Gas Puff Imaging of edge turbulence

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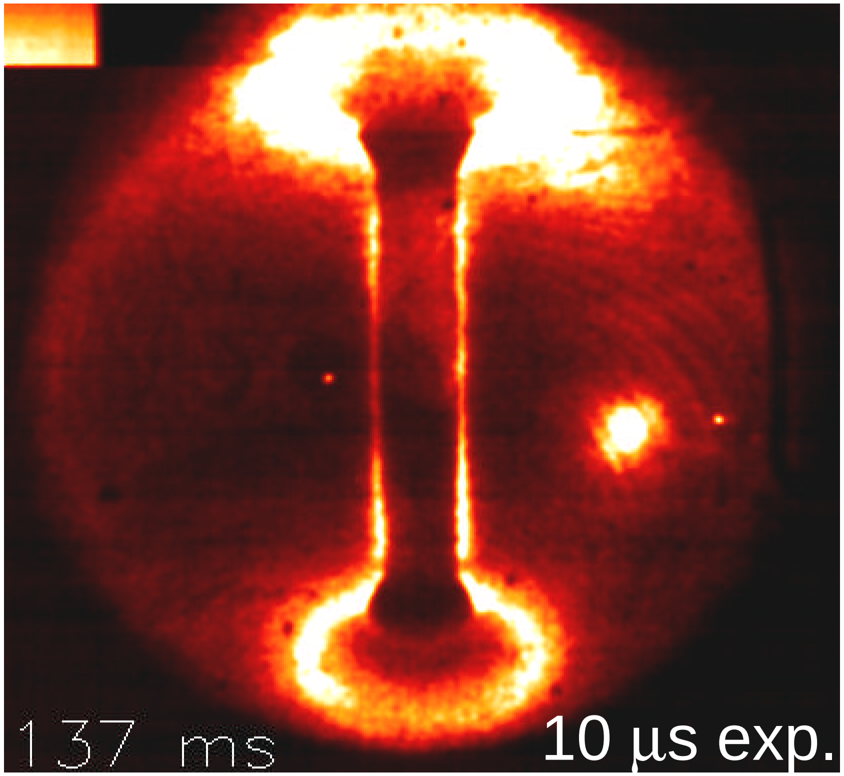

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Turbulent structure aligned with magnetic field ($k_{//} << k_{\perp}$)

Auto-correlation times ≤100 μs

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Objective

- Understand the physics of edge turbulence in plasmas. This understanding will only come from interaction with theory and simulation codes.
- Characterize the 2-D structure vs. time of the edge turbulence.
- Compare experimental results with theory and modeling. For example: BOUT (Boundary Plasma Turbulence) code of LLNL.

Control of edge turbulence ...and its effect on core confinement.

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Outline

- Gas Puff Imaging diagnostic in NSTX
- Results
    - snapshots
    - movies & blob tracking
- Conclusions
- Analysis and experiment plans

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Gas Puff Imaging diagnostic

- Optical system views neutral line emission from He or D_2 gas puff:

  HeI (587.6 nm)

  D_α (656.2 nm)

- Emission: **S(photons/s cm^3) = n_o f(n_e,T_e) A**

  where A is the radiative decay rate (>> 10^7 sec^{-1})

  (**f(n_e,T_e)** presented by Daren Stotler)

- Space and time variation of neutral light emission measured with **fast-gated cameras** and **photodetectors** on discrete fast chords.

- Gas puff changes plasma density but:

  DOES NOT perturb edge turbulence significantly

  DOES NOT introduce fluctuations through **n_o**

- View of gas puff along magnetic field line.

