Alfvén-character oscillations in ohmic plasmas observed on the COMPASS tokamak

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Energetic Particle (EP) driven plasma modes resulting from interaction of shear Alfvén waves with fast (i.e. comparable to plasma Alfvén velocity V_A) ions generated by fusion reactions, NBI or ICRH heating [1] are capable of causing fast particle losses, hence negatively affecting the plasma performance or having detrimental effects on plasma-facing components or vacuum vessel [2]. A number of comprehensive reviews has already been published, describing properties of EP modes, their appearance, excitation and damping mechanisms, etc. (e.g. [1, 2, 3]). The modes are not trivially expected to appear in ohmic plasmas, however, plasma oscillations bearing their typical signatures have been reported in plasmas without an apparent source of EP on a number of devices (such as TFTR [5], ASDEX-U [6], MAST [7], TUMAN-3M [8]). While impact of these specific phenomena on plasma performance does not seem to be as significant, their closer investigation will yield better understanding of the under-

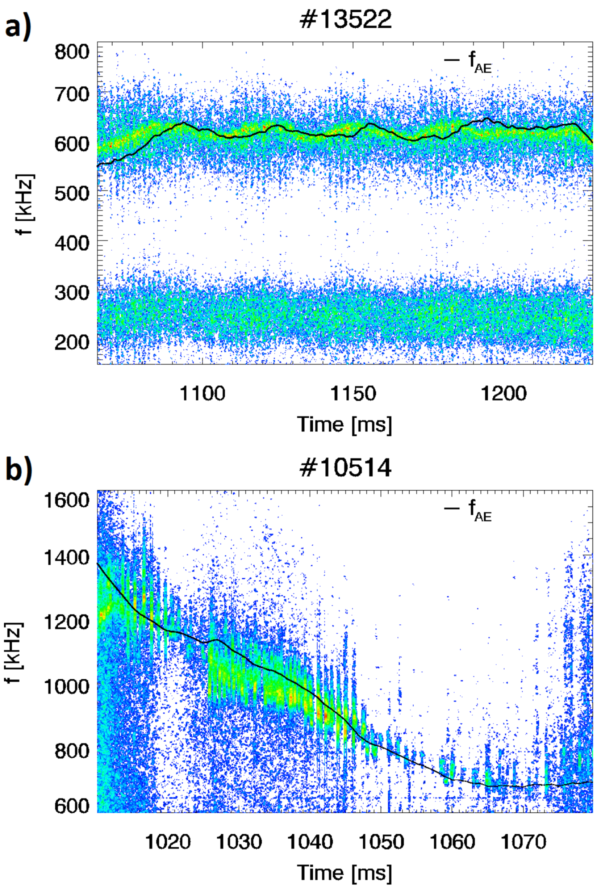

Figure 1: *High-frequency magnetic fluctuations. f_{AE} curve from eq. (1). a) Quasi-coherent oscillations observed on inboard-torus side. b) Chirping coherent oscillations observed close to separatrix on outboard-torus side.*

lying EP mode physics. Here, an observation of two types of such instabilities in ohmic regime plasmas on the COMPASS tokamak [4] is reported and the mode behavior is characterised and compared to that on the other devices.

The first type of such plasma magnetic fluctuations appear on inboard side of the torus (although it also appears as electrostatic fluctuations on divertor) and typically takes form of a set of multiple quasi-coherent bands of different frequencies - see fig. 1 a). Oscillations are pronounced the most in diverted L-mode discharges (at all plasma densities), although they also appear in circular limited plasmas and in H-mode plasmas. Mode spatial structure does not show a clear n or m mode number, but frequency follows parametric scaling associated with toroidal Alfvén eigenmodes [2]:

$$f_{AE}(r) = \frac{1}{2\pi R q(r)} \frac{B_0}{\sqrt{\mu_0 \rho(r)}} \approx \frac{K_C B_0}{q_{95}\sqrt{n_e}} \quad (1)$$

with R being major radius, $q(r)$ safety factor on r radius, B_0 toroidal magnetic field, μ_0 vacuum permeability and ρ dominant ion mass density, n_e line-averaged electron density and K_C a constant specific to the dishcarge parameters that do not change on shot-to-shot basis. The modes follow this relation both within the temporal evolution of parameters of single discharge - fig. 1 a) as well as across plasma current flat-top phases of different discharges - fig. 2 a).

