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NSTX-U

Core heat convection in NSTX-U via modification of electron orbits by high frequency Alfvén eigenmodes

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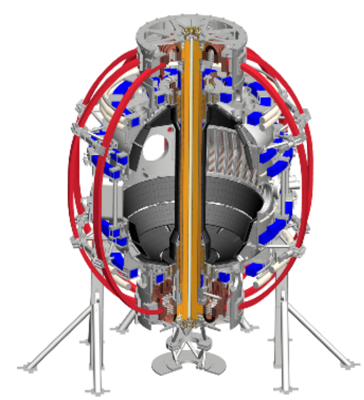
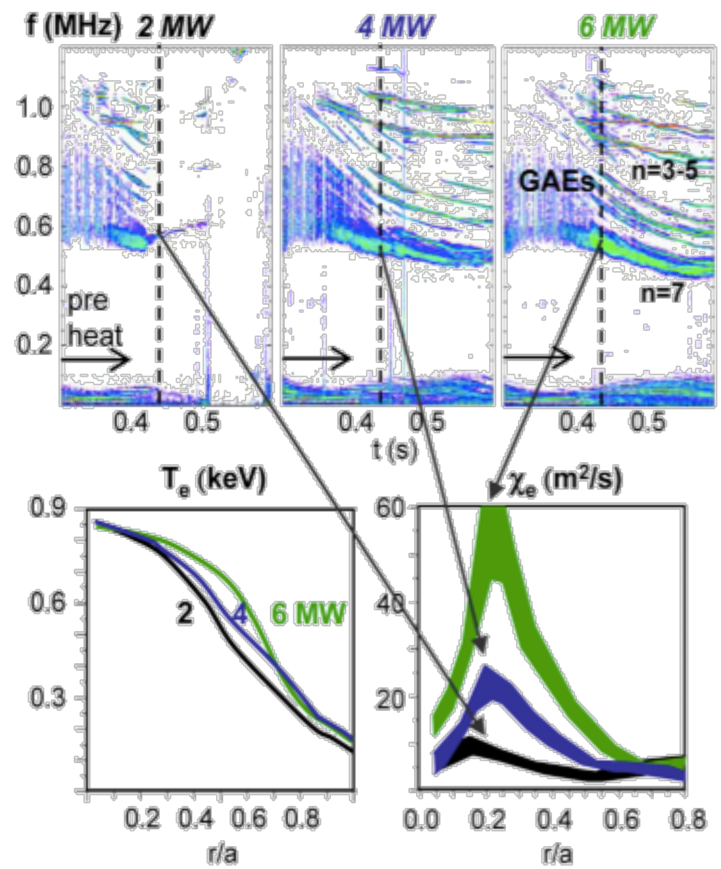


Motivation: CAEs & GAEs candidates for core electron thermal transport in NSTX

- Stochastization of e^- guiding center orbits by CAEs & GAEs posited to cause thermal transport in ST core
  - compressional (CAE) & global (GAE) Alfvén eigenmodes excited by Doppler-shifted cyclotron resonance with beam ions
    [N. N. Gorelenkov, NF 2003]
  - CAE & GAE activity correlates with enhanced χ_e in core of H-mode NSTX beam heated plasmas
    [D. Stutman, PRL 2009; K. Tritz, APS DPP 2010 Invited Talk; N. A. Crocker, PPCF 2011]



[D. Stutman et al., PRL 102 115002 (2009)]

New Results: CAEs & GAEs cause significant convective energy transport

- Effects of modes on e^{-} guiding-center orbits simulated with ORBIT code [R. B. White, PPCF 2010]
  - Experimental spectrum used, with measured amplitudes, frequencies and toroidal mode numbers
- Convective core power loss can match core beam heating from TRANSP modeling – but *very sensitive* to mode amplitude
- Convective transport exceeds diffusive transport for typical L_{Te} $(= T_e / \nabla T_e)$ in NSTX H-mode plasma core
  - $L_{Te} > \sim 1\ \mathrm{m} > \chi / \mathrm{v}_r \sim 4\ \mathrm{cm}$
- Trapped electrons contribute disproportionately to convective transport
- Electrons crossing passing/trapped boundary contribute disproportionately to convection

ORBIT used to simulate effects of modes on electron guiding center orbits

- Uses realistic equilibrium B-field:

  $B = \nabla\times(\psi\nabla\theta - \psi_p\nabla\zeta) = g\nabla\zeta + I\nabla\theta + \delta\nabla\psi_p$, and $\nabla\psi = q\nabla\psi_p$

- Includes time-dependent electromagnetic perturbations via perturbed vector and space potential:

