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INTRODUCTION

JET neutron cameras detect both D-D 2.5MeV and D-T 14MeV fusion neutrons along 19 lines of sight (see in Fig.1). This instrument, unique among similar diagnostics available at large fusion research facilities has a coarse spatial resolution of 15cm and a time resolution currently of 10ms. Both sets of detectors are absolutely calibrated at 2.5MeV for D-D and 14MeV for D-T. The full potential of JET neutron cameras is best exploited from the diagnostic point of view in the trace tritium experiments. This experimental technique[1], designed to study Tritium transport, involves the gas puffing/beam injection of a small amount of Tritium fuel ions (typically $\frac{n_T}{n_D + n_T} \leq 3\%$) which produce a sizeable emission of 14MeV D-T neutrons but do not perturb significantly the background plasma. In this work, two dimensional (2D) spatial profile and temporal evolution of both 14MeV and 2.5MeV neutrons emissivities from D-T and D-D fusion reactions are studied for ELMy H-mode plasmas with gas puffing from the last trace tritium experiments at JET. Various methods and tools have been developed for this study including: 1) Tomographic analysis with the minimum Fisher regularisation, 2) ratio method: a method to obtain directly the tritium density, and 3) Singular Value Decomposition (SVD). Better quantitative studies of tritium transport could likely be performed with the application of SVD analysis, when combined with the ratio method.

1. NEUTRON CAMERAS

The JET neutron cameras[2, 3] consist of 2 concrete shields of which each includes a fan-shaped array of collimators. These collimators define a total of 19 lines of sight, grouped in two cameras. The larger one contains 10 collimated channels with a horizontal view through the plasma while the smaller one has 9 channels with a vertical view. The plasma coverage is adequate for neutron tomography, although the spatial resolution is rough. Neighbour channels are 15-20cm apart and have a 7cm width as they pass near the plasma centre (see Fig.1). Each line of sight is equipped with a set of three different detectors 1) a NE213 liquid organic scintillator with pulse shape discrimination (PSD) electronics for simultaneous measurements of the 2.5MeV D-D neutrons, 14MeV D-T neutrons and γ-rays, 2)a BC418 plastic scintillator, rather insensitive to γ-rays with $E\gamma < 10MeV$ for the measurements of 14MeV D-T neutrons and 3) a CsI(Tl) scintillation detector for measuring the Hard X rays and γemission in the range between 0.2 and 6MeV. Each NE213 detector-photomultiplier unit sends output pulses to pairs of Pulse Shape Discriminators (PSD), one tuned for D-D neutrons and the other one for D-T neutrons, to distinguish neutrons from γ ray induced events. These Pulse Shape Discriminators (PSD) have upper and lower energy detection biases set to detect preferentially unscattered neutrons and to reject scattered neutrons. The Bicron scintillators are located in front of the NE213 scintillators and are coupled to photomultiplier tubes via a light guide. They are sufficiently small that energetic gamma rays cannot deposit sufficient energy to produce a pulse greater than that produced by a neutron of 10MeV. Each Bicron detector has several lower energy detection thresholds to be set for the proton recoil energy providing different sensitivity to the scattered neutrons.

2. TOMOGRAPHIC ANALYSIS AND SINGULAR VALUE DECOMPOSITION

The general properties of tomographic inversion methods applied in plasma physics are reviewed in [5, 6]and [8]. In this paper, 2D images are obtained from running a Minimum Fisher Regularisation (MFR), a simple but robust inversion algorithm suitable for under-determined systems like the neutron profile monitor with its sparse projections. MFR is not constrained by magnetic equilibrium reconstruction. MFR finds a reconstruction matrix M that directly links the measured projections f_i to emissivities in a grid of pixels $g_j = \sum M_{ji} f_i$. It belongs to so-called Philips-Tikhonov regularisation methods that constrain a norm of the solution, thus favouring a smooth reconstruction result. In the case of MFR, the smoothness is determined by minimising: $\Lambda_{MinFisher} = {}^1/_2\, \chi^2 + \lambda I_F$ where χ^2 is goodness-of-fit, λ is a regularisation (smoothing) parameter and I_F the Fisher information of the emissivity distribution g_j [5]. This method was chosen after comparative tests of various tomographic techniques, in particular the maximum entropy.

