Visualizing and Quantifying Blob Characteristics on NSTX

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PPPL

Abstract

Radial motion of blob-filaments in the tokamak edge plasma can affect the width of the heat and particle scrape-off layer (SOL) [1], and the heat load on plasma facing components. High resolution (64x80), high speed (~400,000 frames/sec) edge turbulence movies taken of the NSTX outer midplane separatrix region have been analyzed for blob motion. Regions of high light emission from gas puff imaging within a 25x30 cm cross-section were used to track blob-filaments in the plasma edge and into the SOL. Software tools generate statistics of blob speed, shape, amplitude, size, and orientation. Poloidal and radial motion changes as blobs move through the SOL, e.g., suggesting the influence of sheared flow. Relationships between blob size and velocity are shown for various types of plasmas and compared with simplified theories of blob motion.

[1] Myra, J. R., *et al.*, *Phys. Plasmas* **18** (2011) 012305.

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Objectives

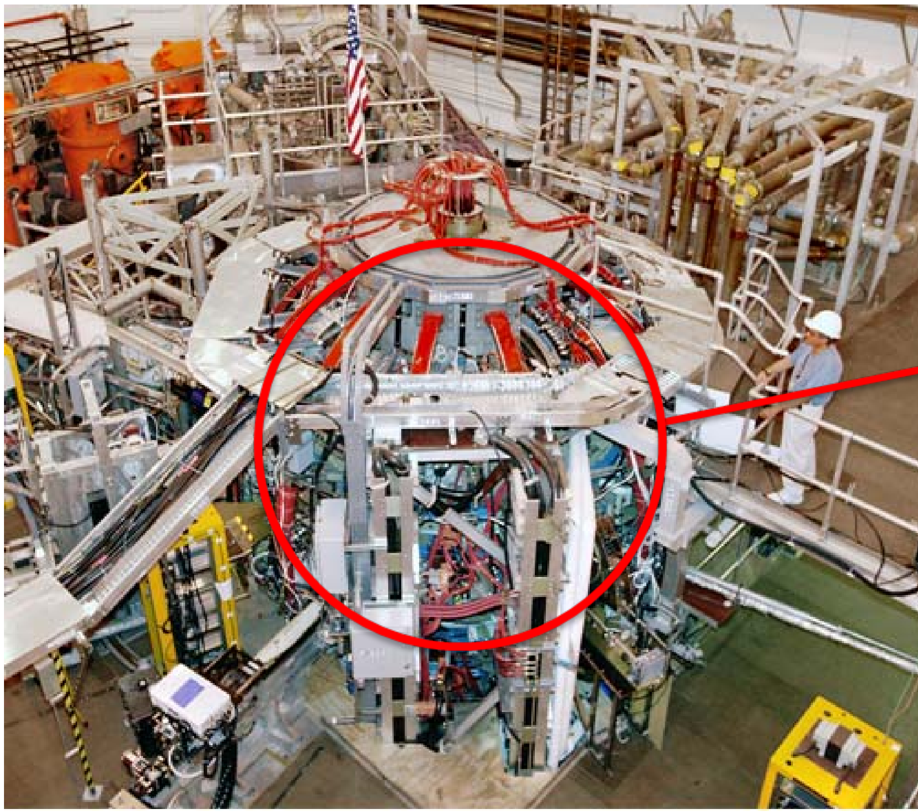
- To better understand the physics of edge turbulence in the Scrape Off Layer (SOL) in general.
- To understand blob formation and transport in particular [2].

Approach

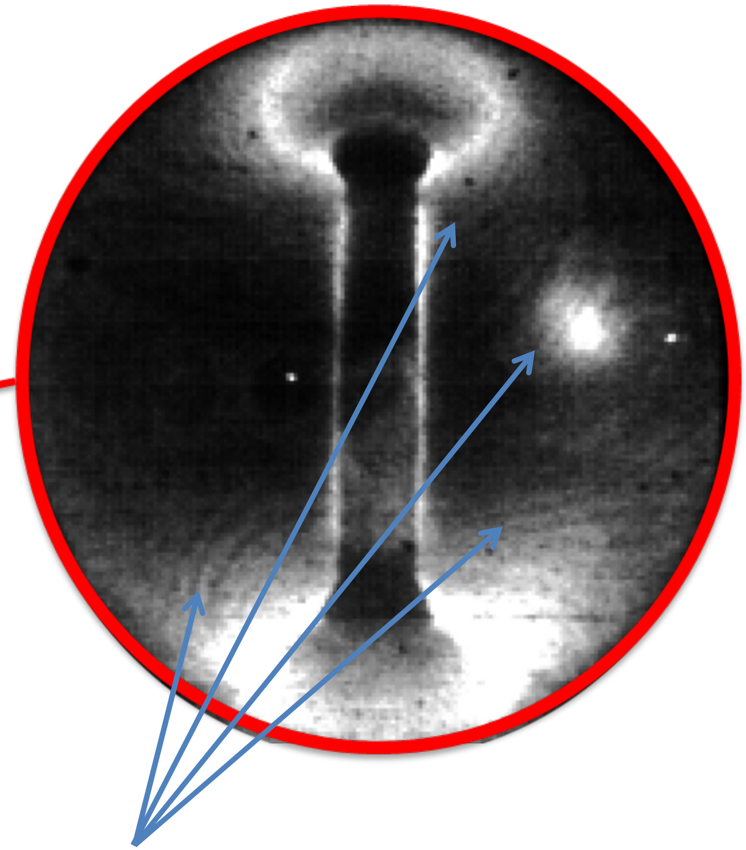
- Automate the fitting and tracking of blob structures from edge turbulence imaging.
- Provide easy-to-use visualization tools.
- Build a large database of blob location, size, orientation, speed, and duration.

[2] D'Ippolito, D. A., *et al.*, "Convective transport by intermittent blob-filaments: Comparison of theory and experiment". *Phys. Plasmas* **18** (2011) 060501.

National Spherical Torus Experiment (NSTX)

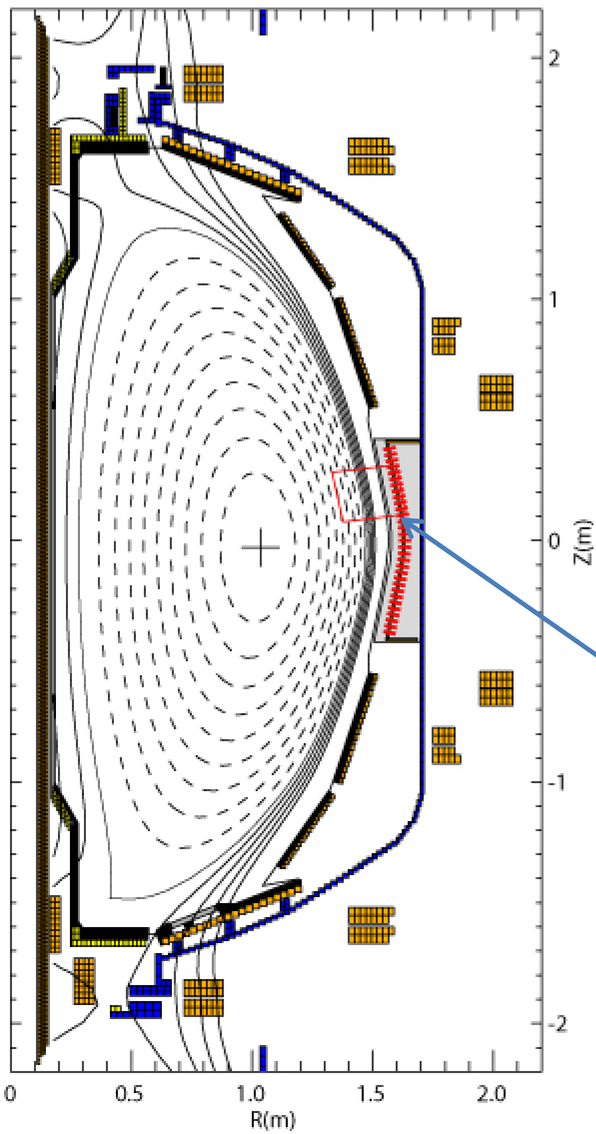


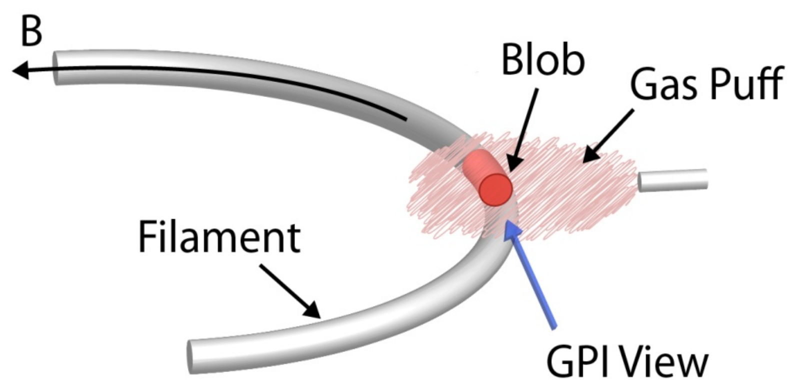
Fusion device at the Princeton Plasma Physics Laboratory



Blob filaments in an NSTX plasma

Gas Puff Imaging Diagnostic on NSTX





GPI camera parameters

- Phantom Camera v710
- Viewing HeI emission (587.6 nm)
- Viewing area 25 cm x 30 cm approximately aligned with flux surfaces.
- 64 x 80 pixels in each frame
- 390,800 frames/sec
- exposure time 2.1 μsec/frame

Blob Track Software Suite

FCplayer: Interactive IDL program for enhancing images, setting blob criteria, and playing movie files from Phantom cameras with blobs identified.

