Modeling of dust transport in NSTX with DUSTT/UEDGE code

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DUSTT/UEDGE code

- DUSTT solves coupled dust dynamics equations including temporal evolution of dust charge, temperature, mass, and radiation
- The DUSTT code operates with plasma parameters simulated with UEDGE
- The statistical averaging over an ensemble of test dust particles is used to obtain dust profiles and impurity source from ablated dust
- DUSTT/UEDGE are iteratively coupled for self-consistent modeling of dust impact on edge plasmas
- For interpretive modeling of dust transport, the background plasma parameters simulated with UEDGE should be matched as close as possible with experimental data
- Validation of the code is needed for various dust/plasma parameters for predictive simulations of dust impact on plasmas in ITER

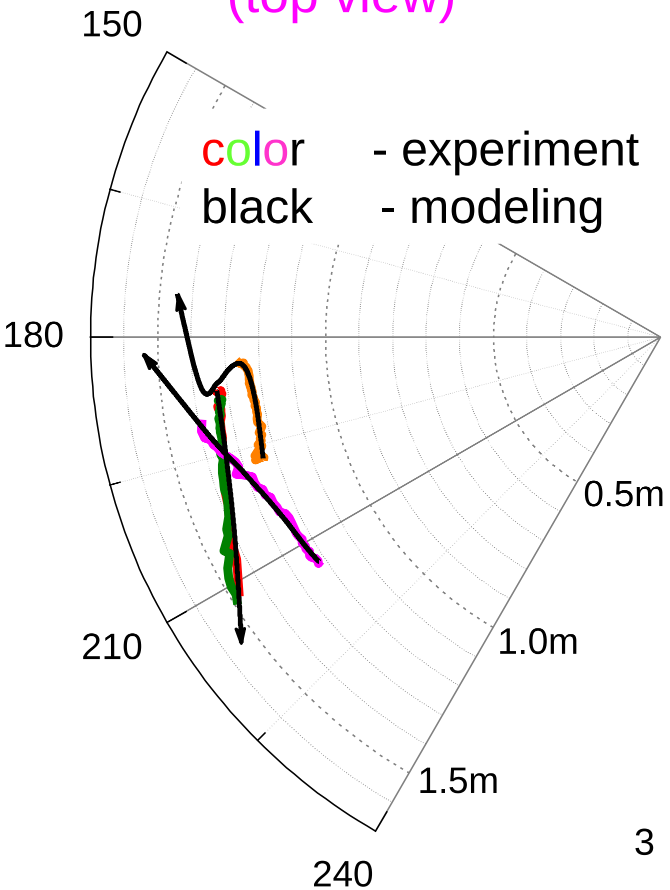
Modeling of Li dust trajectories

- The experimental Li dust trajectories measured in NSTX are used for validation and parametric tuning of the DUSTT code
- NSTX UDN configuration is modeled close to discharge #135353

Reproducible features

Experiment	Modeling
dust speeds ~10-100m/s	matched for dust sizes 10-20μm
Li dust lifetime ~10ms, grains can reach separatrix	reproduced with introduction of heat flux reduction factor (~50) imitating dust shielding by ablation cloud
dust grains with opposite toroidal flight directions are observed, some grains suddenly change direction (curvature ~few cm)	shear plasma flows in SOL with Mach~1 can cause change in toroidal flight direction in near separatrix regions

Li dust trajectories in NSTX (top view)

