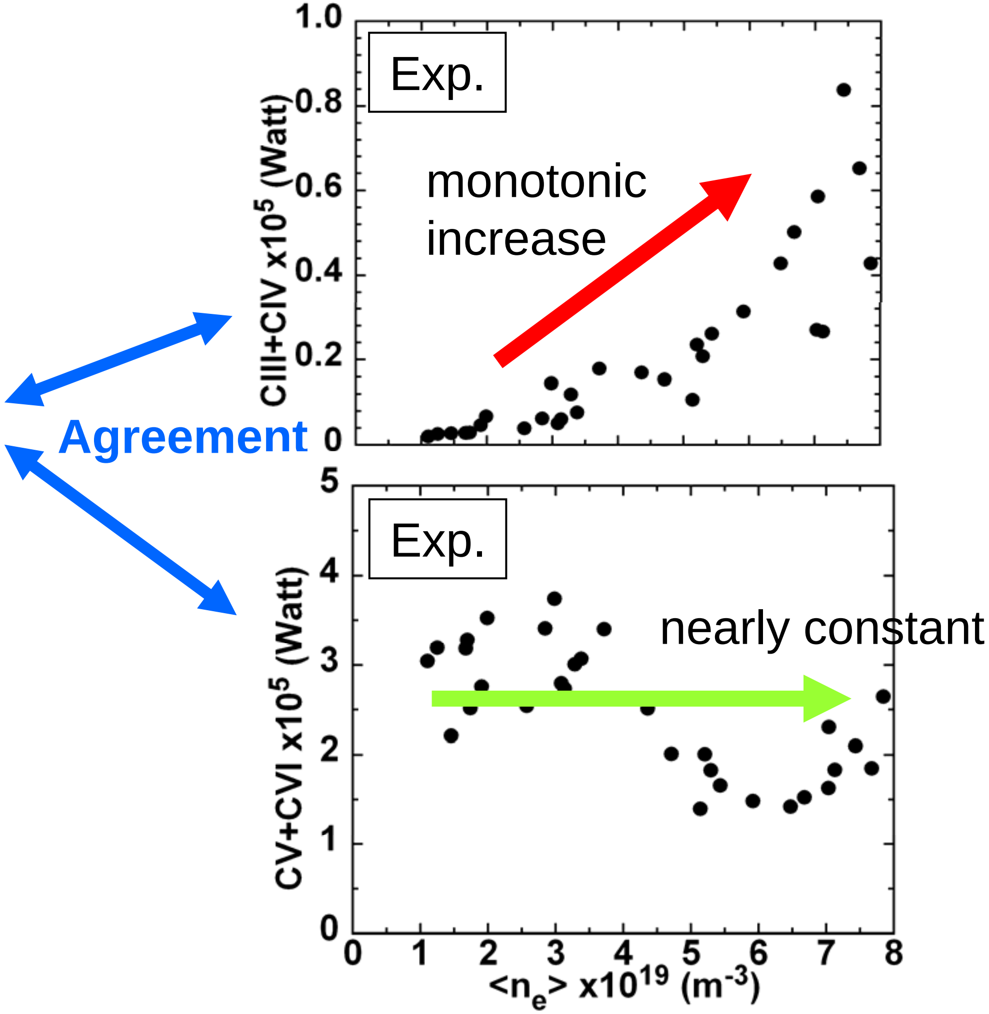
big gap

- Clear separation of profile between C^{+1}~C^{+3} & C^{+4}~C^{+6}

Impurity retention :
C^{+1},C^{+2},C^{+3} ↗ C^{+4},C^{+5},C^{+6} ↘

Qualitative difference btw w/ & w/o retention (friction term)





