PARAMETRIC DECAY IN THE EDGE PLASMA OF ASDEX DURING FAST WAVE HEATING IN THE ION CYCLOTRON FREQUENCY RANGE

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Abstract: For the first time, in an ICRF heated tokamak, parametric decay instabilities were observed in the plasma edge. Two types of decay processes were found. Those instabilities provide a mechanism for the direct energy deposition, seen in many tokamaks, on the ions and electrons of the scrape off layer.

Introduction: During hydrogen second harmonic heating at 67 MHz /1/, frequency spectra were measured with an electrical probe. The measuring probe is 10° toroidally away from one ICRH antenna, and 170° from the other. The target plasma can be pure hydrogen or a hydrogen-deuterium mixture (n_H/n_e=25 to 100 %), ohmically heated (P_{OH}=450 kW) or preheated by neutral injection (P_{NI}=0.8-3.5 MW). Analysis of the frequency spectra, revealed the presence of parametric decay effects /2/. Parametric decay is a process by which a wave, called the pump wave (index 0), decays nonlinearly into two modes (index 1 and 2). These modes have to fulfill the selection rules : $\omega_0 = \omega_1 + \omega_2$ and $\overline{k_0} = \overline{k_1} + \overline{k_2}$. Theoretical studies /2,3/ indicate that several types of parametric decay processes can occur, two of which have been observed on ASDEX.

Parametric decay processes: In a first type, the pump decays into an ion Bernstein wave with frequency close to the pump wave (2e in Fig. 1) and a low frequency electron quasimode (obscured in the spectrum by the zero frequency peak of the spectrum analyser). Growth rate estimates /2/, predict that the convective threshold is easily exceeded.
In the second process, the pump decays into an ion cyclotron quasimode (with frequency near the ion cyclotron harmonic of an ion species in the edge, $\omega_1 = \omega_{ci}$) and an ion Bernstein wave (with, according to the selection rule $\omega_2 = \omega_0 - \omega_1$). The study of this process can benefit from

thorough analysis previously performed in a small research machine /4/. Because of the dependence of the frequency of the quasimode on the magnetic field, it is possible to identify this mode unequivocally. In Fig. 1 three spectra, at different toroidal magnetic field, and for a fixed pump frequency (67 MHz) show clearly how the frequency of the quasimode 1H depends linearly on B_T, and how the frequency of the corresponding ion Bernstein wave 2H then obeys the selection rule. In a multispecies plasma (i = H, D), we find that this proces can occur for both species. In a machine with carbonized walls, there are even indications that C at different ionisation stages can be the ion species supporting the quasimode. On first turn on of the RF in a shot, a more complicated spectrum (Fig. 2) can appear, with splitting of the peaks. This is thought to be due to the initial outgassing of the antenna, which can change the boundary temperature directly in front of the antenna, and the isotope concentration.

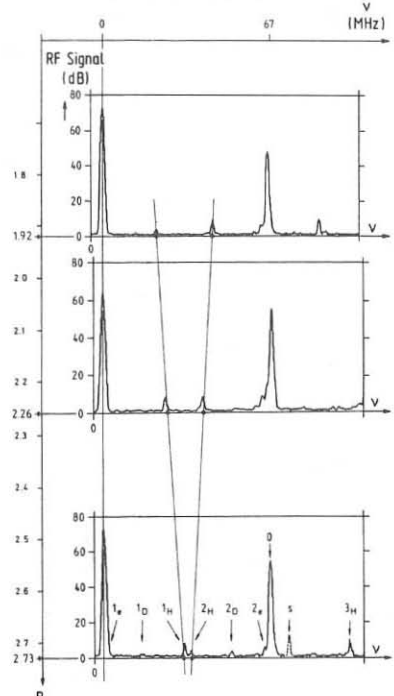

Fig. 1. Frequency spectra for three magnetic fields, showing the B dependence of the modes

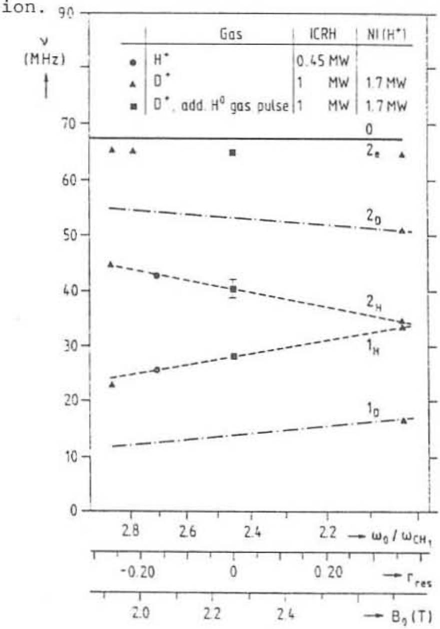

Fig. 3. Parameter region for the appearance of the decay instabilities

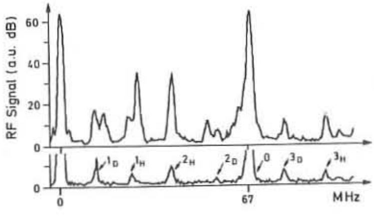

Fig. 2. Spectrum at the first turn on of the ICRH (top) compared to a spectrum (bottom), 800 ms later in the same pulse