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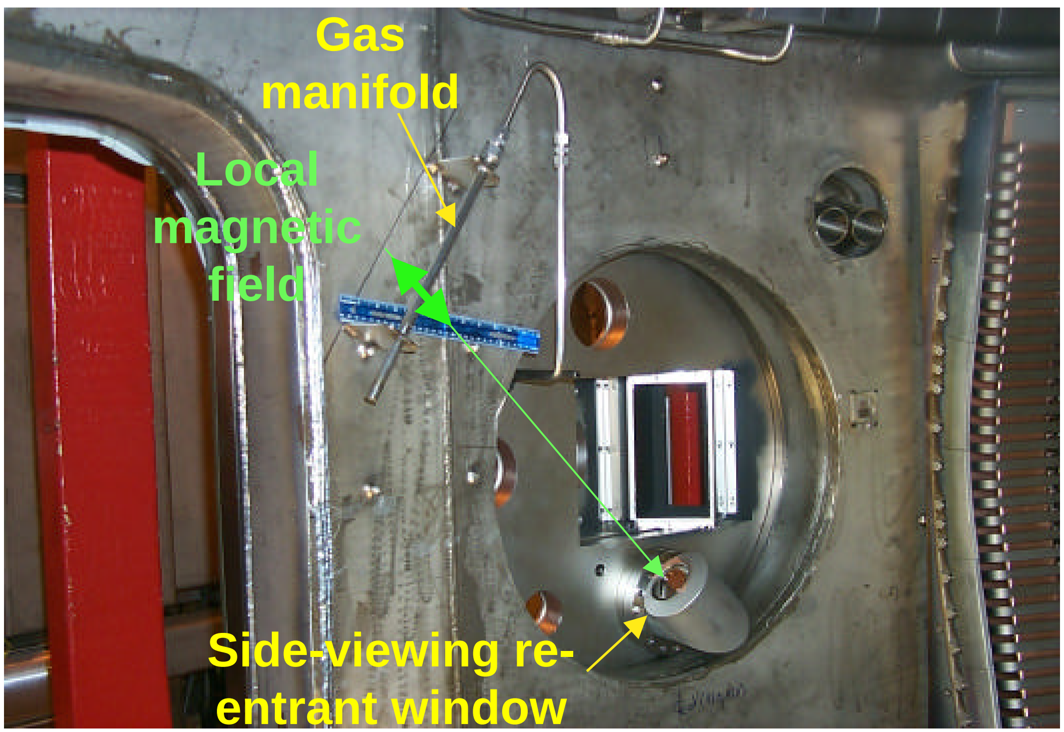
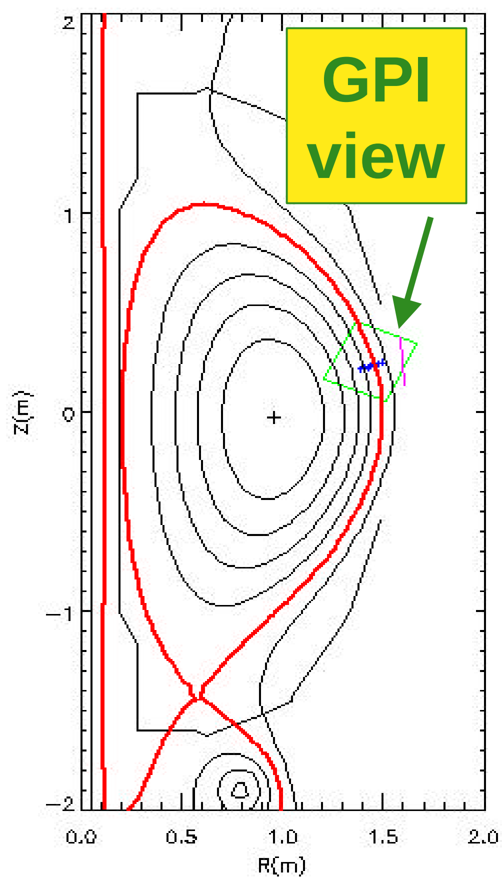
GPI Diagnostic setup in NSTX

- Use re-entrant port and linear gas manifold.
- Use **He**, D_2, or Ar puffs.
- Use beam-splitter and PMTs (100 kHz bandwidth) for discrete fast chords.