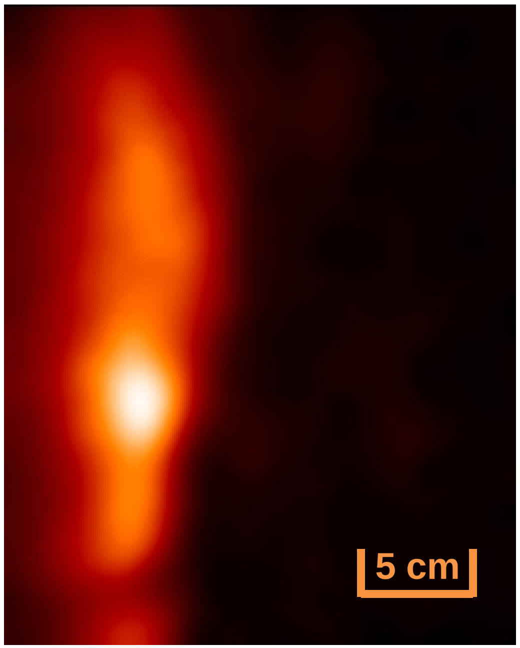
LoadBlobs: Identifies blobs in each frame, tracks blobs in time, and writes results to a database or file.

DbAccess: Plots all combinations of blob characteristics with specified constraints.

BlobTrails: Plots blob tracks, with various constraints, and shows tilt, ellipticity, and the position relative to the separatrix.

(codes available from the author)

Normalizing images adjusts for uneven gas puff illumination



Smoothed Raw Image

Exposure time:
2.1 μsec/frame

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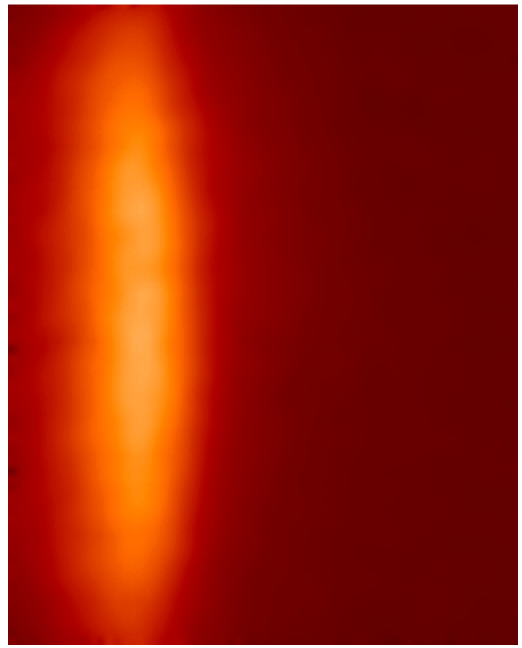
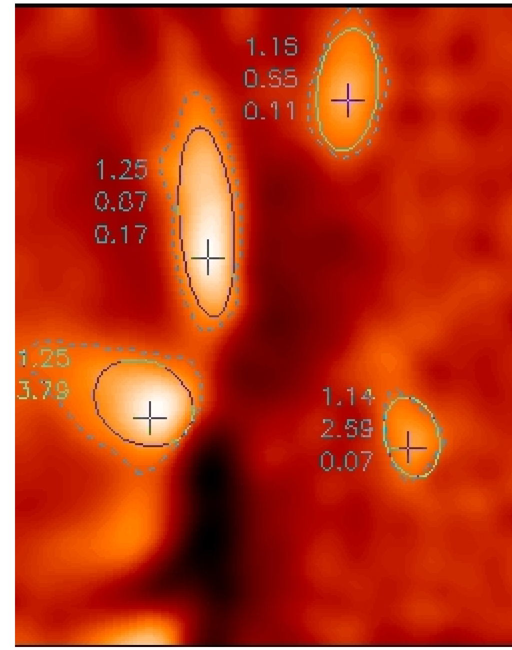


