NSTX

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Turbulent filaments on the divertor target plates of NSTX

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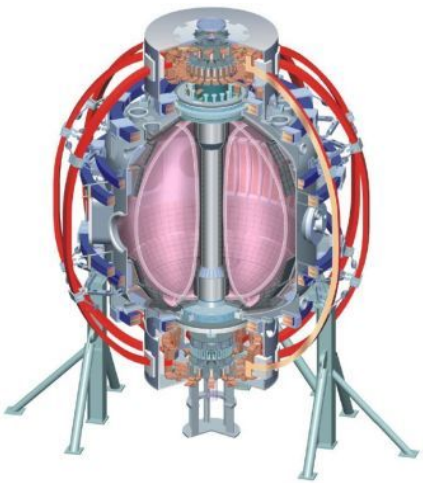

ABSTRACT

Fine structured filaments are seen on the lower divertor target plates of NSTX during H-mode discharges. These filaments, not associated with edge localized modes, correspond to the footprints of the turbulent blobs seen near the midplane of the device with multiple diagnostics. The fluctuation level of the neutral lithium light observed and the skewness and kurtosis of its probability distribution function have similar characteristics than midplane blobs: increasing with increasing radii outside the outer strike point (separatrix). In addition, their toroidal and radial movement agrees with the typical movement of blobs at the midplane. Furthermore, with the appropriate magnetic topology, i.e. mapping between the portion of the target plates being observed into the field of view of the midplane gas puff imaging diagnostic, very good correlation is observed between the midplane blobs and these divertor filaments. The existence of "magnetic shear disconnection" due to the lower X-point, as proposed by Cohen and Ryutov [Nucl. Fusion 37, p. 621, 1997], is analyzed from the measurements obtained.

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NSTX

Background and motivation

- Intermittent events (blobs) are responsible for a substantial fraction of the cross field transport at the low field side, wide far-SOL profiles and interaction with plasma facing components of the main chamber walls.

Are intermittent events seen in the divertor?

-> transport, effect on heat deposition profiles, heat on un-prepared surfaces.

- Long correlation lengths observed for SOL fluctuations, for example: H. Thomsen, *et al.*, Phys. Plasmas 9, p. 1233, 2002.

Is there a relation between divertor intermittent events and midplane blob events?

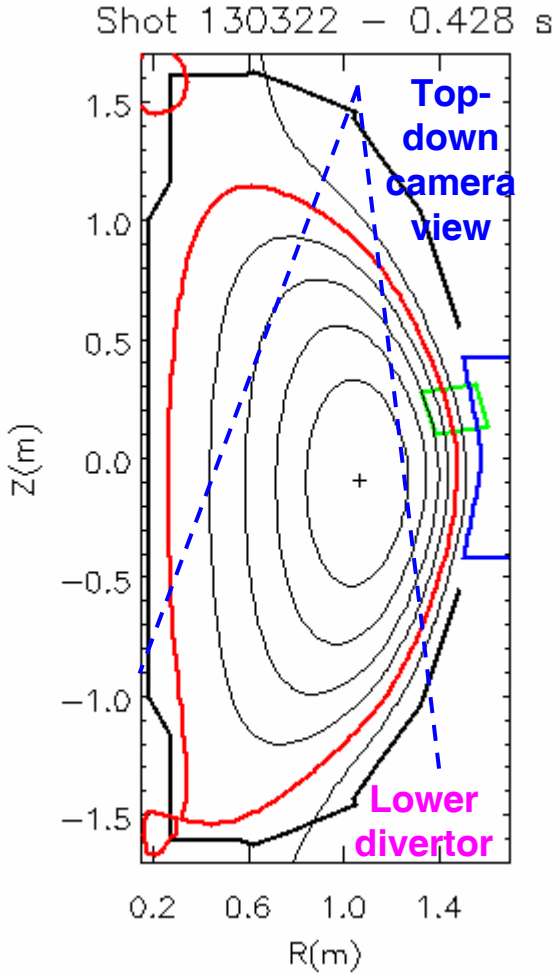
Background and motivation (cont.)

- Shearing of flux tubes near the X-point can result in "disconnection" of field aligned fluctuations in the midplane with respect to those observed in the divertor region as proposed by Cohen and Ryutov [Nucl. Fusion 37, p. 621, 1997] when the "flux tube" width near the X-point is smaller than the gyroradius.

