Simulations of the effect of beam driven Global Alfvén Eigenmodes on electron transport

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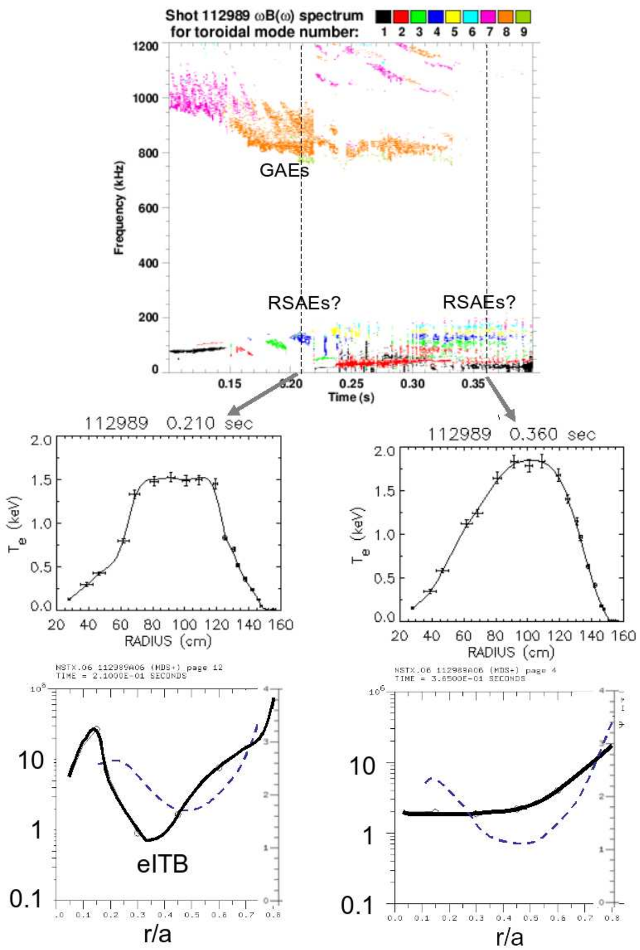
Motivation

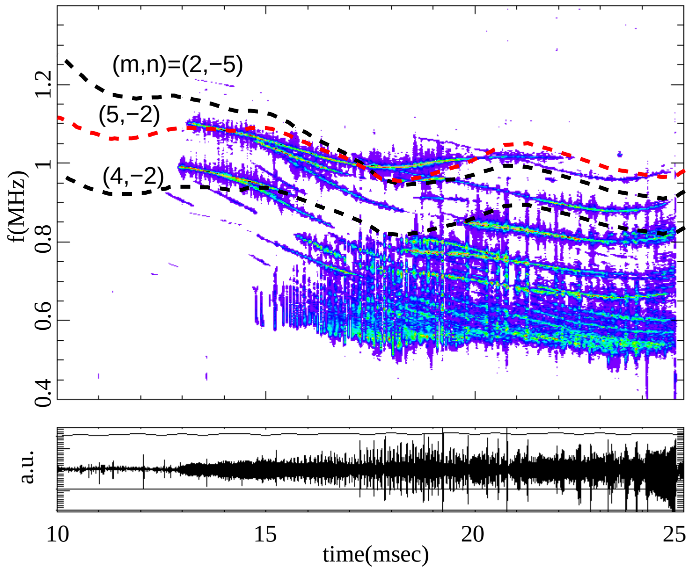


- e-transport seems to be driven by sub-cyclotron modes - D. Stutman, recent presentations
  - GAEs are candidates
- location of T_e-flat region is $r/a <\sim 0.25$ inside of q_{min} surface !!!
- $\Rightarrow$ we can apply theory developed for GAEs/CAEs, ORBIT
  - aim at heat diffusion coefficient on the order $\geq 2m^2/sec$,
  - *what is required mode amplitude?*