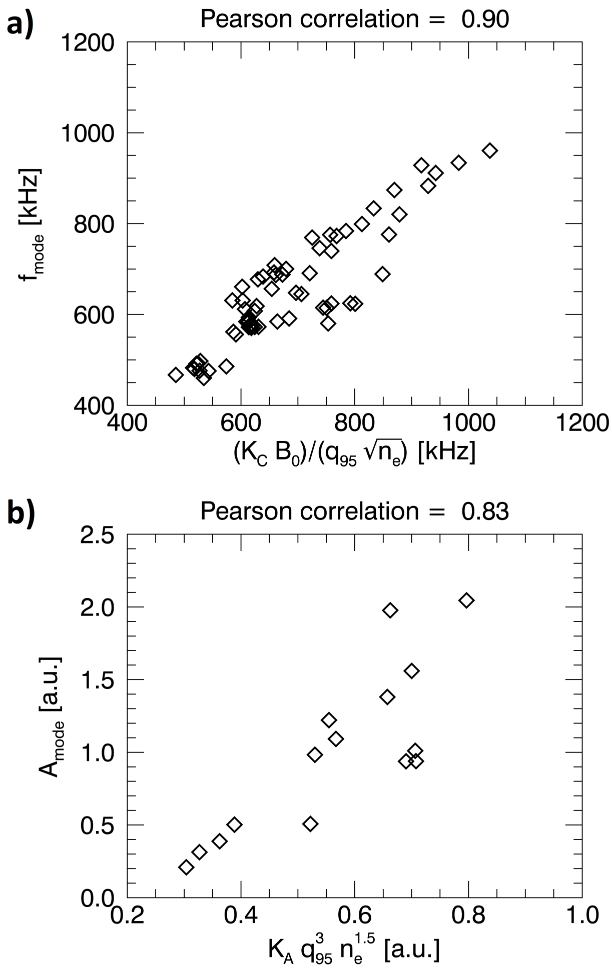

Figure 2: *Multi-discharge comparisons of observed quasi-coherent mode properties to scalings. a) Mode frequencies vs. scaling in eq. (1). b) Mode amplitudes vs. scaling in eq. (2).*

In many aspects, such as presence over the most of the discharge duration, inboard-side localization and appearance as a set of quasi-coherent frequency bands, these fluctuations are very similar to *Alfvén Frequency Modes (AFM)* that have been observed on the TFTR tokamak [5]. Moreover, apart from adherence to eq. (1), they also share the amplitude scaling:

$$A = K_A q_{95}^3 n_e^{3/2}, \quad (2)$$

(with K_A being a constant of analogical character than K_C) as can be seen in fig. 2 b), decrease of mode amplitude upon L-H transition and correlation with the edge MHD events such as ELMs. The excitation mechanism of the quasi-coherent modes may be therefore connected to plasma edge turbulences, in analogy to similar Alfvén-character modes in ohmic plasmas on AUG [6].

Another type of high-frequency ($f \sim 600-2500$ kHz) plasma magnetic fluctuations appears in low-density discharges ($n_e < 3 \cdot 10^{19}$ m^{-3} where n_e is line-averaged density) with large runaway electron (RE) populations. The associated modes have clear coherent structure of $n = 1$ and $m > 1$ and appear on outboard-side of the torus as series of subsequent chirping outbursts, with rare transition to continual mode. The individual bursts are of short duration and on longer time scale their frequency follows Alfvén mode scaling from eq. (1) - see fig. 1 b). These oscillations typically appear for only tens of ms, in contrast to the quasi-coherent modes that last the whole discharge. With taking into consideration also the very short duration of individual chirp bursts, this implies a strong damping mechanism, perhaps even that of Alfvén continuum. Hence their excitation mechanism is principally different from that of the quasi-coherent modes.

