First principle numerical simulations of the SOL in ASDEX Upgrade

A.H. Nielsen[1], L. Aho-Mantila[2], J. Madsen[1], H.W. Müller[3], N. Vianello[4], H. Radhakrishnan[5], J. Signoret[6], M. Wischmeier[7], B. Sieglin[7], D. Carralero[7], G. Birkenmeier[7], R. Coelho[8], J. Juul Rasmussen[1], V. Naulin[1], M. Løiten[1], L. Tophøj[1], R. Schrittwieser[9], S. Costea[9], the EUROfusion MST1 Team[10], the EU-IM Team[11] and ASDEX Upgrade Team

[1]*Tech. Uni. of Denmark, Kgs. Lyngby, Denmark,* [2]*VTT Tech. Research Centre of Finland,* [3]*Uni. of Vienna, Austria,* [4]*EPFL, CRPP, Ch-1015 Lausanne, Switzerland,* [5]*University of Cyprus, Cypres* [6]*CEA, IRFM, France,* [7]*Max-Planck-Institut für Plasmaphysik, Garching, Germany,* [8]*Instituto de Plasmas e FusĂo Nuclear, Lisboa, Portugal,* [9]*Institute for Ion Physics and Applied Physics, Innsbruck, Austria,* [10]*www.euro-fusionscipub.org/mst1,* [11]*www.euro-fusionscipub.org/eu-im*

Introduction

The turbulent transport in the edge and scrape-off-layer (SOL) regions at the outboard midplane of ASDEX Upgrade is investigated numerically and experimentally. Experimental data obtained during the MST1 campaign from a number of L-mode discharges were analyzed, including L-mode detached discharges induced by Nitrogen seeding.

We use the numerical code HESEL, which simulates interchange turbulence on outboard midplane in 2D perpendicular to the magnetic field and where parallel dynamics has been parametrized. In the numerical simulations the divertor conditions are mimicked by use of a sheath boundary condition term in the generalized vorticity equation. This condition affects the dynamics of the cross field motion of blobs. As energy, particles and momentum are mostly transported into the SOL by these blobs, changing the sheath condition will change the overall dynamics. To facilitate comparison of experimental and numerical results we have implemented the Stuttgart probe[1] as a synthetic diagnostics into the HESEL code. We observe reasonable agreement for the radial momentum transport using floating potential as a proxy for the plasma potential. Using plasma potential provides significantly different results in HESEL. We also numerically investigate the energy flux, not accessible experimentally. The energy flux is split into three components: the convective, the conductive, and the triple product. In the near SOL region all three components are equally important whereas the triple product dominates the energy flux in the far SOL region.

A standardised Kepler workflow, with HESEL embedded, is under development within the Integrated Modelling framework by the Code Development EUROfusion project. The workflow allow direct access to diagnostic data and shot parameters from the database at ASDEX

Upgrade.

Model

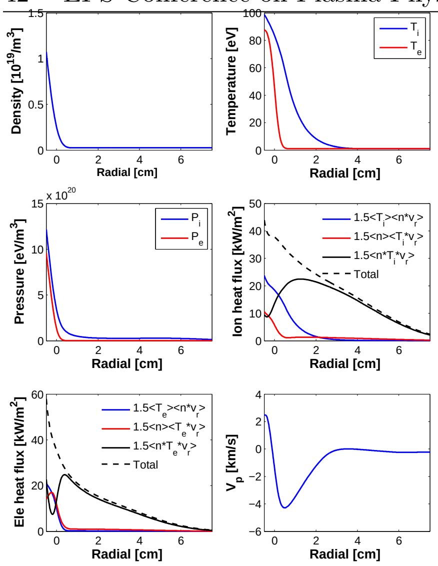
HESEL is an energy conserving four-field model based on the Braginskii equations[2] governing the dynamics of a quasi-neutral, simple plasma. It describes interchange-driven, low-frequency turbulence in a plane perpendicular to the magnetic field at the outboard midplane. In the limit of constant ion pressure the model reduces to the ESEL model, which has successfully modeled fluctuations and profiles in JET, MAST, EAST and TCV, see [3]. The HESEL model includes the transition from the confined region to the region of open field lines (SOL) and the full development of the profiles across the last closed flux surface (LCFS). The model is solved in a local slab geometry with the unit vector $\hat{\boldsymbol{z}}$ along the inhomogeneous toroidal magnetic field. The generalized vorticity is the manifestation of the polarization current in the model and describes charge separation due to the inertia in the ion response to changes in the $\boldsymbol{E} \times \boldsymbol{B}$ and ion diamagnetic drifts.