Experimental Observations and Theory

- Experiment:
  - Multiple sub-ion cyclotron frequency instabilities are observed in NSTX.
  - Frequency typically scales with Alfvén speed and dispersion.
  - Modes are driven by fast super Alfvénic ions.
  - GAE frequencies intersect, polarization $\delta B_\perp > \delta B_\parallel$
  - CAE frequencies do not intersect, polarization $\delta B_\parallel > \delta B_\perp$.
- Theory:
  - GAEs: Appert'82, in NSTX discovered by Fredrickson, with input from HYM (E.Belova presentation tomorrow).
  - Mode identification: shear and/or compressional (magnetosonic) AEs is easier in NSTX due to instability spectrum peak separation.
  - Instability properties can be used to diagnose plasma: fast ion distribution,
    q-profile.
  - damped on electrons if $\omega < \omega_{ci}$: may expect effects on electrons.

Experimental features of GAE instabilities

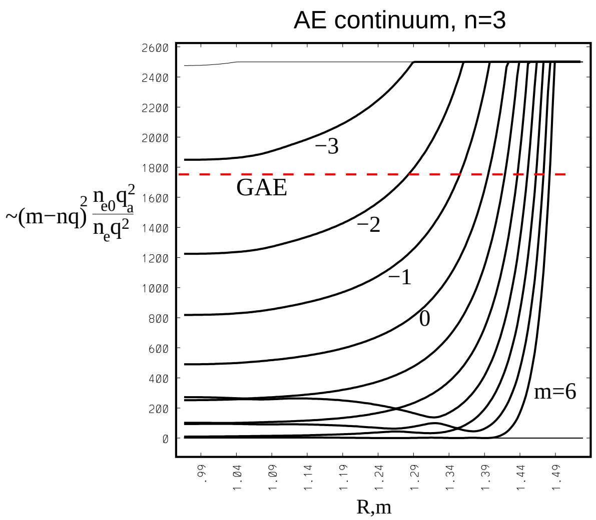


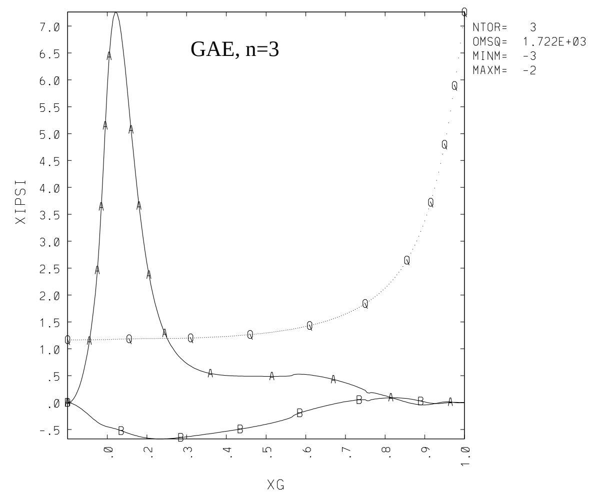
Dashed curves are GAE dispersion $\omega_{GAE} \simeq v_{A0}(m - nq_0)/q_0R$.

- Observed frequencies of different (m, n) modes intersect
  $\Rightarrow$ characteristic of shear Alfvén Eigenmodes.
- We identified them as Global Alfvén Eigenmodes (GAE), (APPERT, 1982).
- GAEs (center) become stable after sawtooth, whereas CAEs (edge) become unstable.

N.N.Gorelenkov, E. Fredrickson, E. Belova et.al., IAEA'02, NF'03.

