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EIRENE modelling with improved CRMs for spectroscopic RT detachment control in EU-DEMO

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EU-DEMO reactor operation is expected to go beyond the ITER requirements of a semi-detached divertor regime [1], and will have to achieve the even higher levels of dissipation needed to demonstrate a realistic power exhaust solution for a fusion power plant. Sustaining the desired degree of detachment will require reliable real time (RT) control. In addition to the actuators (e.g. the impurity seeding rate) one needs reliable, but robust in use (fast, monotonic, free of additional dependences etc) diagnostic signal(s) to characterise the detachment state. Line-of-sight (LOS) integrated spectroscopy is a promising way to provide such a signal, however a deep physics understanding and mature modelling basis is needed for interpretation of the LOS integrated intensities as well as for suggesting the most optimal spectroscopic features (e.g. particular line ratios) to be employed. This work is focused on the related refinement of established modelling tools required for such purposes, namely on development of the atomic and molecular (A&M) collisional-radiative models (CRM) for the EIRENE neutral Monte-Carlo solver, which can also be utilized standalone for investigating A&M effects on a fixed background plasma.

The impact of molecular release of particles from the wall and further reaction sequences in the plasma are known to play a key role in divertor operations including the onset and parameters of detachment. Rotational and vibrational temperatures influence the spectroscopic interpretation of LOS signals. A new CRM [2] is demonstrated that captures part of those effects and provides the regime-changing effects on branching ratios for hydrogen specie emission as a function of plasma parameters. The "free"parameters of the model (H2 source) are calibrated with respect to the underlying SOLPS-ITER (B2.5-EIRENE) EU-DEMO edge plasma backgrounds [3].

Another challenge for simulations on DEMO scale is the overall code performance, which can be improved through new physics features like fluid-kinetic hybridisation of the neutral model, as well as new parallelization paradigms in EIRENE as demonstrated in Ref. [4]. The use of the CRM inside the code can also bear on performance, and this can be partially addressed through following up species internal state variables (sparing the necessity to follow the resolved states as separate species, but implying an approximation in the description of the transport).

This work is a part of the EUROfusion E-TASC activity [5] and feeds into the EU-DEMO exhaust modelling roadmap [6]. Those include interfaces to relevant codes, unification of the underlying data, IMASification etc. Part of the project is focussing also on visualisation tools and synthetic diagnostics including the LOS in the context of 3D DEMO divertor geometry assessment. The modelling can assist in future the EU-DEMO diagnostic design by selecting the optimal number and geometry of the LOS by means of demonstrating reliable synthetic detachment control schemes and predictions.

[1] R.A.Pitts *et al., 2019 NME, vol.20, 100696*
[2] F.Cianfrani *et al., EPS-2022, P2a.105*
[3] F.Subba *et al. 2020 NF 61 106013*
[4] D.V.Borodin *et al., 2022 NF 62 086051*
[5] X Litaudon *et al 2022 PPCF 64 034005*
[6] S.Wiesen *et al., this conference*

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