Studies on impurity Seeding in a Tokamak Plasma: Simulation and Comparison with Aditya-U Experiments

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Abstract

- Effects of N_2, Ne, and Ar impurity seeding in Aditya-U tokamak plasma using 0D and 2D models are presented.
- 0D model gives relative abundance of multiply charged states of the impurity ions and estimates non-coronal radiation cooling.
- 2D model equations couples the interchange plasma turbulence in the edge and SOL regions [3,6-7] with the impurity gas and ions self-consistently.
- Impurity ions fluxes in the presence of different magnitudes of the interchange driving mechanism are studied. A change of the inward (negative) flux suggests the turbulence induced inward motion.
- Radiation energy loss behaves intermittently with time that is in line with the interchange plasma turbulence and is consistent with experiments.
- A few of these simulation results are compared with the Aditya-U results.

Background

- Impurity seeding is important as it reduces heat load on the plasma facing materials, provides radiative improved confinement, and disruption mitigation in future tokamaks [1,2].
- 0D and 2D numerical simulations using Fortran and BOUT++ codes, respectively using input parameters related to Aditya tokamak.
- More realistic non-coronal equilibrium model [1,5] has been used in 0D and 2D.
- The negative fluxes of the impurity ions and the intermittent nature of the radiation loss are not been explored earlier. Therefore, these are the most important and new results in this work.

Model equations

$$\frac{dn}{dt} - D\nabla_\perp^2 n + g\left(T_e\frac{\partial n}{\partial y} + n\frac{\partial T_e}{\partial y} - n\frac{\partial \phi}{\partial y}\right) = \langle \nabla_\parallel J_{\parallel e}\rangle/e + S_n + S_e,$$

$$\frac{d\nabla_\perp^2\phi}{dt} - \nu\nabla_\perp^4\phi + \frac{g}{(n+n_{pol})}\left(T_e\frac{\partial n}{\partial y} + n\frac{\partial T_e}{\partial y}\right) = \langle \nabla_\parallel J_\parallel\rangle_T/[e(n+n_{pol})]$$

$$\frac{dT_e}{dt} - k_e\nabla_\perp^2 T_e + \frac{2}{3}g\left(\frac{7}{2}T_e\frac{\partial T_e}{\partial y} + \frac{T_e^2}{n}\frac{\partial n}{\partial y} - T_e\frac{\partial \phi}{\partial y}\right) = E_{loss} + \frac{2}{3}S_{Te},$$

$$\frac{dG^i}{dt} - AG^i\frac{d\nabla_\perp^2\phi}{dt} - D_{Gi}\nabla_\perp^2 G^i - gG^i\frac{\partial \phi}{\partial y} = -\sigma_0\sigma_{sol}(x)c_s G^i + S_i,$$

$$\frac{\partial G}{\partial t} - D_G\frac{\partial^2 G}{\partial x^2} = S_G - S_{Gi}$$

G is impurity density, and G^i is ith ionization sate. Other symbols are described in Ref.[6,7]

Estimation of the amount of impurity seeding

Using plasma density and impurity continuity equations the amount impurity seeding is estimated:

$$\frac{G}{n} \sim \frac{D}{D_G}$$

For nitrogen, neon and argon gases $D_G \sim v_{th}^2/n\langle\sigma v\rangle_{ion}$. Using edge $T_e = 16$ eV, $n = 5\times10^{18}\ /m^3$, $\langle\sigma v\rangle_{ion}$ from Amjuel databases G/n~0.09%, 0.14%, and 0.6% respectively. In Aditya-U these are about 0.1% that is close to the theoretical estimation.