Imaging cameras

	Kodak EM1012	Phantom v.4	PSI-4*
Intensified	yes	yes (ILS-3)	no
Array size (pixels)	239x192	512x512	160x80
Frame speed (frames/s)	1,000	1,000	≤1,000,000
Max. speed "	6,000	32,000	---
Frame storage	1,638	4,000	28

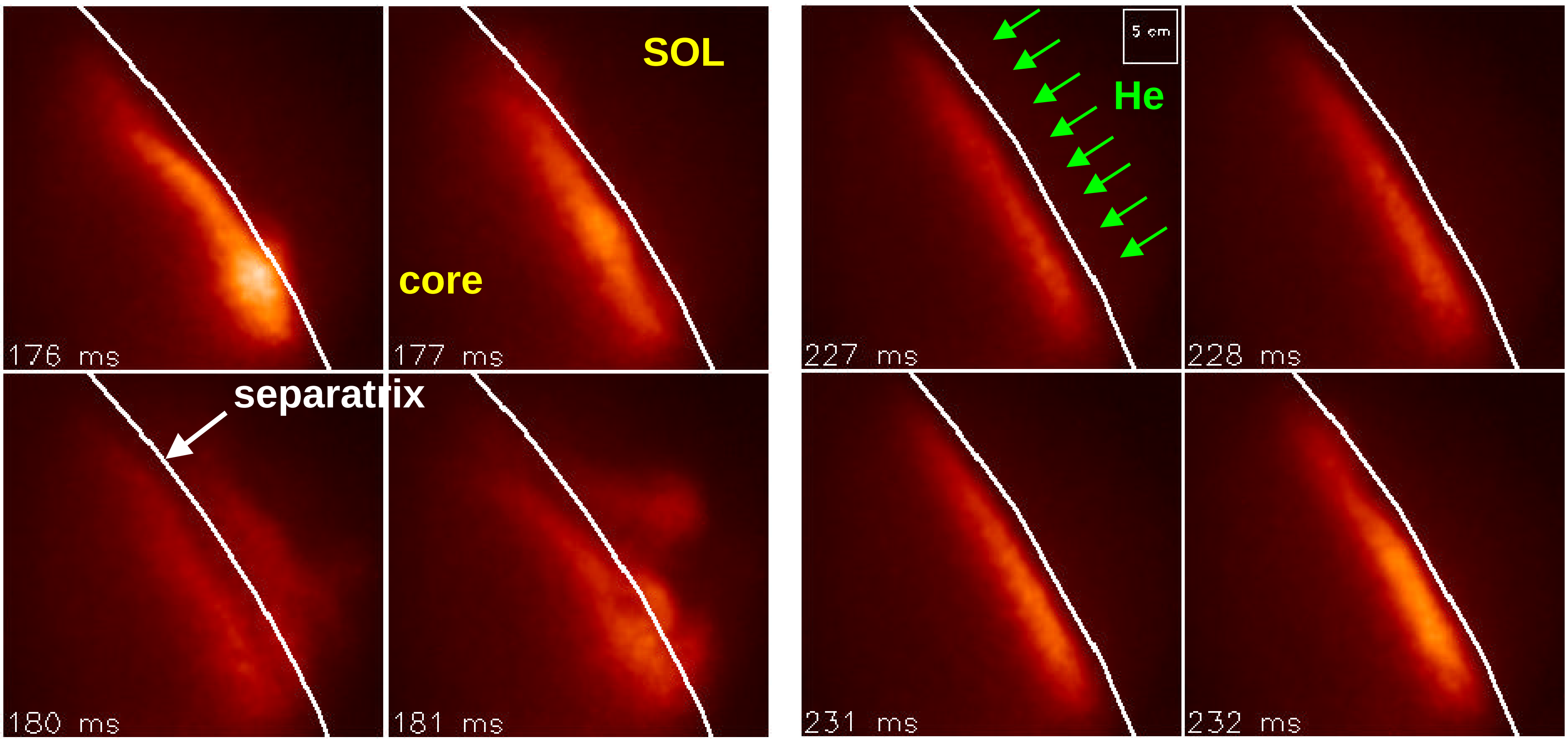
* Princeton Scientific Instruments

Snapshots of edge turbulence

HeI filter (587.6 nm)
10 μs exposure
0.9 MA - 0.35 T

Phantom v.4
ILS-3 intensifier

L-mode H-mode



