Fast Camera Analysis of Plasma Filaments

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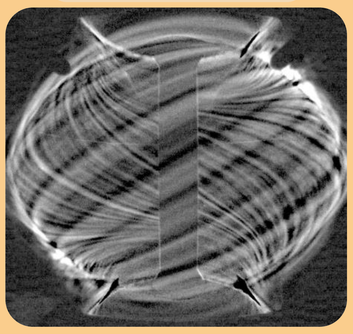
Motivation

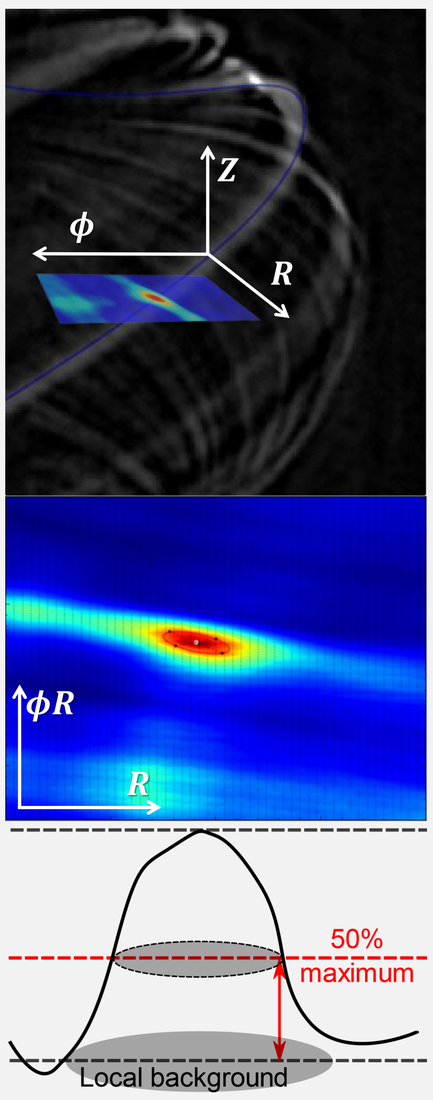


- Coherent filamentary structures dominate turbulent cross-field particle transport in tokamaks [1]
- These intermittent structures properties' govern scrape off layer (SOL) density profile shape [2]
- Unfiltered fast visible cameras (~100 kHz) can passively collect large quantities of filament data
- A better understanding of filaments' dependence on plasma properties can help minimise wall erosion and maximise machine lifetime

Technique

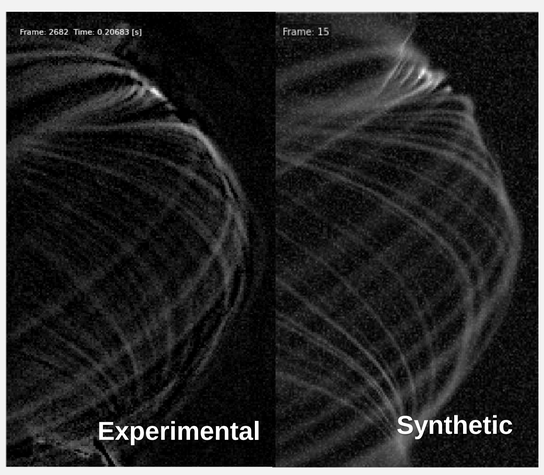
- Unfiltered fast camera collects mostly D_α light
  - Intensity, I, function of neutral & electron density, n_0 & n_e, and electron temperature, T_e:
    - $I = n_0 f(n_e, T_e)$

1. Images are processed to enhance filaments:
   - Background subtraction, noise reduction, sharpening
2. Project field lines onto images:
   - Trace field line (FL) grid with Efit++ equilibria
   - Project FLs onto camera view
   - Extract pixel intensities along FLs
3. Intensity pseudo-inversion (PI) into $R - \phi R$ space:
   - FLs parameterised by $(R, \phi R)$ coordinate of intersection with midplane ($Z = 0$)
   - Representative intensity along FLs, given by (*geometric mean*)^2
4. Identify filaments
   - Ellipses fitted to 2D intensity peaks to extract position and widths