Dependences: Whether or not the H and D decay processes were observed, depends strongly on the plasma composition and heating conditions. By varying the toroidal magnetic field, at constant pump frequency, the position of the second harmonic resonance layer was varied between r=-0.22m and r=+0.38m, with respect to the plasma centre at R=1.67m (with a=0.40m and the antenna protection limiters at r=0.45m). This also changes the ratio ω_0/ω_{ci} in the edge between 2.87 and 2.03. Fig. 3 show some of those conditions.
In a H plasma, with 0.45 MW of ICRH, on the antenna closest to the probe, the decay processes were observed only for positions of the resonance layer r<-0.13m ($\omega_0/\omega_{ci}>2.7$), with data available only up to r=+0.16m ($\omega_0/\omega_{ci}=2.3$). In a D and H mixture (30% H) with 1MW ICRH, on the antenna furthest from the probe, and 1.7 MW NI, they were observed only for r<-0.22m or r>0.38m (corresponding to $\omega_0/\omega_{ci}>2.9$ or <2.0).

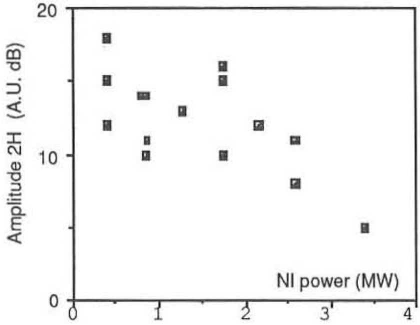

Fig. 4. Dependence of the 2H peak on NI power, for 1.2 MW of ICRH

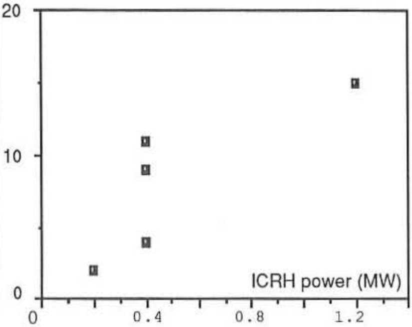

Fig. 5. Dependence of the 2H peak on ICRH power, no NI power

An additional H gas pulse made the instabilities appear, for a near central position of the resonance layer (r=0.03m), under all conditions (any antenna, down to 200 kW ICRH, any NI power). A clear anticorrelation, however, was then found between the amplitude of the 2H peak and the neutral injection power, as shown in Fig. 4. The amplitude of the 2H peak, measured under steady state conditions, increases with ICRH power (Fig. 5). This is in contrast to an experiment where, as the power was ramped up, the amplitude remained almost constant. Those effects can be understood in the following way: a better absorption of the fast wave, provided by the preheating with NI, will reduce the electric fields in the edge and thus the growth rate of the instabilities. The instabilities are also reduced by a higher NI power through the increased boundary temperature (theory predicts that the growth rate of the instabilities decreases for increasing boundary temperature). Higher RF powers result in higher RF electrical fields, and thus more instabilities. The heating of the boundary, due the instabities themselves, seems provide a type of feedback mechanism, so that, when the power is ramped up, the amplitude of the instabilities do not increase. We have also observed the instabilities, with a receiving probe located on the *inside* of the tokamak. Although fewer peaks were present on the spectra, the 1H peak, with the frequency corresponding to the magnetic field at the *outside* egde of the plasma could, under some conditions, be identified.

Importance of those parametric decay instabilities: In many tokamaks direct energy deposition in the scrape off layer, was observed during ICRH. On Alcator, JET, Textor, among others, increases of electron temperatures in the edge were observed. On ASDEX, fast *deuterons* were observed in the edge, with second harmonic *hydrogen* heating /5/. To explain the Fe production at a target plate in Textor/6/, one has to postulate the presence of fast ions, accelerated in the perpendicular direction, in the plasma edge. The parametric decay instabilities, observed on ASDEX in the second harmonic regime, can provide the much sought after mechanism to explain the direct energy deposition in the scrape off layer. Measurements to find them in the minority regime were made on Textor, where now parametric decay instabilities have also been observed /7/.
Edge electron heating could be associated with electron Landau damping of the quasimode. Anomalous ion heating and the production of a suprathermal ion population could result from the damping of the ion quasimode. The ion Bernstein waves, excited in the edge, may be absorbed also on impurities in the boundary. The parametric decay processes may also partly explain why not all the RF power coupled to the plasma is found back in the bulk plasma. Since the probe was not calibrated, we can make no estimate of the total power transferred from the pump wave to the decay modes.

Summary: With the observation of those instabilities an important step was made in the understanding of the direct energy deposition on the ions and electrons of the scrape off layer. This direct energy deposition could be partly responsible for some of the impurity problems encountered with the ICRF heating method. Further investigation of the parametric decay instabilities may provide clues on how to avoid them and can thus contribute to an optimisation of the ICRF antennas and heating scenarios.

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