Link between ablation and line emission for hydrogen fuelling pellet in LHD

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Introduction: Pellet injection is mandatory for the fueling of ITER and DEMO. However, the experimental reproduction of the conditions expected in these machines is not possible in present day tokamaks, and predictions are exclusively based on modeling. It is thus mandatory to validate the available ablation/deposition codes as thoroughly as possible. In this perspective, the instantaneous ablation rate and cloudlet characteristics (dimensions, density and temperature, which are the initial conditions of the drift phase) and the relation between line emission and ablation rate are of particular interest. Up to now, in most cases, the ablation profile was assumed proportional to the ablation cloud H_α emission and only volume-averaged parameters of cloudlets were determined [1].

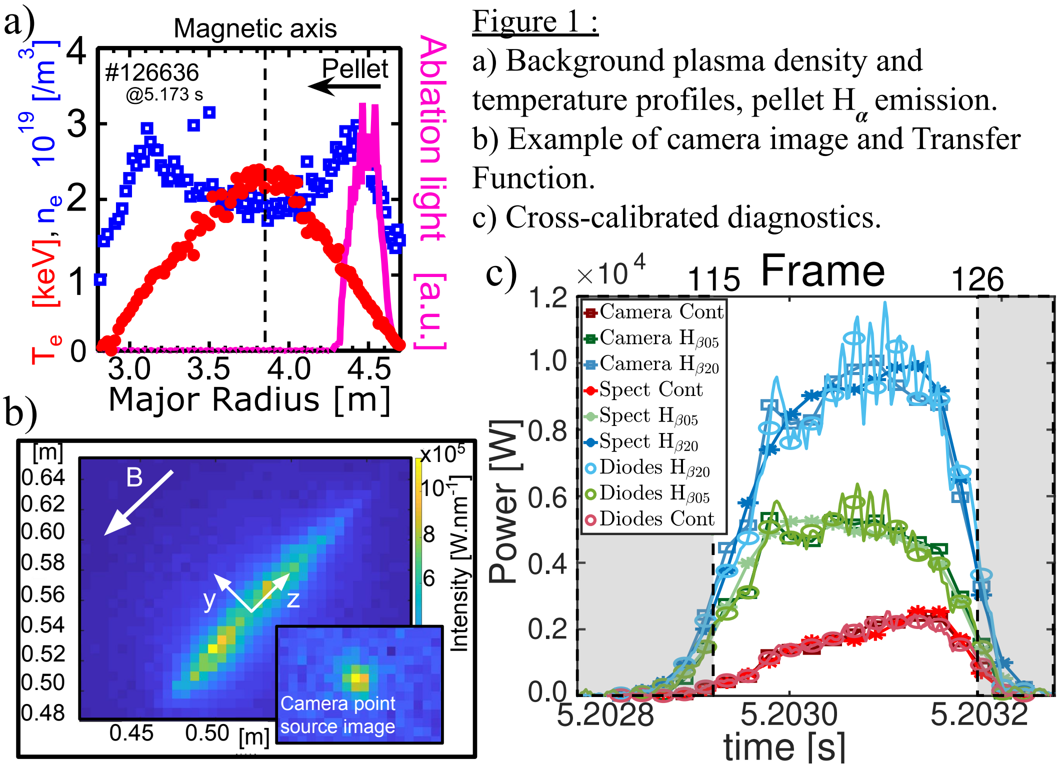

Figure 1 :
a) Background plasma density and temperature profiles, pellet H_α emission.
b) Example of camera image and Transfer Function.
c) Cross-calibrated diagnostics.