  Compressional: $a(q\nabla\theta - \nabla\zeta)$

  Shear: $\alpha B+\nabla\phi$, with ϕ chosen to ensure $E_{\|}=0$

- Equations of motion from Lagrangian formalism:

  $L(\rho_{\|}, \psi_p, \theta, \zeta, \partial_t\rho_{\|}, \partial_t\psi_p, \partial_t\theta, \partial_t\zeta, t) =$

  $[\psi+(\rho_{\|}+\alpha)I + aq]\partial_t\theta + [(\rho_{\|} + \alpha)g-\psi_p - a]\partial_t\zeta - H$

  where $H = \rho_{||}{}^2B^2/2 + \mu B + \phi$, and $\rho_{||}= v_{||}/B$

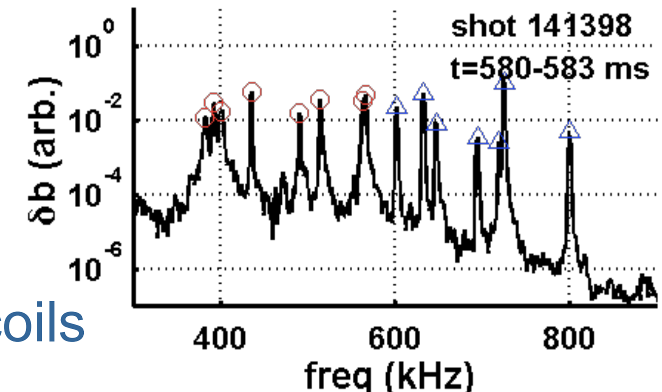
[R. B. White, PPCF 2010]

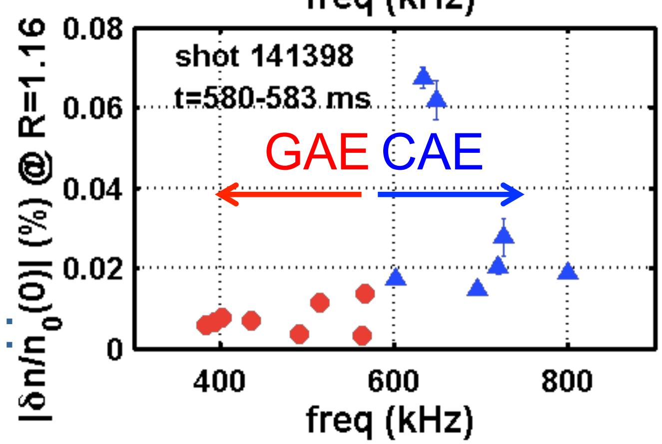
ORBIT simulation used to model energy transport by experimental mode spectrum

- Effects of experimental spectrum of CAEs and GAEs on e^- guiding center orbits simulated with ORBIT
  - simulations collisionless for results presented here
- T_e = 1 keV, isotropic thermal population at $\Psi_N^{1/2}$ = 0.15
  - average radial drift of population ⇒ radial convection
- B-field from experiment (B_{T0}=0.45 T)
- For modes in simulation:
  - f & n measured w/toroidally distributed edge coils
  - polarity (CAE or GAE) identified & m inferred from local dispersion relations: [N. A. Crocker, NF 2013]

    CAE (compressional Alfvén): $\omega^2 = k^2 V_A^2$

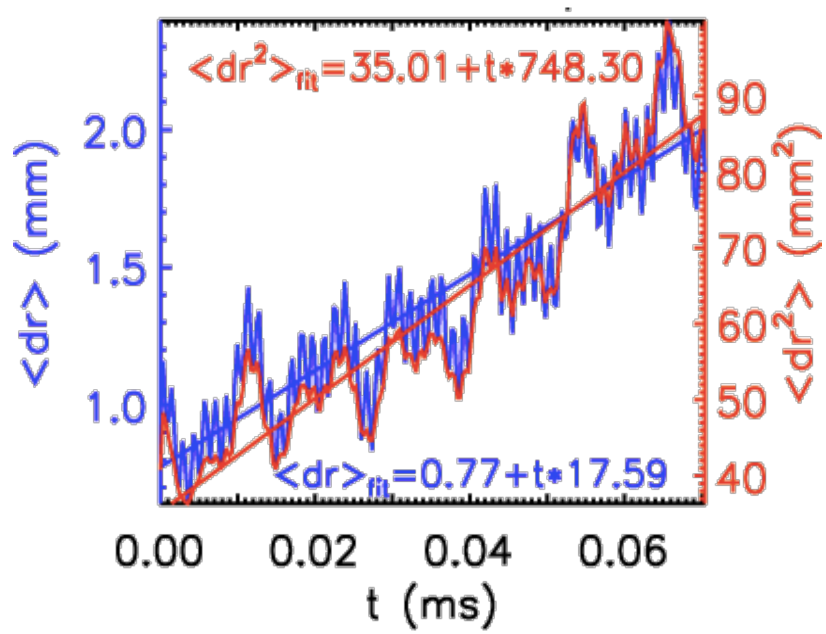
    GAE (shear Alfvén): $\omega^2 = k_{||}^2 V_A^2$
  - modes scaled by reflectometer measurements: total rms $\delta r_{\text{ExB}} \sim$ 3 mm