In a cooperation between the task Turbulence and synthetic diagnostics workflows under WPCD and MST1 a standardized workflow has been developed which is now being tested. In the work flow experimental data including profiles of density n_e and electron temperature T_e, q_{95}, magnetic field, B_0, are read directly from the AUG database and passed to the HESEL actor. The HESEL actor then submits a job to the Gateway Linux cluster. Data from the synthetic diagnostics, such as Langmuir probes and Lithium beam implemented in the HESEL code, together with key parameters are automatically stored for later analysis.

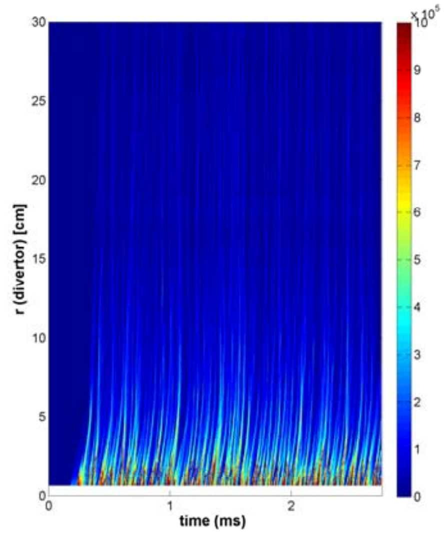
Results

In Fig. 1a we display the profiles from a HESEL simulation using parameters obtained from AUG shot #30301. The first notable thing is that the density and temperature profiles all have sharp gradients close to the Last Closed Flux Surface (LCFS) with density and electron temperature approaching a background value already within 1 cm and ion temperature $2-3$ cm from the LCFS. However we can observe significant ion and electron energy fluxes, $\langle n_e T_\alpha \tilde{v}_r \rangle$, $\alpha = \{i, e\}$, far into the SOL. These fluxes are not transported by convective, $\langle T_\alpha \rangle \langle \tilde{n}_e \tilde{v}_r \rangle$, nor conductive, $\langle n_e \rangle \langle \tilde{T}_\alpha \tilde{v}_r \rangle$, components as these to a large degree follow the mean of the density, $\langle n_e \rangle$ and temperatures, $\langle T_e \rangle$ and $\langle T_i \rangle$, but of the so-called triple product, $\langle \tilde{n}_e \tilde{T}_\alpha \tilde{v}_r \rangle$. This is a consequence of the very intermittent blob dynamics responsible for the energy transport in the SOL.

Figure 1b displays the time evolution of the radial power distribution. Each magnetic field line has been mapped from the outboard midplane in HESEL domain onto the divertor. In mapping the electron and ion energies we assume that the plasma is convected with the local



(a) Profiles.



(b) Power deposition on the divertor.

Figure 1: HESEL simulation simulation using parameters obtained from AUG #30301.

ion sound velocity; $c_s(r,\theta,t) = \sqrt{(T_e(r,\theta,r)+T_i(r,\theta,t))/m_i}$ and a poloidal average has been performed. The individual traces from blob evolutions are clearly visible.

Figure 2 displays the Stuttgart probe head with 14 individual pins each measure either ion saturations current, $I_s = eA_{ip}n\sqrt{(T_e+T_i)/m_i}$ or floating potential, $V_f = V_p - \alpha T_e$ where V_p is the plasma potential, $\alpha \sim 3.2$ for a deuterium plasma. The configuration of the individual pins varies between shots. In HESEL we have implemented a synthetic Stuttgart probe head at different stationary radial locations.

As an example of a comparison between the Stuttgart probe and the synthetic probe Fig. 3 displays the momentum transport at a radial position 1 cm from LCFS. The radial and poloidal velocities are approximated as; $v_r \sim -(V_f^{12} - V_f^{9})/(\delta\theta B_0)$ and $v_\theta = (V_f^{12} - 0.75V_f^{9} - 0.25V_f^{7})/(\delta r B_0)$. We notice that the floating potential and therefore also the velocities will be strongly influenced by electron temperature fluctuations. Also, pin separations and misalignment with respect to a local r_θ coordinates will affect the velocity calculation.

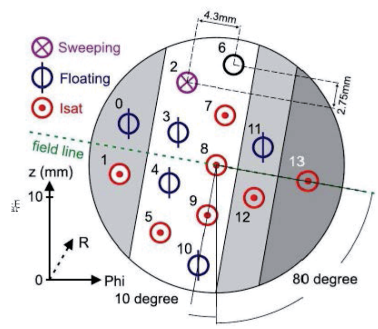


Figure 2: The Stuttgart probe used on the MEM at AUG.