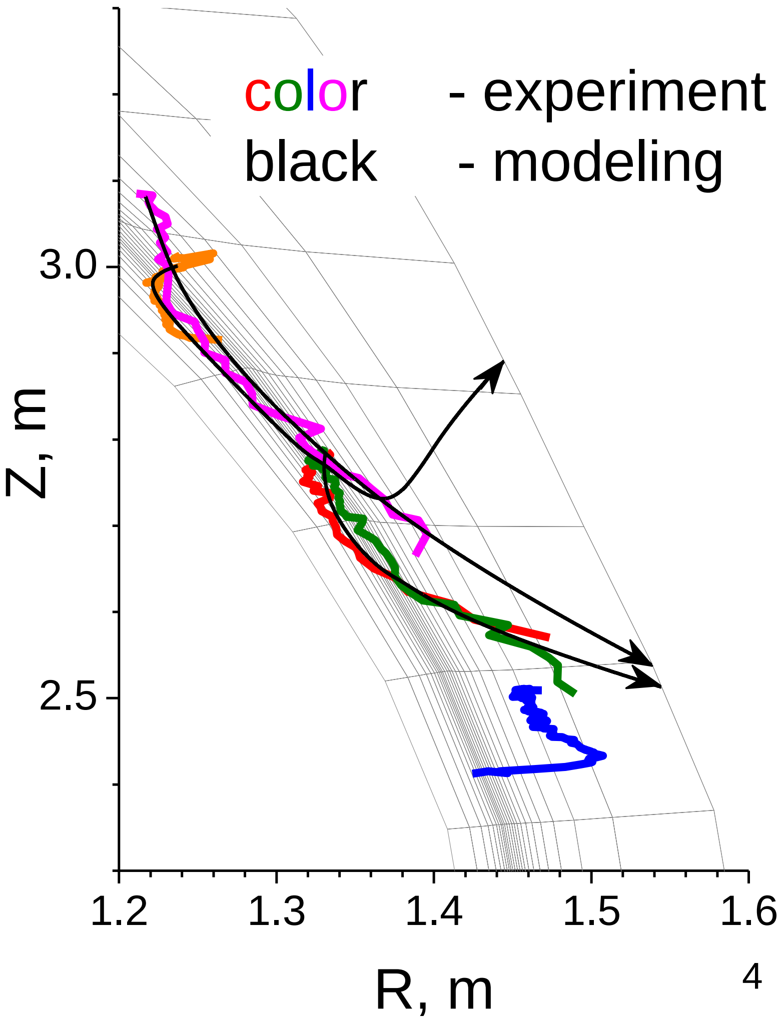


Modeling of dust trajectories (continued)

Non-reproducible features

Experiment	Modeling needs
Li dust lifetime ~10ms, grains can reach separatrix	quantitative dust shielding models for different dust materials
sharp changes in dust trajectories outside the strong shear plasma flow regions	may be caused by non-accounted forces associated with non-uniformity of dust shapes and composition, transient plasma events
irregularities in dust trajectories are observed	

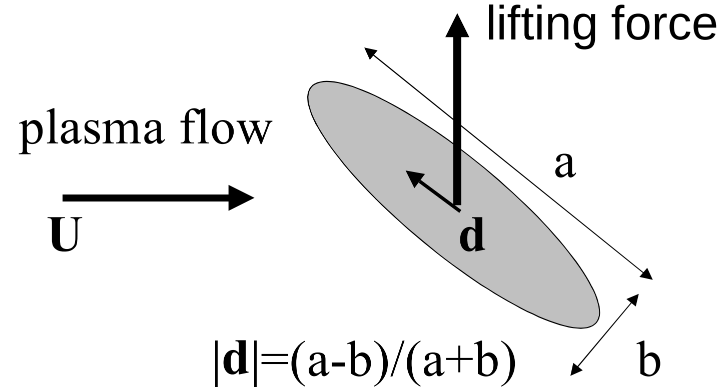
Li dust trajectories in NSTX (poloidal view)

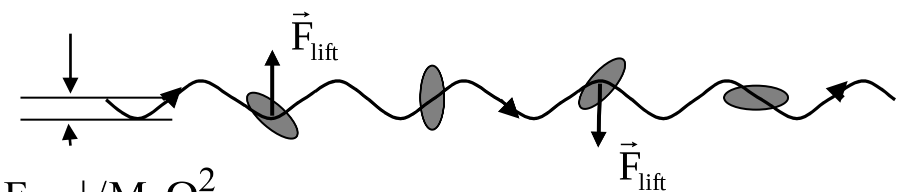


Identification and developing of models for the unaccounted processes affecting dust dynamics are needed

Various unaccounted forces

- The drag force on non-spherical dust grain can be misaligned with plasma flow (S.I.Krasheninnikov, PoP 2010)
- Grain spinning can cause perturbations of grain trajectory, which can be monitored with fast cameras





$$\Delta \sim |F_{lift}| / M_d \Omega_{spin}^2$$

$$\vec{F}_{drag} = C_{drag}\left\{\vec{U} + \xi_d \vec{d}\left(\vec{d}\cdot\vec{U}\right)\right\}$$

$$\xi_d \sim -1$$

"Rocket force" $F_{roc} = \xi_{roc} M_v V_v \Gamma_v \pi R_d^2$ $\xi_{roc} = \left(1 + 2\kappa T_d^2 / R_d q_q E_{ev}\right)^{-1}$