Experimental apparatus: In the LHD stellarator (R = 3.6 m, a = 0.6 m, B = 3 T), pellets (Np ≈ 10^{21} at., Vp = 1 km.s^{-1}) were injected in NBI heated plasmas (P = 7 MW), Fig.1a. Ablation cloud characteristics were investigated by high speed imagining spectroscopy. The system consists in a multibranch fiberscope and a fast camera (one image every 20 μs, exposure time 2 μs). Each objective lens is equipped with a band filter (H_β with two filter widths: 5 and 20 nm, and the continuum close to $\lambda = 576$ nm) [2]. In the cross-field direction, the size of the **T**ransfer **F**unction of this imaging system (**TF**, point-source image) is comparable to that of a cloudlet image, Fig.1b. Convolution by this TF is included in the modeling. A set of ≈ 20 frames are registered per pellet injection, whose ≈ 10 are of accuracy high enough for being analyzed. These images are complemented by the record of a set of fast diodes (same filters, time resolution 2 μs) and by a high-resolution spectrometer, absolutely calibrated, in the domain $\lambda = 370-710$ nm (one spectrum every 16 μs, time resolution 84 μs) [3]. Specific attention was paid for cross-calibrating these different diagnostics and harmonizing their integration times, Fig.1c.

Modeling: Modeling consists in a radiation model coupled to a 3-D radiative transfer calculation. Local thermodynamic equilibrium is assumed. Line emission (H_α, H_β, H_γ), Bremsstrahlung and radiative attachment/recombination are taken into account [3]. The cloudlet is assumed cylindrically symmetric and made of two embedded cylinders, Fig. 2a. It is noticeable that the only cloudlet spectrum can be fitted by several sets of densities n, temperatures T, radii R and lengths Z, and that fitting simultaneously the spectrum and the images is mandatory for extracting reliable cloudlet characteristics.

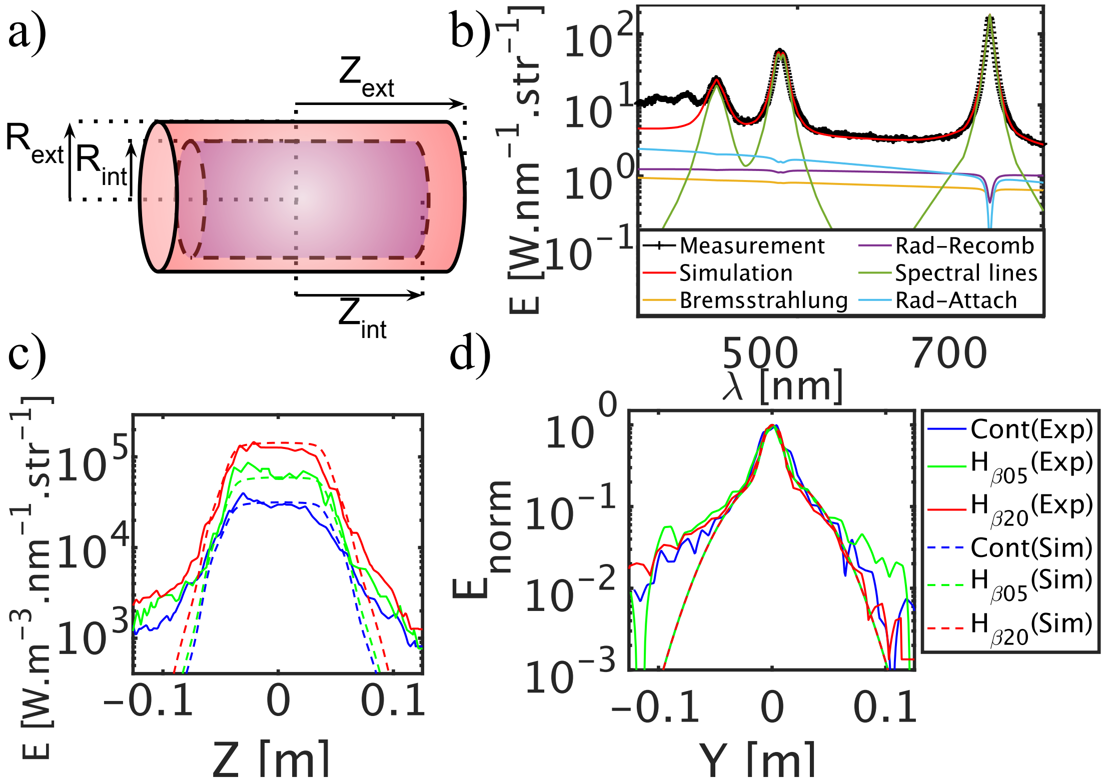

Figure 2: a) Cloudlet geometry. b) Measured and simulated spectra, showing the different components. c) Measured and simulated longitudinal cuts. d) Measured and simulated transverse cuts (normalized).