Singular Value Decomposition (SVD) of time evolution of emissivities g_j has been applied in [5] in order to identify poloidal modes in tomographic reconstructions. A considerable advance for the SVD method came with introduction of rapid MFR [7], in which a time-averaged reconstruction matrix allows to compute a smooth emissivity evolution in a single command line, $g_{j\tau} = \sum M_{ji} f_{i\tau}$ where τ indexes time samples. In Fig.2 an example of recent successful application of SVD at JET is presented, using results of rapid MFR reconstruction of D-T neutron emissivities following a gas Tritium puff. The two spatial terms (topos) show the basic radiation profile and the hollow profile corresponding to Tritium influx, respectively; when these terms are combined, i.e. multiplied by their singular values p and their temporal evolutions (chronos), a 2D dynamic pattern of diffusion character of D-T radiation is clearly revealed. Preliminary studies also show that the SVD analysis, when combined with the ratio method, could potentially enhance quantitative studies of tritium transport.

3. RATIO METHOD

The ratio method was first discussed in [9] and subsequently refined for the interpretation of the first Tritium experiments in JET [10]. The ratio method is a straightforward method to obtain the fuel ratio n_T / n_D, based on the fact that the local tritium density is at first order proportional to the local ratio of DT to DD neutron emission. This measured ratio is then normalized with the ratio of beam-target reactivities in order to get the absolute n_T / n_D value for the fuel ratio. The technique applies to plasmas where beam-target emission is the dominant contribution in the neutron emission. It has been used to analyze 30 ELMy H-mode plasmas with Tritium gas puff from the Trace Tritium experiments. These plasmas have typical beam-target contribution calculated by TRANSP in the range from 2/3 up to 90% of the total neutron emission. Errors induced by neglecting the thermal and the beam-bean contributions are small. This is studied in details in [11]. As demonstrated in the same paper, main advantages of this method are : 1)no assumptions about tritium fluxes and sources are made 2)It is rather insensitive to plasma profiles (temperature, rotation,Z_{eff} ,...) and 3)it is not sensitive to the beam deposition profile, beam slowing-down and beam power calibration. It is therefore a reasonably accurate approach to obtain the tritium density. This method complemented by the tomographic analysis has allowed us to derive the first 2-D reconstruction of Tritium density [11].

4. EXPERIMENTAL RESULTS

The application of tomographic analysis to neutron emission from plasmas with Tritium puff reveal 2-D features. In the D-T 14MeV neutron emission, transient asymmetry between Low Field Side (LFS) and High Field Side (HFS) appear in time near after the tritium puff. In reference[1], an interpretation is proposed for the brighter emission towards the low field side. These profiles are characterized by a large number of trapped fast particles localized on orbits sitting on the LFS, enhancing D-T 14MeV neutrons emission on this side as the Tritium progressively penetrates into the plasma core. In addition to this effect, we report further updown asymmetry which appear systematically and more clearly in high density ELMy-H mode plasmas. Work is on-going to investigate possible mechanisms for this effect. Application of the ratio method combined with the tomographic analysis has led to the 2-D reconstruction of the tritium density. A typical evolution shows a hollow profile n_T / n_D which ’fills up’ progressively as the tritium diffuses into the plasma. This is seen in a sequence of profiles in Fig.3. The diffusion process is also well visible in figure 4 which shows a contour plot n_T / n_D versus time in the case of a high density ELMy-H mode plasma. Preliminary application of the SVD 1) confirms LFS-HFS and up-down asymmetries in high density ELMy-H mode plasmas (Fig.2) and 2)can potentially lead to improvement of quantitative studies of tritium transport.

