NSTX-U Results Review, September 21-22, 2016

Nonlinear simulations of CAEs

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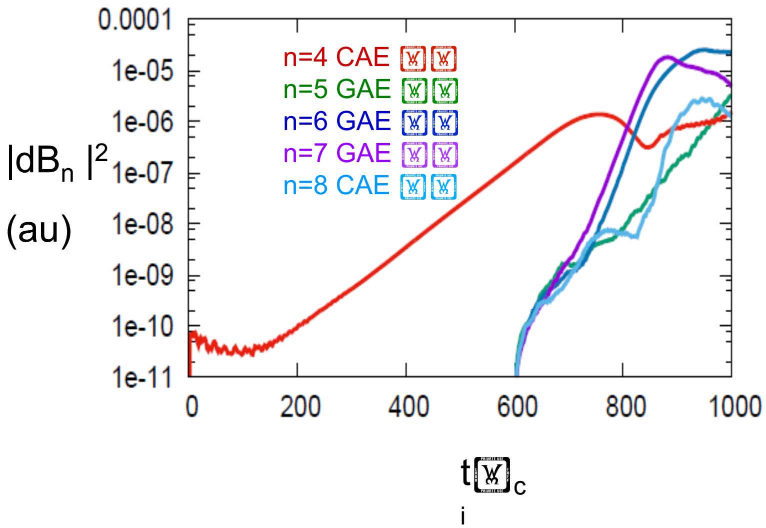
- Completed nonlinear simulations of CAEs, including scaling of CAE-to-KAW energy channeling with the beam power, and saturation mechanism.
- A scan of the beam ion distribution parameter have been performed, which resulted in several new findings (J. Lestz):
  - dependence of number of unstable CAE/GAEs on v_0/v_A
  - comparison with experimental GAE/CAE database
  - dependence on most unstable [illegible] on beam parameters
  - unstable co-GAEs
- Calculated NSTX-U equilibrium using HYM GS solver coupled with FREE_FIX code (Luca G.) for a fixed plasma shape.
- Performed initial simulations of GAEs in NSTX-U: n=7-12 (E. Fredrickson GAEs stabilization experiments).

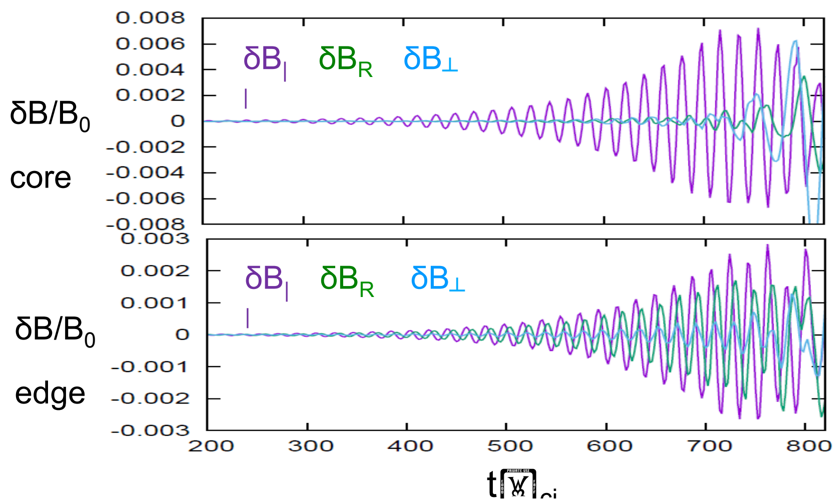
Nonlinear CAE simulations



Time evolution of amplitudes of different toroidal harmonics from fully nonlinear simulations for NSTX shot 141398.

- Fully nonlinear simulations including 32 toroidal harmonics show saturation of the n=4 CAE mode.
- Initial conditions for nonlinear run were obtained by running the n=4 linearized simulations (from t=0-550) to obtain a converged linear mode structure of CAE.
- Nonlinear run starts at t=550, and also shows growth of n=5,6,7 GAEs and n=8 CAE modes.

Nonlinear simulations show CAE saturation amplitudes higher but comparable to experimentally observed



Time evolution of $dB_{||}$ and two components of $\delta \mathbf{B}_{\perp}$ in the core, and close to the plasma edge on LFS.

- In the core, the compressional perturbation is 3-4 times larger than the shear perturbation.
- Mixed compressional/shear polarization near the plasma edge on LFS .