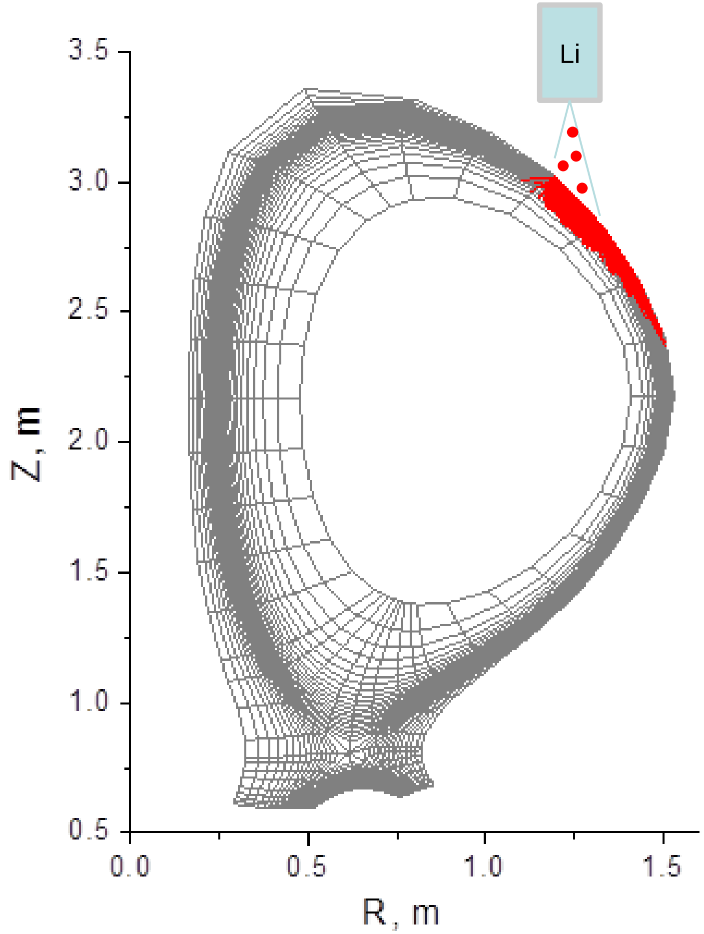
Magnetic force $\mathbf{F}_M = -\pi R_d^3 \varepsilon_M \frac{B_{sat} B_{tor}}{4\pi R} \frac{\mathbf{R}}{R}$

- These forces become important in stagnated plasma flow regions and may be responsible for "unusual" dust dynamics
- Injection experiments with specifically designed dust (non-spherical, bi-material, magnetic, etc.) may be used for evaluation of the forces

Modeling of Li dust injection

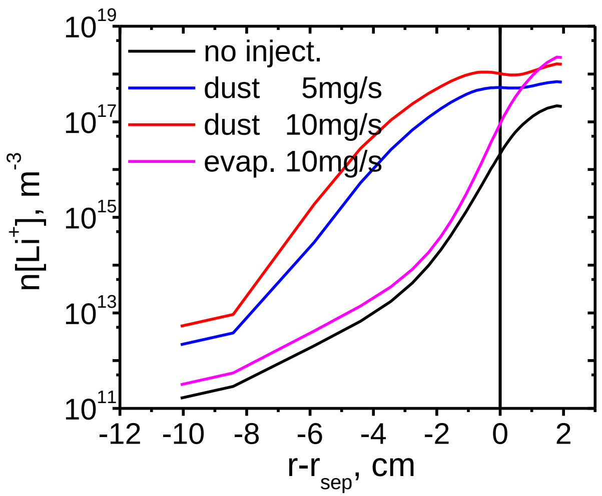
- NSTX L-mode LSN configuration is modeled
- ~40μm Li dust is injected in the upper outer poloidal position
- Dust hit the plasma with average speed ~5m/s and with shifted downward cosine angle distribution relative to vertical direction
- Divertor plates are assumed to be covered with Li film with recycling coefficients set at 0.8 for D and at 0.5 for Li
- Core D^+ density is fixed at $5.1 \times 10^{13} cm^{-3}$
- Core heating power 3MW

