Towards non-linear simulations of full ELM crashes in ASDEX Upgrade

Alexander Lessig[1], Matthias Hölzl[1], Karl Lackner[1], Sibylle Günter[1]

[1]Max Planck Institute for Plasma Physics, Boltzmannstr. 2, 85748 Garching

Abstract

Edge localized modes (ELMs) are a severe concern for the operation of ITER due to large transient heat loads on divertor targets and wall structures. Using the non-linear MHD code JOREK, we present first simulations of full ELM crashes in ASDEX Upgrade, taking into account a large number of toroidal Fourier harmonics. The evolution of the toroidal Fourier spectrum and the drop of pedestal gradients are studied. In particular, we confirm a previously introduced quadratic mode coupling model [1, 2] responsible for the excitation of low toroidal mode numbers and present first results concerning the evolution in the fully non-linear phase.

Eventually, we aim to identify different ELM types in our simulations as observed in experiments [3] and to compare the results to experimental observations, e.g., regarding the pedestal evolution and the heat deposition patterns. Work is ongoing to increase poloidal resolution and include diamagnetic drifts which act stabilizing on high mode numbers.

Edge-localized modes

- driven by large pressure gradients and current densities
- relaxation-like oscillatory instability at the boundary of H-mode plasmas (pedestal collapse)
- eject particles and energy on very short time-scales
- **advantageous:** control of impurity and particle density
- **negative:** high heat loads on plasma-facing components

Model: Reduced resistive MHD

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) = \nabla\cdot(D_\perp\nabla_\perp\rho) + S_\rho$$

$$\mathbf{e}_\phi\cdot\nabla\times\left\{\rho\frac{\partial\mathbf{v}}{\partial t} = -\rho(\mathbf{v}\cdot\nabla)\mathbf{v} - \nabla p + \mathbf{j}\times\mathbf{B} + \mu\Delta\mathbf{v}\right\}$$

$$\mathbf{B}\cdot\left\{\rho\frac{\partial\mathbf{v}}{\partial t} = -\rho(\mathbf{v}\cdot\nabla)\mathbf{v} - \nabla p + \mathbf{j}\times\mathbf{B} + \mu\Delta\mathbf{v}\right\}$$

$$\frac{\partial\Psi}{\partial t} = R[\Psi,u] + \eta j - F_0\frac{\partial u}{\partial\phi}$$

$$\frac{\partial(\rho T)}{\partial t} = -\mathbf{v}\cdot\nabla(\rho T) - \gamma\rho T\nabla\cdot\mathbf{v} + \nabla\cdot\left(\kappa_\parallel\nabla_\parallel T + \kappa_\perp\nabla_\perp T\right) + S_T$$

$$[A,B] = \mathbf{e}_\phi\cdot(\nabla A\times\nabla B)$$

$$\mathbf{v} = v_\parallel\mathbf{B} - R\nabla u\times\mathbf{e}_\phi$$

$$\mathbf{B} = \frac{F_0}{R}\mathbf{e}_\phi + \frac{1}{R}\nabla\Psi\times\mathbf{e}_\phi$$

$$W = \frac{1}{R}\mathbf{e}_\phi\cdot(\nabla\times\mathbf{v}_\perp) = \nabla_\perp^2 u$$

