Particle-in-cell modelling of high density and emissive sheaths

D. Tskhakaya, M. Komm, A. Podolnik

Institute of Plasma Physics of the CAS, Prague, Czech Republic

Collaborations: ISFN, TSVV-3, 4, 7

Description of main tasks (2021-2022)

➢ Modelling of W sputtering in high density divertor plasma

Milestones. Development of kinetic models of COMPASS-U and ITER SOLs, estimation of W erosion rates under different scenarios.

Deliverables.

- W gross erosion rates for COMPASS-U and ITER divertors.
- plasma background profiles in the SOL/divertor plasma, to be used in impurity transport codes (e.g. ERO/ERO2)

➢ Simulation of thermionic currents from W surface for intra- and inter-ELM conditions

Milestones: Verification of scaling laws for ITER-relevant plasma conditions

Deliverables:

- Scaling lows of thermionic, secondary and backscattered electron emissions in inter- and intra-ELM conditions in ITER
- Estimation of power load of heated PFC gaps with emitting surfaces.

➢ iii. Multi-dimensional kinetic modelling of the plasma sheath

Milestone. Development of multi-dimensional sheath model (2022-2025)

Deliverables.

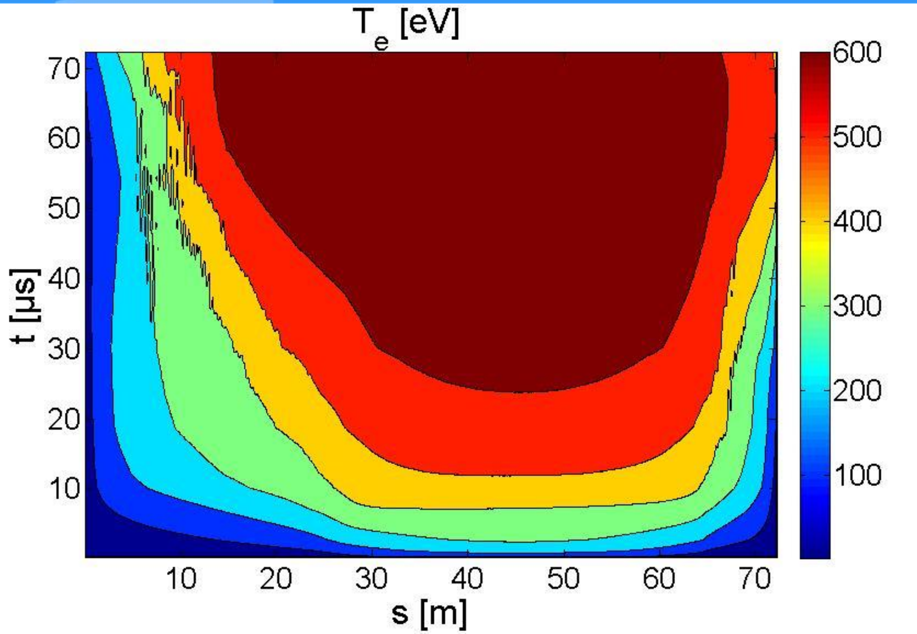
- First self-consistent multi-dimensional model of the plasma sheath in the presence of radial/toroidal gradients of density, temperature and potential, as well as roughness
- Corresponding boundary conditions at the sheath entrance.

