EMC3-EIRENEによる 周辺プラズマ・不純物輸送モデリング

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目次

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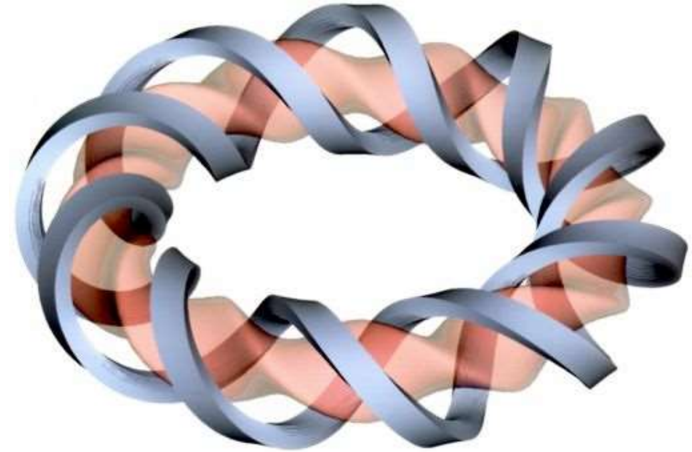
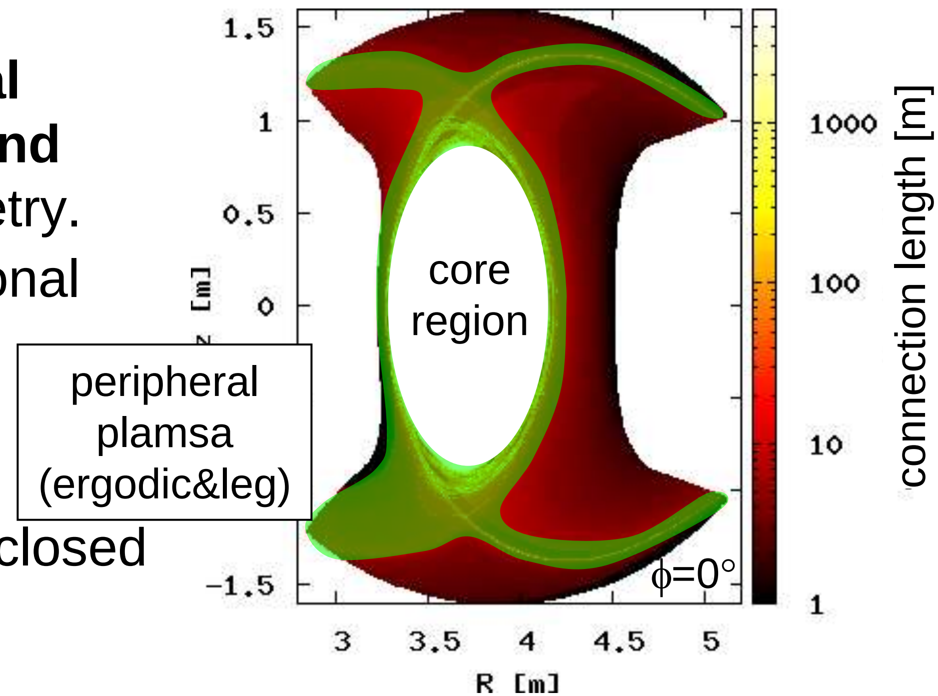
- LHDにおける周辺プラズマ解析
- タングステンダイバータ損耗再堆積解析
- 直線装置プラズマモデリング

Transport simulation of LHD peripheral plasmas

- Background and Motivations
  - Understandings of **plasma-neutral-impurity interactions** and realization of predictive simulation.
  - Evaluation of **different divertor configuration**; open and closed.
- Approach
  - Realization of **three-dimensional** transport simulation in **ergodic and leg** regions in the realistic geometry.
  - Development of a three-dimensional transport code for LHD; **EMC3-EIRENE**
  - Validation by measurements.
  - Comparisons of results for open/closed divertor configurations.





EMC3-EIRENE code

- EMC3 solves fluid equations of flux tube plasma in SOL:

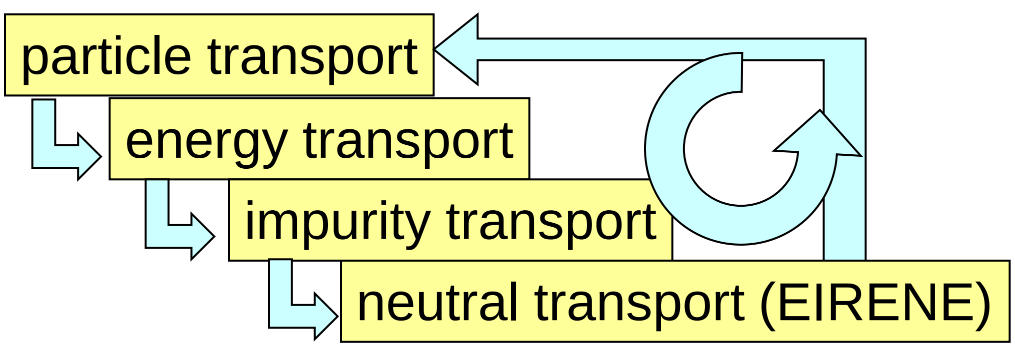
$$\nabla_\parallel \cdot \left(n\mathbf{v}_\parallel\right) + \nabla_\perp \cdot \left(-D\nabla_\perp n\right) = S_p$$

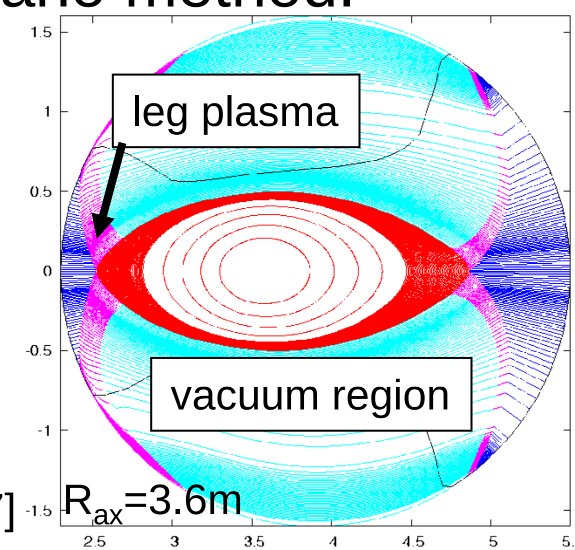
$$\nabla_\parallel \cdot \left(m_i n \mathbf{v}_\parallel \mathbf{v}_\parallel - \eta_\parallel \nabla_\parallel \mathbf{v}_\parallel\right) + \nabla_\perp \cdot \left(-m_i \mathbf{v}_\parallel D \nabla_\perp n - \eta_\perp \nabla_\perp \mathbf{v}_\parallel\right) = \nabla_\parallel p + \mathbf{S}_m$$

$$\nabla_\parallel \cdot \left(-\kappa_i \nabla_\parallel T_i + \frac{5}{2} n T_i \mathbf{v}_\parallel\right) + \nabla_\perp \cdot \left(-\chi_i n \nabla_\perp T_i - \frac{5}{2} T_i D \nabla_\perp n\right) = k\left(T_e - T_i\right) + S_{ei}$$

$$\nabla_\parallel \cdot \left(-\kappa_e \nabla_\parallel T_e + \frac{5}{2} n T_e \mathbf{v}_\parallel\right) + \nabla_\perp \cdot \left(-\chi_e n \nabla_\perp T_e - \frac{5}{2} T_e D \nabla_\perp n\right) = -k\left(T_e - T_i\right) + S_{ee}$$

- EMC3 can simulate plasma with ergodic magnetic field in LHD by solving them with the aid of Monte Carlo method.