$$j = -R\mathbf{e}_\phi\cdot\mathbf{j} = \Delta^*\Psi$$

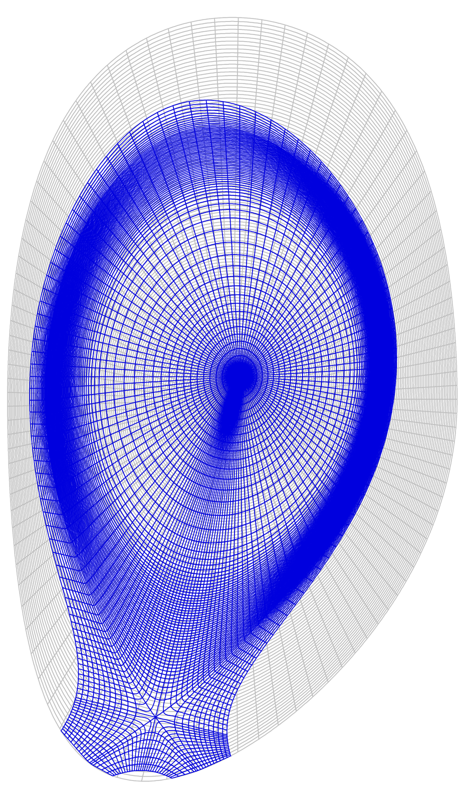
$$p = \rho T$$

Simulations

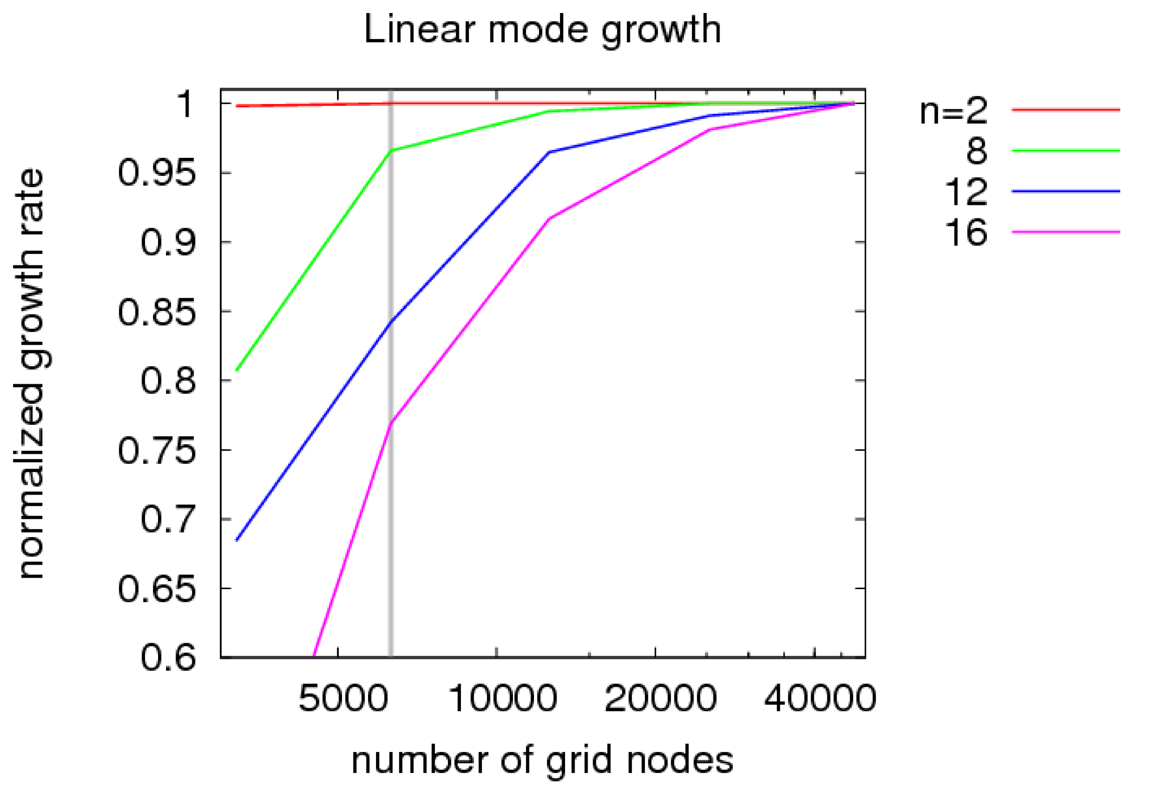
- based on ASDEX Upgrade discharge #29342@4.25s
- input profiles for T, ρ, FF' as well as $\Psi|_{\text{bnd}}$ from CLISTE equilibrium reconstruction [4]
- large number of toroidal harmonics ($n = 0, 1, \ldots, 22$)
- particle & heat diffusivities/sources such that background profiles of density and temp. do not change with time
- resistivity 10 times real. value (computational limitations)
- ideal wall and Bohm boundary conditions
- more than 100 compute nodes on HELIOS (Japan)

