# Internal Amplitude Measurements of CAE and GAE

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Compressional and Global Alfvén modes (CAE and GAE) are seen in beam heated, low aspect ratio tokamaks such as NSTX, MAST and START. Alfvén modes in this frequency range have been hypothesized to increase electron transport, to 'channel' fast ion energy to ions or electrons, and to cause redistribution of fast ions. Direct evidence of fast ion transport correlated with the GAE activity has been seen in the 'passive FIDA' signal [1] with the BES diagnostic, and GAE avalanches are observed in some cases to trigger TAE avalanches providing indirect evidence of fast ion redistribution.

The CAE and GAE are weaker and much higher frequency than TAE modes, making measurements of their internal structure challenging. In this paper we focus primarily on internal measurements utilizing the multi-channel array of reflectometers on NSTX. This array consists of reflectometers operating at fixed frequencies from 30 GHz up to 75 GHz, corresponding to ordinary mode cut-off densities from ≈1.1 x $10^{13}$/cm$^3$ up to ≈7 x $10^{13}$/cm$^3$.

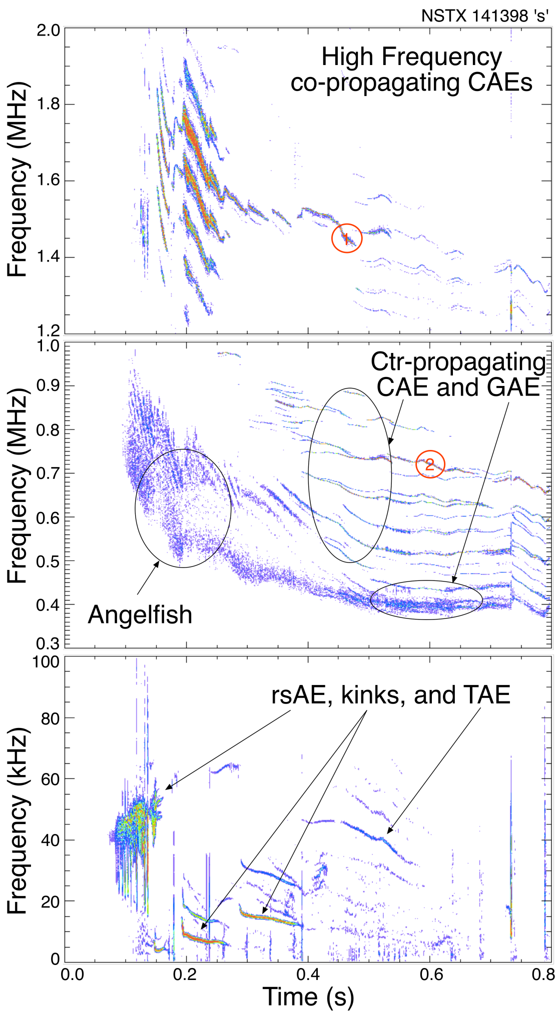


Fig. 1. Spectrograms of magnetic fluctuations. Red circles indicate modes for which reflectometer data will be shown.

Figure 1 shows spectrograms of a Mirnov coil signal with various types of mode activity identified. The high frequency Alfvénic activity (CAE/GAE) exhibits a broad range of behaviours, including bursting, frequency chirping (Angelfish), avalanching of GAE, and continuous mode activity. In this paper we present internal amplitude measurements of GAE avalanches and co and counter propagating CAE. Early high frequency CAE (Figs. 1a, 2) are correlated with the presence of low frequency kinks.

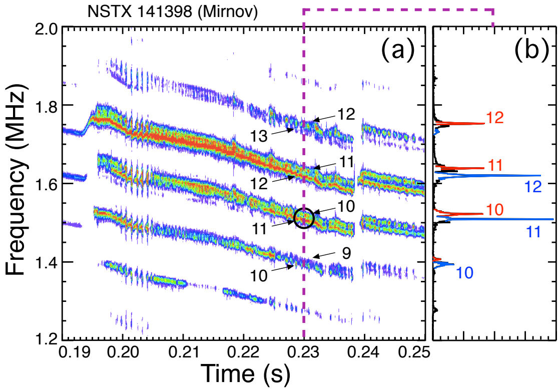

Fig. 2. Detail of spectrogram in Fig. 1, showing detail of high frequency, co-propagating CAE cluster. Toroidal mode numbers are indicated.

