Recovery of relative contributions of SOL emission and divertor stray light in Balmer-alpha spectroscopy in ITER

V.S. Neverov[1], A.B. Kukushkin[1,2], A.G. Alekseev[1], S.W. Lisgo[3]

[1] *National Research Centre "Kurchatov institute", Moscow, Russia*

[2] *National Research Nuclear University "MEPhI", Moscow, Russia*

[3] *ITER Organization, Route de Vinon sur Verdon, St Paul Lez Durance, France*

1. Introduction. The verification of a number of essential features of the theoretical model [1] proposed for the H-alpha diagnostics in ITER was carried out in [1], using only spectroscopic data (i.e. without independent knowledge of background plasma parameters) from the recent experiments on tokamak JET with ITER-like wall (JET-ILW). The model [1] is aimed at the recovery of the density of neutral hydrogen, and its isotopic contents, in the SOL by solving a multi-parametric inverse problem with allowance for: (i) strong divertor stray light (DSL) in the signal measured on the lines of sights (LoS) in the main chamber, (ii) significant deviation of the velocity distribution function (VDF) of neutral atoms in the SOL from a Maxwellian, (iii) the data of direct observation of the divertor.

The accuracy of the model should be tested in the frame of a "synthetic" diagnostics which simulates "phantom" experimental spectra using the predictive numerical modelling and allows comparison of "true" values with those recovered from the "phantom" data. Such a test of the recovery of only the VDF parameters in the SOL without the DSL was done in [2] using the modelling by the SOLPS4.3 (B2-EIRENE) code [3] (on an expanded numerical mesh with allowance for the poloidally resolved recycling from the first wall [4]) for background plasma on the flat-top of Q = 10 inductive operation of ITER. Here we extend the test [2] to allow for all three sources of signal on the LoS in the main chamber: inner and outer sections in the SOL on the LoS, and the DSL. We estimate the accuracy of: (i) fitting the Balmer-alpha line shapes of hydrogen isotopes in the SOL with allowance for a strong line shape asymmetry, using the model [5]; (ii) fitting the DSL spectrum using the spectroscopic data for direct observation of divertor from the top on the sixteen LoS; (iii) recovery of partial contributions of the above-mentioned sources in the measured signal. The details of the formalism are reported in [6].

2. Separation of inner- and outer-SOL light without DSL. First, we consider the case when the signal measured on the LoS in the main chamber along the major radius from the equatorial port plug contains the contributions from the inner and outer sections of the

SOL plasma and does not contain the DSL. In this case we solve the inverse problem very similar to that formulated and solved for JET-ILW in [1] for the limiter stage of the discharge, but with the “phantom” experimental signal (instead of the measured one) calculated with the local Balmer-alpha emissivity and the VDF values, obtained with SOLPS4.3 (B2-EIRENE) code. Since the “true” value of fraction of the light from the inner/outer section of the SOL is known, we can estimate the error of the inverse problem solution. We use the data calculated for the six ITER operation scenarios (cf. [4,7]): low (“d”,”e”)/middle (“f”,”g”)/high (“h”,”i”) density in the far SOL in the L-mode (“d”,”f”,”h”)/H-mode (“e”,”g”,”i”) regime for deuterium plasma. Figure 1 shows the typical results of the inverse problem solution. Without the DSL, the absolute value of the error of recovering the fraction of the inner SOL light in the total signal does not exceed 0.2.

