NSTX-U

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Fast 2-D Camera Control, Data Acquisition, and Database Techniques for Edge Studies on NSTX

W.M. Davis[1], S.J. Zweben[1], R.J. Maqueda[1,2], A.L. Roquemore[1], F. Scotti[1], M. K. Ko[3]

[1]Princeton Plasma Physics Laboratory, Princeton, NJ 08540

[2] Lodestar Research Corporation, Boulder, CO 80301

[3] Princeton H.S., Princeton, NJ 08540

PPPL

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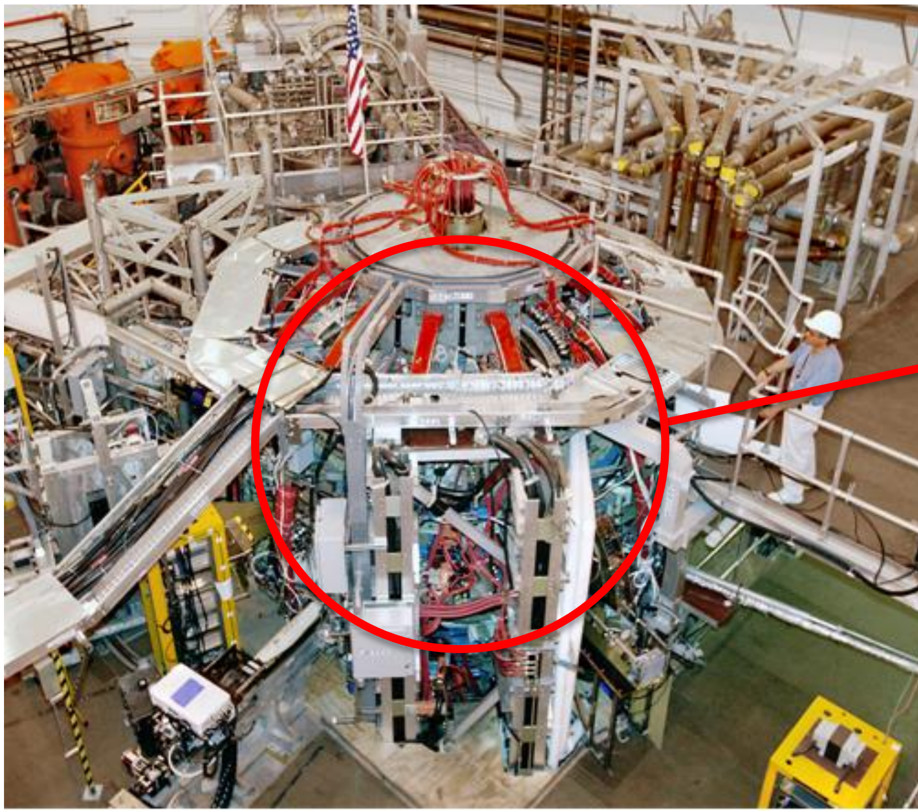
Poster P3-01 Abstract Number ????

Abstract

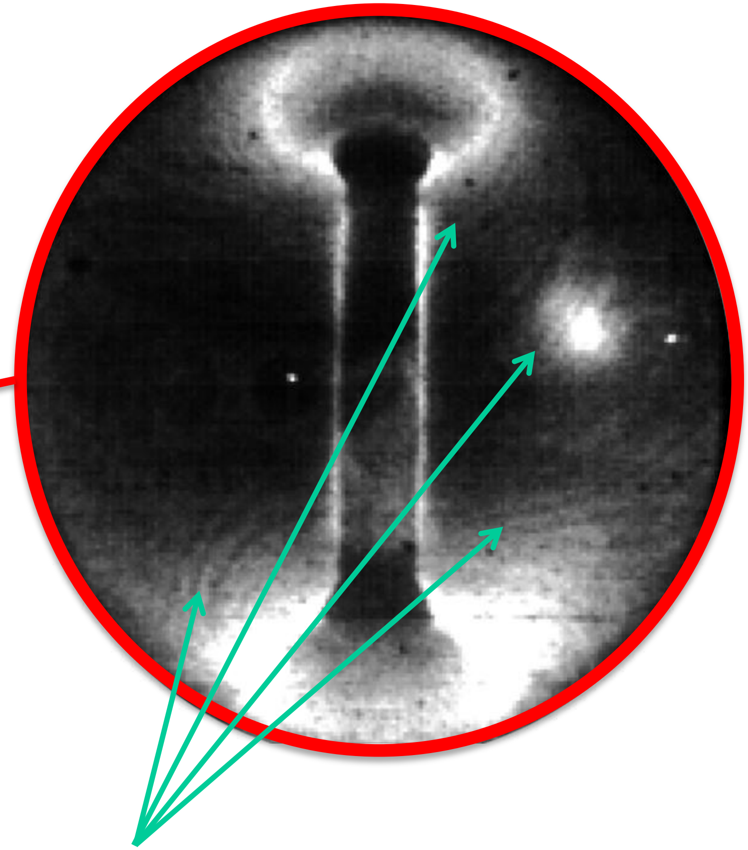
Fast 2-D cameras examine a variety of important aspects of the plasma edge and vessel components on the National Spherical Torus Experiment (NSTX). Timely access to several Gigabytes of data from each camera can itself be a challenge, but analysing all this data using manual frame-by-frame examination is simply not practical. This paper describes image analysis, database techniques, and visualization methods used to organize the fast camera data and to facilitate physics insights from it. An example is presented of analysing and characterizing the size, movement and dynamics of coherent plasma structures (typically referred to as "blobs") near the plasma edge. Software tools that generate statistics of blob speed, shape, amplitude, size, and orientation are described. The characteristics of emitted blobs affect plasma confinement and heat loads on plasma facing components, and are thus of particular interest to future machines like ITER.