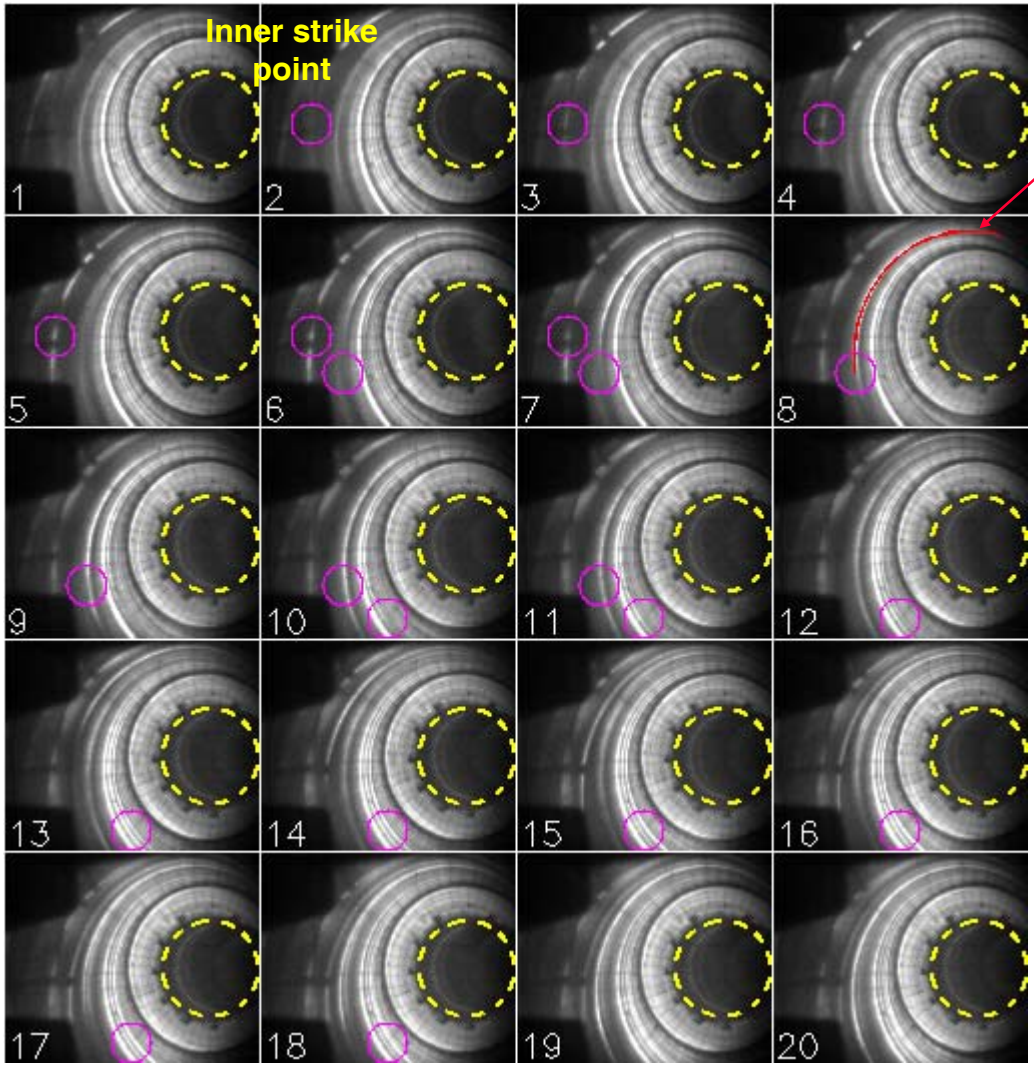
Is the "magnetic shear disconnection" seen?

Experimental setup

- Lower single null discharges in H-mode confinement.
- **Periods with NO ELMs are used.**
- Discharges with low and high X-point positions are compared (differing flux expansion at divertor target plates).
- Lower divertor LiI emission @ 670.8 nm (neutral lithium) observed from above at 88889 frames/s. (Lithium evaporators in NSTX result in almost-uniform coverage of divertor target surfaces.) Spatial resolution: ~1.4 cm.
- Low ionization energy of neutral lithium (5.4 eV) causes emission to originate close to material surfaces.



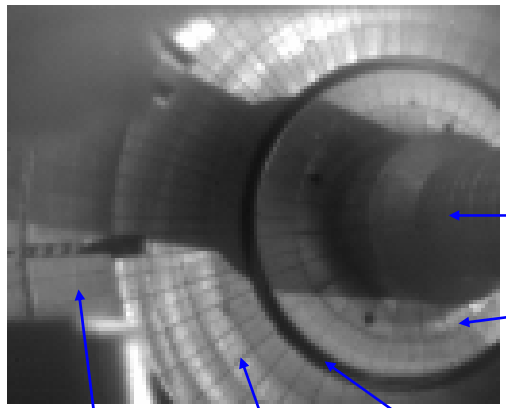
Moving striations seen on divertor target