The momentum transport, M_r, is divided into contributions from the Reynolds stress, $Re = \langle n \rangle \langle \tilde{v}_p \tilde{v}_r \rangle$, the convective term, $\langle v_p \rangle \langle \tilde{n}\tilde{v}_r \rangle$ and the so called triple product, $\langle \tilde{n}\tilde{v}_p\tilde{v}_r \rangle$, where $\langle f \rangle = \int_0^t f(t)dt$. Based on results from the HESEL we conclude that if the velocities are based on plasma po-

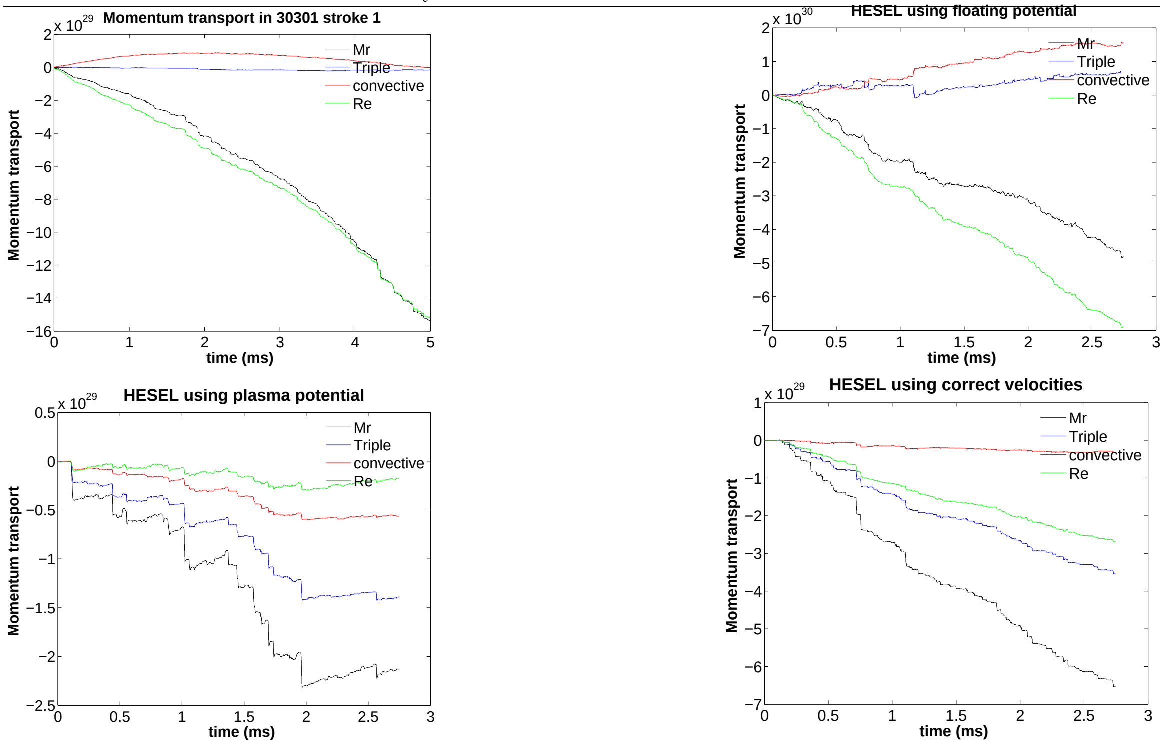


Figure 3: Momentum transport calculated from the Stuttgart probe and synthetic data.

tential the derived momentum are overall in agreement with the results based on the correct velocities. If, on the other hand, velocities are based on floating potential using cold probes we obtain strong deviations. It should be noted that the synthetic probe data applying the floating potential indeed are in close agreement with the measured ones. Thus, one may apply the simulated data to provide a more correct estimates for the momentum fluxes.

Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] B. Nold *et al.* New Journal of Phys. 14 (2012) 063022.

[2] S.I. Braginskii. *In Review of Plasma Physics, (ed. Leontovich, M. A.). New York, NY: Consultants Bureau*, Vol. 1, p. 205 (1965).

[3] W. Fundamenski *et al.* Nucl. Fusion, **47**, 417 (2007); F. Militello *et al.* Plasma Phys. Controlled Fusion, **55**, 025005 (2013); N. Yan *et al.* Plasma Phys. Controlled Fusion, **55**, 115007 (2013); O.E. Garcia *et al.* Phys. Plasmas, **12**, 062309 (2005).