JOREK

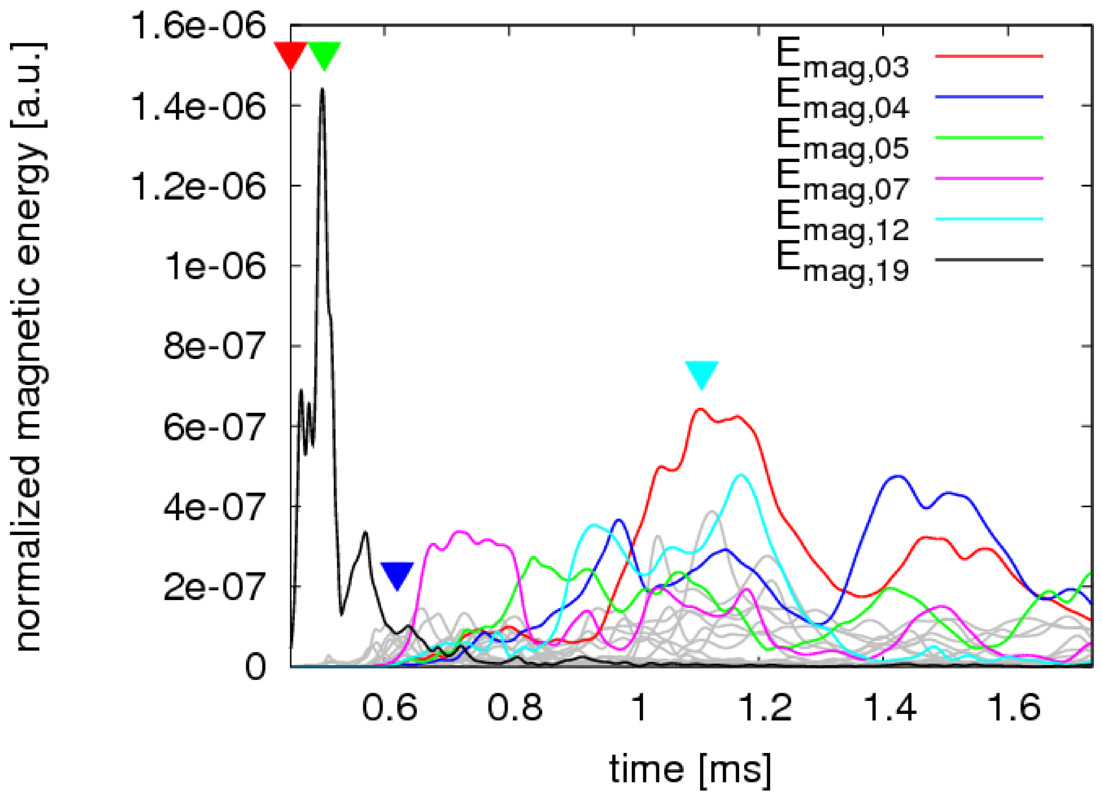
- originally developed by G.T.A. Huysmans [5, 6]
- models for reduced (used here) and full MHD equations
- full toroidal X-point geometry including seperatrix and open field lines
- 2D isoparametric Bezier finite elements in poloidal plane
- pseudo-spectral discretization in toroidal direction
- Grad-Shafranov equation solved on initial grid using input-profiles for T, ρ, FF' as well as $\Psi|_{\text{bnd}}$ → construction of flux surface aligned grid
- fully implicit time stepping → large sparse matrix solved by generalized minimal residual (GMRES) method
- physics-based preconditioner neglects coupling between toroidal modes → submatrix for each harmonic solved separately using direct solver PaStiX
- OpenMP/MPI hybrid parallelization