The magnetic fluctuations are measured externally with Mirnov coils. The Mirnov coil measurements provide information on the toroidal mode number n, on the polarization of the magnetic fluctuations near the plasma edge (shear or compressional) and some limited information on the poloidal structure in the outboard-midplane region. The profile of the internal density fluctuations is measured with the multi-channel, fixed frequency reflectometer array with spatial resolution and coverage determined by the equilibrium density profile. L-mode or monotonically peaked density profiles provide optimum reflectometer coverage, but many H-modes also show some density peaking and useful profiles of mode structure can be obtained for these plasmas.

To date, the identification of high frequency modes as CAE or GAE has relied primarily on comparison of frequency evolution with simplified dispersion relations, and to a lesser extent, on the measured mode polarization at the plasma edge. The mode polarization measured at the plasma edge is not a reliable indicator of internal mode character, as the plasma geometry in a low aspect ratio toroidal device can introduce significant coupling between shear and compression eigenmodes.

Most of the high frequency Alfvén modes, that is with frequencies between roughly 300 kHz and 1.5 MHz, are propagating in the direction counter to the plasma current and neutral beam injection. These waves are believed to be excited through a Doppler-shifted cyclotron resonance where the mode frequency in the fast ion frame approximates the cyclotron frequency. There are some higher frequency modes, however, which propagate in the co-plasma current direction (Fig. 2). These tend to have higher frequencies (>1.5 MHz) and toroidal mode numbers which allows them to satisfy a direct resonance with some beam ions. These modes are believed to be

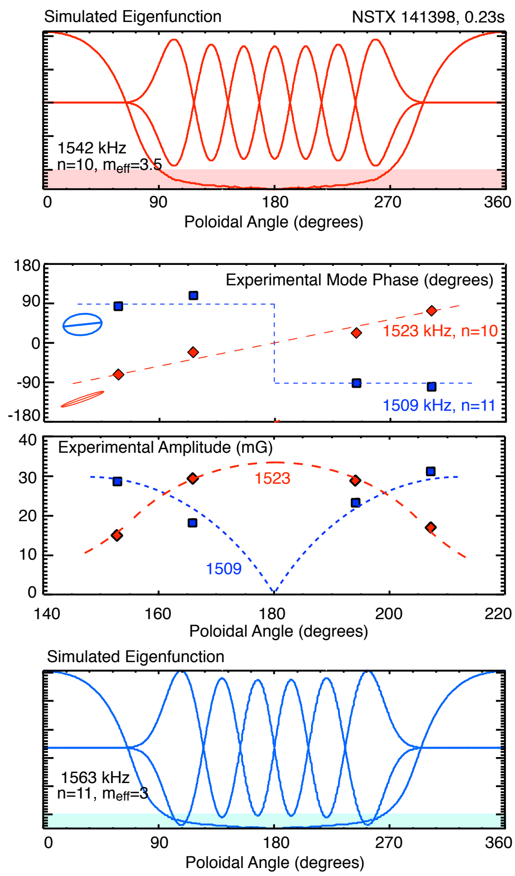


Fig. 3. Relative phase and amplitude for outboard midplane poloidal array of Mirnov coils. Figures above and below show simulated poloidal eigenfunctions.

CAE, and most commonly appear in conjunction with a low frequency kink mode.

The CAE are predicted to be 'trapped' in a well on the outboard side of the plasma (*e.g.*, Figs. 3a and 3d). They are free to propagate toroidally, but the modes would have a 'standing' wave structure poloidally, although the well can be shallow, allowing partial propagation. The experimental mode frequencies evolve in parallel and the frequency spacing is roughly consistent with a simplified CAE dispersion relation [2]. The predicted frequency spacing for a δn of 1 is ≈ 90 kHz, and between poloidal harmonics is ≈70 kHz, compared to a spacing of ≈110 kHz in Fig. 2.

Each 'band' in Fig. 2 consists of at least two modes, *e.g.*, the modes ≈1.5MHz

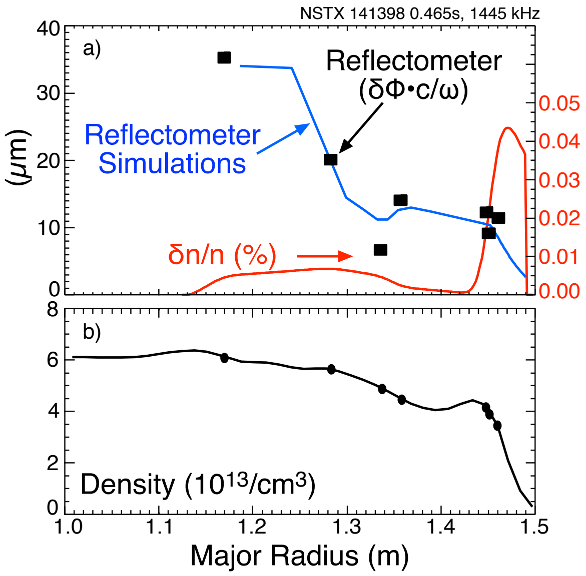


Fig. 4. a) Reflectometer data (black squares) compared to simulation (blue) for inferred profile of density perturbations (red curve) for co-propagating CAE, b) density profile.

