Modeling of lithium dust injection and divertor conditioning effects on edge plasmas with DUSTT/UEDGE code

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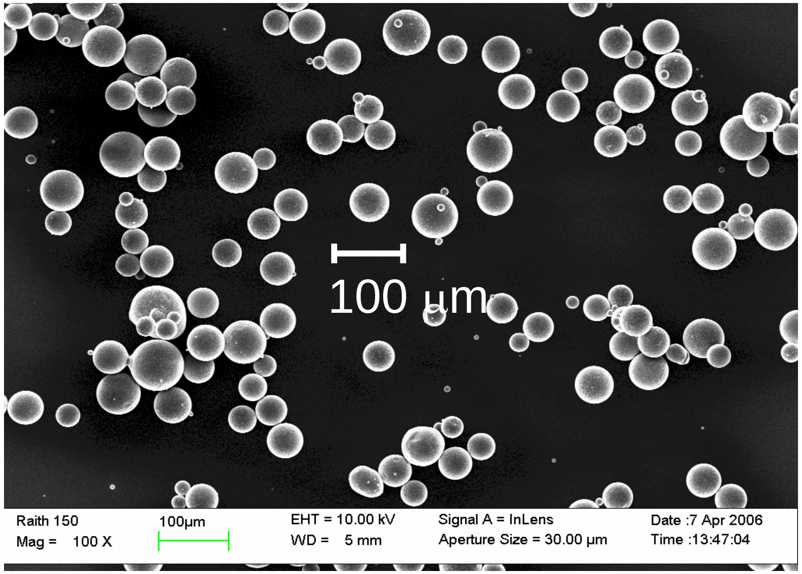
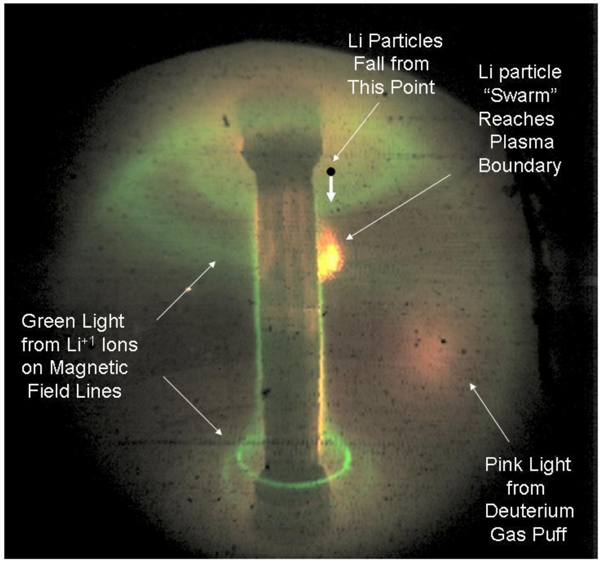
Motivation

- Recent NSTX experiment demonstrate that lithium aerosol injection can be used to achieve continuous wall conditioning
- Dust injection may be used for edge plasma control instead of gas impurity seeding





D.K. Mansfield et al., PSI-19, San Diego, CA 2010 (to be published J. Nucl. Mater.)

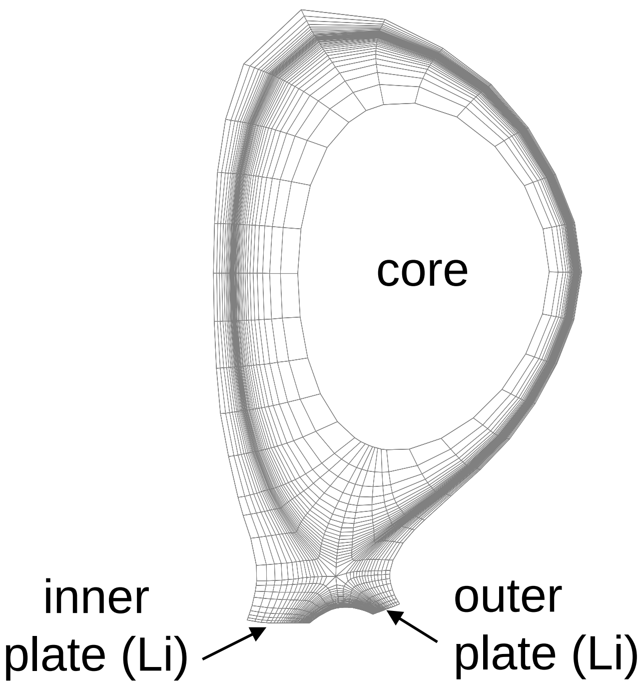
Outline

- Modeling of lithium divertor operation
  - Parametric scan of divertor recycling regimes
  - Plasma profiles and transport in low recycling regimes
  - Thermal instability of liquid lithium divertor
- Modeling of lithium dust injection with DUSTT/UEDGE
  - Code validation using 3D reconstructed dust trajectories
  - Dust impact on edge plasmas

