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Comparison of HESEL SOL turbulence simulations with BES measurements on EAST

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Abstract

The HESEL code [1] has been used to simulate scrape-off-layer (SOL) electrostatic interchange-driven low-frequency turbulence in EAST tokamak discharges [2]. The recently installed Lithium Beam Emission Spectroscopy (LiBES) diagnostic system on EAST provides well resolved non-intrusive 2D measurements of SOL turbulence [3]. This paper presents the use of the RENATE synthetic beam emission diagnostic [4] to produce synthetic fluctuation signals to be processed using the methods designed to analyse the measured data. Spectral features in the simulated and measured signals are similar advocating the need for careful quantitative comparisons.

Keywords: tokamak; plasma; turbulence; simulation; beam emission spectroscopy; synthetic diagnostic

Introduction. Understanding transport processes in the outermost layer of tokamak plasmas is vital for both assessing the plasma performance and conditions for the plasma-facing components. Scrape-off layer (SOL) turbulence is strongly intermittent and modelling this dynamic behaviour is an essential feature. This paper features modelling by the HESEL code, which is a 4-field drift-fluid model that describes interchange driven L-mode turbulence in the SOL region [1]. Validation of SOL turbulence codes is hard due to limitations in measurement capabilities. The spatial and/or time resolution of diagnostic systems is comparable to the spatial and time range of the studied phenomenon. A straightforward way for the comparison of measurement and simulation is to apply a synthetic diagnostics on the simulated turbulent density and temperature fields, similarly

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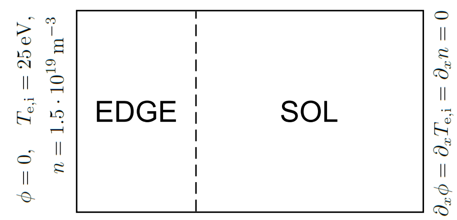

Figure 1: *HESEL simulation domain with boundary conditions. Upper and lower boundaries are periodic.*

to Yan et.al. for Langmuir probes on the EAST tokamak [2]. EAST also features a 2D radial-poloidal view lithium beam emission spectroscopy (Li-BES) diagnostic [3] that was designed to measure SOL and edge fluctuations. This is a non-intrusive 2D diagnostic system which is a great advantage over Langmuir probes. This paper presents the development of a synthetic BES diagnostic based on the RENATE BES simulation tool [4] with the aim of comparing HESEL simulations to actual SOL fluctuation measurements.

EAST LiBES diagnostic system. The Li-BES system on EAST features a lithium atomic beam of 50 keV energy, 1 mA equivalent current and 20mm FWHM width. The beam penetrates the plasma near the outer midplane almost perpendicularly to the flux surfaces. The special feature of this Li-BES system is the viewing geometry. The viewing periscope is positioned in the opposite corner of the same large midplane port as the beam. This allows good light collection efficiency by the closely positioned first lens of radius 38 mm, and a 2D radial-poloidal resolution due to the usage of a 4x16 2D APDCAM detector array, observing the magnetic field lines at an acute angle. This arrangement is suitable for the measurement of 2D density fluctuation structures up to 500 kHz. The radial and the poloidal resolution in the order of cms infers a significant spatial smoothing, necessitating the application of a comprehensive synthetic diagnostic modelling.

Selected discharge. Prior to the development of the synthetic diagnostic tool an actual Li-BES measurement was processed to establish the conformity of the Li-BES system with the requirements of SOL turbulence measurements. An L-mode discharge with intense electron cyclotron resonance heating (ECRH) was selected where a significant part of the detector array was viewing the SOL region. The deuterium discharge #64616 of the 2016 campaign featured 450 kA plasma current, 2.25 T toroidal field on axis. 100 eV electron temperature and 10^{19} m^{-3} electron density were estimated from Thomson scattering data. All 11 detector channels in the SOL region showed elevated low frequency features in the 10-20 kHz range that is characteristic of SOL turbulence and not present in the signals of the edge channels.

