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Simulating impurity transport during Edge Localized Modes with JOREK

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MHD stability in tokamaks

One of the challenges in controlled tokamak fusion is formed by Edge Localized Modes (ELMs). These are ballooning mode instabilities, caused by the large pressure gradient in the pedestal in the H-mode. They deposit a huge amount of energy into the divertor in a very short time. The extrapolation of the behaviour of these ELMs to ITER is difficult, and key to sustained operation. The Aster project was set up to simulate these, and in 2007 non-linear ELM simulations were first performed with the JOREK code [1, 2]. An example of an ELM simulation is shown in figure 1.

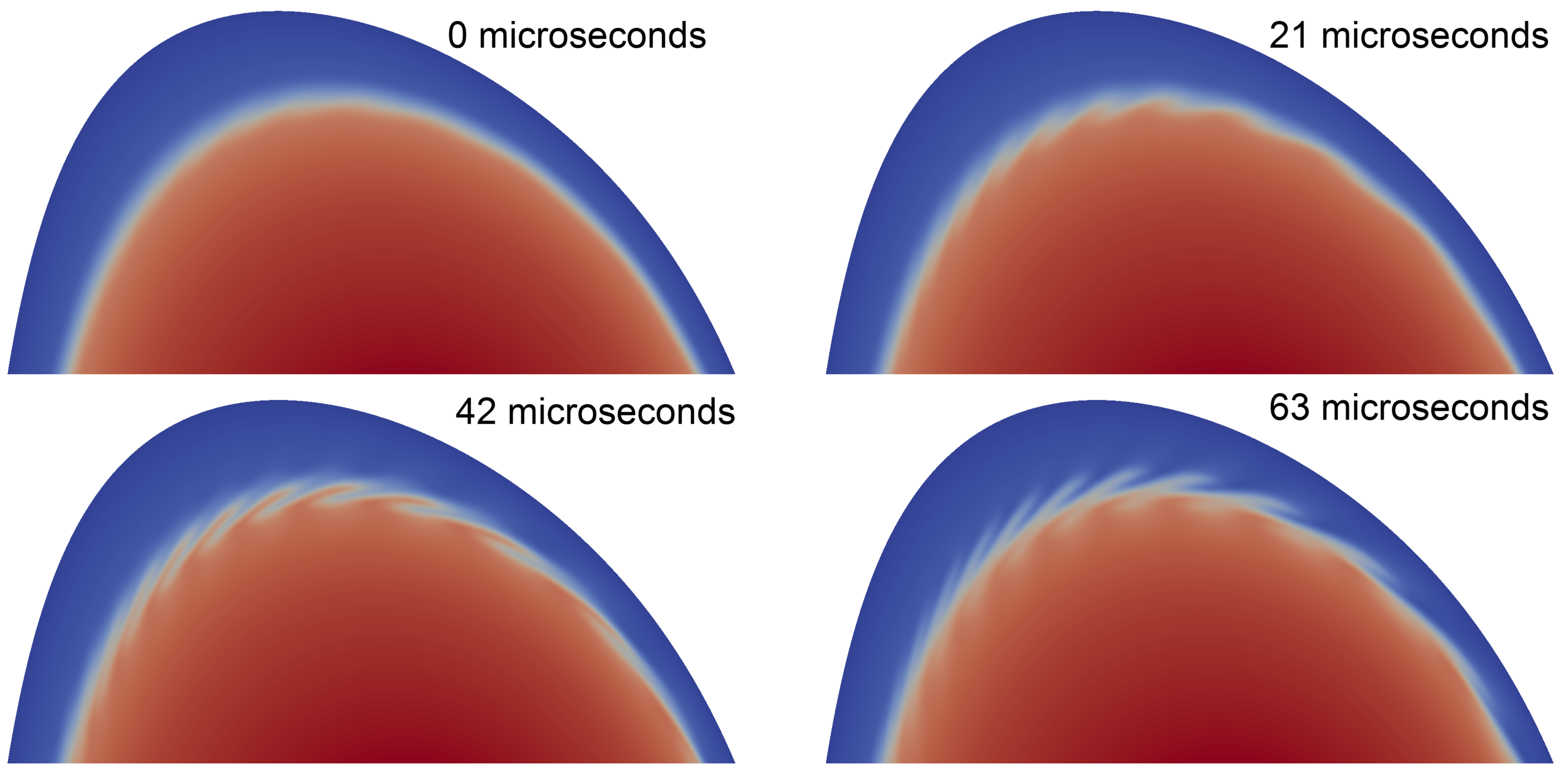
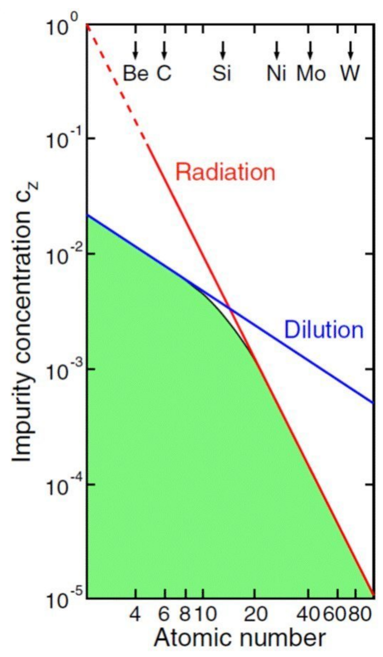


Figure 1: Density perturbations during an ELM.