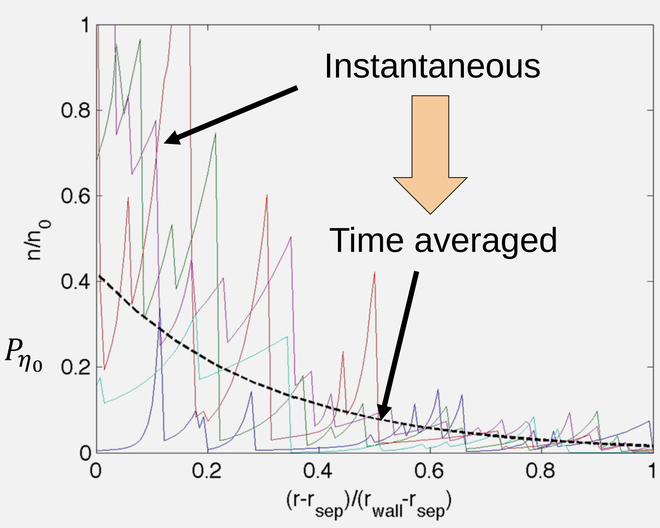
Benchmarking

- A synthetic diagnostic enables analysis of camera frames with known filament properties
- Enables algorithmic benchmarking and error quantification
  - Detect 80% of input filaments
  - 30% false positive rate
- See more in T. Farley *et al.*, RSI (2018)



Analytic Framework

- Describes SOL density profile shapes and statistics given input filament properties
- Assumes constant generation of independent filaments
- Inputs:
  - Distribution of initial amplitudes, P_{η_0}
  - Distribution of perp. widths, P_w
  - Average waiting time, τ_w
  - Radial shape, $\Lambda(r - r_{sep}, w)$
  - Parallel drainage rate, $F(t)$
  - Radial velocity variation, $V(t)$

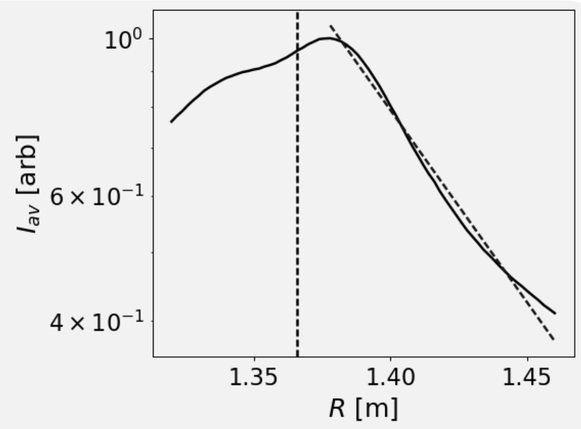


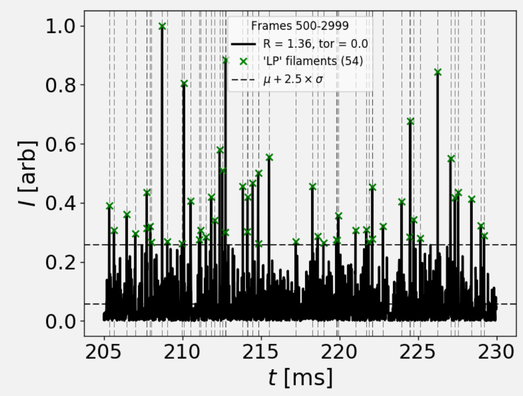
- See Militello NF Letters [2] and PPCF [3] (2016)

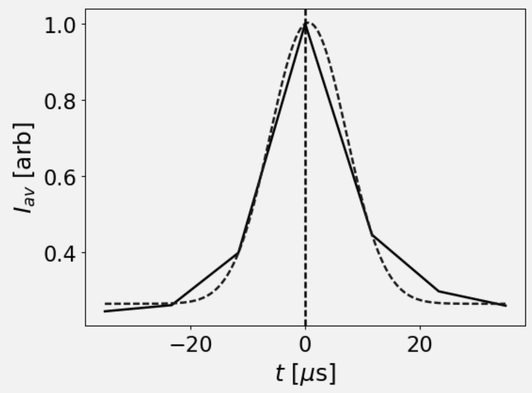
$$N(x) = \frac{1}{\tau_w}\int_{-\infty}^{\infty} dt \int_0^{\infty} d\eta_0 \int_0^{\infty} dw\,[\eta(x,t)P_{\eta_0}(\eta_0)P_w(w)]$$

