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EDGE2D modelling of edge profiles obtained in JET diagnostic optimised configuration

A. Kallenbach[1], Y. Andrew[2], M. Beurskens[3], G. Corrigan[2], T. Eich[1], S. Jachmich[4], M. Kempenaars[3], A. Korotkov[2], A. Loarte[5], G. Matthews[2], P. Monier-Garbet[6], G. Saibene[5], J. Spence[2], W. Suttrop[1], EFDA-JET workprogramme contributors
[1]MPI für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany,
[2]EURATOM/UKAEA Fusion Association, Culham, UK
[3]FOM-Rijnhuizen, Ass. Euratom-FOM, TEC, NL; [4]ERM, Brussels, Belgium
[5]EFDA Close Support Unit, Garching; [6]CEA Cadarache, France

Introduction

Characterising and understanding the machine size dependence and inter-relation of edge temperature and density profiles is essential to improve the performance predictions for a fusion reactor. Measurements on JET are of particular importance to test the size dependence predicted by different models. However, resolving the very steep gradients occurring in the edge transport barrier (ETB) region under H-mode conditions appeared to be a challenging task due to the limitations of the available diagnostics and the equilibrium reconstruction.

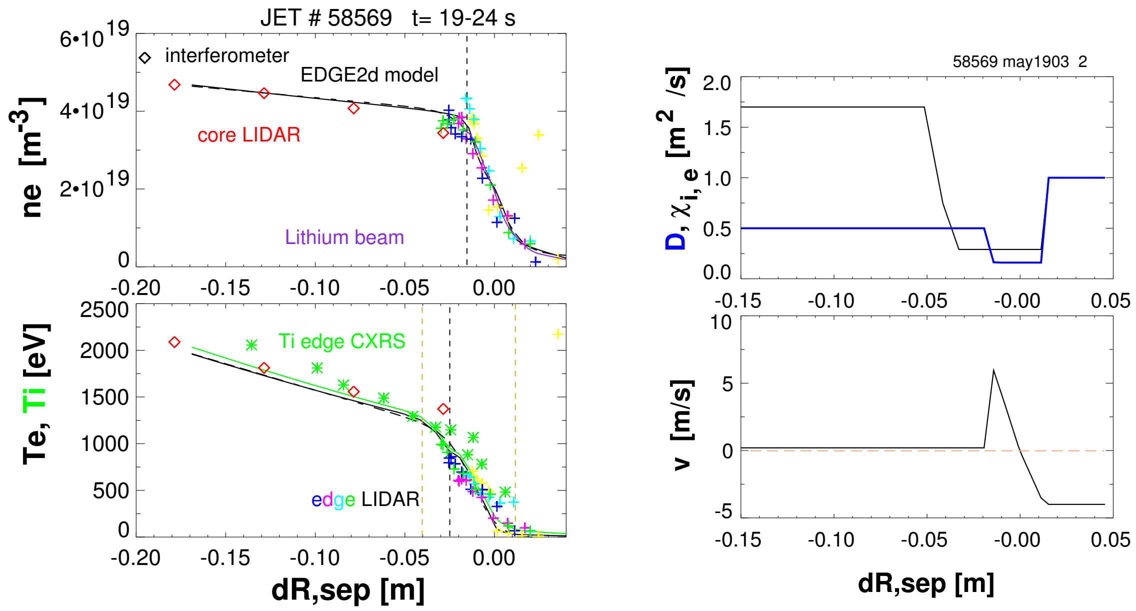

Figure 1: Edge temperature and density profiles from various diagnostics and EDGE2d modelling for a diagnostic optimised configuration, taken at 1/3 τ_{ELM} before the next ELM. Several Li beam and edge CX profiles were mapped on a common grid and averaged with a median filter. The dashed lines show mtanh fits of the profiles used for barrier parametrization. Vertical dotted lines indicate transport barrier in $\chi_{i,e}$ (orange) and inner positions from mtanh fit (black). Also shown are the transport coefficents used to model the inter-ELM transport. I_p= 2 MA, $P_{heat} \approx$ 13 MW

To exploit the maximum achievable diagnostic spatial resolution, H-mode discharges in diagnostic optimised configuration (DOC) have been performed in JET to obtain information about plasma parameters and gradients over the edge transport barrier region. The DOC discharges have been designed to optimise the spatial resolution of the edge LIDAR system used to measure electron density and temperature profiles [1], the edge charge exchange diagnostic for ion temperatures and carbon densities and to allow simultaneous measurements with the divertor infrared camera (IR, power flux densities) and Lithium beam (edge density) as well as target parameters from Langmuir probes using strike point sweeps.

