HIGH TIME-RESOLVED MEASUREMENTS OF RADIATION EMITTED BY IMPURITIES INJECTED ON THE MT–1M TOKAMAK

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Abstract

The shape and evolution of the dense impurity cloud surrounding an ablating micro-pellet in a hot plasma is investigated. The observations can be understood by assuming near-spherical expansion of the cloud close to the pellet and a one-dimensional flow along the field lines far from it. Distortion of the regular one-dimensional flow is often seen if the lifetime of the observed ions is long enough.

1. INTRODUCTION

The ablation of small fragments ($\leq 5 \cdot 10^{15}$ atoms) of impurity material and the evolution of the cloud of the ablatant in hot plasma was investigated. Aluminum micro–pellets were injected by laser acceleration method[1] into the MT-1M tokamak ($R = 40cm$, $a = 12.5cm$, $B_T = 1T$, $I_p = 20kA$, $n_e(0) = 2 \cdot 10^{13} cm^{-3}$, $T_e(0) = 200eV$, discharge duration $= 8ms$, hydrogen plasma). The radiation emitted by atoms and ions of the pellet cloud was measured with good temporal and spatial resolution using CCD cameras, single- and multichannel photomultipliers.

2. QUALITATIVE MODEL OF THE PELLET CLOUD

Schematic view of a pellet cloud for "small" and "large" pellets are shown on FIG. 1. The processes playing important role in its formation can be outlined the following way. When a micro–pellet reaches the hot region of the plasma the energetic plasma particles heat it up and the pellet starts to ablate. The ablated atoms form a dense ($\leq 10^{22}$ atoms$/m^3$) and spherically symmetric neutral cloud around the pellet that expands with a velocity of a few times $10^3 m/s$.

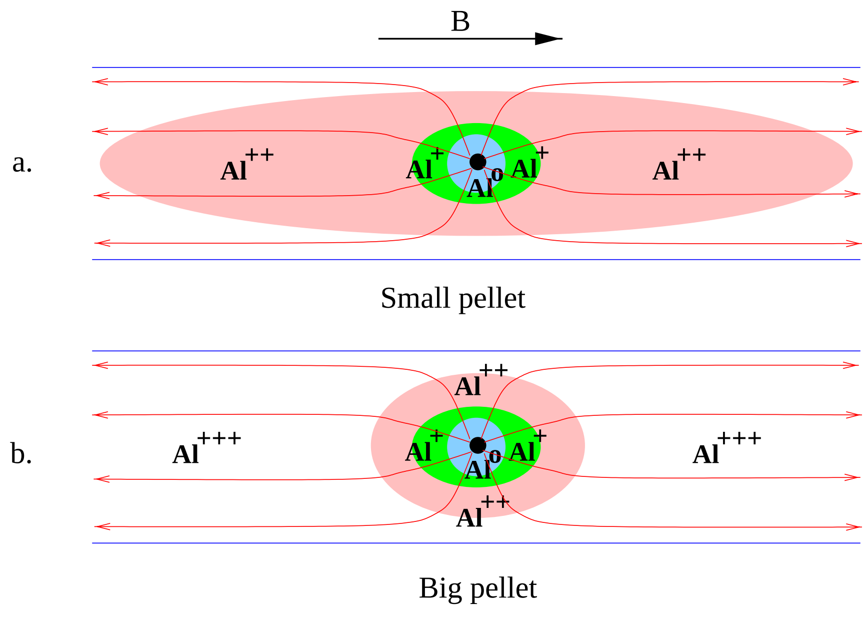

FIG. 1. *Structure of the pellet cloud for small (a.) and large (b.) pellet.*

This expansion is unaffected by the magnetic field as long as the cloud remains neutral. The atoms are ionized first by the background plasma then by the secondary electrons arising from the ionization process and the neutral cloud becomes partially ($\geq$ a few ten percent) ionized. The expansion perpendicular to the magnetic field is stopped approximately at the ionization radius where the MHD force acting on the conducting cloud balances the kinetic pressure. After this early stage the ablated material fills a flux tube – the bent lines in the figure symbolize the flow structure around the pellet – and the pellet cloud starts to expand along the field lines. The background plasma particles interact with the cloud particles and the energy deposited in the cloud is spent on radiation and further ionization of atoms and ions, and on the expansion and temperature increase of the cloud.

Close to the pellet – where the density is high – the evolution of the cloud is determined by the electrons emerging from the ionization of ablated material. For small pellets (FIG. 1a) the ablation rate is small, which results in low cloud and hence electron density. In this case the ions have longer lifetime and can travel to a considerable distance along the flux tube. For bigger pellets, the ablation rate and hence the cloud electron density is higher and the ions have shorter lifetime. The low ionization stages are confined to a small volume around the atomic cloud, where the expansion is nearly spherical, as shown on FIG. 1b.