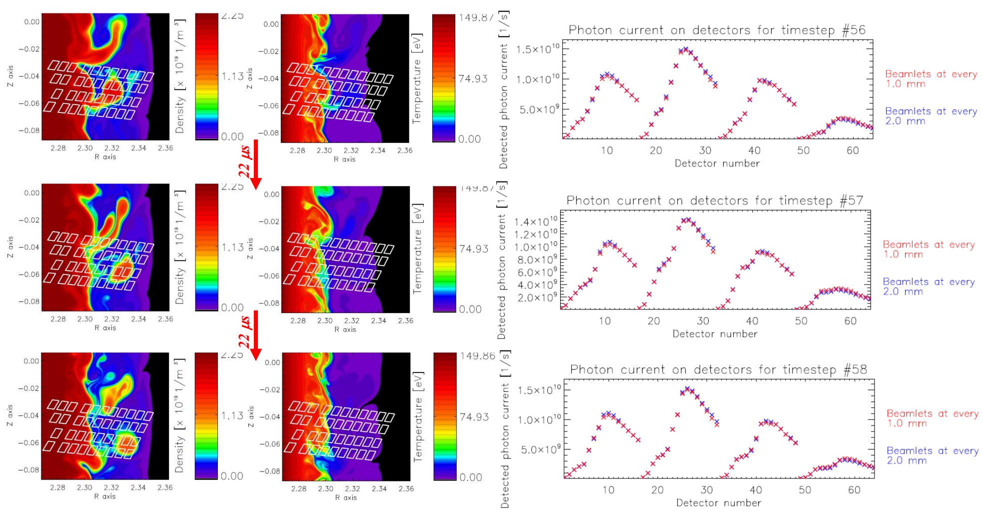

Figure 2: *Electron density and temperature fields output by HESEL with detector field of views indicated (left) and the simulated signals for each detector calculated for two different beamlet resolutions (right). Detector numbering starts from the right top corner. Three consecutive time points are plotted* 22 μs *in between.*

SOL turbulence simulation. For the first trial runs of the synthetic diagnostic tool a HESEL simulation of similar parameters was taken. Figure 1 shows the simulation domain to be of 2D slab geometry located at the outboard midplane with Neumann boundary conditions at the wall and Dirichlet boundary conditions towards the core. HESEL features damping of fields in the SOL region due to parallel transport. Plasma parameters in this particular simulation were slightly different from the ones in the measurements, thus allowing only qualitative comparisons.

BES synthetic diagnostic. The newly developed full 3D BES synthetic diagnostic tool has been built heavily on the previously proven RENATE BES simulation tool [4]. In fact it is rather a new feature of RENATE. In order to reproduce all possible geometric effects, the lithium beam was represented by an array of 1D beamlets, and the collisional-radiative model was solved separately for each beamlet. Contribution to each detector signal was summed up using the pinhole optical model of the observation system. The key step in the synthetic diagnostic is the extension of the 2D density and temperature fields provided by HESEL into 3D fields for detailed Li-BES modelling. This was performed assuming homogeneous density and temperature along magnetic field lines, which is valid beyond any doubt for the small toroidal extent of the lithium beam. To avoid interpolation errors in the reconstruction of the 3D density and temperature fields, beamlet positions were projected along magnetic field lines to the central poloidal plane of the beam. In the vicinity of the projected points, HESEL input density and temperature was averaged for a region matching the

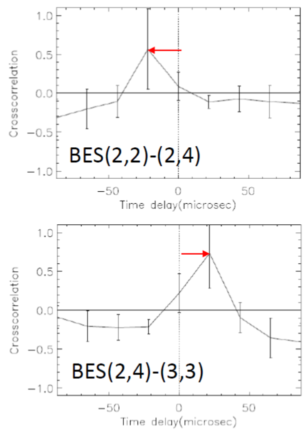

Figure 3: *Radial correlation (top) and vertical (bottom) cross-correlation functions*

spatial resolution of beamlets, which acts as spatial anti-aliasing during the effective down-sampling of input data. For more exact modelling of the Li-BES diagnostic in the actual scenario the temperature field provided by HESEL was scaled up by a factor of 4 to 100 eV at the inner boundary.

Figure 2 shows 3 consecutive time instances of the HESEL density and temperature data with the sensitive areas of the detectors on the vertical beam central plane plotted over. Detector positions serve here only for general orientation purposes, as the real simulation integrates the light collection from the 3D sensitive volumes. The detected photon current on all 64 detectors, placed in 4 rows, is the end result of the emitted light integration. The effect of the blob structures in the SOL is clearly visible on the rising edge of the light profiles recorded by the detector rows. The simulated diagnostic signals were calculated for different beamlet resolutions, and a convergence was found for beamlet spacing of about 1 mm, which is illustrated by the red and blue signs on the photon current plots of Figure 2.

Comparison of simulation to measurement. Having produced the synthetic Li-BES signals, the same statistical analysis can be performed that is used to analyse the measurements. Power spectra of the simulated signals showed a broad peak at around 10 kHz, which is in good qualitative agreement to the measured SOL spectral features. Figure 3 shows cross-correlation functions calculated between channels displaced radially and poloidally yielding 750 m/s radial outward and 500 m/s poloidal downward average blob flow velocity, respectively. Simulation results are in the same order of magnitude as the expected values, but a quantitative comparison of simulations and measurements will require precise matching of parameters and longer simulated time series with added detection noise.

Conclusions. The 2D radial-poloidal view lithium beam emission spectroscopy (Li-BES) diagnostic [3] on EAST tokamak allows detailed SOL and edge fluctuation studies. Li-BES measurements can be compared to turbulent transport simulations utilizing the RENATE [4] synthetic BES diagnostic featuring 3D beam and observation system modelling. Turbulent density and temperature fields were modelled in the SOL region by the HESEL code [1, 2]. Application of RENATE as a synthetic diagnostic shows good test results. Synthetic fluctuating signals were processed applying the methods used to analyse the measured data showing high spectral power in the range around 10 kHz, just like the measured signals, and the blob propagation velocities inferred from cross-correlations were in the expected range. For quantitative comparison and validation of HESEL more exact correspondence of experiment and simulation parameters will be needed.

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