This work was supported by DOE Contract DE-AC02-09-CH11466.

National Spherical Torus Experiment (NSTX)



Fusion device at the Princeton Plasma Physics Laboratory

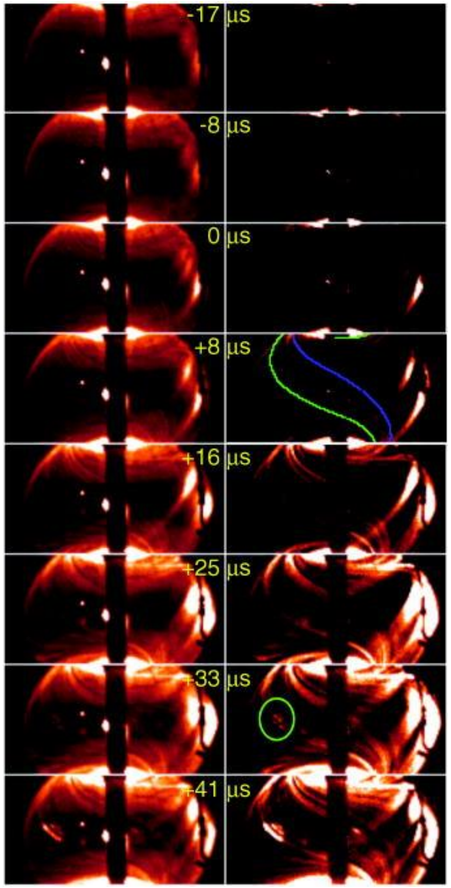


Blob filaments in an NSTX plasma

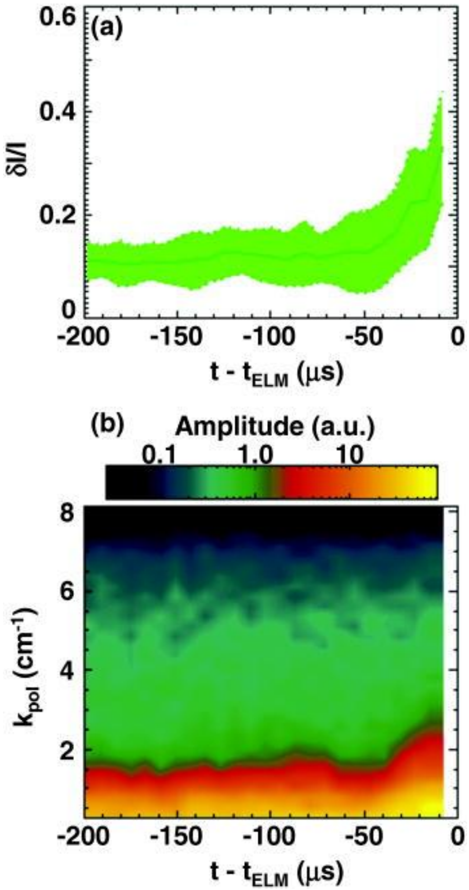
Fast 2-D Cameras on NSTX can record:

- Global plasma shape and position
- Edge turbulence in gas puffs
- The propagation of ELMs and MARFEs
- Heat loading on plasma facing components
- Dust tracking
- Fast Lost Ion pitch angle and gyroradius

Looking for ELM Precursors[1]



Sequence of wide-angle-view images showing an increasing number of primary filaments during the same type III ELM as in Fig. . These false color images were obtained without interference filtering. Raw frames are shown in the left column and contrast enhanced on the right