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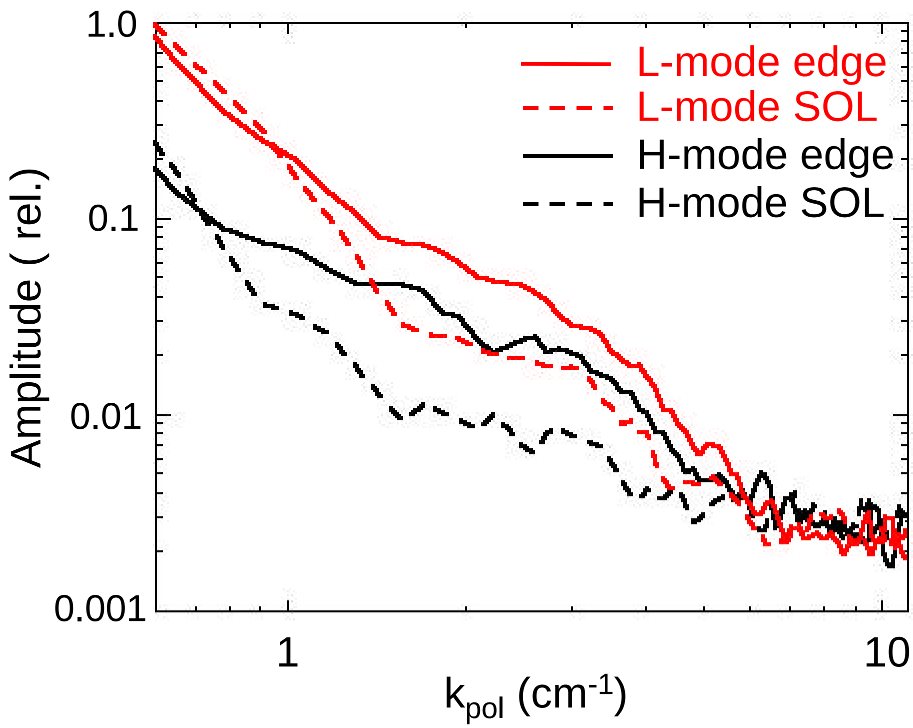
Poloidal k spectra in NSTX

- GPI emission normalized to same total time averaged emission from edge.



- Smaller fluctuation amplitudes observed in H-mode than L-mode.

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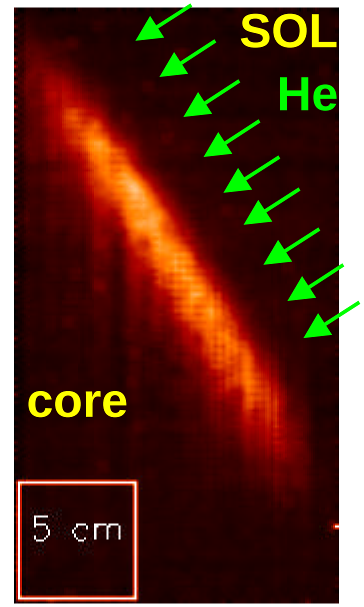
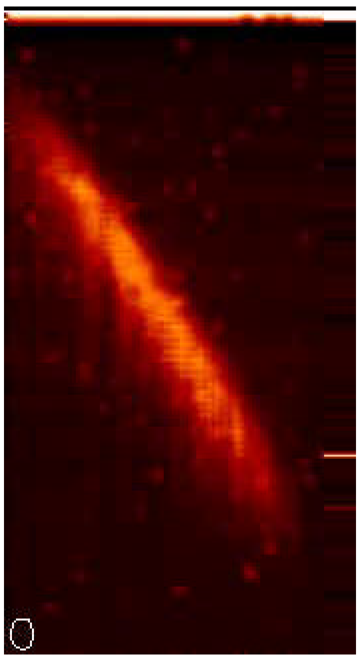
Videos of edge turbulence in NSTX