3. EXPERIMENTAL RESULTS

To check the validity of the picture outlined above we carried out systematic measurements on the spatial distribution and time evolution of Al I, Al II, Al III line radiation of micro–pellet clouds of different pellet sizes. Pellets – used in the experiments – were disc shaped, $10\mu m$ thick and their diameter varied between $30\mu m$ and $110\mu m$, that is their particle content ranged from about $5 \cdot 10^{14}$ to $6 \cdot 10^{15}$ particles. The pellets were injected from the downside of the plasma, along a vertical central chord. Their velocities were between $200 m/s$ and $600 m/s$. The micro-pellets were totally ablated in the plasma and only the largest ones caused noticeable perturbation to the main discharge characteristics (loop voltage, plasma current and bolometer signal).

To measure the radial and toroidal distribution of the cloud light emission, a gateable CCD camera and a multichannel photomultiplier viewed quasi perpendicularly both to the pellet path and the magnetic field. Interference filters were applied in front of the imaging objectives for wavelength selection (Al I: 3944Å, Al II: 6243Å, Al III: 5697Å). The CCD camera measured with about $0.1 mm$ spatial resolution and a minimum integration time of $1\mu s$, while the multichannel photomultiplier provided a few mm spatial and $1\mu s$ time resolution.

Making long exposure time (a few milliseconds) images of the whole pellet ablation using

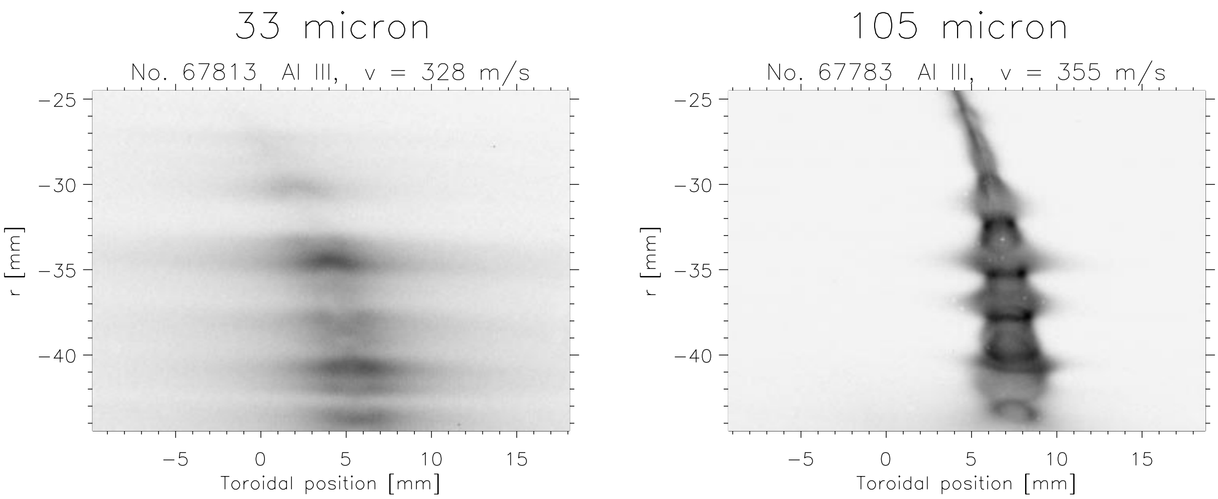

FIG. 2. *Time integrated pictures of the Al III light of ablating pellets of different diameters. The pellets travel upwards, the magnetic field is horizontal.*