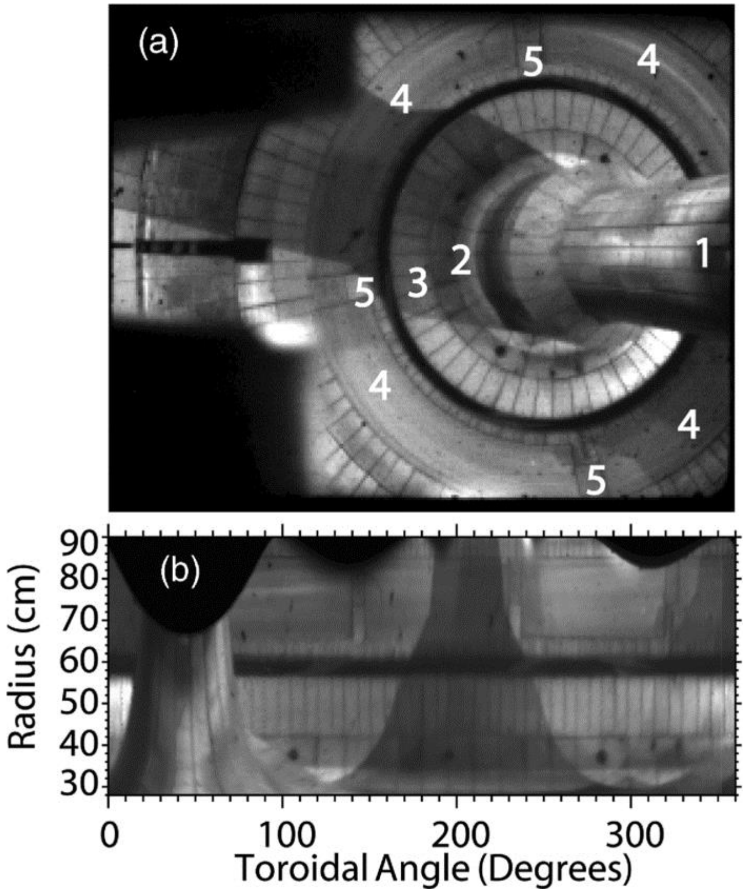


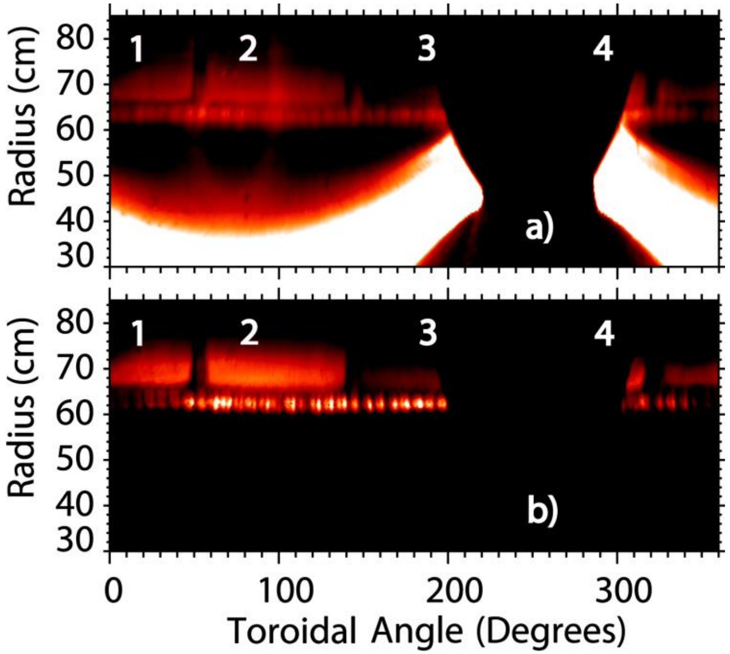
Characteristics of the time evolution of the edge leading to type III ELMs: (a) relative fluctuation level (rms) and (b) poloidal amplitude spectrum. The ELM perturbation is seen to locally start 40–50 μs before the ELM crash occurring at t_{ELM}.

[1] R.J. Maqueda, *et al*., “Primary edge localized mode filament structure in NSTX” Phys. Plasmas **16**, 056117 (2009)

Full Toroidal Imaging of Strike Points[2]

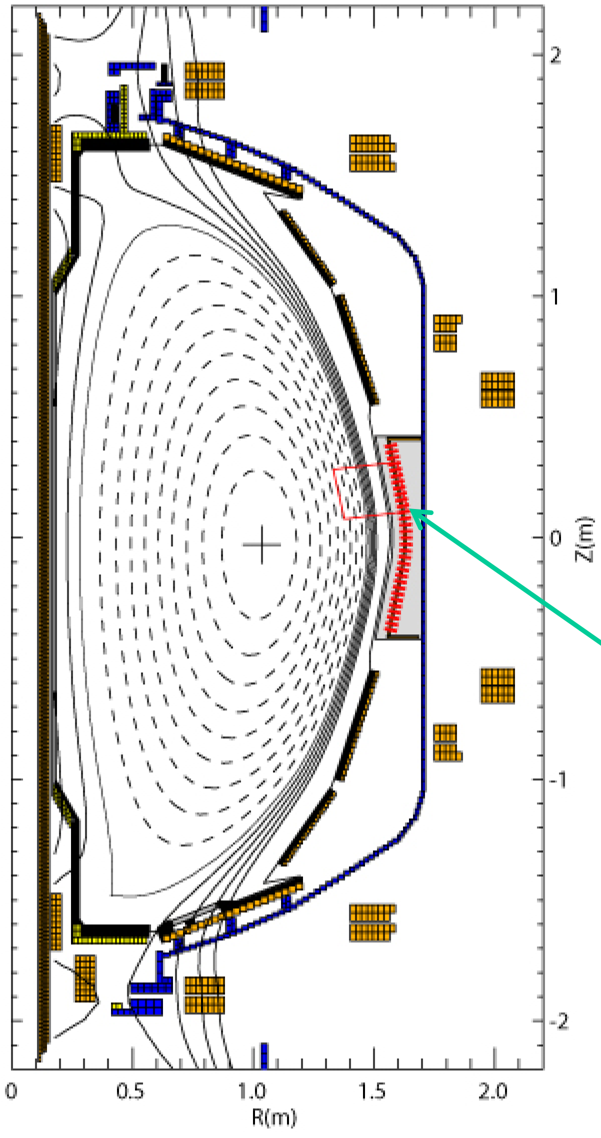
Custom polar remapping procedure enabled the easier visualization and quantitative analysis of non-axisymmetric plasma material interaction (e.g., strike point splitting due to application of 3D fields and effects of toroidally asymmetric plasma facing components).

