Toroidally and Poloidally Localized ELMs

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ASDEX Upgrade

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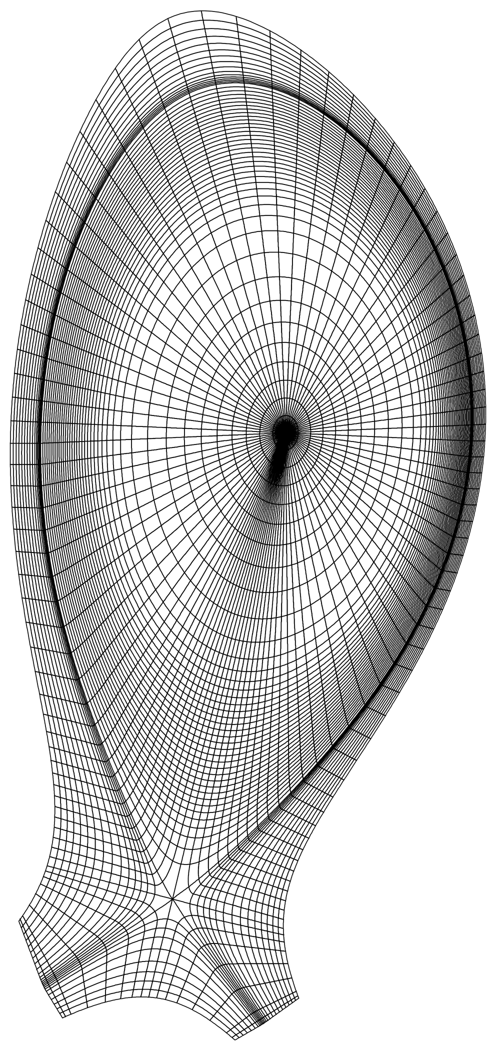
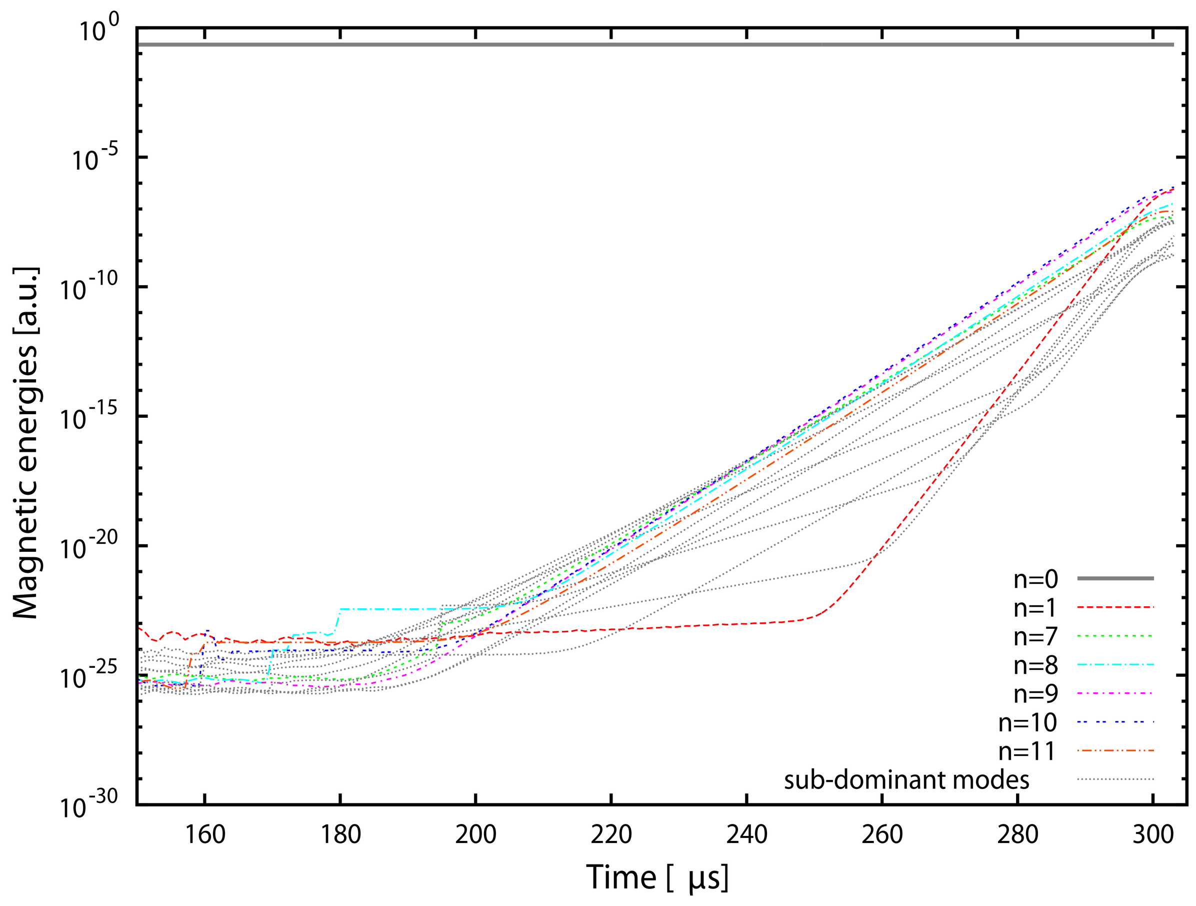
We use the non-linear reduced-MHD code JOREK [1] to study ELMs in the geometry of the ASDEX Upgrade tokamak. Toroidal mode numbers, poloidal filament sizes, and radial propagation speeds of filaments into the scrape-off layer are in good agreement with observations for type-I ELMs in ASDEX Upgrade. The observed instabilities exhibit a toroidal and poloidal localization of perturbations which is compatible with the solitary magnetic perturbations (SMPs) recently discovered in ASDEX Upgrade [2]. This localization can only be described in numerical simulations with many toroidal modes.

