# HIGH-FIELD-SIDE HIGH-DENSITY REGION IN GLOBUS-M2 DIVERTOR

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## 1. INTRODUCTION

In large future facilities such as ITER [1], DEMO [2], STEP [3], one of the main challenges is to control the power density deposited at the divertor plates. The divertor is expected to operate in the highly radiative, partially detached regime [4]. Plasma exhaust is a key challenge especially for the low aspect ratio of spherical tokamaks (R/a ∼ 1.5), where the situation is challenging for the inner divertor target due to the small radius of the strike point, which consequently restricts the available area for power dissipation. L-mode detachment studies in ASDEX Upgrade (AUG), equipped with a full W wall, revealed that during the fluctuating detachment state, where the inner divertor is already partially detached at the near separatrix region while the outer is still attached, a region of high electron density is formed in the inner far Scrape-off Layer (SOL) at a distance of about 5 times the heat flux e-folding width, $\lambda_q$, mapped to the outer midplane [5]. Existence of high-field side high density (HFSHD) front was also demonstrated in the full carbon AUG [6] and in JET, equipped with the ITER-Like wall (Be/W) [7]. In the paper [8], divertor Thomson scattering diagnostics showed the presence of the HFSHD regime in AUG in both L and H-modes. It should be noted that in machines with metallic plasma facing components and hence without an intrinsic radiator, N seeding acts like the intrinsic C radiator in carbon machines [9, 10].

## 2. TOPIC OF THE REPORT

Here we report on the formation of the HFSHD front in a wide range of parameters, with the central $n_e$ varying from 2 $10^{19}$ to 1.4 $10^{20}$ $m^{-3}$, observed in Globus-M2 with full C wall. The recent commissioning of divertor Thomson scattering (DTS), based on the laser and polychromators developed for ITER, has made these results possible [11]. The geometry of the experiment also allowed us to measure grad $n_e$ and $T_e$ along an open magnetic surface passing along the vertical probing chord at R=24 cm that is the X-point region from the side of strong magnetic field. In different discharges this corresponded to $\rho_\psi \in [0.95, 1.05]$. The measurements obtained along the probing chord of DTS in the inner leg were compared with $n_e$ and $T_e$ edge profiles measured by equatorial Thomson scattering at the outer midplane. The magnetic reconstruction was conducted using the pyGSS code [12]. Infrared camera is used to simultaneously measure the divertor heat loads at both lower strike points. The discharge duration of 200 milliseconds provided stable plasma parameters during approximately 50 milliseconds. The 100 Hz repetition rate of the DTS measurements allows up to five measurements to be taken per discharge. The experimental campaign yielded data indicating the presence of an elevated electron density region within the inner divertor of the Globus-M2 tokamak, exceeding $n_e$ of the outer equatorial plasma boundary by a factor of 1.5-3 at a comparable electron pressure (see Fig. 1) in both ohmic and NBI heating (0.4 MW of absorbed power) modes. Furthermore, a joint analysis of several subsequent measurements showed that the movement of the plasma column did not lead to a change in the plasma discharge mode. This shows that the HFSHD phenomenon in a spherical carbon-wall tokamak is independent of the confinement mode.

This phenomenon was also confirmed in the modelling by the SOLPS-ITER code [13] with full account of drifts and currents, and with the EIRENE Monte-Carlo description of deuterium atoms and molecules and carbon atoms. This approach resulted in a significant enhancement of the simulation accuracy in comparison with previous GLOBUS-M and GLOBUS-M2 modelling [14-16], where neutrals motion was described with a fluid approach.