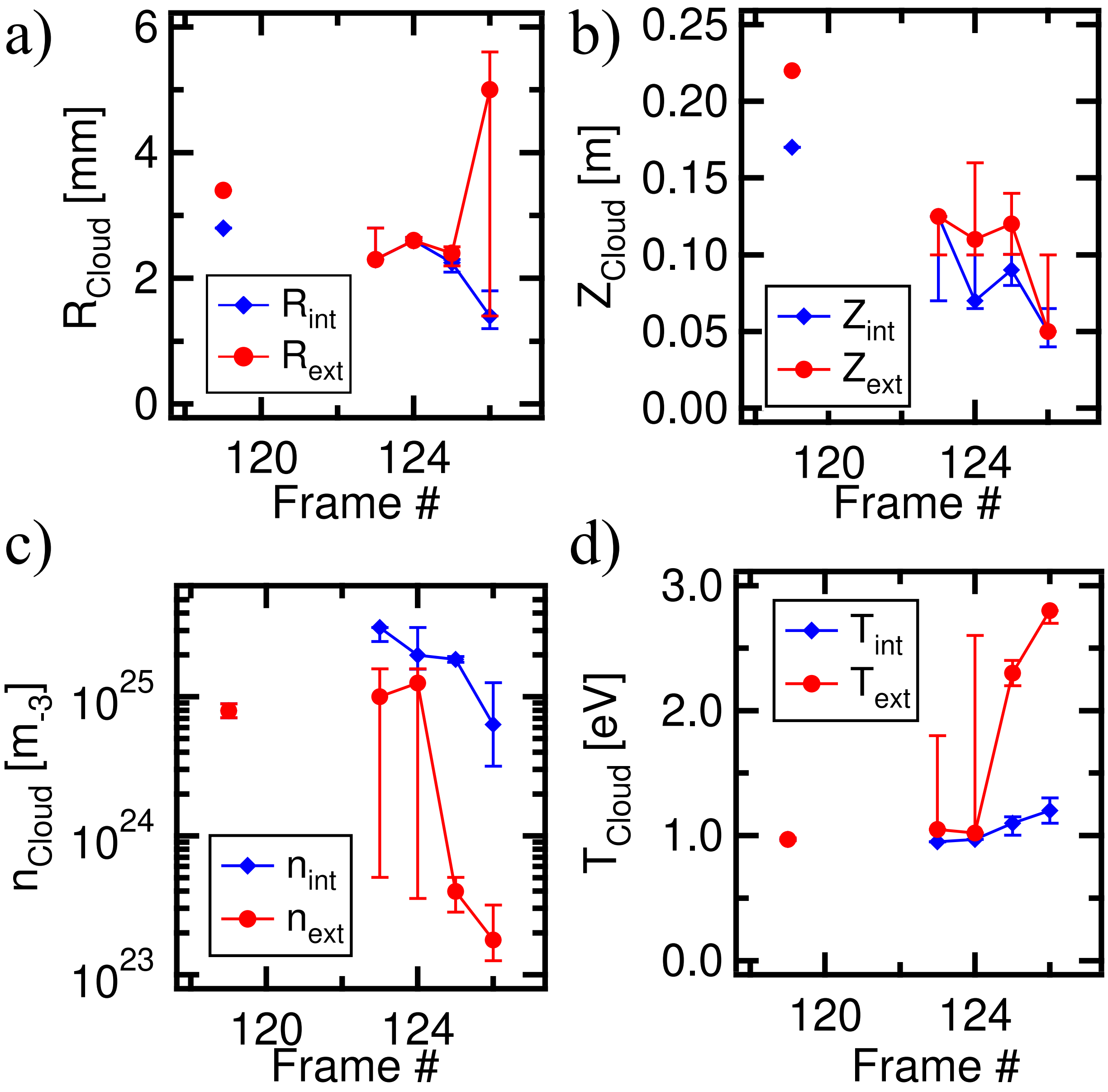

Figure 3: Cloudlet parameters a) Radii. b) Lengths. c) Densities. d) Temperatures.