$$\frac{\partial \Psi}{\partial t} = \eta j - R[u,\Psi] - F_0 \frac{\partial u}{\partial \phi},$$
$$\frac{\partial \rho}{\partial t} = -\nabla\cdot(\rho \mathbf{v}) + \nabla\cdot(D_\perp \nabla_\perp \rho) + S_\rho,$$
$$\rho \frac{\partial T}{\partial t} = -\rho \mathbf{v}\cdot\nabla T - (\kappa - 1) p \nabla\cdot\mathbf{v} + \nabla\cdot\left(K_\perp \nabla_\perp T + K_{||}\nabla_{||} T\right) + S_T,$$
$$\mathbf{e}_\phi\cdot\nabla\times\left\{\rho \frac{\partial \mathbf{v}}{\partial u} t = -\rho(\mathbf{v}\cdot\nabla)\mathbf{v} - \nabla p + \mathbf{j}\times\mathbf{B} + \nu\Delta\mathbf{v}\right\},$$
$$\mathbf{B}\cdot\left\{\rho \frac{\partial \mathbf{v}}{\partial t} = -\rho(\mathbf{v}\cdot\nabla)\mathbf{v} - \nabla p + \mathbf{j}\times\mathbf{B} + \nu\Delta\mathbf{v}\right\}.$$

Simulation grid (~5500 2D-Bezier elements)

