Generation of suprathermal ions in ECR heated plasmas in the stellarator TJ-II.

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Introduction

The majority ions present in Electron Cyclotron Resonance (ECR) heated plasmas in the stellarator TJ-II are heated through collisions with electrons. Since there is no direct heating of plasma ions their thermal distribution is expected to be Maxwellian. However, during recent experiments in TJ-II a population of suprathermal ions, with energies in the range 600 - 1000 eV and with a non-Maxwellian distribution, was observed during the ECR only heating phase by neutral particle analysers. This result is in line with previous observations made with optical spectroscopy [1]. A possible explanation for this phenomenon is a reduction of the power that triggers the parametric decay instability (PDI) when certain conditions of the density profile, magnetic field and turbulence are fulfilled, as explained in [2]. It is considered that one of the daughter waves from this PDI may heat resonant ions and give rise to the non-Maxwellian distribution. This work presents a series of experiments in TJ-II in which one of its gyrotrons is operated continuously during the whole discharge while the other one is modulated. During the last full power phase of the discharge, cryogenic pellets are fired into the plasma to assess their impact on the suprathermal ion production.

Experimental set-up

The flexible heliac TJ-II is a medium-sized stellarator ($R_0 = 1.5m$, $< a > \leq 0.22m$, $B_0 = 1T$) located at the *Laboratorio Nacional de Fusión (Madrid, Spain)*. Its gyrotrons create and heat the plasma using the 2nd harmonic of the fundamental frequency of the electrons at the centre (53.2 GHz) in X-mode with a maximum nominal power of 250 kW per gyrotron. The microwave power is transferred to the plasma along two quasi-optical transmission lines, the waves beign finally redirected and focused to the plasma by steerable mirrors inside the vacuum vessel. These mirrors, steerable both toroidally and poloidally, allow heating the plasma at different minor radii without inducing current.

The neutral particle analyser (NPA) diagnostic used for this experiment is an Acord-12 with a single row of detectors. It collects hydrogen or deuterium atoms at 12 different energies and its energy range can be changed from shot-to-shot basis, so it can scan the full range of energies in the plasma [3].

The pellet injector [4] is a four-barrel pipe gun device equipped with a cryogenic refrigerator for in-situ pellet formation, fast propellant valves for pellet acceleration (velocities between 800 and 1200 m/s can be achieved) and straight delivery lines. It can inject hydrogen pellets with four different diameters from 0.42 mm to 1 mm. The lines-of-flight of two of the pellet types approach the plasma centre for standard configurations, whereas the other two flight paths have nearest approach at $\rho = 0.27$ and $\rho = 0.45$, respectively, where $\rho = r/a$ is the normalized plasma radius.

During these experiments the plasma is created using both gyrotrons, then one of them is modulated at 100% power. This results in discharges with two very different phases: one with full ECRH power (times 1060-1085, 1110-1135 & 1160-1185 ms), the other with half power (times 1085-1110, 1135-1160 & 1185-1210 ms). The position of one mirror is changed between discharges to investigate the effect of heating radius on the production of suprathermal ions. In addition a gas puff just in front of the NPA line-of-sight increases the flux of neutrals reaching the detectors.

Results

Equation 1 predicts, for a given energy, the flux of neutrals reaching the NPA detectors is proportional to the line integral of the product of neutral density (n_0), ion density (n_i) at the energy of interest and charge-exchange reaction rate ($< \sigma v >_{cx}$) along the diagnostic line-of-sight. The only quantities that can vary along a discharge for a given energy channel are the neutral or ion densities.

$$\phi(E) \propto \int n_0 n_i(E) < \sigma v >_{cx} dl \tag{1}$$

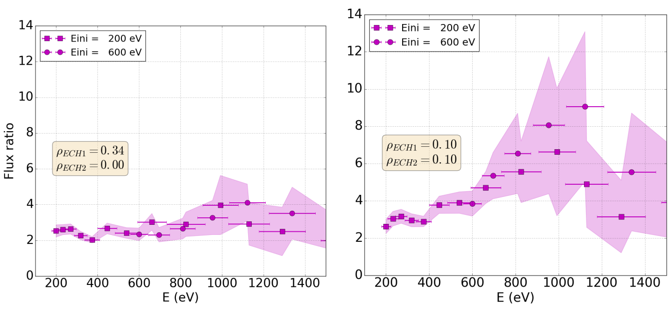

Figure 1: Flux ratios off-centre (left panel) and central (right panel) heating schemes. Two shots per heating scheme are shown, one covering the range 200-1290 eV (E_{ini} = 200 eV), the other covering the range 600-3870 eV (E_{ini} = 600 eV). This is done to increase the number of channels in the range of interest. Eini is the energy set in the lowest energy channel of the NPA, the energies of the other channels are a multiple of this one.

The method used here to assess suprathermal ion production is to calculate and compare the flux ratios for each energy channel during two phases of a discharge ($\phi_{ratio} = \frac{\phi(t=fullECH)}{\phi(t=halfECH)}$). In cases where the ratios for all energy channels are equal, then any change can be credited to a change in neutral density as it is the only parameter common to all energy channels. Otherwise, if a difference exists between channels, it can be attributed to a change in ion density for the energy range covered by the channel.