Shot 124750: 596.525 ms to 596.739 ms

Footprint of 3 cm diameter flux tube

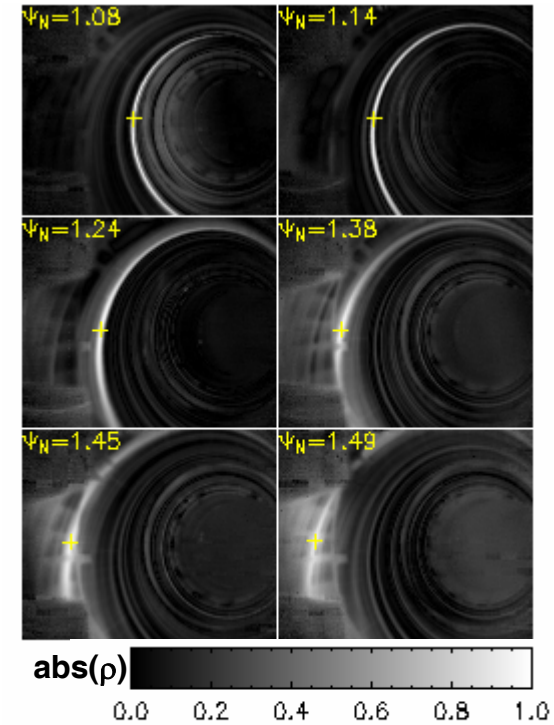
Vessel illumination

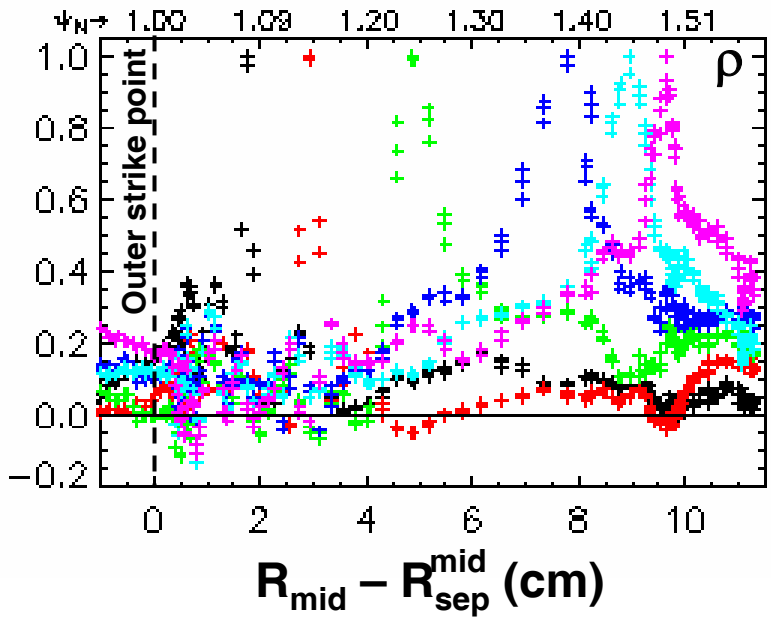


- Striations move toroidally (counter-clockwise from above) and radially outwards.
- **See movie on display PC.**

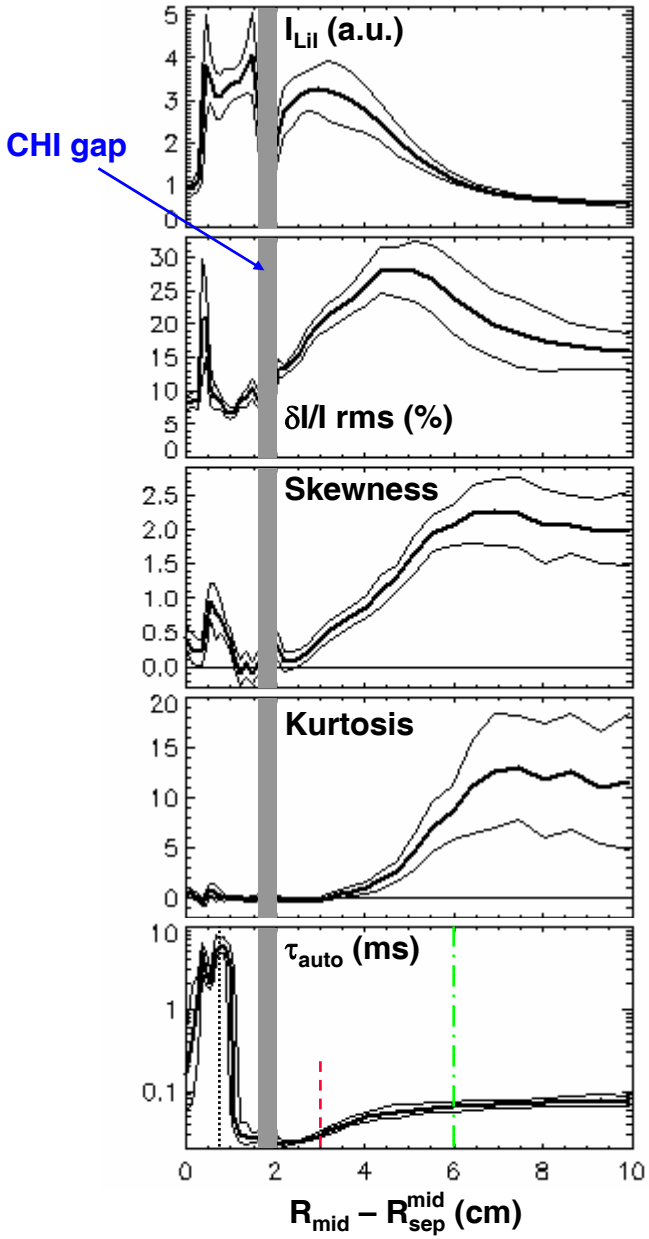
Striation width increases with radius

Cross-correlation images and profiles (0-time delay)





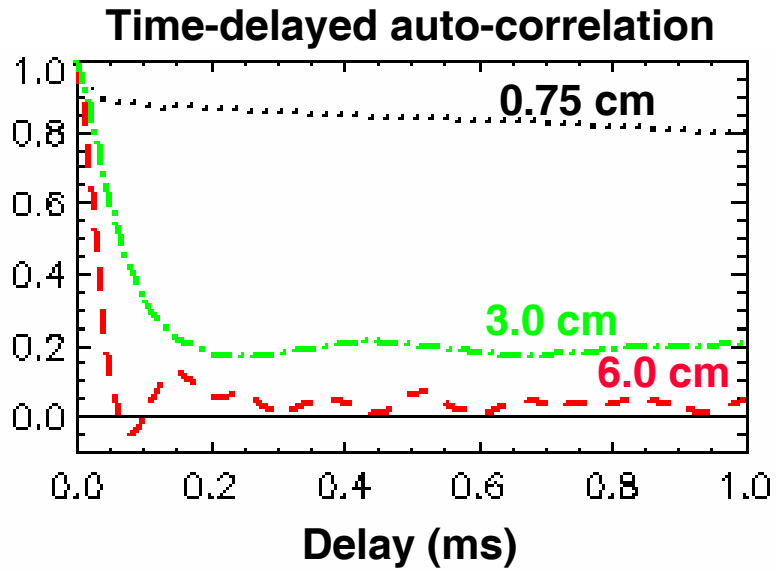
- Striation auto-correlation widths at ψ_N=1.08 is ~0.3 cm when mapped to outboard midplane.
- **NOTE: These widths are not to be confused with "radial correlation lengths". A midplane flux tube still cover the same flux range albeit "stretched" into a toroidally elongated striation.**