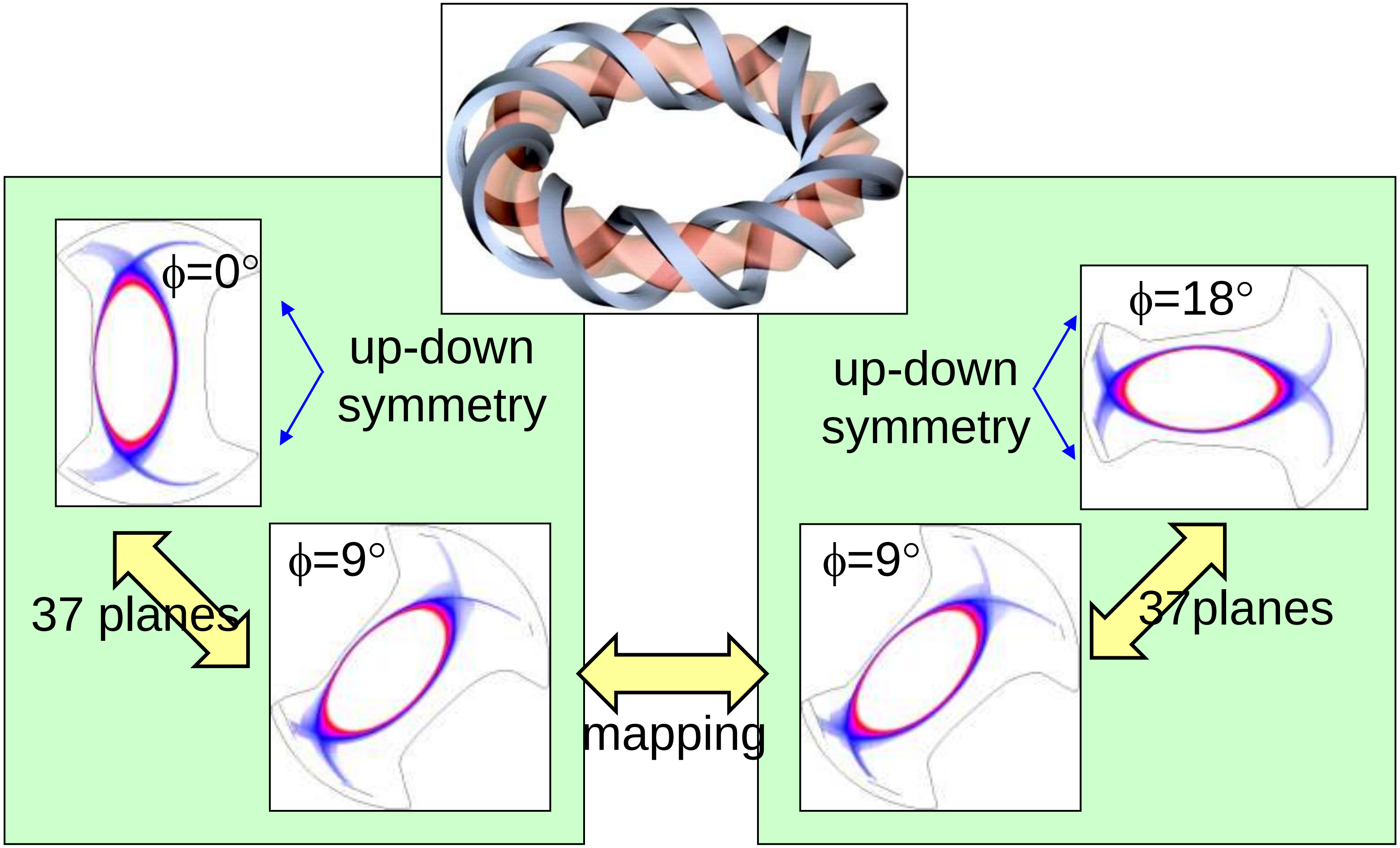




[G. Kawamura et al., Contr. Plasma Phys. 54 (2014) 437]

Simulation box

- 18°-section (1/20 of the torus) is realized in simulation by using the periodicity and assumption of up-down symmetry.
- Meshes are generated on poloidal planes every 0.25°.



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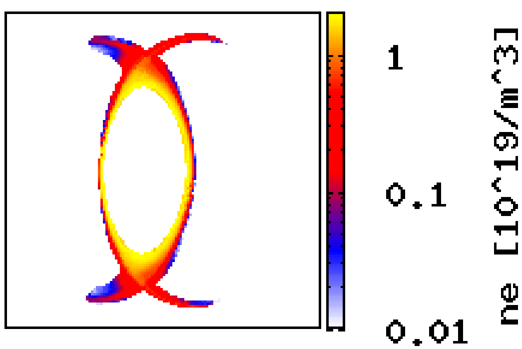
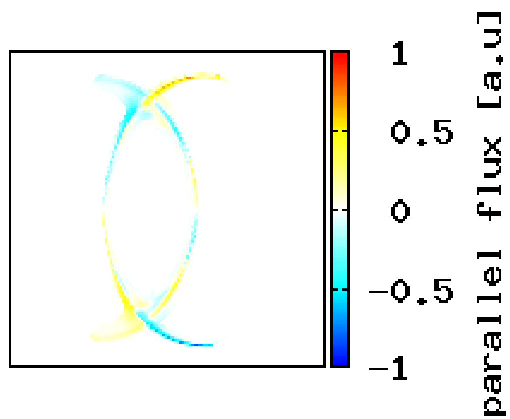
Simulation conditions and examples

♦ Conditions and Assumptions

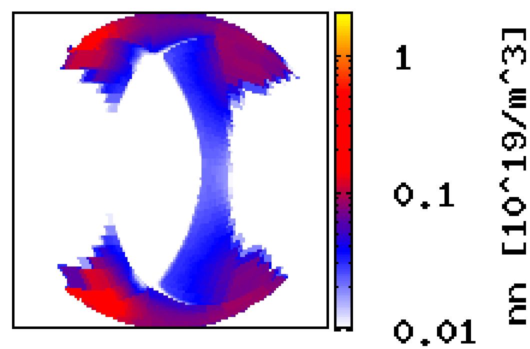
- Input power: 8MW
- Electron density: $2\times10^{13}/cm^3$ at LCFS
- Bohm condition is assumed at divertor plates
- Magnetic configuration: $R_{ax}=3.6m$
- Perpendicular transport coefficient: $D_{perp}=1\ m^2/s$, $\chi_{perp}=3\ m^2/s$
- No neutral-pumping (100% recycled)



electron density
$[10^{17} - 2\times10^{19}\ /m^3]$



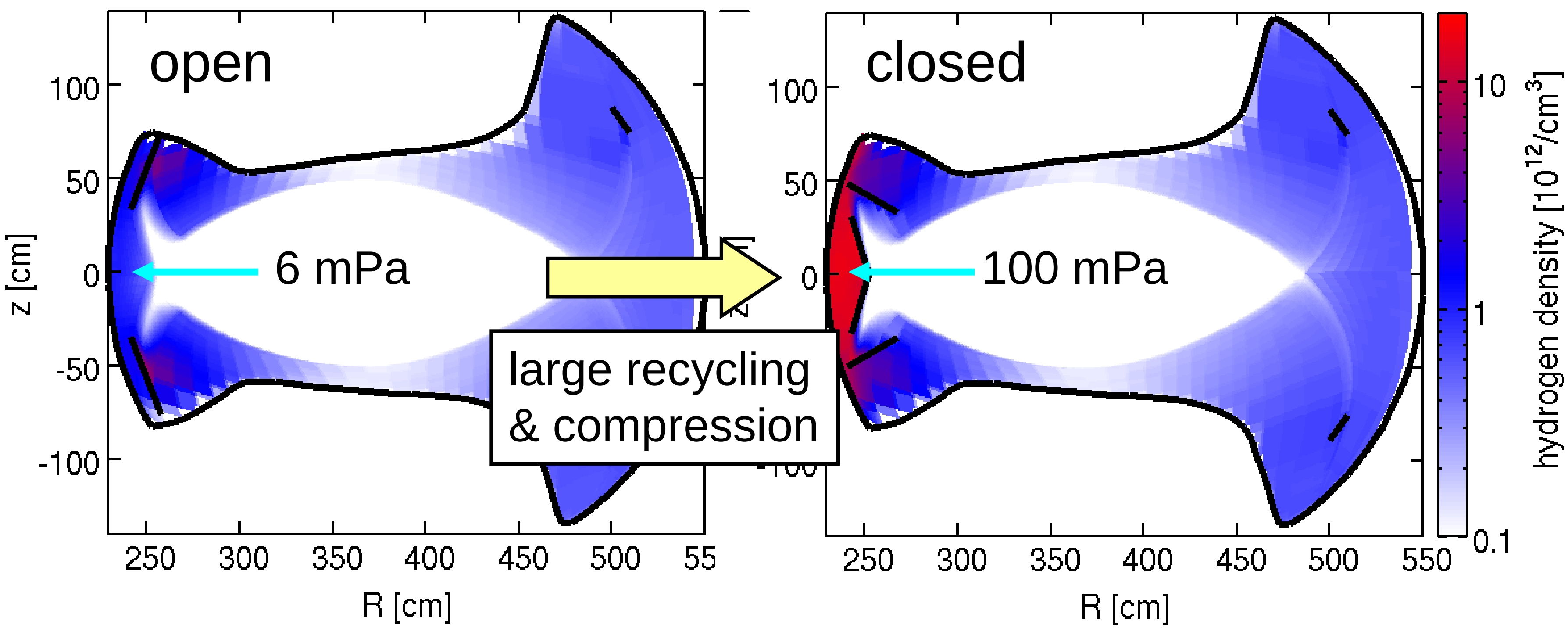
parallel particle flux
[a.u]