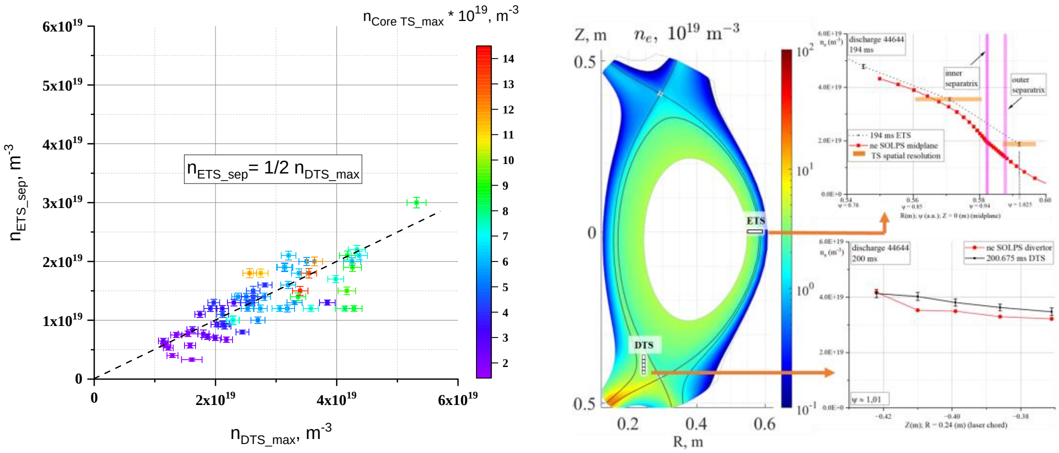


*Fig.1 Electron density measured by midplane outer Edge TS (ETS)* $\boldsymbol{n_{ETS\_sep}}$ *as a function of maximum* $n_e$ *measured by Divertor TS (DTS) in the inner leg* $\boldsymbol{n_{DTS\_max}}$.

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## REFERENCES

[1] LOARTE, A., et al, “Chapter 4: Power and particle control” Nucl. Fusion **47** (2007) S203–63.

[2] YOU, J.H., et al, “Divertor of the European DEMO: Engineering and technologies for power exhaust” Fusion Eng. Des. **175** (2022) 113010.

[3] OSAWA, R.T., et al., “SOLPS-ITER analysis of a proposed STEP double null geometry: impact of the degree of disconnection on power-sharing” Nucl. Fusion **63** (2023) 076032 (16pp).

[4] PITTS, R.A., et al., “Physics basis and design of the ITER plasma-facing components” J. Nucl. Mater. **438** (2013) 48.

[5] POTZEL, S., et al., “A new experimental classification of divertor detachment in ASDEX Upgrade” Nucl. Fusion **54** (2014) 013001 (19pp).

[6] McCORMICK, K., et al., “Main chamber high recycling on ASDEX upgrade” J. Nucl. Mater. **390–391** (2009) S465.

[7] POTZEL, S., et al., “Formation of the high-density front in the inner far SOL at ASDEX Upgrade and JET”, J. Nucl. Mater. **463** (2015) 541–545.

[8] CAVEDON, M., et al., “Experimental investigation of L- and H-mode detachment via the divertor Thomson scattering at ASDEX Upgrade” Nucl. Fusion **62** (2022) 066027.

[9] NEU, R., et al., “Overview on plasma operation with a full tungsten wall in ASDEX Upgrade”, J. Nucl. Mater. **438** (2013) S34.

[10] BREZINSEK, S., et al., “Residual carbon content in the initial ITER-Like Wall experiments at JET, J. Nucl. Mater. **438** (2013) S303.

[11] ERMAKOV, N. V., et al., “Divertor Thomson Scattering on Globus-M2 Plasma Physics Reports **49** Issue 12 (2023) p.1480-1489.

[12] KISELEV E.O., et al., “Free-Boundary Plasma Equilibrium Computation in Spherical Globus-M2 Tokamak by Means of the pyGSS Code, Plasma Phys. Rep. **49** (2023) 1560–1577.

[13] BONNIN, X., et al. “Presentation of the new SOLPS-ITER code package for tokamak plasma edge modelling” Plasma Fusion Res. **11** (2016) 1403102.

[14] E. VEKSHINA, V. Rozhansky, E. Kaveeva, I. Senichenkov and N. Khromov, “Modeling of Globus-M connected double null discharge” Plasma Phys. Control. Fusion **61** (2019) 125009.

[15] E. VEKSHINA, K. Dolgova, V. Rozhansky, et al., “Experiment with nitrogen seeding at the Globus-M2 tokamak.” Phys. Plasmas **30** (2023) 042504.

[16] K. DOLGOVA, E. Vekshina and V. Rozhansky, “Modeling of high-field-side high-density regime in the Globus-M2 tokamak.” Plasma Phys. Control. Fusion **66** (2024) 035001.