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Effect of energetic ions on edge-localized modes in tokamak plasmas

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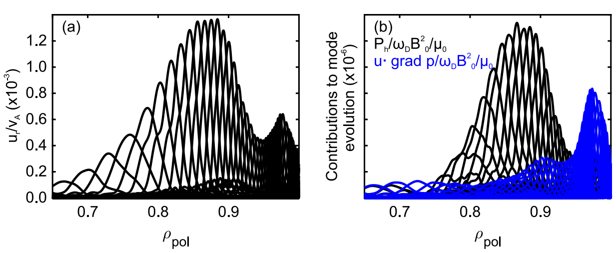
CONTENTS

SUPPLEMENTARY NOTE 1. ORIGIN OF RADIAL BROADENING OF ELMS IN HYBRID SIMULATIONS

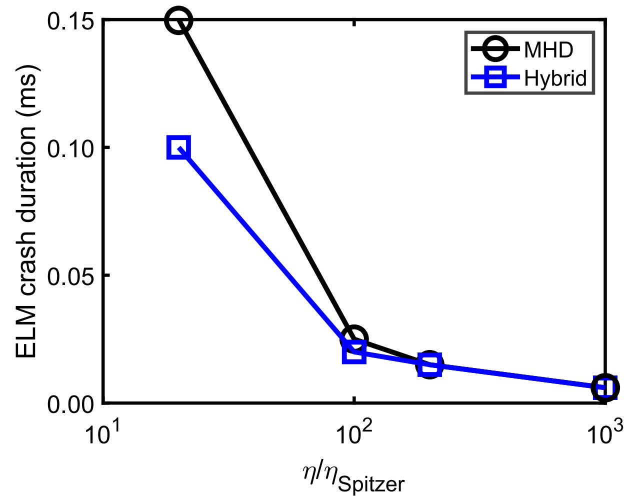
To identify the origin of the ELM radial broadening in the presented multi-n hybrid simulation, the fast-ion and bulk plasma pressure gradient drives to the $n = 8$ ELM perturbation, have been analyzed separately as a function of the plasma radial coordinate and compared with the radial structure of the mode. Fig. 1 shows the mode radial structure (a), and (b) the contribution to the mode drive by the fast-ions (black) and bulk plasma pressure gradient (blue). As can be seen, the drive for the ELM broadening is dominated by the fast-ions. While in the presented simulations, no fast-ion driven Alfvén Eigenmode (AE) [1] or Energetic Particle Mode (EPM) [2] is observed, our results indicate that, in other simulation setup, or experiments, in the presence of fast-ions, a strong coupling between fast-ion driven AEs and or EPMs with radially extended (due to fast-ions) ELMs could happen. This will be the subject of a future work.



Supplementary Fig. 1. **Physics of mode radial broadening**. Amplitude of $n = 8$ normalized radial velocity u_r/v_A (a), contribution of the power exchange (P_h) between $n = 8$ and energetic particles (black, b) and of the thermal plasma pressure gradient ($\mathbf{u} \cdot \nabla p$, dot product between plasma velocity and thermal plasma pressure gradient) to $n = 8$ mode (blue, b) at $t = 0.16$ ms. ρ_pol is the radial coordinate, v_A is the Alfvén speed at the magnetic axis, ω_D is the deuterium gyro-frequency at the magnetic axis, B_0 is the magnetic field at the magnetic axis and μ_0 is the vacuum magnetic permeability.

SUPPLEMENTARY NOTE 2. IMPACT OF RESISTIVITY ON ELM CRASH DURATION

In MHD simulations, the selected resistivity determines the required spatio-temporal resolution, and thus, the computational resources, through resistive skin depth effects [3, 4]. Consequently, the selected resistivity has, indeed, an impact on the spatio-temporal structures that are allowed to evolve. In the presented simulations, this is reflected in the ELM crash duration as previous work reports [5]. The same tendency is observed for the pure MHD, and hybrid single-n simulations analyzed in this manuscript as Fig. 2 of this section shows.



Supplementary Fig. 2. **Resistivity effects on ELM crash duration**. ELM crash duration as a function of resistivity in the MHD (black) and hybrid (blue) single-n ($n = 0, 10$) simulation.

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