# NON-LINEAR SIMULATIONS OF ELMS IN ASDEX UPGRADE INCLUDING DIAMAGNETIC DRIFT EFFECTS

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## ABSTRACT

Large edge localized modes (ELMs) are a severe concern for ITER due to high transient heat loads on divertor targets and wall structures. It is therefore important to study ELMs both theoretically and experimentally in order to reveal their fundamental properties which is necessary for the prediction of ELMs and the design of ELM mitigation systems in ITER and DEMO.

Using the non-linear MHD code JOREK [1, 2], we have performed first ELM simulations for ASDEX Upgrade (AUG) including diamagnetic drift effects. We compare the results to a previous simulation of a full ELM crash in AUG without diamagnetic drift effects and investigate the influence of the diamagnetic terms onto the evolution of the toroidal mode spectrum. In particular, we confirm the diamagnetic stabilization of high mode numbers and the key role of diamagnetic drift effects for multi-ELM simulations. On the long term 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 include a consistent bootstrap current [4] as well as toroidal and neoclassical poloidal rotation in our simulations.

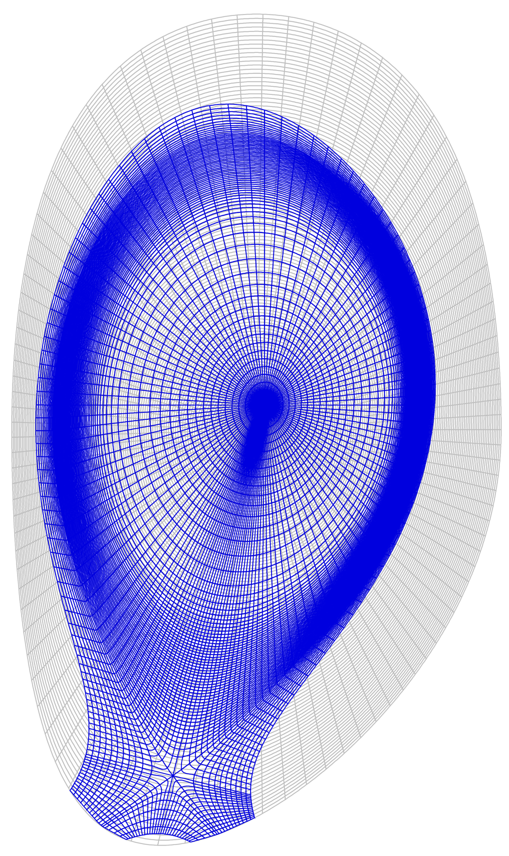
## EDGE-LOCALIZED MODES

- relaxation-like oscillatory instability at the boundary of H-mode plasmas (pedestal collapse)
- driven by large pressure gradients and current densities
- eject particles and energy on very short time-scales

- **advantageous:** control of impurity and particle density
- **negative:** high heat loads on plasma-facing components (in particular divertor targets)

## JOREK

- originally developed by G.T.A. Huysmans [1, 2]
- models for reduced (used here) and full MHD equations including two-fluid effects
- 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 $T$, $\rho$, $FF'$ as well as $\Psi|_{\mathrm{bnd}}$ → construction of flux surface aligned grid
- ideal wall and Bohm boundary conditions
- 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



## REDUCED RESISTIVE MHD

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

$$\mathbf{e}_\phi \cdot \nabla \times R^2 \left\{ \rho\left(\partial_t + \mathbf{v}\cdot\nabla\right)\mathbf{v} = -\nabla p + \mathbf{j}\times\mathbf{B} + \mu\Delta\mathbf{v} \right\}$$

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

$$\partial_t p + \mathbf{v}\cdot\nabla p + \gamma p \nabla\cdot\mathbf{v} = \nabla\cdot\left(\kappa_\parallel \nabla_\parallel T + \kappa_\perp \nabla_\perp T\right) + S_T$$

$$\partial_t \Psi = R[\Psi, u] + \frac{\eta}{\mu_0}(j - j_0) - F_0 \partial_\phi u - \frac{R\tau_{\mathrm{IC}}}{\rho}[\Psi, p] + \tau_{\mathrm{IC}} F_0 \partial_\phi p$$