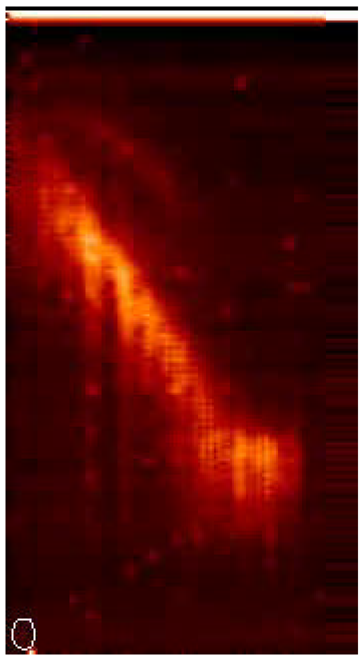
- PSI-4 camera (28 frames) at 100,000 frames/s and 10 μs exposures.
- http://w3.pppl.gov/~szweben/psi/
- **H-mode**



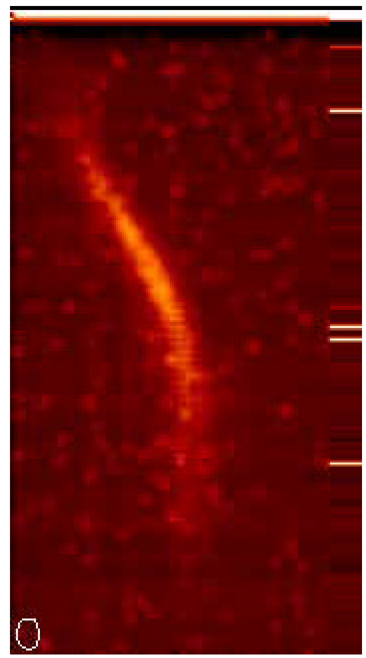
Shot 108316



Shot 108315



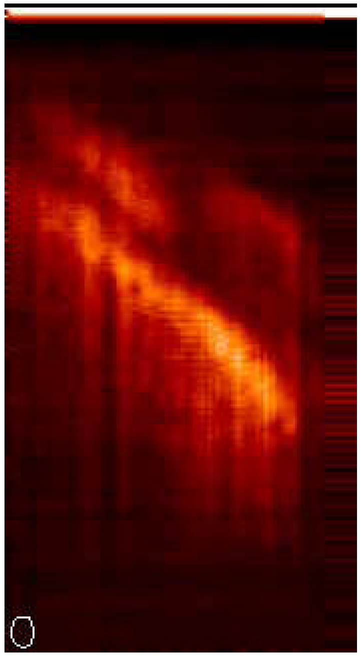
Shot 108466



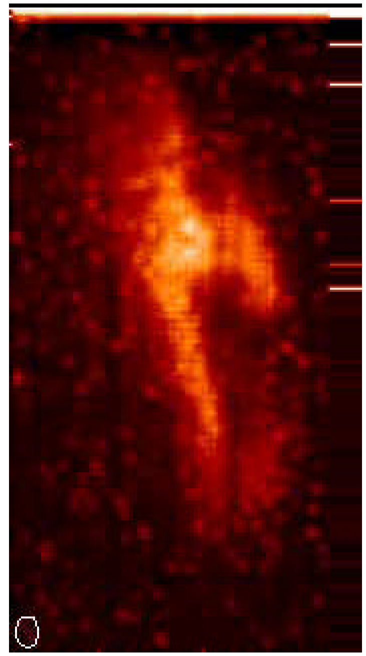
Videos of edge turbulence (cont.)

- **L-mode**

Shot 108301



Shot 108609



- Clear differences seen between L-mode and H-mode.
- Edge turbulence structure, a combination of “blobs” and “waves”, followed in time.
- Complex blob movements observed.

