Inter-ELM pedestal fluctuations and their parametric (in-)dependencies

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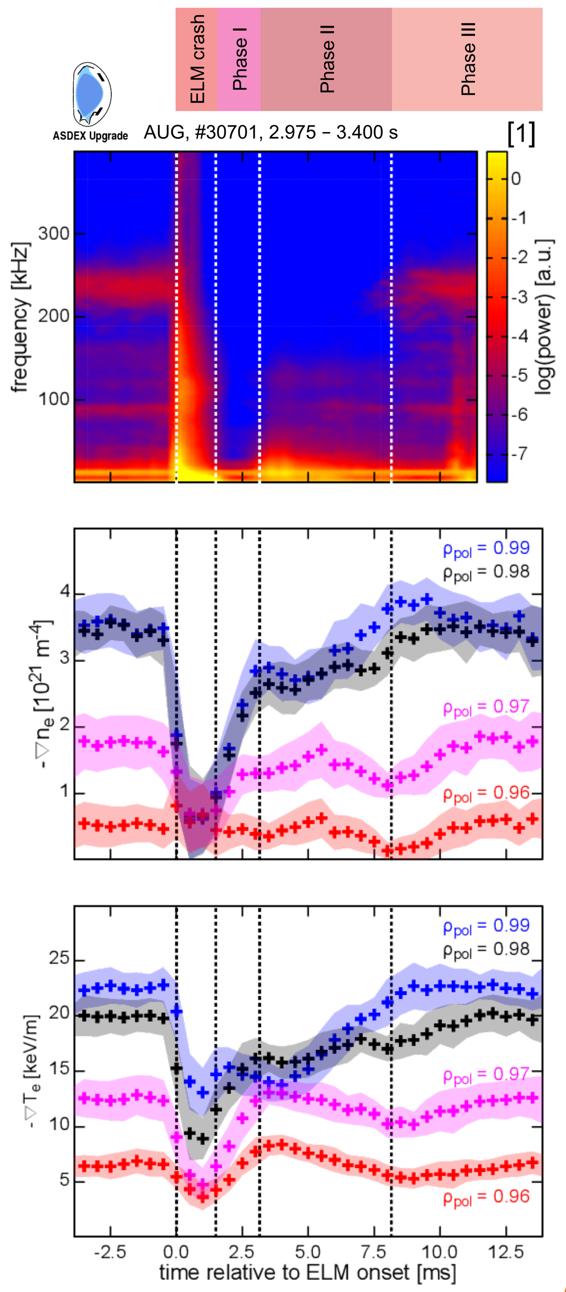
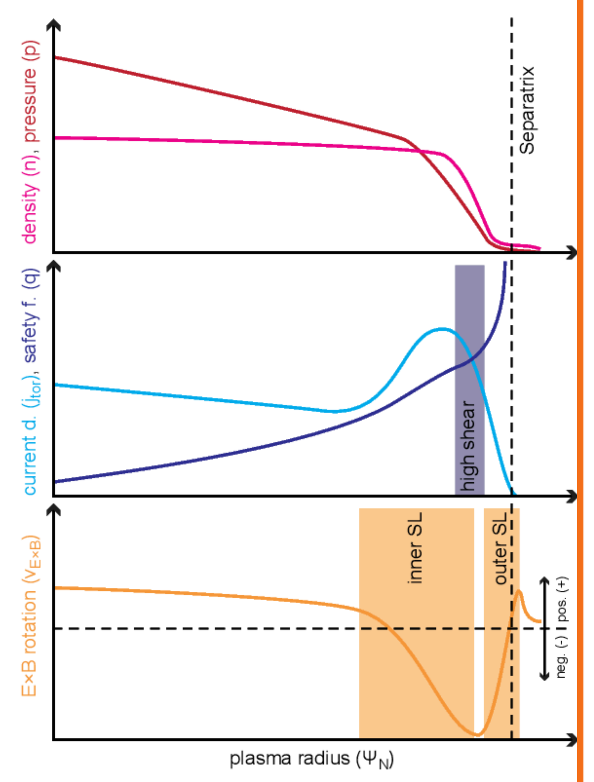
1. Introduction and Motivation

- High confinement mode (H-mode) in a tokamak has steep pressure gradients at the edge, the pedestal
  - Pedestal stability is limited by edge localized modes (ELMs)
  - ELMs expel large particle and heat fluxes towards the divertor and wall
    → Potential risk for ITER or a fusion power plant
- Fundamental knowledge on underlying mechanisms leading to stability limit is required
  - Study of pedestal dynamics in between ELMs
- Distinct pedestal recovery phases
  - Phase I: Electron density (n_e) gradient
  - Phase II: Electron temperature (T_e) gradient
  - Phase III: gradient saturation
    → Different recovery timescales
- Pedestal fluctuations linked to profile evolution
  - Characteristic onsets with recovery phases
    → What causes fluctuations to appear?
    → Under which conditions do they exist?



