Investigation of Impurity Cooling Factor Robustness against Transport and Application to GEM Detectors for W Core Density Reconstruction on WEST

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1. Introduction

Recent tokamaks like WEST are equipped with metallic walls, in particular tungsten (W), to keep fuel retention in the plasma-facing components and erosion under acceptable levels. However, heavy impurities radiate a lot of energy out of the plasma core and represent one of the current major source of concern, thus robust diagnostic and control tools are needed for future operations. W core density can be reconstructed using Soft X-ray (SXR) tomography (in the range 1 - 15 keV) thanks to the W radiation function L_W^η convoluted with the spectral response η of the detector, so called the W filtered cooling factor.

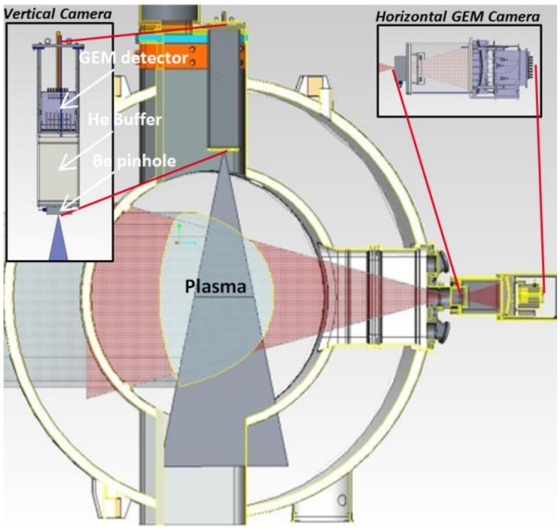

Figure 1. GEM based SXR diagnostic integration on the tokamak WEST

2. Soft X-Rays and Impurity Cooling Factor

The soft x-ray emissivity ε_S (in W.m^{-3}.eV^{-1}) of a species S inside the plasma is expressed as:

$$\varepsilon_S(h\nu) = n_e . n_s \sum_{q=0}^{Z_S} f_{S,q}\left(T_e, \vec{\Gamma}_{S,z\in[\![0;Z_S]\!]}\right) . \left[k_{S,q}^{ff}(h\nu, T_e) + k_{S,q}^{fb}(h\nu, T_e) + k_{S,q}^{bb}(h\nu, T_e)\right] \quad (1)$$

where n_e and T_e are respectively the electron density and temperature, $f_{S,q}$ the fractional abundance of the *q-th* ionization state of *S*, $h\nu$ the photon energy, $\overrightarrow{\Gamma_{S,z}}$ the radial particle flux of S^{z+} - usually expressed as the combination of a convective and a diffusive terms: $\overrightarrow{\Gamma_{S,q}} = n_{S,q} . \overrightarrow{V_S} - D_S . \vec{\nabla} n_{S,q}$ - and $k_{S,q}^{ff}$, $k_{S,q}^{fb}$, $k_{S,q}^{bb}$, the emission coefficients respectively accounting for

Bremsstrahlung (free-free) emission, radiative recombination (free-bound), and line radiation (bound-bound) calculated thanks to the OPEN-ADAS database [1].

For a detector with spectral response $\eta(h\nu)$, the observed filtered W emissivity Σ_W^η ($W.m^{-3}$) is:

$$\Sigma_W^\eta = \int \eta(h\nu)\varepsilon_W(h\nu)dh\nu = n_e.n_W.L_W^\eta(T_e) \quad (2)$$

with L_W^η the filtered cooling factor of W (in $W.m^3$). Solving the ionization equilibrium allows to retrieve the fractional abundances $f_{W,q}$ of each W ionization state to compute L_W^η.

$$\frac{\partial n_{W,q}}{\partial t} + \vec{\nabla}.\vec{\Gamma}_{W,q} = n_e\big(R_{W,q+1}.n_{W,q+1} + I_{W,q-1}.n_{W,q-1} - (R_{W,q} + I_{W,q})n_{W,q}\big) + s_{ext,q} \quad (3)$$

where $R_{W,q}$ and $I_{W,q}$ are the recombination and ionization coefficients of W^{q+} ions [1]. Unfortunately, the ionization equilibrium depends on transport, and considering that the global impurity cooling factor is not affected by transport is not necessarily always a safe assumption. Thus, in this work the robustness of L_W^η against particle transport is investigated with a focus on application to Gas Electron Multiplier (GEM) detectors for W core density reconstruction in the tokamak WEST.

