# Experimental investigation of the physics controlling core-localized compressional and global Alfvén eigenmode spectra, structure, and amplitude in NSTX-U

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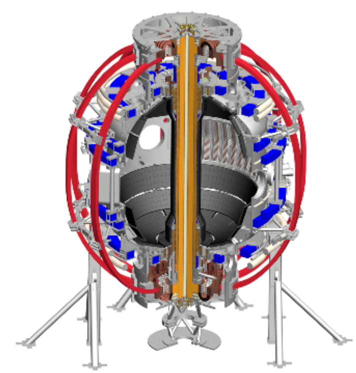
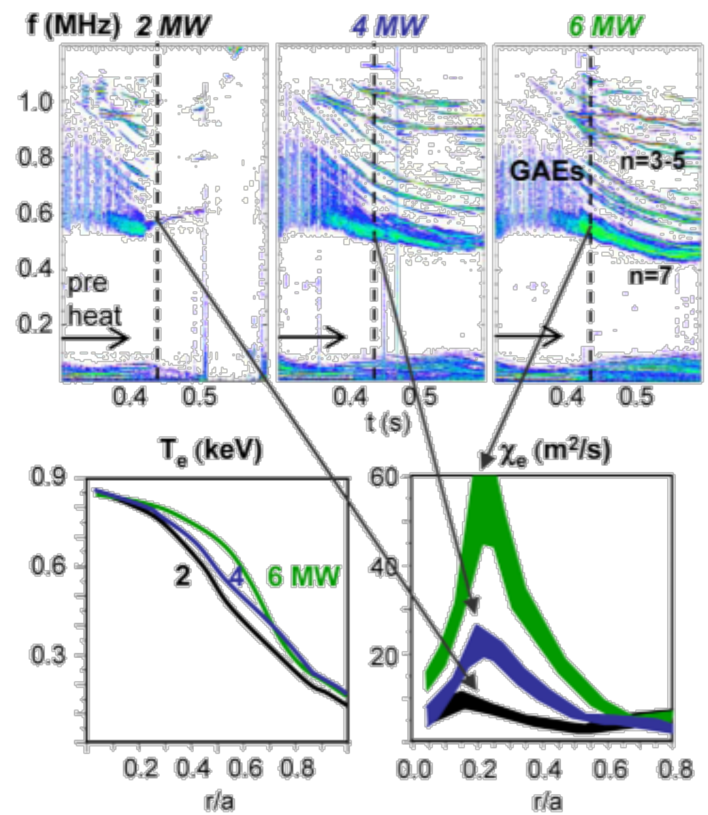


# Overview

- High frequency compressional (CAE) and global (GAE) Alfvén eigenmodes are leading candidates to explain core anomalous electron heat transport with increasing toroidal field and beam power
- No validated model for predicting the spectra, structure, and amplitude of these eigenmodes
  - Motivates analysis across wide range of plasma parameters to establish scaling laws and threshold studies
- A database across many shots is compiled for the purpose of better understanding the CAE and GAE activity
- Preliminary analysis shows mode activity increases with beam power as expected

# Anomalous electron transport correlated with high frequency Alfvén activity

- Beam-heated spherical torus plasmas feature high frequency Alfvén eigenmodes (AE) (f > ~ 400 kHz): Compressional (CAE) & Global (GAE)
- CAEs & GAEs correlate with enhanced core $\chi_e$ in NSTX
- Resonant interaction of multiple modes with $e^-$ guiding center orbits proposed to stochastize orbits, enhancing thermal transport




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

# CAEs and GAEs driven by Doppler-shifted cyclotron resonance with beam heating ions

- CAEs (compressional) and GAEs (global) are Alfvén eigenmodes, where approximately

