Ion Cyclotron Emission from the ohmically heated plasma in the TUMAN-3M tokamak

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ABSTRACT

- Unique observation of Ion Cyclotron Emission from ohmically heated plasma in the absence of energetic ions (ohmic ICE) is presented
- Ohmic ICE originates from a peripheral plasma and has a frequency corresponding to IC resonance in close vicinity of magnetic probe
- Up to 15 equidistant harmonics in the spectrum of the ohmic ICE can be detected
- Possible mechanisms of the ohmic ICE generation are:
  (1) thermal emission of gyrating ions or
  (2) growth of Ion Cyclotron Drift Instability *(Mikhailovsky NF(1971) 323)*
- Ohmic ICE can be used for measurement of hydrogen isotopes ratio

BACKGROUND

- Until now in laboratory experiments ICE was found to be driven by resonant interaction of waves with energetic ions produced either by powerful auxiliary heating (NBI, RF) [1] or in fusion reactions [2]
- Non-monotonicity or anisotropy of ion distribution function in velocity or physical space is considered as an energy source for the instability which in turn generates e.m. waves [3]
- ICE in the ohmically heated plasma in the absence of energetic ions has been observed for the first time [4]. Experiments were performed in the circular shaped limiter tokamak TUMAN-3M [5] with the following plasma parameters R(0)=0.53 m, a=0.22 m, B_T=1 T, I_p=150 kA, $\bar{n}_e$=(1-4)·10^{19} m^{-3}, T_e(0)=0.6 keV, T_i(0)=0.2 keV
- Paper reports characterization of the ohmic ICE, its properties, analysis of underlying mechanisms, its possible use for measuring hydrogen isotopes' ratio
- Note: In TUMAN-3M ICE driven by NBI was observed as well. Study of NBI ICE is presented at this conference in a separate report [6]

DESCRIPTION OF EXPERIMENT

MAGNETIC PROBES SETUP

Measurements of the ohmic ICE were performed using low inductance probes sited inside tokamak vessel. Each probe consists of 7 turns having area of 0.5 cm^2. Magnetic axes of most probes are directed poloidally. Schematic layout of the probes is shown in Fig.1. In addition, a set of 16 probes equidistantly placed at the inner surface of vessel was used. Sampling rate of the data acquisition system is 250 MHz.

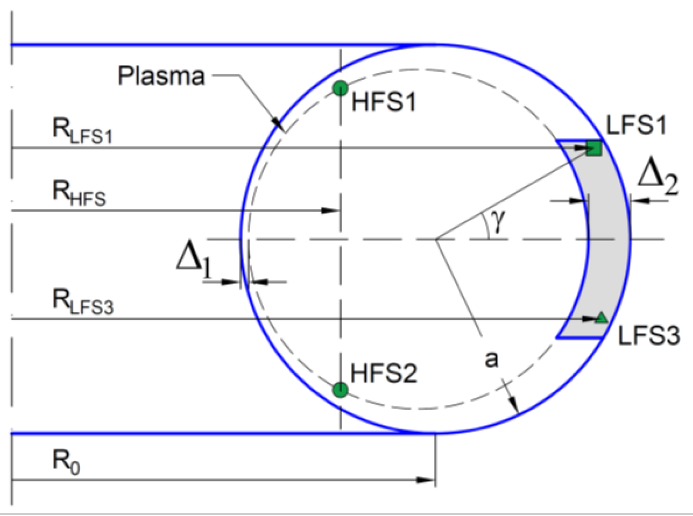

Fig.1. Projection of the probes location (green symbols) on poloidal cross-section, HFS1, HFS2 – probes locations at high toroidal magnetic field side, LFS1, LFS3 – probes locations at low field side. γ – poloidal angle, dashed line – plasma cross-section, grey area – limiter.

OHMIC ICE PROPERTIES

In Fig.2 ohmic ICE spectrogram is shown. It is obtained in deuterium plasma using probe HFS1 sited at R_{probe}=0.43 m. Proportionality of harmonics' frequencies to toroidal field is justified by the coincidence of scaled B_T trace with third harmonic frequency evolution as seen in the figure. No variation of the ohmic ICE frequency (f_{exp}) with density was observed.

