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A.B. Kukushkin, V.S. Neverov, M.F. Stamp, A.G. Alekseev, S. Brezinsek,
A.V. Gorshkov, M. von Hellermann, M.B. Kadomtsev, V. Kotov,
A.S. Kukushkin, M.G. Levashova, S.W. Lisgo, V.S. Lisitsa, V.A. Shurygin,
E. Veshchev, D.K. Vukolov, K.Yu. Vukolov and JET EFDA contributors

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A.B. Kukushkin[1], V.S. Neverov[1], M.F. Stamp2, A.G. Alekseev[1], S. Brezinsek[3],
A.V. Gorshkov[1], M. von Hellermann[4], M.B. Kadomtsev[1], V. Kotov[3], A.S. Kukushkin[4],
M.G. Levashova[1], S.W. Lisgo4, V.S. Lisitsa[1], V.A. Shurygin[1], E. Veshchev[4],
D.K. Vukolov[1], K.Yu. Vukolov[1] and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]Tokamak Physics Institute, NRC "Kurchatov Institute", Moscow, 123182, Russia
[2]EURATOM-CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[3]Forschungszentrum Jülich, Euratom Association, Jülich, 52425, Germany
[4]ITER Organization, Route de Vinon sur Verdon, 13115 St Paul Lez Durance, France
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ABSTRACT.

We report on the first results for the spectrum of divertor stray light (DSL) and the signal-to-background ratio for D-α light emitted from the far SOL and divertor in JET in the recent ITER-like wall (ILW) campaign. The results support the expectation of a strong impact of DSL upon the H-alpha (and Visible Light) Spectroscopy Diagnostic in ITER.

1. INTRODUCTION

The use of an all-metal first wall in future magnetic fusion reactors equipped with a divertor may impose severe limitations on the capabilities of optical diagnostics in the main chamber because of a divertor stray light (DSL) produced by multiple (diffusive and/or mirror) reflections of intense light emitted in divertor. For optical diagnosis of hydrogen, various neutral and low ionized impurities in the far scrape-off layer (SOL) of the main chamber one should expect strong contribution of the DSL in the same spectral lines. Preliminary analysis of the DSL problem for the H-alpha (and Visible Light) Spectroscopy Diagnostic in ITER suggested that there may be a substantial dominance of Balmer-α DSL over the Balmer-α light emitted from the SOL (SOLL), up to two orders of magnitude for highly reflecting walls and high-power operation. To meet the ITER Measurement Requirements, one has to develop a detailed assessment of the measurement accuracy for the fuel ratio and the recycling flux from the first wall. First results [1] have shown that a test of the elaborated approach in the currently running machines with all-metal first wall is required to benchmark the analysis method.

Here, we report on the first results of the signal-to-background ratio (SOLL/DSL) for D-α light emitted from the far SOL and divertor in JET in the recent ITER-like wall (ILW) campaign. The SOLL/DSL ratio is found via solving an inverse problem. The developed synthetic H-α diagnostic is tested on the example of data from predictive modeling of ITER operation. The implications for the H-alpha (and Visible Light) Spectroscopy Diagnostic in ITER are formulated.

2. INTERPRETATION OF DATA

We analyze high-resolution spectrometer data on resolving power at D-α with direct observation of the divertor from the top (KSRb Tracks 1-10 cover the outer divertor; the Zeeman σ-components are filtered out) and with observation of the inner wall from equatorial ports (KSRb Track 11 is a radial line-of-sight (LoS) at vertical coordinate $Z = \sim +200$ mm, targeted at a 200 mm spot which covers partly the inboard poloidal limiter and partly the inner wall cladding tile in the 8th octant; KSRb Track 12 is a tangential LoS at $Z = \sim 0$, targeted at a similar spot at one side of the beryllium inboard poloidal limiter in the 7th octant, with the angle between the LoS and toroidal field $\Phi = 35.5^o$ at the inner wall and $\Phi = 66.4^o$ at the outer wall).

We developed the following subroutines to solve the final inverse problem.

a) A subroutine for the spectral line shape calculation of the Balmer-α DSL for given divertor emission parameters (relation between emissivity and temperature on each LoS) to be recovered from direct observation of divertor from the top (KSRb Tracks 1-10, Zeeman π-component only). We use the model [1] for the DSL spectrum (Doppler-Zeeman line shape, uniform/isotropic intensity throughout the vacuum chamber), but make the ratio of Zeeman π- and σ-components a variable parameter to allow for possible angle anisotropy of the DSL due to a local shadowing of the light by a (poloidal) limiter.

b) A subroutine for the spectral line shape calculation of the Balmer-α local emissivity at any point of the SOL. First, we assume, for each Zeeman component, a three-Gaussian (dubbed the M3 case) or two-Gaussian (M2 case) line shape. Second, we developed a model for the spectral line shape asymmetry caused by the inward flux of atoms with an essentially non-Maxwellian velocity distribution function (VDF). The latter model is suggested by the results of the 1D model [2] for neutral hydrogen VDF in the SOL, tested against simulations with the B2-EIRENE (SOLPS4.3) code [3-5]. Our model assumes, for all Maxwellians except the coldest one, an additional Maxwellian, which has the same temperature and only the inward flux of atoms, and is distorted by the velocity-dependent suppression factor determined by the ionization and charge-exchange loss of these neutral atoms on their way from the wall.