By S. Morita, M. Chowdhuri

Experimental evidence of impurity retention in ergodic layer

Implication for high Z impurity

Z-dependence & neutral penetration length

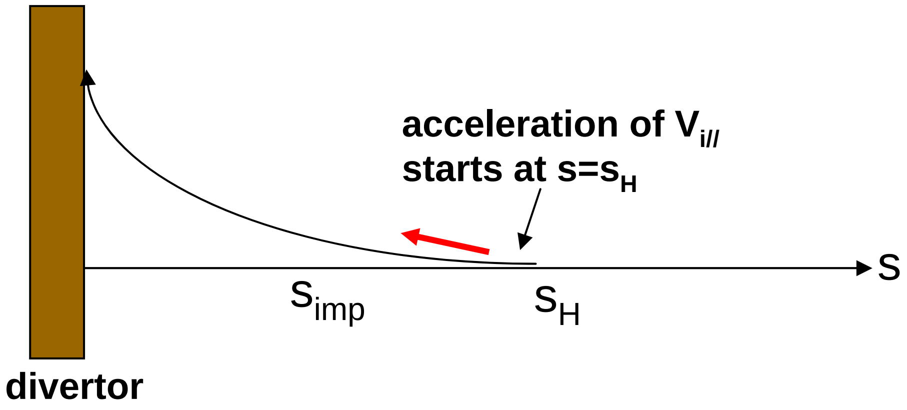
Z-dependence

$$V_{z//} \approx V_{i//} + C_i \frac{\tau_s}{m_z} Z^2 \nabla_{//} T_i$$

Since $\tau_s \propto T_i^{1.5} / (n Z^2)$, **$V_{z//}$ becomes Z-independent.**

Neutral penetration length

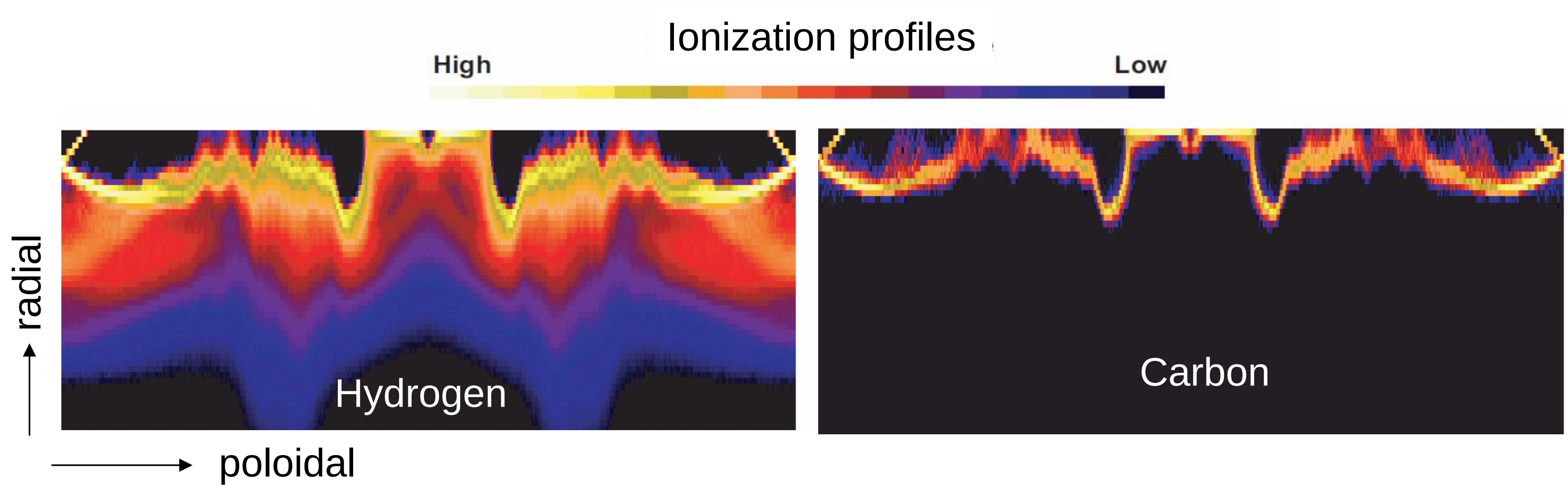
Location of ionization source of impurity & bulk plasma :



