Investigation of the pellet cloud radiation dynamics at ASDEX Upgrade

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Cryogenic pellet injection is one of the prime candidates to fuel large scale fusion devices - like ITER and DEMO - in different operational regimes, and also a promising tool to control Edge Localised Modes (ELMs). Impurity pellets are also often injected into magnetically confined plasmas mainly for diagnostics purposes. To allow for an efficient use of the pellet injection tool, the predictive understanding of the underlying processes of the pellet ablation is indispensable. Theoretical and experimental investigations performed in the last decades revealed that pellet ablation is a complex 3D process - taking place on the μs timescale -, which is still not satisfactory explained. Although several proposals have been published [1,2,3,4,5,6] such basic questions as the origin of the fluctuation in the light emitted by the cloud of both cryogenic and impurity pellets ("striation") are still not well understood. Recently the pellet diagnostics at ASDEX Upgrade was upgraded with a fast framing camera system capable to run up to 1MHz frame rate, opening new possibilities to investigate pellet ablation dynamics with the necessary spatio-temporal resolution. For the investigations presented in this contribution the ASDEX Upgrade inboard pellet launching system, injecting pellets with different size and speed, was used.

Fast framing movies (up to 600kHz frame rate) recorded during cryogenic pellet ablation clearly show that from time to time cloudlets are erupted from the main cloud located around the pellet. The erupted cloudlets emit visible light for a while and therefore also contribute to the visible radiation detected during pellet ablation. We think that the reason of the light fluctuation is this repetitive release of the drifting clouds, therefore we try to separate the radiation of the main cloud and the released drifting cloud. Two independent approaches were used to calculate the main and drifting cloud radiation seen on the recorded movies: besides the manual processing the radiation along the flux tube was calculated. The pellet cloud is elongated along the magnetic field lines, therefore it is logical to calculate the total radiation along the field lines. Taking a frame the field line is over plotted and the total radiation is calculated for a two pixel narrow region along the field line (see fig.1.). The starting point of the field line is shifted along the pellet trajectory and this flux radiation is calculated. The obtained curve is plotted on fig.1., showing the main cloud and also the drifting cloud. It is also recognised that the two clouds can be separated by fitting two Gaussian distributions.