H_2 molecule density
$[10^{17} - 10^{19}\ /m^3]$

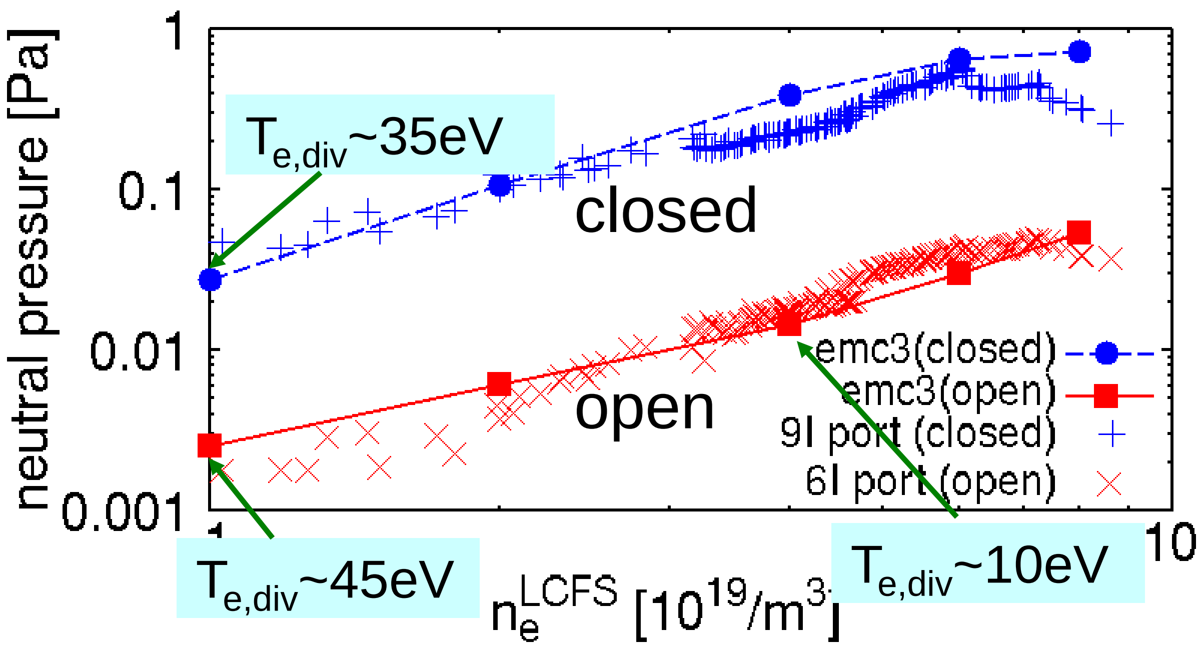
Neutral gas transport

- Influence of the closed configuration on neutral-gas pressure
  - Compression of hydrogen gas
  - Simulation gives 17 times higher density under the dome structure.
  - It agrees with experimental measurement (10~20 times)



Scaling of neutral pressure with electron density

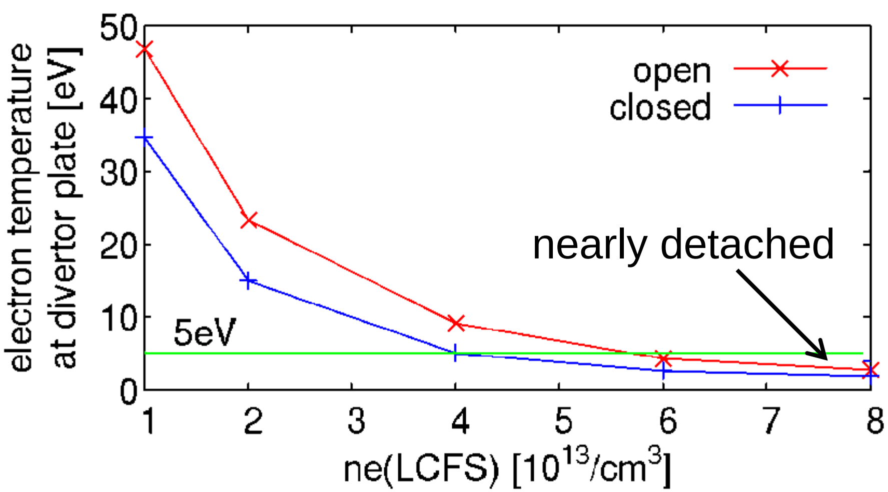
- A series of simulation were carried out.
  - Constant input power: 8MW, n_e at LCFS: 1, 2, 4,6, $8\times10^{13}/cm^3$.
- Dependence of neutral pressure on electron density.
  - Simulation results has the same scaling law as the experimental measurements independently of configurations.



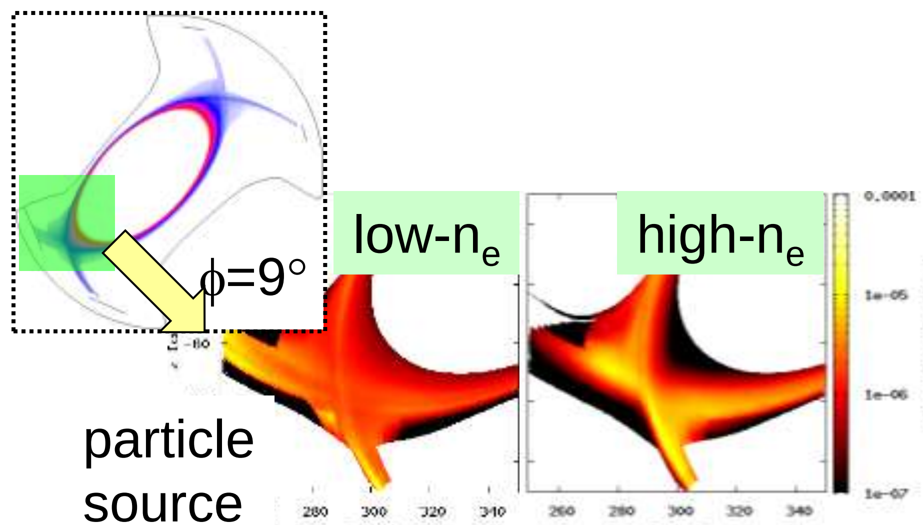
Comparison of neutral pressure; measurements of two discharges and simulation results (solid lines: 500K H_2 gas)

Hydrogen recycling

- Recycling in open/closed configuration
  - Closed configuration causes large particle source, i.e. large recycling.
  - Large ionization leads to large energy loss.
- Contribution of divertor legs on recycling
  - Major contribution in low-density discharges, $1 \sim 4\times10^{13}/cm^3$
  - Minor contribution in high-density discharges, $6 \sim 8\times10^{13}/cm^3$



