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Deconvolution of JET CORE LIDAR Data and Pedestal Detection in Retrieved Electron Temperature and Density Profiles

D.Stoyanov[a,c], T.Dreischuh[a,c], L.Gurdev[a,c], M.Beurskens[b,d], O.Ford[b,d], J.Flanagan[b,d], M.Kempenaars[b,d], I.Balboa[b,d], M.Walsh[b,d] and JET EFDA Contributors[*]

[a]Institute of Electronics, Bulg.Acad.Sci.72 Tzarigradsko Shosse, 1784 Sofia, Bulgaria
[b]JET -EFDA Culham Science Centre OX14 3DB, Abingdon, UK
[c]EURATOM-INRNE Fusion Association, 72 Tzarigradsko Shosse, 1784 Sofia, Bulgaria
[d]EURATOM-UKAEA Fusion Association, Culham Science centre, Abingdon, UK
[*]*See appendix of F. Romanelli, IAEA, Geneva, Switzerland, 2008*

The high-confinement mode (H-mode) is considered as one of the most promising regimes of operation of the thermonuclear reactors. The H-mode is characterized by the formation of an edge pedestal region in which steep gradients in the density and temperature are observed as a result of formation of a particle and energy transport barrier near the plasma edge. The Lidar Thomson scattering diagnostic [1] (Fig.1) has been successfully used for reliable and robust measurement of the electron temperature T_e and density n_e profiles on JET. The resolution of 12-15 cm is however practically insufficient for resolving the narrow pedestal area.

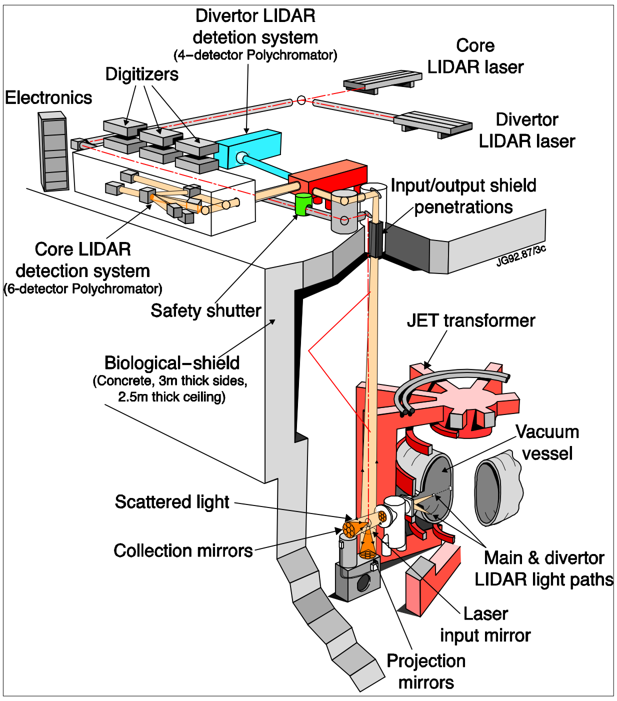


Fig.1

Deconvolution techniques [2, 3] can be used to improve the achievable spatial resolution with the existing core Lidar system. As an inverse problem the deconvolution is noise sensitive and requires careful analysis of each processing step [4]. Here we present the first results on deconvolution of JET core Lidar data and their comparison with untreated data. The deconvolution is applied to the raw JET Lidar profiles $L_p^{out}(r)$, $p=1..6$ is the spectral channel number, and r is a LOS coordinate. The output lidar profiles are given by:

$$L_p^{out}(r) = R_{TS}^p(r) \otimes L_p^{inp}(r) + \tilde{W}_p(r), \quad R_{TS}^p(r) = R_{ADC}^p(r) \otimes R_{\det}^p(r) \otimes R_{las}(r) \qquad (1)$$

where "⊗" denotes convolution; $R_{TS}^p(r)$ is the total instrument function for the *p-th* channel, expressed in (1) by a convolution of the partial instrument functions of the ADCs $R_{ADC}^p(r)$, the photon detectors $R_{\det}^p(r)$ and the laser pulse shape $R_{las}(r)$; $L_p^{inp}(r)$ are the input lidar profiles at $\delta-$type total instrument function; $\tilde{W}_p(r)$ are noises. The main differences in retrieved convolved & deconvolved electron temperature and density profiles can be expected in the pedestal area as it follows from (1). The deconvolved profiles inside the torus will tend to the convolved profiles in the area of their low spatial variations. Thus, the deconvolution of JET data can be estimated as a good approach to analyze the plasma parameters in the pedestal area or in other areas with steep gradients inside the torus.