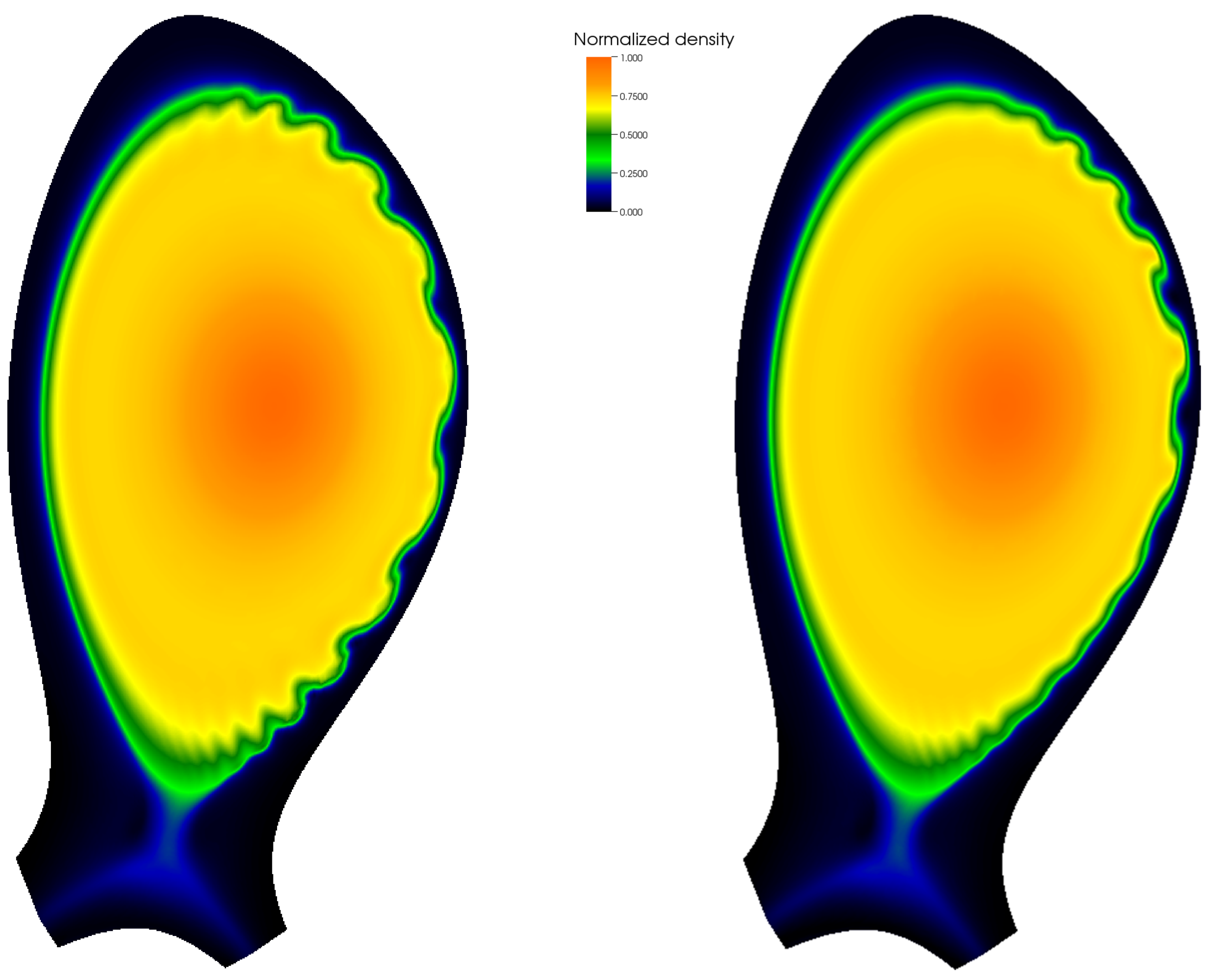
Periodicity 1: n=0, 1, 2, ..., 15, 16
Periodicity 2: n=0, 2, 4, ..., 14, 16
Periodicity 4: n=0, 4, 8, 12, 16
Periodicity 8: n=0, 8, 16