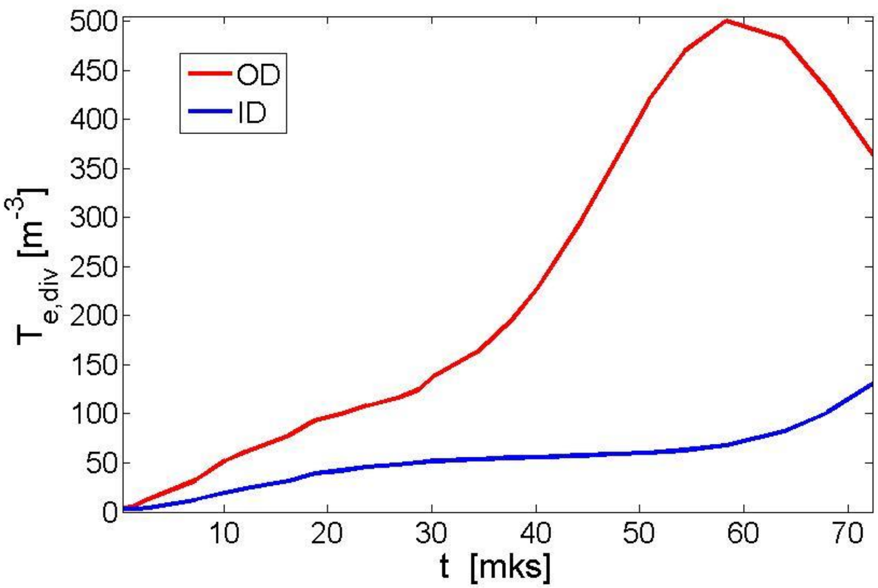
Modelling of W sputtering at JET

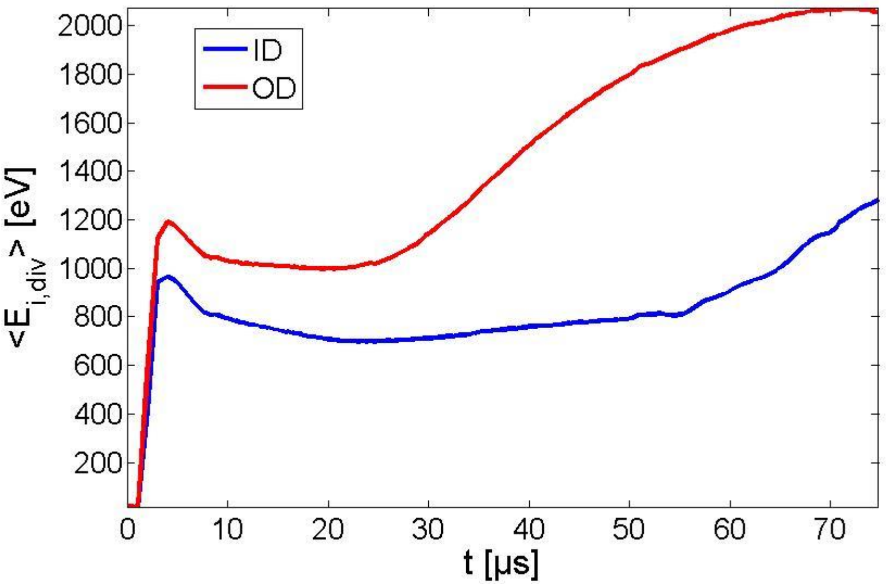
1. We are performing BIT1 smulations of the JET SOL in order to estimate W sputtering rates during the ELMs (0.1, 0.15 and 0.22 MJ)

Strong I/O assimetry due to sassymetries of the collection length and divertor plasma parameters *[Huber NF, submitted; EPS 2021]*

$T_{e,div}$ can axceed 450 eV (0.22 MJ ELM)







Properties of high density sheath

- Plasma flow in high density sheath is **sub-sonic.** The corresponding Mach number depends on the ion-neutral collisionality and the plasma current

- A new definition of the magnetic presheath entrance (SE) is proposed:

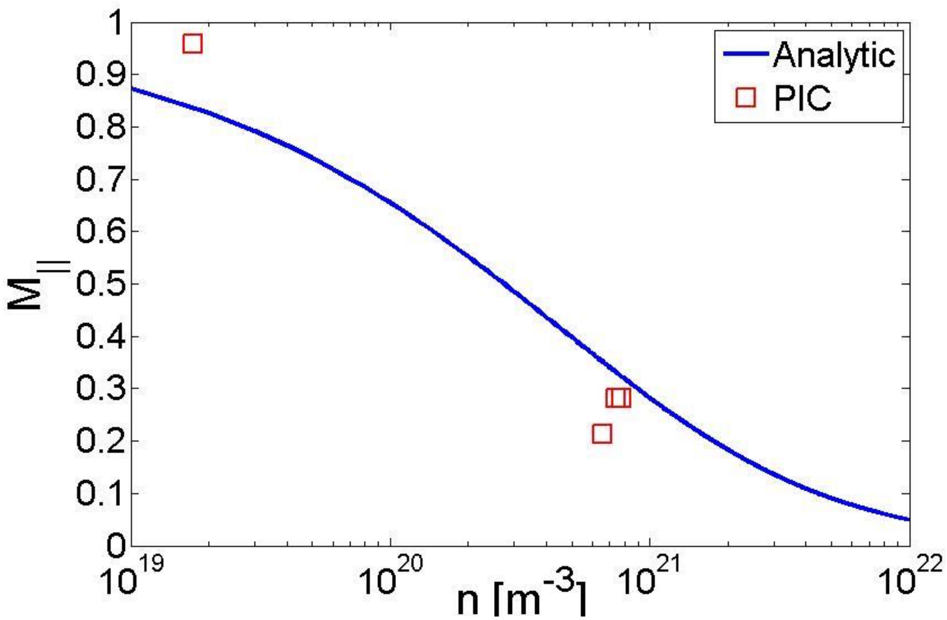
a nearest point to the wall surface, where plasma is still magnetised.

