*29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. **26B**, P-5.031 (2002)*

Studies of Suprathermal Electrons in the W7-AS by Means of Pellet Injection

V.M. Timokhin, B.V. Kuteev, V.Yu. Sergeev, V.G. Skokov, R. Burhenn*

and the W7-AS team

State Polytechnical University, Politekhnicheskaya 29, St. Petersburg, 195251, Russia, e-mail: timokhin@phtf.stu.neva.ru

**Max Plank Institut fur Plasmaphysic, EURATOM Association, Boltzmannstrasse 2, Garching, 85748 Germany, e-mail: burhenn@ipp.mpg.de*

Introduction. Suprathermal electrons affect plasma transport properties in tokamaks and stellarators [1]. The appearance of such electron groups in W7-AS stellarator plasma was registered by ECE-diagnostics in regimes with ECR-heating [2,3]. However, the mechanisms of fast electron generation, electron energy, density and localization require additional investigation. An additional information on the suprathermals can be obtained from ablation rate profiles of carbon pellets injected into plasmas [4,5]. In our experiments the carbon pellets ablation studies with high spatial resolution were carried out in a wide range of plasma parameters and two W7-AS magnetic field configurations. The analysis of the data obtained has allowed us to determine the localization, energy and density of suprathermal electrons, and also to suggest a hypothesis on their generation mechanisms.

Experiments. In the experiments, spherical carbon pellets of 0.395±0.015 mm size were accelerated up to 150-350 m/s velocities in the direction of plasma core using DIM-6 injector [5]. The pellet ablation was observed from two directions by CCD cameras and a wide-view photodetector. The CII (723 nm) line emission was registered through interference filters. The details of the experimental setup are described in [5,7]. The ablation rate profile $\dot{N}(r)$ was determined from the CII line emission I_{cl} assuming that $\dot{N}$ is proportional to I_{cl} [7].

The following range of plasma parameters has been studied: 1) the ECRH power of 140 GHz corresponding to the second harmonic of cyclotron frequency P_{ECRH} = 200-900 kW; 2) the electron density at the magnetic axis $n_e(0)$ = (2-6)×10^{13} cm^{-3}; 3) the magnetic configuration was either "Bmax" or "Standard" [8].

Typical ablation rate curves for regimes with different P_{ECRH} and $n_e(0)$ are shown in Fig 1. One can see that in shots with high density and low heating power (the black curve in Fig. 1a)) the ablation rate changes smoothly while the pellet penetrates into the plasma. Below this type of the ablation curve is referred to as "smooth". If the ECRH power increases or the electron density decreases, momentary flashes appear on the ablation curve.

The localization area of these flashes is about 2-4 cm and it is maximal at the minimal density and maximal P_{ECRH}. The emission amplitude during these flashes is several times higher than the normal emission level. The characteristic peak width is usually 1-3 mm. The new type of the $\dot{N}(r)$ curves (red and blue curves in Fig. 1a), all curves in Fig. 1c)) is referred to as curves with narrow localized enhanced ablation (NLEA). This NLEA type differs essentially from the "smooth" ones studied also in [5,7].

For "Bmax" and "Standard" magnetic configurations, the dependence of the NLEA zone behavior on plasma parameters is similar. The experiments have shown that in "Bmax" regime the threshold of NLEA effect appearance lies at lower $n_e(0)$ and higher P_{ECRH} values in comparison with the "Standard" magnetic configuration. For instance, at P_{ECRH} = 700 kW, the density threshold lies above 6×10^{13} cm^{-3} for the "Standard" configuration, and approximately at 5×10^{13} cm^{-3} for "Bmax".

In Figs. 1b), d) the ECE spectrum signals are placed for shots shown in Figs. 1a), c) correspondingly. The ECE signal level in the low-frequency area (130-133 GHz) is higher for lower $n_e(0)$ and higher P_{ECRH} (red symbols in Fig. 1b) and red and blue symbols in Fig. 1d)). The appearance of the such low frequency "hump" in ECE spectra corresponds to NLEA zones, however the "hump" threshold lies at higher P_{ECRH} and lower $n_e(0)$ values (for example, at P_{ECRH} =900 keV for $n_e(0)$=4.5×10^{13}cm^{-3}).

Discussion. The appearance of the ECE "hump" is associated with suprathermals [2]. The dependence of the NLEA zones behavior on plasma parameters and the correlation of the NLEA existence to the behavior of the low-frequency part of the ECE spectra testify that these zones are caused by suprathermal electrons.

Evidently, the suprathermals are generated at the ECRH cross-section. Thermalising due to collisions, they propagate later along the magnetic surface. Arriving at the pellet injection cross-section, these electrons produce the effects observed on $\dot{N}(r)$ curves. Thus, a pellet can indicate the suprathermal groups and one can determine their exact localization. Such detection is impossible on the basis of ECE diagnostics only. Accounting for the peak position on the $\dot{N}(r)$ curve and assuming the low-frequency "hump" of the ECE spectrum corresponds to the suprathermal emission one can estimate the suprathermals energy as E_{st}=3-20 keV. Using the energy value E_{st} the density of the suprathermal population n_{st} can be estimated from the ratio of thermal and suprathermal energy fluxes onto the pellet surface: $n_{st} \propto n_e (T_e / E_{st})^{3/2}$ where n_e and T_e are the bulk plasma density and temperature correspondingly. So the observed effects on the $\dot{N}(r)$ curve might be produced by the suprathermal electrons with densities ~10^{11}-10^{12} cm^{-3}, which corresponds to 1% (for E_{st}=20 keV) up to 15% (for E_{st}=3 keV) of the bulk plasma density.