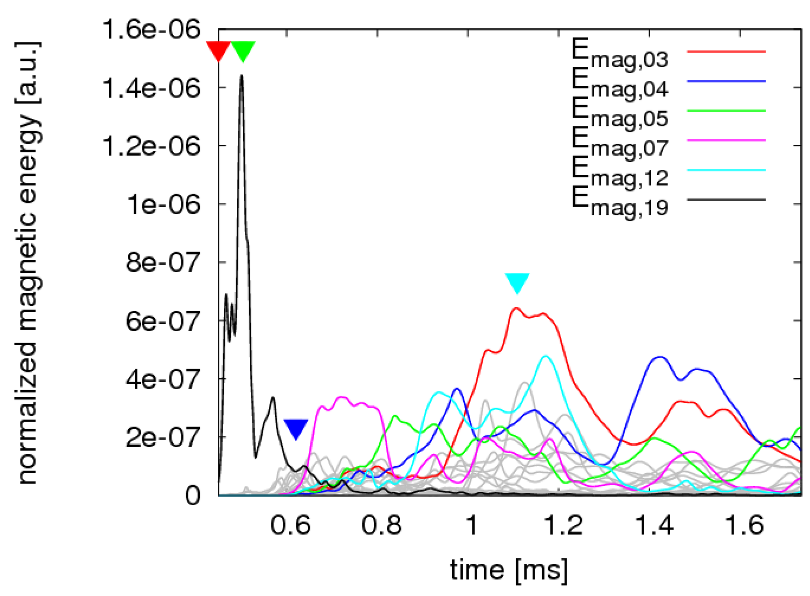
$$j = -R\mu_0 j_\phi = \Delta^* \Psi$$

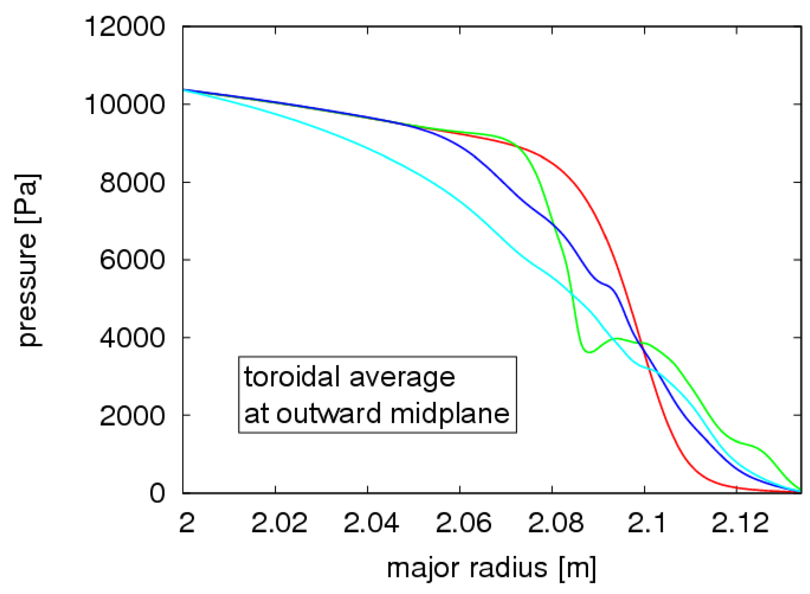
$$\mathbf{B} = \frac{F_0}{R}\mathbf{e}_\phi + \frac{1}{R}\nabla\Psi \times \mathbf{e}_\phi$$

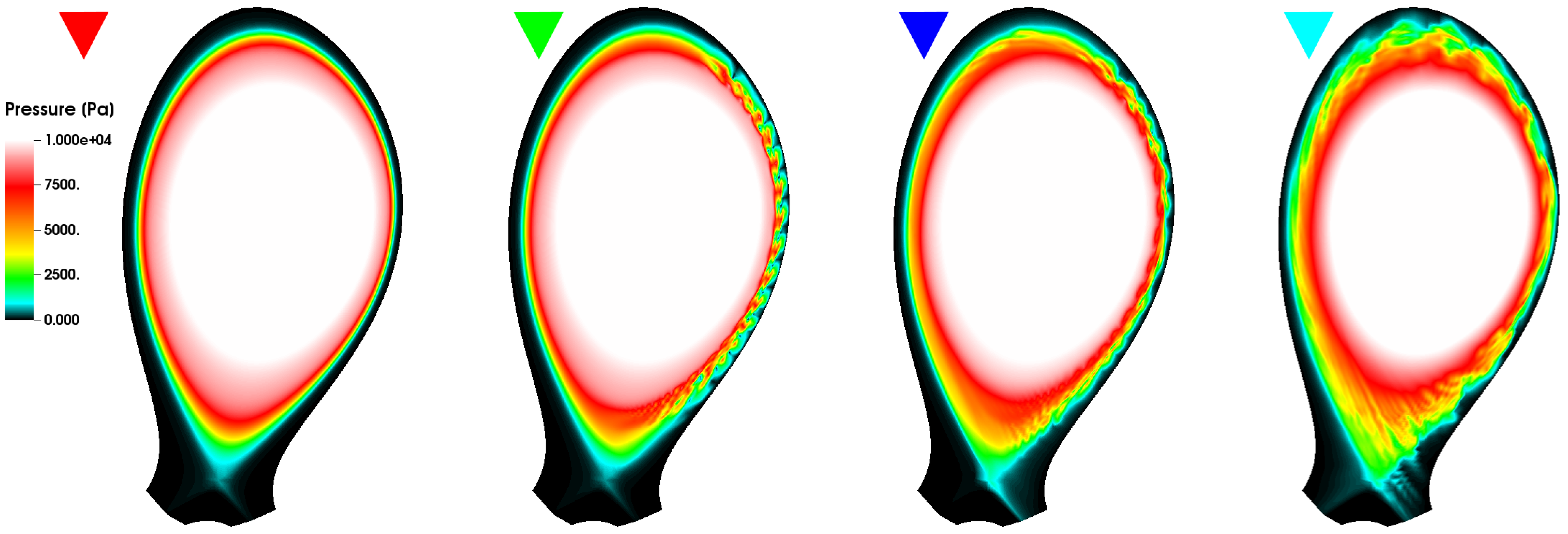
$$\mathbf{v} = -R\nabla u \times \mathbf{e}_\phi + v_\parallel \mathbf{B} - \frac{\tau_{\mathrm{IC}} R^2}{\rho}\nabla p \times \nabla\phi$$