Configuration of modeled Li dust injection

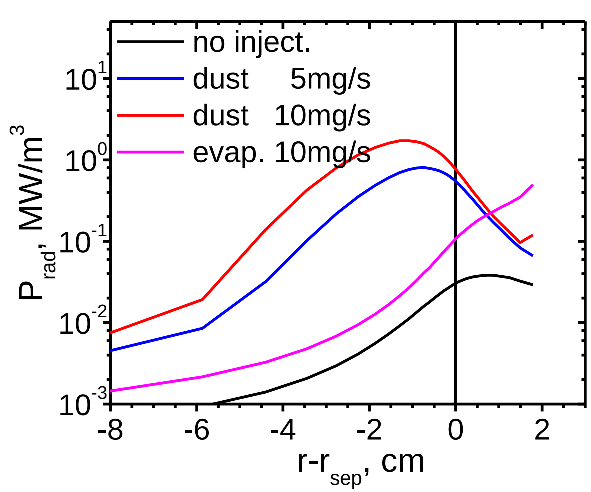


Impact of Li dust on edge plasmas

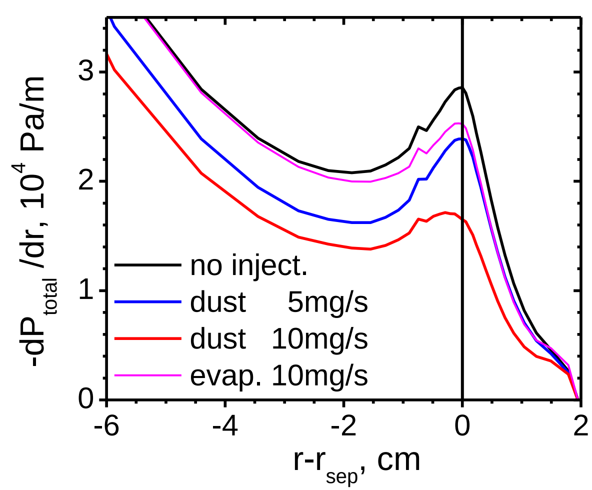
Li^+ density



Impurity radiation



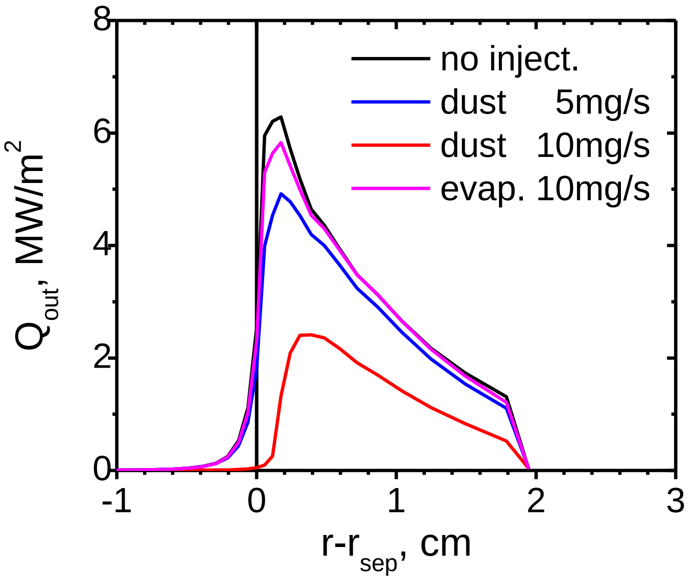
Radial pressure gradient



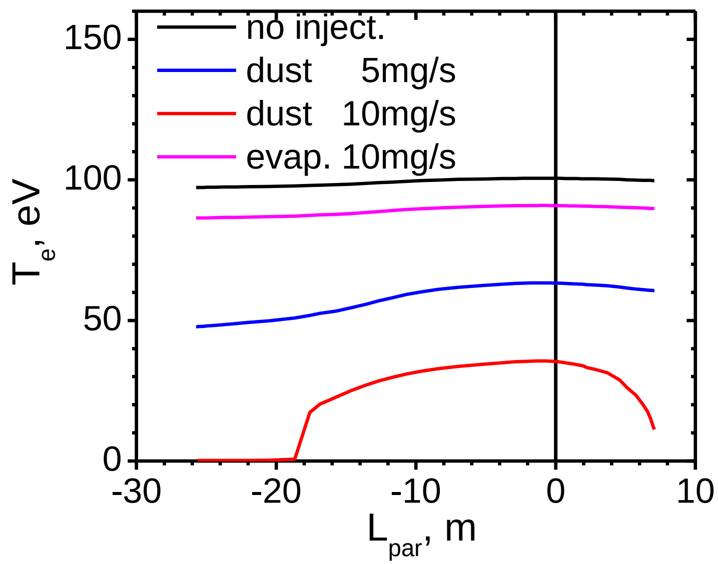
- Li dust injection with rates >~10mg/s can significantly increase impurity concentration and impurity radiation power losses in the edge.
- The radial plasma pressure gradients are substantially ~40% decreased in the edge improving plasma stability
- Gaseous impurities of the equivalent amount do not penetrate as deep into the plasma as the dust does

Impact of Li dust on divertor operation

Divertor heat load profile



Electron temperature



- The power load to the outer divertor plate is significantly reduced
- Complete plasma detachment in the inner divertor at 10mg/s Li dust injection rates is developed
- ITER safety limit on dust accumulation (C,W,Be) implies dust production rate ~1g/s, impact of which on the edge plasmas needs to be evaluated

Summary

- The coupled DUSTT and UEDGE codes allow self-consistent modeling of dust transport and its impact on the edge plasmas.
- Main features of the experimental Li dust trajectories in NSTX can be reproduced with the simulations, validating basic modeling concepts. Non-reproducible dust dynamics features need further investigation.
- The simulations demonstrate that Li dust injection with rates >~10mg/s can have profound effects on edge plasma parameters, transport and stability in modern tokamaks.
- More studies are needed to investigate effects of dust injection in various scenarios and assess potential applications to heat flux mitigation on NSTX-U.
- Controlled dust injection experiments with well characterized and specifically designed dust can be used for validation and improvement of the simulation models for predictive ITER simulations.
- At present, rates of production and thermo-physical properties of natural tokamak dust are little studied, that makes modeling of such dust difficult.