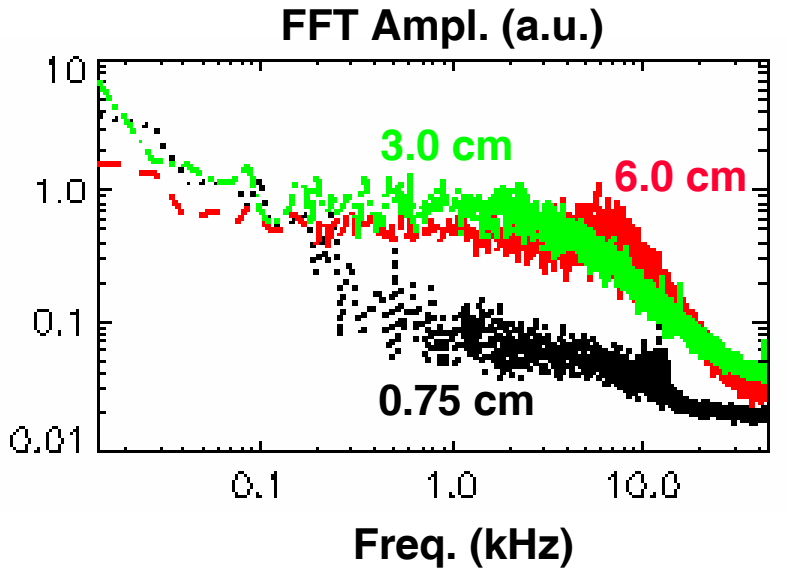


Striations show increasing intermittent characteristics with radius

- Fluctuation levels increase with radius, rolling over in the far SOL.
- Intermittent characteristics increase with radius as determined by the moments of the PDF. In the far SOL. The **skewness** (asymmetry) increases to ~2 and the **kurtosis** (weight of tails) increases to 10-12.
- Auto-correlation times of ~80 μs are typical in the far-SOL.

Time domain shows different characteristics in the far SOL

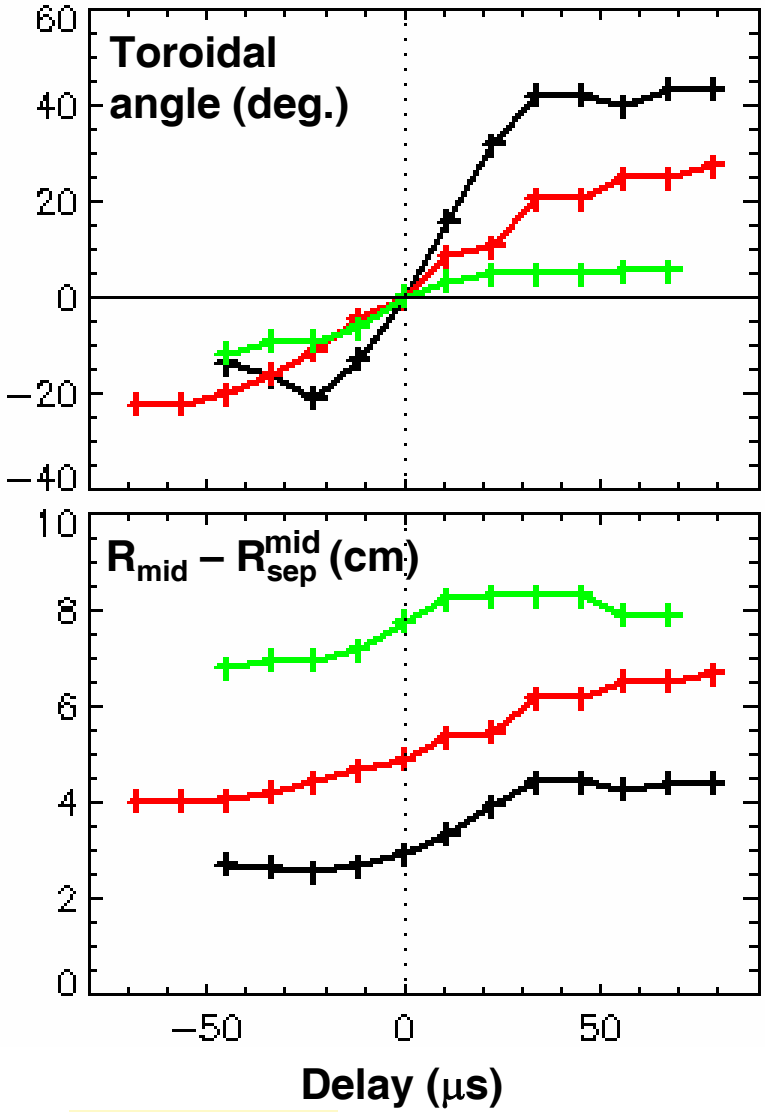




Labels indicated $R_{mid} - R_{sep}^{mid}$

- Time-delayed auto-correlation shows the typical functional forms for intermittent blobs in the far SOL.
- The Fourier analysis for the far-SOL show relatively flat spectra, inflections points and power law decays at higher frequencies.

Average movement of striations



- Movement obtained from time-delayed cross-correlation. Only points with ρ>65% shown.
- Toroidal rotation (counter-clockwise) and radial movement (0.2 km/s to 0.6 km/s, mapped to midplane) observed.
- The data points with large delays (both + and -) have the centroid of the filament outside the field of view of the images.
- NOTE: Due to finite toroidal coverage of images, toroidal movement may result in an apparent radially inward movement as in the "barber pole" effect.