Alfvén continuum and GAE structure from NOVA

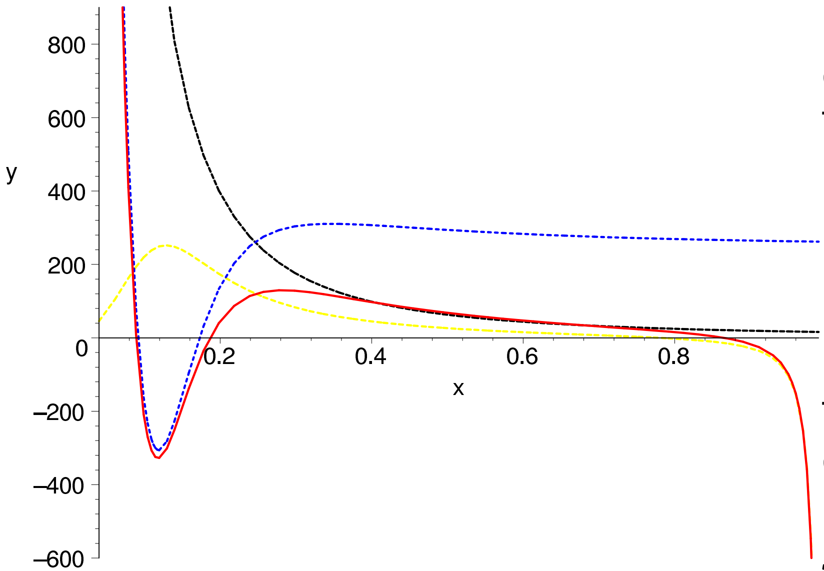




$\omega_{GAE} \simeq v_{A0}(m - nq_0)/q_0 R.$

- Many radial modes can exist below each A-continuum line
  - Frequencies are shifted downward from the continuum up to 30%.
- HYM GAE modeling will be presented tomorrow by E.Belova on WEP session

GAEs are localized in the core due to density and q-profiles



GAEs are localized near the center. Potential well is

$$V(x) \simeq V'(x) = \left(m^2 - 1/4\right)/x^2$$
$$+2\sigma\omega_{A0}^2/D\left(g - x^\delta\right) + C$$

for the Alfvén continuum $\omega_A^2 = \omega_{A0}^2 + Dx^\delta$. GAE dispersion

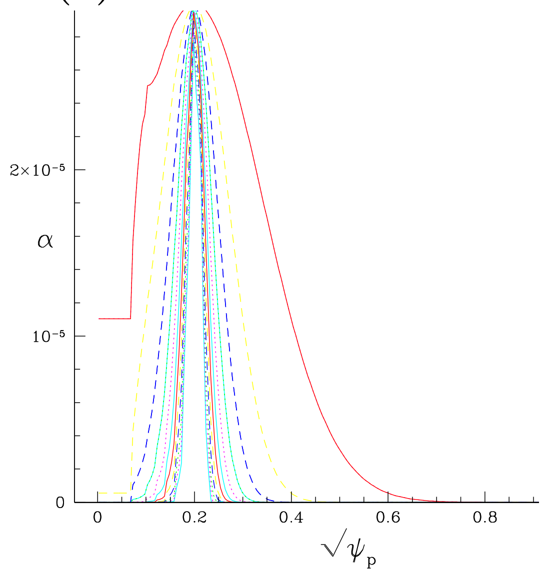
$$J_{m-1}\left(\left(\frac{-2\sigma\omega_{A0}^2}{Dg} - C\right)^{1/2}(-g)^{1/\delta}\right) = 0$$

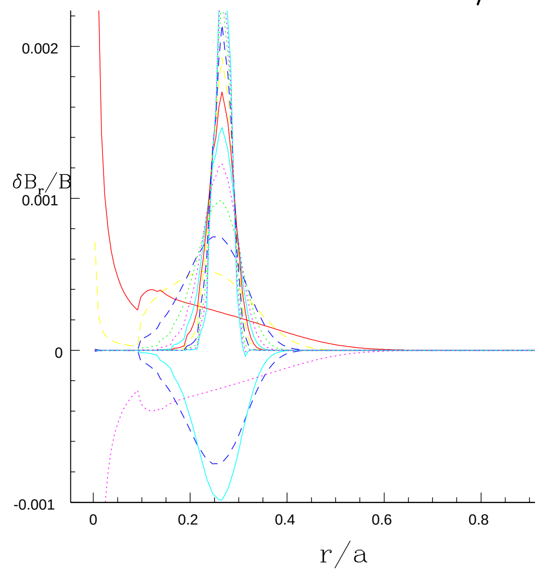
Standard continuum damping calculation produces damping rate to the order of magnitude $\Im\delta\omega/|\omega_0| \sim (x_2/x_s)^{2m+\delta}$ is small for large to medium m's (Gorelenkov, NF, '03).