Smoothed Frame averaged over 1 msec

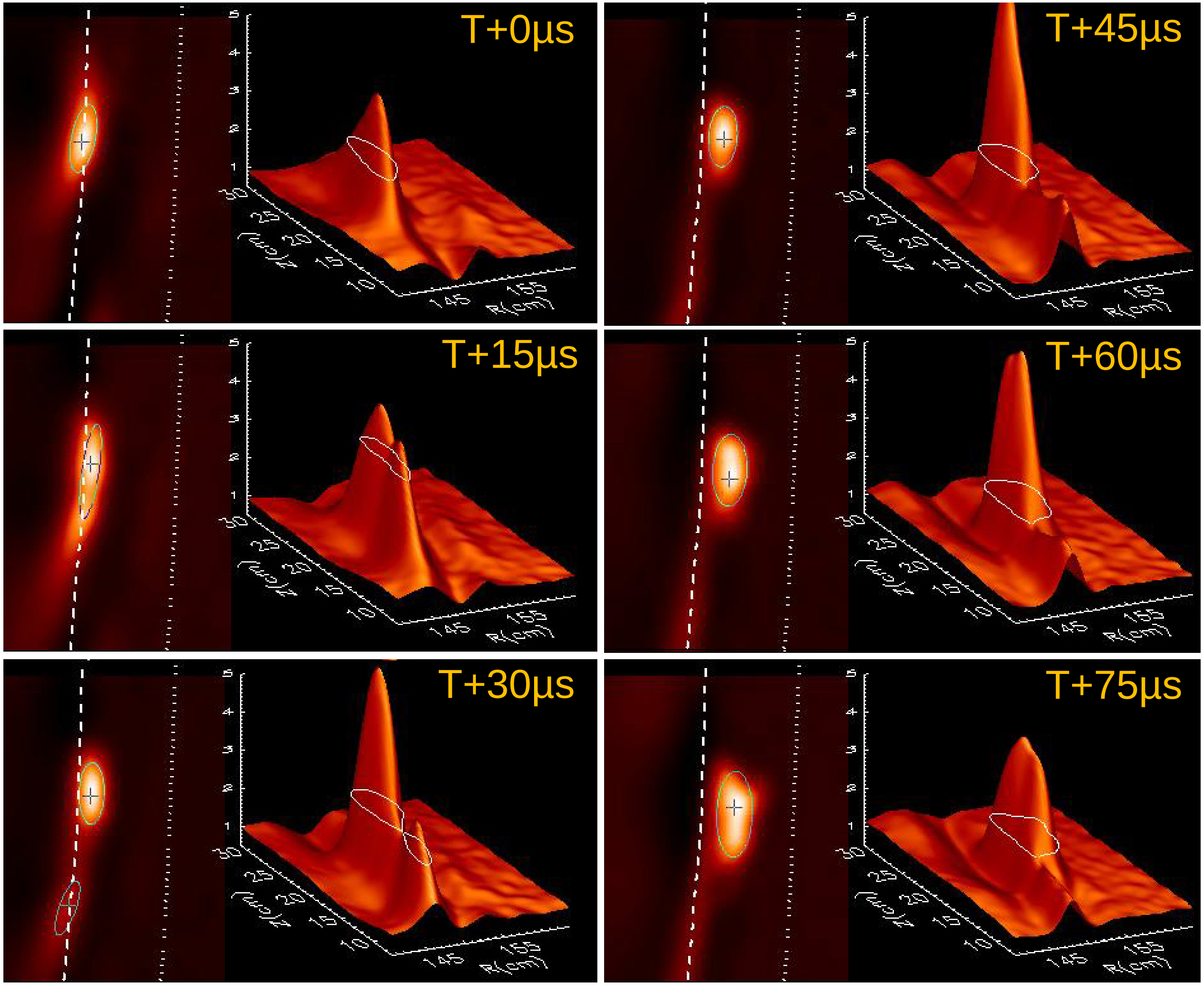
=



Resulting Normalized Image to which ellipses are fit

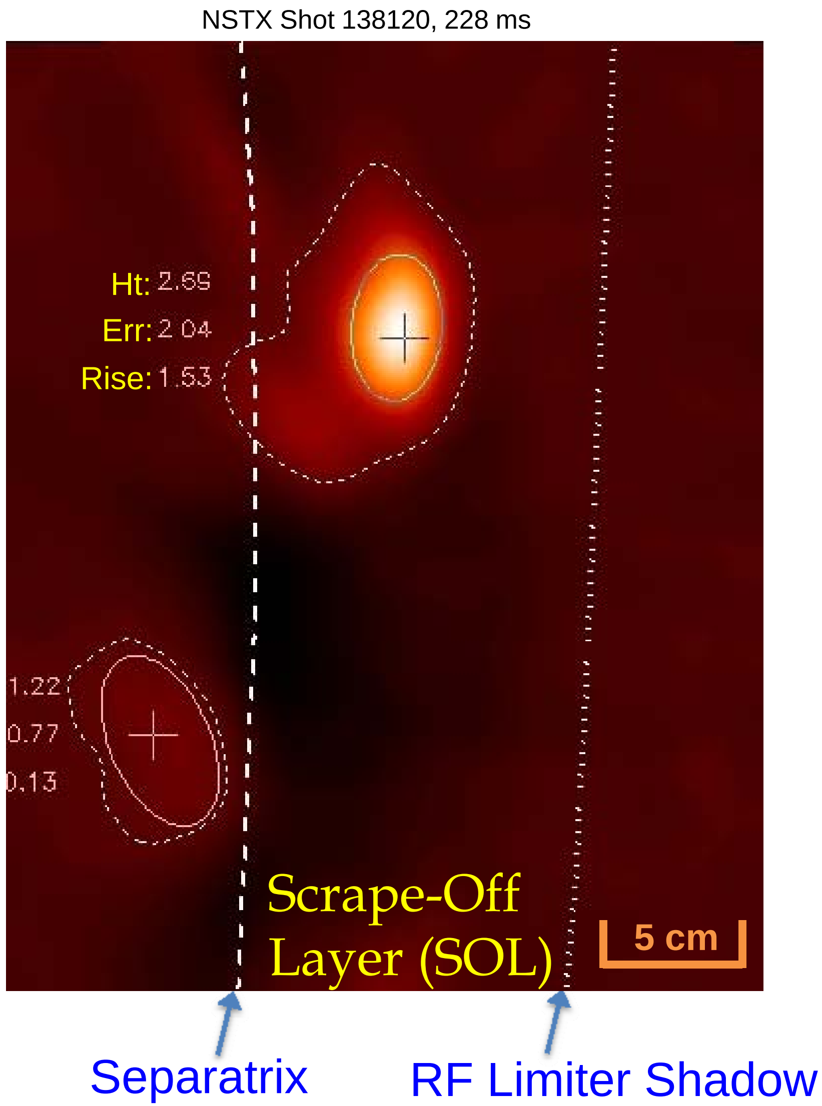
NSTX Shot 138114, 231.6545 ms

Blobs can be tracked in time as scaled images or as surface plots



NSTX Shot 138234
532.061 ms

Ellipses are fit to mid-level contours



- Lowest closed contour, fitting the size constraints, is found (dashed line).
- Ellipse is fit to the contour at half max.
- Height, Mean Squared Error of fit, and rise from base to top are listed.
- Locations of maxima (indicated by plus signs) can be tracked from frame to frame.

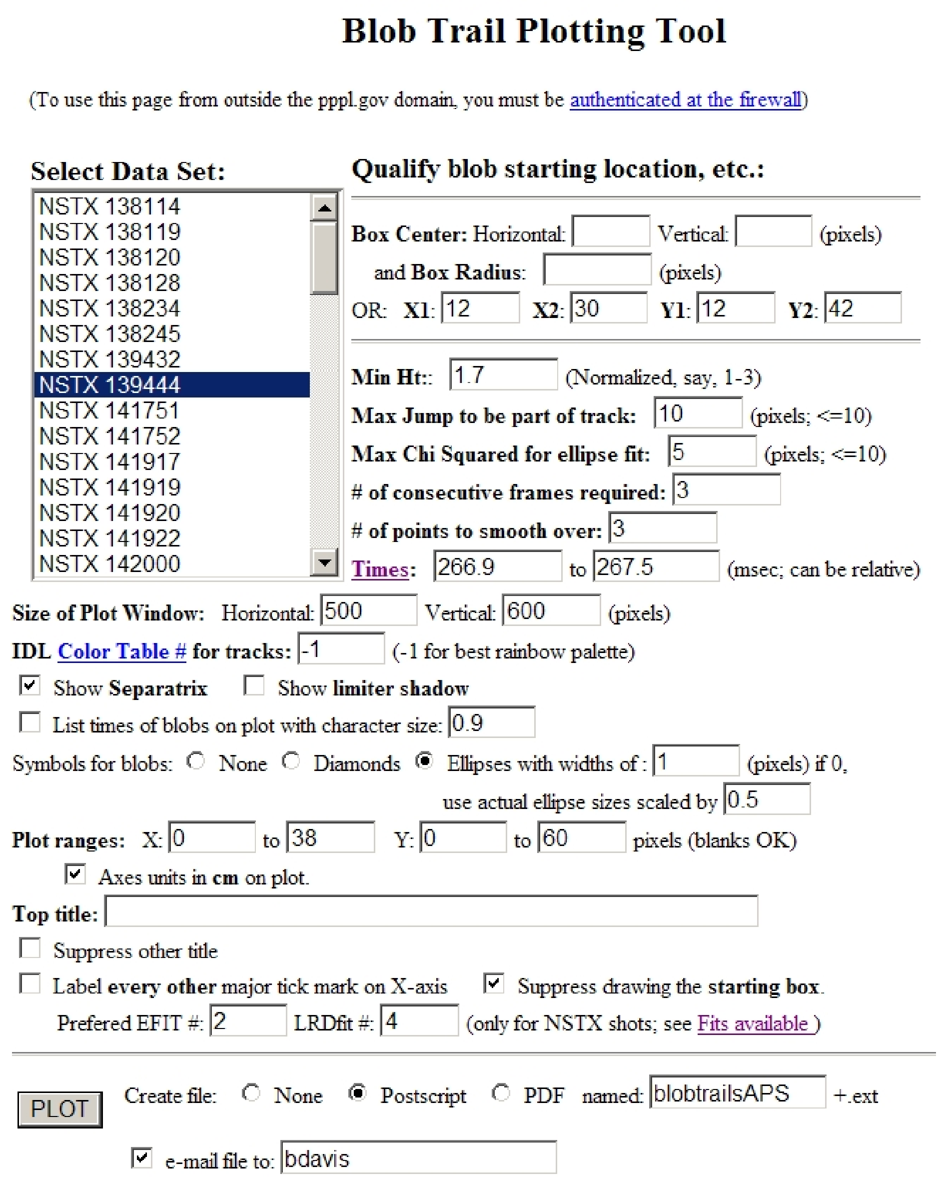
Contents of Blob Database

- **40 NTSX shots, and counting**
- **Physical Characteristics**
  - Location of blob center in Radius and Z
  - Average value of region enclosed by fitted ellipse
  - Ellipticity
  - Tilt
  - Area
  - Normalized height (brightness) of blob
  - Normalized height of base
  - Rise from base to top
  - Distance from Separatrix
- **History**
  - Parent blob # (where it came from)
  - Child blob # (where it is in the next frame)
  - Change in area from previous frame
  - Lifetime - total time blob has been tracked
  - First blob in it's lifetime
  - Starting location of blob in Radius and Z
- **Dynamics**
  - Time of blob instance
  - Radial velocity of blob
  - Poloidal velocity of blob

Web interface to Blob Database

http://nstx.pppl.gov/nstx/Software/WebTools/blobtrails.html

- Select desired shot
- Restrict location of blob starts
- Set other constraints such as blob height (brightness)
- Specify fit type for separatrix display (defaults to “best fit” which is typically EFIT02).
- Displays in browser or Emails Postscript or PDFs



Blob Trail Plotting Tool

(To use this page from outside the pppl.gov domain, you must be authenticated at the firewall)

Select Data Set:

NSTX 138114
NSTX 138119
NSTX 138120
NSTX 138128
NSTX 138234
NSTX 138245
NSTX 139432
NSTX 139444
NSTX 141751
NSTX 141752
NSTX 141917
NSTX 141919
NSTX 141920
NSTX 141922
NSTX 142000

Qualify blob starting location, etc.:

Box Center: Horizontal: [ ] Vertical: [ ] (pixels)
and Box Radius: [ ] (pixels)
OR: **X1**: 12 **X2**: 30 **Y1**: 12 **Y2**: 42

Min Ht:: 1.7 (Normalized, say, 1-3)
Max Jump to be part of track: 10 (pixels; <=10)
Max Chi Squared for ellipse fit: 5 (pixels; <=10)
# of consecutive frames required: 3
# of points to smooth over: 3
Times: 266.9 to 267.5 (msec; can be relative)

Size of Plot Window: Horizontal: 500 Vertical: 600 (pixels)
IDL Color Table # for tracks: -1 (-1 for best rainbow palette)
[x] Show **Separatrix** [ ] Show **limiter shadow**
[ ] List times of blobs on plot with character size: 0.9
Symbols for blobs: ( ) None ( ) Diamonds (•) Ellipses with widths of : 1 (pixels) if 0,
use actual ellipse sizes scaled by 0.5
Plot ranges: X: 0 to 38 Y: 0 to 60 pixels (blanks OK)
[x] Axes units in **cm** on plot.
Top title: [ ]
[ ] Suppress other title
[ ] Label **every other** major tick mark on X-axis [x] Suppress drawing the **starting box**.
Prefered EFIT #: 2 LRDfit #: 4 (only for NSTX shots; see Fits available)