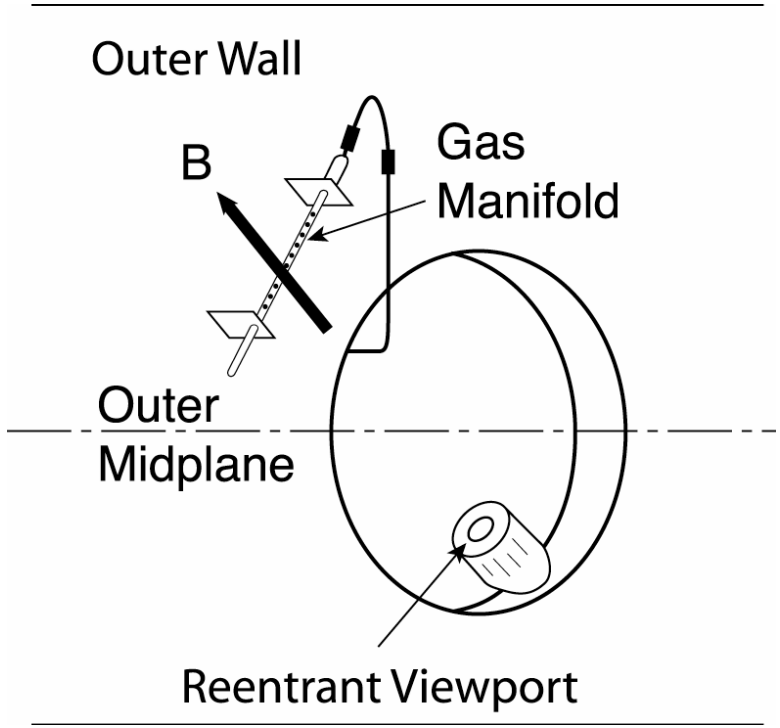
Summary of midplane SOL blob characteristics in NSTX

S. J. Zweben, et al., Nucl. Fusion 44, p. 134, 2004

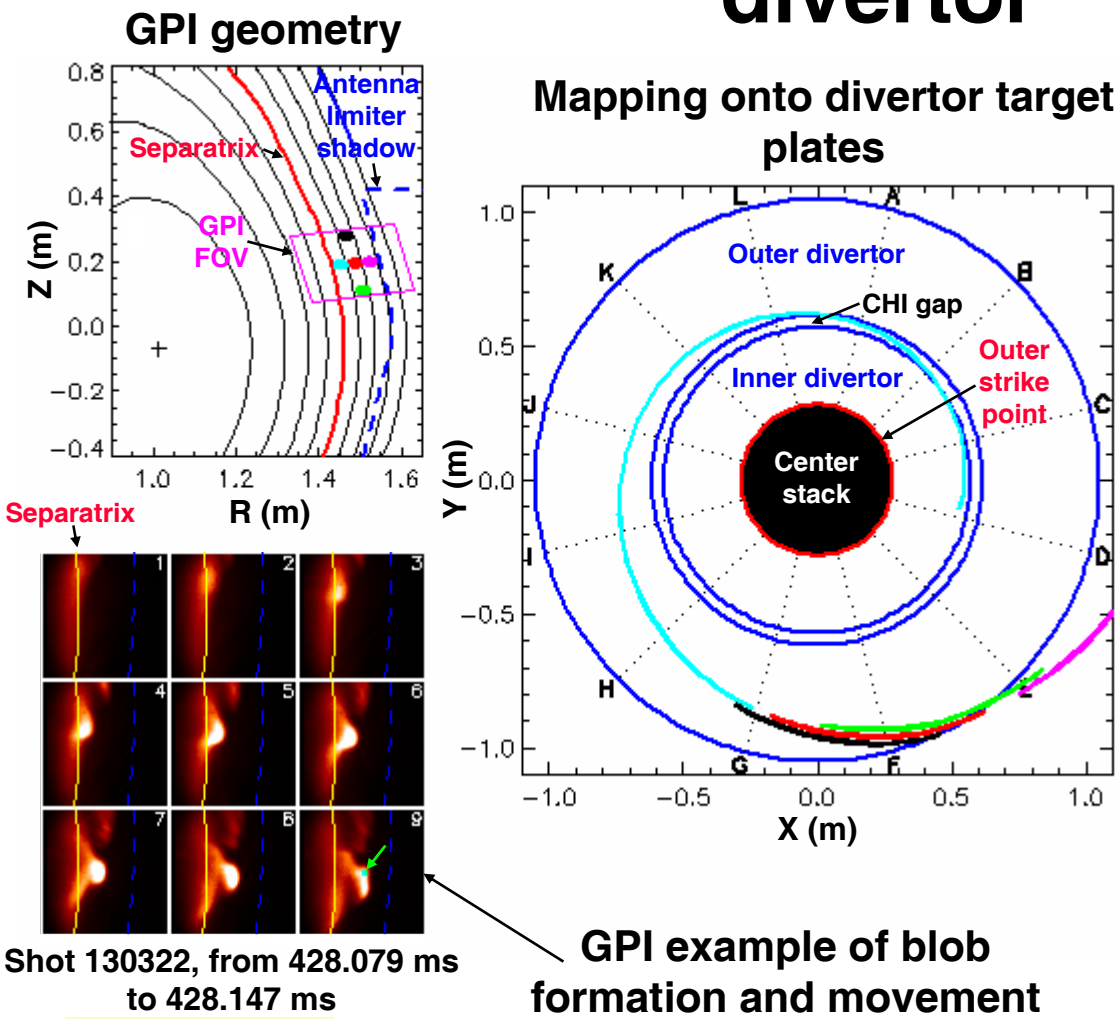
- Relative fluctuation level increases with radius.
- Auto-correlation lengths, poloidal and radial, of 3-4 cm.
- Broadband frequency spectra with inflection point and power law decay at higher frequencies
- Auto-correlation times of ~30 μs.
- Skewness and kurtosis off-Gaussian in the far SOL.
- Radially outwards and poloidally downwards (ion diamagnetic drift) observed.
- Radial and poloidal velocities of up to 2 km/s.