Friction force is effective only when $s_{imp} < s_H$

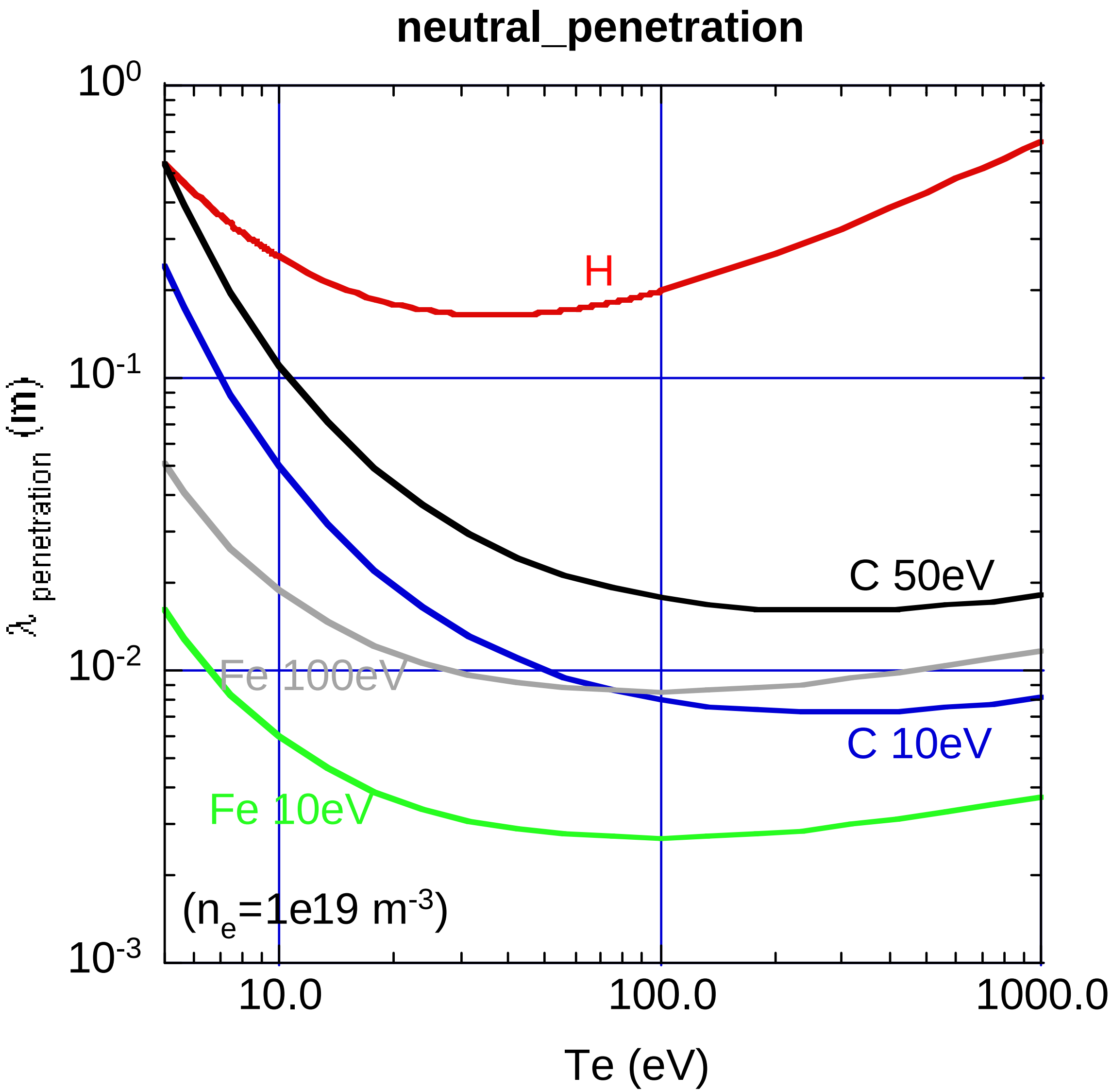
(S_H, S_{imp} : penetration length of neutral hydrogen & impurity)

Penetration length of Hydrogen & Carbon



$S_H >> S_C$

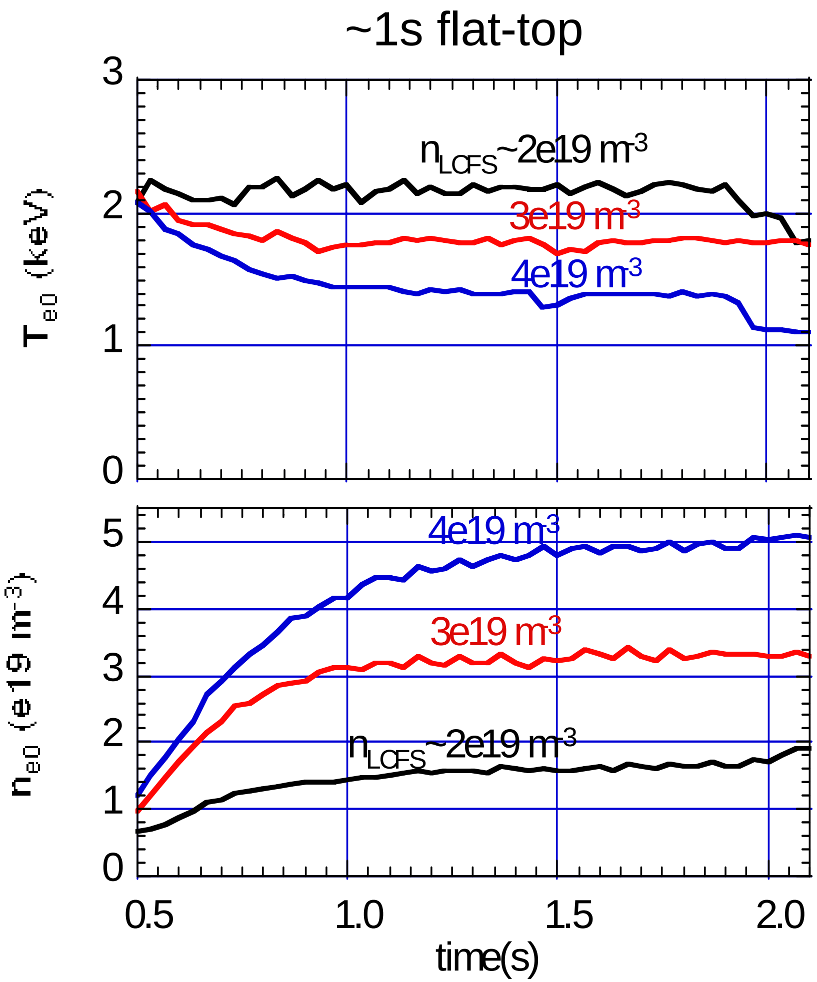
Impurity retention will be effective also for high Z impurity (Fe)