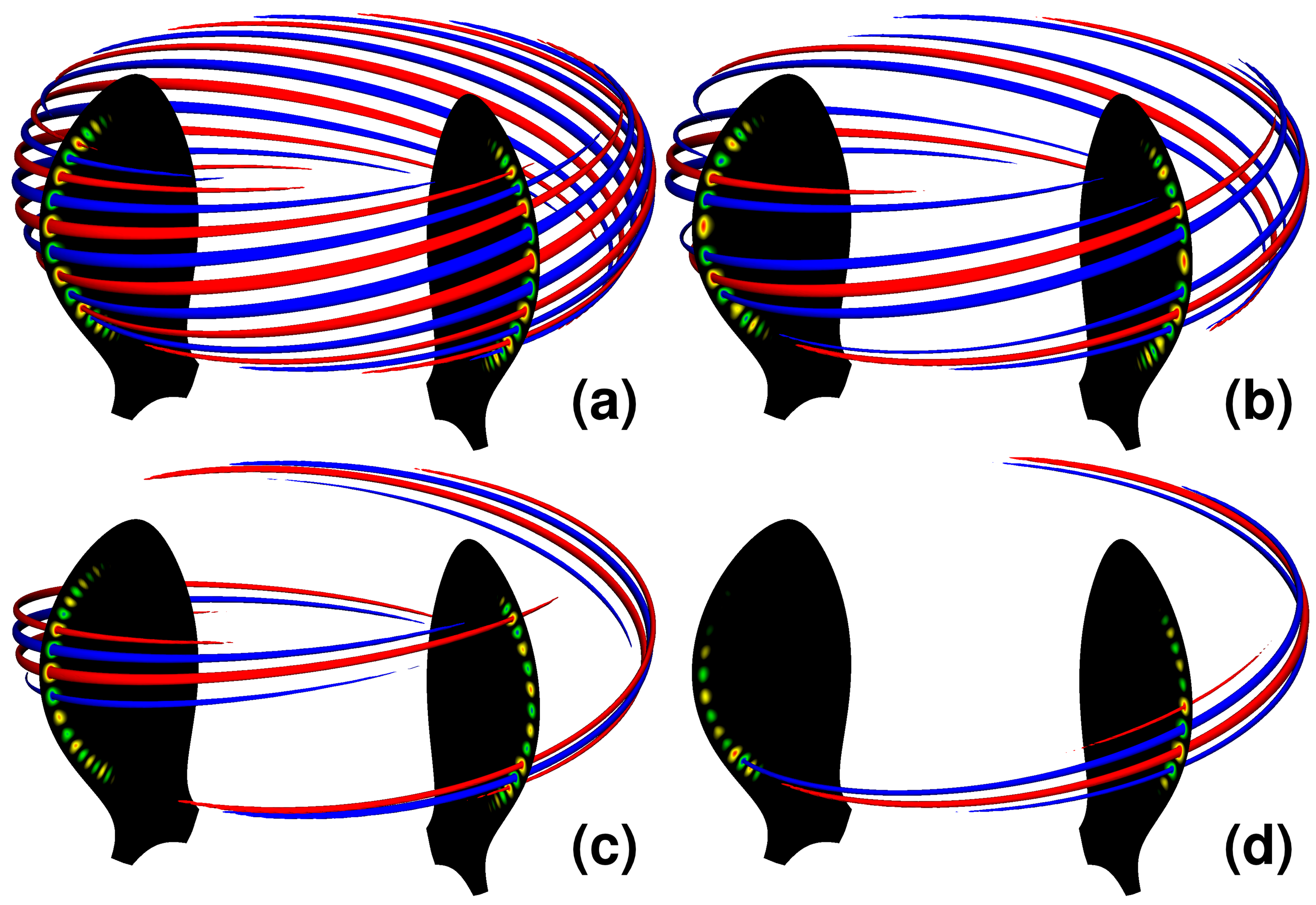
• n=10 is most unstable while low-n are driven non-linearly (periodicity 1 shown).
• No indication for “explosive ballooning”

Two modes with toroidal mode numbers n_1 and n_2 drive modes with $n_3=\pm n_1 \pm n_2$ non-linearly as soon as they are sufficiently strong



• Regular ballooning fingers develop at the low-field side (periodicity 8)