Modelling the radial structure of the H-mode edge

The DOC discharges have been analysed with the EDGE2d-Nimbus code package [2] to obtain a physics-based regularisation of experimental edge profile measurements, in terms of interpolation, smoothing and mapping corrections. The boundary conditions used in the code are adapted to the external experimental parameters. The heating power is fed uniformly into the innermost grid ring, as well as the particle flux corresponding to the neutral beam fuelling rate. Gas fuelling is done in the divertor with a rate set to match the pumped neutral flux as determined from the measured divertor neutral pressure and the pumping rate of the cryopump. Midplane D_α measurements are used to match the main chamber recycling using an outward drift in the SOL periphery in combination with a fixed outer D=1 m^2/s.

The shift of the experimental data is done using the following procedure: edge LIDAR T_e and n_e profiles are shifted (after an initial 5.2 cm correction along the laser l.o.s.) in the outer midplane to match the separatrix T_e from modelling. The Li beam n_e profile is shifted to match the LIDAR n_e profile in the region of overlap. Edge CXRS data (ion temperature and carbon density) are shifted to match the steep decay of the C^{6+} density profile around the separatrix as predicted by EDGE2d due to the pronounced decrease of T_e, using C^{6+} as a marker for T_i. Typical diagnostic shifts are 1 cm in the outer midplane, the maximum shift was 2 cm.

ELMs are taken into account using an ad-hoc model based on repetitive increase of the transport coefficients with frequency and duration taken from the experiment. To get a realistic description of energy and particle losses during the ELM and their recovery afterwards, a wide calculation grid extending 20 cm inside the separatrix is used. The inclusion of ELMs in the model is necessary to obtain a realistic model description of the time dependent experimental parameters in between ELMs. As can be seen in Fig. 2, the assumption of time independent transport gives a good description of the stored energy change in between ELMs.

Shot	I_p	P_{heat}	Γ_{puff}	Γ_{pump}	$n_{e,sep}$	f_{Green}	H_{98}	ν_{ELM}	W_{ELM}	T_{ped}	n_{ped}	dR_χ	$\chi_{i,e}$	dR_T	dR_n
	MA	MW	at/s	at/s	m^{-3}			Hz	kJ	keV	m^{-3}	cm	m^2/s	cm	cm
			10^{21}	10^{21}	10^{19}						10^{19}				
55428	1.2	7	6	4.5	1.1	0.9	1.07	34	80	0.38	3.5	3.5	0.33	1.8	2.4
55429	1.2	7	14	8	1.7	1.0	1.0	48	65	0.30	3.8	3.1	0.37	2.1	1.8
55936	2	12	10	6	1.6	0.7	1.15	22	210	1.06	3.4	3.9	0.24	2.4	1.6
55937	2	12	17	8	1.8	0.75	1.08	28	170	0.88	4.2	3.8	0.21	2.4	1.7
55938	2	12	20	10	2.3	0.78	1.0	30	140	0.91	3.8	4.2	0.3	2.9	1.2
55947	2	12	47	16	3.3	0.87	0.87	60	87	0.60	5.3	3.8	0.26	3.4	0.9
58569	2	13	10	8	2.0	0.69	1.15	27	210	1.07	3.9	4.1	0.29	2.5	1.7
58628	2	13	34	17	2.2	0.79	0.95	50	140	0.88	4.9	4.1	0.24	2.5	1.8
58638	3	16	30	17	3.0	0.74	0.94	28	250	1.31	5.7	4.8	0.25	3.2	1.9

Table 1: Experimental parameters for the selected type-I ELMy DOC-L discharges. NBI particle source is about 10^{21} at/s for 11.5 MW beam heating. Pumped particle rates are calculated for a subdivertor temperature of 400 K. dR_χ is the radius of the inner ETB boundary in the χ profile in the outer midplane relative to the separatrix. $dR_{T,n}$ denote inner barrier positions obtained from the mtanh fit.