The total instrument function $R_{TS}^p(r)$ is extracted by a computer model, based on the expressions in (1) and some well known models for the partial functions $R_{ADC}^p(r)$, $R_{\det}^p(r)$ and $R_{las}(r)$. Then, tuning precisely the parameters of partial instrument functions during the deconvolution process and controlling the quality of deconvolved profiles, one could find the best estimate of $\tilde{R}_{TS}^p(r)$ providing the tolerable quality of deconvolved profiles (Fig.2a). The success of such approach can be explained by the low number of samples per FWHM as well as by the smoothness of the Fourier spectrum within the entire spectral range without any zero spectral components (Fig.2b). The FWHM of $\tilde{R}_{TS}^p(r)$ providing the tolerable performance is ~ 13.6 cm. This value corresponds to the estimates of the JET core Lidar resolution.

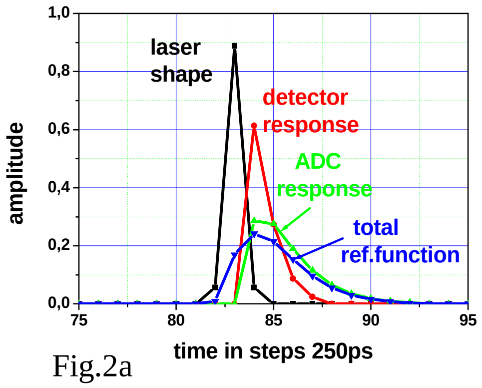


Fig.2a

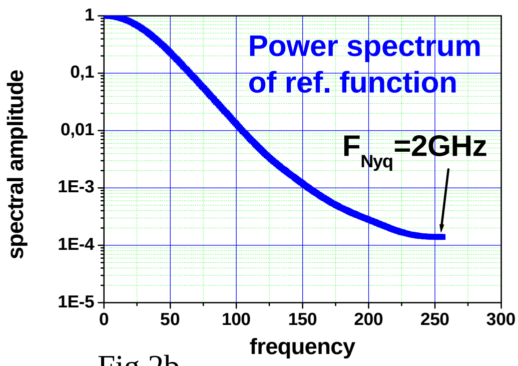


Fig.2b

Examples of 6-channels untreated and deconvolved lidar profiles for the JET pulse #73337, laser shot #77, are shown in Figs.3a and 3b, respectively. As seen, the deconvolved profiles are slightly noisier than the untreated ones as can be expected. They are steeper in the pedestal area (marked on both the figures) as a result of deconvolution.

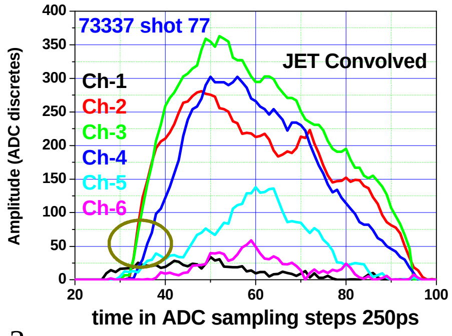


Fig.3a

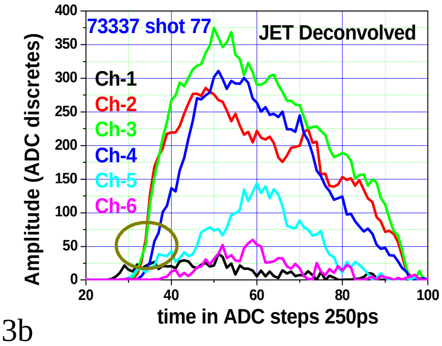


Fig.3b

The T_e and n_e retrieval algorithms are based on the dependence of the mass center of the relativistic Doppler spectrum on the electron temperature and the calibration parameters of the JET Lidar. In the simulations, we found this approach as less affected by the uncertainties in the determination of the plasma light and the spectral channel sensitivities. The electron density is calculated using the electron temperature profile, measured lidar signals and the full relativistic Doppler spectrum. The plot in Fig.4a displays the mean electron temperature profiles extracted from convolved & deconvolved profiles averaged over 25 laser shots within a stationary state period of the H-mode of the pulse #73337. As is seen, the T_e profile, retrieved from deconvolved profiles provides better determination of the pedestal area with respect to the untreated profiles. Inside the torus both profiles are overlapped. The pedestal width is of the order of one ADC discrete (3.75 cm) as can be expected. The retrieval of the pedestal area in electron density profiles is given in Fig.4b.

The profiles of standard deviation in retrieving T_e and n_e profiles before and after deconvolution are shown in Fig.5a,b. Here we also displayed the T_e and n_e profiles, but averaged over 25 single temperature and density profiles, retrieved from each of the single laser shots. The standard deviation of T_e profiles (Fig.5a) is below 250 eV inside the torus. It is increased up to 750 eV within the pedestal mainly due to noises, as SNR is lower just in this area. The fluctuations of averaged T_e profiles are of the order of 50 eV for the both convolved and deconvolved profiles. The standard deviations for n_e profiles (Fig.5b) have a similar behavior as in Fig.5a. Here the fluctuations (~0.12 of the maximum) are not increased within the pedestal area as for the profile of T_e. The next Fig.6 displays the retrieved history of deconvolved n_e profiles for the entire JET pulse, containing 117 laser shots. The creation of the H-mode is well seen.