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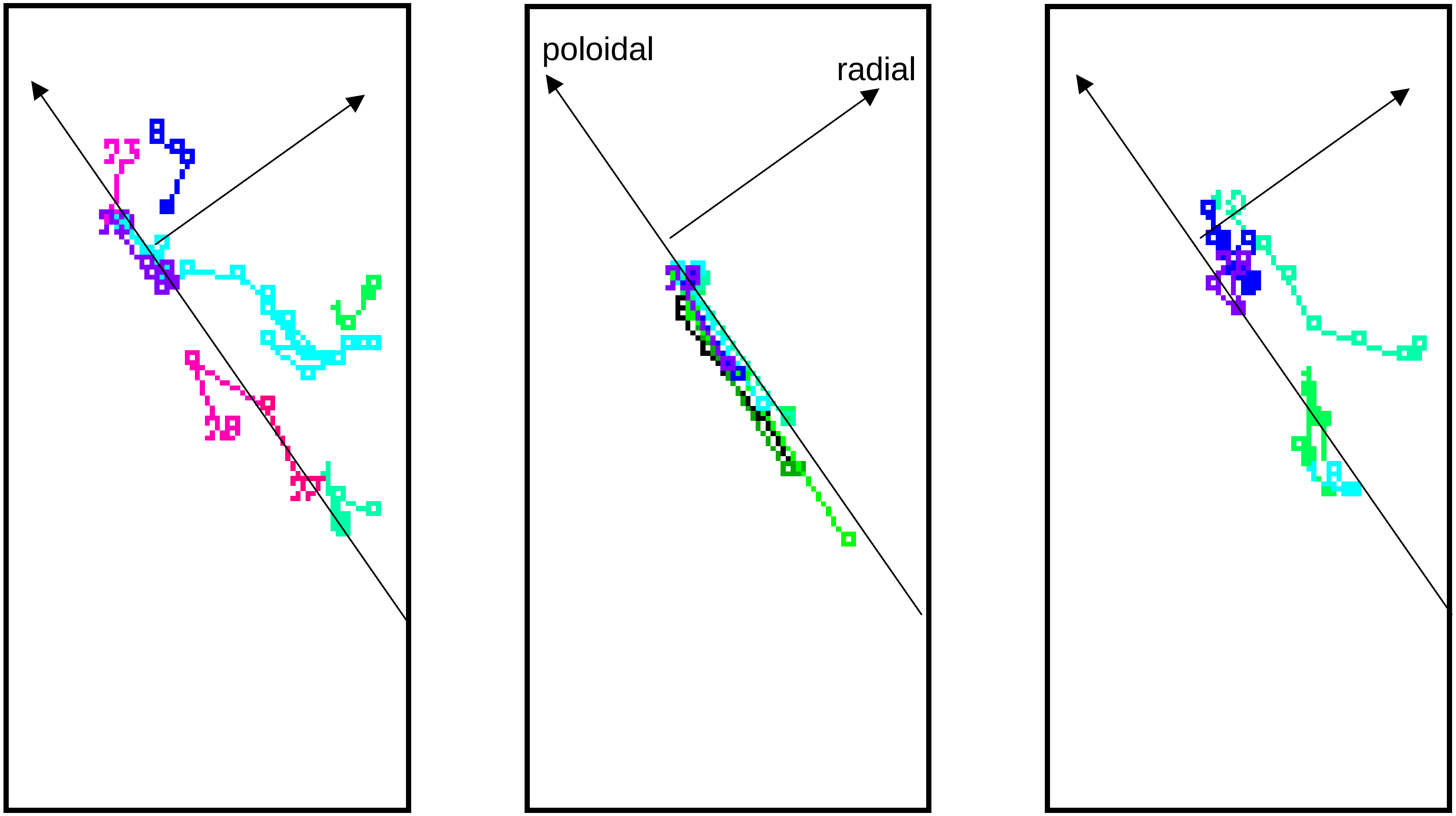
Blob tracking