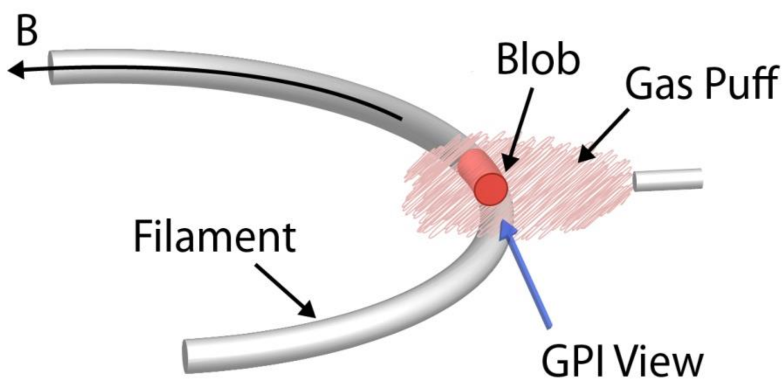




[2] Scotti, F., *et al.*, "Full toroidal imaging of non-axisymmetric plasma material interaction in the NSTX divertor" *Rev. Sci. Instrum.* **83** (2012).

Gas Puff Imaging Diagnostic on NSTX

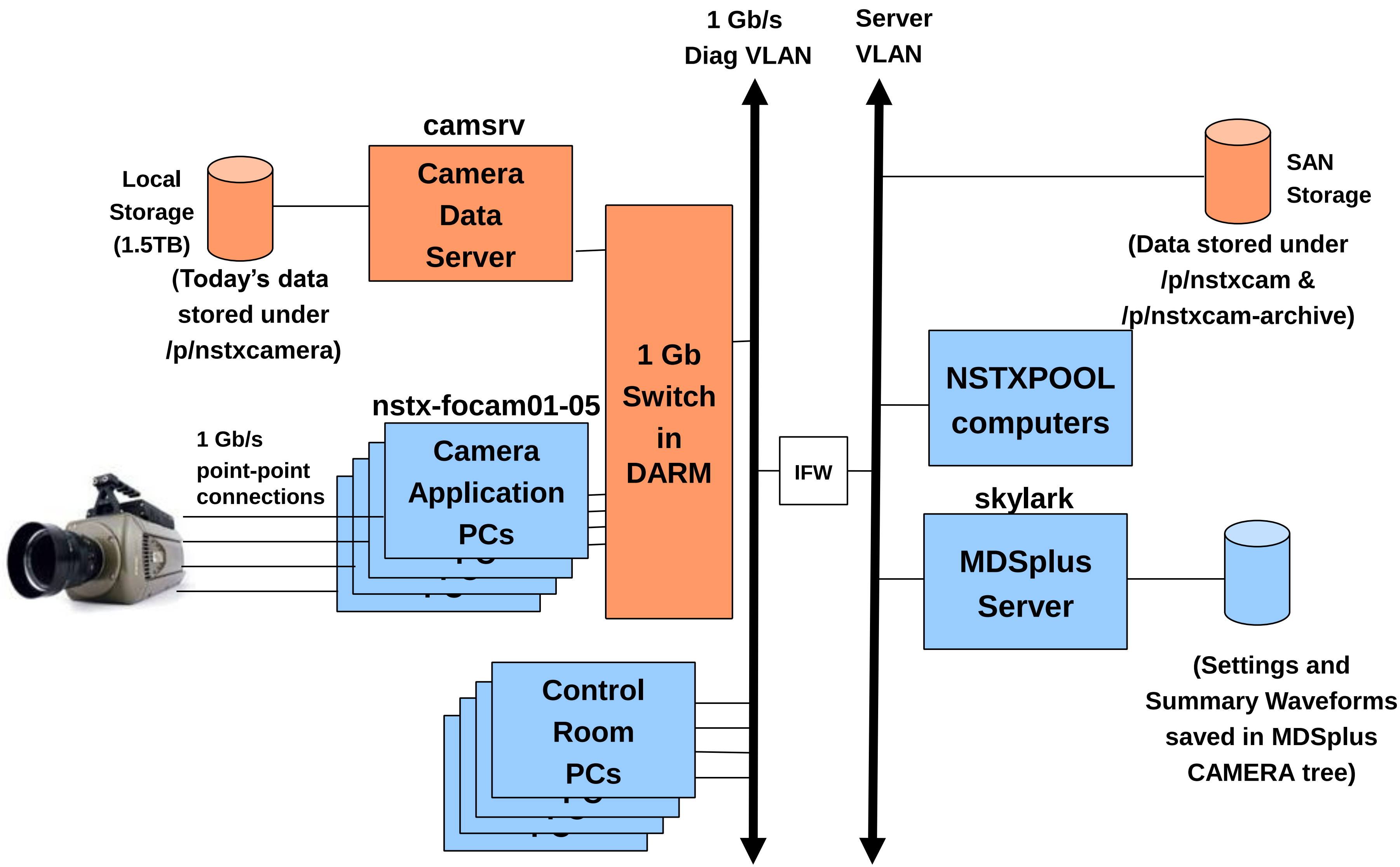