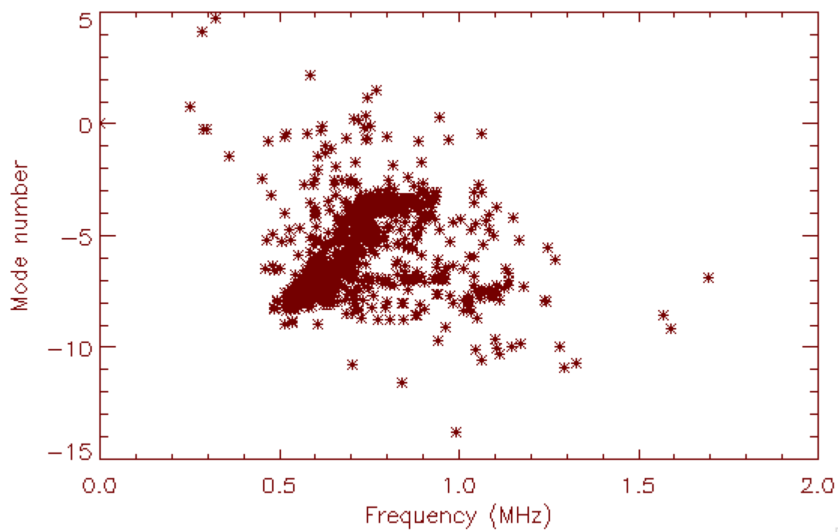
  $\omega^2 = k^2 V_A^2$ (CAE)

  $\omega^2 = k_{||}^2 V_A^2$ (GAE)

- For cyclotron resonance the parallel resonance condition is: $\omega - k_{||} v_{B||} = \omega_{CB}$
- The perpendicular resonance condition requires finite orbit widths, e.g.:
  - CAEs: $1 < k_\perp \rho_{\perp b} < 2$
  - GAES: $2 < k_\perp \rho_{\perp b} < 4$
  - $k_\perp \rho_{\perp b}$ is stabilizing in some ranges and destabilizing in others → anisotropy important to instability

[N.N. Gorelenkov et. al., N.F. **43** (2003) 228-223]

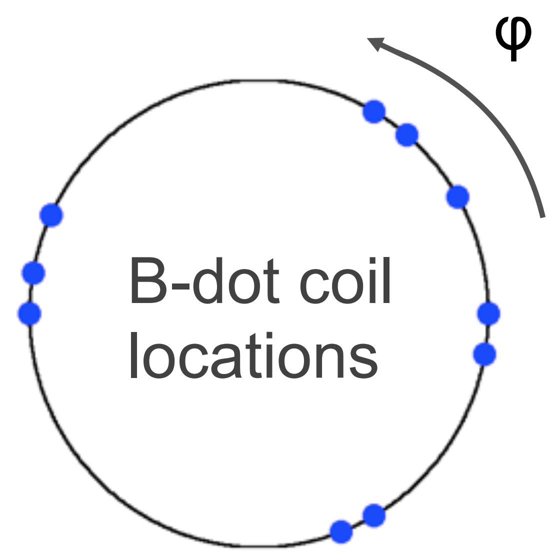
# Broad survey of mode activity performed



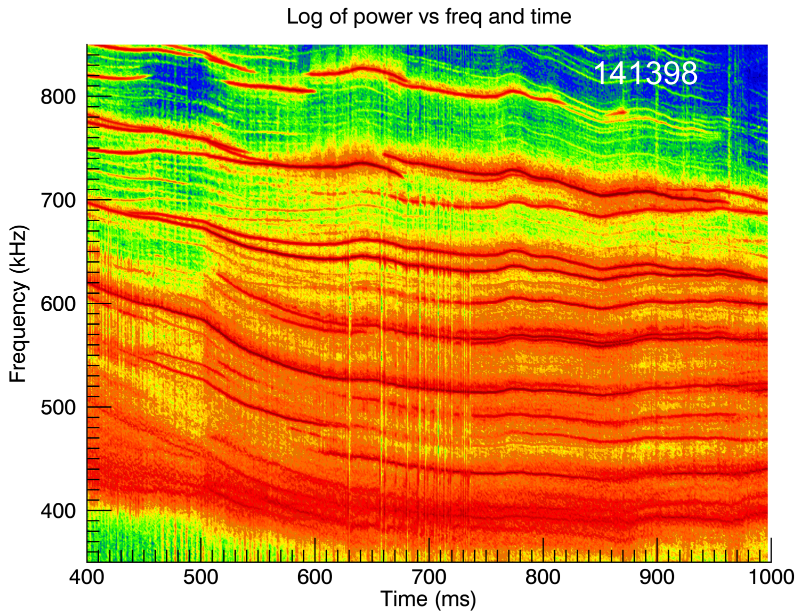

- Coherent modes identified in CAE/GAE frequency range in broad range of shots
  - Initial rule of thumb: f > 200kHz based on observation
- Edge magnetic coils yield mode activity measurements for each discharge
  - Frequency, toroidal mode number, amplitude