The algorithm for the evaluation of the DSL/SOLL ratio for the Balmer-α light in JET is as follows.

a) Evaluation of spatial distribution of the temperature of emitting plasma in divertor from Balmer-α π-component spectrum from KSRb Tracks 1-10. Here we solve an inverse problem assuming a three-Gaussian line shape (i.e. on each LoS, temperature profile is approximated by a histogram with only three possible values of temperature found from an optimization).

b) Evaluation of space-average parameters of velocity distribution function (VDF) of emitting atoms in the SOL from the Balmer-α SOL spectrum for KSRb Tracks 11 and 12 at the very initial, limiter phase of discharge, prior to the onset of the DSL. Here we solve an inverse problem using the subroutine “B” in the M3 case.

c) Evaluation of the DSL/SOLL ratio from the Balmer-α spectra – independently from KSRB Tracks 11 and 12 – at divertor phase of discharge. Here we solve an inverse problem using the subroutine “A”, the subroutine “B” in the M2 case, and taking the ratio of Zeeman π- and σ-component of the emission from the SOL (dependent on the toroidal angle Φ at emissivity maximum), determined on the step 2.

The results of applying this interpretation procedure to JET ILW data for the pulse with moderate power of the NB injection are illustrated with figures 1-3.

The similarity of the (normalized) line shapes of the DSL and the outer wall SOLL (due to closeness of the π-to-σ Zeeman components intensity ratios and stronger overlapping of Zeeman components on the outer wall) substantially influences the inverse problem solution. It appears that a good fitting of the measured spectrum may be attained even with the neglect of the DSL at diverted stage of discharge. However this would require the dominance of the outer wall SOLL over the inner wall SOLL by an order of magnitude that contradicts the visible camera data while similar ratio at the NBI stage in the case of Fig. 3b lies in the range ~1-2 for track 11 and 0-0.5 for track 12. Such an uncertainty means one has to allow for the data from other diagnostics. Anyway the solutions of the inverse problem with neglect of the outer wall SOLL (as suggested by the limiter stage of this discharge, see Fig.1) and without this neglect seem to characterize the range of possible values of the DSL/SOLL ratio.

Note that the fitting of experimental spectra (accuracy of reconstruction) in the final phase of discharge, after the NBI is switched off ($t > 14$ s), is not good because of transient processes not described well by analytic models [1] and [2].

Similar results are obtained for high-power diverted discharge (Pulse No: 83551, NBI ~25 MW).

3. TEST OF A SYNTHETIC H-α DIAGNOSTIC

The accuracy of the developed synthetic H-α diagnostic may be tested on the example of data from predictive modeling of the flat-top of $Q = 10$ inductive operation of ITER with the B2-EIRENE (SOLPS4.3) code (with account of the poloidally resolved plasma recycling from the FW in the frame of the “extended grid” [6]). We use the simulations of the neutral deuterium VDF with the EIRENE code [4] to compare the LoS-average results for temperatures (for non-Maxwellian fractions of VDF, effective ones) from the “local kinetic model” (L) with those recovered from the developed algorithm which originally operates with the LoS-average parameters (“LoS-integral model” (I)). The comparison is given in Tables 1 and 2 for various scenarios of predicted ITER divertor operation (cf. notations in [1]) for the case M3 of the inverse problem. For comparison the temperature interval was divided to equalize the respective fraction of the “phantom” observed intensity in the L and I models. The respective fractions of non-Maxwellians are indicated. The agreement of temperatures is worse for the high-temperature populations because of poor Monte-Carlo statistics for the VDF’s tail.