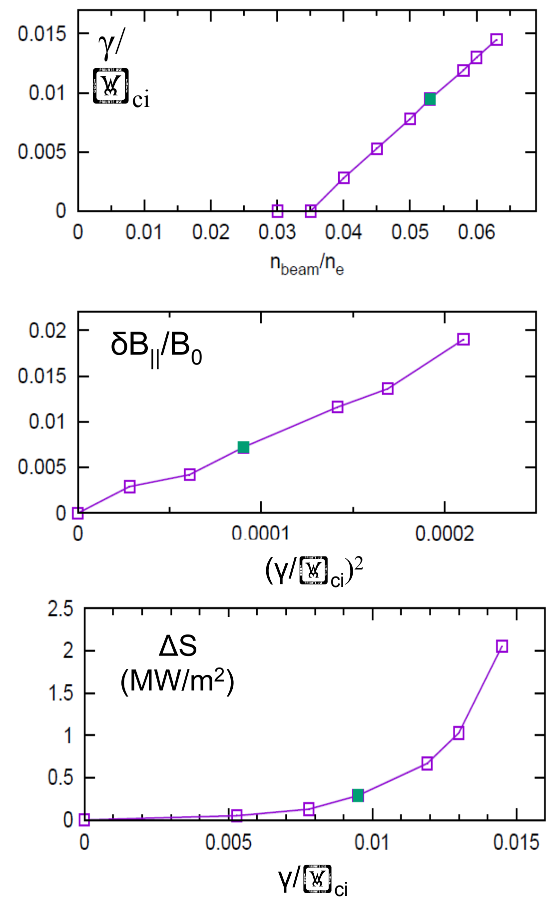
- Saturation amplitude of the n=4 CAE: $\delta B_{||}/B_0 = 6.6\times10^{-3}$.

- Measured plasma displacement $|\xi|$= 0.1-0.4 mm [Crocker,2013] corresponds to $\delta B/B_0 = (0.9\text{-}3.4)\times10^{-3}$ (based on HYM-calculated mode structure for n=4 CAE).

Rate of change of the beam ion energy, calculated as $\int (\mathbf{J}_{beam}\mathbf{E})\, d^3x$, is ~1.5MW for calculated the n=4 CAE saturation amplitude $\delta B_{||}/B_0 = 6.6\times10^{-3}$.

CAE-to-KAW energy channeling shows strong scaling with the beam power

(a) Growth rate of the n=4 CAE vs beam ion density
(b) Saturation amplitude vs γ^2
(c) Calculated change of the energy flux at the resonance location vs γ



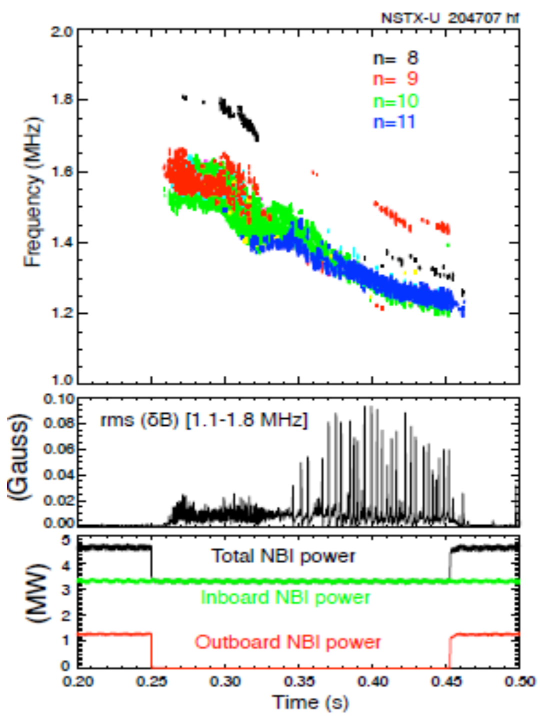
- From density threshold – damping rate due to CAE/KAW coupling is large $\gamma_{damp} = 0.66\ \gamma_{dr.}$

- Threshold value of the beam power needed for the excitation of the n=4 CAE can be estimated as P~4MW.