UEDGE simulation model

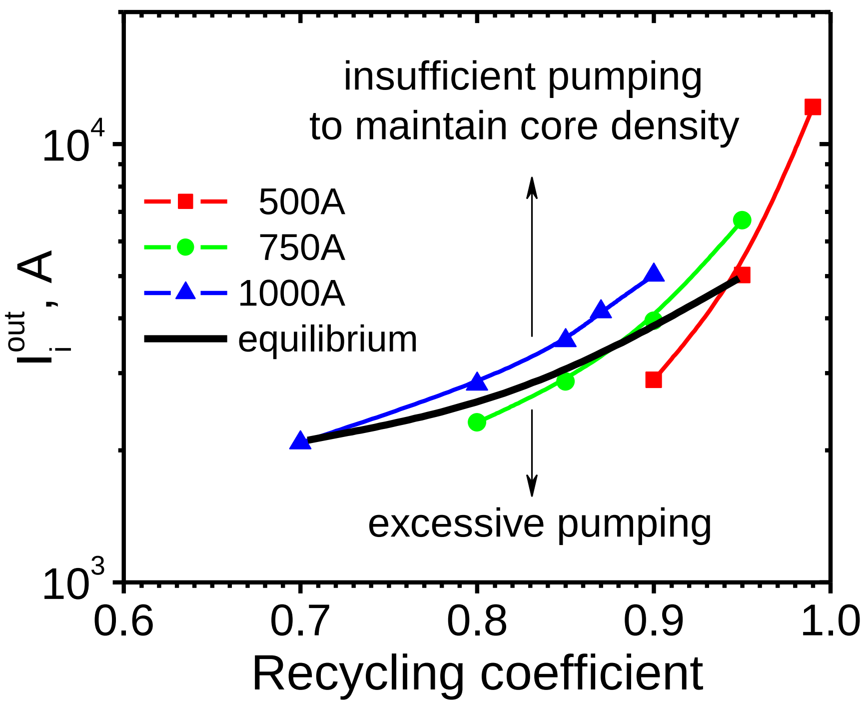
- Gas puffing 500-1000 A
- Core interface density ~$5 \times 10^{19} m^{-3}$
- Separatrix Te~70-100 eV; Core Te~500 eV
- Lower single-null magnetic configuration
- Recycling coefficient at divertor plates varied from 0.70 to 0.99
- Plate surface temperature has asymmetric Gaussian profile
- with the peak temperature 600-900K

UEDGE mesh for NSTX single-null configuration



Effect of Li pumping

Ion current
to the outer divertor plate



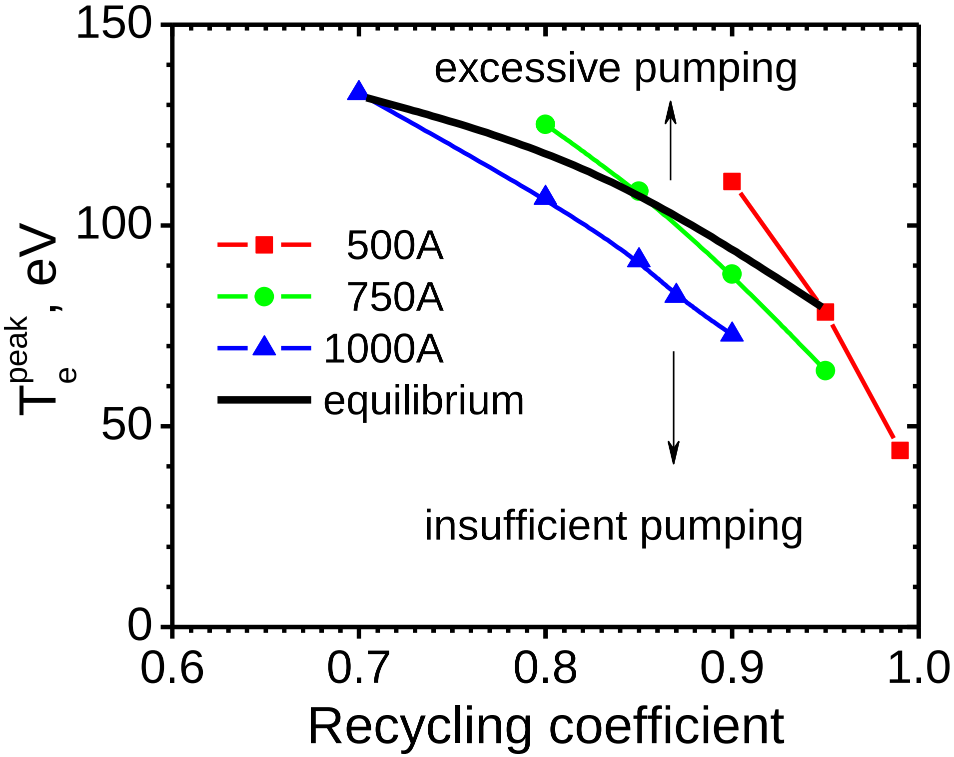
To maintain equilibrium in the core larger gas puffing rate is required in the low-recycling regimes