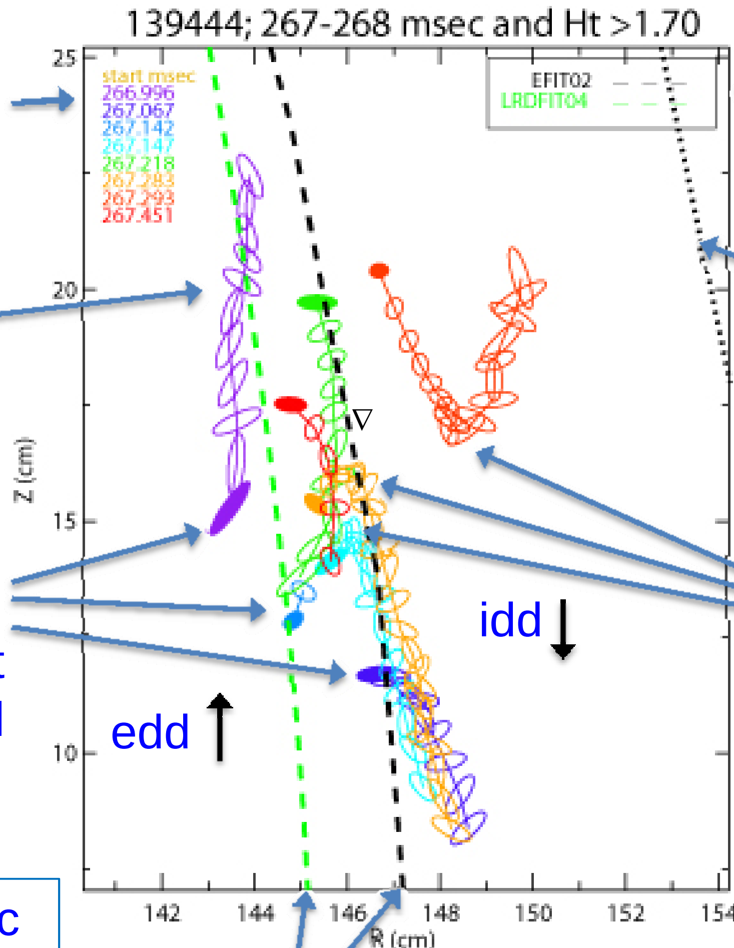
PLOT Create file: ( ) None (•) Postscript ( ) PDF named: blobtrailsAPS +.ext
[x] e-mail file to: bdavis

Sample Output from BlobTrails.html

Starting times of blobs (2.5 μsec/frame)

Tilt and elongation are from ellipse fit

Solid ellipses indicate the start of a blob trail



Fits used for Separatrix location

Limiter shadow

idd

edd

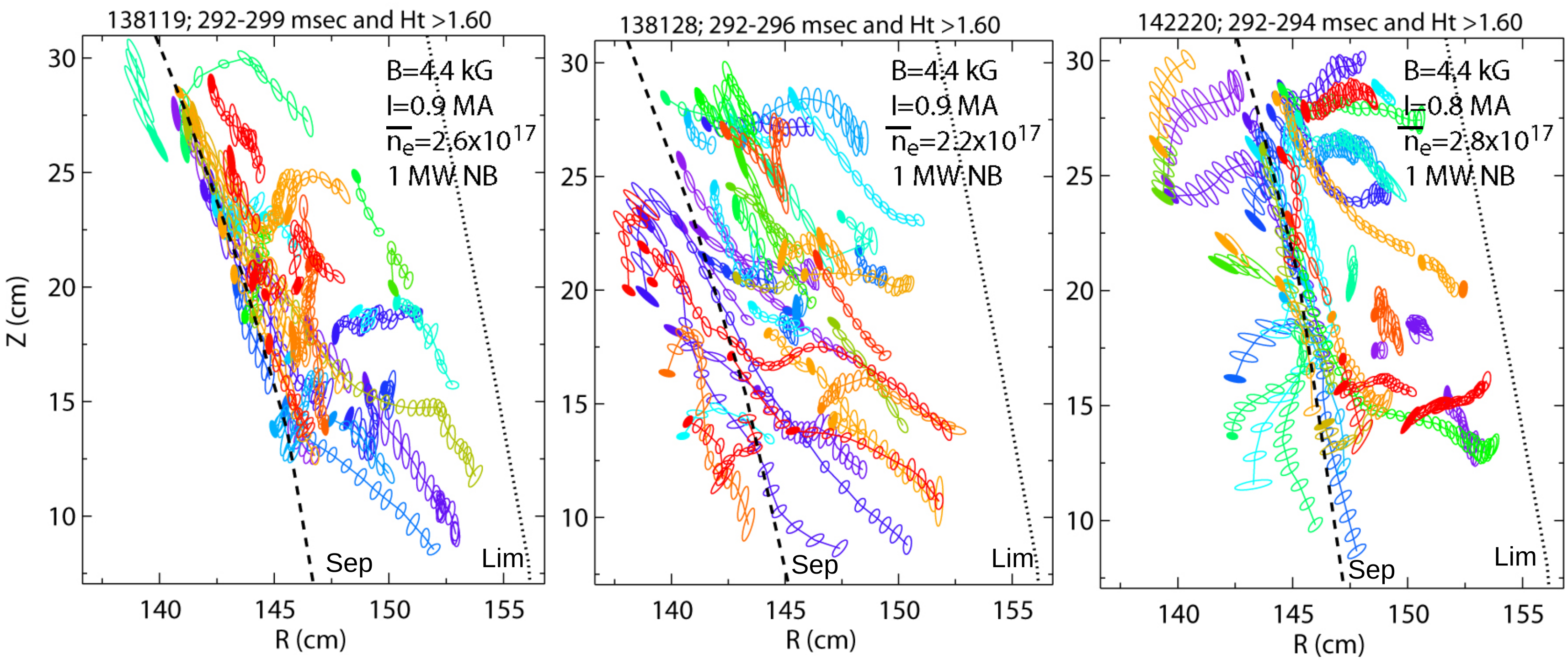
Direction change is evidence of sheared flow

Separatrix from different equilibrium fits (EFIT02 & LRDfit04)

edd – Electron diamagnetic drift direction

idd – Ion diamagnetic drift direction (ion $\nabla \vec{B}$)

Blob Tracks in Similar NBI-only shots

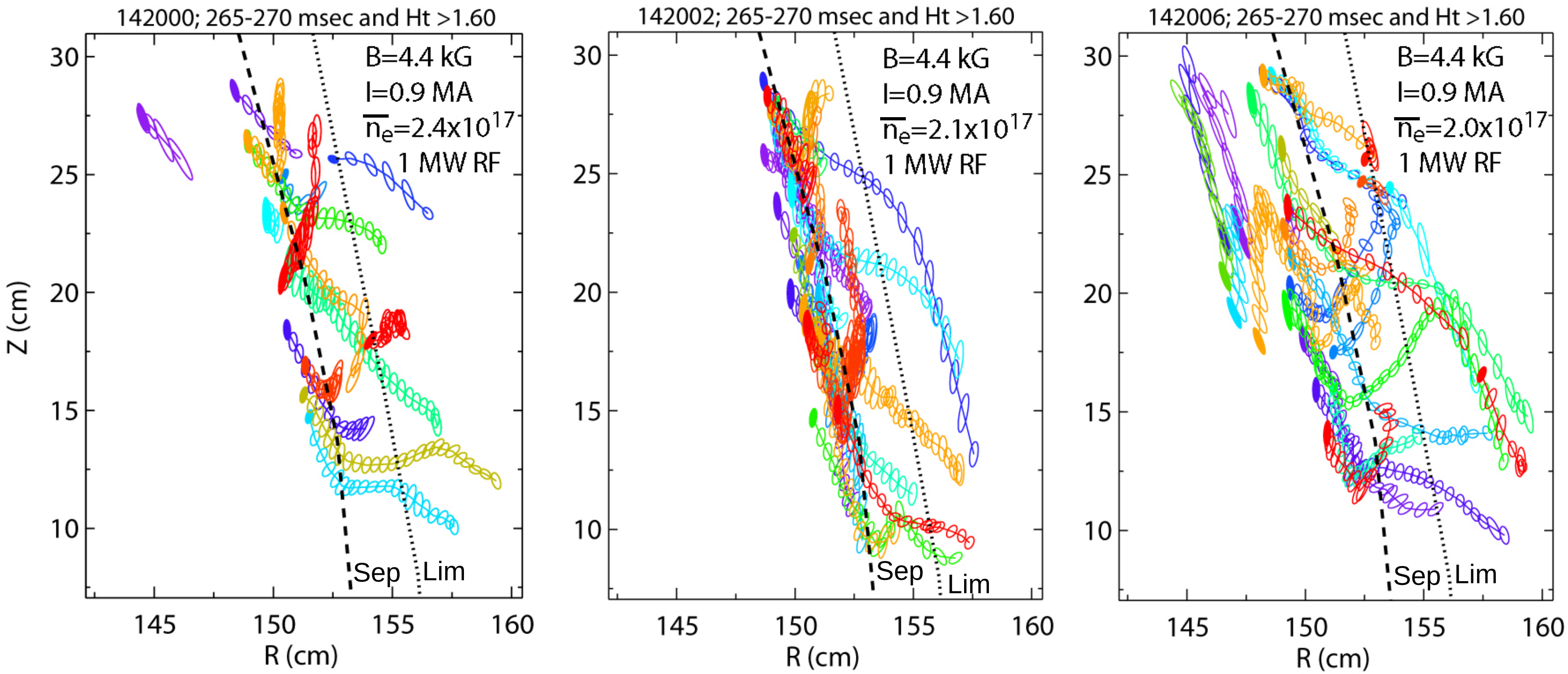


- Few blobs inside Separatrix, *even though the other NB shots here are very similar in other respects*