Figure 3 shows target power profiles obtained from IR measurements for a similar discharge (slightly lower heating power and gas flux, see Table 1) compared to the modelling. The spatial apparatus function has been deconvoluted from the IR data. Shown are modelled cases without

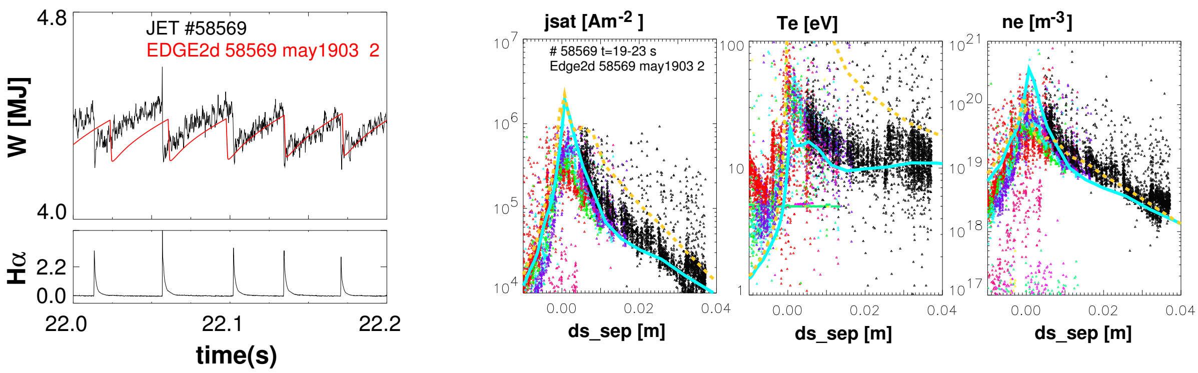

Figure 2: left: Time variation of the stored energy durings ELM cycles and EDGE2d modelling. right: Langmuir probe measurements along the outer target mapped to the outer midplane obtained from a strike point sweep compared to EDGE2d modelling (lines) in between ELMs (light blue) and during an ELM (orange dotted). The lower boundary of the experimental data corresponds to inter-ELM phases, ELMs lead to vertical excursions.

flux limiters and with electron and ion parallel power fluxes limited to 1.0 $\times$ their sound speeds. The flux limiters may be important for the parameters very close to the separatrix, they are not used for the cases summarized in Table 1. The divertor in-out symmetry seen in the experiment is reasonably reproduced by a ballooning like transport ansatz, namely the fluxes being driven by gradients in real space rather than flux space.

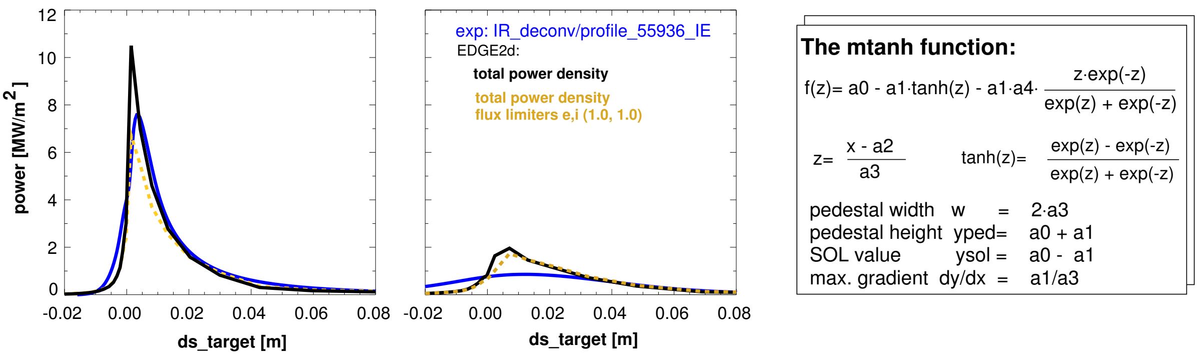

Figure 3: Experimental power flux density at the targets from deconvolution of IR measurements (blue) versus EDGE2d modelling without flux limiters (black) and with flux limiters set to 1.0 $\times$ sound speed for electrons and ions (orange dotted). # 55936, 11 MW NBI, 2 MA H-mode with low gas puff.