GAE mode radial width is proportional to m^{-1}.

Employ ORBIT to study e-transport due to GAEs

$\alpha(r): \delta\mathbf{B} = \nabla \times \alpha\mathbf{B}$ $\delta B_r/B$





ORBIT ideal MHD perturbation:

$$\alpha = \alpha_0 e^{-m^2(r-r_0)^2/\delta r^2}.$$

Baseline case:

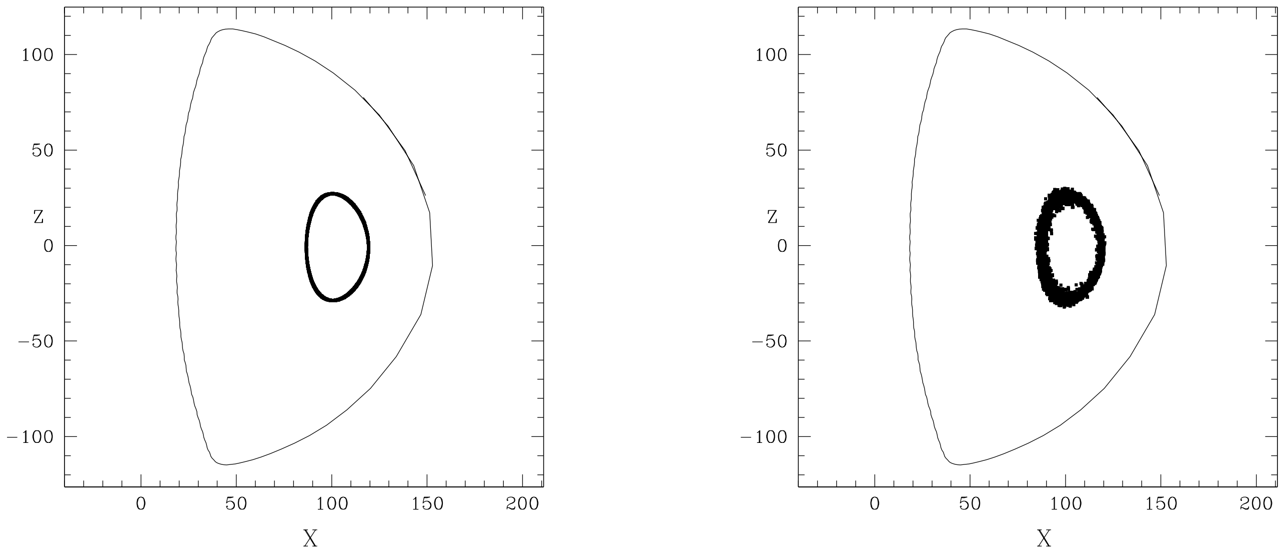
- $\alpha_0 = 3\times10^{-5} \Rightarrow \delta B_r/B = 10^{-3}$ at $r/a = 0.2$ (modes peak).
- 15 GAEs with $n = 1-10$, m is such that $f = 400-600kHz$.

Characteristic frequencies

- $f_{GAE} \sim 400 - 600kHz$, may go higher.
- transit (passing) frequency $f_{te} = \frac{1}{2\pi}\frac{v_{\parallel}}{qR} = 1.5MHz\ T_e = 1keV$,
- bounce (trapped) frequency $f_{be} = \frac{1}{2\pi}\frac{v_{\perp}}{qR}\sqrt{\frac{r}{2R}} = 430kHz$ at $q = 2$, $R = 1m$, $a = 0.8m$, $r/a = 0.2$.
- electron Coulomb scattering frequency $\omega_{ce} = 0.7 \times 10^{11} sec^{-1}$, $\nu_e/\omega_{ce} = 3 \times 10^{-7}$, e-i collisions double this.
- thermal ion cyclotron frequency $f_{ci} = 3MHz$.