Mean T_e on divertor plates

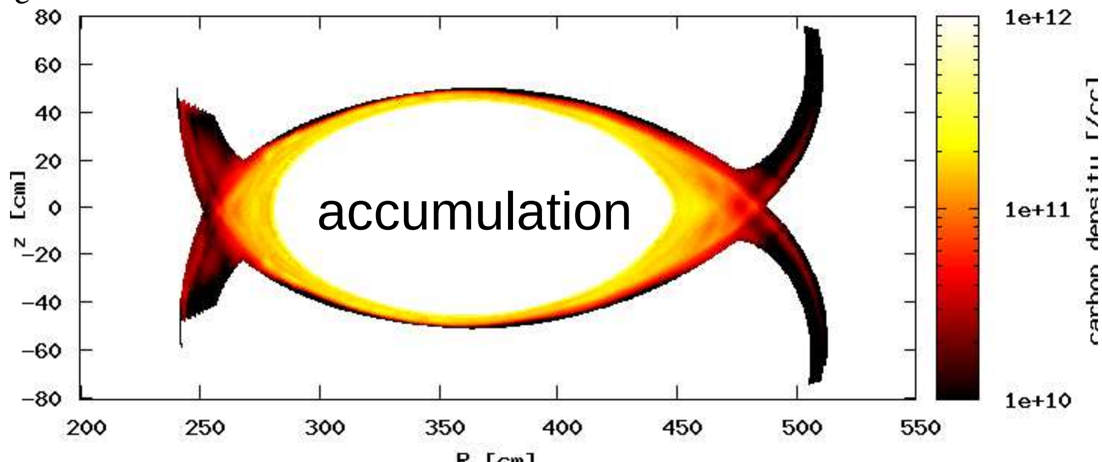


Impurity transport

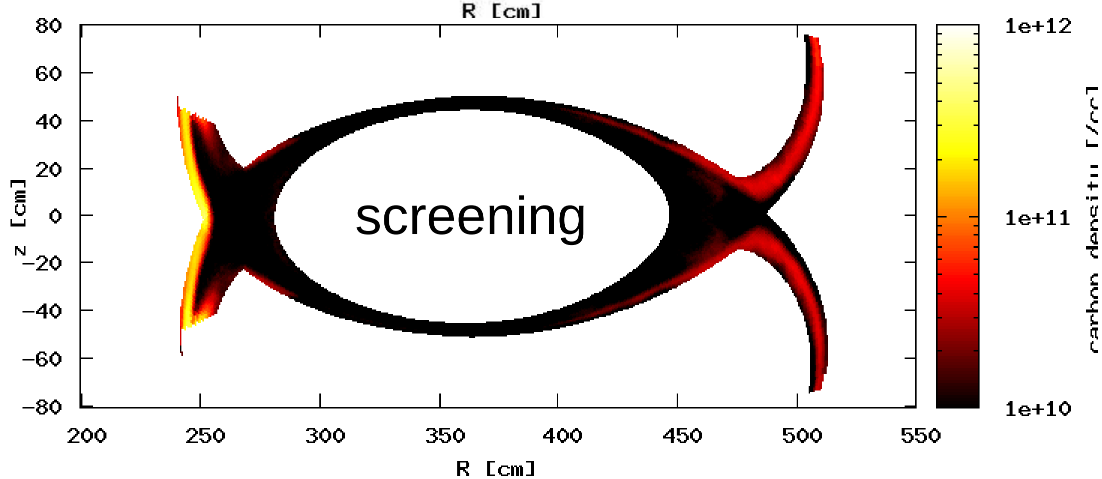
- Impurity screening [M. Kobayashi et al., JNM 390 (2009) 325]

$$\begin{cases} \text{Friction force} \propto w_{\parallel} \rightarrow \text{divertor plates} \\ \text{Thermal force} \propto \nabla_{\parallel} T_e \rightarrow \text{core} \end{cases}$$