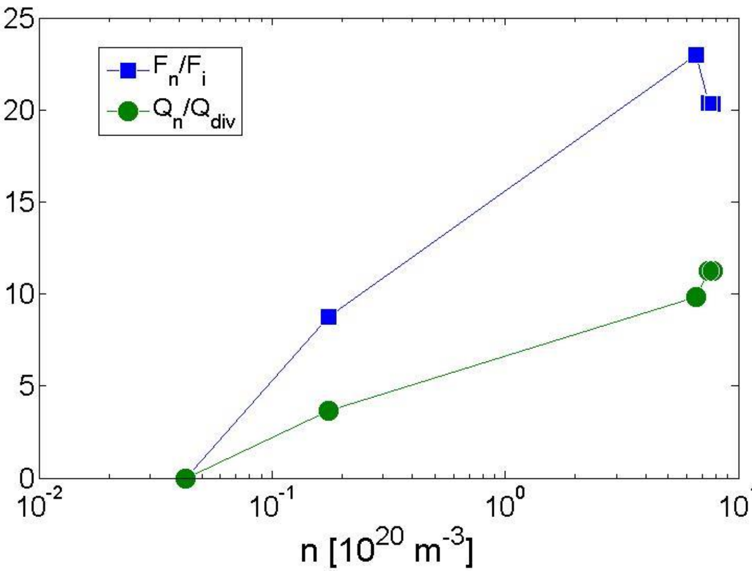
- Neutral particles represent the main particle and heat flux curriers in the collisional sheath.

$$M_{\parallel} = 1 + \chi - \sqrt{\chi^2 + 2\chi}$$

$$\chi = \left(\upsilon_{mt} \left(1 - \frac{V_{\parallel}^{n}}{V_{\parallel}} \right) + \upsilon_{ei} \frac{I}{I_{sat}} \right) \frac{x_{se}}{2 c_s \sin(\theta)}$$

[Tskhakaya EPS 2021]