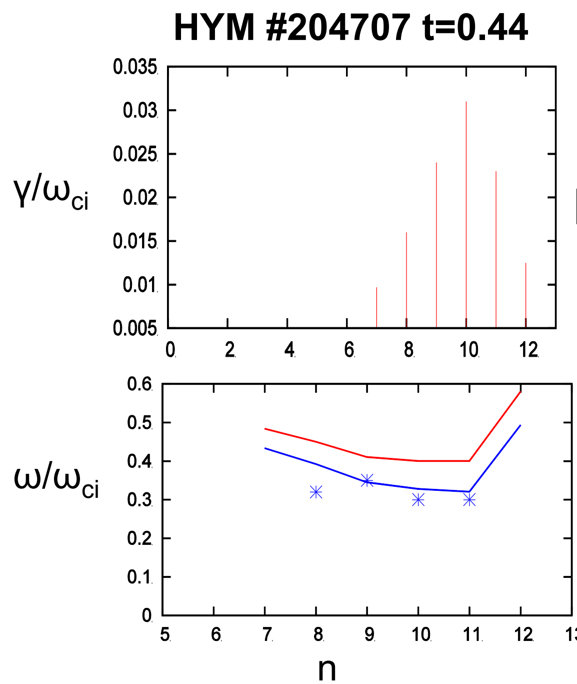
- Absorption rate shows a very strong scaling with growth rate: $\Delta S \sim (\gamma/\omega_{ci})^5$, implying that the energy loss at the resonance scales as a fifth power of the beam ion density (beam power).

NSTX-U simulations: GAE stabilization

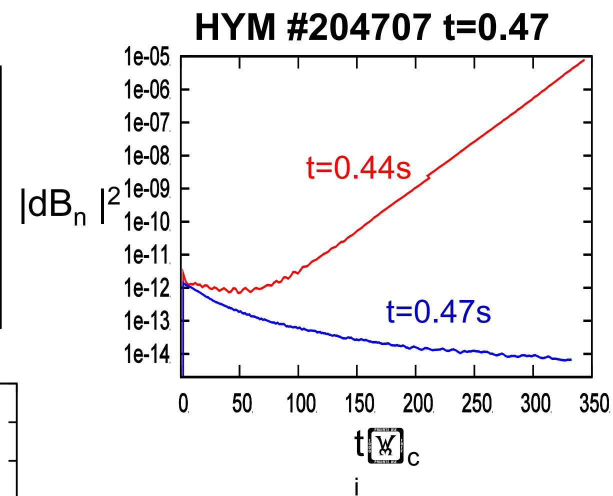
Off-axis neutral beam injection reliably and strongly suppresses GAEs



(a) Spectrogram on magnetic fluctuations
(b) rms magnetic fluctuations;
(c) injected beam power.



(a) Growth rates and (b) frequencies of unstable counter-GAEs from HYM simulations for t=0.44s. Blue line is Doppler-shift corrected frequencies, points – experimental values.



Time evolution of magnetic energy of n=10 GAE from HYM simulations for t=0.44s (red), and t=0.47s (blue).

HYM shows suppression of n=10 counter-GAE by additional beam injection.

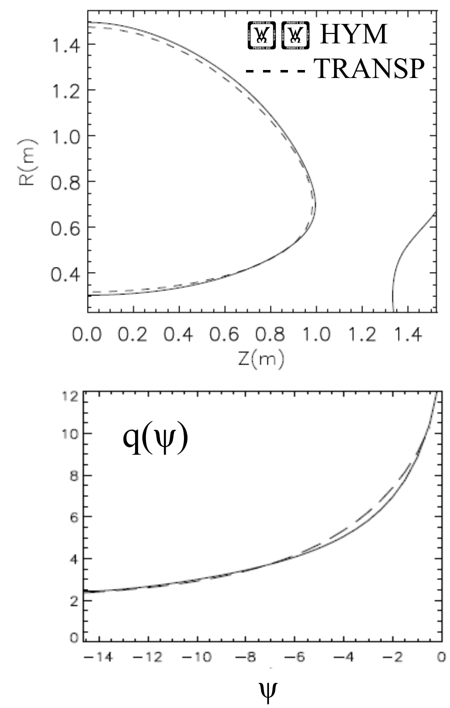
HYM plans

Code development

- Improve the fast ion distribution function model.
- Improvement of numerical model (equilibrium solver, parallel scaling).
- Include thermal ions kinetic effects (Hall, FLR).
- Include the effects of bulk plasma rotation.

Physics

- Understanding conditions for preferential excitation of GAEs and CAEs.
- Continue NSTX-U simulations – GAEs stabilization.
- Comparison of the relative importance of the energy channeling vs anomalous electron transport mechanisms.
- Comparison with experimental results including mode structure, saturation amplitudes and etc for several shots.



Plasma shape and q-profile for NSTX-U shot 203262A03 t=0.220 from TRANSP and HYM GS solver + FREE_FIX.