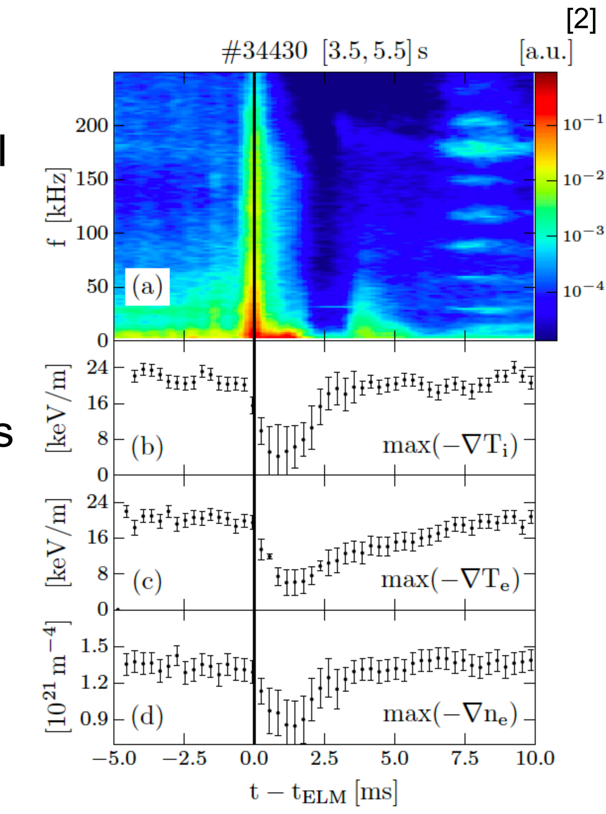
2. Pedestal: Drives for instabilities

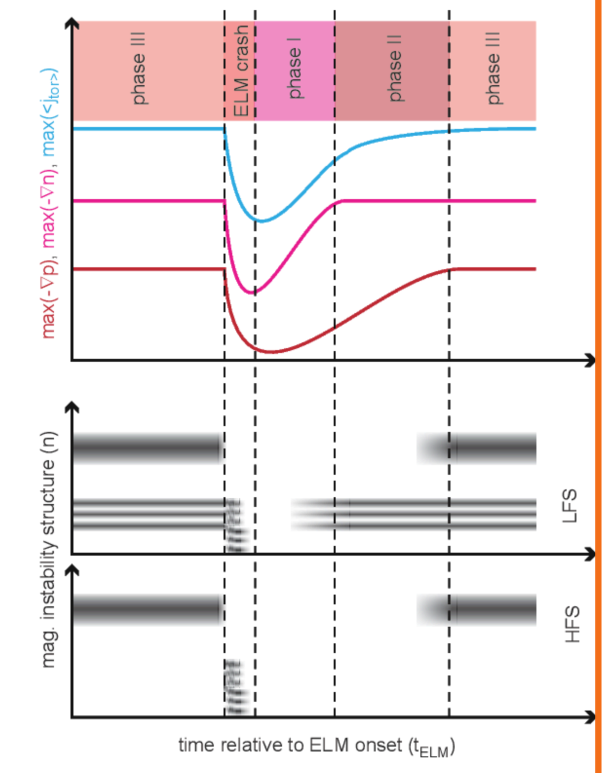
- Pressure gradient (∇p)
  - Typically drives ballooning-type instabilities
    → ∇p linked to density and temperature
- Edge current density
  - Main contribution is bootstrap current (j_{BS})
    $j_{BS} \propto \sqrt{\varepsilon}\, \nabla p / B_\theta$
    → Order: $\nabla n \sim 0.5$, $\nabla T_e \sim 0.15$ and $\nabla T_i \sim 0.1$
  - Modifies the safety factor profile (q)
    → Region of high magnetic shear
- E×B rotation
  - Radial electric field (E_r)
    $E_r = \frac{\nabla p_\alpha}{Z_\alpha e n_\alpha} - v_{\Theta,\alpha} B_\phi + v_{\phi,\alpha} B_\Theta$
  → Sheared flows tear apart instabilities