Neutral particle and heat fluxes to the divertor

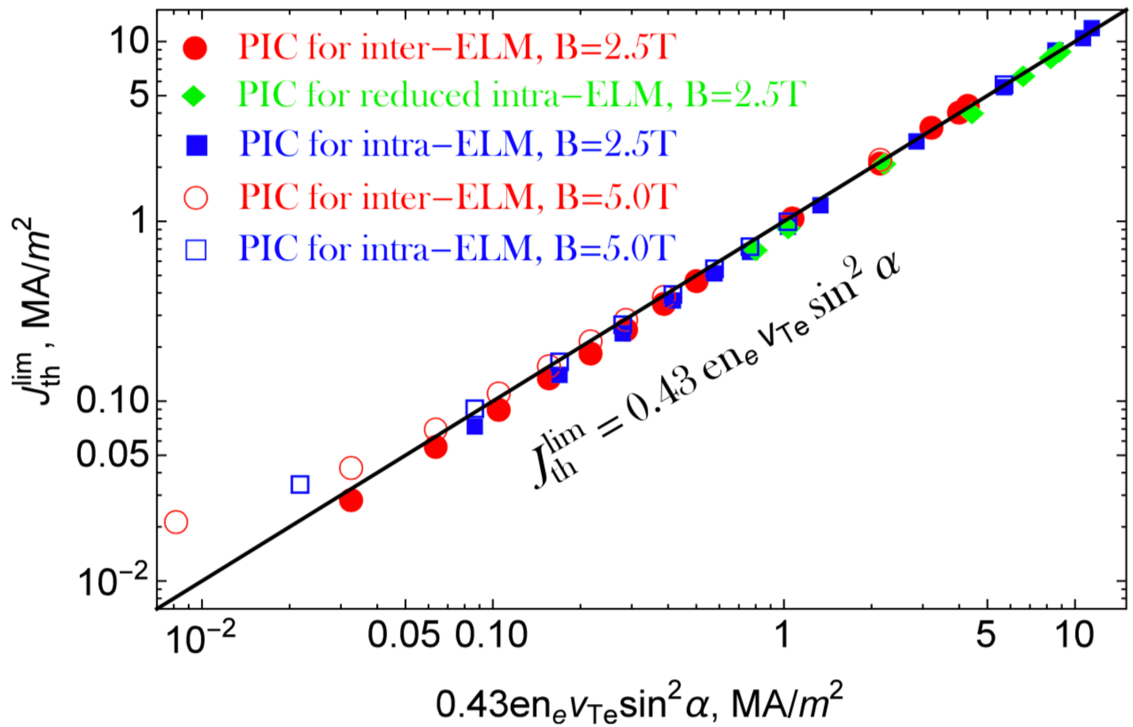
Thermionic emission

1. Simulations of thermionic emission at hot tungsten surfaces

SPICE2 has been extensively used to model escaping thermionic current in conditions relevant to AUG and JET melting experiments

We managed to derived an “extended Takamura formula”, which includes the effect of inclined magnetic field. This effect reduces the escaping current as $\sin^2\alpha$

This formula is valid for both inter- and intra-ELM plasma conditions provided that Te < 100 eV



[Komm PPCF 2017]

[Komm Phys. Scr. 2017]

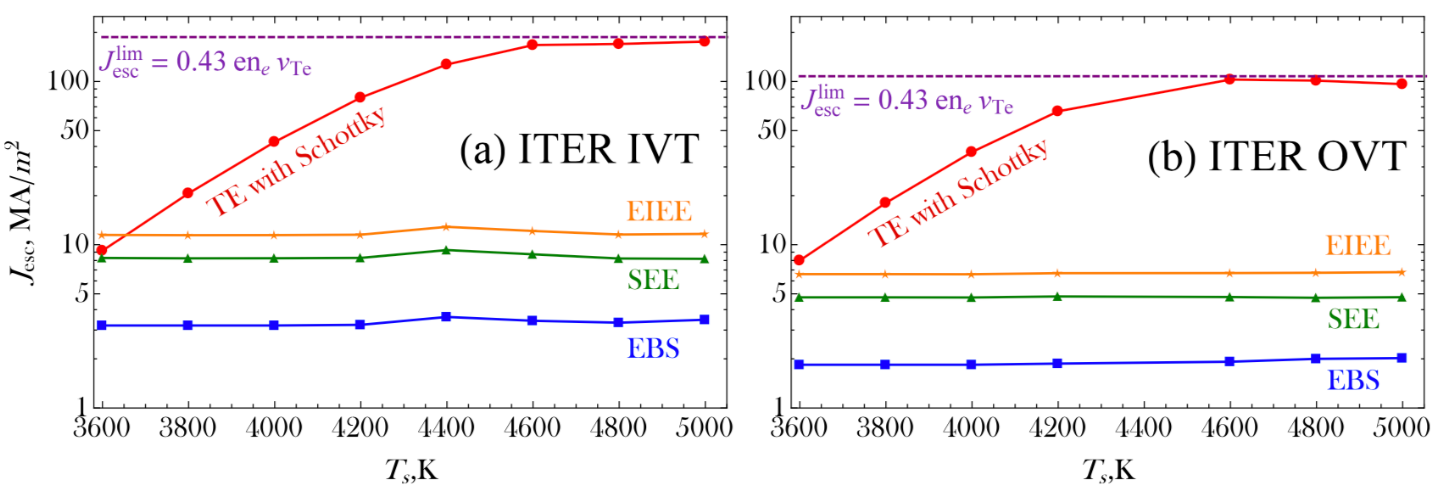
[Komm NF Let. 2020]