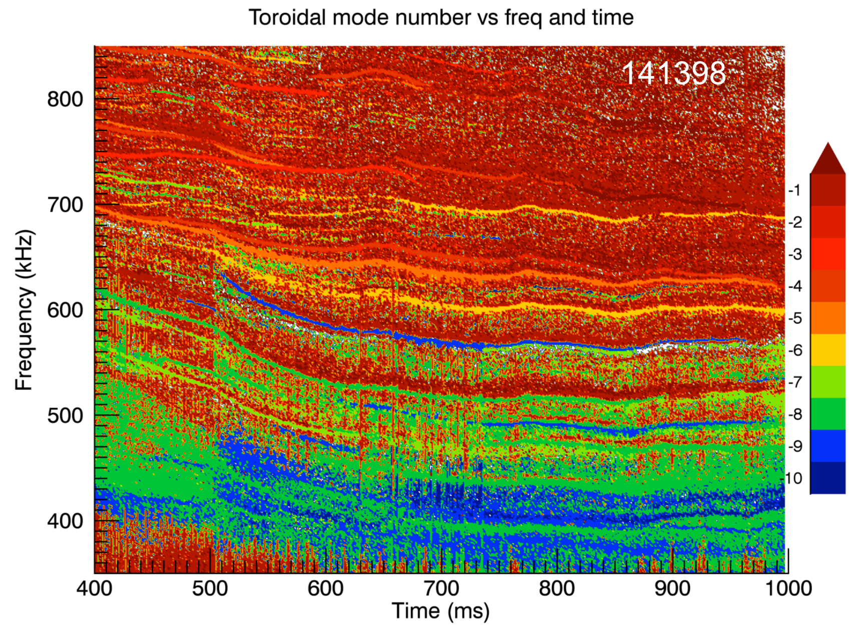
# Mode activity characterized using edge B-dot array

- δb measured by a toroidally distributed array of poloidal magnetic field sensing coils (Mirnov coils)
  - 10 coils
- Statistical analysis yields frequency, toroidal mode number, and amplitude



# Modes identified by testing quality of fit to single toroidal mode number




- For each *t, f* find best fit *n* which minimizes:

$$\chi^2 \equiv 1 - \left|\sum_{\forall\phi} \delta b e^{-in\phi}\right|^2 \Big/ \left(N_\phi \sum_{\forall\phi} |\delta b|^2\right)$$

  – Low chi-square → $\delta b(t,f)$ dominated by single toroidal mode

- Coils are distributed toroidally with smallest coil spacing of $\varphi = 10°$ → can resolve $|n| \leq 18$ ($N_\varphi = 10$)

# Isolating CAEs/GAEs from noise important for fidelity of data set

- In choosing modes we apply a mask of $\chi^2 < 0.5$
  - Initial tests show that most mode power is concentrated in points that pass this mask
- Modes identified as $n = 0$ are excluded
  - Coherent noise produces spurious $n = 0$ modes
- Further work needed to refine noise isolation process