Low-density discharge:
n_e(LCFS)=1x10^{13}/cm^3



Hight-density discharge:
n_e(LCFS)=6x10^{13}/cm^3

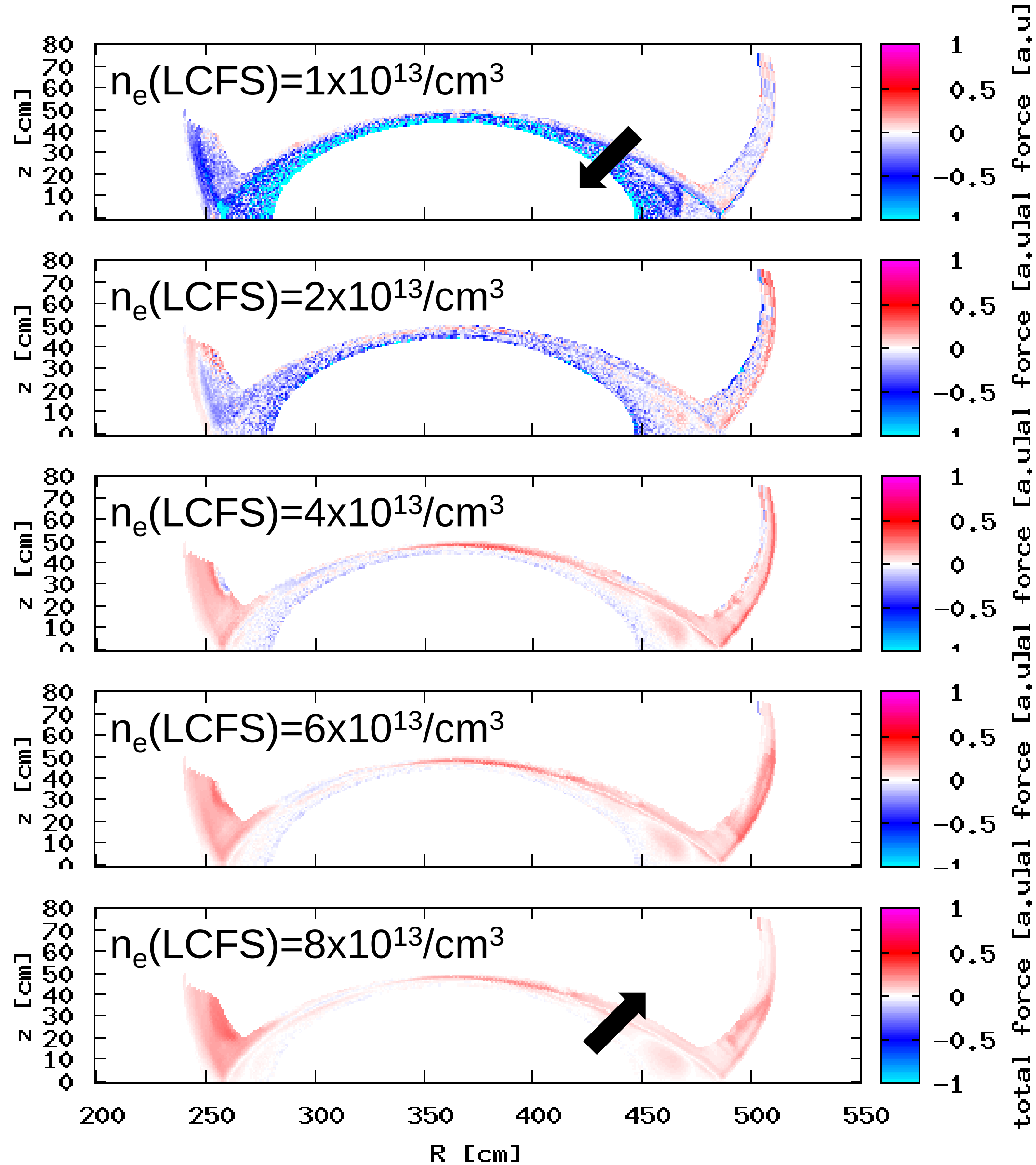


Force balance on impurity ions

- Friction force
  vs. thermal force

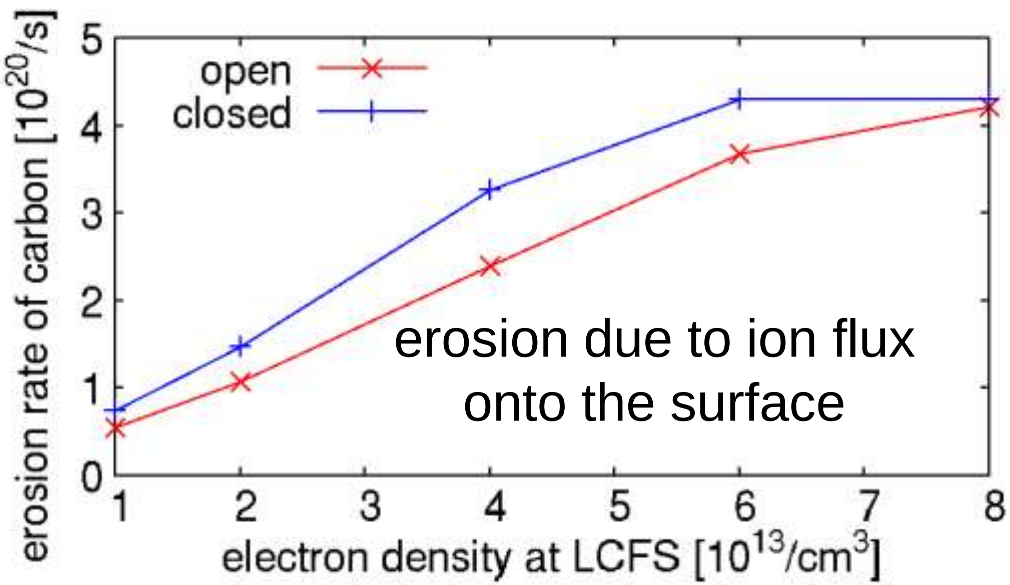
thermal force dominant
toward the upstream

friction force dominant
toward the downstream



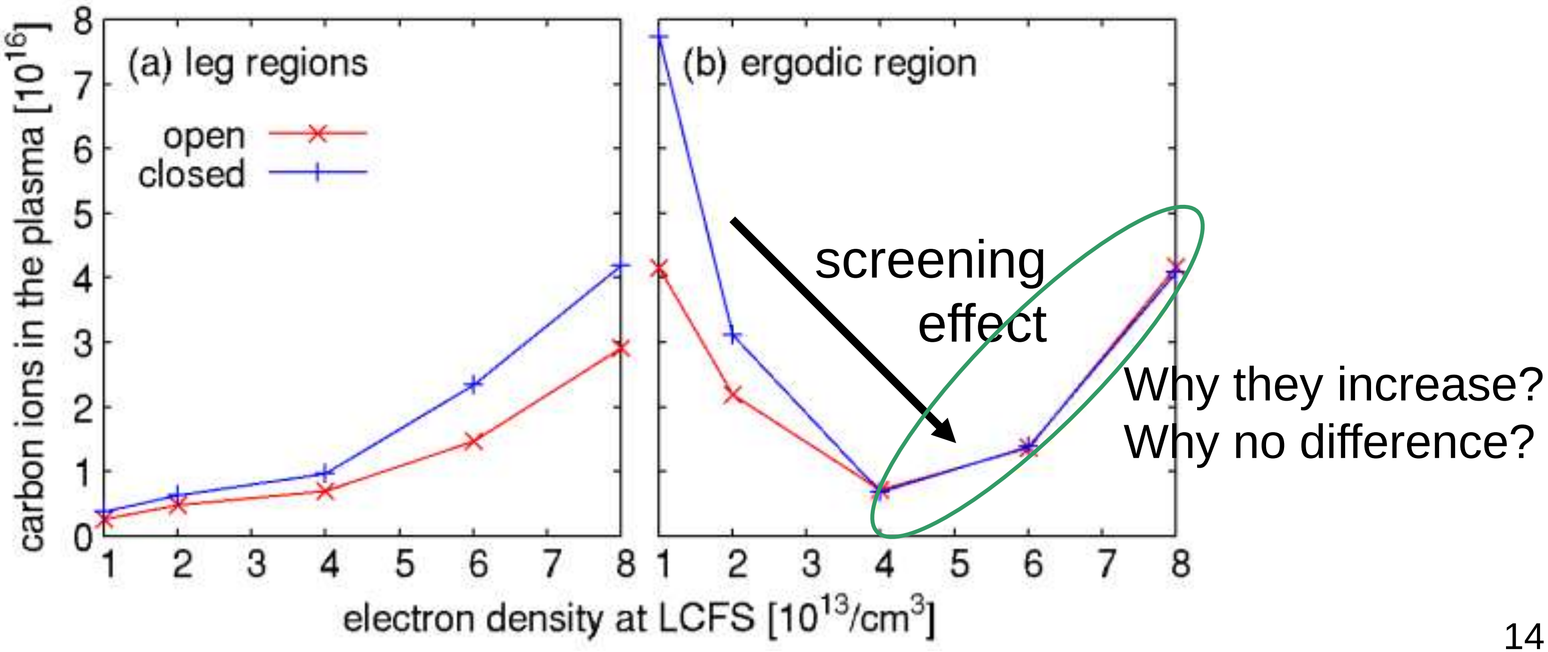
Erosion rate of the divertor plates

- Assumptions for qualitative comparison
  - Sputtering yield is fixed to 1%.
  - Self sputtering is not included.
  - Sputtered carbon is treated as an atom.
- Large recycling flux leads to large erosion.
- Modification to the closed configuration causes large erosion.
- Amount of the generation ≠ Accumulation in the plasma



Impurity retention in the plasma

- Total carbon amount, i.e. $[C^{+}]+[C^{2+}]+\ldots+[C^{6+}]$
  - Leg regions
    - Impurity retention increase according to the electron density.
  - Ergodic region
    - Screening effect of the plasma flow significantly reduces the retention in the ergodic region.
    - No influence of configurations is observed in the case of high-density discharges. —— Why?



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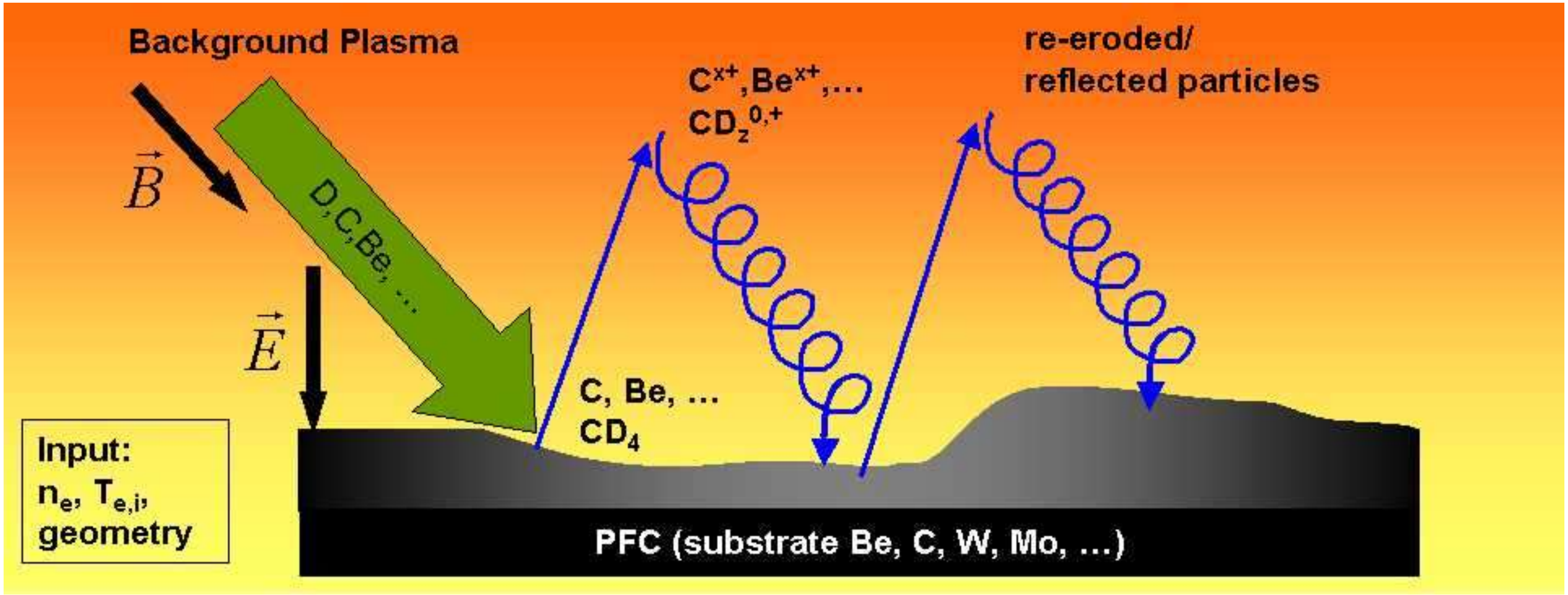
ERO code