- Apparent shear flow, with inside blobs moving up, those near separatrix moving down, and outward motion farther outside the separatrix

- Rather chaotic blob movement

Blob Tracks in Similar RF shots

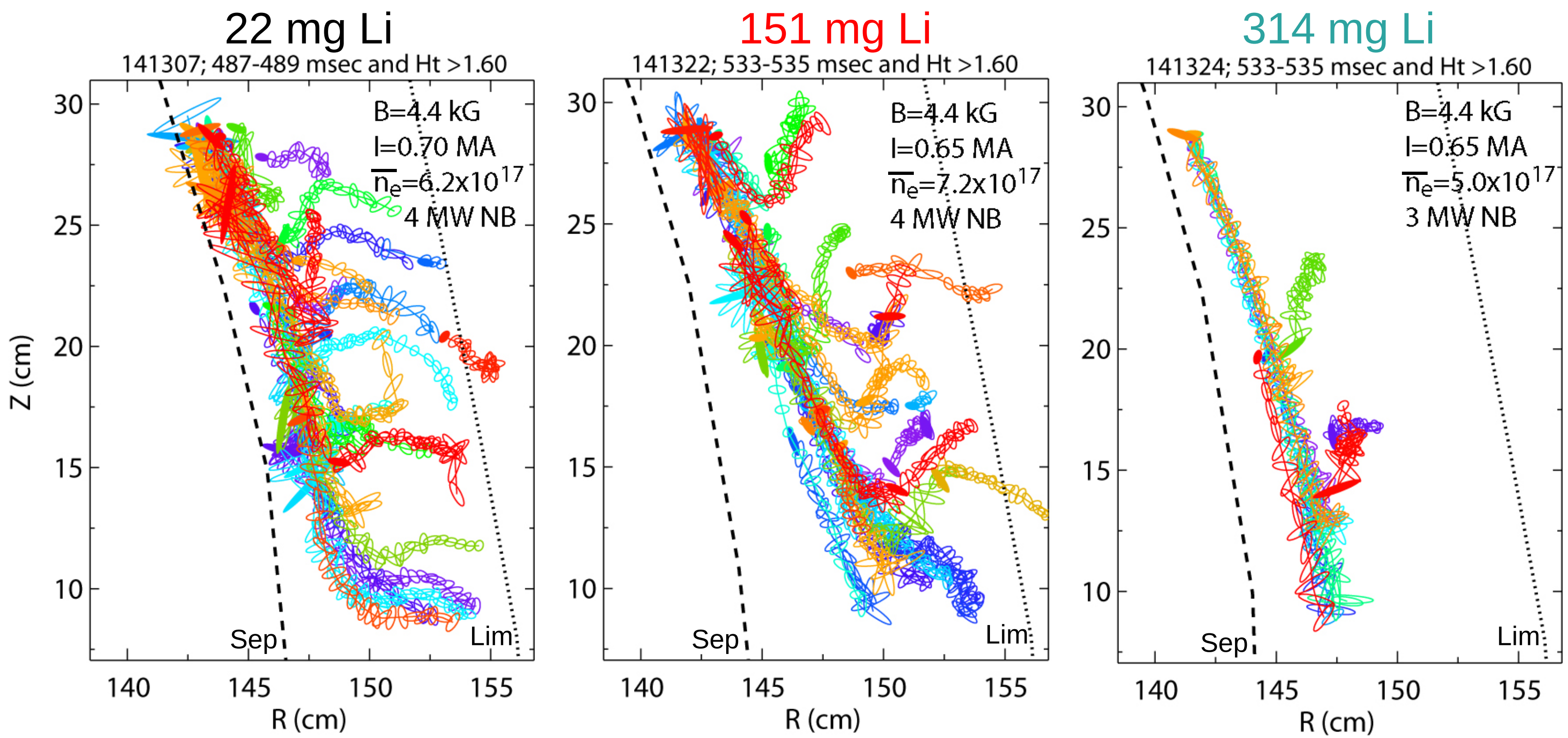


- Most blobs moving downward, with radial motion increasing outboard of the separatrix

- Similar to shot 142000, with a bit more clustering around the separatrix.

- Upward motion well inside the separatrix, then steeply downward, then more radial motion.

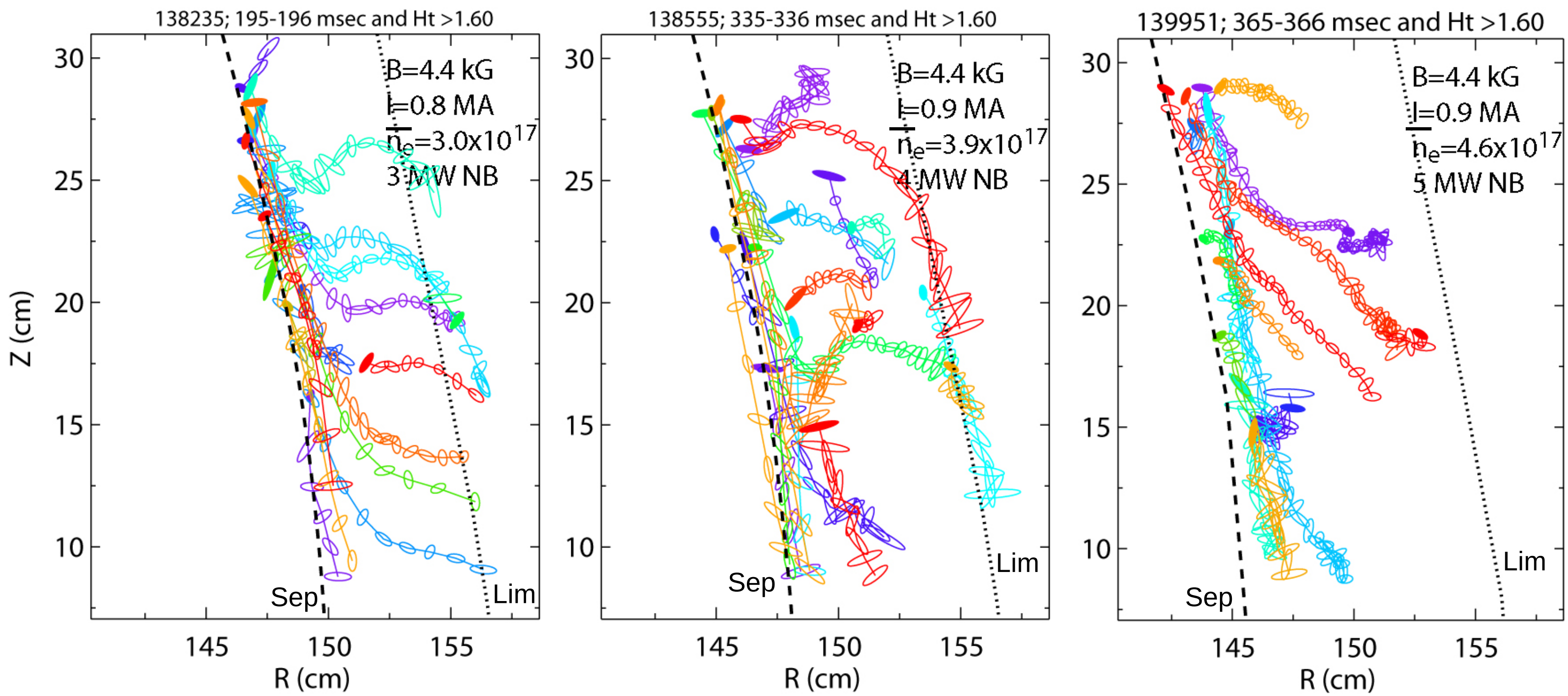
Blob Tracks during a Lithium Scan [3]



- The least amount of Lithium had the most blobs and the most radial motion.
- More Lithium seemed to subdue radial motion somewhat.
- Clear localization radially, with only a few blobs escaping.

[3] Cao, B., *et al.*, “Edge turbulence velocity changes with lithium coating on NSTX” *Plasma Phys. Control. Fusion* **54** (2012).

