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Observation of fast chirping modes at frequencies above the Alfvén frequency in JET

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Introduction

Modes propagating with frequencies above the Alfvén frequency ($\omega>\omega_A$) are not normally observed in currently operating tokamaks as the plasma on these machines contains only a modest number of energetic ions with velocities above the Alfvén velocity ($v>v_A$). Notable exceptions are the spherical tokamaks NSTX and MAST, where the injection of super-Alfvénic beams produced significant populations of ions verifying the condition ($v>v_A$) [1], [2]. In these spherical tokamaks, modes with frequencies in the range $\omega_A<\omega<\omega_C$ are routinely observed. Here, ω_C is the cyclotron frequency of beam ions. These modes have been identified as CAE (Compressional Alfvén Eigenmodes) and in few cases as GAE (Global Alfvén Eigenmodes) or a mix of CAE and GAE. The distinction between CAE and GAE is usually quite difficult. Experiments carried out in the conventional tokamak DIIID using low magnetic fields so the injected beam was super-Alfvénic allowed to observe similar MHD activity [3]. CAE/GAE are likely to be destabilized by alpha particles in ITER and they may be important for stochastic heating of thermal ions [4] as well as be used for alpha particles diagnostics [5].
This paper reports on the observation of modes with frequencies in the range $\omega>\omega_A$ which occurred in JET experiments. Contrary to the previously reported cases, in JET, the modes in the super-Alfvénic range of frequencies were destabilized by ICRH accelerated ions and not by beam-injected ions. JET experiments used low plasma densities and high ICRH power, which allowed a significant population of energetic ions in the MeV range of energies to build up in the plasma [6].

MHD activity in the frequency range $\omega>\omega_A$

Figure 1 shows two distinct spectrograms obtained with Mirnov Coils using an acquisition frequency of 1 MHz during JET low plasma density high ICRH power experiments. The nearly constant frequency modes observed between 200 kHz and 250 kHz are TAE, the modes with slowly decreasing frequencies observed in the same range of frequencies are tornado modes, i.e. TAE localized inside the q=1 surface. The fast chirping modes (FCM) are observed to cover nearly all the frequencies ranges shown in figure 1.

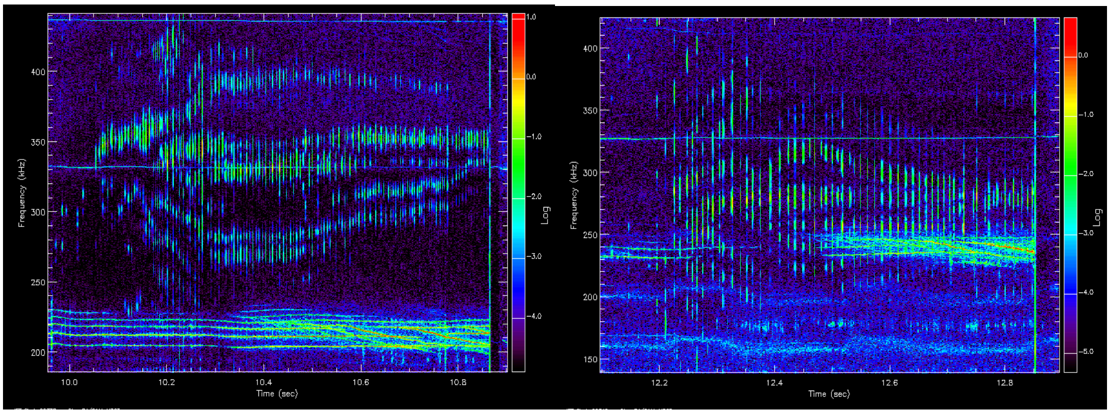

Figure 1: Spectrogram of MHD activity obtained with Mirnov Coils using an acquisition frequency of 1 MHz.

All these modes are suppressed by the monster sawtooth crashes observed near the end of the represented time periods (vertical lines). The FCM present a bursting behavior and are composed by several different frequency bands that may change slowly in frequency as time evolves. In particular, the FCM seem to be affected by the presence of tornado modes. In this set of experiments, a few Mirnov coils were acquiring at a frequency of 2 MHz (see figure 2).

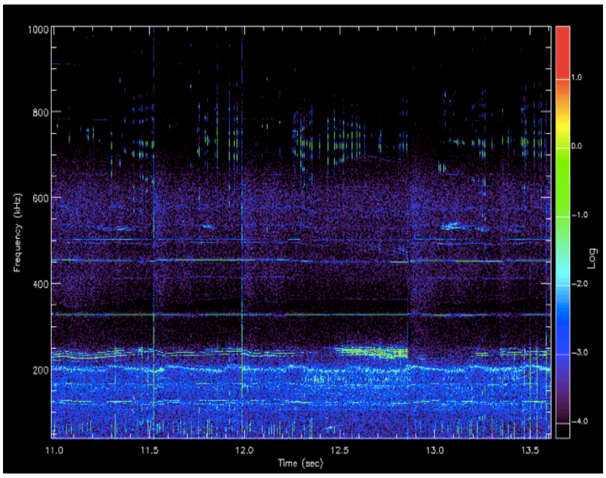

Figure 2: Spectrogram of MHD activity obtained with Mirnov Coils using an acquisition frequency of 2 MHz.