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

## FULL ELM CRASH

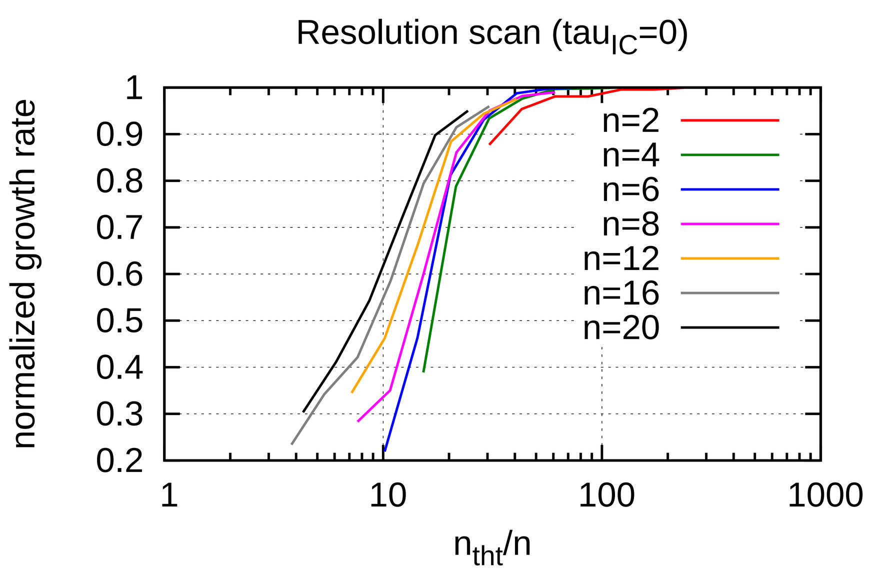


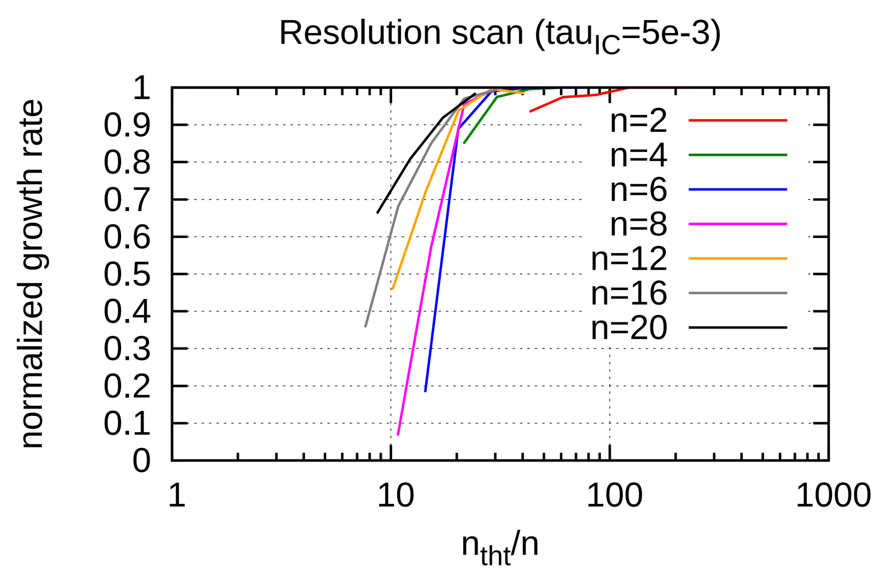



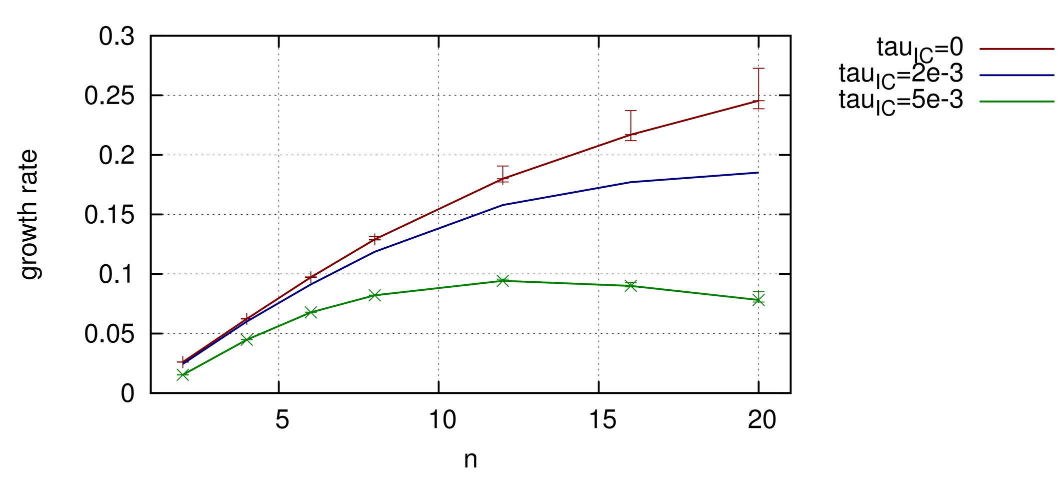



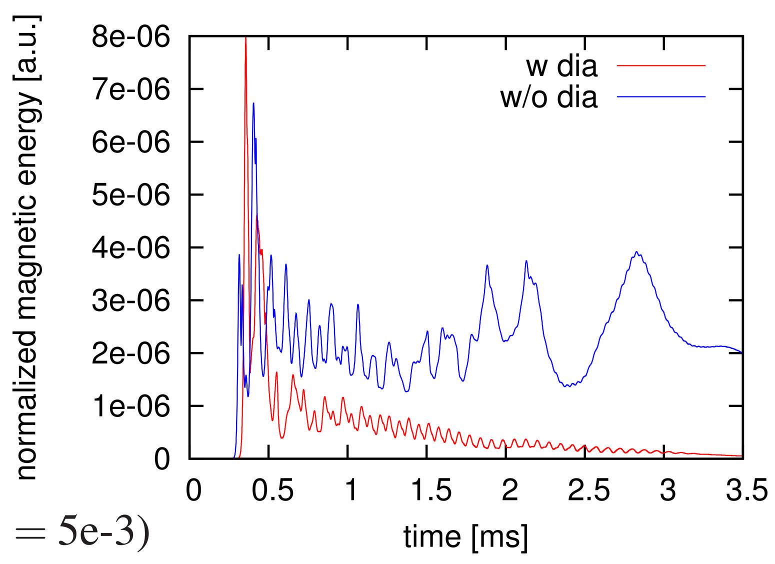

- based on AUG discharge #29342@4.25s **without** diamagnetic drift
- resistivity one order of magnitude larger than Spitzer value due to computational limits
- transition from high toroidal mode numbers at onset of ELM to low-n components in agreement with experimental findings [5, 6]
- pedestal collapse qualitatively reproduces experimental observations [7]
- strong magnetic activity after crash ('ballooning turbulence') instead of 2nd ELM
- equilibrium is stable when diamagnetic drift effects are included

## DIAMAGNETIC STABILIZATION




- based on AUG discharge #23221@4.25s **with** diamagnetic drift ($\tau_{\mathrm{IC}} = 5\mathrm{e}{-3}$)
- stabilization of high-n components through diamagnetic drift effects
- intermediate mode numbers linearly dominant as observed experimentally [3]
- diamagnetic drift suppresses ballooning turbulence as observed in simulation of ELM cycle in JET [8]

## SUMMARY

- evolution of toroidal Fourier spectrum and pedestal in qualitative agreement with experimental findings
- stabilization of high-n components through diamagnetic drift effects
- intermediate mode numbers linearly dominant as observed experimentally when diamagnetic drift included
- diamagnetic drift suppresses ballooning turbulence which is necessary for multi-ELM simulations

## REFERENCES

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