Li pumping substantially decreases the ion flux to plate despite the increasing gas puffing

Ion flux tends to saturate for very low recycling coefficients indicating that the recycling plasma source does not play an important role in such regimes

Divertor Te in low-recycling

Peak electron temperature
at the outer divertor plate



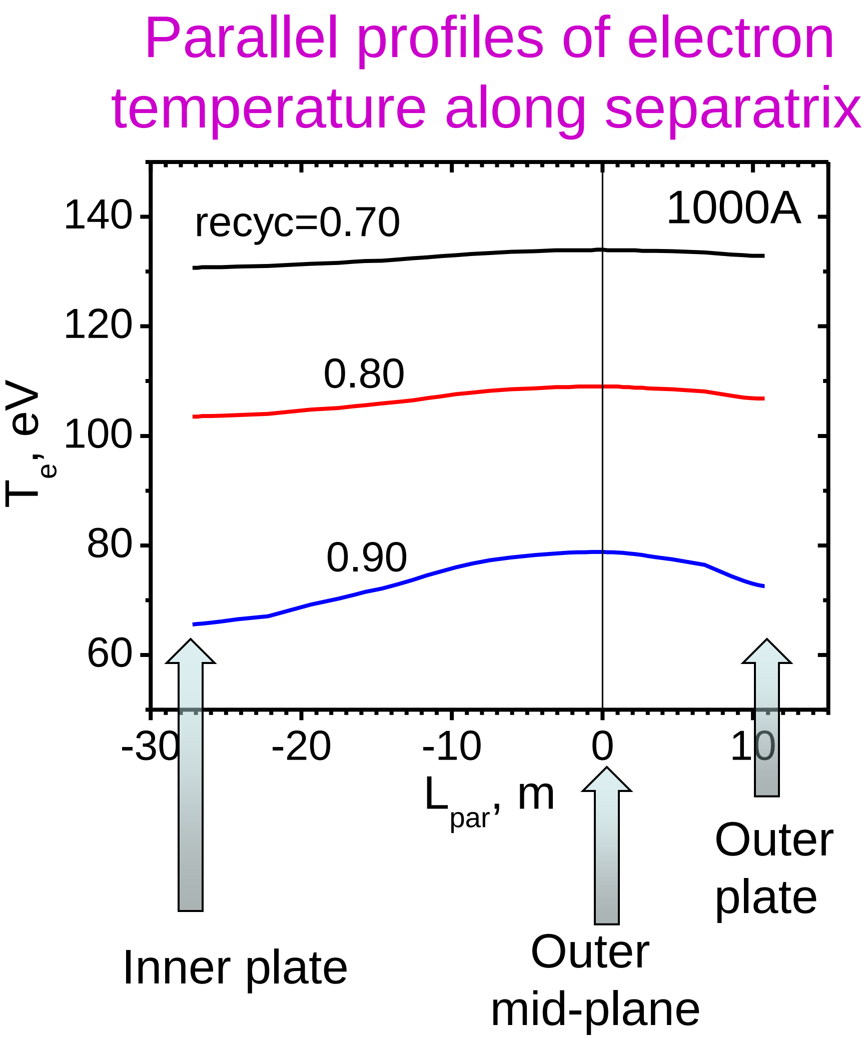
Electron temperature at the plate is peaked near separatrix

The higher the Li pumping (smaller R), the higher is the peak Te at plate

High temperature indicates convection limited regime of heat transport in the

Small Te (<20eV) can mean small Li pumping

Low-recycling results in flux limited heat transport regimes



Because of low upstream density and high Te, the electron mean free path is large