Blob Tracks in NBI Power Scan

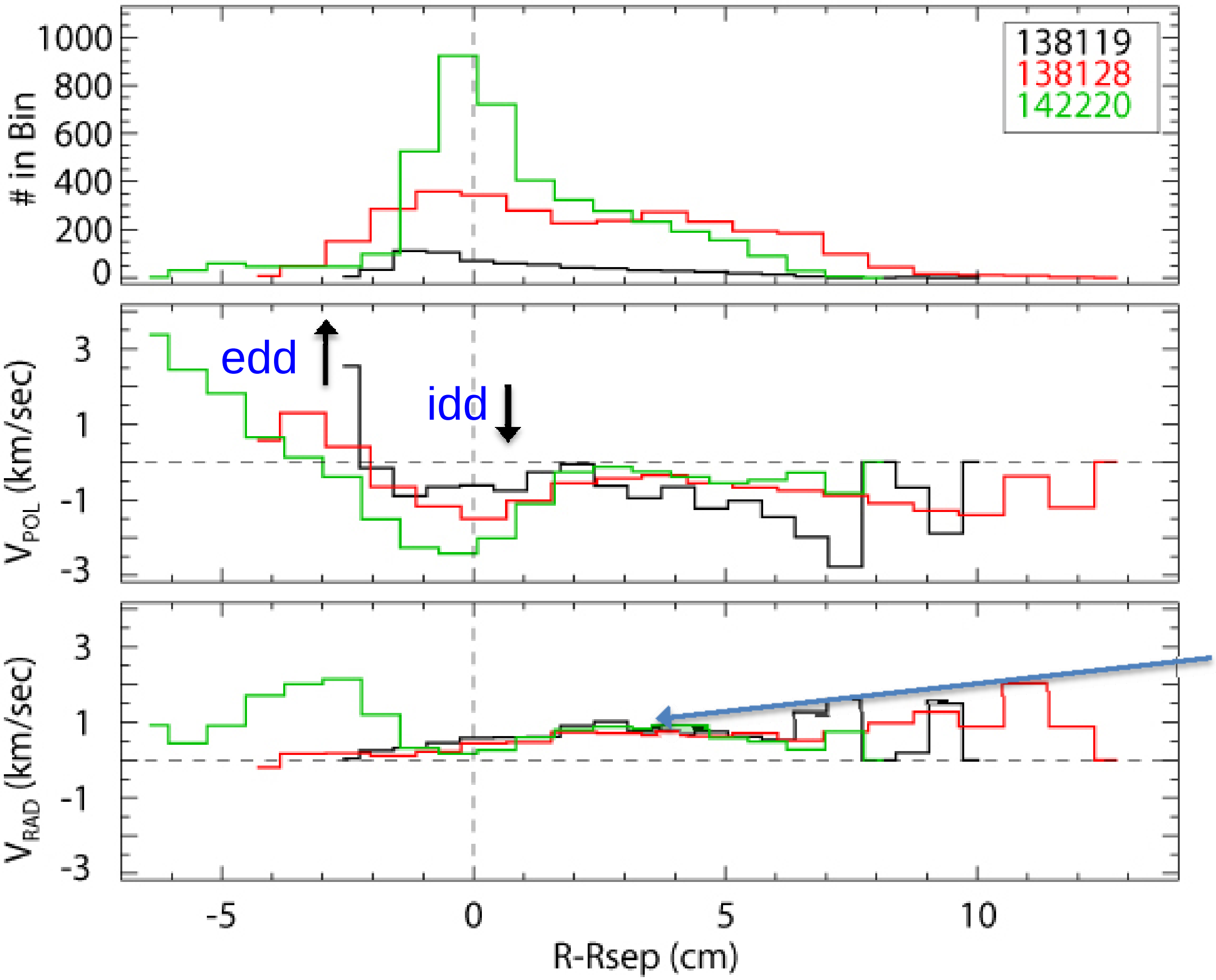


- Few blobs inside separatrix
- Tilt of ellipses seems almost random
- Very little poloidal flow in SOL

- More variety (randomness) in poloidal flow in SOL
- Far outside of separatrix, almost no radial flow (along field line)

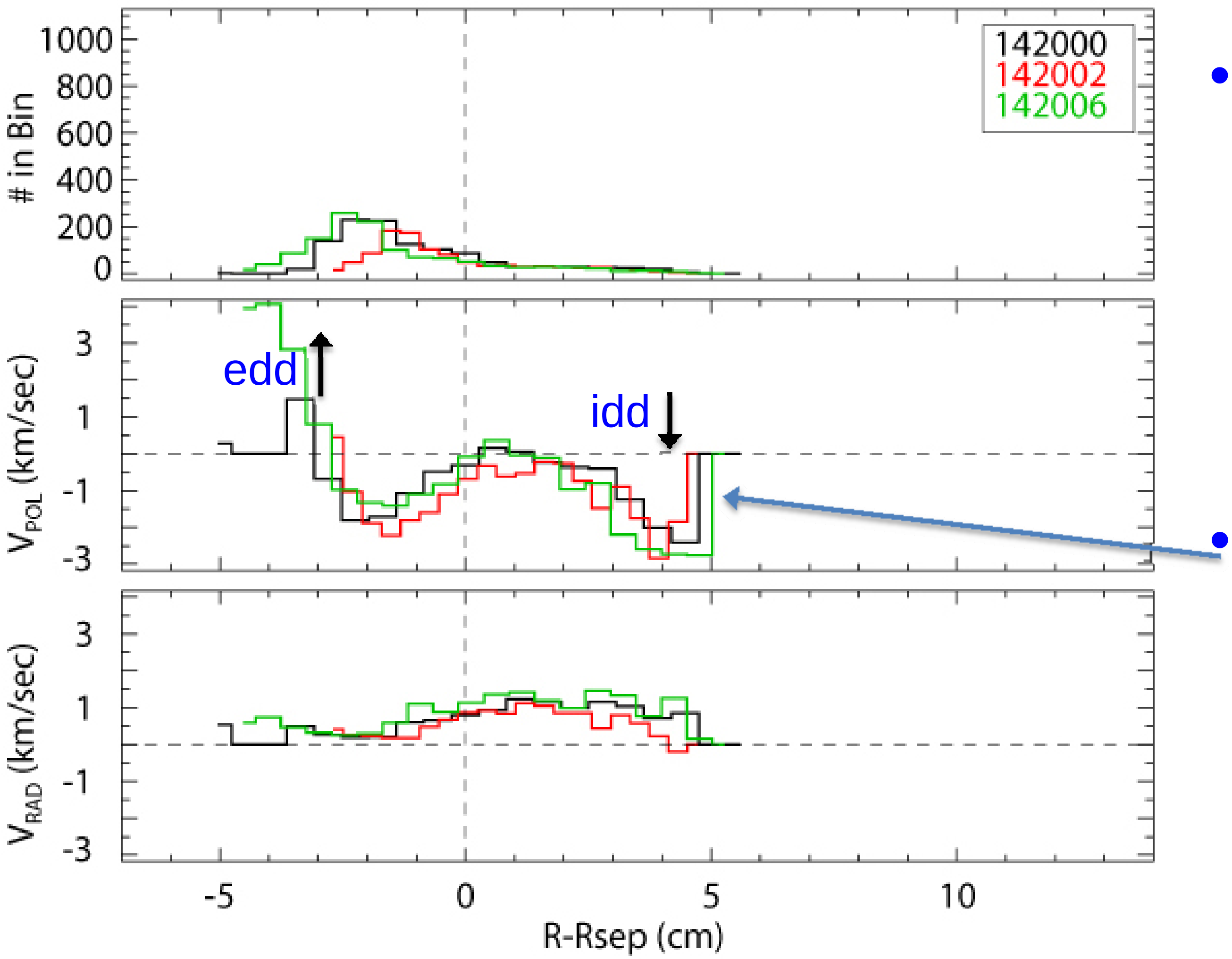
- Although some outward radial flow in SOL, there is almost equal poloidal flow

Blob Velocity Averages in NB-only shots



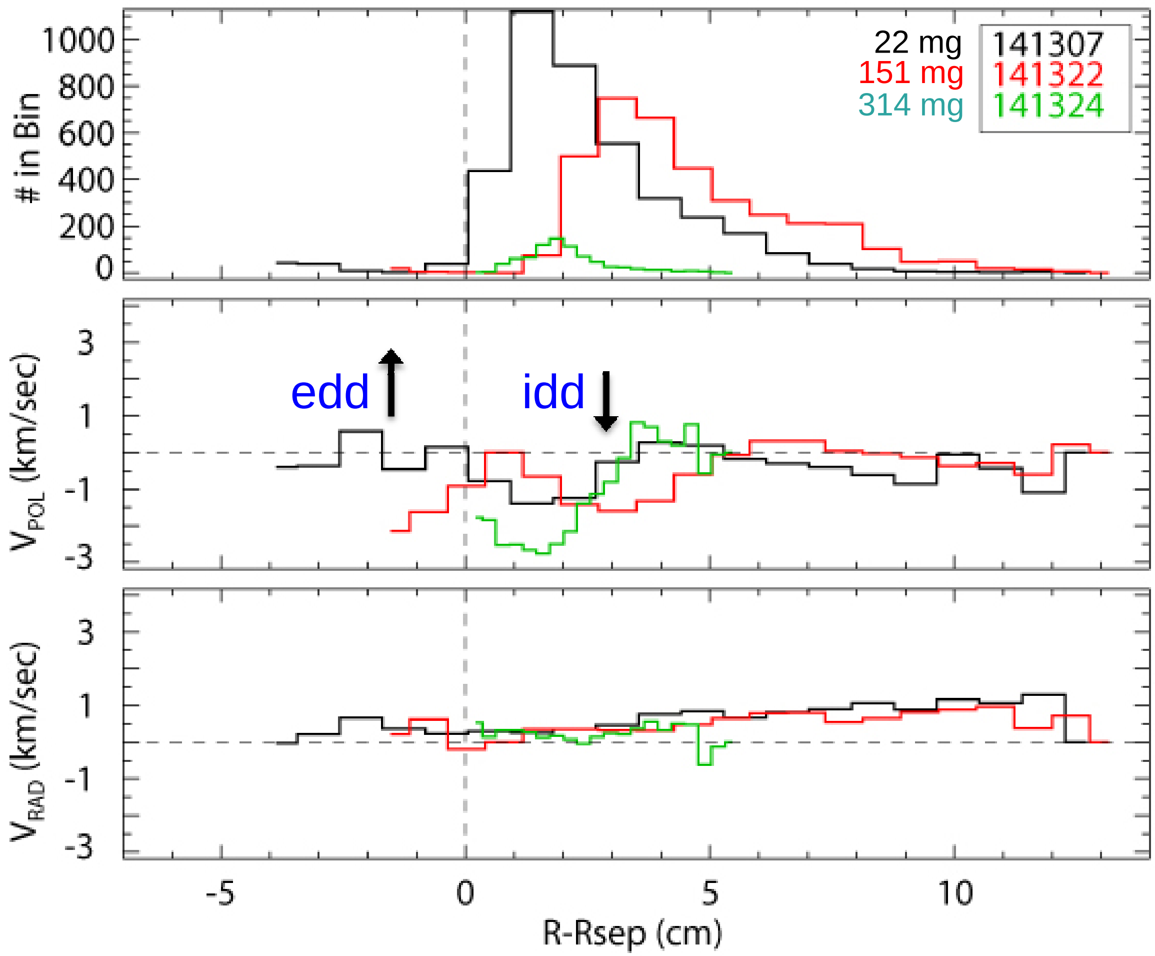
- Substantial differences between these shots, and the following RF shots, *even though all 6 shots are very similar in major parameters*
- Dominantly outward flow (consistent with blob theory)