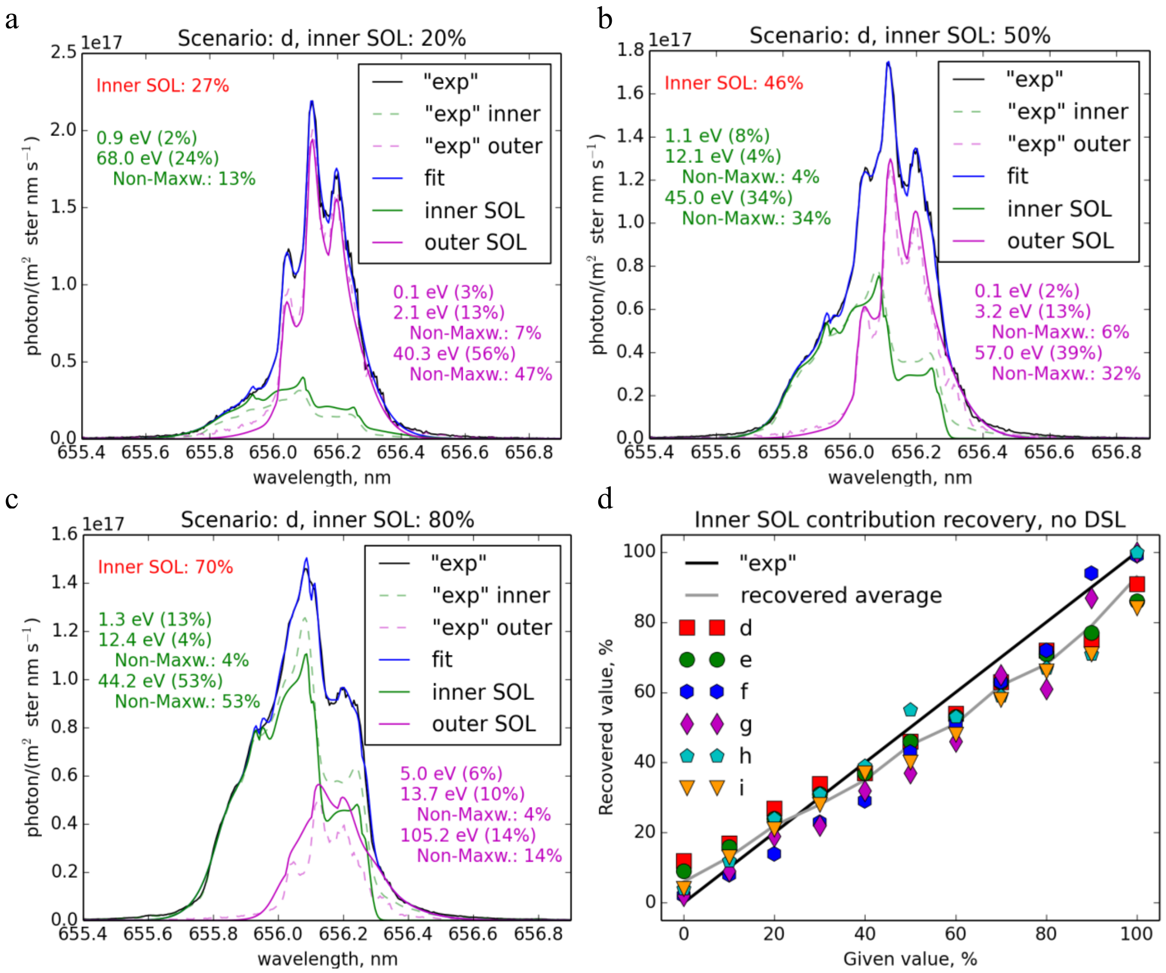

Figure 1. Fitting the “phantom” experimental signal for 20% (a), 50% (b), 80% (c) input (i.e. phantom experimental) fraction of the inner SOL light in the total signal for the scenario “d”. The “true” inner and outer SOL light spectra are shown with dashed lines, respectively, while the recovered spectra with solid lines of the same color. Comparison of the recovered values of the fraction of the inner SOL light in the total signal with the “true“, phantom experimental values (black curve) for the six ITER operation scenarios (d). The recovered value, averaged over six scenarios, is shown with gray curve.

3. Separation of inner-and outer-SOL light, and strong DSL. In this case we need to model the DSL spectrum. In [1] we used the data from direct multiple-LoS observation of the JET-ILW divertor from the top to recover the parameters of the neutral atoms in the divertor and simulate then the DSL spectrum with only one free parameter, the fraction of the pi-component in the Zeeman triplet. Here we perform the same procedure but for the "phantom" experimental data and the 16 observation chords in ITER. Our calculations show that the recovery of the characteristic temperature of the neutral atoms and the isotope ratio in the divertor may be done with a high accuracy. This is not surprising for a single source of the signal and for symmetric lines shapes of the Balmer-alpha emission in the divertor. However the recovered DSL spectrum poorly reproduces the "phantom" one (Figure 2(a)), which is calculated here using the semi-analytical formula (2) from [6]. The difference between these spectra results in a high error of the inverse problem solution in the case of a high fraction of the DSL in the signal (see Figure 2 (b)).