3. General pedestal dynamics

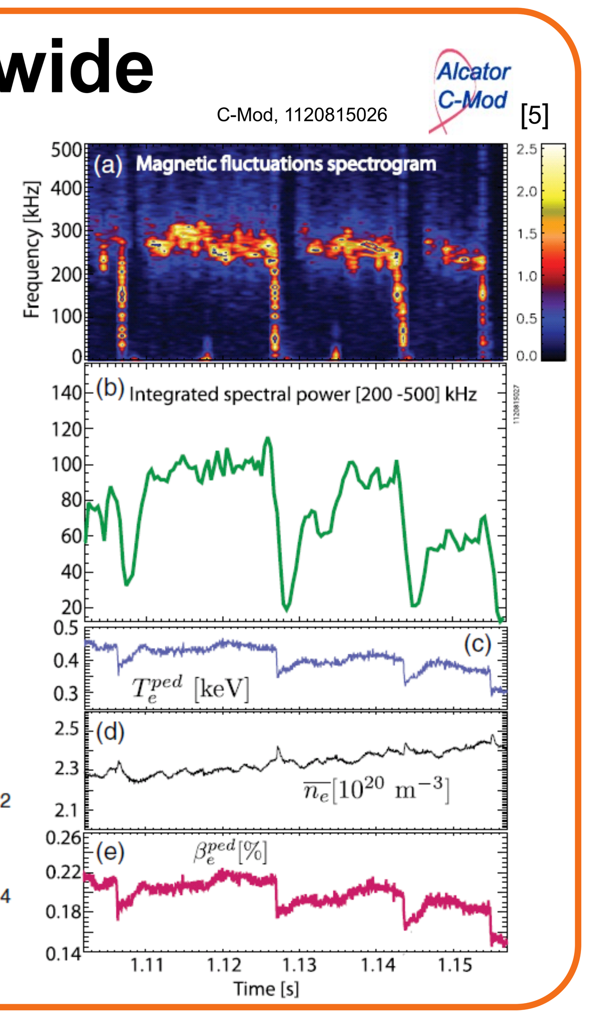
- Ions important for pedestal pressure evolution
  - Ion temperature (T_i) pedestal recently studied
    → T_i pedestal evolves on timescale of n_e pedestal
- Sequence of pedestal evolution phases and connected fluctuations
  - ELM crash
    → Fast profile relaxation, low n filament structures
  - Phase I
    → ∇n_e and ∇T_i recover
    → Build up of bootstrap current
    → Low fluctuation power over full spectral range
  - Phase II
    → Saturation of ∇n_e and ∇T_i
    → Onset of medium frequency fluctuations
    → Further evolution of ∇T_e
  - Phase III
    → Saturation of ∇T_e and therefore ∇p
    → Onset of low and high frequency fluctuations
- Typical frequency band structure
  - Low and medium frequency are well defined
    → Low frequency components are mostly obscured by core MHD activity
  - Higher frequency broadband
    → Instability extends into both shear layers or mode structure is imperfect, burst-like modulation behavior [9,10]

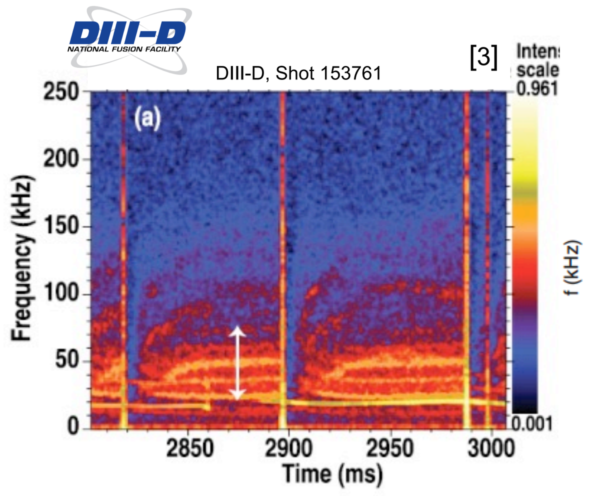


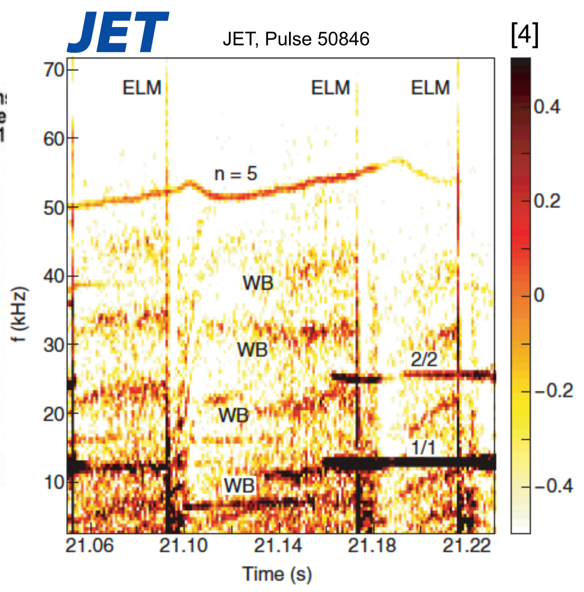


4. Similar observations worldwide

- Pedestal fluctuations found in several tokamaks
  - In AUG, C-Mod and DIII-D their onsets are linked to the profile evolution
    → Points to one robust generation mechanism