$f_{GAE} \sim f_{be}$ and may be $\sim f_{te}$!!!

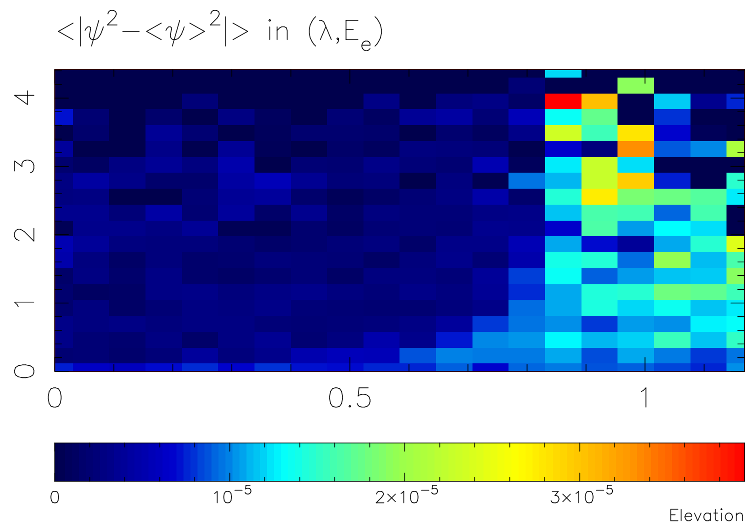
Test particle initial and final e-distributions



Initial ring distribution of electrons on one surface.

ORBIT run for $3ms$ with Maxwellian electrons with $T_e = 1keV$.

Which electrons are interacting?



Evaluate characteristic displacement for different electrons $T_e = 1keV$

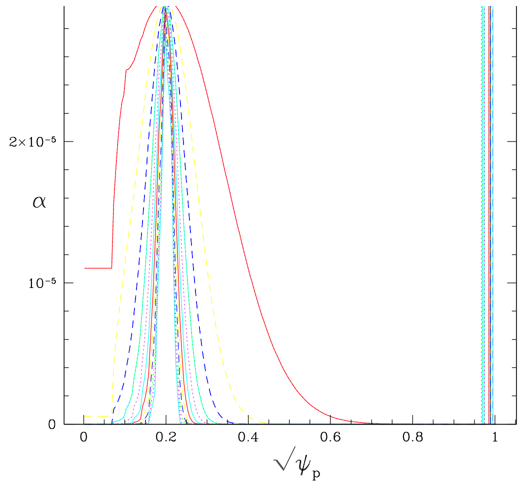
$$\left\langle \left| \psi^2 - \langle\psi\rangle^2 \right| \right\rangle,$$

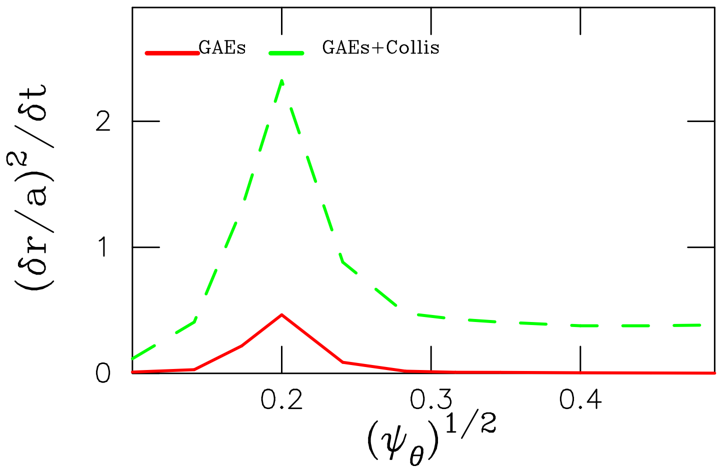
in $\lambda = \mu B_0/E$, E plane.