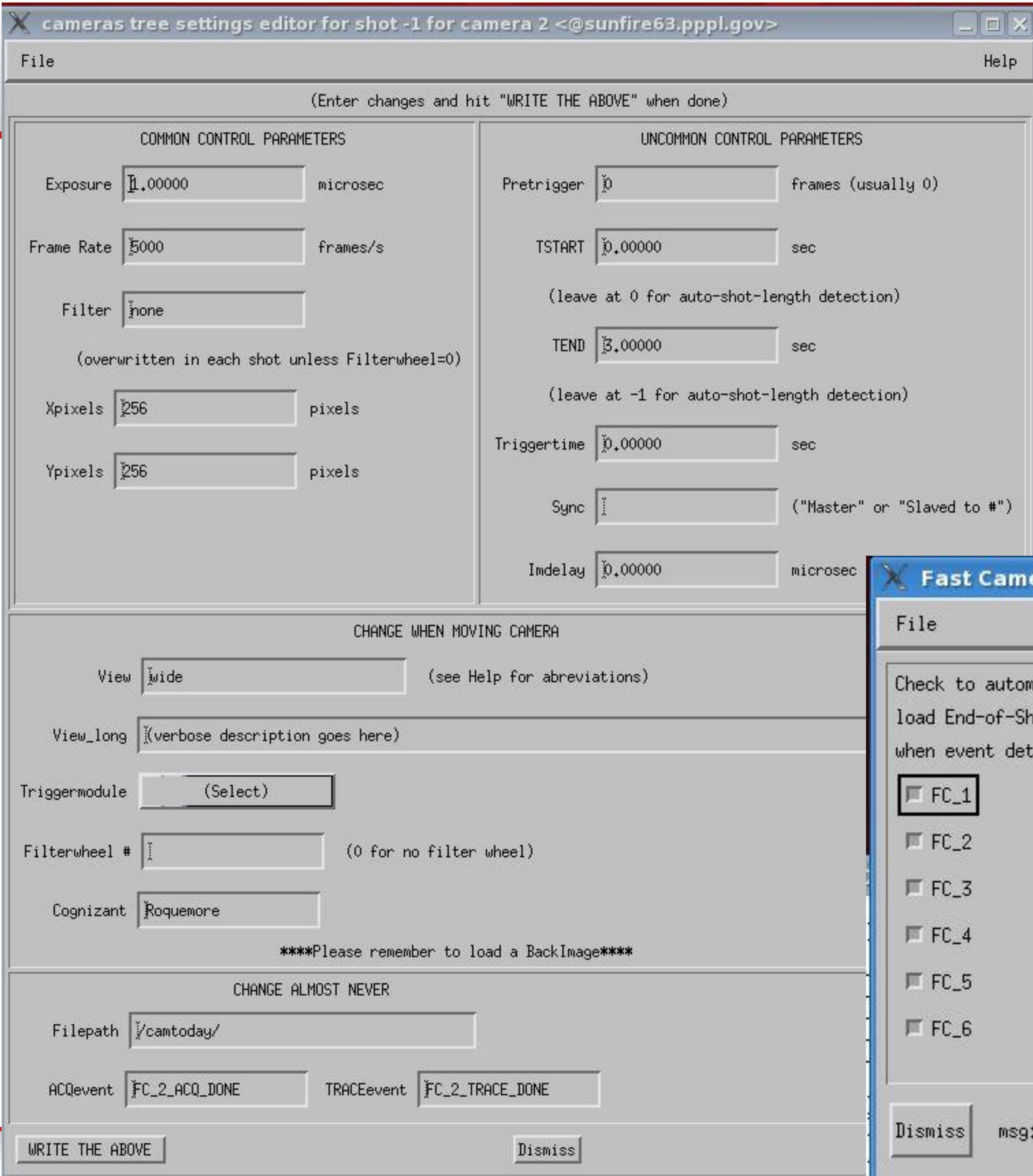
GPI camera parameters

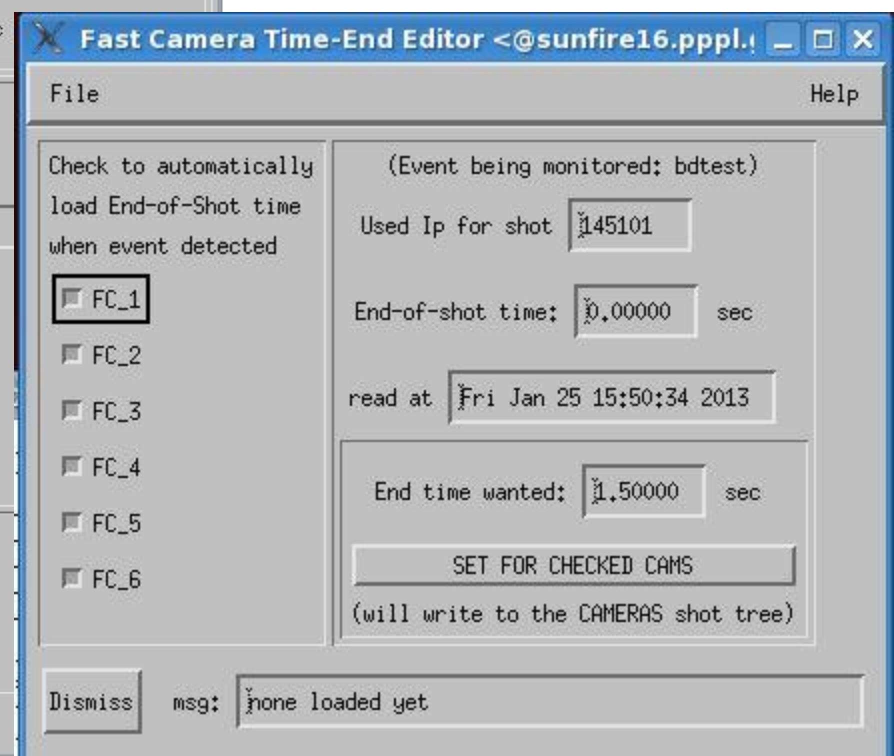
- Phantom v710 camera
- Viewing HeI emission (587.6 nm)
- Viewing area 25 cm x 30 cm approximately aligned with flux surfaces.
- 64 x 80 pixels in each frame
- 390,800 frames/sec
- exposure time 2.1 μsec/frame