CONCLUSIONS

The data from the JET KSRb Diagnostic (direct observation of outer divertor from the top and radial and tangential lines-of-sight (LOS) in nearly equatorial plane) allow to evaluate the spectrum of divertor stray light (DSL) and the signal-to-background ratio for D-α light emitted from the far SOL and divertor in JET ILW. Despite at limiter phase of discharge the contribution of the outer wall SOL light (SOLL) is small, the solution of the inverse problem appears sensitive to including the outer wall SOLL at divertor stage of discharge. The results show the DSL/SOLL ratio to vary from ~2 to ~5 if neglecting the outer wall SOLL, and from ~1 to ~2 if allowing for it, in moderate-power diverted discharge (Pulse No: 83624, NBI ~12MW). Similar results are obtained for high-power diverted discharge (Pulse No: 83551, NBI ~25MW). Such an uncertainty means one has to allow for the data from other diagnostics on JET to improve the accuracy of recovering the DSL/SOLL ratio. The developed synthetic H-α diagnostic is tested on the example of data from predictive modeling of the flat-top of Q=10 inductive operation of ITER with the B2-EIRENE (SOLPS4.3) code. The results support the expectation of a strong impact of the DSL upon the H-alpha (and Visible Light) Spectroscopy Diagnostic in ITER. In ITER, we expect to diminish the uncertainty of recovery of the SOLL and DSL by using the bifurcated-LOS measurements (targeting at an optical dump and very close to it) [1].

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Scenario	Non-Maxw. Fraction, %		Temperatures, eV						Non-Maxwellian $(T_a)_{eff}$, eV			
			Low		Middle		High		Low		High	
	L	I	L	I	L	I	L	I	L	I	L	I
D	64.3	64.2	0.16	0.15	4.0	3.1	132.2	117.1	15.2	6.2	54.7	20.6
E	64.9	64.2	0.11	0.10	4.1	2.4	154.0	105.6	16.5	5.0	81.1	18.6
F	60.7	59.2	0.12	0.10	5.7	3.1	94.5	87.7	6.5	5.0	64.9	36.3
G	60.0	58.1	0.16	0.10	6.2	2.7	102.6	68.4	7.7	5.0	67.4	33.3
H	52.9	51.9	0.5	0.16	7.9	4.8	61.0	50.0	13.7	9.2	46.3	16.8
I	52.2	51.2	1.1	0.5	10.6	7.0	52.5	49.7	14.8	12.4	67.6	15.1

Table 1: Comparison of temperatures from local kinetic (L) and LoS-integral models (I) for M3 case.

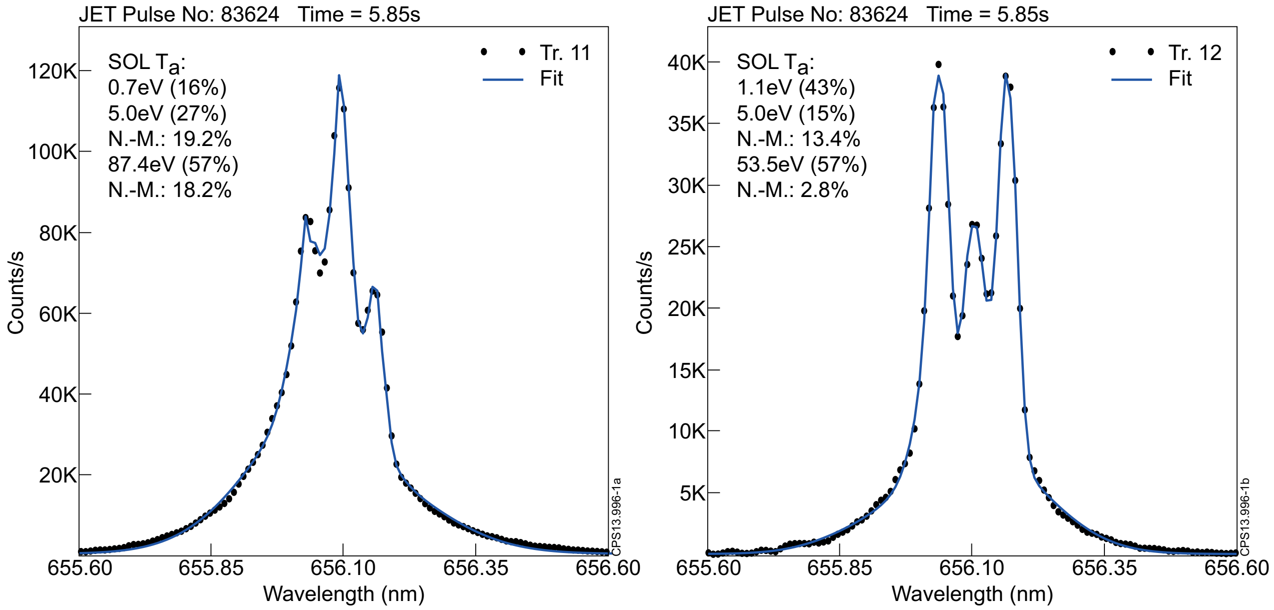

Figure 1: The result of optimal fitting of the spectrum on the KSRb Tracks 11 (a) and 12 (b) for JET Pulse No: 83624 at limiter phase of discharge (time t = 5.85s, the DSL is negligible). The subroutine B in the M3 case is used. Atomic temperatures and their partial contribution to observed D-α intensity are indicated. For two temperatures the partial contribution of respective non-Maxwellian component is indicated as well. The Zeeman splitting corresponds, with an accuracy of 5-10%, to the inner wall magnetic field.