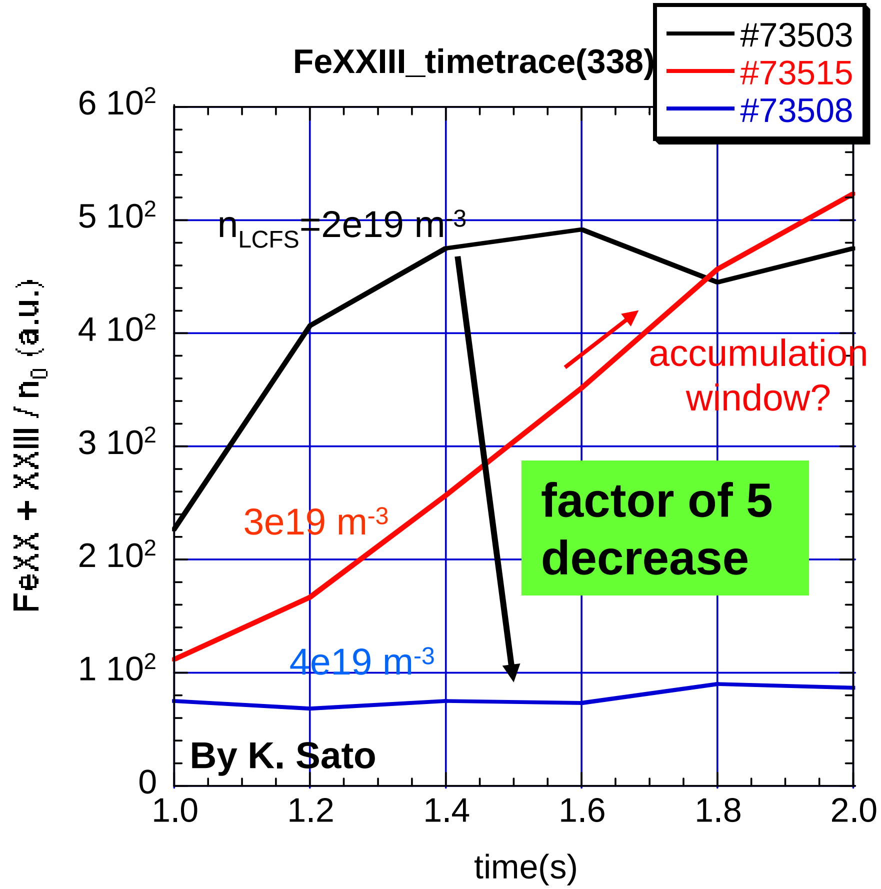


$S_H >> S_C >> S_{Fe}$

Strong reduction of FeXX, XXIII radiation was observed at high density.

Large Helical Device





Implication of reduction of Fe^{+19} & Fe^{+22} @ high density

Similar behavior was reported with lower power exp. in Y. Nakamura et al., NF 43 (2003) 219.)

Summary

The impurity transport in the ergodic layer of LHD is analyzed, using the edge transport code (EMC3-EIRENE) in comparison with experimental data.

- The 1D impurity model indicates that when the plasma becomes dense and cold, the impurity is retained at the edge region (screening).
- The retention effect is demonstrated in the ergodic layer of LHD by the 3D code.
- The edge surface layer plays an important role to switch on impurity retention.
- Geometrical advantage of LHD :

  Ergodic layer surrounding plasma

  The retention is effective for all poloidal & toroidal direction.
- The carbon line radiation measurements in exp. show clear evidence of the impurity retention in the ergodic layer.
- The retention model could apply also for high Z impurity :

  Balance btw friction & thermal force is Z-independent

  High Z impurity has shorter neutral penetration length than low Z impurity.
- In experiments, FeXX & XXIII line radiation intensity decrease at higher density, indicating reduction of Fe in core.

Further experimental confirmation needed :

TESPEL injection, in order to separate core & edge transport.

Ar, Ne puff by fixing source rate.