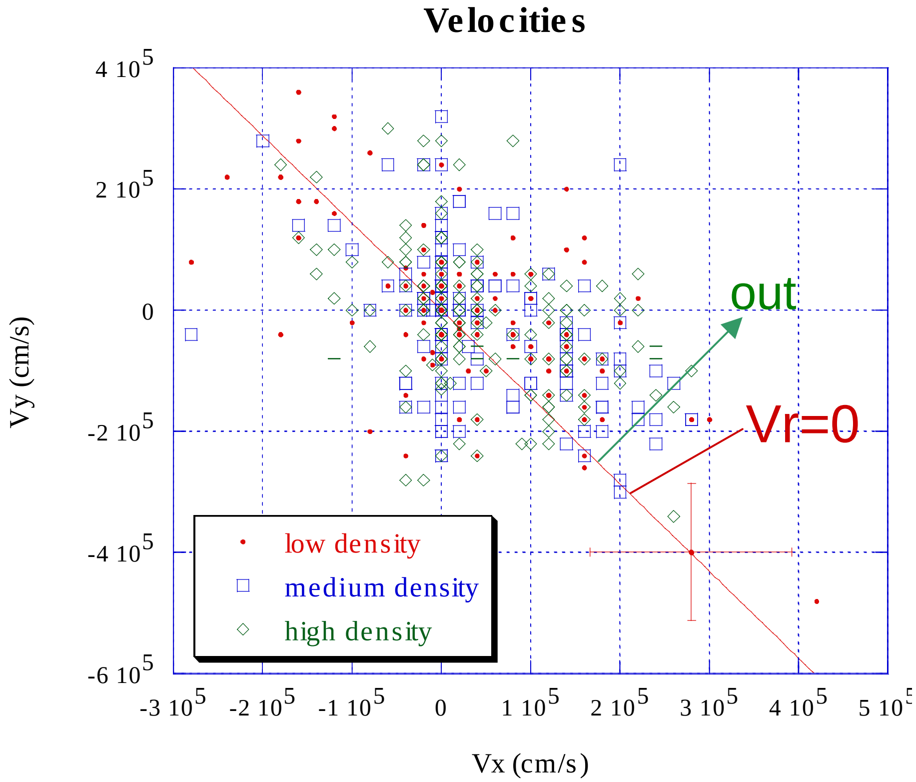
Algorithm developed by A. Keesee (WVU)



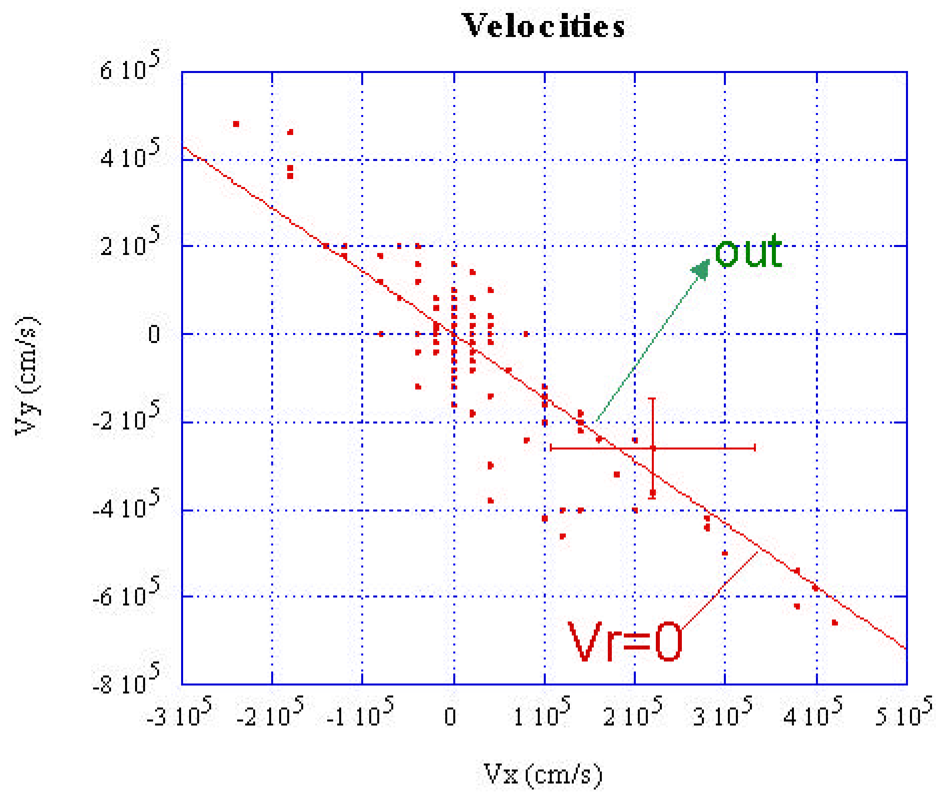
shot 108164 - ohmic   shot 108316 - H-mode   shot 108979 - L-mode