have n=10 (f=1.51 MHz) and n=11 (1.52 MHz). Like the other modes in the series, the n=11 mode appears to be a standing wave with a node on the outboard midplane (Figs. 3b&c). The n=10 mode and others in that series, is not a purely standing wave, but clearly has a different poloidal structure. The measured polarization at the plasma edge for all modes is predominantly compressional.

The high frequency CAE occur early in the H-mode phase while the density profile is still very flat or hollow; thus reflectometer measurements of the

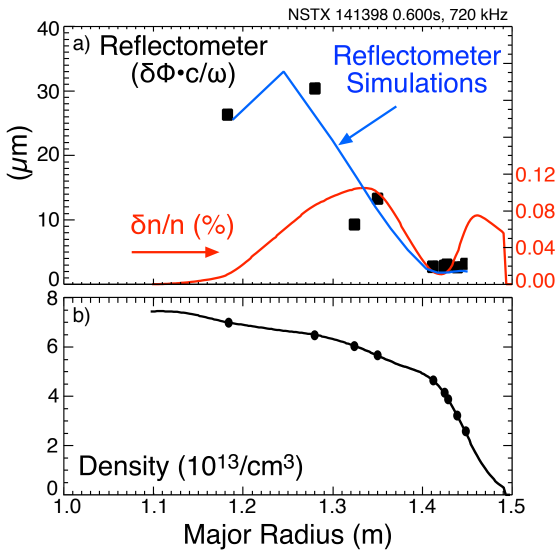


Fig. 5. a) Reflectometer data (black squares) for ctr-propagating CAE at 0.72 MHz, 0.6s in Fig. 1. Blue curve is reflectometer response calculated for a density perturbation (red curve), b) density profile.

mode structure are generally not possible. However, occasionally, one or more of these modes will persist as the H-mode density profile peaks. In Fig. 1a an n=12 co-propagating CAE is seen beyond 0.47s. In Fig. 4a a simulated reflectometer response (solid blue curve) is compared to the data (black squares). The trial density perturbation function used for the simulation is shown as the solid red curve. A similar result that the reflectometer data implies a large edge density perturbation is found for the lower frequency, counter-propagating CAE at 720kHz, 0.6s (Fig. 1b, Fig. 5).

In contrast, profile measurements of strongly bursting high frequency modes, believed to be GAE avalanches, in an L-mode plasma find the density fluctuations peak near or inside the region of $q_{min}$ as seen in Fig. 6. In this example, the density perturbation reaches ≈1%, compared to <0.1% for the CAE above.

Mode profile measurements of high frequency modes believed to be CAE and GAE have been done in L-mode and peaked density profile H-modes with a multi-channel reflectometer. Mode amplitudes reached ≈1% for GAE, albeit for only a few microseconds, and much less for the CAE.

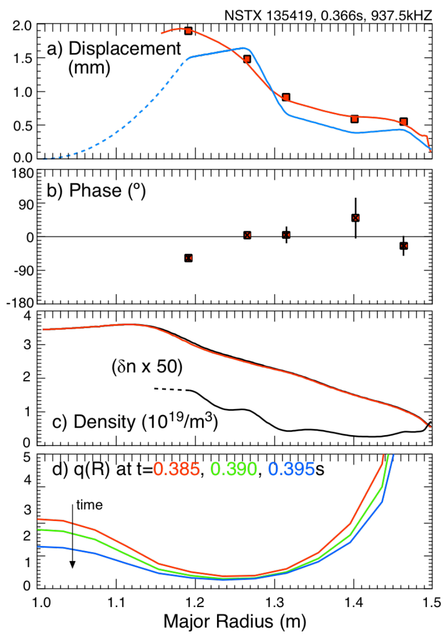


Fig. 6. a) Mode amplitude profile from reflectometer array, b) relative phase of mode, c) density profile, d) q-profile.

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