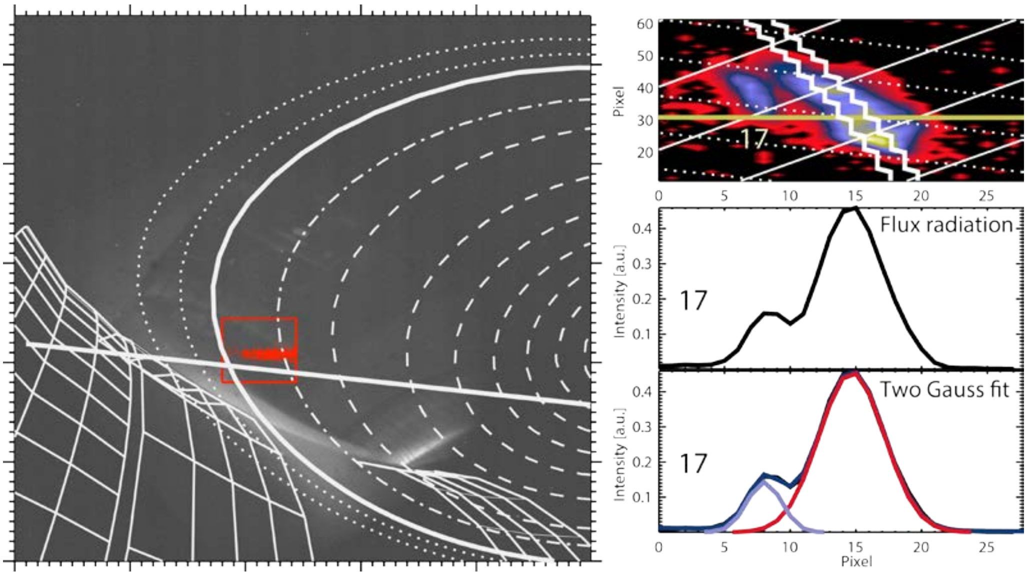

Fig. 1. The injection geometry (left): the red rectangular area is the selected region of interest (64x64 pixels) with 581250Hz frame rate (1.7μs). The red points represent the calculated positions of all pellets in shot #29456. Pellets are injected from left to right with a speed of 570m/s, nominal deuterium pellet volume is 7.2mm^3. The upper right plot is a part of a frame showing the main cloud and a cloudlet drifting upward (over plotted dotted white lines are vertical while the white solid lines are horizontal). A two pixel wide region along the magnetic field line is also over plotted. The total radiation is calculated within this region (flux radiation), the starting point is shifted along the pellet trajectory. This way the flux tube radiation along the pellet trajectory is calculated (middle figure on the left) which can be well fitted by two Gaussian distributions (lower left figure).

By the calculation of the flux tube radiation the dimensions are reduced by one, therefore the whole movie about the ablating pellet can be plotted as seen on fig.2. The other advantage is that the two Gaussians represent the main and the drifting cloud therefore their radiation can be separated even if they are overlapping. It can be observed that the position of the main cloud (the position of the Gaussian) follows well the pellet trajectory, while the position of the drifting cloud is moving away according to the fast drift (see fig.2). The same movies were also processed manually by using a MATLAB GUI: the centre of the main and drifting clouds are selected manually and a routine determined their envelopes by applying an appropriate threshold.

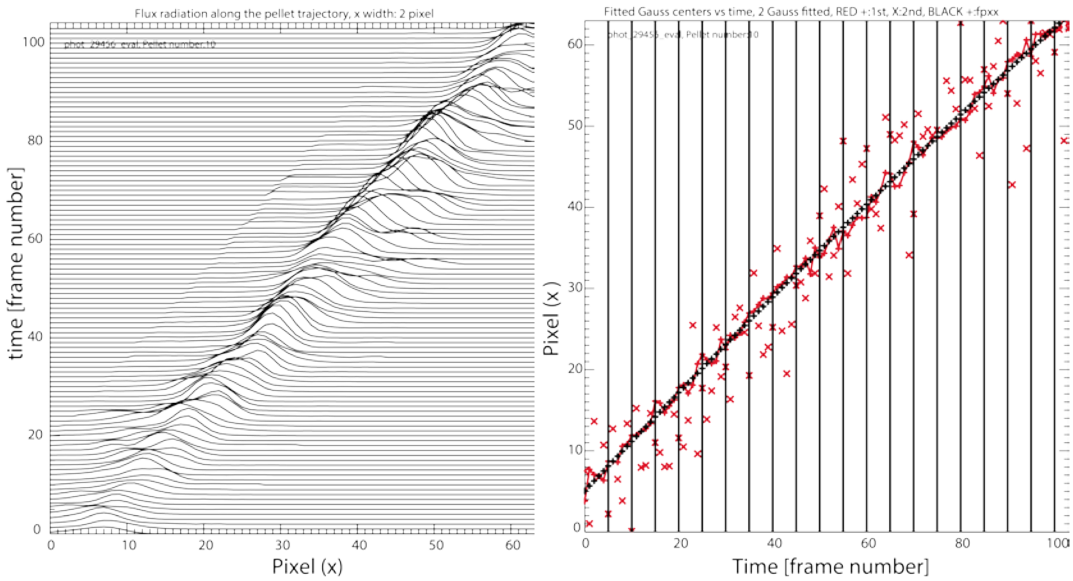

Fig.2.The fitted (2 Gaussians) flux radiation (left) and the position of the centre of the fitted Gaussians (right) as a function of time. + represents the fitted pellet trajectory, + is the first Gaussian (main cloud) and x is the second one (drifting cloud).