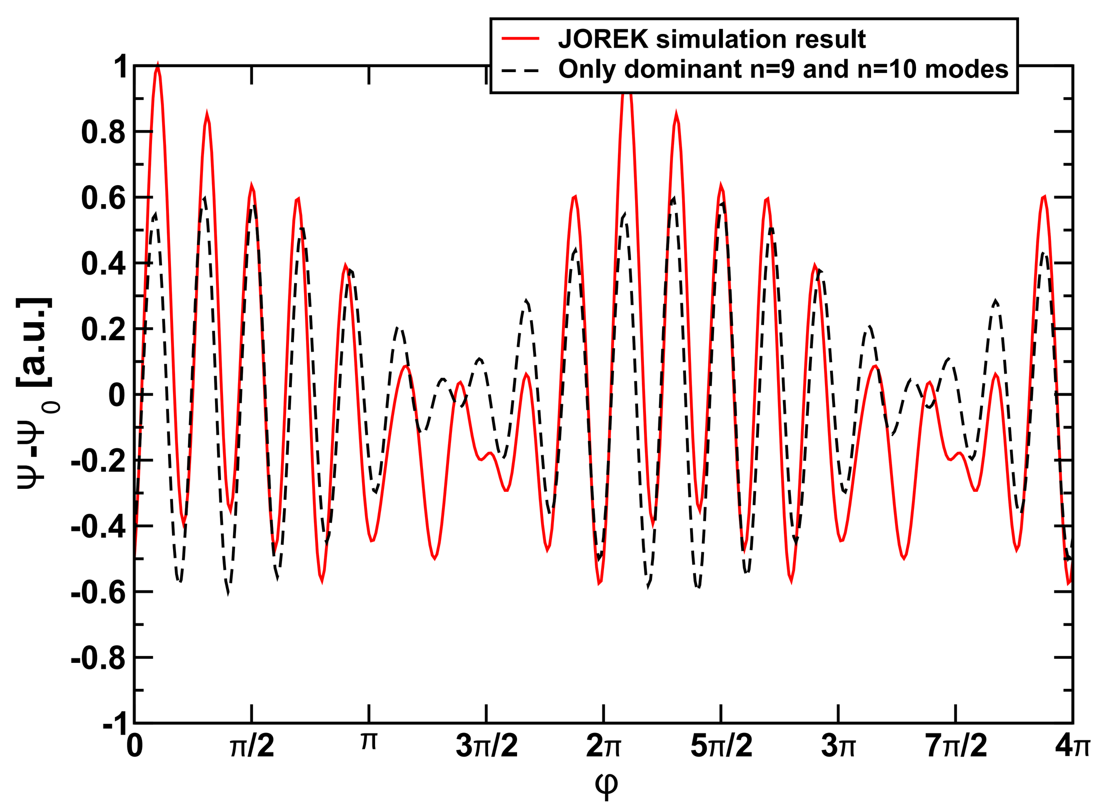
• Density filaments become localized due to mode-coupling (periodicity 1)



Poloidal flux perturbations get localized for low periodicities (8, 4, 2, and 1 are shown).
The localization is similar to Solitary Magnetic Perturbations recently observed at ASDEX Upgrade [2].

Some comparison to experiment:
• n~10-13 dominant
(Exp: ~8-24 [3], ~15 [4], ~18 [5])
• Poloidal filament width ~10-12 cm
(Exp: 5-10 cm [4])
• Radial filament velocity up to 3 km/s
(Exp: average 1km/s, maximum ~3km/s [6,7])
• Non-linear growth of low-n might explain strong interaction with core-modes

Mechanism of localization:
• Interference: The interaction of two modes with similar amplitudes and Δn=1 is already sufficient to produce some localization
• Interference of more modes increases the localization



Poloidal Flux Ψ along the toroidal direction at (R,Z)=(2.10, 0.11)m

Summary
• Dominant mode-numbers, filament size and velocity are similar to experiment
• Low-n modes non-linearly important
• Strong localization observed in simulations with periodicity 1
• Similar to Solitary Magnetic Perturbations in ASDEX Upgrade

Part of this work is presented in more detail in an article submitted to Physics of Plasmas (preprint at http://arxiv.org/abs/1201.5765)

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