ACKNOWLEDGEMENTS

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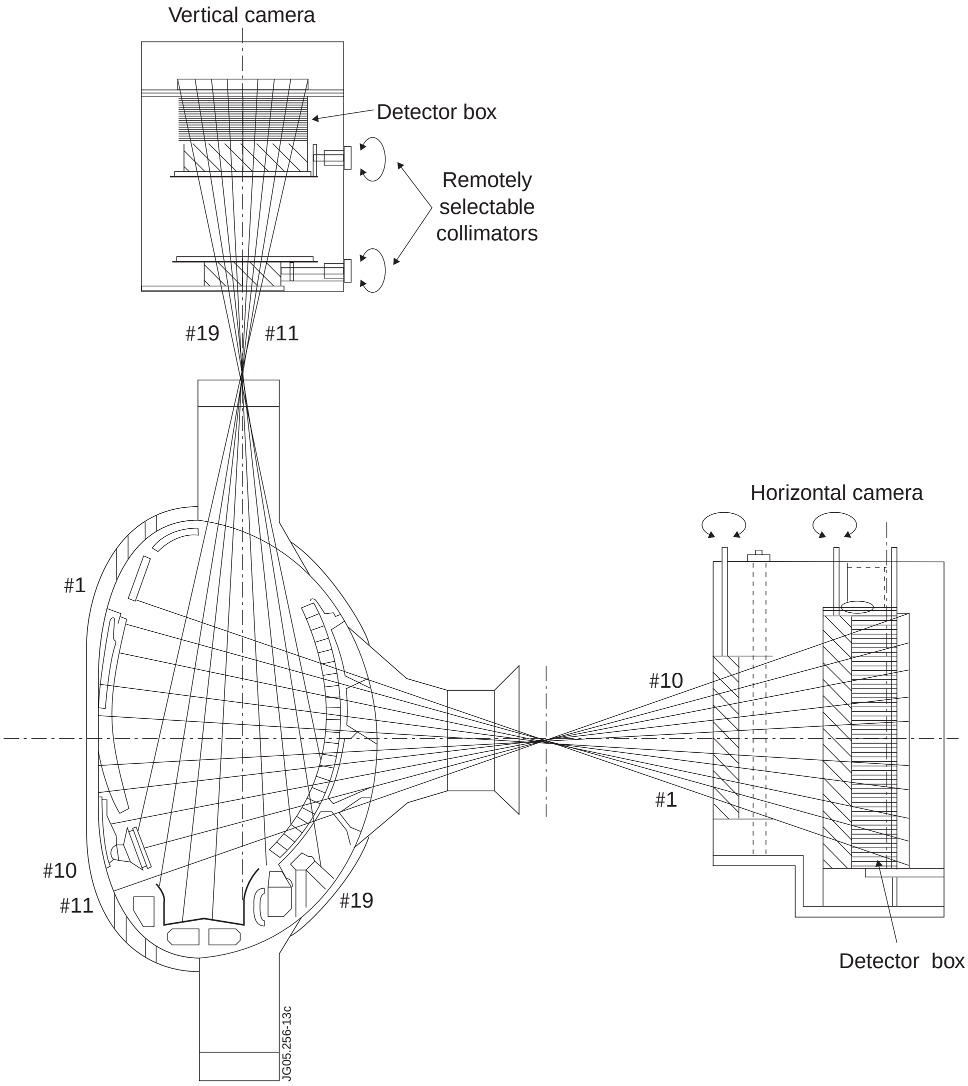

Figure 1: The JET neutron cameras.