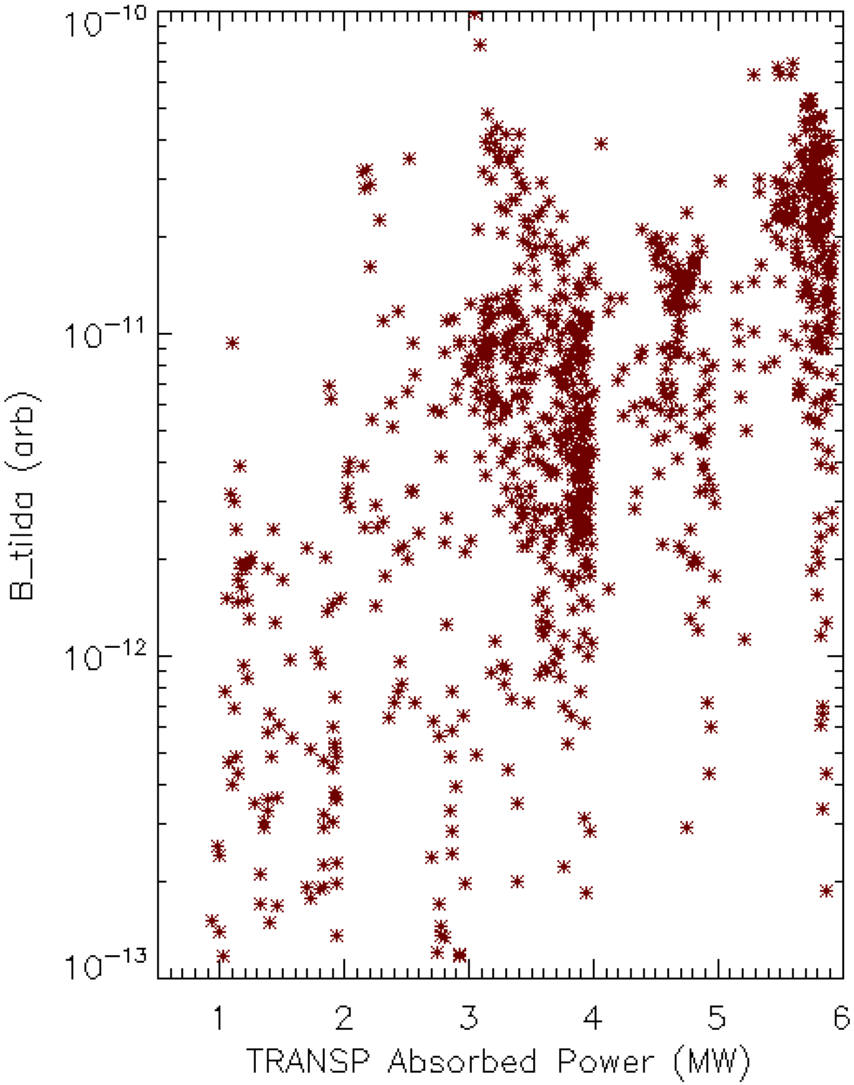
# Existing database of beam-heated shots extended to include CAE/GAE mode activity

- An existing database compiled by Fredrickson et.al. expanded upon
  - 173 total TRANSP shots and 1051 total time slices
  - Analysis done on 50ms intervals
  - TRANSP runs calculated assuming no anomalous fast ion diffusion
- Extended database to include calculations of total CAE/GAE mode power, frequency, mode number
  - Initial application of this analysis is to extend the database

[E.D. Fredrickson, N.F. **54** (2014) 093007]

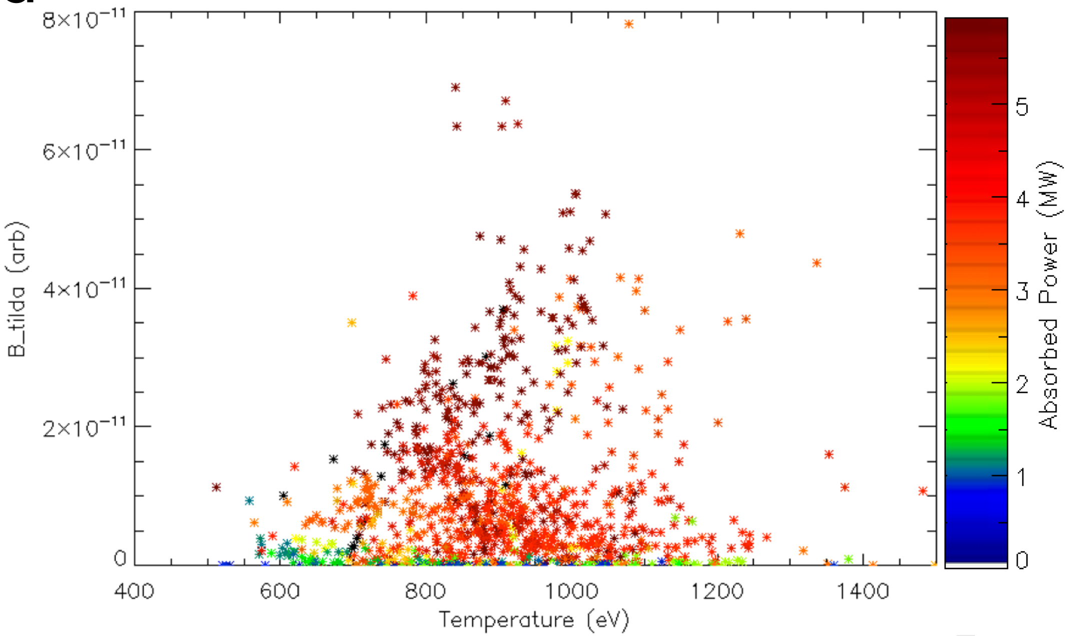
# Total mode power increases with beam power

- Correlation observed between total mode power ($|\delta b|^2$) and TRANSP calculated absorbed beam power
- Consistent with excitation of CAEs and GAEs by Doppler-shifted cyclotron resonance with beam ions