- Monte Carlo simulation code of erosion and redeposition
- Background plasma distribution is fixed in simulation.
- Code modification to use EMC3-EIRENE results is on going.



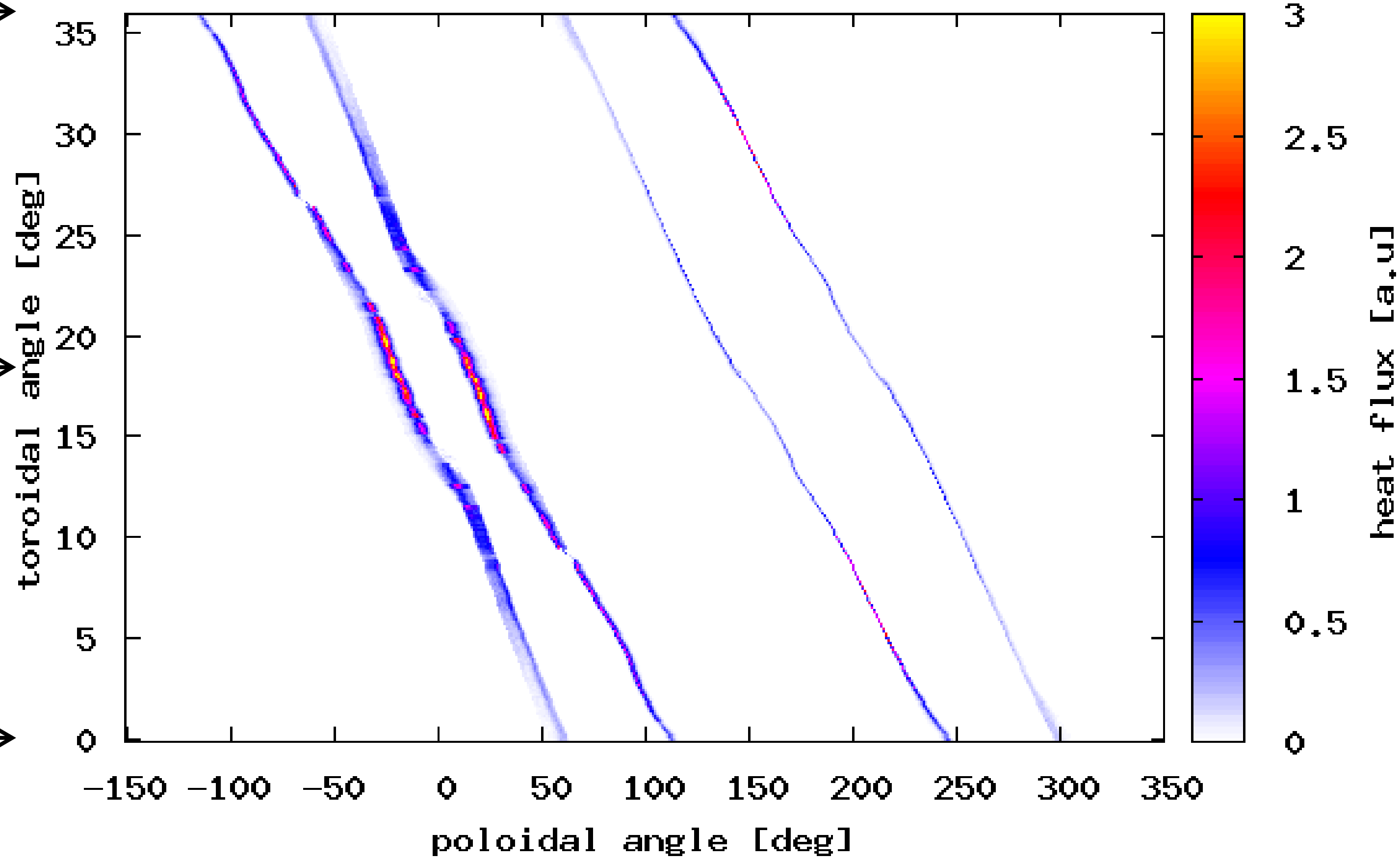
Heat load pattern

- EMC3-EIRENE results of heat load on divertor tiles.
  - Global estimation of erosion.
  - Influence of plasma parameters on the pattern.