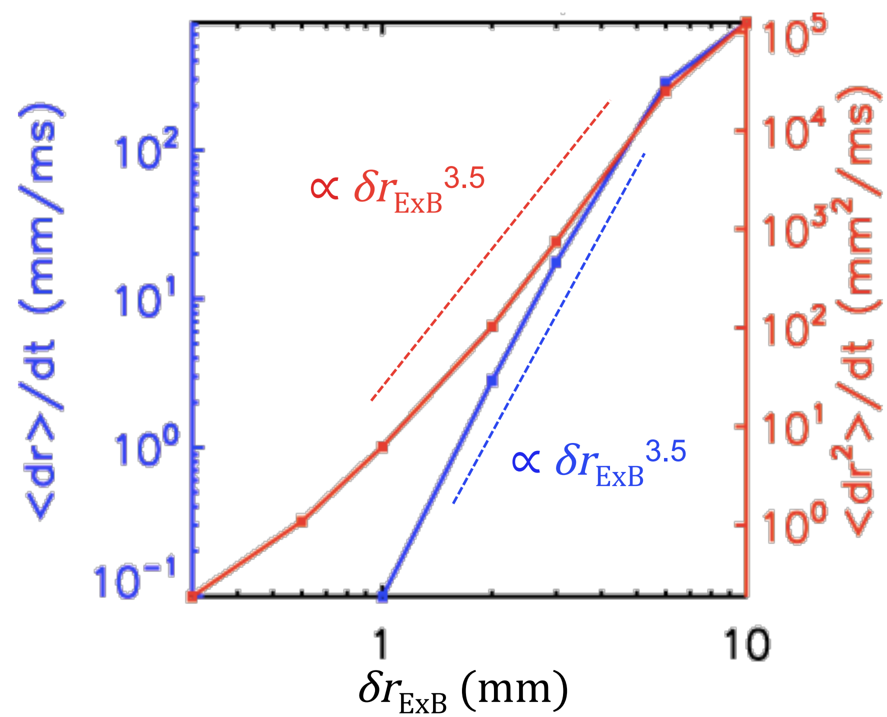
Simulation shows experimental modes can cause heat convection comparable to heating

- Average e^{-} radial velocity: v_r=17.6 m/s
  - very sensitive to mode amplitude (next slide)



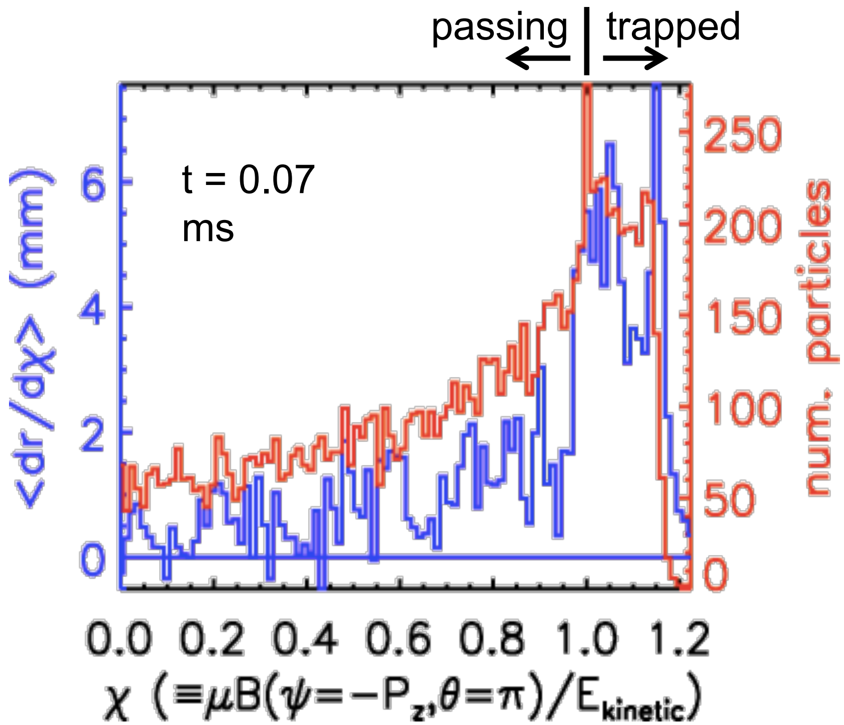
- Convective transport *exceeds* diffusive transport for typical L_{Te} in NSTX H-mode plasma core
  - χ/v_r=(748 mm^2/ms)/(17.6 mm/ms) $\sim$ 4 cm < $L_{Te}\sim$ 1 m
- Convective heat flux: $q = 1.5\,T_e n v_r = 296\ \mathrm{kW/m^2}$
  - $n\sim$ 7 x10^{19} m^{-3}; $T_e\sim$ 1 keV
- Convective heat loss : $qA \sim 1.4$ MW
  - flux surface area: $A = 2\pi^2 r R_0$= 4.6 m^2 ($r\sim$ 11 cm, $R_0\sim$ 1.05 m)
- TRANSP modeling: ~ ½ MW beam heating within $\Psi_N^{1/2} \leq$ 0.15

