Turbulent transport in the divertor volume: Analysis of high speed imaging from MAST and TCV

N.R.Walkden[1], J.R.Harrison[1], B.Labit[2], H.Reimerdes[2], F.Militello[1], T.Farley[1,3], S.A.Silburn[1], A.Kirk[1], the MAST Team[1], the TCV Team[2] and the MST1 Team[*]

[1] *CCFE, Abingdon, Oxfordshire, OX14 3DB, UK*

[2] *SPC-EPFL, Lausanne, Switzerland*

[3] *University of Liverpool, Liverpool, UK*

[*] *H.Meyer et al, "Overview of Progress in European Medium Sized Tokamaks towards and integrated plasma-edge/wall solution", accepted for publication in Nuclear Fusion*

Most of the heat and particle deposition onto plasma-facing surfaces in a tokamak is handled by the divertor target. Localisation of this region from the core plasma is achieved with a poloidal field null producing an X-point in the poloidal flux. The plasma wetted area of the divertor target is determined primarily by the competition of transport mechanisms perpendicular and parallel to the magnetic field line, both of which can be impacted by the X-point. In particular cross-field transport has a significant non-diffusive component where particles and heat are advected radially away from the core plasma in coherent bundles called filaments [1]. Filaments follow magnetic field lines in shape and become severely deformed by magnetic shear and flux-expansion around the null region indicating that the X-point may impact cross-field transport [2]. Following recent work [3-6], this paper investigates cross-field processes around and below the X-point (i.e in the divertor volume) using high speed visible imaging in MAST and TCV.

The camera view used in both MAST and TCV is directed tangentially into the vessel. In the case of MAST this produces images extending from around 20cm above the X-point through to the divertor target; in TCV the view encompasses the entire plasma cross-section, though shadowing from the viewing port obscures the outboard midplane, top of the plasma and lowest strike point. A background subtraction is applied to the movie to isolate the fluctuating component of the light from the slow time varying background component. Figure 1 shows views from a lower single-null plasma in MAST, and a low-field side snowflake minus plasma in TCV. In table 1 below, the operational parameters of the cameras used for each experiment are given.

	Model	Framerate	Integration time	Pixel density	Resolution
MAST	Photron SA1.1	120kHz	8μs	128 x 176	~1cm
TCV	Photron APX-RS	50kHz	20 μs	160 x 196	~5mm

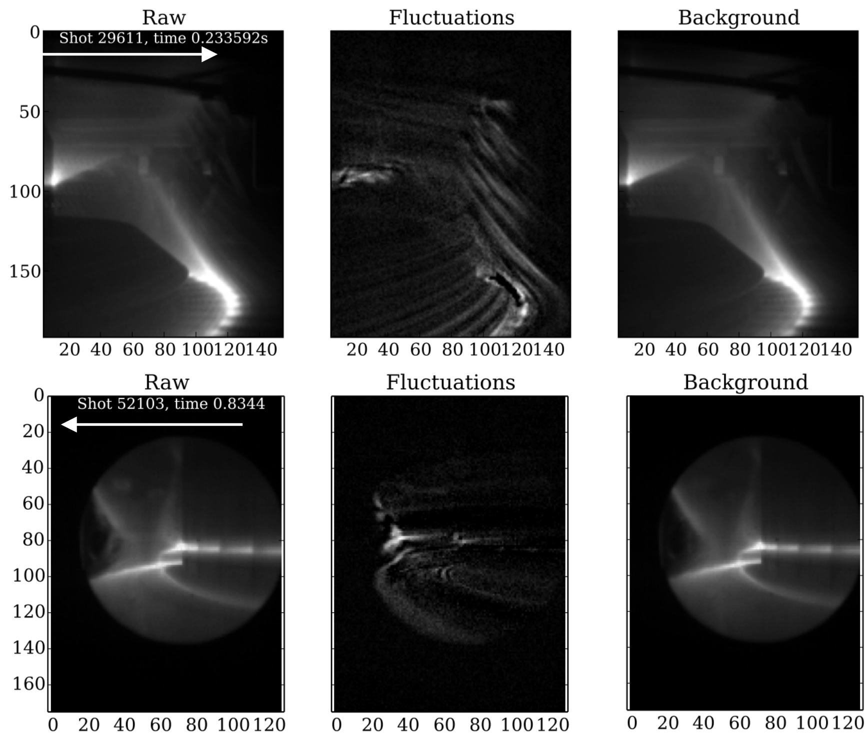

Figure 1: Images of the raw, fluctuating and background components of fast visible movies captured in a MAST LSN plasma (upper row) and a TCV snowflake plasma (lower). White arrows indicate the direction of increasing major radius in the camera view.