vertically elongated plane →

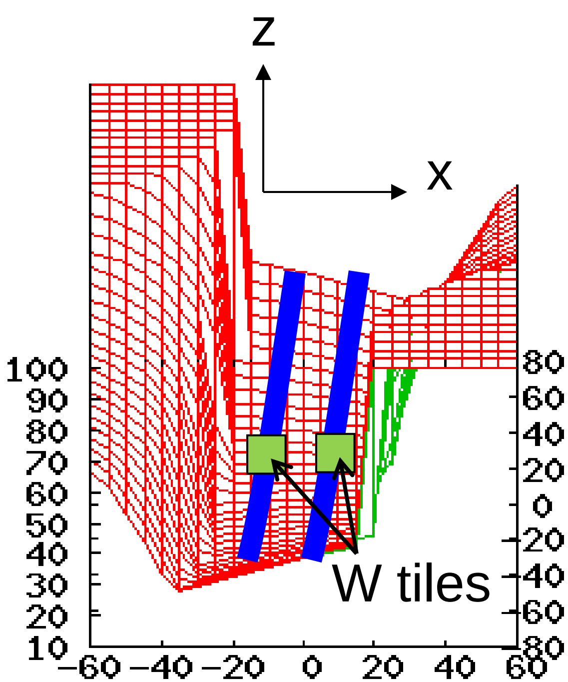
horizontally elongated plane →

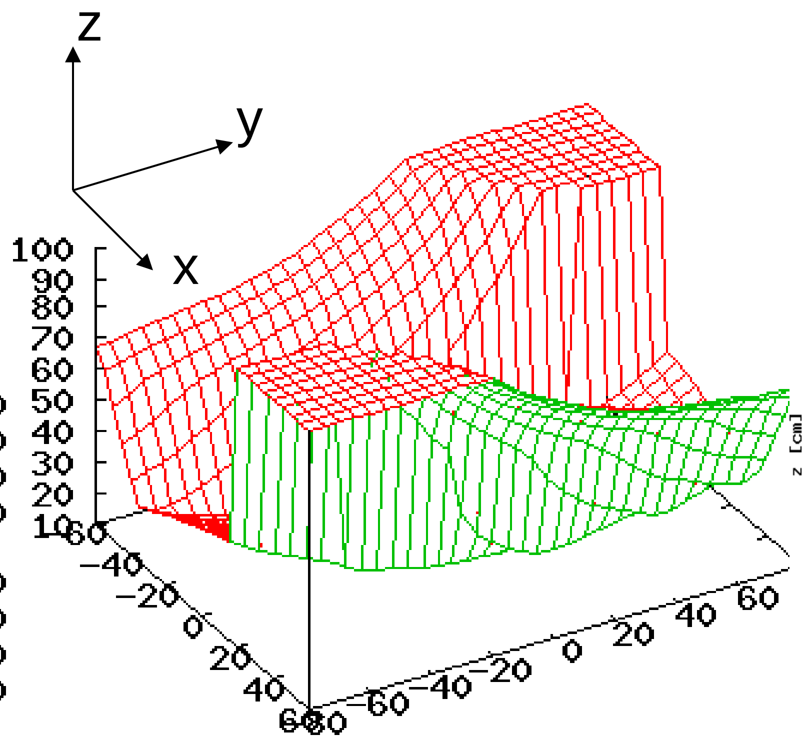
vertically elongated plane →



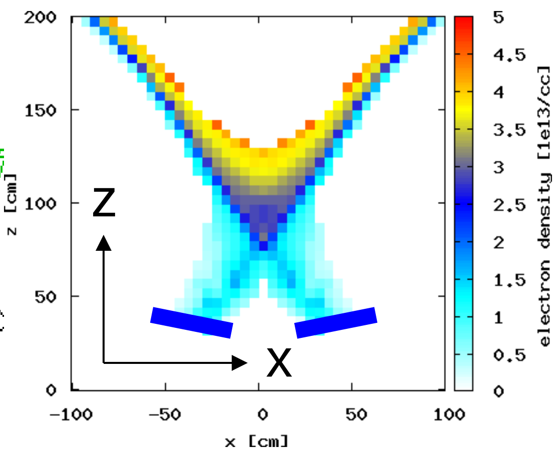
ERO simulation modeling

- Background plasma from EMC3-EIRENE
- How poloidal/toroidal plasma-distribution affects deposition/erosion of W.





simulation box of ERO



electron density [10^{19} /m^3]

W measurement in LHD

- A W-coated tile is installed.
- Other tiles are made of CFC.

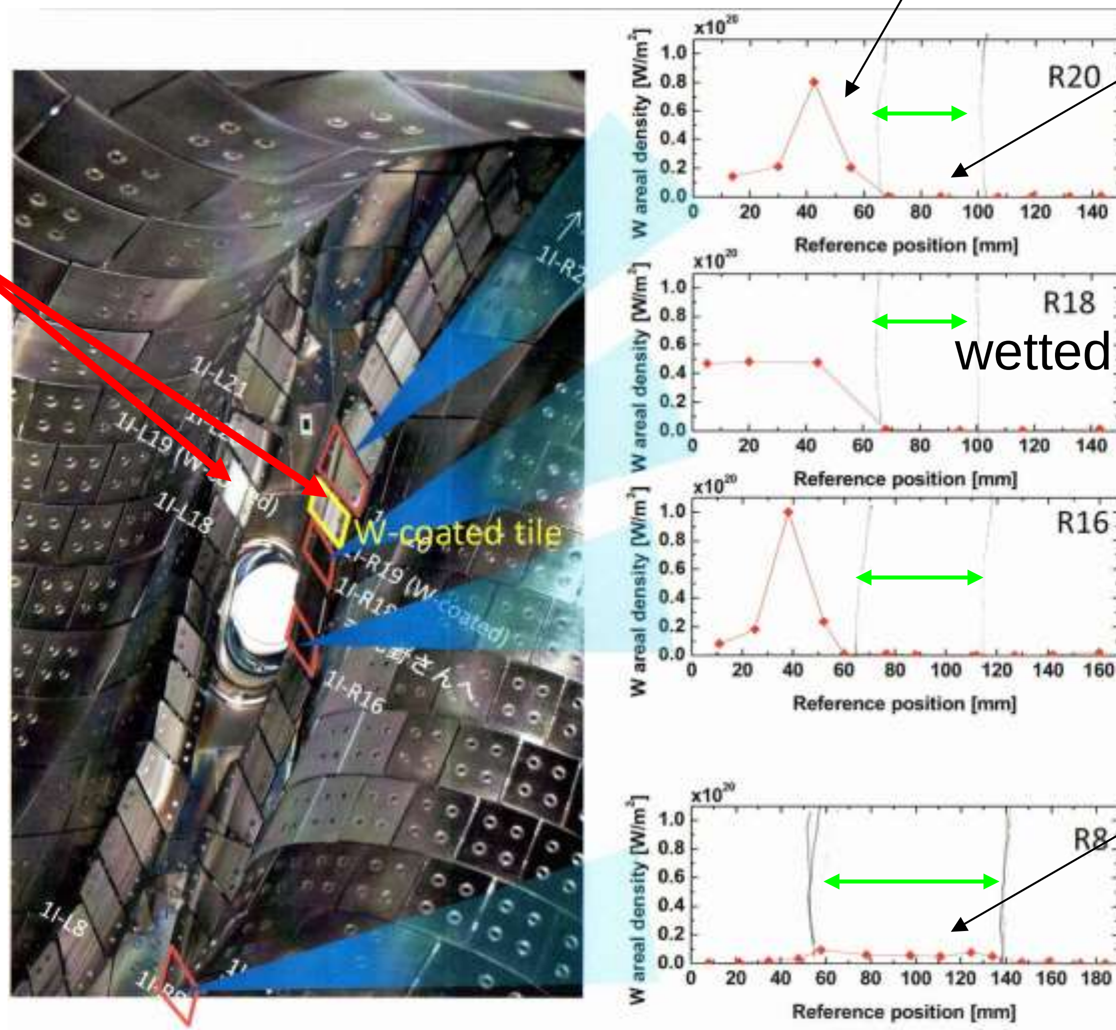
W-coated tiles

W-deposition only in the private side

erosion dominant

wetted area

wide deposition distribution



[M. Tokitani]

目次

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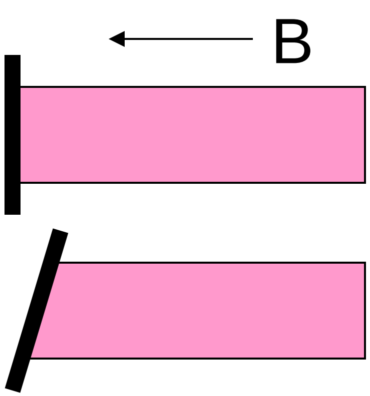
Simulation modeling of linear device

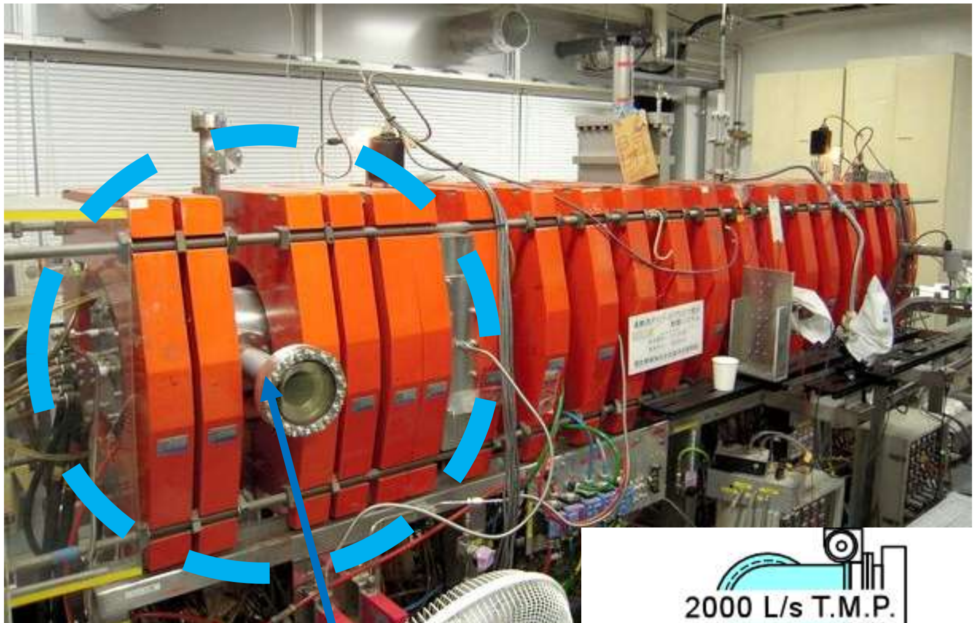
H. Tanaka, M. Kobayashi, G. Kawamura (NIFS)
N. Ohno, T. Kuwabara, M. Urakawa (Nagoya Univ.)
Y. Feng (Max-Planck IPP)

- Linear devices for divertor simulation and PWI
  - GAMMA10, NAGDIS-II, MAGNUM-PSI, PISCES-B, PILOT-PSI, PSI-2, JULE-PSI etc.
- Divertor-plasma codes have been developed for tokamak/helical devices.
  - 2D: B2-EIRENE (SOLPS), EDGE2D-NIMBUS, UEDGE-DEGAS2
  - 3D: EMC3-EIRENE
- Simulation of linear device has been reported but relatively new and challenging issue.
  - B2-EIRENE
  - Cylindrical plasma and device
- Advantage of EMC3-EIRNE code
  - 3D geometry of plasma and walls can be simulated.
  - Realistic geometry without cylindrical assumption.