$mfp(m)=2\times10^{10}\ [T(eV)]^2/ne(cm^{-3})$

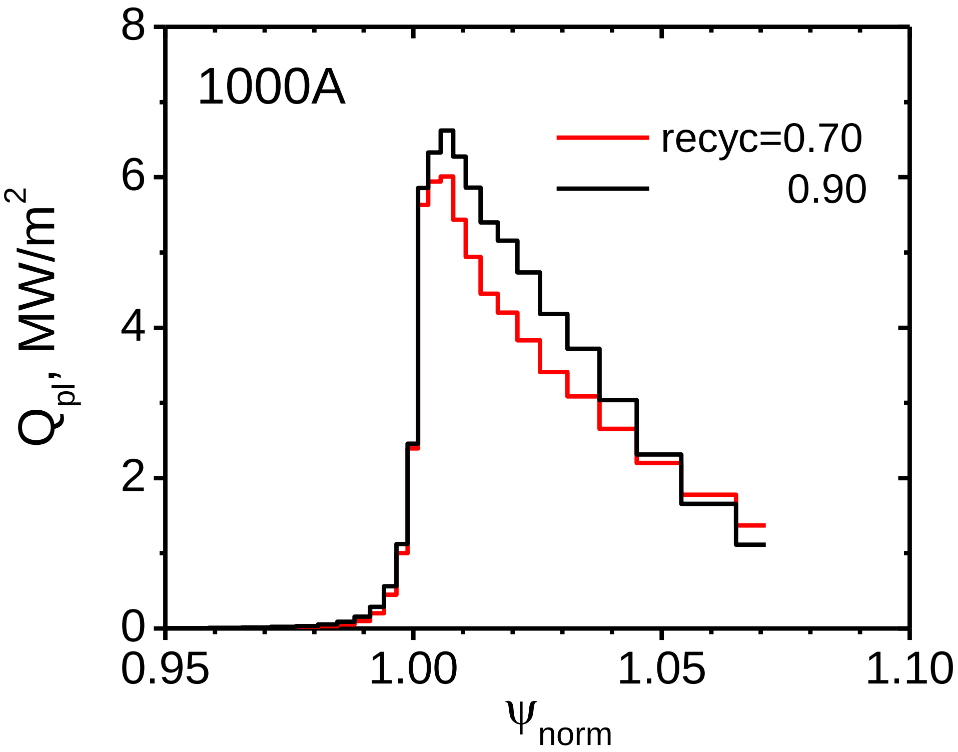
For Te~100eV ne~10^{13} cm^{-3}
mfp~20m

mfp exceeds the connection length to the outer divertor plate and mid-plane (10m)

Te significantly increases and its profile along the magnetic field line is rather flat in the low-recycling regimes

Heat flux to plate in low recycling regime

Radial profiles of the heat load to the outer divertor plate



Input plasma power 3MW

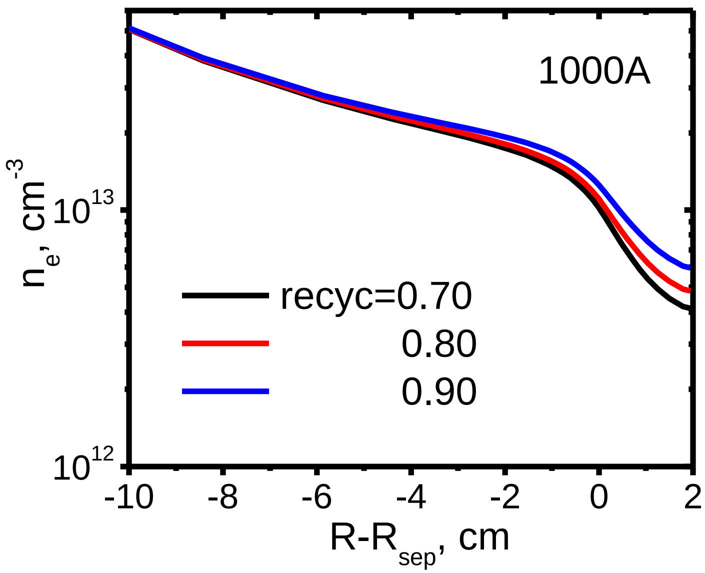
Heat flux in the SOL is carried predominantly by the electrons

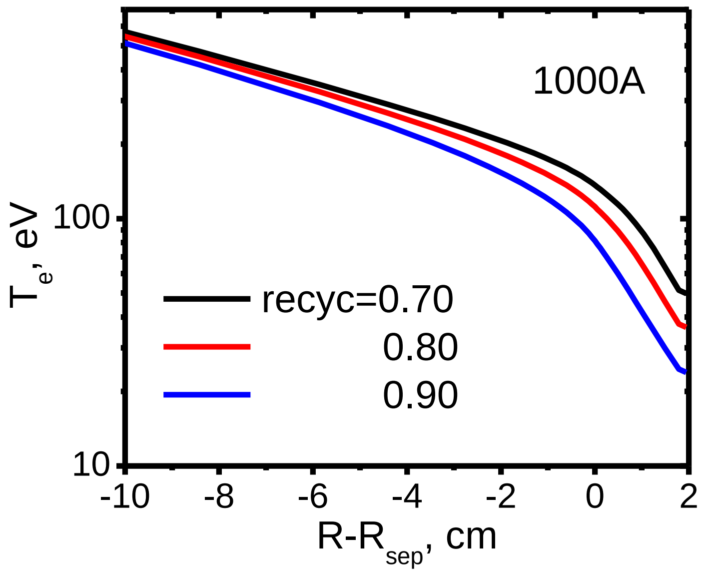
Flux-limited parallel electron heat conduction dominates

The profile narrows in the low-recycling regimes due to faster parallel plasma transport

In the low-recycling regime, the peak heat flux to outer plate may be high enough to melt Li at the strike point