0D simulation results (non-coronal radiation power)

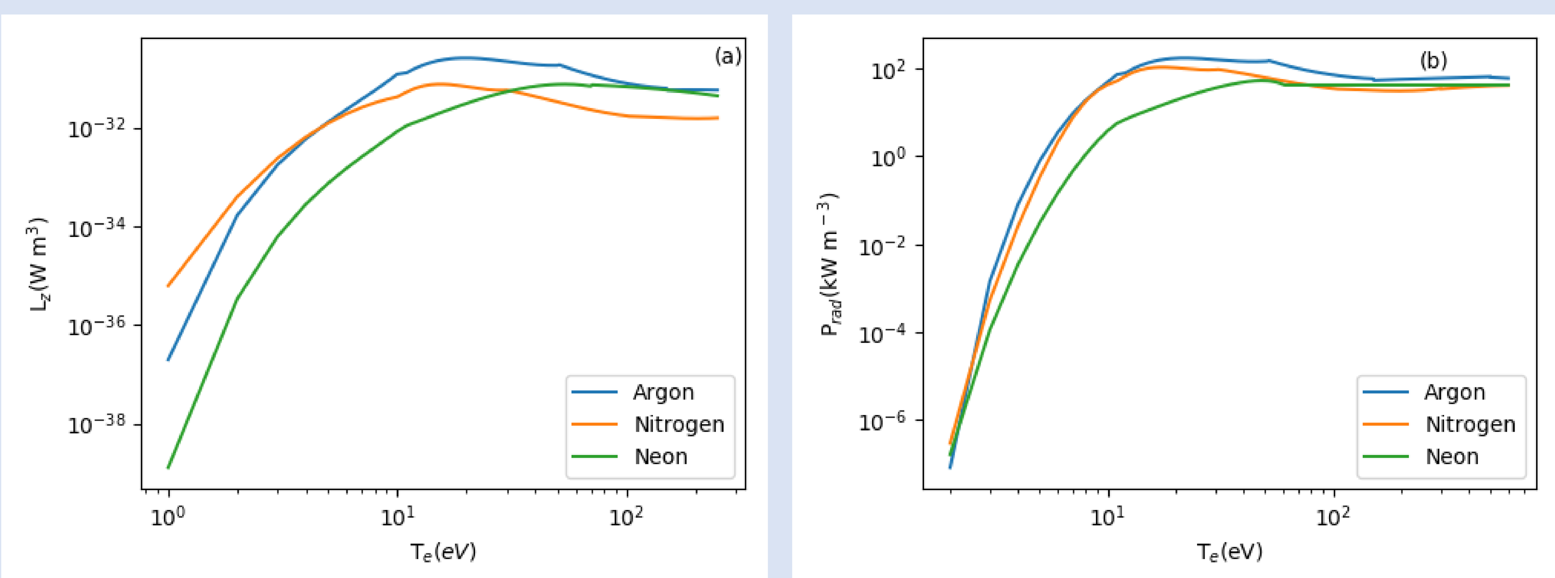

FIG. 1: (a) Non-coronal polynomial fitting parameter L_z for N, Ne and Ar gases. (b) radiative power loss from 0D simulation. In 0D simulation we have used T_e from 1-250 eV.