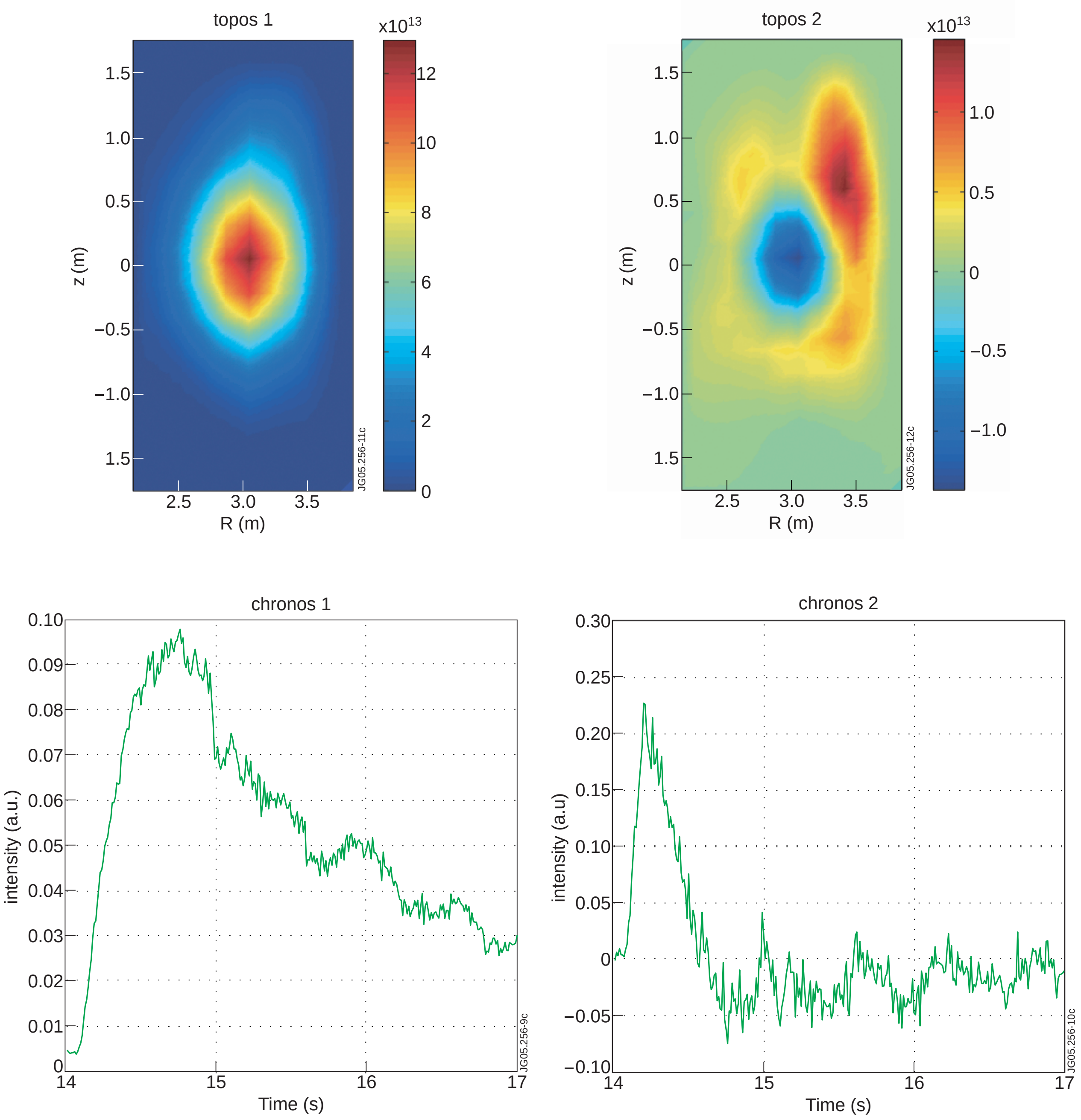

Figure 2: SVD of D-T neutron emissivity in Pulse No: 61103 (two highest orders).