Radial plasma profiles





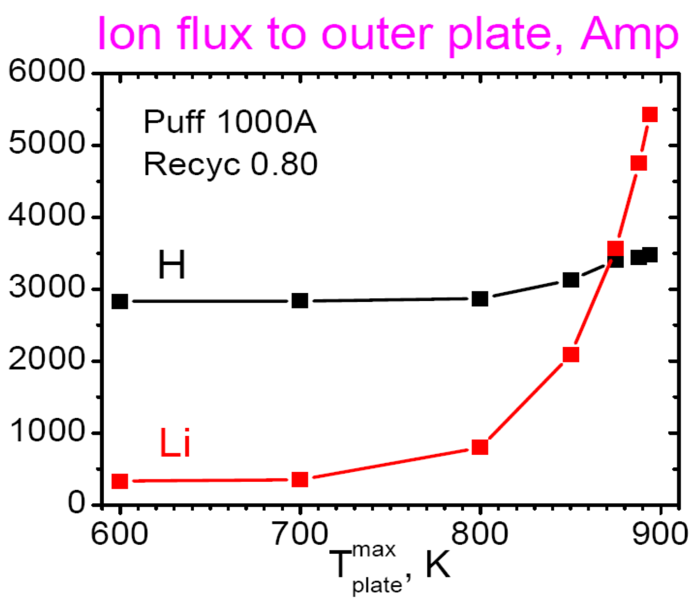
SOL plasma transport transits to a free-streaming regime in the low-recycling cases

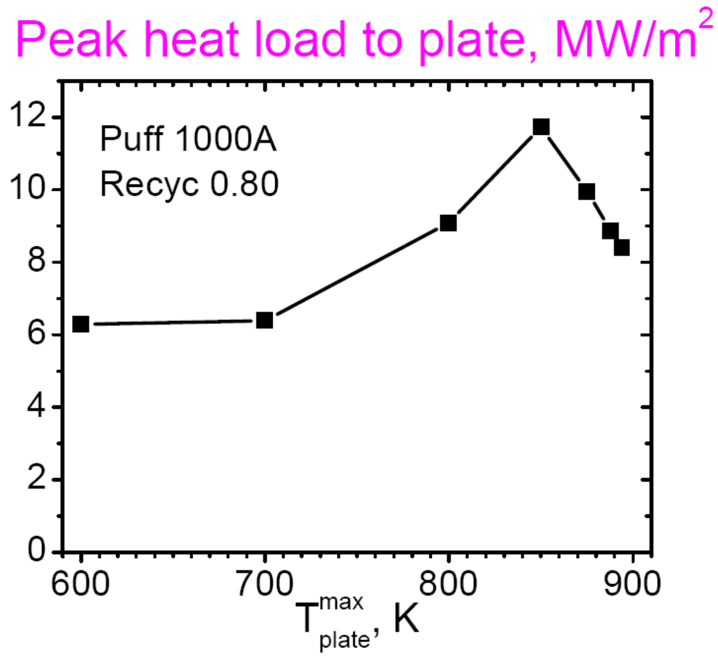
The radial plasma density gradient increases and the density at the separatrix is reduced slightly reflecting the increased pumping action of the divertor

The strong parallel plasma transport in the SOL also reduces radial plasma flux to the wall

The radial profiles of the electron temperature become flatter due to the raised overall electron temperature and heat conduction

Vapor instability modeled with UEDGE





Increase in Twall enhances the evaporation and the heat flux to wall leading to possible thermal instability

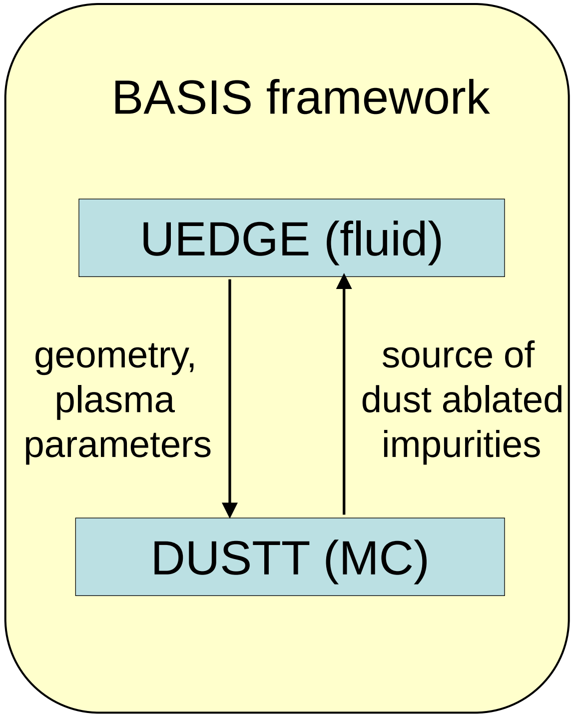
Possibly, the instability can be stabilized by impurity radiation upstream reducing the heat flux.