GPI diagnostic

- Camera used to view visible D_α emission from 24 x 24 cm box of the edge plasma just above low field side (outer) midplane. Camera captures images at 117647 frames/s.
- Deuterium gas puff is injected to increase image contrast and brightness. Gas puff does not perturb local (nor global) plasma.
- View aligned along B field line to see 2-D structure ⊥ B. Typical edge phenomena has a long parallel wavelength, filament structure.
- For more details: R.J. Maqueda et al., Rev. Sci. Instrum. 74(3), p. 2020, 2003.
- Clocks of GPI and top-down divertor cameras running independently. Time bases checked to match to within ~11 μs.



As blob filaments move in the SOL, their footprints move toroidally/radially in the divertor

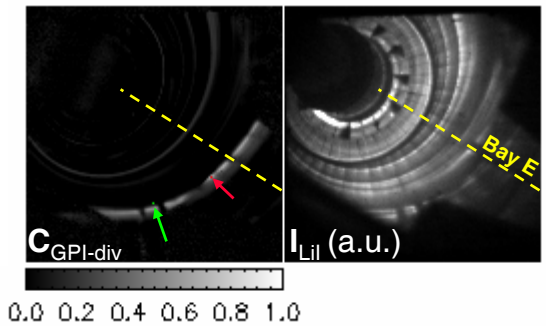


- Radial movement (cyan-red-purple) results in movement "along" the striation spiral.
- Poloidal movement (black-red-green) results in toroidal movement (or, due to barber-pole effect, inward radial movement).
- Connection length from GPI plane to divertor is ~4 m in the far SOL.

Good correlation observed between GPI and divertor target Li light

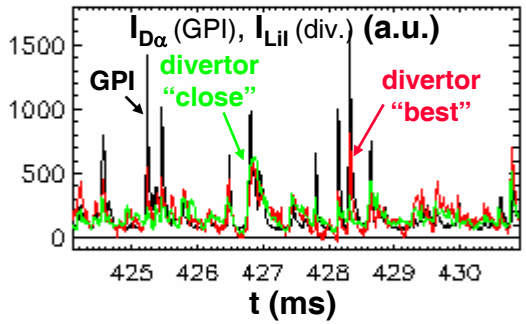
- **Red arrow** indicates position of best cross-correlation.
- Green arrow indicates position of mapping between GPI image (slide 12) and divertor.

Cross-correlation image 0-time delay

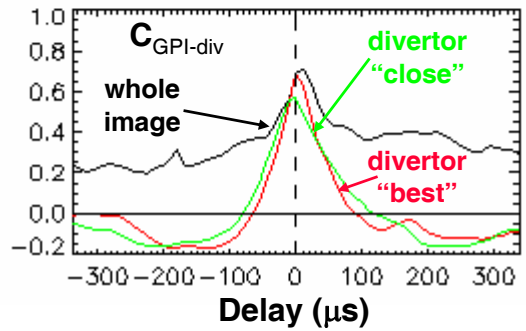


Reference LiI image showing striations

- Toroidal mismatch between red and green positions due to high uncertainty (uniformity) in the toroidally elongated footprints.
- Radial mismatch possibly due to uncertainty in the separatrix position at the midplane. Good correlation is observed 1.2 cm (mapped to midplane) outboard of green mapped position.