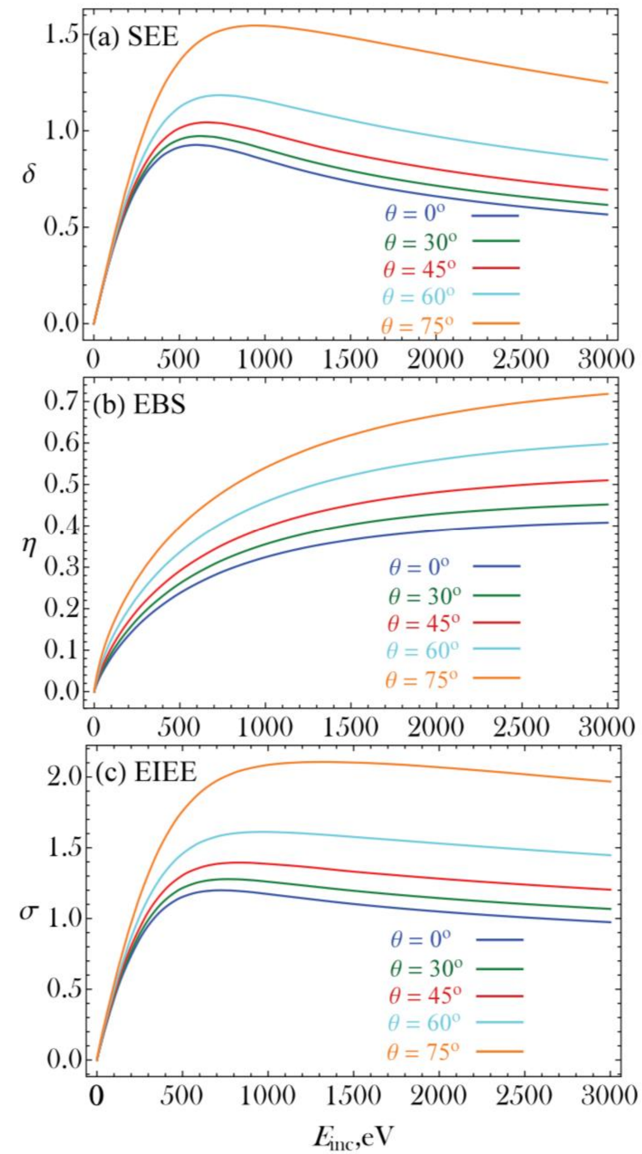
Electron emission effects in ITER

The T_e during ELMs in ITER (assumption) > 100 eV

At these temperatures, **secondary electron emission** and **electron back-scattering** can become important. Also the TE should be corrected for Schottky effect (which changes the work function of the material).

Detailed models of SEE and EBS have been implemented in SPICE2 *[Tolias NME 2020]* and first simulations for **ITER intra-ELM plasmas** were performed for **normal incidence of B field**





SPICE CODES

SPICE2

- 2D3V cartesian code, fixed B field, self-consistent E field
- Grid size up to ~4000x4000 cells (~ 40x40 mm on cont. tokamaks, ~4x4 mm for ITER)
- Variable inclination of magnetic field with adjusted injection scheme (J.P. Gunn)
- Model of **thermionic emission**, **secondary electron emission**, **electron back-scattering** (in collaboration with S. Ratynskaia and P. Tolias)
- Coulomb collision module under development
- Flexible geometry of simulated region: tiles with gaps, misaligned tiles, Langmuir probes,...
- Used for: studies of TE+SEE+EBS at hot tungsten surfaces, heat flux distribution at castellated tiles, flush-mounted probes, domed probes,...
- Scaling: up to 64 cores (serial Poisson solver)

SPICE3

- 3D3V extension of SPICE2. Grid size up to 256x256x256 cells
- **Parallel Poisson solver** based on PETSC library (**thanks to HLST**) -> scaling up to 256 cores
- Used for: TE at hotspots, gap crossings, Katsumata probes, Langmuir probes, flush mounted probes, rough surfaces

Both codes installed at Marconi, IT4I and other machines

BIT1

- 1D3V electrostatic PIC + MC code, fixed B field (2D3V for neutral particles)
- Capable to simulate whole flux tube in the SOL
- Nonlinear momentum and energy conserving collision operators, linear PSI
- Massively parallel (typical run ~2300 cores, scaling > 4000), first simulations 2009

BIT3

- 3D3V extension of BIT1
- Suitable for simulation of divertor plasmas (3D SOL → exascale era)
- Not active yet (coupling to Poisson Solver: HLST K.S. Kang)
- Expected minimum scaling 12 000