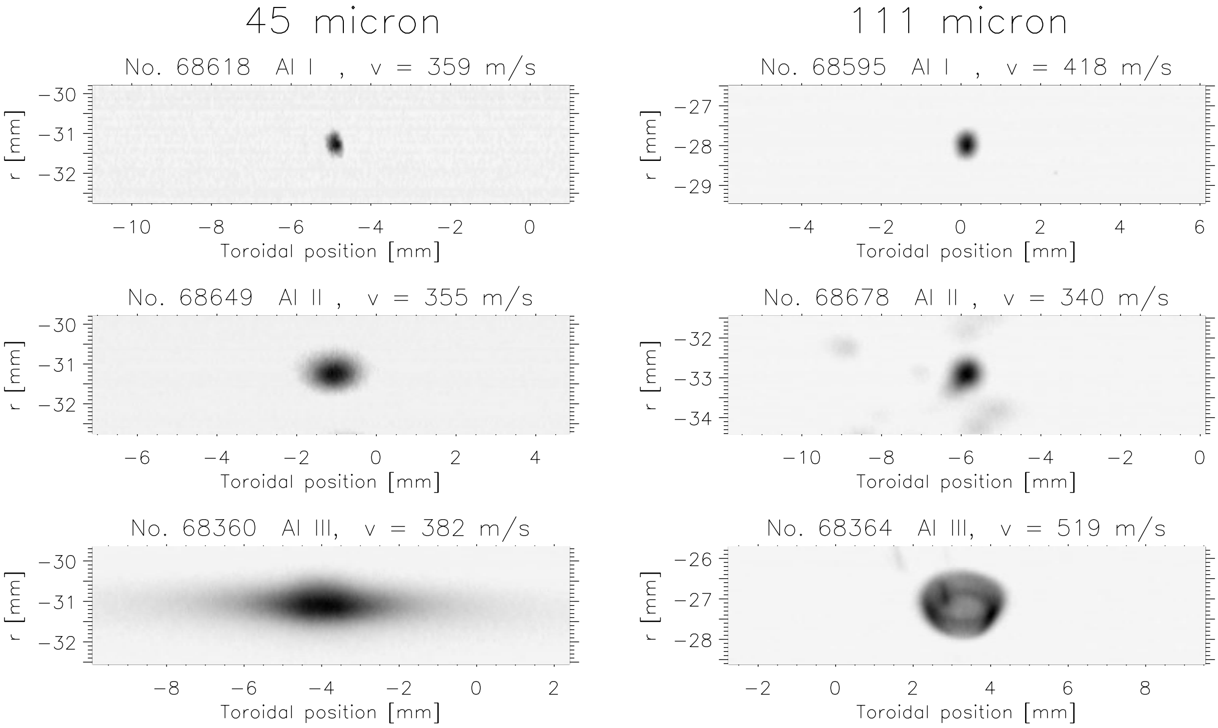

FIG. 3. *1 μs exposure images of the pellet cloud in Al I, Al II and Al III light for two different pellet diameters.*

Al III filter in front of the CCD camera, one can observe striation as it is shown on FIG. 2. This effect is present for both small and large pellets but 1 μs exposure snapshot images reveal differences between the two cases. FIG. 3. shows short ($1\mu s$) exposure time images of the spatial distribution of Al I, Al II, Al III line radiation for different pellet sizes. The distributions are nearly circularly symmetric for all cases except in the case of Al III light of the smaller pellet, when it is definitely elongated along the magnetic field line. This supports the above ideas that the Al^{+} ions, and at the larger pellet the Al^{++} ions as well, are confined to that region where the cloud expansion is nearly spherical. In the case of smaller pellet the expansion of Al^{++} ions is one dimensional along the flux tube. For small pellets the cloud shape often deviates from the one shown on FIG. 2. – it becomes bent or irregular. Such images are not observed for larger pellets, where the modulation effects only the emission intensity and the cloud size, but not the shape.

To see the differences in the time evolution of pellet cloud radiation distribution we detected the radial profile of light distributions with high time resolution (1MHz sampling rate) using a 29 channel photomultiplier. This device integrates the light emission in the toroidal direction and resolves it in the radial direction . The spatial separation of the channels was about 1mm, but due to the finite spatial resolution of the multichannel photomultiplier ($\geq 2mm$), the radial width of the profile is larger on FIG. 4. than on the snapshots on FIG. 3.. For the Al I and Al II radiation a symmetrical radial distribution moving with the pellet velocity was detected as shown in the left column on FIG. 4. The right column on FIG. 4. shows that the picture is different for Al III radiation, in which case both the center and the width of the distribution fluctuates. This fact clearly indicates, that striation during the pellet ablation is connected to an irregular motion of the ionized pellet cloud around the pellet and its neutral cloud. In the case of larger pellets no irregular motion of the cloud is seen, the striation manifests itself in the light amplitude modulation. This can be understood on the basis of FIG. 1. For larger pellets the Al^{++} ions are confined to a smaller region around the pellet and they haven't got enough lifetime to move away from it. Most probably striation is accompanied by irregularly shaped clouds in this case as well, but it could only be observed by detecting the radiation of Al^{+++} ions which lie in the vacuum ultraviolet spectral range and thus unreachable to our cameras.