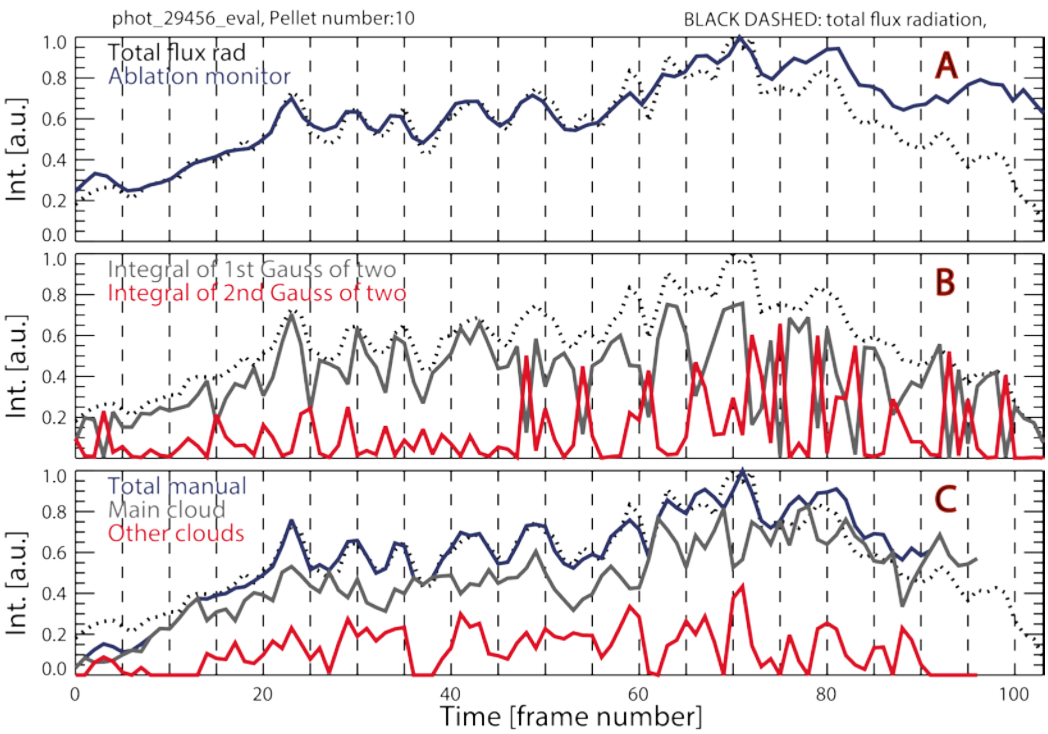

Fig.3. The total flux radiation (dotted) and the ablation monitor signal (A). The total radiation of the main (gray solid) and the drifting cloud (red solid) calculated from the fitted flux radiation (B). The result of the manual processing (C).

The results of the data processing are summarized on fig.3. Fig.3(A) shows the ablation monitor (signal of a wide angle view photodiode) together with the total flux radiation. As expected the total flux tube radiation has the same fluctuation as the ablation monitor. On fig.3(B) the total radiation of the main and the drifting clouds (the integral of the first and second Gaussian) are plotted. It is clearly seen that the periodic appearance of the drifting cloud causes the fluctuation. Main and drifting cloud radiation are in anti-correlation, which can be the consequence of the material flow from the main to the drifting cloud. It seems to be that the fluctuation amplitude of the main cloud is enhanced relative to that of the total radiation. Even such cases are observed where the radiation intensity of the drifting cloud is larger than the main cloud, that is, substantial amount of the main cloud particles are erupted. The last plot (C) is the total radiation of the manually separated clouds. This manual approach gives similar anti-correlation between the main and drifting cloud radiation, however if only the main cloud is considered the highest peaks are disappearing from the main cloud radiation, therefore decreasing the extent of the fluctuation, but still not completely compensating for that.

Summarily it is obvious from our observations that drifting clouds play an important role in the intensity fluctuation detected during pellet ablation. Considering the separated main cloud radiation only, its total radiation still fluctuates. The flux tube approach – which takes into account that the pellet cloud is elongated along the magnetic field lines - probably gives better separation of the radiation of the different clouds therefore we can conclude that substantial amount of the main cloud particles are erupted by the drift process. This would imply that shielding of the pellet also changes therefore a fluctuation in the pellet ablation rate is also expected. This speculation will be further investigated by building a synthetic diagnostics - which connects the cloud particle density and temperature distribution with the detected light intensity pattern – and investigating the fast time evolution of the pellet caused target plasma cooling which may reflect the fluctuation of the ablation rate if any.

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