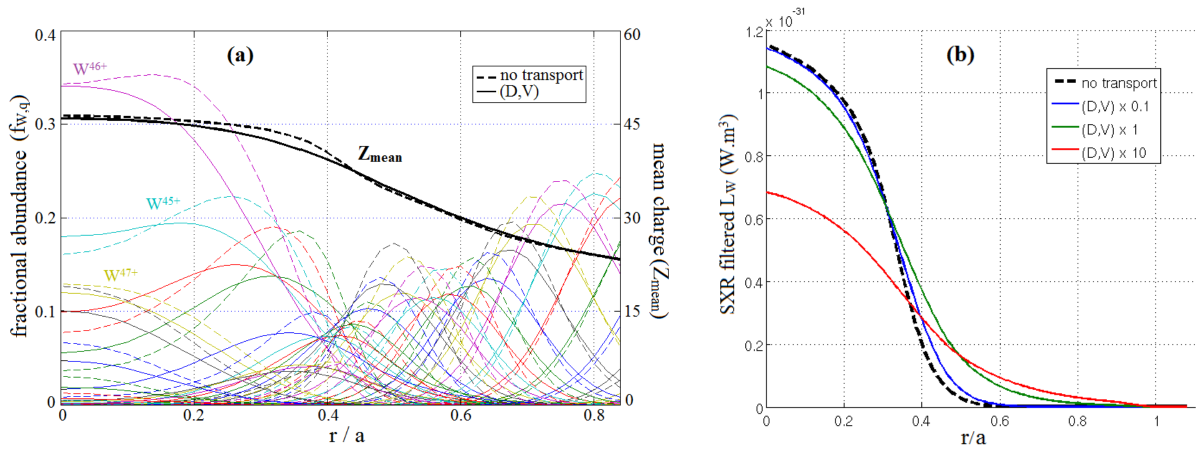

Figure 2. (a) W ionization equilibrium and (b) W SXR filtered cooling factor perturbed by transport

3. Reconstruction of W core density using GEM synthetic diagnostic

The new SXR diagnostic of WEST is composed of two GEM cameras [2] working in photon counting mode, thus allowing tomographic inversions [3] in tunable photon energy bands. A GEM synthetic diagnostic developed in [4] is used to retrieve the expected GEM spectrum for a given WEST plasma scenario and reconstruct original W density using a Minimum Fisher Information (MFI) tomography method [3] and equation (2).

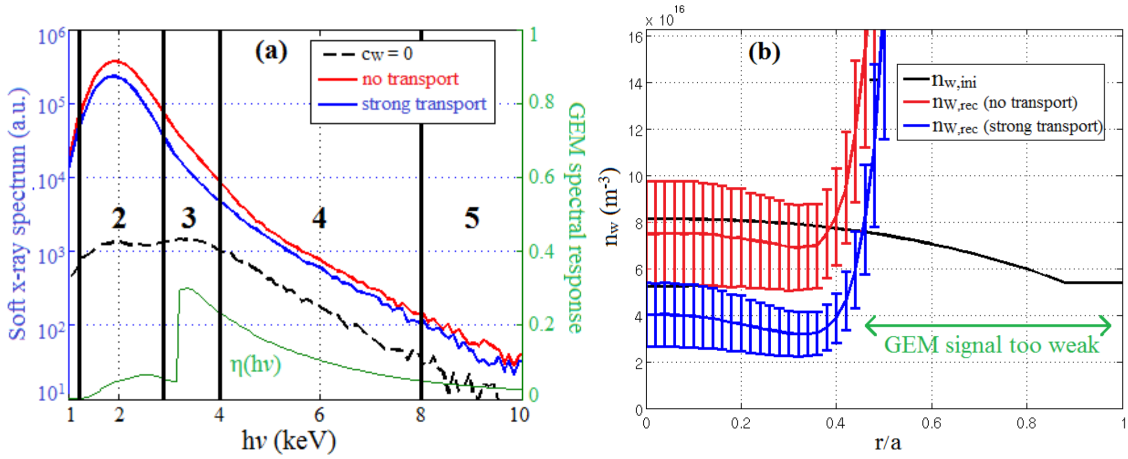

Figure 3. (a) Synthetic GEM spectrum obtained for 3 different simulations and decomposed in energy bands, (b) W density reconstruction without and with strong transport effect

4. Robustness on the W Cooling factor against transport in different energy bands

The L_W^η dependency to particle transport [5] is studied using a set of various (D,V) profiles multiplied by a transport level factor ranging from 0.01 to 50 to perturb the ionization equilibrium, with different resulting n_W profiles, e.g. flat, homothetic, hollow or peaked profiles. The W cooling factor robustness against transport is investigated through the error map of L_W^η versus electron core temperature and intensity of transport of W^{q+} ions. Eq. (2) is projected radially (1D), at steady state without source term, assuming toroidal and poloidal symmetry:

$$\frac{\vec{\nabla}_r(\vec{\Gamma}_{S,q})}{n_e n_S} = R_{S,q+1} f_{S,q+1} + I_{S,q-1} f_{S,q-1} - (R_{S,q} + I_{S,q}) f_{S,q} \tag{4}$$

The study is focused on finding a GEM photon energy band which optimizes the stability of L_W^η against transport in the validity domain defined by the chosen (D,V) scenarios.