FY10 Fast Camera Network Configuration



Editors for camera setup parameters





Camera Data Surveying Software

Since it is impractical to go through 1000's of frames per shot, tools are needed for data browsing:

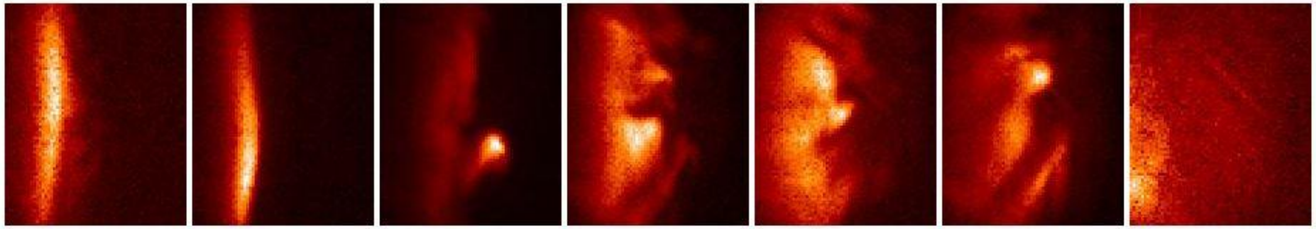
GPIthumbnails.pro: Create several thumbnails and summary waveforms for a series of shots, for easy browsing.

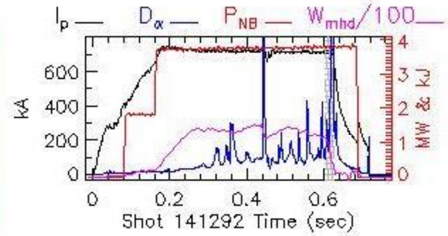
Fcthumbnails.html: Create 112 thumbnails from a time range of camera data for a shot.

BigSheets.html: Scroll through a series of shots with 112 thumbnails each over a time range (like for the good GPI data).

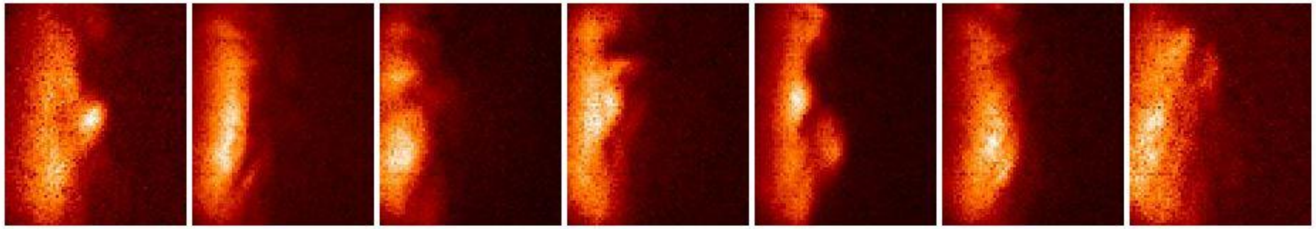
(IDL, Perl and HTML codes available from the author)

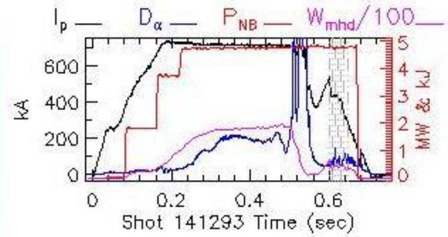
Sample from GPIthumbnails.pro



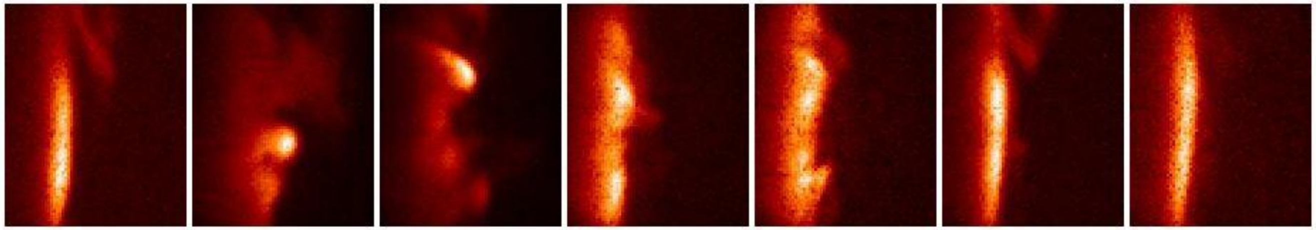


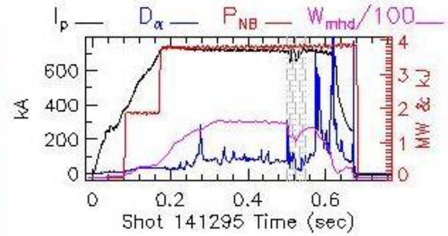
(thumbnails) Shot 141293, at 600, 608, 615, 623, 631, 639, 647 ms:



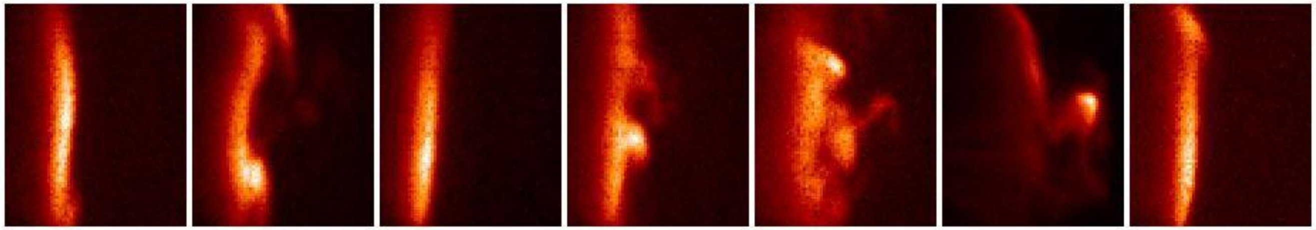


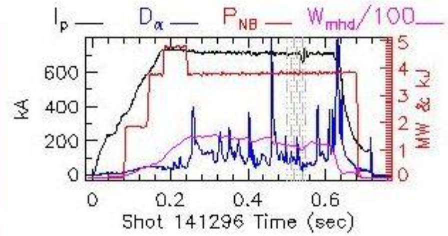
(thumbnails) Shot 141295, at 501, 508, 516, 524, 532, 540, 547 ms:

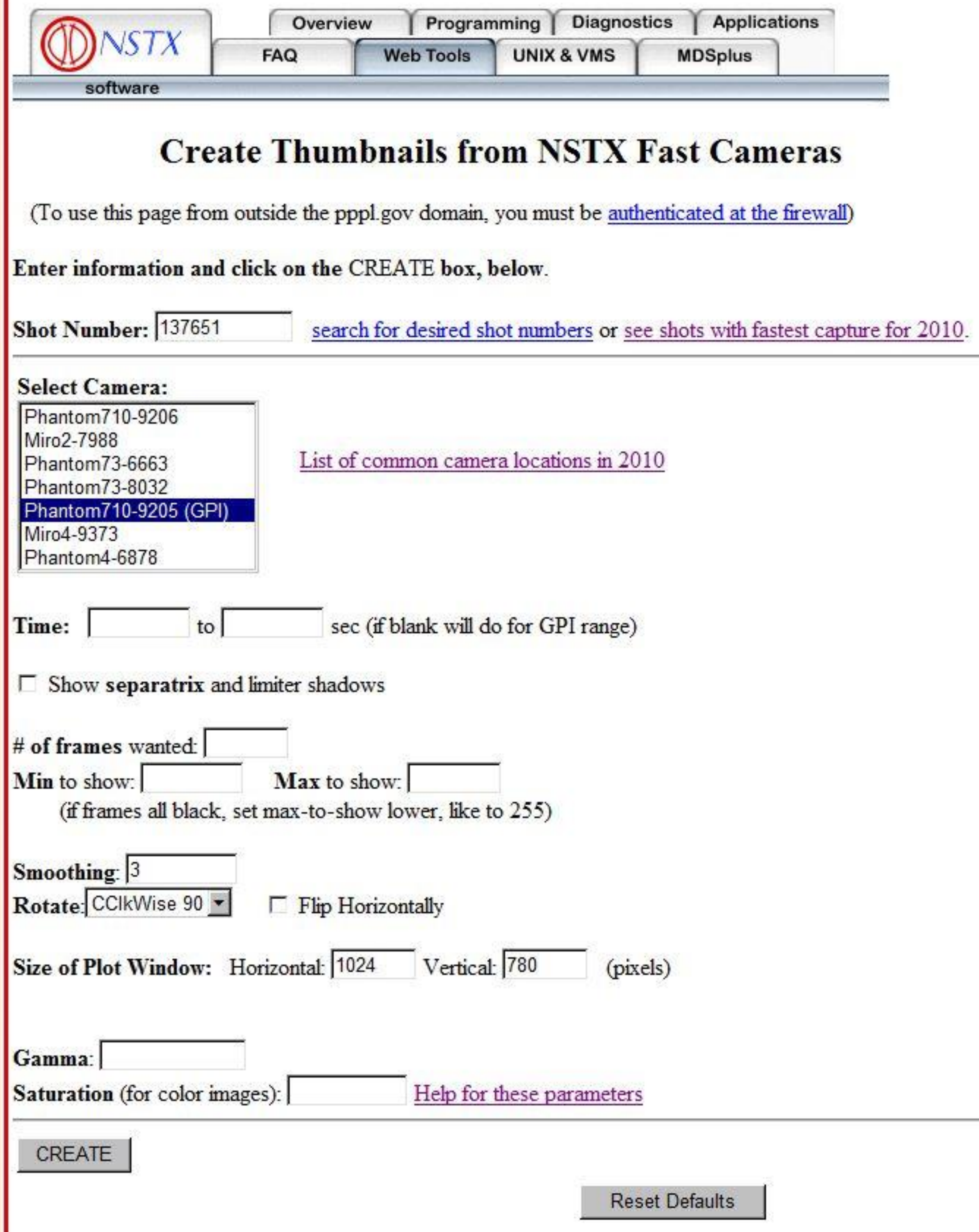




(thumbnails) Shot 141296, at 502, 510, 518, 526, 534, 542, 550 ms:







NSTX software

Overview | Programming | Diagnostics | Applications
FAQ | Web Tools | UNIX & VMS | MDSplus

Create Thumbnails from NSTX Fast Cameras

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

Enter information and click on the CREATE **box, below.**

Shot Number: 137651 search for desired shot numbers or see shots with fastest capture for 2010.