Results: Figs. 2b-d display an example of spectrum (with the different emission components as calculated by the model described above) and image best fit (longitudinal and normalized transverse cuts) for a cloudlet emitted in the second half of the pellet path (Frame #125). The geometrical and physical characteristics of all the analyzed cloudlets are displayed in Fig. 3. Cloudlets are composed of a dense ($\approx 10^{25}$ m^{-3}) and cold ($\approx$ 1 eV) core surrounded by a thin less dense ($\approx 10^{24}$ m^{-3}) and hotter ($\approx$ 2 eV) external layer whose contribution to the spectrum is small but whose presence is required for an accurate fit of the images. Ablation rate is calculated as Nν, the product of the cloudlets particle contents N (i.e. the ablation rate multiplied by the time for building a cloudlet) and cloudlet ejection frequency ν (i.e. the inverse of the time for building a cloudlet), determined from the oscillations of the diode signals (from 50 to 100 kHz, increasing along the pellet path, see Fig. 1c). The ablation rate and emission dependence with time are displayed in Fig. 4. Although the general trend of the ablation rate and line emissions are similar (Fig. 4a), no clear proportionality can be established between them (Fig. 4b), indicating that one cannot accurately infer the ablation profile from line emission.

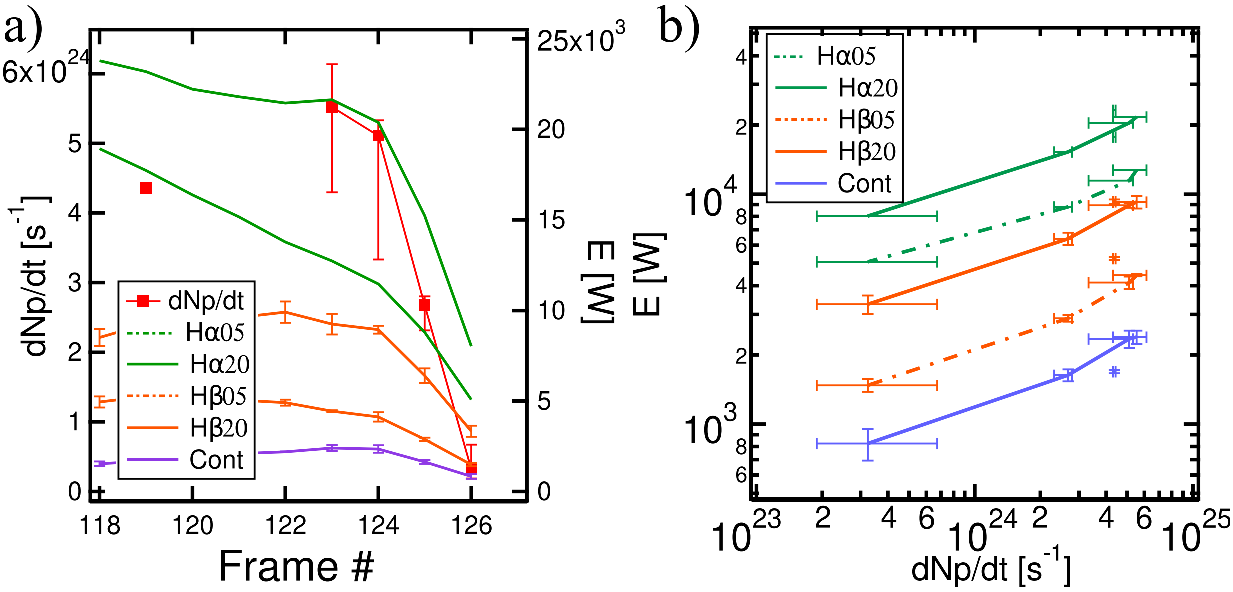

Figure 4: a) Comparison of cloudlet emission in different wavelength domains with ablation rate. b) Line emission in different wavelength over the ablation rate.

Summary: The unambiguous determination of ablation cloudlet characteristics requires the knowledge of calibrated images and spectrum. The model and procedure described here allows to evaluate:

- The cloudlet geometry, density and temperature distributions,
- The local (i.e. instantaneous) ablation rate,
- The relation between line emission (H_α, $H_\beta\ldots$) and the ablation rate. No strict proportionality is observed between them.

References

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