Instability may potentially affect lithium divertor performance at high heating power

Dust injection

DUSTT/UEDGE coupled codes

- 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 multi-fluid edge plasma transport code 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
- Present modeling is limited to 2D toroidally symmetrical plasmas

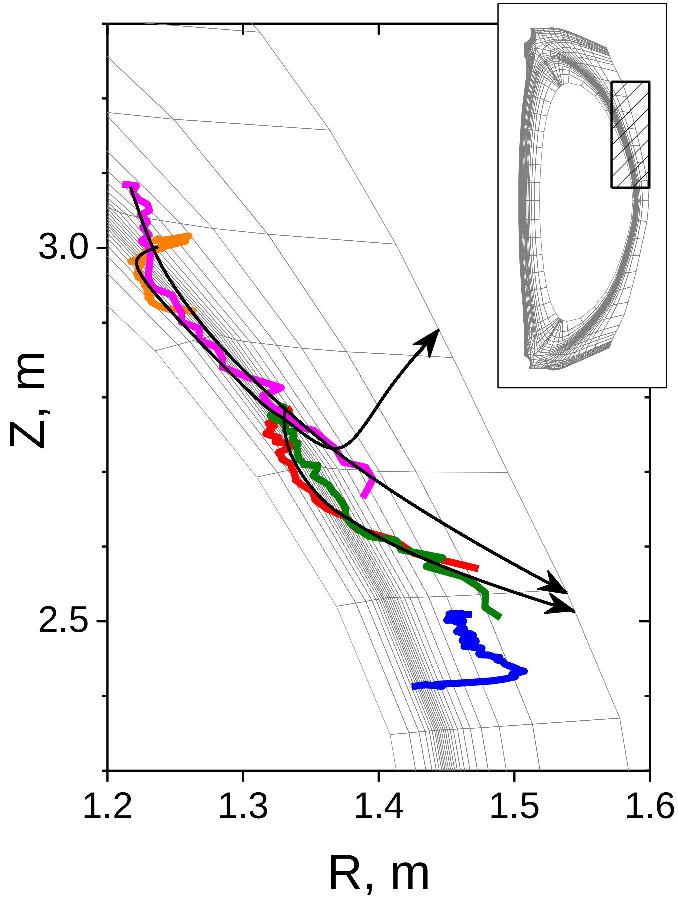


DUSTT code validation

- The experimental trajectories are compared with the DUSTT simulated ones using plasma parameters modeled with UEDGE