NAGDIS-II in Nagoya University

- Linear Device for PSI and detachment

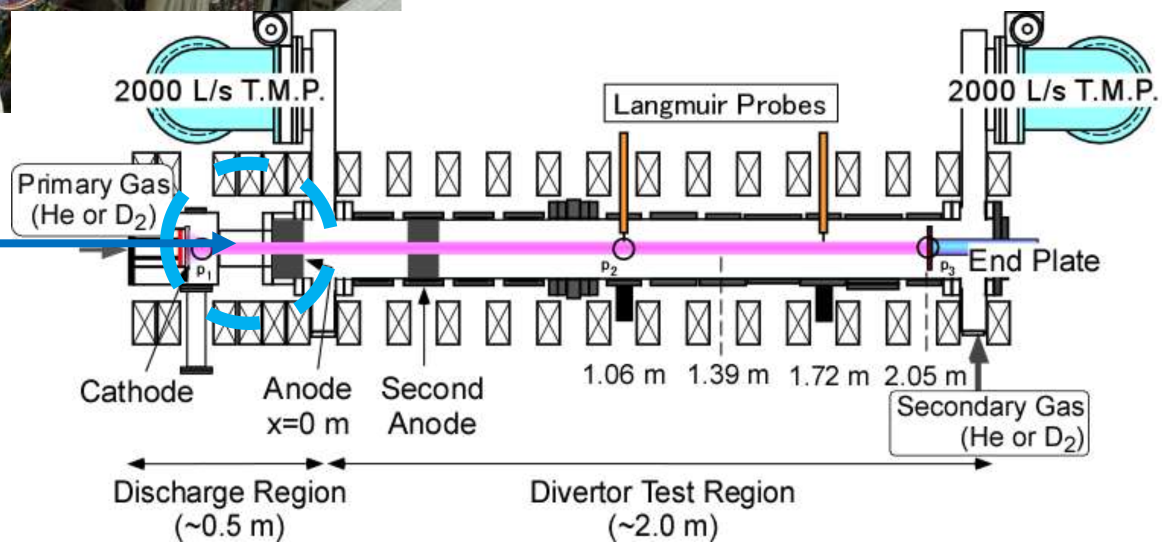


uniform magnetic field
(< 0.25 T)
steady state DC discharge
(hours)

plasma parameter

n_e<10^{20}m^{-3}, T_e<10eV

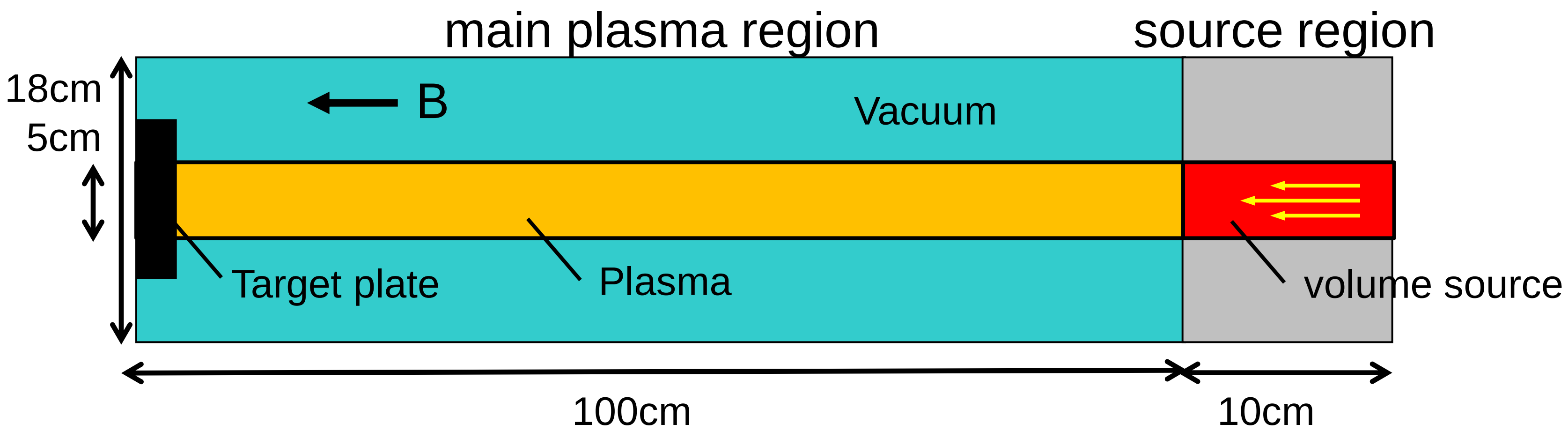
plasma
source

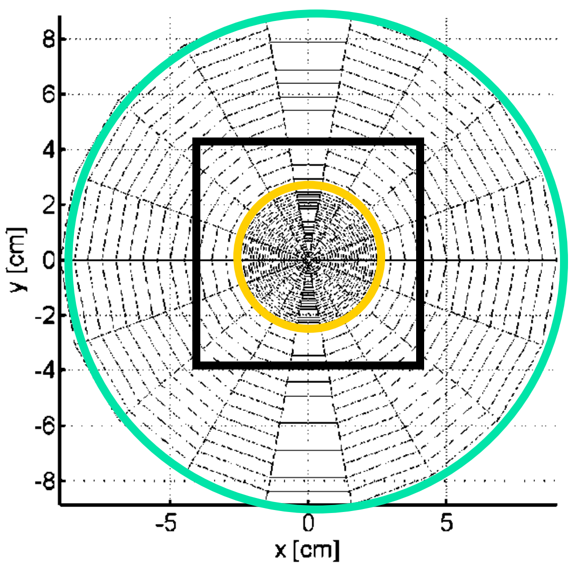


N. Ohno, *et al*., Nucl. Fusion **41** (2001) 1055.

Modeling of linear plasma

- Development is in progress.





- Cylindrical mesh system.
- Wall and target plates with 3D shape
  - V-shaped target in future
- Detachment studies
  - NAGDIS-II
- PWI studies
  - NAGDIS-II, GAMMA10

Summary of the recent progress

- EMC3-EIRENE code and calculation mesh have been extended to LHD with the closed divertor configuration.
- A validation by neutral gas pressure
  - Influence of dome structure in closed configuration was analyzed.
  - The scaling of neutral pressure to n_e(LCFS) is in good agreement.
- Impurity screening effect in the open/closed configuration.
  - Screening effect due to the flow is recovered in the ergodic region.
  - Increase of impurity generation in the closed configuration.
- Application to ERO simulation
- Modeling of a linear device

Future plans

- Neutral particles
  - Pumping under the dome, wall pumping, gas-puffing
  - Penetration to the core (TASK3D)
- Impurities
  - Divertor configuration
  - Transport related to screening
- PWI
  - Local simulation at LHD W tile (ERO)
  - Global erosion estimation
- Measurements
  - Transport coefficient modeling from Thomson scattering
  - 2D imaging of impurity radiation
- Detachment
  - LHD (impurity seeding, RMP)
  - NAGDIS-II (1D)