Impact of Li-granule injection on the improvement of bulk energy and particle transport and expulsion of mid/high- Z impurities in the LHD heliotron

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ABSTRACT

Continuous Li injection with the Impurity Powder Dropper [1] in LHD:

- Improves plasma performance and energy confinement by strongly reducing plasma turbulence.
- Enhances the transport of mid/high-Z impurities injected by TESPEL due to a more positive convection coefficient and increased classical transport.
- Reduces intrinsic impurity levels via a more positive E_r in the Scrape Off Layer and a wall-conditioning effect due to Li-deposition.

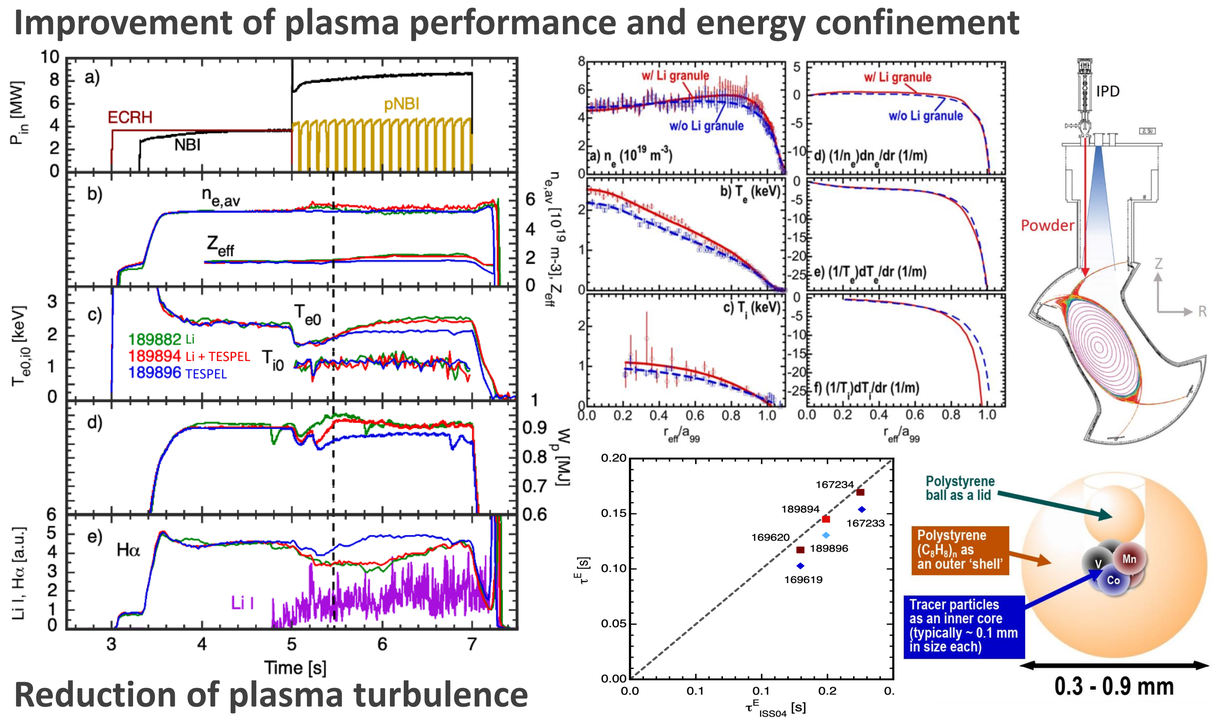
BACKGROUND

A major challenge for the development of stellarator-based fusion reactors is the establishment of operational scenarios that sustain long-duration confinement of bulk particles and energy while mitigating high-Z impurity accumulation. These have not been achieved simultaneously before, but prior investigations on LHD showed some progress:

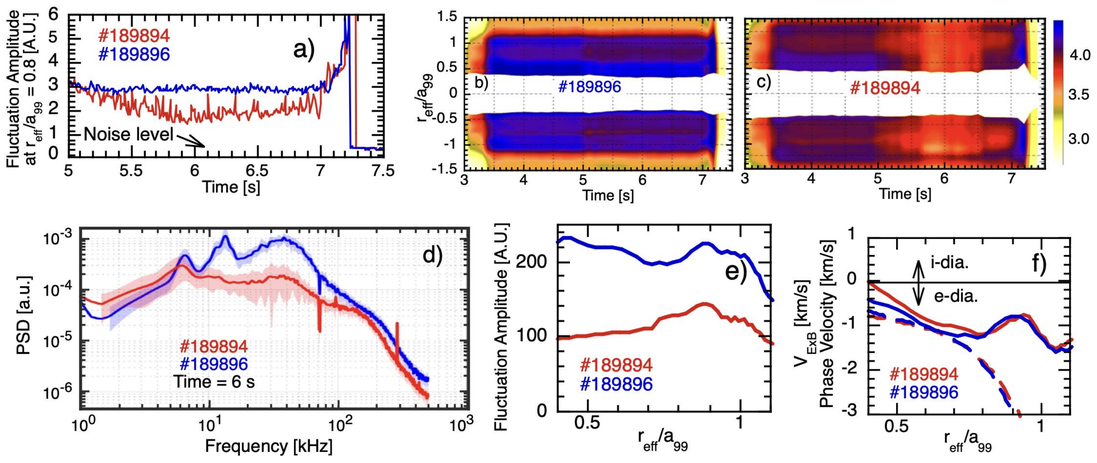
- At low-n_e, high-T_i: the "impurity-hole" allows obtaining a highly hollow impurity profile due to enhanced thermo-diffusion [2].
- At high-n_e: supplementary ECRH enhances the expulsion of core impurities [3].
- At low-n_e: low-Z (B, BN or C) powder injection with IPD improves energy confinement by reducing turbulence [4, 5, 6].

EXPERIMENTAL RESULTS

Improvement of plasma performance and energy confinement



Reduction of plasma turbulence



Reduction of mid/high-Z core impurities injected with TESPEL [7]

Ti^{19+}: ~17 % reduction in τ, 40% in V

w/o Li: D = 0.11 m^2/s V = -1.55 m/s

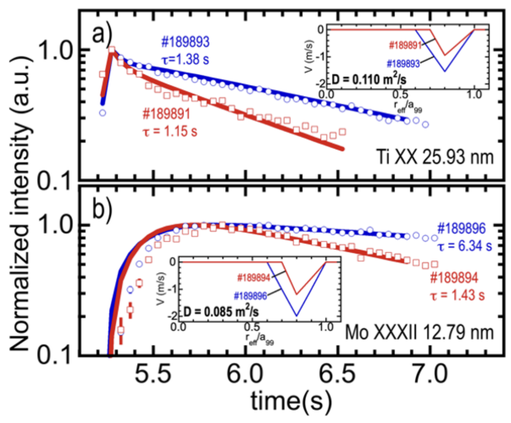
with Li: D = 0.11 m^2/s V = -0.95 m/s

Mo^{31+}: ~ 78 % reduction in τ, 40% in V

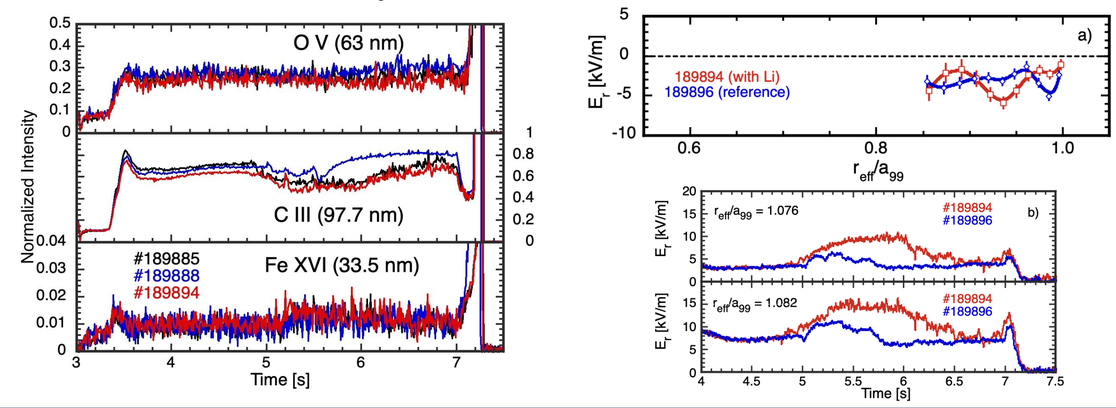
w/o Li: D = 0.085 m^2/s V = -2 m/s

with Li: D = 0.085 m^2/s V = -1.2 m/s

Possible τ dependence on Z: the higher Z, the stronger τ reduction with Li-injection.