Spectrograms made using signals acquired at 2 MHz show the FCM at frequencies between 750 and 800 kHz. This means the FCM observed in figure 1 are aliases (signals that are undistinguishable from the real signals and that are observed at lower frequencies due to an insufficient sampling rate). The Alfvén frequency in the plasma core in these experiments was typically around 450 kHz, which is well below the FCM frequency. The sub cyclotronic modes in the range of frequencies $\omega_A<\omega<\omega_C$ observed in DIIID, NSTX and MAST may span over a large frequency range, in some cases the modes are observed up to around the cyclotron frequency. In JET, the anti-aliasing system prevents higher frequency modes to be observed in the magnetic spectrograms (which would be observed as aliases), so there is no information regarding the higher frequency limit of the FCM. Despite the presence of JET anti-aliasing system, in the analysis it is considered the possibility of the mode observed around 800 kHz still be an alias.

FCM were sometimes observed during the ramp up phase of the magnetic field. When this happened, the frequency of the central band was observed to change proportionally to the change in the magnetic field (see figure 3), suggesting the FCM has frequency dependence on $B/(n_E)^{1/2}$, characteristic of Alfvénic modes.

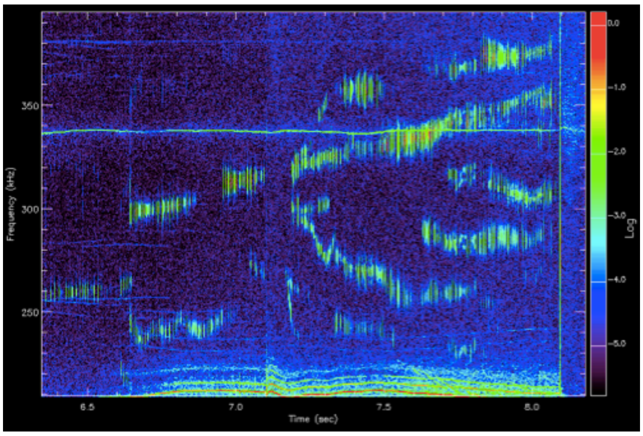

Figure 3: Spectrogram of MHD activity obtained with Mirnov Coils during the magnetic field ramp up phase using an acquisition frequency of 1 MHz.

FCM are observed both with positive and negative toroidal mode numbers n, this is, they propagate both in the co and counter current directions. This suggests the drive of FCM to be associated with the free energy in the velocity space, implying the distribution in energy must have a local "bump-on-tail" like distribution ($\partial F/\partial E>0$). The loss of fast ions from the plasma in this set of experiments was measured by a scintillator plate. These measurements indicated that FCM have little or no influence on the loss of fast ions.

Comparison of FCM with CAE/GAE in NSTX, MAST and DIIID

The sub cyclotronic modes in the range of frequencies $\omega_A<\omega<\omega_C$ observed in DIIID [3], NSTX [1][7] and MAST [2][8] were identified as CAE. In NSTX and DIIID, a mixture of CAE and GAE were sometimes observed. A bursting behavior of the modes, similar to JET FCM, has been observed in all three tokamaks, though sometimes, modes were observed as continuous (not bursting) modes. In DIIID, NSTX and MAST, groups of modes at different frequency ranges were observed. In JET only one group, near the lower frequency limit, was observed but in case there were other groups of modes present in the plasma they wouldn't be observed due to the inexistence of appropriate diagnostics acquiring at a sufficiently high sampling rate. Each of these groups of modes presented a finer frequency splitting and a presence of "bands". FCM in JET also showed the presence of bands. In all three mentioned tokamaks, modes propagating both in the co and counter current direction were observed (in DIIID, toroidal mode numbers were inferred, not measured), consistent with the drive of both CAE and GAE which is associated with a local positive gradient of the fast ion distribution in energy. Finally, the CAE and GAE observed in the three mentioned tokamaks showed a frequency dependence on

$B/(n_E)^{1/2}$ (as it had to be, since it is a characteristic of Alfvénic modes). FCM in JET presented the same frequency dependence.

Summary and discussion

The observation of fast chirping modes with frequencies above the Alfvén in JET is reported. Contrary to the modes observed in this ranges of frequencies in other tokamaks, namely DIIID, MAST and NSTX, in JET the modes were not destabilized by the injection of super-Alfvénic beams into the plasma but by high power ICRH applied on a low density plasma. Alfvénic modes known to exist in the range of frequencies $\omega_A<\omega<\omega_C$ are the Compressional Alfvén Eigenmodes and the Global Alfvén Eigenmodes. Indeed, fast chirping modes in JET exhibited a frequency dependence characteristic of the Alfvénic modes. While all the aspects mentioned in this and previous section suggest the fast chirping modes observed in JET to be CAE/GAE modes, there is still an open issue related with the mode frequency. The lower frequency limit of CAE/GAE in DIIID, MAST and NSTX deviate significantly from the cyclotron frequency of the energetic ions. Similarly, in JET the FCM frequency deviates significantly from the cyclotron frequency. However, when CAE/GAE are destabilized by super-Alfvénic beams, the ions can resonate with the lower frequency CAE/GAE through the Doppler shifted wave particle resonance because the parallel velocity of the energetic ions is large. This is not the case of ICRH accelerated ions. So, if the fast chirping modes observed in JET are indeed CAE/GAE, the ICRH accelerated ions must possess a significant drift velocity.

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