In conclusion, we demonstrated a successful deconvolution of JET core Lidar data and retrieving the electron temperature and density profiles of improved resolution. We evaluated the standard deviations of retrieved electron temperature and density profiles. As a result of

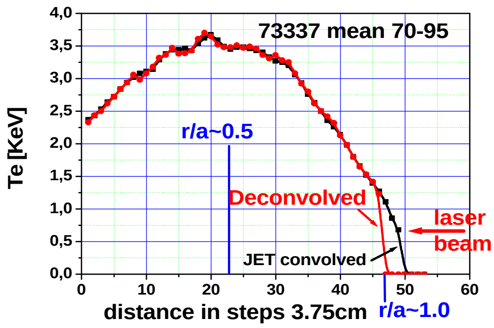


Fig.4a

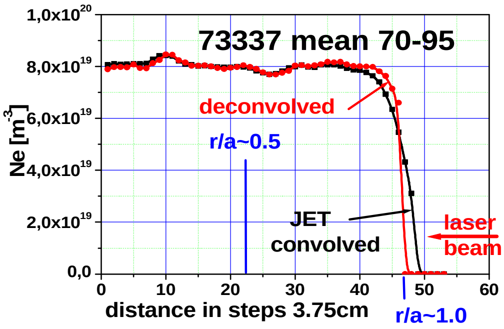


Fig.4b

deconvolution the pedestal area can be detected and the pedestal parameters can be estimated. The resultant improvement of resolution is about 3 times. As mentioned above, the JET core Lidar system is very successful and a workhorse for the JET operations. However, the technology employed is quite old. This extends particularly to the detectors and the data acquisitions systems. A recent upgrade to the Edge Lidar system [5] has shown that this technology can be deployed very successfully. The basic spatial resolution has been enhanced by more than a factor of 2 and the sampling rate has been increased up to 20GS/s from 4GS/s. With a hardware upgrade of detectors, digitizers and improved optics, and combined with a deconvolution, the spatial resolution of JET core Lidar can be brought down to 1 cm; similar to the best performing JET diagnostics.

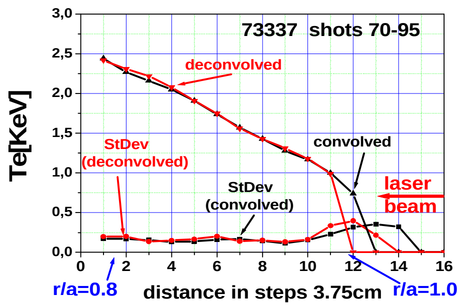


Fig.5a

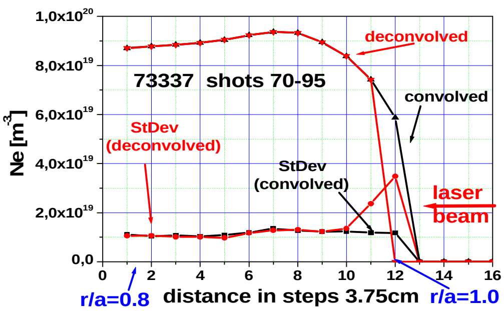
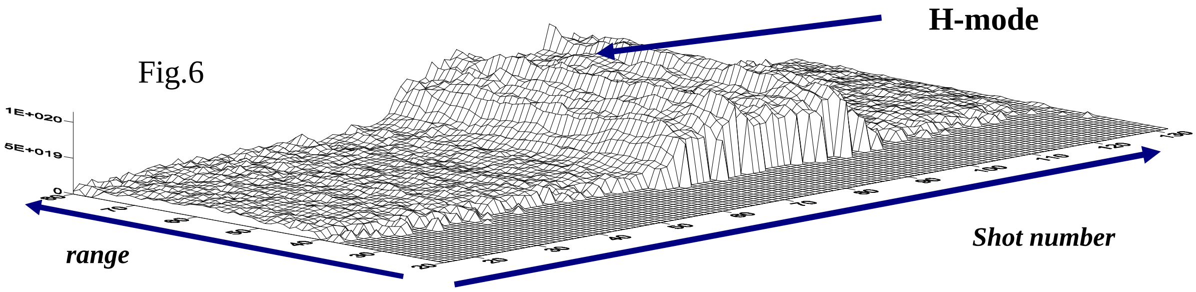


Fig.5b

Fig.6



References: [1] H.Salzmann, et al., Rev. Sci. Instrum. **59**, 1451 (1988); [2] L.Gurdev, et al., D.Stoyanov, *JOSA A* **10**, No.11, pp.2296-2306 (1993); [3] L.Gurdev, et al., Proc. of SPIE 7027, 702711 (2008); [4] O.Ford et al., 36th EPS Conference on Plasma Physics, Sofia, Bulgaria, 29th June 2009; [5] M.Kempenaars et al., Rev. Sci. Instrum. **79**, 10E728 (2008)