Pseudo-Langmuir probe analysis

- Taking radial slices through the PI gives time varying radial emission profiles
  - Time averaged radial shows exponential fall off with characteristic flattening in the far SOL
- Time varying intensity of a single field line can be treated like a Langmuir probe (LP) ion saturation signal
  - Consider peaks with intensity $I > \mu + n\sigma$
  - Time trace indicates peaks above 2.5 σ
- Conditional averaging
  - Use 1 σ from here for improved statistics
  - Largely symmetric average filament peak shape observed
  - Absence of sharp rising edge consistent with LP measurements on MAST [4]

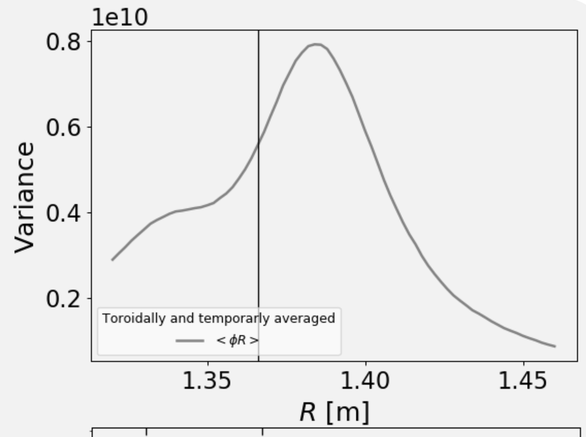


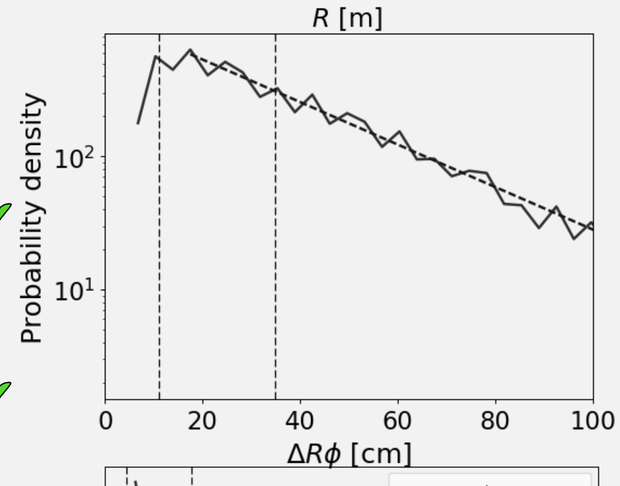


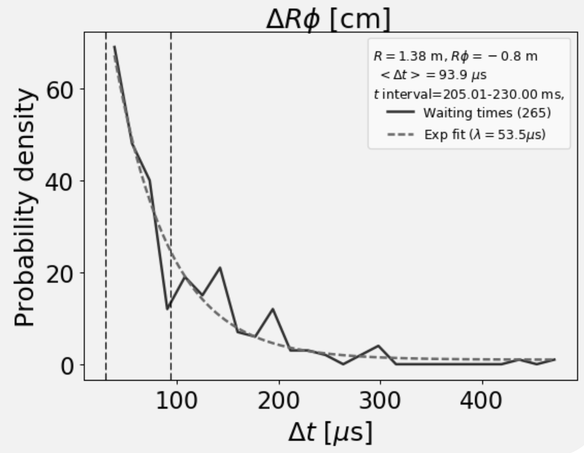


Filament statistics

- Filament statistics are calculated to inform inputs to the analytic framework
- Variance of fluctuations
  - Variance increases outside the Separatrix as commonly observed
- Toroidal filament separation
  - Exponential distribution indicates toroidal positions are independent ✓
  - No effective quasi-mode number
- Waiting times
  - Exponential distribution indicative of Poisson process ✓
- Support assumptions in analytic framework
- See Fulvio Militello's invited talk (Friday 11.00, Room: 102ABC)







Future work

- Analysis of SOL density profile flattening and broadening study
  - Use analytic framework to interpret phenomena given measured filament statistics
- Generate large filament database to explore dependence of filament properties on machine and physics parameters

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For further information on data and models please contact publicationsmanager@ccfe.ac.uk.

References
[1] D'Ippolito *et al.*, PoP, 18(6), 60501 (2011)
[2] Militello, F. & Omotani, J. T., NF, 56(10), 104004 (2016)
[3] Militello, F., & Omotani, J. T. PPCF, 58(12), 125004. (2016)
[4] Militello *et al.*, PPCF, 55(2), 25005 (2013)