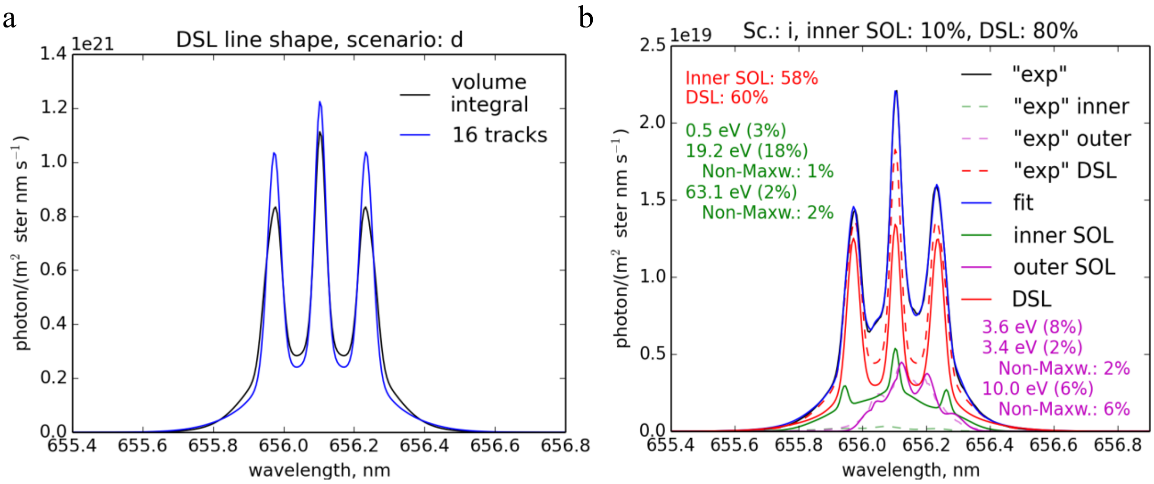

Figure 2. Comparison of the DSL spectra calculated with Eq. (2) in [1] (black curve) and recovered from the direct observation of the divertor on the 16 chords (a). Fitting the "phantom" experimental signal for the 80% fraction of DSL in the measured signal and 10% fraction of the inner SOL light in the total SOL light (b).

It appears that the solver of the inverse problem is confused with distinguishing the contributions of the DSL and the inner-SOL light. Figure 3 shows that already for 40% fraction of the DSL in the total signal the accuracy of identifying the contributions of the inner- and outer-SOL light is unacceptably low and becomes even worse for a higher fraction of the DSL. We have checked that the increase of the accuracy of the DSL modeling, even for an unknown fraction of the Zeeman pi-component, makes it possible to recover the inner and outer SOL contributions with a high accuracy even for the DSL fraction as high as 80%.

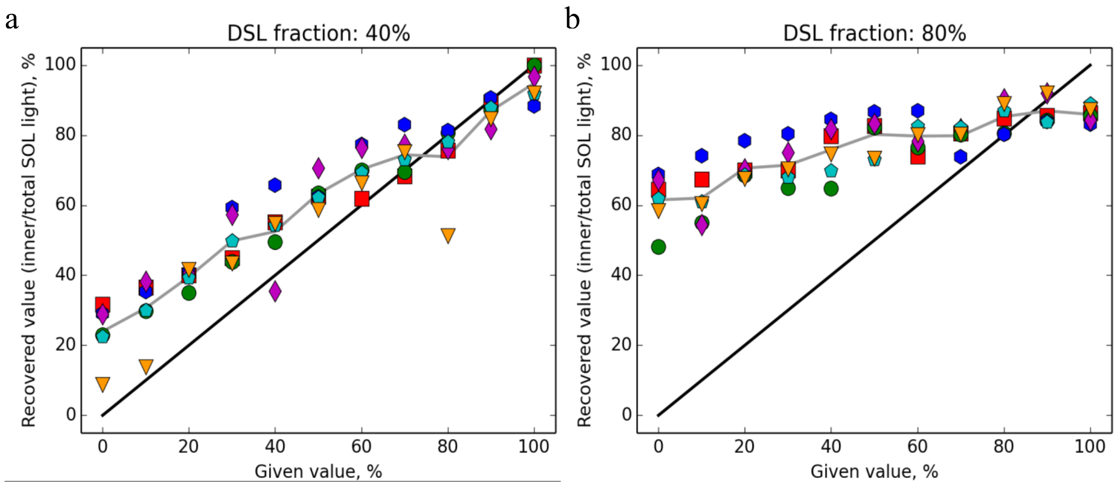

Figure 3. Comparison of the recovered values of the fraction of the inner SOL light in the total SOL light with the “true“, phantom experimental values for the six scenarios, for the 40% (a) and 80% (b) DSL fraction in the total measured signal (see the legend in Figure 2(d)).

3. Conclusions. We tested the accuracy of the theoretical model [1], proposed for the H-alpha diagnostics in ITER, in the frame of a “synthetic” diagnostics which simulates the “phantom” experimental spectra using the predictive numerical modelling with the SOLPS4.3 (B2-EIRENE) code for the flat-top stage of Q=10 inductive operation of ITER. The error assessment for the line of sight along the major radius from the equatorial port-plug in ITER shows that: (i) without the DSL, the absolute value of the error of recovering the fraction of the inner-SOL light in the total signal does not exceed 0.2; (ii) already for the 40% fraction of the DSL in the total signal, the absolute error of recovering the contributions of the inner- and outer-SOL light is unacceptably high, 0.4, because of poor accuracy of predicting the DSL. Unification of the theoretical models [1] and [7] is needed to increase the accuracy.

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