Trapped electrons are mostly effected by GAEs $\lambda \simeq 1$.
Weak passing electron interactions are due to $\omega - k_\| v_\| = 0$ or $\omega = k_\| \sigma_\| \sqrt{2E}\sqrt{1-\lambda}$.

Radial dependence of electron diffusion

$\alpha(r): \delta\mathbf{B} = \nabla \times \alpha\mathbf{B}$ $D(r)$





Peak of $D(r)$ is near the mode amplitude peak.

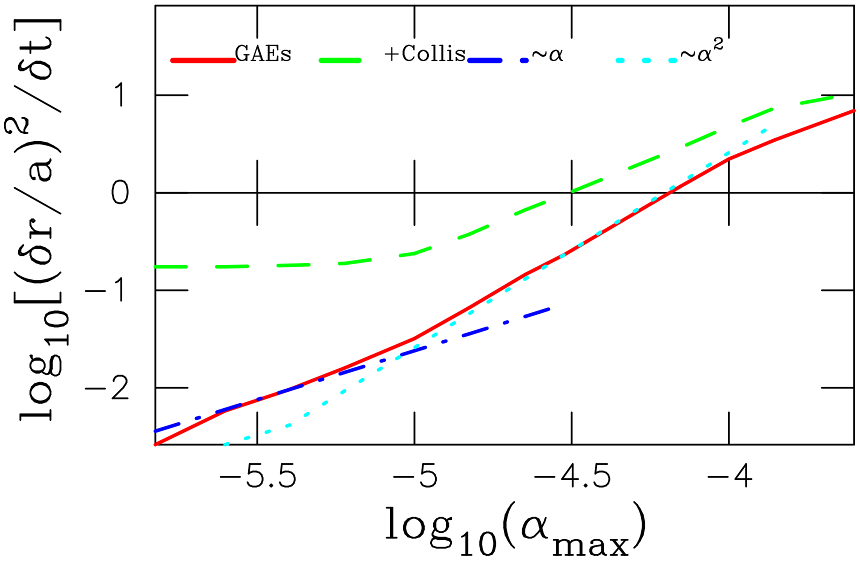
Low-m modes contribute more to the diffusion.

Baseline radial point is at $r/a = 0.22$.

χ_e is on the same order as D_e ($\chi_e = 3D_e/2$ for Maxwellian)

$$\frac{\chi_e}{D_e} = \frac{\langle \mathscr{E}^2 D_e \rangle}{T_e^2 \langle D_e \rangle} - \frac{\langle \mathscr{E} D_e \rangle^2}{T_e^2 \langle D_e \rangle^2}.$$

GAE amplitude dependence of electron diffusion



Baseline case $v_e/\omega_{ce} = 6\times 10^{-7}$.
Shown is diffusion at $r/a = 0.22$.

Expected diffusion at resonance island overlap is $D \sim \alpha$.
$\Rightarrow$ if $D \sim \alpha^2$ then secondary islands generations/overlaps are expected.

For $D \simeq 10m^2/sec$ diffusion we need $\alpha \sim 10^{-4}$ or $\delta B_r/B \simeq 3\times 10^{-3}$ or $\frac{\xi_r}{R} \sim \alpha \frac{m}{k_\parallel r} \sim \frac{\alpha}{\varepsilon} \sim 5\times 10^{-4}$.

Summary

- GAEs with sufficiently strong amplitude can induce electron transport in NSTX.
- Electron transport is due to resonances of trapped electrons with GAEs at $f = 400 - 600 kHz$.
- Phase space resonance overlapping is the mechanism of e-transport.
- For trapped electrons $E_{\|}$ is not important, but maybe important for passing electrons diffusion.
- $E_{\|}$ can be introduced to increase diffusion.
- Velocity dependence of Coulomb scattering frequency will also increase the diffusion.