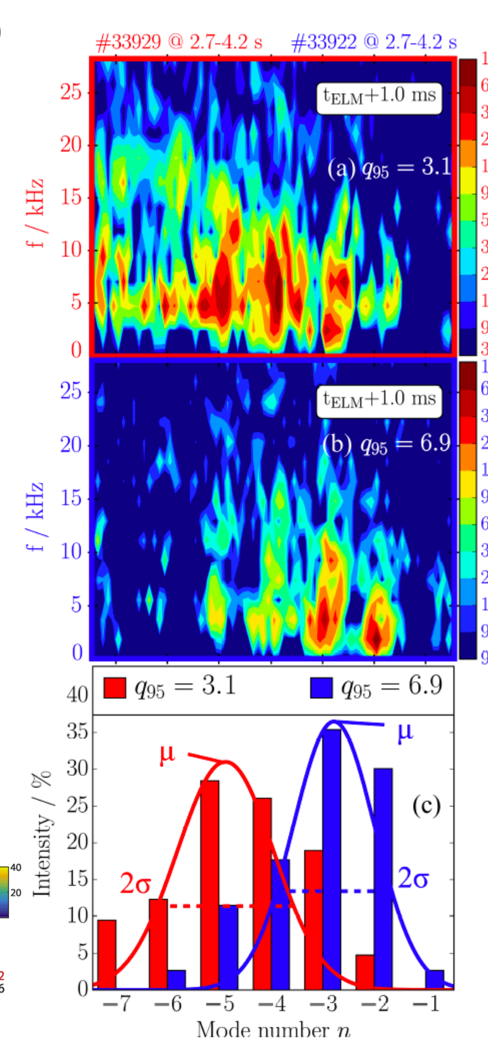


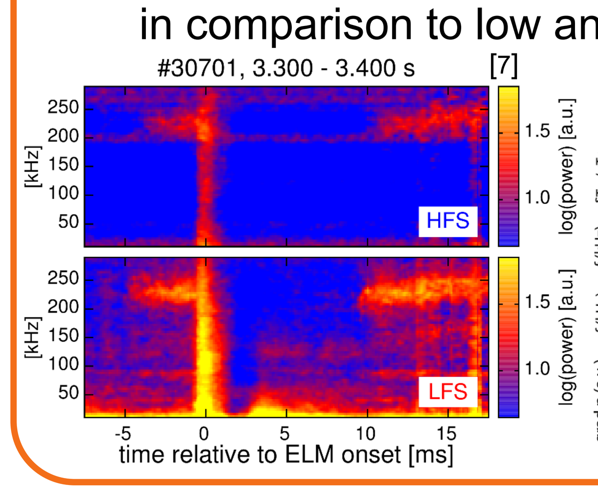


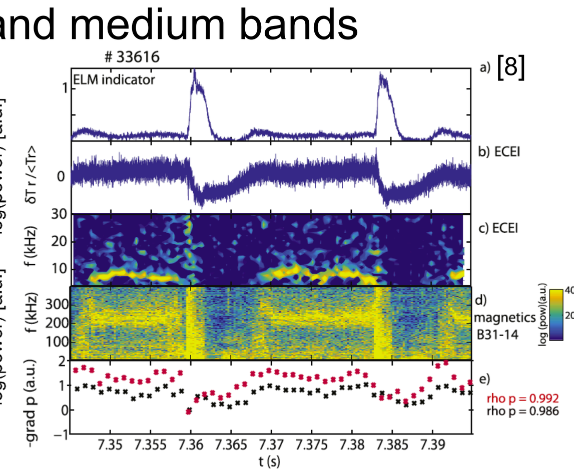


5. Mode structure of fluctuations

- Distinct frequency bands
  - Low frequency (Phase III)
    → Located towards the pedestal top; close to the E×B zero crossing (inner SL)
  - Medium frequency (Phase II)
    → Located outside of the E×B minimum (outer SL)
  - High frequency (Phase III)
    → Located in E×B minimum
- Medium frequency toroidal mode structure varied by q
  - Toroidal mode number (n) decreases with q
    → One dominant poloidal mode number (m)
    → Result of radial mode coupling for minimal n
- High frequency bands shows HFS signature
  - Different mode structure in poloidal cross section in comparison to low and medium bands







6. Summary

- Pedestal fluctuations with similar behavior identified and characterized across experiments and for wide parameter ranges
  - Underlying mechanisms are independent over achievable range of parameters
    → Driving terms and stabilizing terms are strongly interlinked
- Distinct frequency bands correspond to radially separated modes
  - Characteristic poloidal mode structure of medium frequency bands
  - High frequency bands typically more broadband

7. Outlook

web version

- Manipulation of pedestal fluctuations to ultimately control them
  - Application of heat pulses or edge currents perturbations
    → Testing of possible actuators
- High frequency bands show modulated burst-like behavior
  - Do they cause additional transport?

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