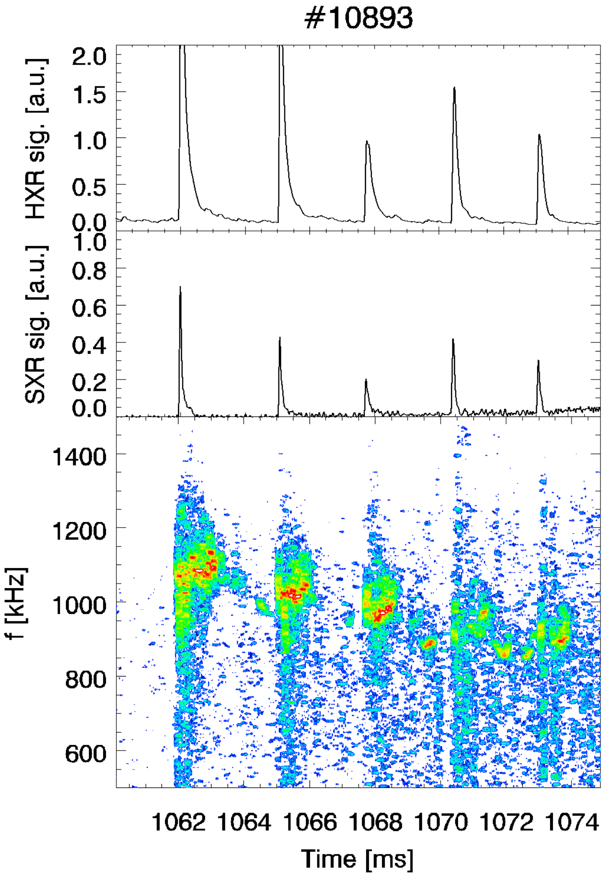

Figure 3: *Correlation of chirping oscillation bursts shown on spectrogram to hard X-ray radiation (scintillator detector outside of chamber) and soft X-ray radiation (bolometer inside vacuum vessel with line of sight through the plasma center) signals.*

Similar short-duration, Alfvén-character magnetic plasma fluctuations in ohmic-heated plasmas have been reported on MAST [7] and TUMAN-3M [8] tokamaks, with mode appearance coincidential with MHD events such as internal reconnection events during sawtooth crashes. This has also been observed to be valid for COMPASS chirping modes. Moreover, the correlation of the individual mode outbursts with X-ray spikes shown in fig. 3 connects the mode excitation with RE crossing the saparatrix as they escape the plasma. The amplitude of the mode oscillations is also coupled with the intensity of the X-ray radiation and the mode sequence tends to be trigerred by a pronounced X-ray spike in the early discharge phase.

Two different types of Alfvén-signature magnetic fluctuations of the plasma have been reported in ohmic discharges on the COMPASS tokamak. Both of these are different from those reported in the past work [9] which were all present in ohmic H-mode regimes at lower frequencies. Long-lived oscillations that have the appearance of several simultaneous quasi-coherent bands, poloidally localized on the inboard side of the torus, share many similarities with the so-called Alfvén frequency modes reported on the TFTR tokamak [5], as well as with ohmic-plasma TAE oscillations reported on the ASDEX-Upgrade tokamak [6]. Their possible excitation mechanism might be associated with interaction of edge plasma turbulece with shear Alfvén waves, similar to the one mentioned in [6], which will be further investigated.

Higher-frequency (up to 2.5 MHz) coherent magnetic fluctuations of Alfvén-character present on the outboard torus side seem to have different excitation mechanism, implied by their appearance in low-density, RE-rich discharges as a series of short frequency bursts that are correlated with X-ray radiation spikes. One such mechanism might be periodic MHD events in core plasma, such as internal reconnection events during sawtooth crashes, in analogy to the modes reported on MAST [7] and TUMAN-3M [8] tokamaks. Additionally, COMPASS observations also imply excitation by the interaction of the RE beam with shear Alfvén plasma modes present close to the plasma edge and this too will be a subject to future studies.

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