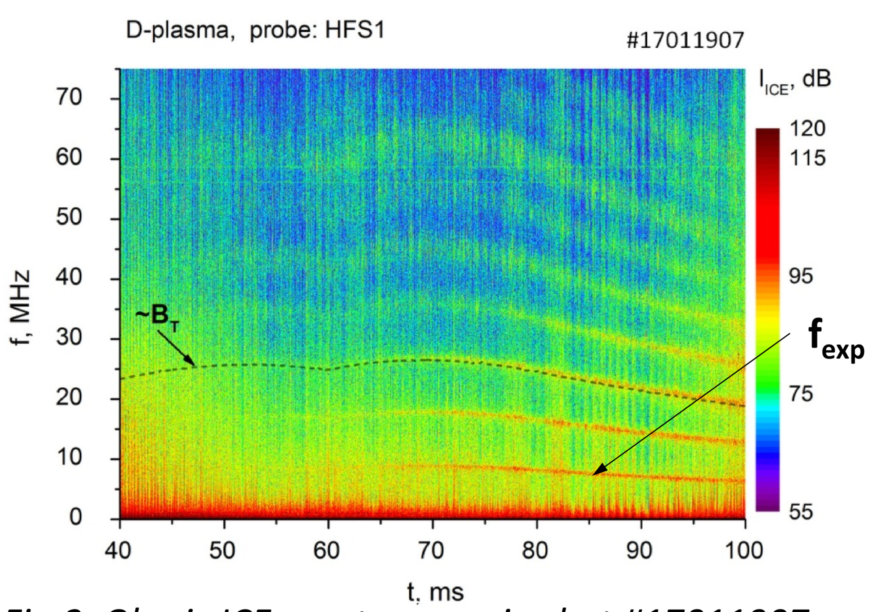

Fig.2. Ohmic ICE spectrogram in shot #17011907. f_{exp} matches IC resonance frequency in vicinity of the probe location

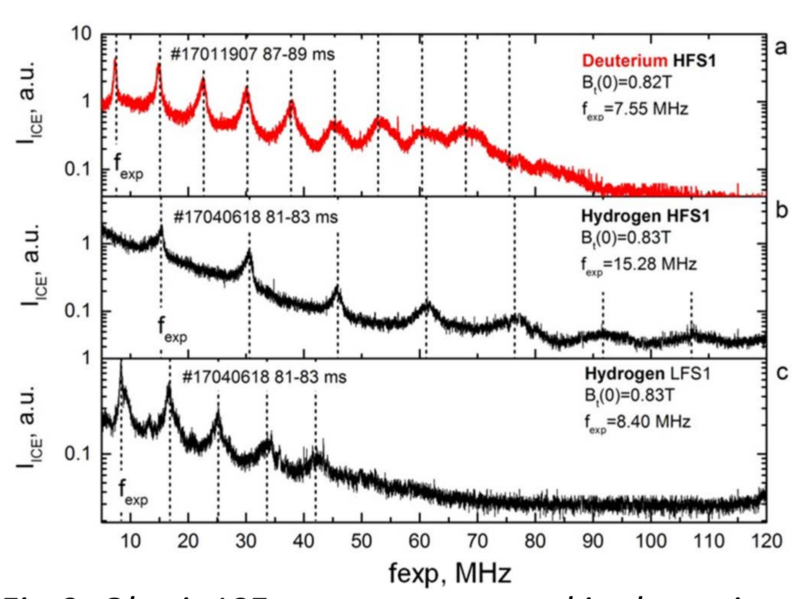

Fig.3. Ohmic ICE spectra measured in deuterium – a and hydrogen – b plasmas using probe HFS1 and in hydrogen plasma using probe LFS1 – c

Ohmic ICE frequency is inversely proportional to working gas mass. That is seen in Fig.3, where comparison of spectra measured in deuterium (a) and hydrogen (b) plasmas using probe HFS1 is presented. Mass dependency of f_{exp} was confirmed in shots with helium working gas. Frames (b) & (c) in Fig.3 illustrate f_{exp} dependence on probe location.

Number of observable ohmic ICE harmonics depends on density, the higher $\bar{n}_e$, the higher number of harmonics could be detected. In shots #17011907 & #17040618, see Figs.2&3, $\bar{n}_e$ was 1.2-1.7·10^{19} m^{-3} and 5-9 harmonics are resolved, whereas in spectrum obtained at higher density $\bar{n}_e$ =3.2·10^{19} m^{-3}, see Fig.4 (shot #18122706), up to 15 harmonics are visible. Note the number of harmonics in helium is small – not more than two harmonics were detected.

Other distinction of spectrum recorded in shot with higher density #18122706 is its non-monotonous character – in the range of 1-6 harmonics amplitude of peaks increases with frequency and then (range of 6-15 harmonics) decays, whereas in shots with lower density #17011907 & #17040618 the amplitude decreases monotonously.

Strong effect of density on fundamental harmonic width was found. In the spectrum in Fig.3 (frame 1) the FWHM of the first peak is 0.5 MHz. The narrowness of the peak indicates that source of the emission is strongly localized in both the major and minor radius directions.

DESCRIPTION OF EXPERIMENT (cont.)