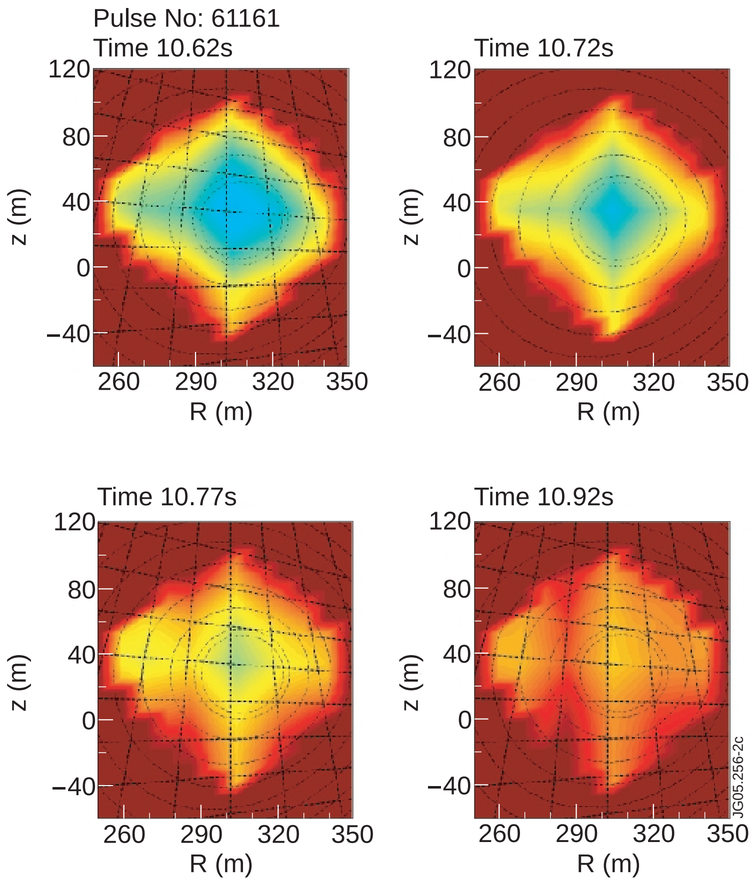

Figure 3: Pulse No: 61161:2-D images of n_T/n_D *at consecutive times*

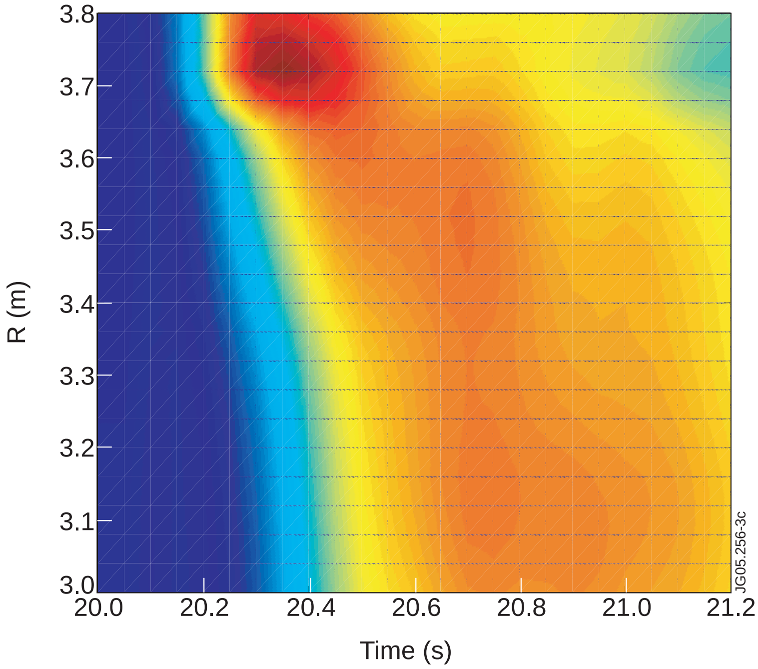

Figure 4: Contour plot of n_T/n_D *versus time for Pulse No: 61372*