The data from the videos of the MAST divertor is relatively well understood from a phenomenological standpoint [3-6]. Filamentary objects are observed in MAST divertor in three places:

1. In the private flux region (PFR) filaments are generated along the inner divertor leg in the region of bad curvature that is present there.

2. In the outer scrape-off layer (OSOL) of the outer divertor leg filaments are present with extremely deformed cross-sections. These are consistent with filaments that are born as circular objects upstream and follow magnetic field-lines into the divertor.

3. In the inner scrape-off layer (ISOL) of the outer divertor leg filaments are present in a region approximately half-way up the divertor leg extending to the target. These filaments are small, fast and not consistent with a birth position upstream.

In addition it has recently been shown [5,6] that the region of the scrape-off layer surrounding the X-point is quiescent, indicating that close to the separatrix filaments are losing their coherency preventing them from being identified in the quiescent X-point region (QXR). In figure 2 the three forms of filament in the MAST divertor, alongside the QXR are identified using cross-correlations in shot 29611 within the same series of movie frames. This technique involves correlating the signal from a selected pixel in the image with the signal from all other pixels. The result is the typical shape of a fluctuation as seen by the camera that is present when a fluctuation on the selected pixel occurs.

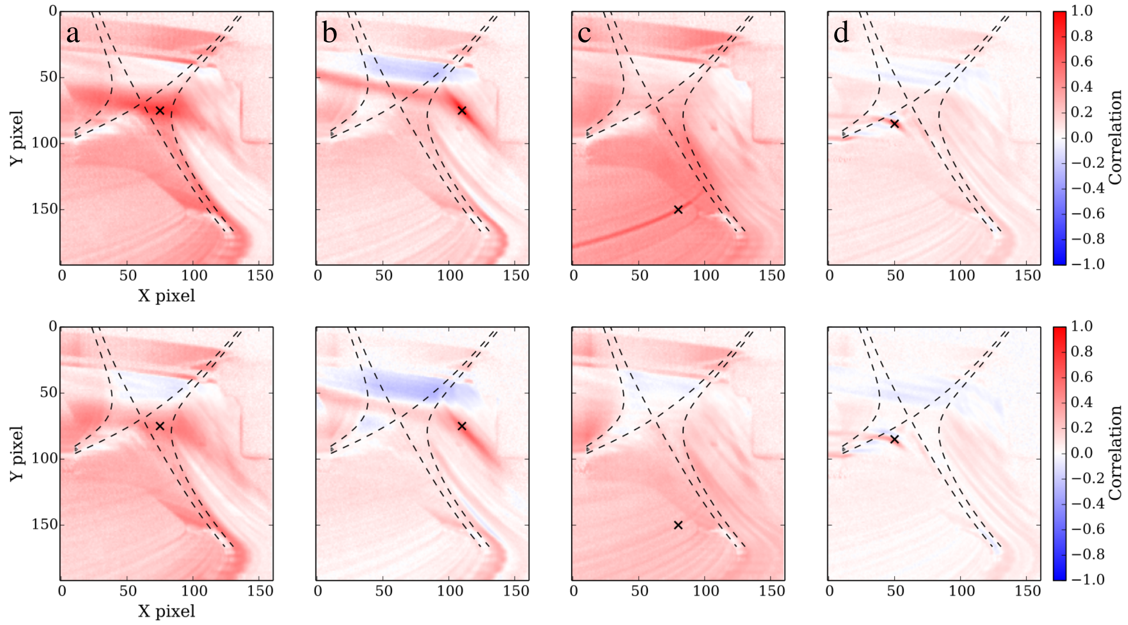

Figure 2. Cross-correlation analysis showing typical filament structures in the QXR (a), OSOL (b), ISOL (c) and PFR (d) with a time delay of 0 (upper) and 32 (bottom) μs allowing for the evolution of the filament structures to be tracked.

The structure observed in the QXR is similar in nature to that of the OSOL and indicates that no filaments exist within the QXR in the poloidal plane. The structure apparent in the QXR represents a filament at larger major radius in the poloidal plane, that wraps toroidally around the plasma such that its parallel structure is picked up in the camera image. The evolution timescale of the OSOL and PFR filaments are of a similar order and indicate that they may be driven by similar physical mechanisms, whilst the ISOL filament decays in amplitude much faster than the former two. This suggests that the ISOL filaments may be born through a different physics mechanism. This is consistent with the OSOL and PFR filaments being driven by bad curvature, which is not present in the case of the ISOL filaments.