Heating position During these experiments, the focus of the modulated gyrotron is moved from the centre ($\rho_{ECRH1} = 0$) to a more external position ($\rho_{ECRH1} = 0.42$) between shots whereas the other one is always heating the plasma centre ($\rho_{ECRH2} \leq 0.1$). Neutral flux ratios are shown in figure 1 for the range 200 - 1500 eV for two different heating schemes. In the first instance some significant differences are found for part of, but not all of, this range. For instance, in the largest off-axis heating case (left panel) a large spread in flux with no clear trend, other than a maximum of about 4 at 1 keV, is seen. In the more central heating case (right panel) this ratio increases steadily from 400 eV to 1 keV where it reaches its maximum of 8. From these graphs it is apparent that, for both heating schemes, the ratios are similar at low energy values (E < 400 eV), thus giving an indication that the increase at low energies can be attributed to the increased neutral density. In contrast, above 400 eV the flux ratio increases significantly. It is hypothesized here that this increase must be due to an increased ion density at the scanned energy.

Pellet injection During the final full-power heated part of these discharges, hydrogen pellets are injected into the plasma. This is done to modify plasma conditions and to check the influence of injected particles on the production by ECRH or expulsion of the suprathermal ions. Figure 2 shows the temporal evolution of the flux ratio between a full and half heating power phase for discharge #48267. In this discharge two pellets enter the plasma simultaneously during a full power phase (at $t_{pellet} = 1169.2$ ms when $1160 < t_{full} < 1185$ ms) In figure 2 it is seen that before pellet injection the flux ratios are very similar for the time intervals indicated with a steadily increase in the range 400 –800 eV. After pellet injection the flux ratios in the range 400 –800 eV decrease and become almost flat for the energy range 200 –800 eV. In addition, it is seen how the pre-injection population of ions with E < 1 keV recovers before increasing after 6 ms.

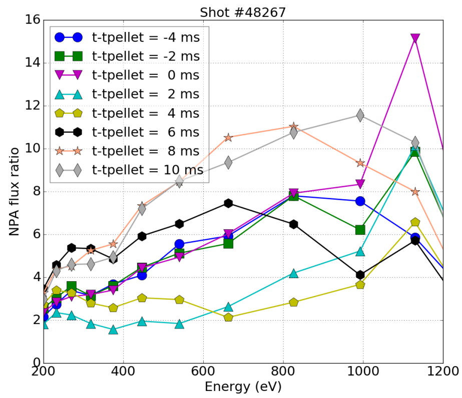

Figure 2: The temporal evolution of the NPA flux ratios for discharge #48267. The flux ratios are calculated during the full ECH phase (1160 < t < 1185 ms) of the discharge when the pellet is injected (tpellet = 1169 ms) for comparison with the flux during the half power phase (t = 1150 ms).

Figure 3 shows density profiles measured by Thomson Scattering for three discharges for a set of experiments. The profile for shot #47688, which is flat inside $\rho = 0.7$, is taken 3.8

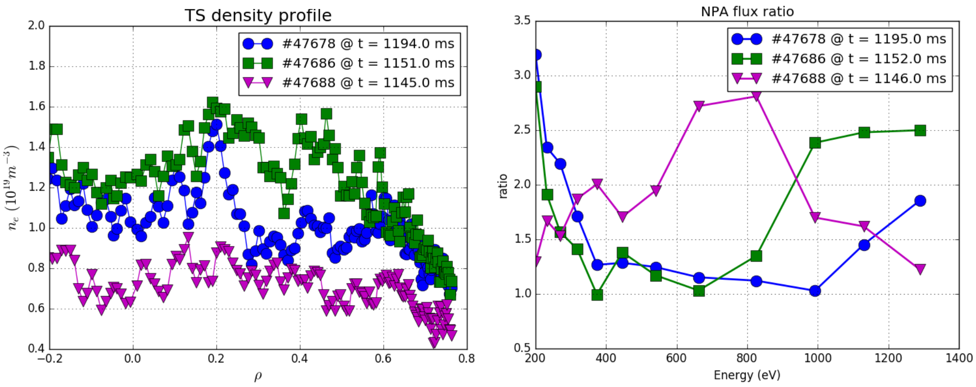

Figure 3: Left: Electron density profiles measured at different time instances by Thomson Scattering in three different discharges. Right: NPA flux ratios collected 1 ms after the Thomson Scattering firing time.

ms before a pellet enters the plasma. The other two profiles, taken after a pellet enters the plasma ($\Delta t = 1.1ms$ for #47678 and $\Delta t = 2.2ms$ after first pellet for #47686), show centrally peaked profiles. In the same figure, the right panel shows the neutral flux ratios between full (at times indicated in the figure) and half heating power (t= 1169 ms for #47678 and t = 1129 ms for #47686 and #47688) 1 ms after the density profiles are taken. It is seen here that the flux ratios obtained just after the pellet injection become flat in the energy range 400 –800 eV (the flux ratios were higher in the same range before the injection), thus it is concluded that pellet injections can inhibit the formation of suprathermal ions.

Conclusions

The experiments presented in this work investigate the generation of suprathermal ions in electron cyclotron heated plasmas in TJ-II stellarator under certain conditions of heating power. The production of suparthermal ions is in the range 600-1200 eV with a maximum at 1 keV, independent of ECR heating position. It is found that the more centrally focused the heating beam the more suprathermal ions that are produced but without change in the energy of the maximum. When an injected pellet reaches the plasma core the plasma conditions change and suprathermal ion production ceases temporally. The ultimate reason for the suppression of the suprathermal ions is not fully understood at the moment, it could be because of the different density profile or the change of collisionality or density.

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