Tungsten impurities in tokamaks

ITER will have a Tungsten divertor. This material can cause problems if it enters the plasma due to the high atomic number. In general, impurities present problems due to radiation and dilution. In the figure on the right the maximum allowable concentration of different impurities is shown due to these effects. (Figure from Karl Krieger, IPP) Since these atoms will not be fully ionized, they can emit line radiation and efficiently cool the plasma.



The JOREK code

The non-linear MHD code JOREK resolves realistic toroidal X-point geometries with a C1-continuous flux-surface aligned grid including main plasma, scrape-off layer and divertor region. Space is discretized with cubic Bezier finite elements in the poloidal plane, and with a fourier series in the toroidal direction. The timestepping is fully implicit (Crank-Nicholson by default) and the element matrix is solved with PaStiX and GMRES. The code is parallelized using MPI and OPENMP and typically runs on 256–1024 processors. Full as well as reduced MHD models are available.

Simulating impurity transport

By combining a Particle-In-Cell method with JOREK we can simulate impurities. In figure 2 the different stages in the proposed hybrid code are shown. Collisions are particle-background collisions: ionisation and recombination, and particle-wall collisions: recycling. Sputtering (background-wall) is implemented as a particle source.

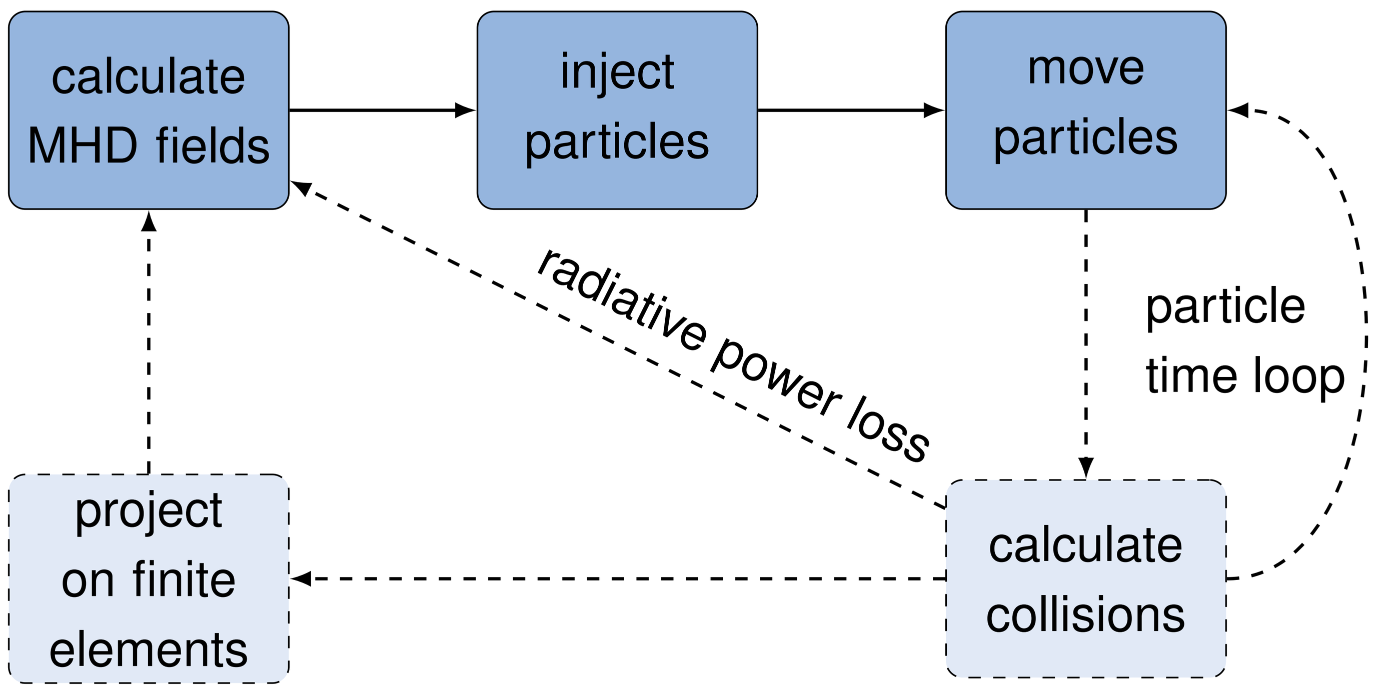


Figure 2: Diagram of the steps required to integrate MHD and PIC methods. Dotted lines are not implemented yet in JOREK.