2D simulation data

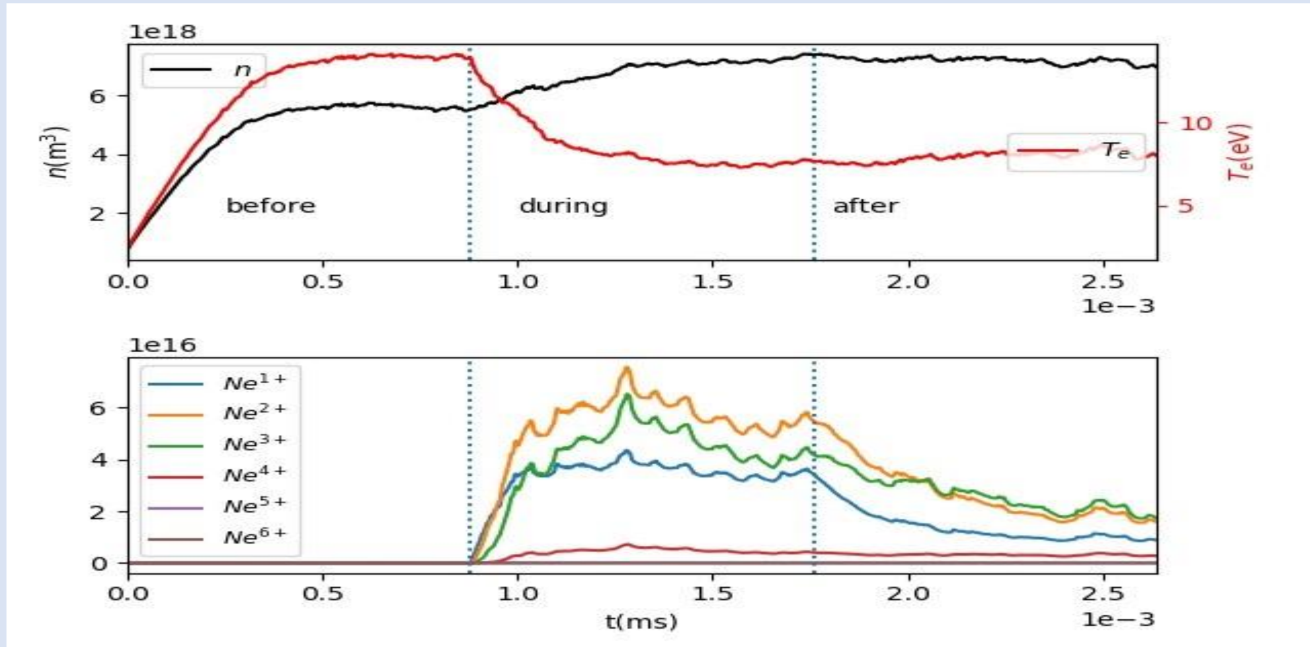

FIG. 2: Temporal evolution of spatial averages of n, Te, and Ne ions species. The vertical dotted lines indicate the start time of gas and termination of the seeding.

Impurity profiles and radial impurity fluxes

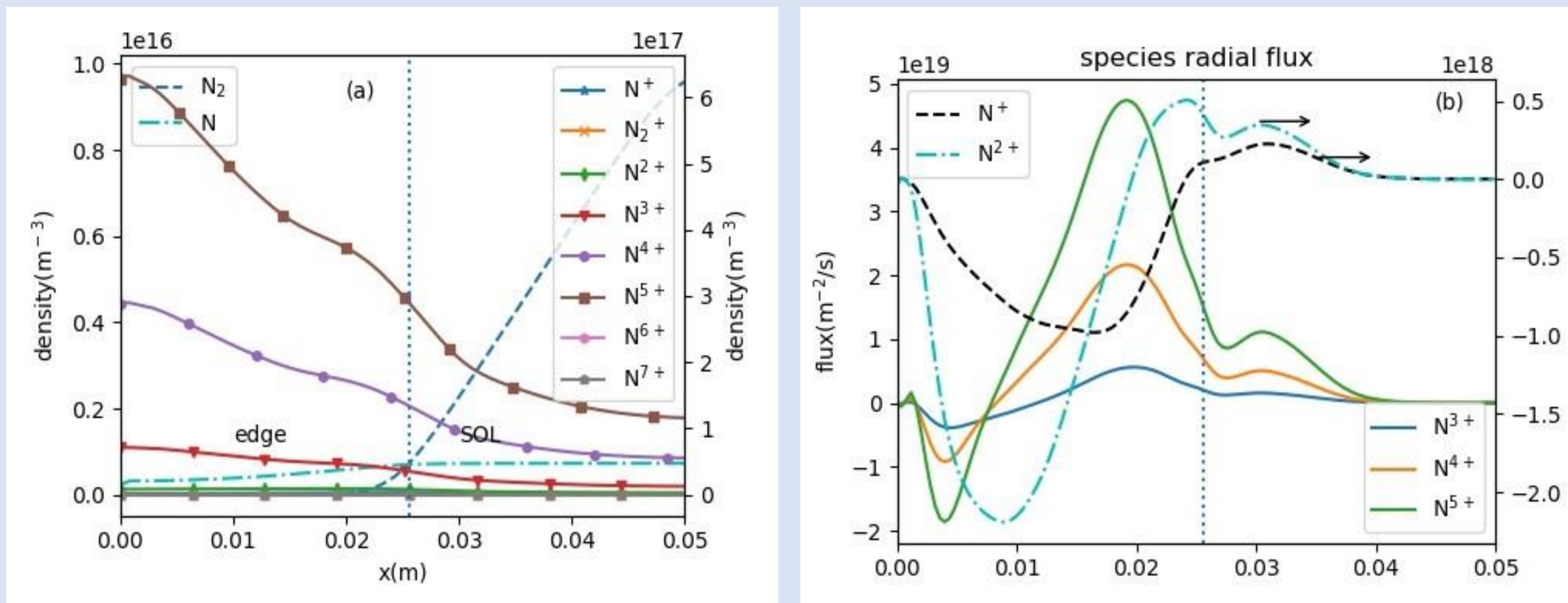

FIG. 3: Radial profiles (a) and radial fluxes (b) of different N ions. The vertical lines indicate the positions of LCFS.