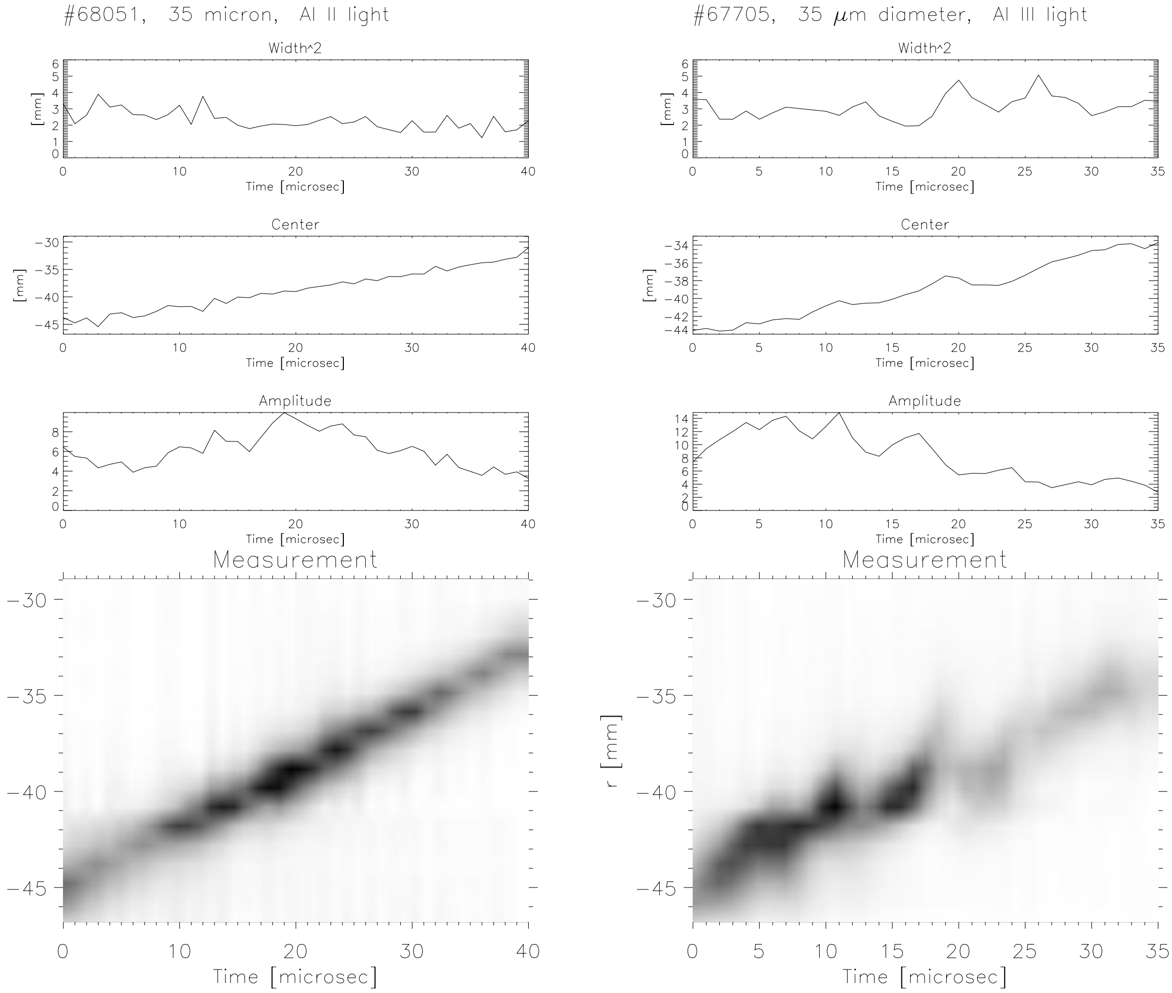

FIG. 4. *Time evolution of the radial distribution of Al II and Al III light during the ablation of a small (35 μm diameter) pellet. The horizontal axis on the 2D plots is time, the vertical is the radial coordinate. The radially integrated amplitude, the center of mass and the width of the profiles are plotted as a function of time on the curves above the images.*

4. SUMMARY

Summarizing our results we observed that depending on the pellet size, i.e. depending on the density of the pellet cloud (which is higher at larger pellet and lower at smaller pellet) the expansion of the different ions of the cloud changes. At larger pellet the Al^{++} ions are confined to that region where the expansion is nearly spherical while at the smaller pellets the Al^{++} ions have a lifetime long enough to enter the one-dimensional flow region along the magnetic field lines. We observed that in this case the Al^{++} ions not only expand simply along the field lines but this part of the pellet cloud swings around the pellet position too, possibly causing (or being the result of) the phenomenon of striation. To reveal this irregular expansion of the cloud one have to select the ablation rate of the pellet (e.g. by selecting an appropriate pellet size) in a way that ions with an observable line radiation enter the one-dimensional flow region.

REFERENCES

[1] S. Zoletnik, G. Kocsis, G. Bürger, P.N. Ignácz, B. Kardon, S. Kálvin and J.S. Bakos, *Rev. Sci. Instrum.* **66** 2904 (1995)

Acknowledgments. This work was sponsored by the Hungarian Science Foundation (OTKA) under contract numbers 23524 and 17489.