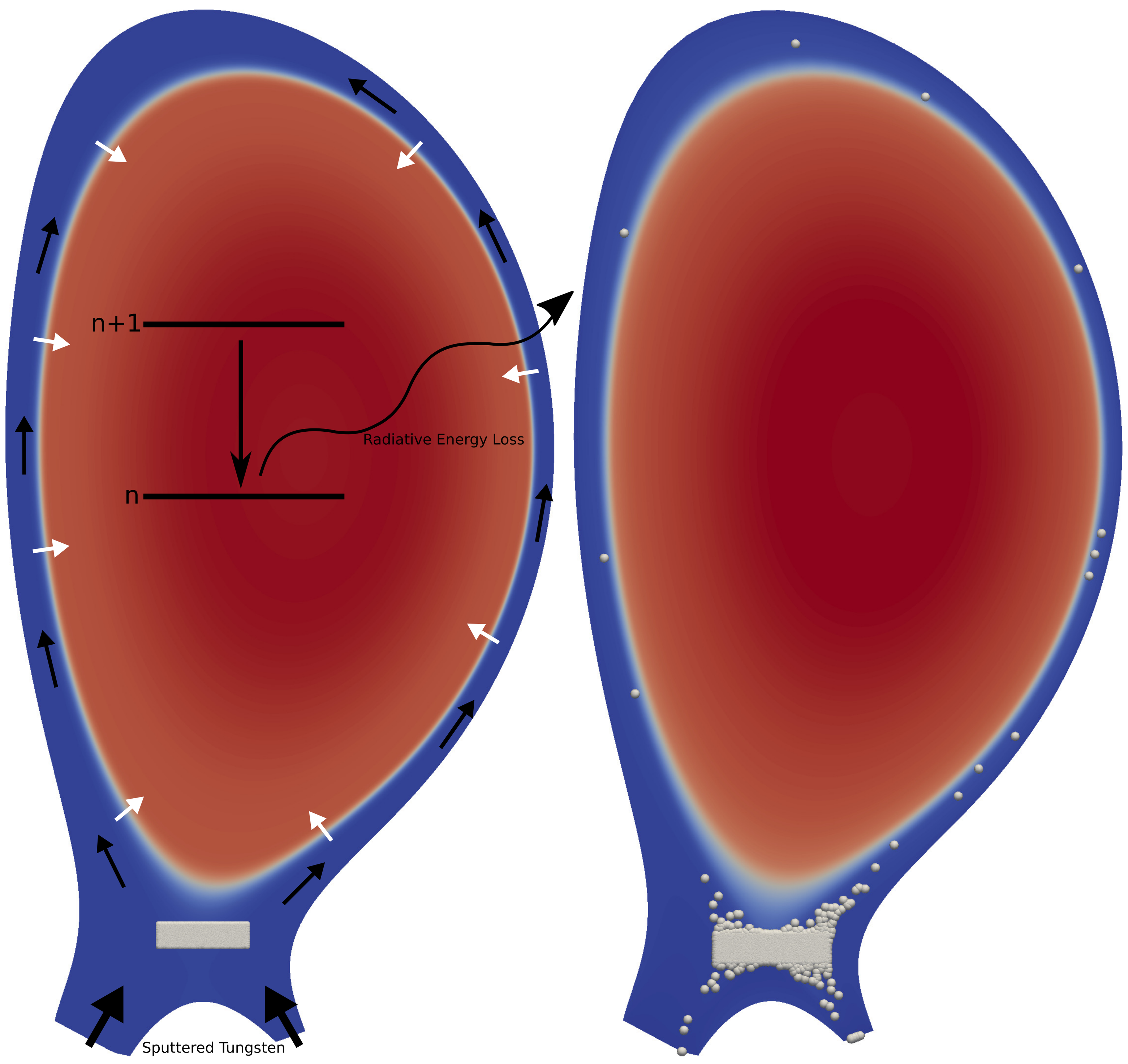


Figure 3: Tungsten impurities enter the plasma at the divertor, move along the flux surfaces (black) and diffuse into the core (white).

References

[1] G.T.A. Huysmans and O. Czarny. MHD stability in X-point geometry: simulation of ELMs. *Nuclear Fusion*, 47(7):659–666, 2007.

[2] G.T.A. Huysmans, S. Pamela, E. van der Plas, and P. Ramet. Non-linear MHD simulations of edge localized modes (ELMs). *Plasma Physics and Controlled Fusion*, 51(12):124012, dec 2009.

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