OHMIC ICE PROPERTIES (cont.)

The size of the emitting area was estimated to be less than 2.5 cm. The peak width increases with harmonic number. FWHM of the 5th harmonic is 3 MHz. It should be noticed that narrow fundamental harmonic peak is the characteristic of the low density plasma. With the increasing density the line width rises. At $\bar{n}_e$ of 3.2·10^{19} m^{-3} FWHM of the peak goes up to 2-2.5MHz.

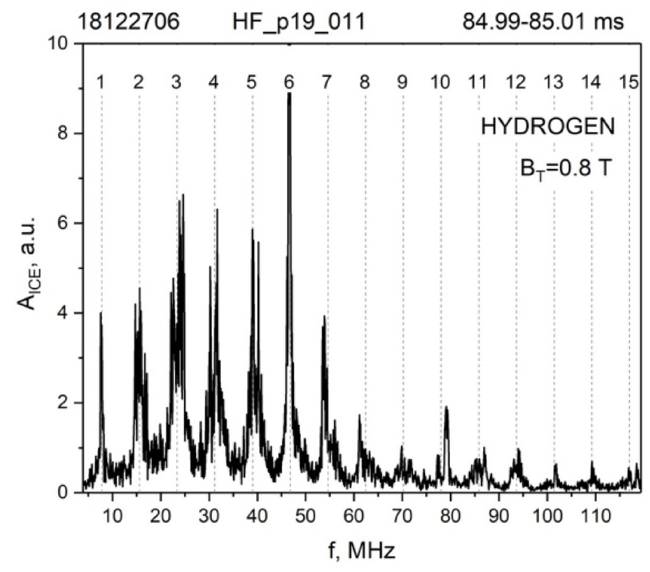

Fig.4. Ohmic ICE spectrum in shot with $\bar{n}_e$ =3.2·10^{19} m^{-3} (#18122706), working gas – hydrogen. Probe location – 11° above equatorial plane in poloidal direction.

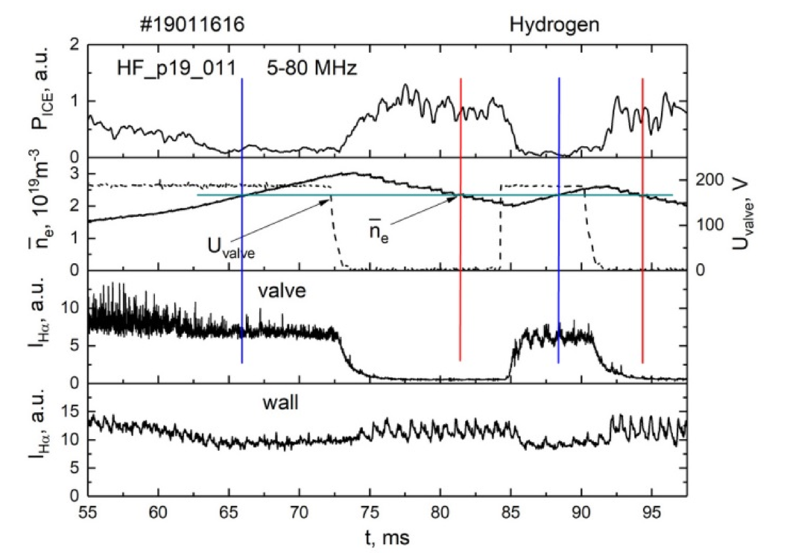

Fig.5. Evolution of the ICE power in the range of 5-80 MHz – frame 1, $\bar{n}_e$ – frame 2, H-alpha Intensity in vicinity of puffing valve – frame 3 and far from valve – frame 4. Probe location – same as on Fig.4.

Density isn't the only factor influencing ohmic ICE intensity. Experiments with dynamic density perturbations have shown substantial reduction of the emission power within the frequency range 5-80 MHz when puffing is switched-on. Fig.5 shows variation of P_{ICE} by a factor of 8 at the same density (green horizontal line) with gas puffing switched on (blue vertical lines) or off (red vertical lines). Possible cause of the observed variation is a change in the edge ion temperature due to alteration of the charge-exchange losses.