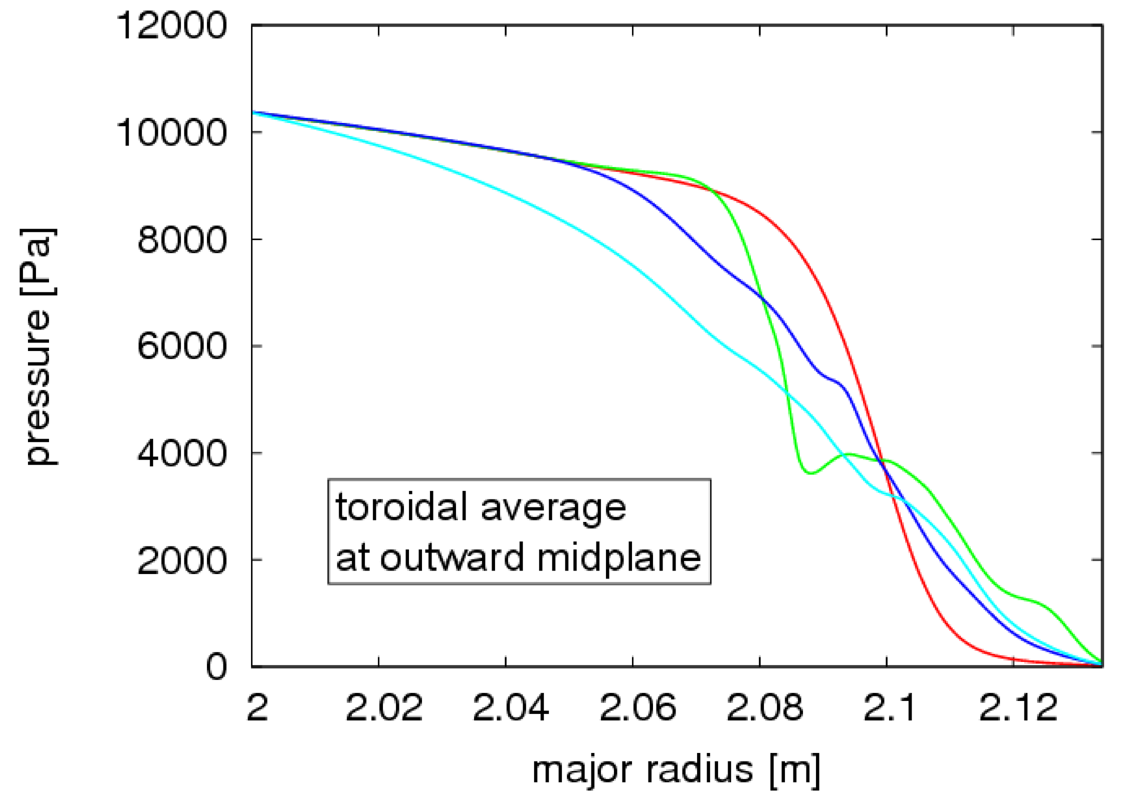


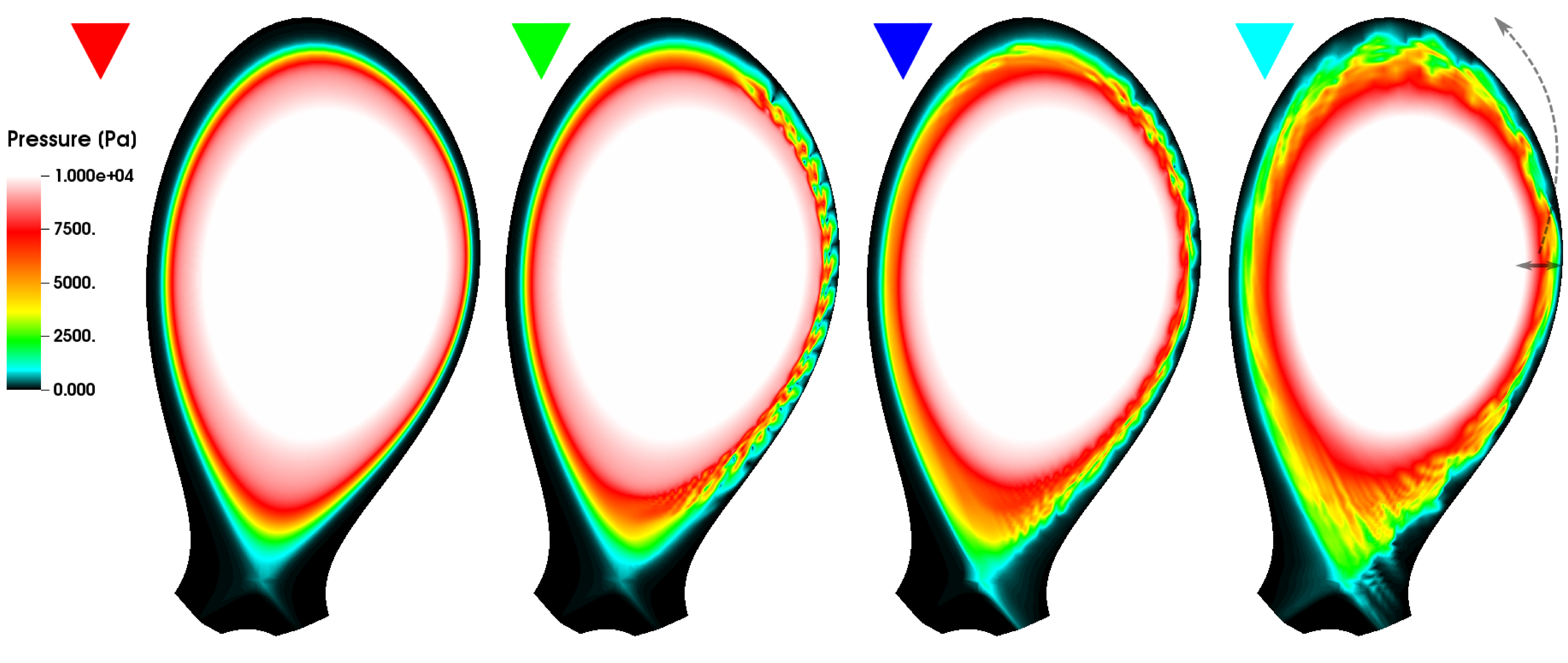
Resolution Scan



Full ELM crash

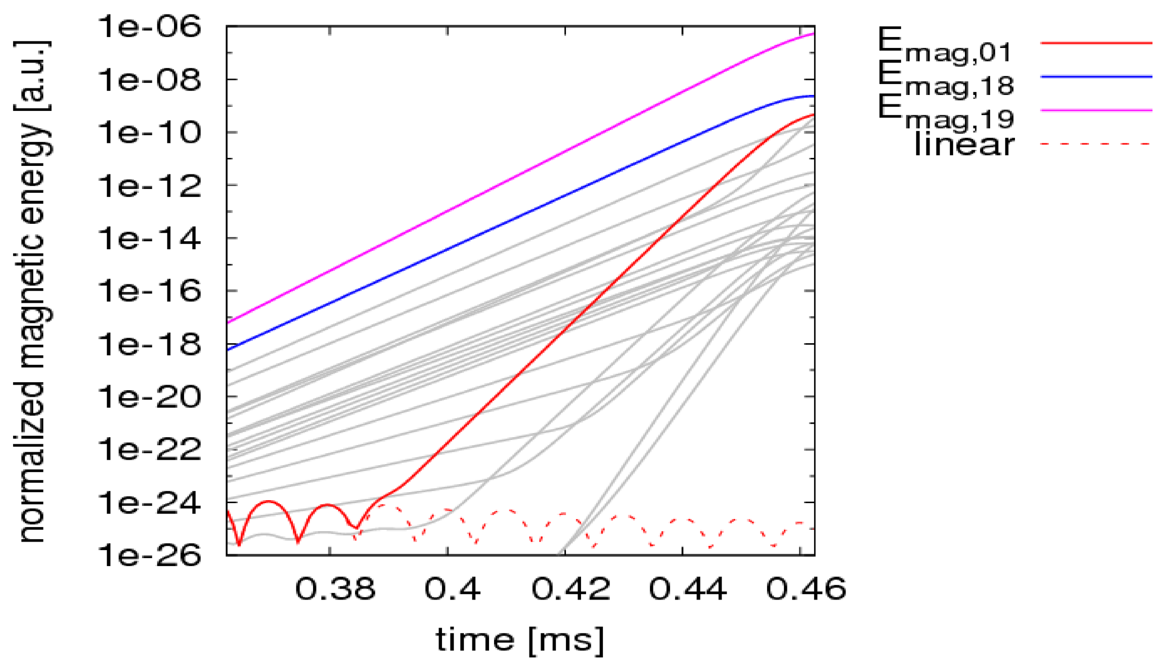






- transition from high toroidal mode numbers at onset of ELM to low-n components in agreement with experimental findings [7, 8]
- pedestal collapse qualitatively reproduces experimental observations [9]

Mode coupling



Evolution of magnetic energies; quadratic mode coupling of modes n and m drive $|n \pm m|$ harmonics [2]

Summary

- realistic simulation of high-n components requires high grid resolution → computational limits
- first non-linear simulation of full ELM crash in ASDEX Upgrade
- evolution of toroidal Fourier spectrum and pedestal in qualitative agreement with experimental observations
- quadratic mode coupling responsible for transition from high-n to low-n components

References

This project has received funding from the Euratom research and training programme 2014-2018.

[1] **M. Hölzl, et al.** *Phys Plasmas*, 19, 082505 (2012).
[2] **I. Krebs, et al.** *Phys Plasmas*, 20, 082506 (2013).
[3] **H. Zohm**. *Plasma Phys Control Fusion*, 38, 105 (1996).
[4] **M. Dunne**. private communication (2014).
[5] **G. Huysmans et al.** *Nucl Fusion*, 47, 659 (2007).
[6] **O. Czarny et al.** *J Comput Phys*, 227, 7423 (2008).
[7] **J. Boom, et al.** *Nucl Fusion*, 51, 103039 (2011).
[8] **R. Wenninger, et al.** *Nucl Fusion*, 53, 113004 (2013).
[9] **P. Schneider, et al.** *Plasma Phys Control Fusion*, 56, 025011 (2014).