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

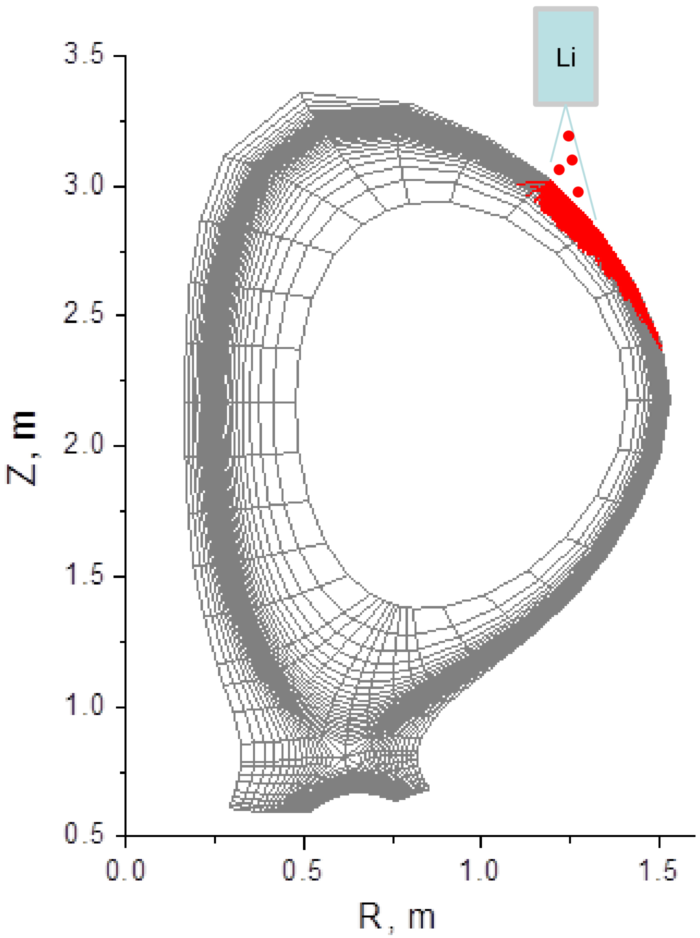
Li dust trajectories in NSTX



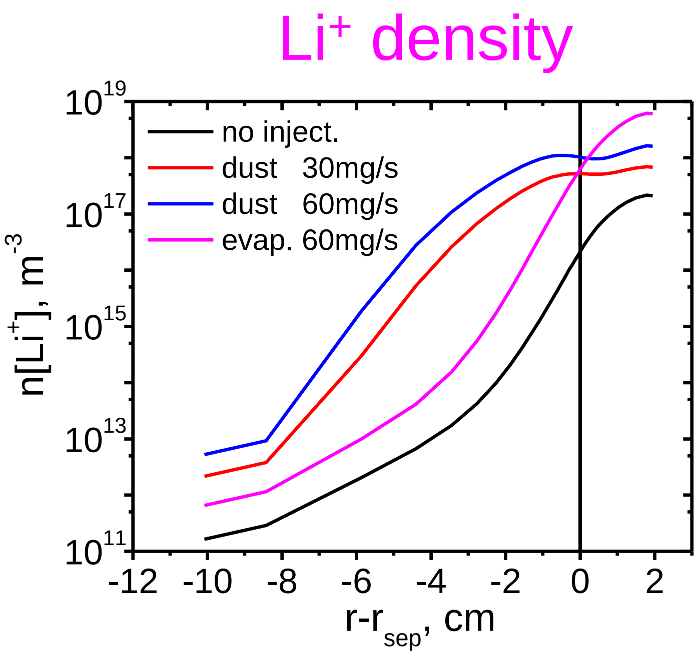
Modeling of Li dust injection

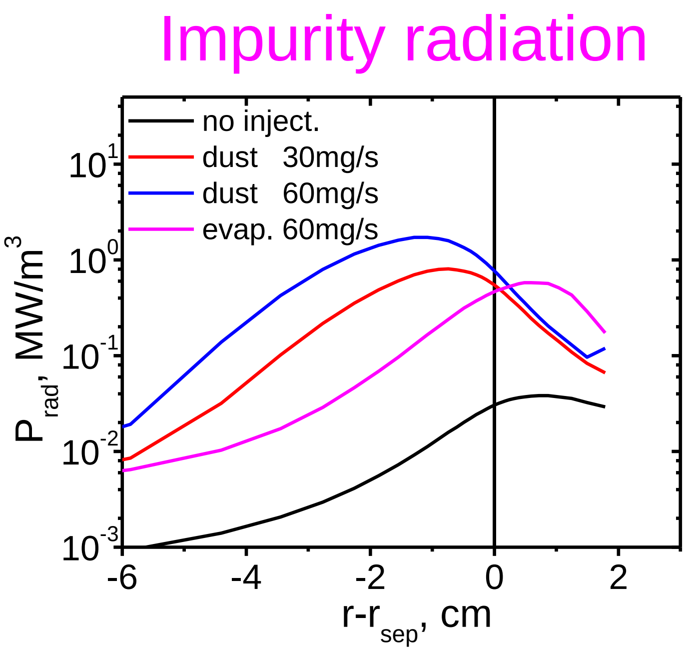
- NSTX L-mode LSN configuration is modeled
- ~20μm radius Li dust is injected in the upper outer poloidal position
- Dust hit the plasma with average speed ~5m/s and with shifted downward cosine angle distribution relative to vertical direction
- Divertor plates are assumed to be covered with Li film with recycling coefficients set at 0.8 for D and at 0.5 for Li (low-recycling regime)
- Core D^+ density is fixed at $5.1 \times 10^{13} cm^{-3}$
- Core heating power 3MW
- Plasma transport coefficient are fixed