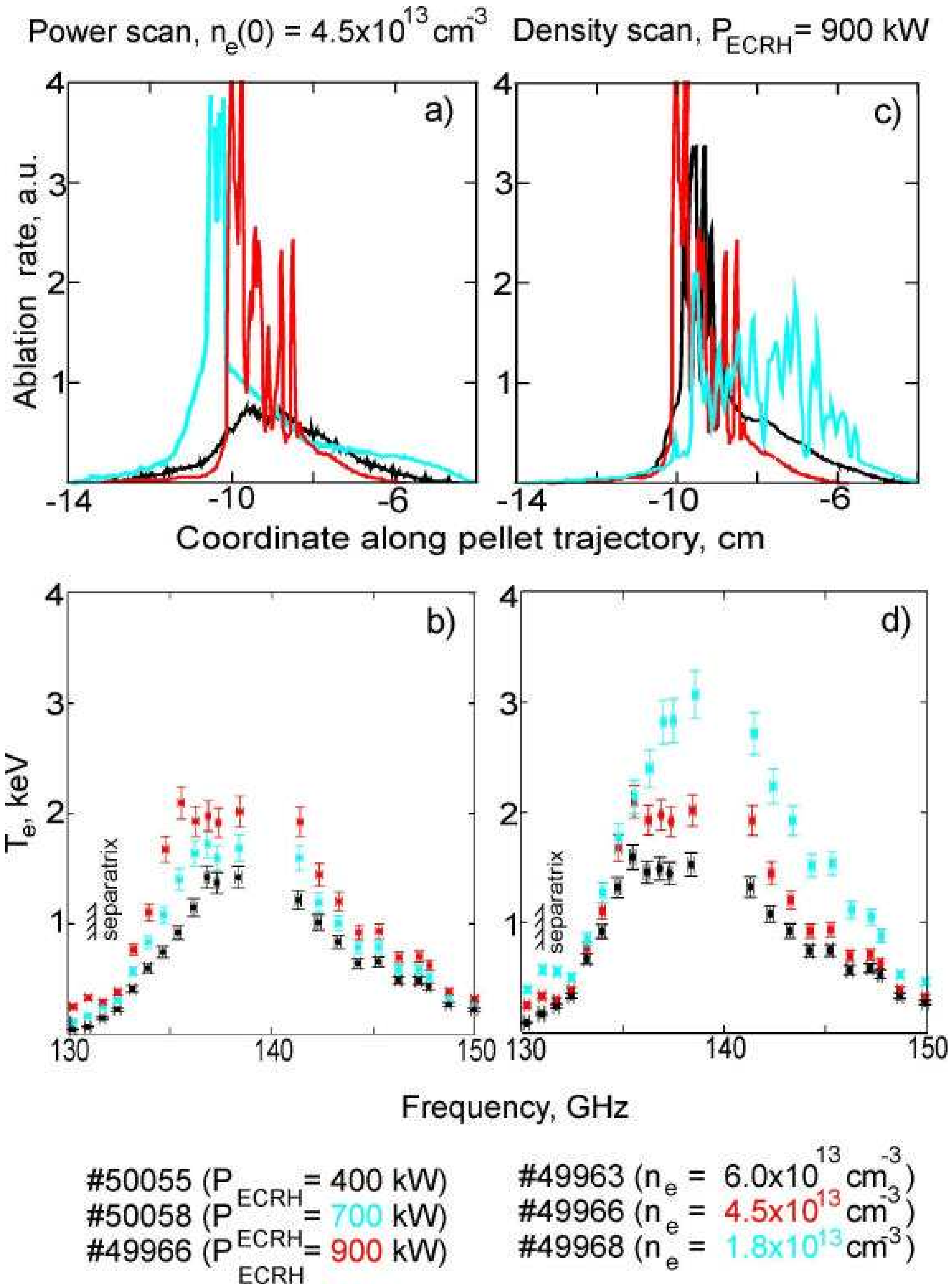

Fig. 1. Ablation rates (upper part) and the ECE signals (lower part) for the power and density scans.

On the other hand, the magnetic surface where the suprathermals are observed should meet the resonance conditions in the ECRH launch cross-section. From the equation for the electron cyclotron frequency $\omega_{ce} = eB/m_0 c\gamma = 140 GHz$, electron energies ~30-50 keV could be obtained. Here e is the electron charge, B is the magnetic field in the suprathermal generation zone (about of 10 cm from magnetic axis to high field side in ECRH launch cross-section), m_0 is the electron rest mass, c is the light velocity and γ is the relativistic factor. In this case, the density values decrease to ~10^9-10^{11} cm^{-3}, which comprises 0.001-1% of the bulk plasma density.

Conclusions. The narrow localised enhanced ablation of carbon pellets was observed in the ECRH regimes of the Wendelstein 7-AS stellarator. The dependence of the NLEA zones behaviour on plasma parameters and the correlation of the NLEA existence to the behaviour of the low-frequency part of the ECE spectra testify that these zones are caused by suprathermal electrons. The estimates from the relativistic mass shift show that the observed effects could be caused by suprathermals with the energy of~30-50 keV and density of ~10^9-10^{11} cm^{-3}. The shape of ECE spectra confirm that electrons with energies ~3-20 keV exist in NLEA regions as well. Previously this "hump" on ECE spectra was associated with radiation of suprathermals in the plasma centre with 10 keV energy and 1% of the bulk plasma density in assumption of the bi-maxwellian electron distribution function [9]. It would be desirable to perform additional ECE measurements in lower-frequency range of the ECE spectrum (down to 120 GHz) where electrons with energies up to 50 keV radiate.

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