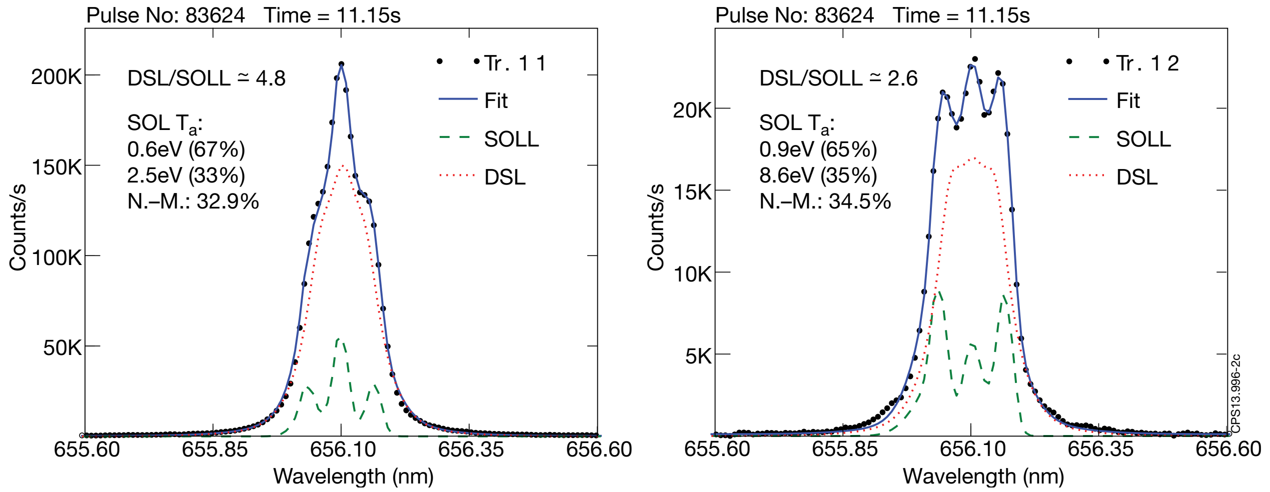

Figure 2: The result of optimal fitting the spectrum on the KSRb Tracks 11 (a) and 12 (b) for JET Pulse No: 83624 at high power phase of discharge (time t = 11.15s, NBI ~ 12MW) without an account of the outer wall SOLL. For SOL, the subroutine B in the M2 case is used.

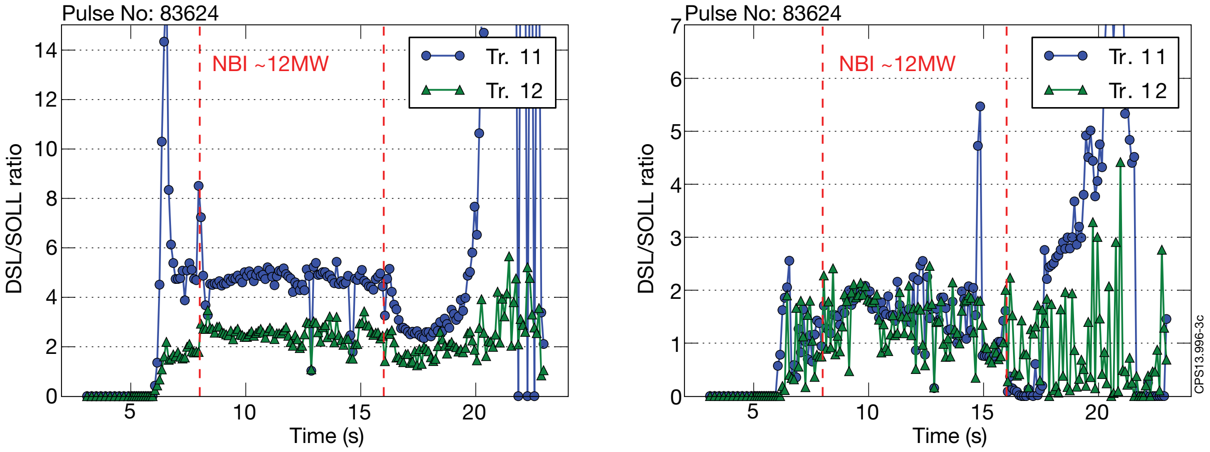

Figure 3: Time dependence of the DSL/SOLL ratio recovered from the data from KSRb Tracks 11 and 12 for JET Pulse No: 83624, NBI 12MW with (a) and without (b) neglect of the outer wall SOLL. For both outer and inner SOL, the subroutine B in the M2 case is used that totally gives 9 (case 'a') and 15 (case 'b') free parameters for inverse problem. The interval of strong NBI action is indicated.