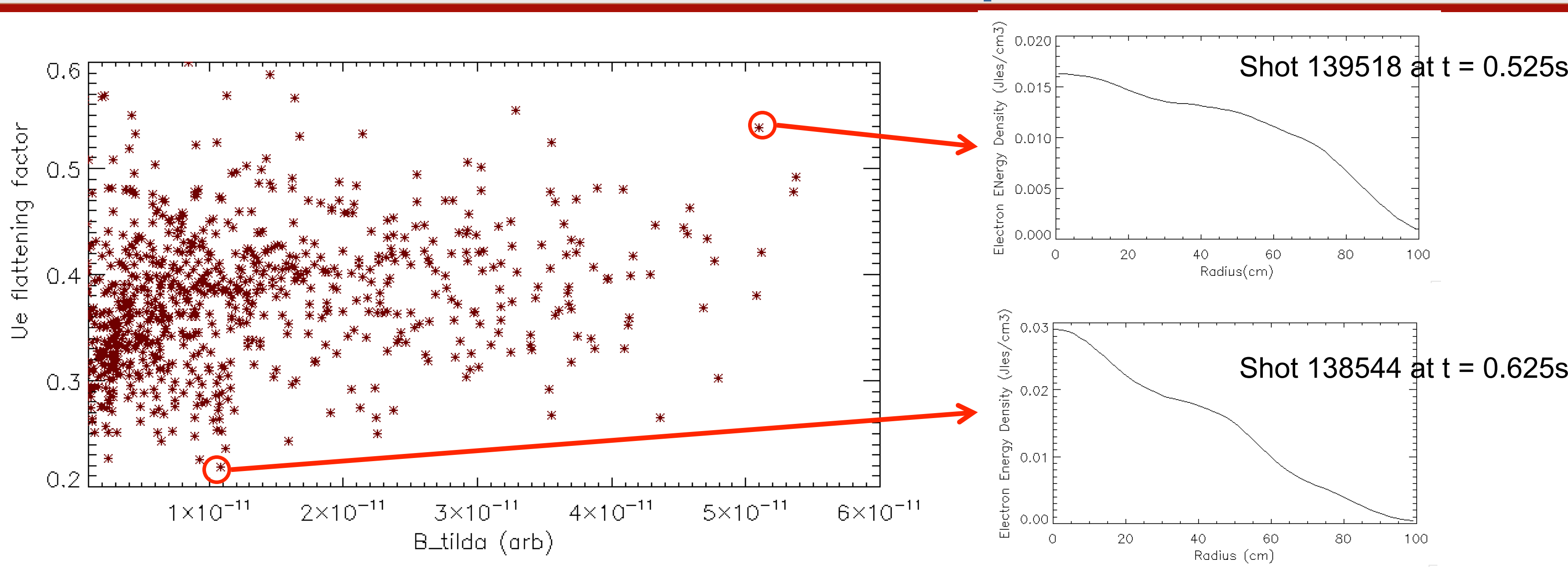
# $|\delta b|^2$ correlates with $T_e$ at high beam power

- Total mode power found to correlate with temperature at high beam power
- Further investigation required
  - Cause of correlation unknown




- $T_e$ may be important for its role in Landau damping and anisotropy of beam ion distribution

# Electron energy density profile flattens with increased mode power




- $U_e$ flattening factor approximated by volume averaged electron energy density ($U_e$) over peak $U_e$: $\dfrac{U_e(0)}{\langle U_e \rangle}$
- Correlation consistent with theory of anomalous electron transport by CAE/GAEs
  - TRANSP calculations assumed no anomalous fast ion diffusion
- Further analysis needed to explore implications of this result

# Next steps

- Potential for investigating scaling laws and threshold studies
- Expanding database to include more parameters to understand physics controlling CAE/GAE activity
- Refinement of analysis technique
  - Implement multi-mode fit
  - Improve noise isolation method

# Summary

- Evidence of anomalous electron transport motivates research on CAE/GAEs and their effect on transport
- Need to develop a predictive capability for these modes in order to understand the physics controlling them
- Initial results show a correlation between mode power and beam power
  - Consistent with existing theory that CAE/GAEs are excited by Doppler-shifted cyclotron resonance with beam ions
- Other results obtained that need further investigation
  - Mode power correlates with $T_e$ at high beam power
  - Electron energy density profile flattens with mode power