Configuration of modeled Li dust injection



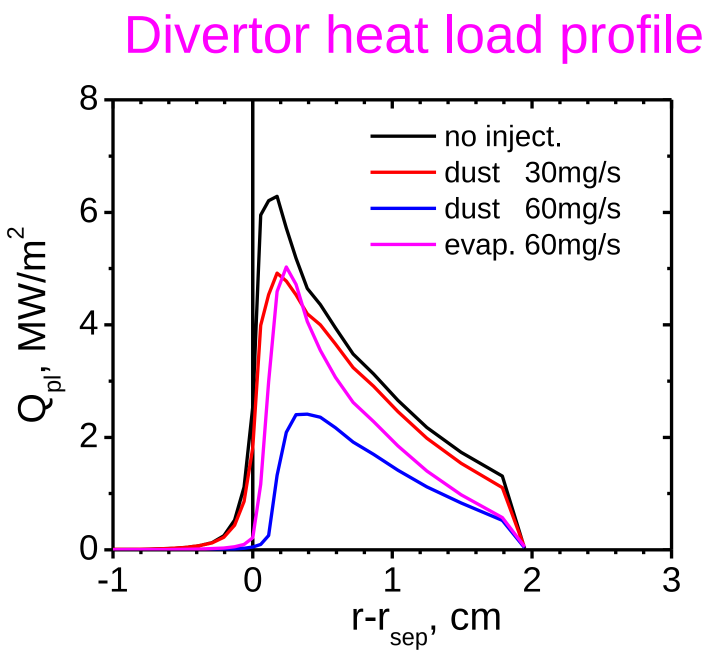
Dust originated impurities

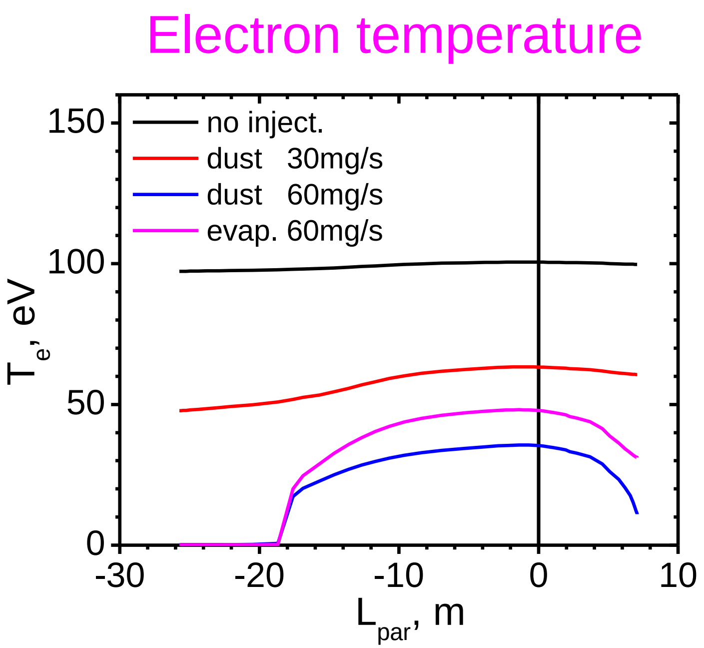




- Radial profiles at poloidal position of the dust source are shown
- Dust injection with rates ~ several 10mg/s can significantly increase impurity concentration and radiation power losses
- Gaseous impurities do not penetrate as deep into the plasma as the dust does

Impact of Li dust on divertor operation

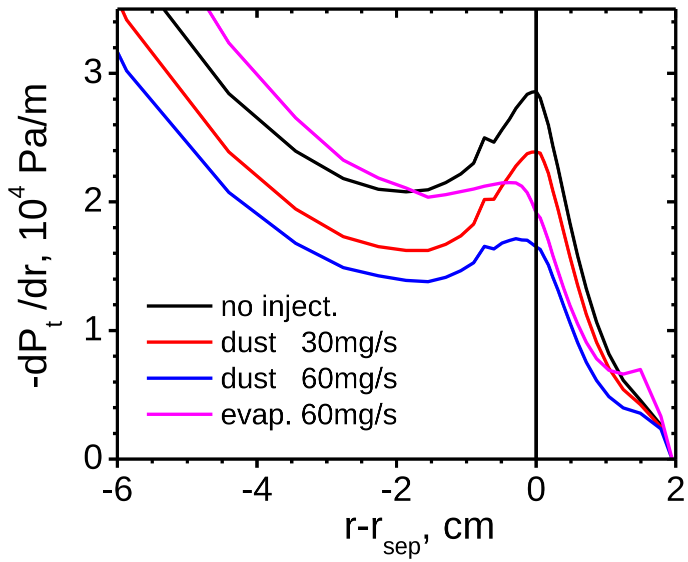




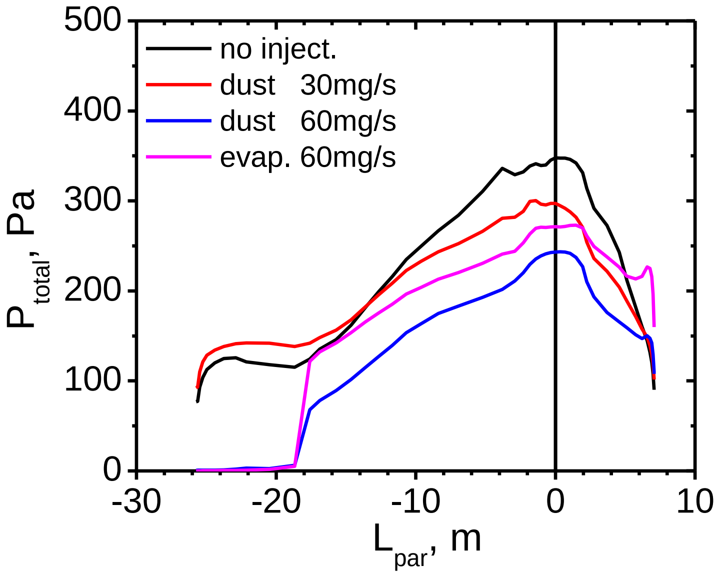
- The peak power load to the outer divertor plate is significantly reduced
- Broader heat load profile compared to gas injection
- Complete plasma detachment in the inner divertor at 60mg/s Li injection rates is developed

Pressure profiles

Radial pressure gradient



Parallel pressure profiles



- Radial plasma pressure gradients are substantially up to ~40% reduced in the edge
- Peeling/ballooning stability of the edge plasma can be improved, suppressing anomalous transport and ELM formation

Summary

- The coupled DUSTT - UEDGE codes allow self-consistent modeling of dust transport and impact on the edge plasmas
- The validation of the coupled DUSTT/UEDGE code has been performed using 3D reconstructed dust trajectories measured on NSTX
- Dust injection with rates ~ several 10mg/s in modern tokamaks can significantly affects edge plasma parameters, transport and stability
- Effects of lithium wall conditioning and plasma impurities can be analyzed separately using the modeling
- Further modeling of different dust injection scenarios and dust impact on edge plasmas is undergoing