Blob Velocity Averages in RF shots



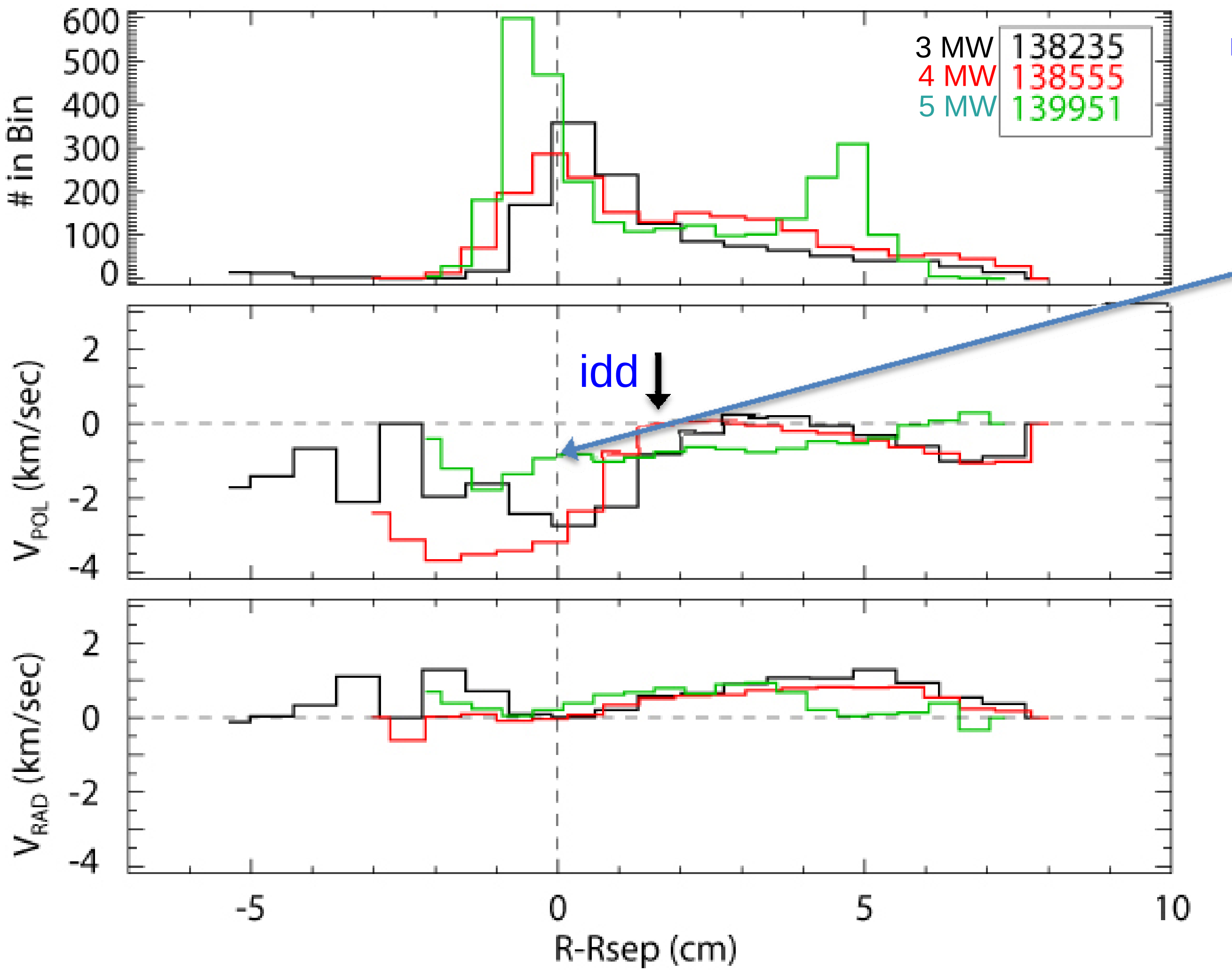
- The velocity profiles of these shots are very similar, as are the major shot parameters
- Radial electric fields induced by RF antenna like C-MOD?

Blob Velocity Averages in Li Scan



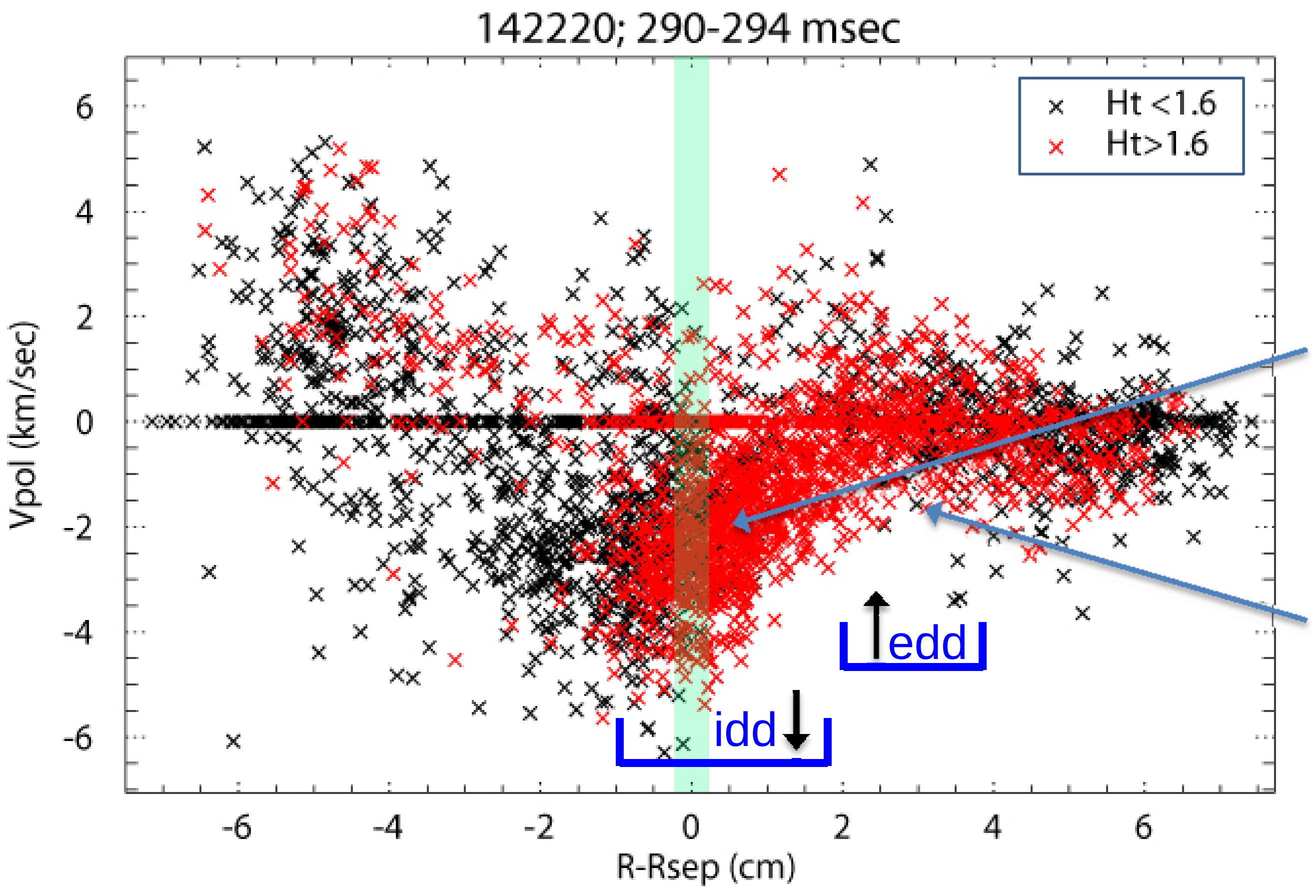
- Increasing Lithium deposition (22, 151, 314 mg.) reduces the number of blobs and correlates with changes in the velocity profiles

Blob Velocity Averages in NB Power Scan



- 5 MW shot (in green) does not have as much shear.