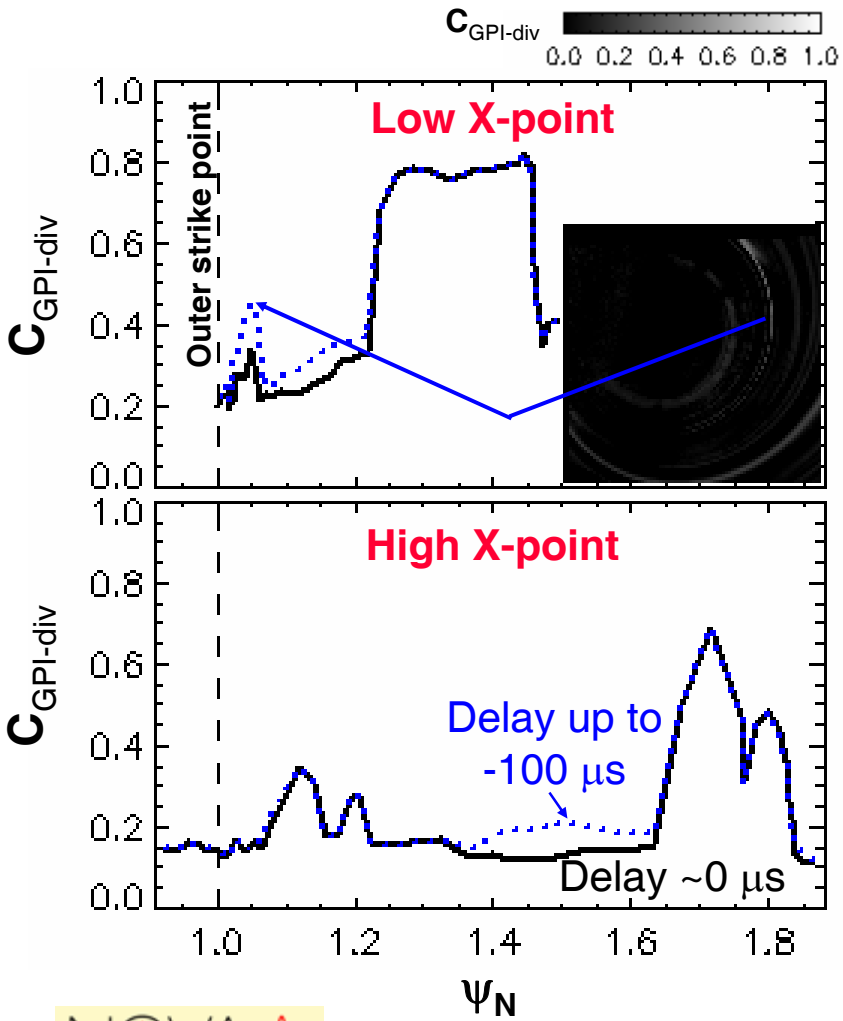


Raw time-series check (divertor linearly scaled to GPI)



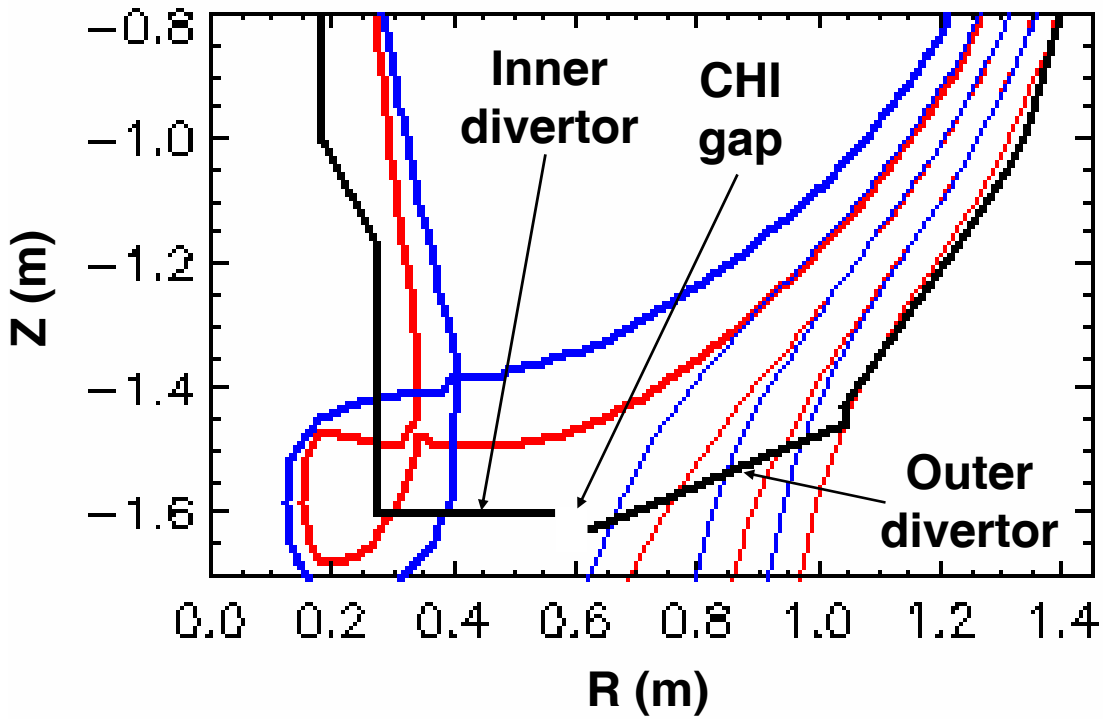
Time-delayed cross-correlation

Good correlation observed down to ψ_N ~ 1.04, in low X-point case



- Allowing correlation to "early" (within 100 ms) divertor events, correlation can be obtained in extended regions of the top-down images.
- In the case of a low X-point an "early" band of correlation at ψ_N ~ 1.04 appears, corresponding to the striation going one whole turn around the center column (insert).
- No improvement is seen at small ψ_N in the case of a high X-point.

Topological difference between low and high X-point cases

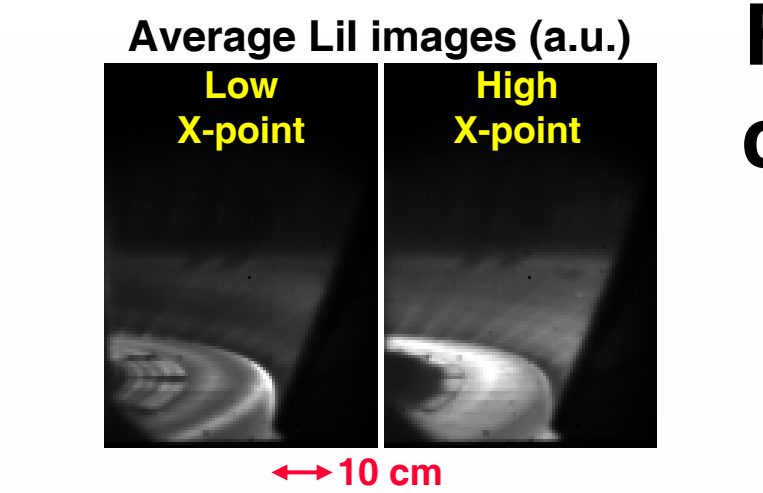


Low X-point (130324)

High X-point (130316)

- Despite differences in the divertor region, the midplane separatrix (outer gap) remains relatively at the same position for these two cases.