HYDROGEN ISOTOPE RATIO MEASUREMENT

In order to explore possibility of measuring isotope ratio in hydrogen plasma a discharge with plasma current of 150 kA and hydrogen working gas was formed, see Fig.6. At 57 ms, when quasi-stationary current and density are achieved, hydrogen puffing was replaced with deuterium one. In Fig.6 ohmic ICE spectra for 58.45 and 79.75 ms are presented. First (black) spectrum contains only a proton line at f_{cH}=17,8 MHz, in second spectrum (red) deuteron line f_{cD}=8,9 MHz appears. In second spectrum line 17,8 MHz consists of fundamental proton frequency and second deuteron harmonic f_{cD2} lines. Input f_{cD2} into intensity of 17,8 line was calculated as 0.5(I(f_{cD})+I(f_{cD3})), where I(f_{cD3}) – intensity of 3rd deuteron harmonic. In Fig.7 red trace presents calculation of $n_D/(n_H+n_D)$ using described algorithm, blue symbols with horizontal error bars were obtained using spectroscopic measurements of H-beta/D-beta lines intensities. Non-zero relative concentration of deuterium in the pre-puffing phase appears due to the insufficient contrast of the deuterium registration channel for hydrogen scattered light.

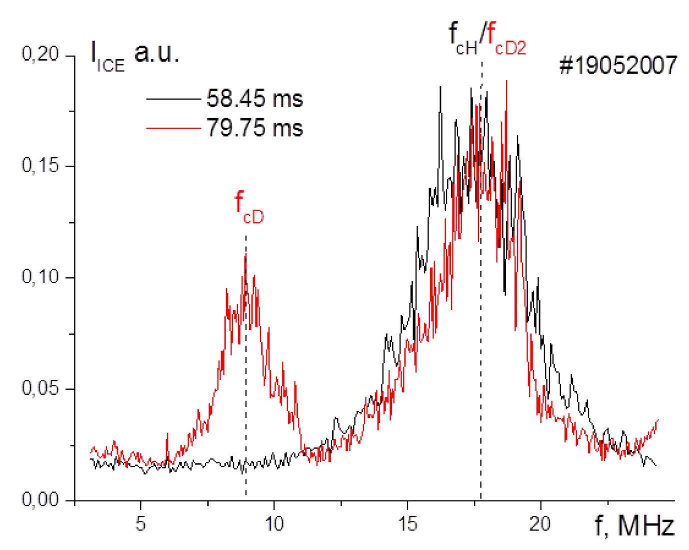

Fig.6. Ohmic ICE spectra obtained in hydrogen discharge before (black) and after (red) deuterium puffing

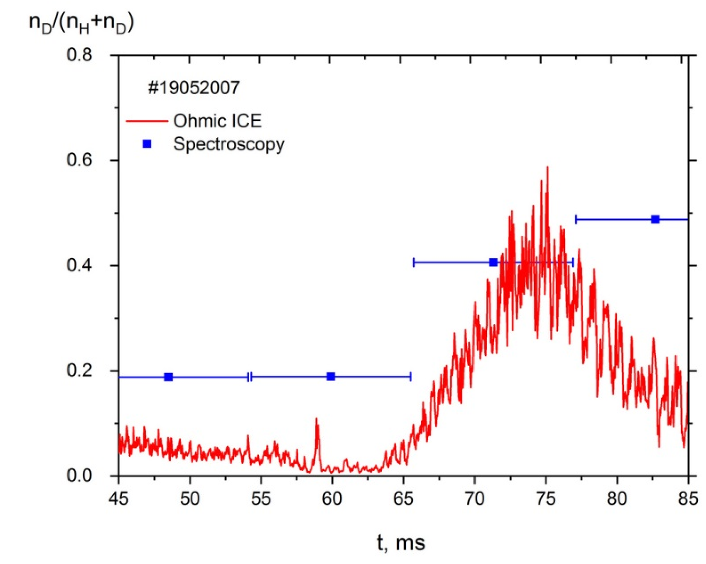

Fig.7. Evolution of $n_D/(n_H+n_D)$ ratio obtained using intensities of ohmic ICE (red curve) and derived from H-beta/D-beta measurements (blue symbols)

DISCUSSION

Two possibilities are considered as possible mechanisms of the ICE generation in the absence of energetic ions. First, the ohmic ICE at the multiple harmonics of IC resonance frequency can be generated as a result of a thermal emission of gyrating ions. In this case amplitude of a fundamental harmonic linearly depends on concentration of the thermal ions and proportional to ω^2 in low to medium dense plasma.

Another possible mechanism of the ohmic ICE generation is excitation of Ion Cyclotron Drift Instability (ICDI) in the presence of a plasma density inhomogeneity [7]. According to [7] the condition of ICDI excitation in a single component plasma is: $\rho_i/\alpha > 2(m_e/m_i)$^0.5, where ρ_i – ion Larmor radius, α=n/(dn/dr) – radial scale of the density gradient, m_e and m_i – electron and ion masses, respectively.

Our simulations have shown that above criterion could be fulfilled in the experimental conditions of TUMAN-3M. In this case relationship between amplitudes of isotope fundamental harmonic depends on ICDI saturation level which will be further analyzed.

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