A similar analysis has been performed for an Ohmic L-mode low-field side snowflake minus plasma in TCV. In the snowflake divertor the power and particle load to the target is shared between multiple divertor legs. The efficiency of this configuration depends on the level of cross-field transport in the divertor, since this is a primary mechanism by which such a load can be shared. In figure 3 a cross-correlation analysis has been conducted for the TCV case, where two classes of fluctuating structure have been identified.

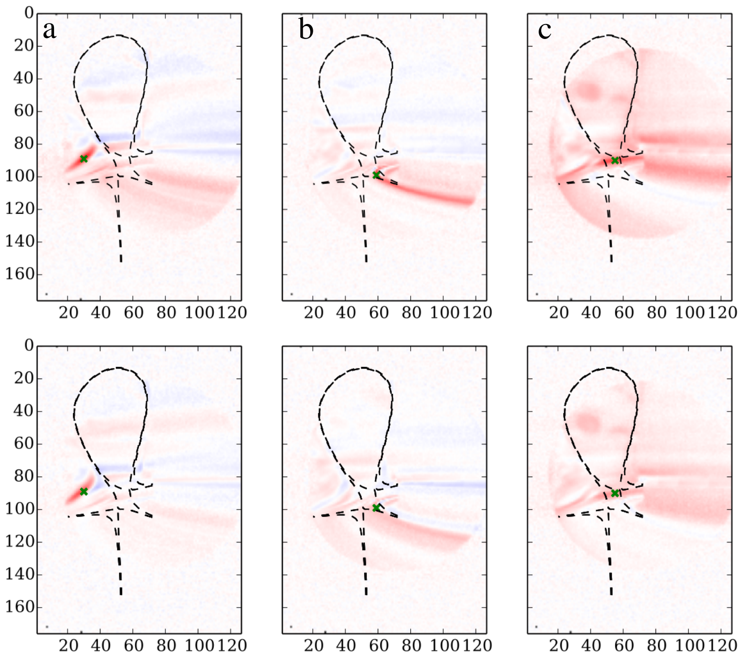

Figure 3. Cross-correlation analysis showing typical filamentary structures present in the OSOL (a), ISOL (b) (which occupies the space between the two nulls in the snowflake configuration) and QXR (c). The upper row corresponds to 0 time delay, whilst the lower row corresponds to 40 μs time delay.

In the TCV case OSOL filaments are observed with a similar structure to that of MAST. Close to the X-point a QXR is identifiable, where the structure observed corresponds to a filament wrapping toroidally behind the poloidal plane, such that it is not a structure local to the X-point. In the ISOL, which corresponds to the region between the two nulls in the snowflake, filamentary structures are identified in the lower divertor leg that terminates on the centre column. Contrary to the ISOL filaments on MAST, the TCV ISOL (which here describes the region between X-points) filaments appear to be longer lived and propagate radially, which is more suggestive of the MAST PFR filaments. It is not presently clear how localised these ISOL filaments are from upstream, however their presence may provide a mechanism for transport towards divertor legs connects to the secondary null.

Understanding the physical mechanisms driving the ISOL filaments, the PFR filaments and the QXR is an important task which will likely require complex numerical simulations.

[1] D.A.D'Ippolito, J.Myra and S.J.Zweben, Phys. Plasmas **18** (2011) 060501
[2] D.Farina, R.Pozzoli and D.D.Ryutov, Nucl. Fusion **33** (1993) 1315
[3] J.R.Harrison, G.M.Fishpool and B.D.Dudson, Journ. Nucl. Mater. **463** (2015) 757
[4] J.R.Harrison, G.M.Fishpool, A.J.Thornton and N.R.Walkden, Phys. Plasmas **22** (2015) 092508
[5] N.R.Walkden et al, Nucl. Mater. Energy (2016) http://dx.doi.org/10.1016/j.nme.2016.10.024
[6] N.R.Walkden et al, Nucl. Fusion, (2017) Submitted, https://arxiv.org/abs/1706.06318
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 and from the RCUK Energy Programme [grant number EP/P012450/1]. To obtain further information on the data and models underlying this paper please contact PublicationsManager@ukaea.uk. The views and opinions expressed herein do not necessarily reflect those of the European Commission.