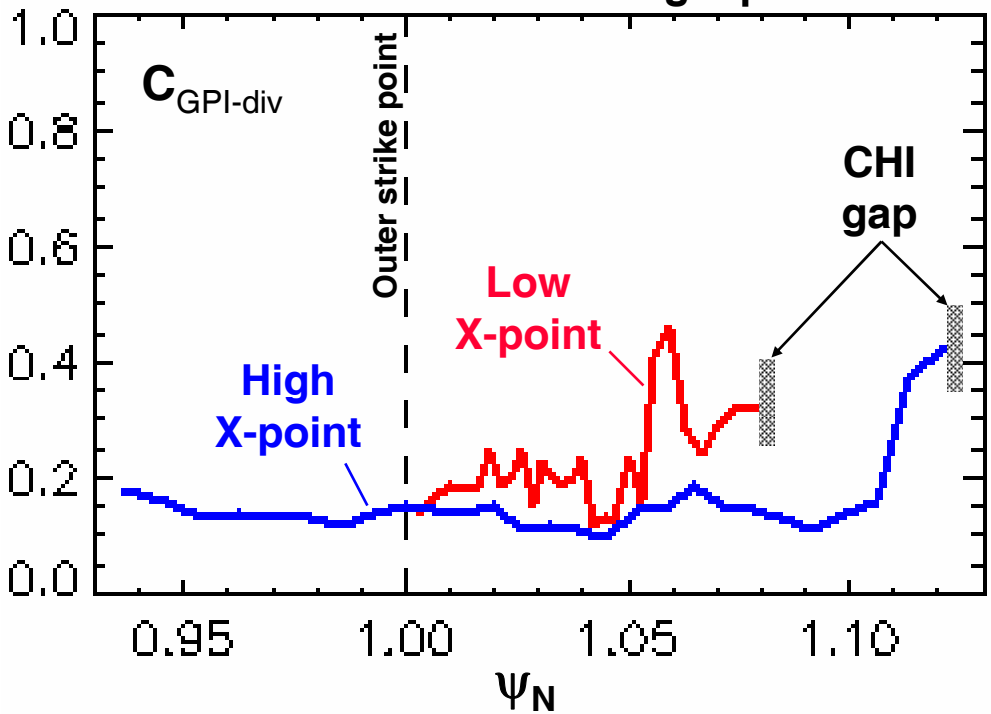
Fine scale striations seen close to outer strike point



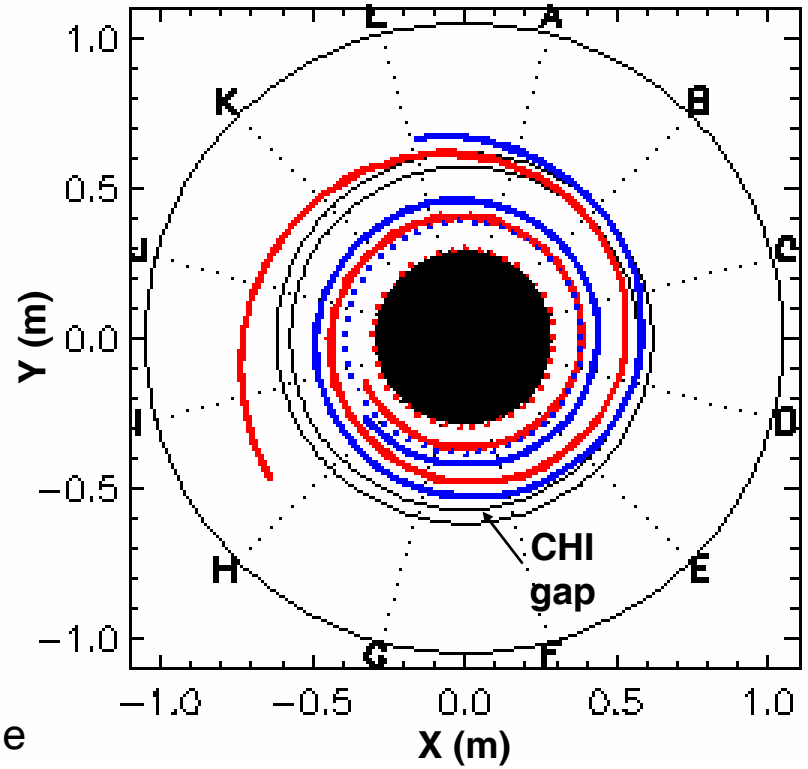
- **See movie on display PC.**
- Striations seen on inner divertor target plate.
- While in the low X-point case, striations are seen close up to outer strike point position, in the high X-point case they are not seen for $\psi_N < 1.026$.
- No structure seen within private flux region in high X-point case.

Striations close to outer strike point are not related to midplane blobs

Correlation between midplane GPI and inner divertor target plate



Footprints of 3 cm diam. midplane blobs



- No correlation seen between divertor and midplane GPI at low ψ_N, even though footprints should "spiral" around center stack.
- Striations at low ψ_N consistent with toroidally symmetric fluctuations (i.e., non-spiral).

Summary and conclusions

- Fast-moving striations observed on the divertor target plates.
- Analysis show striations have characteristics of intermittent events (for example: PDF moments off-Gaussian), broadband frequency spectra and short auto-correlation times.
- In the far-SOL, striations correspond to “footprints” of midplane blobs.
- The correlation between the GPI diagnostic (blobs) and divertor light (neutral lithium) is remarkable, but only obtained if the two observation regions are mapped along field lines.

Summary and conclusions (cont.)

- Good correlation (filament “connection”) between the midplane and the divertor target plate can be observed down to ψ_N~1.04 in the case of a low X-point.

- Striations at low ψ_N not related to midplane blobs and are consistent with toroidally symmetric fluctuations (circular rather than spiral).