Intermittent radiation cooling results

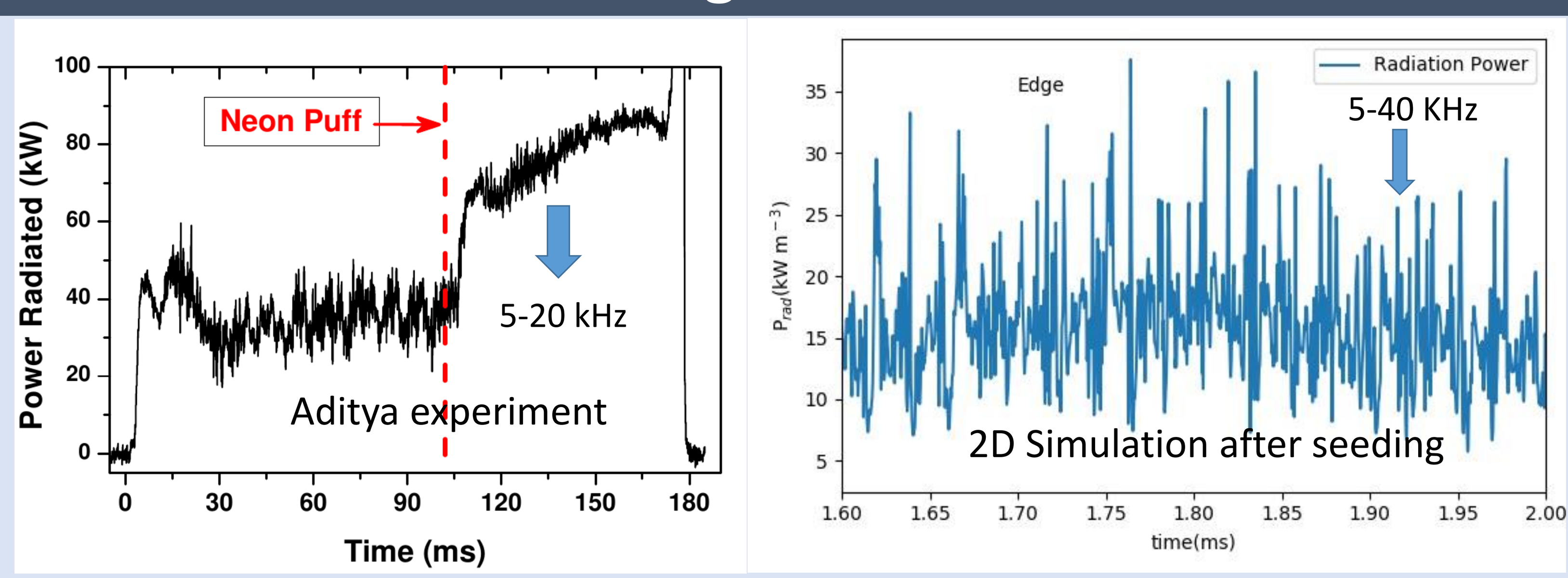

FIG. 4: Radiation cooling from Aditya and Simulations. Both are intermittent.

Conclusions

- Simple theoretical estimation of the seeding rate is consistent with the Aditya experimental seeding rate.
- The self-consistent coupling between interchange plasma turbulence and impurity seeding (N, Ne, Ar) gives two important results, (1) negative fluxes of impurities (inward), and (2) intermittent radiation cooling.
- The inward propagation of the impurities is much faster than the diffusive processes. Mainly governed by the turbulence.
- Intermittent radiation cooling fluctuates with a frequency range 5-20 kHz both in the 2D simulations and Aditya experiments.

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