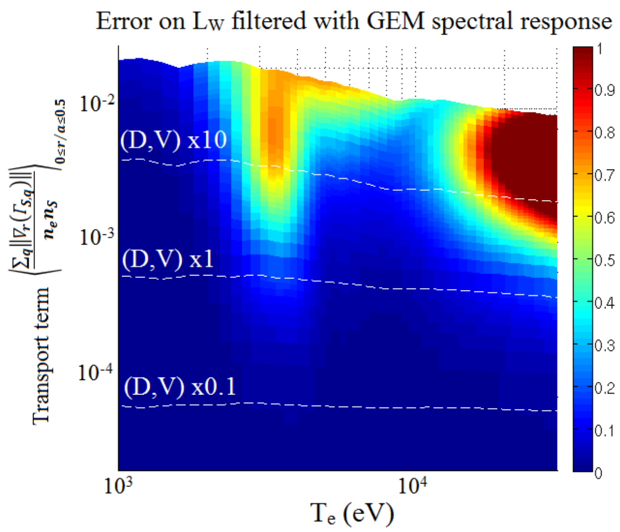

Figure 4. Error map of L_W filtered with the full GEM spectral response

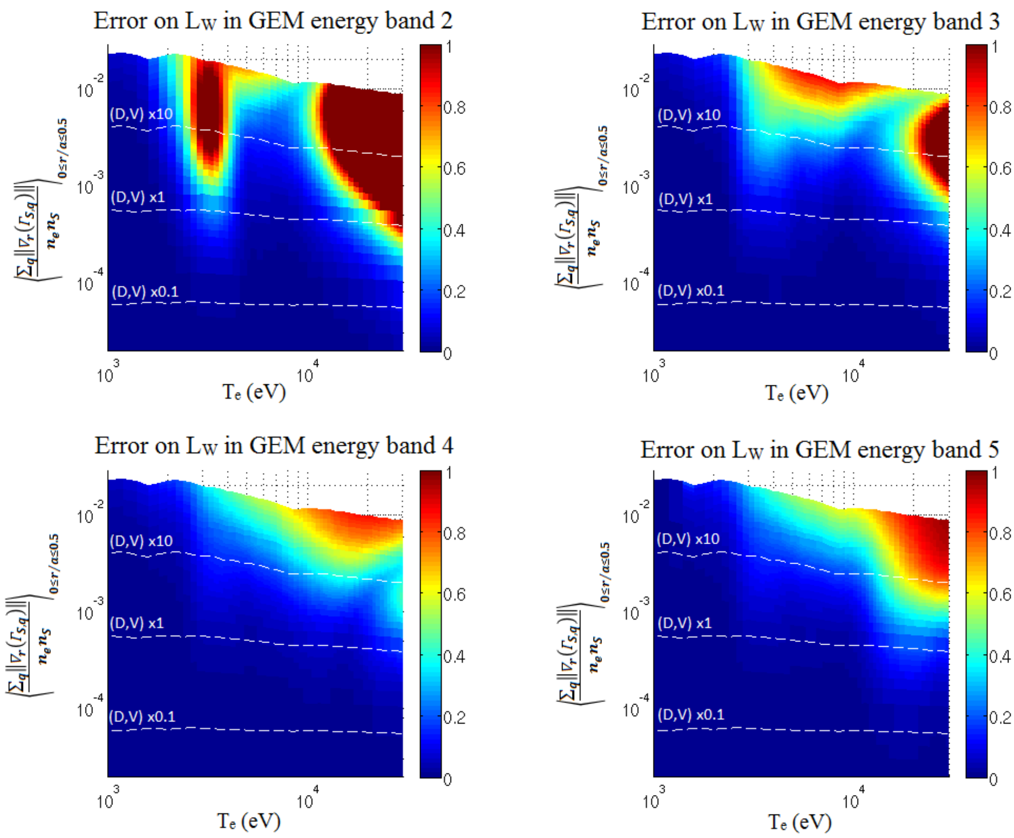

Figure 5. Error map of L_W filtered in the different GEM energy bands

5. Conclusion

WEST will be the first tokamak to use the GEM technology as SXR diagnostic for plasma tomography. The GEM will allow poloidal tomography with resolution in energy bands. In this work, tungsten core density is reconstructed using a synthetic diagnostic, and the robustness of filtered W cooling factor against transport is investigated in several GEM energy bands. Preliminary studies on a WEST case show that W cooling factor is more robust in the energy bands $\gtrsim 4\ keV$ where line radiation is no more dominant over other SXR contributions, but where the GEM signal is expected to be weaker. Since transport coefficients are *a priori* unknown during experiments, a genetic algorithm is being developed to determine empirically the transport coefficients from measurements [6] and check the L_W^η stability assumption.

References

[1] Open ADAS project: http://open.adas.ac.uk

[2] D. Mazon et al, 2016 JINST 11 C08006

[3] A. Jardin et al, 2016 JINST 11 C07006

[4] A. Jardin et al, in proceedings of the *43rd EPS conference on Plasma Physics*, 2016, P5.023

[5] D. Vezinet et al, Nucl. Fusion 54 (2014) 083011

[6] D. Villegas et al, Nucl. Fusion 54 (2014) 073011