Reduction of intrinsic impurities and effect on Er

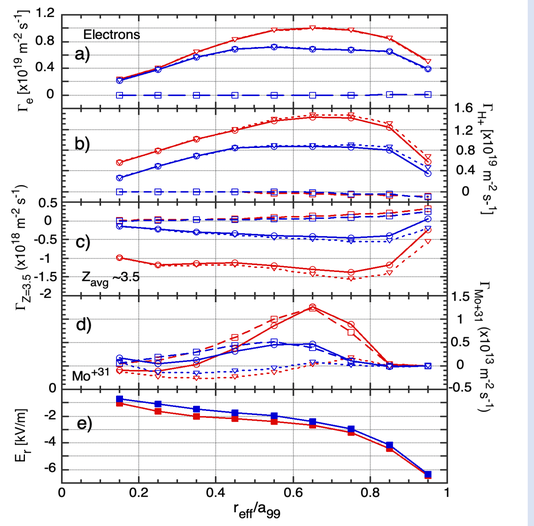


SIMULATIONS

NC particle fluxes computed by SFINCS [7]

- NC bulk particle fluxes become more positive while classical is minimal.
- NC Z_{avg} fluxes become more negative to keep ambipolarity, this allowing deeper Li penetration and reduced core turbulence
- Classical transport dominates for Mo^{31+}

It doubles due to Li, this enhancing high-Z flush out from the plasma core.

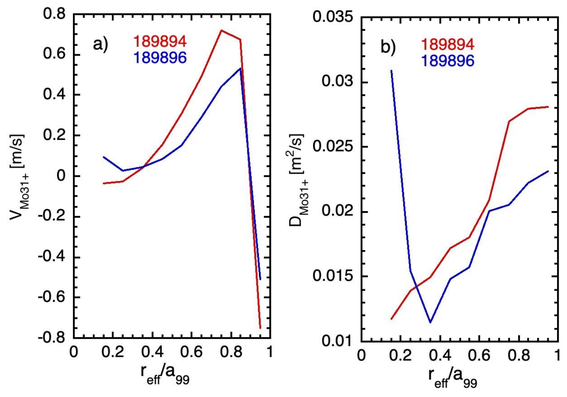


Comparison of transport coefficients estimated by SFINCS [8] & STRAHL [9]

Square-root dependence of V on charge is observed in STRAHL:

$$-2\frac{m}{s} \sim -1.55\sqrt{\frac{Z\ Mo^{31+}}{Z\ Ti^{19+}}}$$

$$-1.2\frac{m}{s} \sim -0.95\sqrt{\frac{Z\ Mo^{31+}}{Z\ Ti^{19+}}}$$



And D: 4-5 times NC prediction → observed enhanced impurity transport shows a combination of collisional and turbulent effects.

CONCLUSION

Low-Z impurity powder dropping can improve plasma performance, provide real-time wall conditioning and flush out mid/high Z impurities [6].

- As turbulent transport is reduced across the full plasma radius → plasma performance and energy confinement are improved → steepening of the temperature profiles and increase of outward neoclassical transport → shoulder in the hollower electron density profile.
- First-observation of mid/high-Z core impurities removal → mainly due to an increase of classical transport [10] by collisions between Ti or Mo and the Li that led to more positive V, even in presence of reduced turbulence.
- The reduction of intrinsic impurity levels is possibly due to a two times more positive E_r in the SOL, the conditioning effect of Li deposition on the chamber walls and increased collisions with Li-atoms at the plasma edge.

ACKNOWLEDGEMENTS / REFERENCES

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