Direct Measurements of Parallel Blob Extension in Diverted TCV Plasmas

N. Offeddu[1], W. Han[2], C. Theiler[1], T. Golfinopoulos[2], C. Tsui[3], H. de Oliveira[1], C. Wuethrich[1], B.P. Duval[1], J. Terry[2], E. Marmar[2] and the TCV Team[4]

1) EPFL, Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland

2) MIT, Plasma Science and Fusion Center (PSFC) , Cambridge, MA 02139, USA

3) University of California-San Diego, La Jolla, CA 92093, USA

4) See the author list of S. Coda et al 2019 Nucl. Fusion 59 112023

Introduction

Understanding the physics of turbulence and anomalous transport in tokamaks is one of the most important open issues in plasma physics for fusion devices. A prominent feature of turbulence in the Scrape Off Layer (SOL) region are blobs, coherent filamentary plasma structures that drift across the magnetic field lines at high velocities (~km/s) and interact with the vessel wall. Besides providing cross-field transport of particles and energy, blobs are a concern for future fusion reactors since they pose a potential threat to plasma-facing components.

The main goal of this study is exploring the propagation regimes of blobs, their parallel extension along the field and their connection to the divertor. We do so by employing the recently commissioned midplane Gas Puss Imaging diagnostic (GPI) [1] and the Reciprocating Divertor Probe Array (RDPA) [2]. We perform scans in density over an order of magnitude, taking measurements in both attached and detached plasmas, and we compare these with theoretical models.

Theoretical Background

In [3], scalings of the the normalized velocity $\hat{v}$ and size $\hat{a}$ of filaments have been estimanted. These scalings depend on where the filaments are in a parameter space defined by a normalized collisionality and size (Λ and Θ). The normalised parameters can be written as:

$$\Lambda = \frac{\nu_{e,i} L_{||}}{\Omega_e \rho_s} = 1.7 \cdot 10^{-14} \frac{n_e L_{||}}{T_e^2} \qquad \Theta = \hat{a}^{5/2} = 4.35 \cdot 10^{-5} \frac{a_b^{5/2} B^2 R^{1/2}}{L_{||} T_e} \qquad \hat{v} = \frac{v_R}{c_s \left(2 L_{||} \frac{\rho_s^2}{R^3}\right)^{1/5}} \quad (1)$$

where the expressions are in the units of n_e [cm^{-3}], B [G], $L_{||}$ and R and a_b [cm], T_e [eV]. One can therefore explore this parameter space by modifying, for example, the temperature and the density of the plasma. According to this model, the normalised size and velocity follow the scalings shown in Fig. 1.

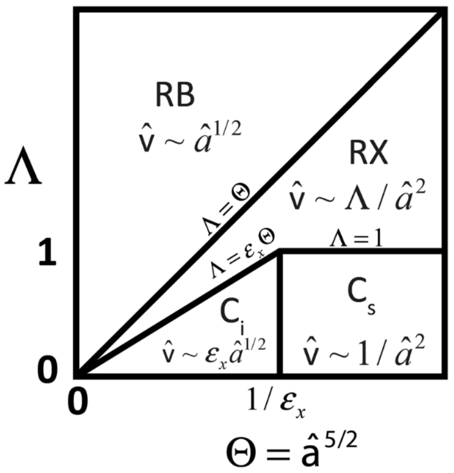

Figure 1: From [3], propagation regimes in the Λ-Θ space and the respective velocity scalings.

Experimental Setup - GPI and RDPA

For the GPI, gas is injected locally in the midplane LFS. The injection system reaches the desired gas flow within ~20 ms, typically of the order of a few 10^{19} particles/second. Puffing times are chosen between 50 and 100 ms. We then image tangentially to the magnetic field with an acquisition frequency of 2MHz. With a spatial resolution of 0.5mm and a time resolution of $0.5\mu s$, we are capable of measuring filaments size and velocity.