Transport in simulation very sensitive to total mode amplitude



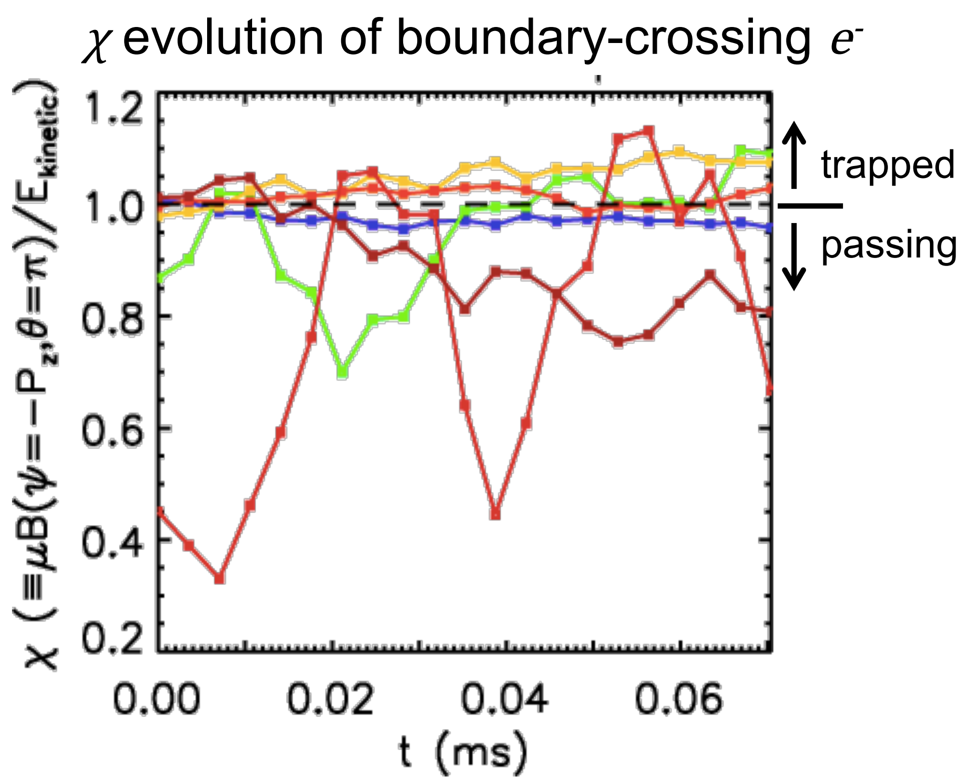
- Experimental modes rescaled to assess transport sensitivity to amplitude
- v_r scales strongly with mode amplitude: $v_r \propto \delta r_{\mathrm{ExB}}{}^{3.5}$
- Experimental amplitude is *just large enough* to balance beam heating ⇒ Does convective transport regulate amplitude?

Trapped electrons contribute disproportionately to convective transport



- $<dr/d\chi>$ much larger for trapped e^-
- Trapped fraction is 25%, but trapped e^- contribute 45% of total $<dr>$

Electrons crossing pass/trap boundary contribute disproportionately to convection



- 15% of e^- cross passing/trapped boundary at least once
- Boundary crossing e^- contribute 42% of total $<dr>$

Conclusions

- Simulation shows experimental CAEs/GAEs spectrum can modify e^- orbits ⇒ connective heat loss from core can balance beam heating
  - Transport very sensitive to mode amplitude
  - Experimental amplitude is *just large enough* to balance beam heating ⇒ Does convective transport regulate mode amplitude?
- Trapped e^- and e^- crossing passing/trapped boundary contribute disproportionately to transport
- Convective transport exceeds diffusive transport for typical L_{Te}
- More work needed: Simulation is *not self-consistent* — convective transport should affect E_r, but E_r not included