Blob velocity

Ohmic density scan



H-mode



Algorithm to track wave-like structures needs to be developed

Blob velocity summary

Plasma Condition	<Vr> (cm/s)	<|Vr|> (cm/s)	<Vp> (cm/s)	<|Vp|> (cm/s)
Ohmic; low density	2.6 +/- 7.1 E4	5.6 +/- 5.1 E4	-0.3 +/- 1.5 E5	1.1 +/- 1.1 E5
Ohmic; med density	2.4 +/- 7.6 E4	6.0 +/- 5.2 E4	-0.5 +/- 1.3 E5	1.1 +/- 0.9 E5
Ohmic; high density	2.3 +/- 7.0 E4	5.4 +/- 5.0 E4	-0.3 +/- 1.1 E5	9.0 +/- 7.9 E4
H-mode	0.2 +/- 1.0 E5	6.8 +/- 8.0 E4	-0.5 +/- 1.9 E5	1.1 +/- 1.6 E5
L-mode	0.5 +/- 6.8 E4	4.9 +/- 4.7 E4	-0.7 +/- 1.9 E5	1.5 +/- 1.3 E5

Velocity spread (standard deviation) is large respect to means.

On average there is:
- an outward radial flow
- a “negative” poloidal flow, in the direction of the ion diamagnetic drift.

Summary of results

	NSTX	Alcator C-Mod
frequency spectrum	broad	broad
fluctuation level	10%-100%	15%-135%
autocorrelation times	10-100 μs	10-20 μs
poloidal correlation length	6-9 cm	~0.8 cm
radial correlation length	<4-6 cm	~1 cm
blob velocity	0.5-1 m/ms	~0.5 m/ms
poloidal k spectrum	broad	broad
H vs. L differences	yes	not seen*

Edge turbulence study is a combined multi-machine effort!

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Alcator C-Mod

Conclusions

- GPI measurements on NSTX consistent with previous Langmuir probe, reflectometer and BES measurements in other experiments.
- Complex movement of 2-D edge structure can be followed with newly developed ultra-fast cameras.
- Notable differences (turbulence/blob reduction) observed in NSTX between H-mode and L-mode.
- No trends (nor “visible” differences) observed in density scan.
- Characterization of edge turbulence is progressing… specially with the commissioning of other complimentary diagnostics such as Langmuir probes (UCSD) and reflectometry (UCLA and ORNL).
- Initial comparison with BOUT 3-D edge turbulence code certainly encouraging.

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Plans

EXPERIMENTAL

- Continue statistical analysis (wave number spectra, time spectra, blob and wave analysis, etc.).
- Compare GPI fluctuations with Langmuir probe and reflectometry.
- Measure poloidal distribution of turbulence (inner midplane, X-point region, etc.).

ANALYSIS

- Obtain BOUT runs matching experimental conditions (Xu and Nevins, LLNL).
- Calculate expected GPI patterns from turbulence simulations using DEGAS 2 and compare with measured patterns.
- Search for coherent structures and characterize it (e.g., blob statistics and motions).
- Calculate spatial shadowing and possible time-dependent effects using DEGAS 2.

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