The infrared measurements of the target power load profile also allow to estimate the extension of the high transport region during ELMs into the scrape-off layer plasma: The measured power width stays roughly constant during regular type-I ELMs. If the transport enhancement would stop at the separatrix, the higher temperature during an ELM would cause a narrowing of the power width profile. Comparison of experiment and modelling suggests a transport rise during ELMs extending about 0.5-1 cm outside the separatrix.

Results and comparison to ASDEX Upgrade

Transport coefficients around the edge transport barrier are obtained from the EDGE2d analysis, including estimates of the barrier widths for a H-mode gas scan. The n_e and T_e profiles obtained from the modelling are fitted with a modified tanh function [3] (see Fig. 3) allowing to directly compare barrier parameters derived from experimental data to the underlying transport coefficients. As can be seen in table 1, the inner barrier position obtained from the fit is usually closer to the separatrix than the χ boundary used in the modelling. Results from mtanh fits of the EDGE2d output are shown in Fig. 4 and compared to ASDEX Upgrade data [3]. The total plasma energy per volume from the experiment compared to the derived pedestal pressure shows good correlation indicating an experimental situation close to stiff core profiles.

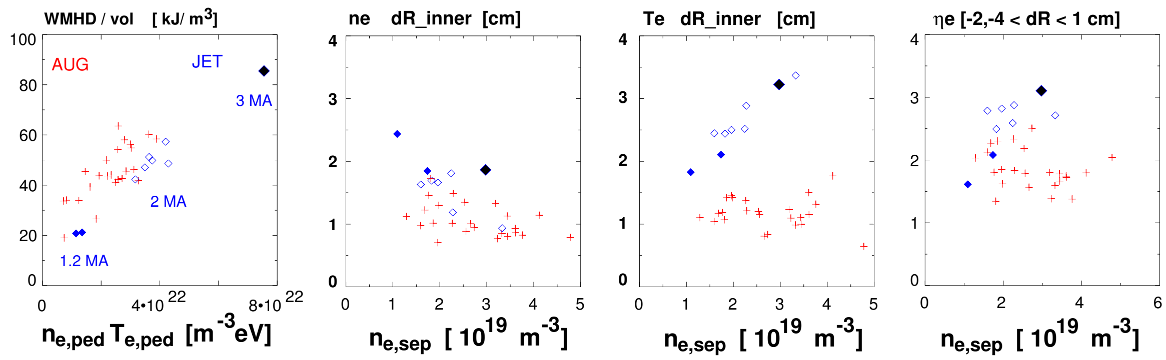

Figure 4: Pedestal parameters and inner barrier width for the discharges of Table 1 compared to ASDEX Upgrade [3]. Also shown is $\eta_e = (\frac{dT_e}{dr}\frac{1}{T_e})/(\frac{dn_e}{dr}\frac{1}{n_e})$ evaluated from a fit (- 4 cm $<$ dR,sep $<$ 1 cm) for JET and (-2, 1 cm) for AUG.

A pronounced difference is seen between the inner boundary of the steep gradient regions of T_e and n_e in JET type-I ELMy H-modes. While the width of the steep T_e gradient region inside the separatrix increases with density, a slight narrowing is seen in the density profile. The edge barrier width in JET is roughly a factor 2 broader compared to ASDEX Upgrade. The behaviour of the density profile could be compatible with the neutral penetration model [4], while the temperature barrier has to be driven by different physics. A possible candidate for the relative T_e and n_e profile shapes is the $\eta_e \approx$ const constraint [3] related to a feature of drift wave turbulence to produce a particle inward drift to satisfy $\eta_e \approx 2$. The accuracy of the JET gradient measurements is not yet good enough for a quantitative evaluation of η_e mainly due to the limited spatial resolution of the edge LIDAR [1], Fig. 4d shows the actual status. Since the density profile is measured by the Li beam, Te in the gradient zone is the most uncertain quantity. Care has to be taken for the definition of the edge transport barrier zone. If a tanh function is used to parametrize the width, a smaller value is obtained compared to the χ barrier used in the transport model. This is partly due to the fact that the temperature gradient is inverse proportional to the density for constant χ in combination with the narrow density profile.
Although the transport model is constrained by the match to several diagnostics, the experimental profile resolution still requires further improvement, in particular in the region around the pedestal top.

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