RDPA [2] consists in a set of Langmuir probes mounted on a mecanical actuator that sweeps the divertor region, raising from the floor of TCV up to 36cm in altitude. 24 probes acquire data in ion saturation current at 2MHz. This way, we measure fluctuations which can be correlated to the ones measured upstream by GPI.

Data Analysis - CAS and Correlation

To determine the properties of filaments, we use Conditional Average Sampling (CAS) applied to a normalized signal $S(\vec{x},t)$, derived from a measured light intensity $I(\vec{x},t)$:

$$\hat{S}(\vec{x},t) = \frac{I(\vec{x},t) - < I(\vec{x},t) >_{\Delta t}}{< I(\vec{x},t) >_{\Delta t}}, \tag{2}$$

where $< \cdot >_{\Delta t}$ indicates the moving average over a period of 2ms.

In CAS, we observe $S(\vec{x},t)$ at a set of chosen locations, and whenever the signal exceedes the chosen threshhold of $\delta(\vec{x}) = 2.5\sigma(S(\vec{x,t}))$, a trigger is set for that location. The whole FoV is then averaged over the triggered instances. By also averaging the previous and subsequent frames, one gets an averaged motion of a blob passing by the chosen locations. At the moment of the trigger, we then measure the size of the filament by taking the largest HWHM in poloidal direction. This is the quantity we refer to as the filament size in this study.

With field line tracing, we can approximately align the field of view of GPI to RDPA in the divertor. The sweeping movement of RDPA ensures that at a given moment in time the two diagnostics are field aligned. For RDPA, we normalize the signal $D(\vec{y},t)$ in the same fashion as for the GPI. We then proceed to search for the highest correlation within subsequent time windows $\Delta t = 1\text{ms}$ defined as:

$$C(t,\vec{x},\vec{y}) = \frac{1}{\Delta t}\int_t^{t+\Delta t} S(\vec{x},t')\cdot D(\vec{y},t')dt' \tag{3}$$

During this time, RDPA has moved vertically 3mm, which is less than the typical expected blob size, if we assume a mapping of the geometry from the midplane to the divertor.

Experimental Results

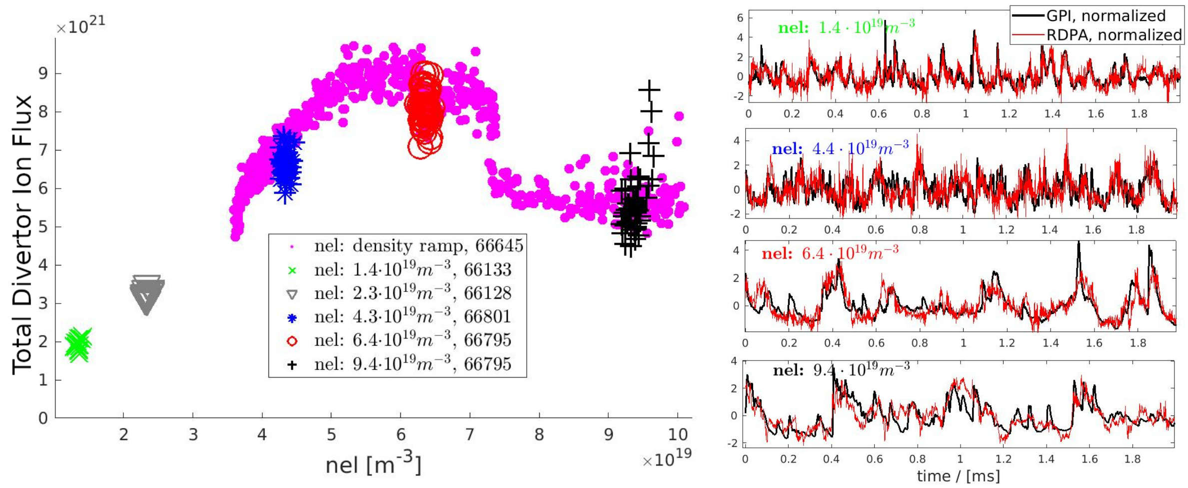

Figure 2: Left panel: Measurements at different densities showed a clear roll-over in the total ion flux at the target probes. Right panel: Although the overall correlation is maintained throughout the density scan, some sub-ms structures seem to correlate less well at higher densities.