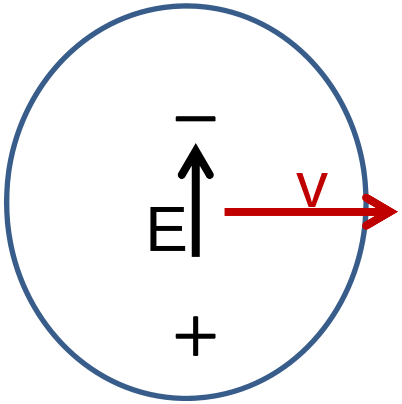
Poloidal velocity vs. distance from separatrix



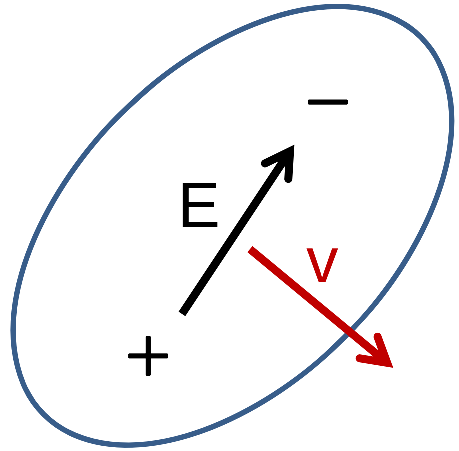
- A wide spread in poloidal velocity, even during a small time window in the same shot.
- Downward flow >-1 cm evidence of shear in this shot.
- Shear reverses between 2 & 4 cm.
- Larger blobs (red) more likely to be ejected through separatrix?

Blob motion is controlled by polarization charges

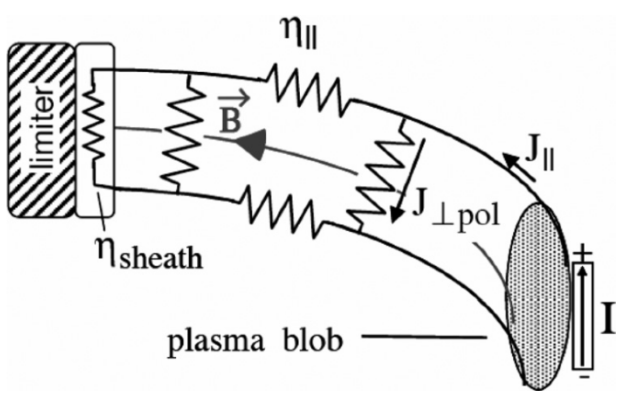
J.R. Myra, et al, 24th IAEA Fusion Energy Conference, San Diego (2012)



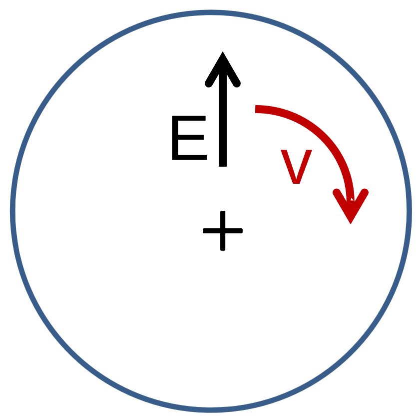
∇B and κ forces charge-polarize the blob $\Rightarrow$ outward convection



Background flows rotate and shear, converting radial motion to poloidal



Current flows neutralize charges; asymmetrically in SOL

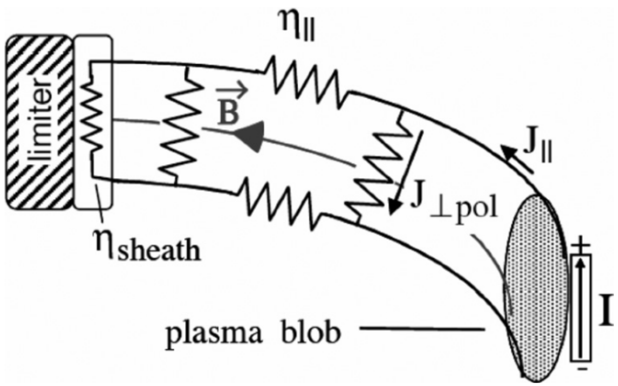


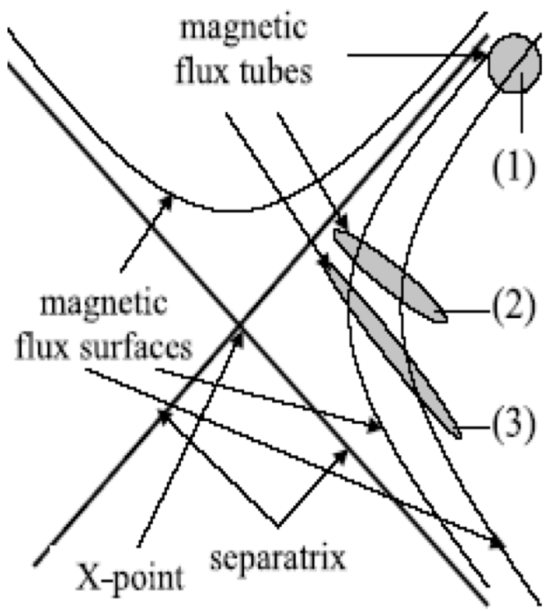
Additional monopole charge component $\Rightarrow$ rotation of dipole

Related Refs.: Diamond and Kim, PF 1991; Terry, RMP 2000; Furno, PRL 2011; Bisai, PoP 2012; Myra PoP 2004; Manz TTF 2012, Horton RMP 1999

From J.R. Myra, Lodestar

X-points short parallel currents





- For low collisionality plasmas, especially without X-points, $J_{||}$ flows *along* the fields lines from the + and – charged regions to the plate where the circuit is completed.
- For higher collisionality plasmas, or when X-points are present, $J_{||}$ can easily flow *across* field lines, shorting out the + and – $J_{||}$.
- Current flows easily across thin highly sheared elliptical fans in the X-point region

Krasheninnikov, Ryutov, and Yu, *J. Plasma Fusion Res.* 2004

Simulation model

D. A. Russell, et al, Phys. Plasmas 16, 122304 (2009)

Scrape-Off-Layer Turbulence (SOLT) code

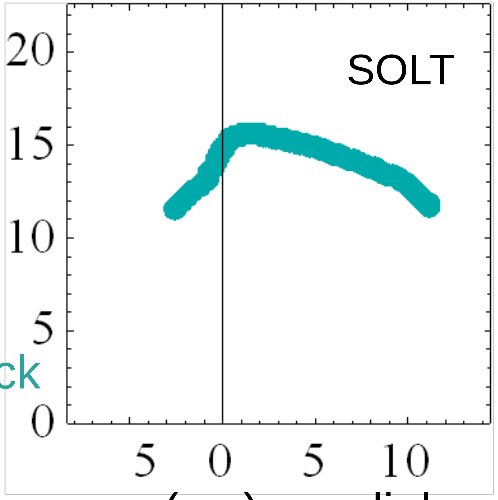
- 2D fluid turbulence code: model SOL in outer midplane
  - classical parallel + turbulent cross-field transport
- Evolves n_e, T_e, Φ with parallel closure relations
  - sheath connected, with flux limits, plus collisional regimes
- Strongly nonlinear: $\delta n/n \sim 1 \Rightarrow$ blobs
- Model supports drift waves, curvature-driven interchange modes, sheath instabilities

- Here:
  - Seeded blob simulations (initial value)
  - Quasi-steady turbulence simulations

From J.R. Myra, Lodestar

Trajectory for base case NSTX seeded blob

- experimental blob-tracking database ⇒ mean blob scale size, amplitude, birth location for each blob
- shot diagnostics ⇒ background plasma profiles, SOL connection lengths, machine parameters (R, B)
- In SOLT, initialize a typical blob on the background profiles and follow its trajectory



- Blob flows up in the edge (e-direction) and down in the SOL (i-direction)
- Track reversal near separatrix (like data)

From J.R. Myra, Lodestar

Summary of Connections to Theory

- Coherent structures (blobs) can be observed under essentially all conditions [1].
- More outward blob motion radially than inward.
- Changes in the poloidal motion of blobs are observed, which are related to sheared flows.
- Evidence of elliptically sheared structures, which are related to Reynolds stress, are consistent with blob trapping in shear layers (little radial motion) and intermittent ejection.
- Possible (?) differences in edge conditions in NBI and RF shots (could be ICRF edge interactions).

[1] Myra, J. R., *et al.*, *Phys. Plasmas* **18** (2011) 012305.

Summary and Conclusions

- Plasma edge turbulence is prevalent, complex, and varies with conditions.
- Visualization tools help track blobs and create meaningful statistics of size, orientation, and motion, for comparison with theory.
- Characteristics of some blobs in some plasmas fit the behavior predicted by simplified theory [5,6].
- Experimental conditions affect blob characteristics, such as Lithium increasing confinement or Neutral Beams inducing poloidal flows.

[5] J.R. Myra, et al, 24th IAEA Fusion Energy Conference, San Diego (2012)
[6] D. A. Russell, et al, Phys. Plasmas 16, 122304 (2009)