In a series of L-mode lower single null shots of constant current ($I_p = 230kA$) and constant magnetic field ($B = 1.4T$), we performed a density scan taking measurements in both attached and detached plasmas. Detachment is identified by the roll-over of the total ion flux to the divertor (see Fig. 2). We scanned the density over an order of magnitude, measuring an averaged line density between $1.4\cdot 10^{19}\text{m}^{-3}$ and $9.4\cdot 10^{19}\text{m}^{-3}$. The correlation between the midplane GPI views and the divertor measurements of RDPA showed a clear correlation throughout the whole density scan. Some sub-ms structures seem to correlate less well at higher densities, though a correlation is still visible (see Fig. 2, right panel).

This is coherent with the observation of the $\Lambda - \Theta$ space: most of the filaments we measured are in the RX regime. Furthermore, the measured normalised velocities, even if slightly below in magnitude, seem to respect the expected descending trend ($\hat{v}_{RX} \approx \Lambda/\tilde{a}^2$) with size (Fig. 3,

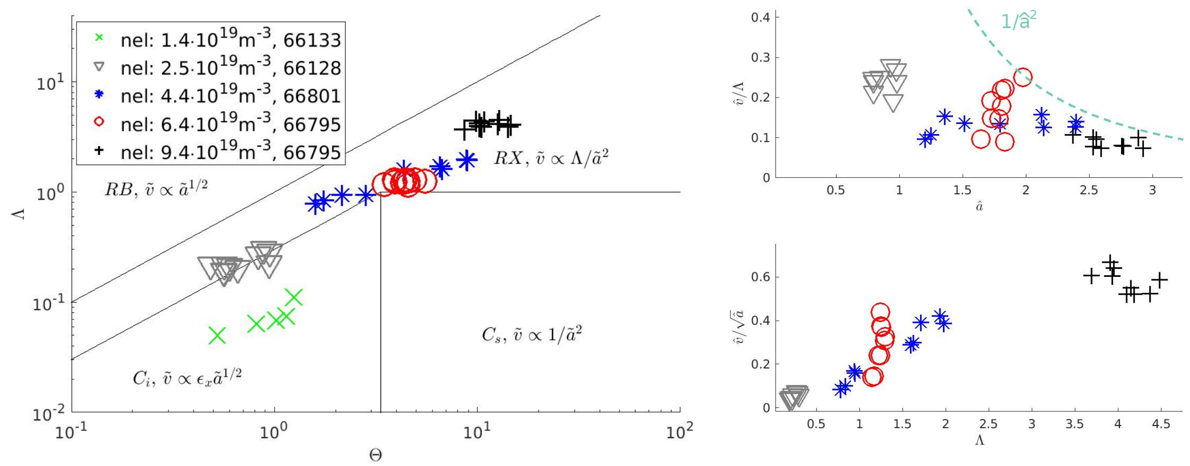

Figure 3: Left panel: location of the discharges in $\Lambda - \Theta$ space, showing mostly filaments in the RX-regime. Upper-right panel: v/Λ slightly lower than the RX regime velocity ($\hat{v}_{RX} \approx \Lambda/\tilde{a}^2$). In the lower panel, the dependence on Λ excludes the RB regime ($\hat{v}_{RB} \approx \sqrt{\tilde{a}}$).

upper-right panel). The RB regime, for which a scaling of $\hat{v}_{RB} \approx \sqrt{\tilde{a}}$ is expected, is excluded by the dependency of $\hat{v}/\sqrt{\hat{a}}$ on Λ (Fig. 3, lower-right panel).

Conclusions

Using GPI, we estimated the propagation regime for SOL filamentary turbulence at TCV in LSN L-mode discharges. We found filaments to be mostly in the RX regime. This finding is corroborated by the correlation of GPI and RDPA, which indicates a parallel extension past the X-point and down into the divertor.

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