Select Camera:

- Phantom710-9206
- Miro2-7988
- Phantom73-6663
- Phantom73-8032
- Phantom710-9205 (GPI)
- Miro4-9373
- Phantom4-6878

List of common camera locations in 2010

Time: ____ to ____ sec (if blank will do for GPI range)

☐ Show **separatrix** and limiter shadows

# of frames wanted: ____
Min to show: ____ **Max** to show: ____
(if frames all black, set max-to-show lower, like to 255)

Smoothing: 3
Rotate: CClkWise 90 ☐ Flip Horizontally

Size of Plot Window: Horizontal: 1024 Vertical: 780 (pixels)

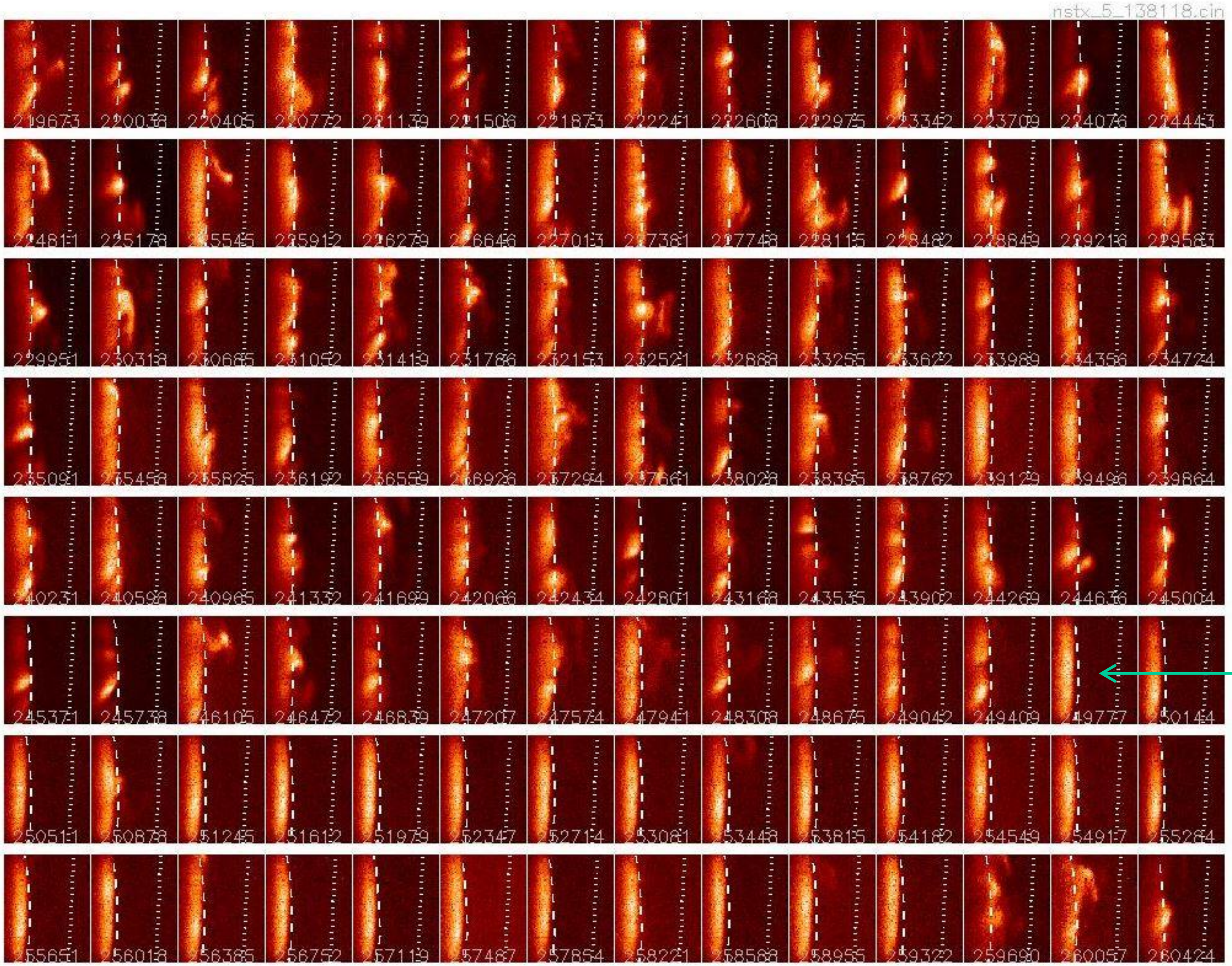
Gamma: ____
Saturation (for color images): ____ Help for these parameters

CREATE

Reset Defaults

Web Page for creating thumbnail summaries of fast camera data

Sample from FCthumbnails.html



Easy to spot the L-H transition, indicated by the suddenly stable edge

Motivation for Blob Tracking

- Radial motion of blob-filaments in the tokamak edge plasma can affect the width of the heat and particle scrape-off layer (SOL), and the heat load on plasma facing components.
- Blob movement can act as tracers for dynamics near the edge which can effect confinement, including sheared flow.
- Variations in blob movement with heating types and amounts of Lithium deposition contribute to understanding L-H transitions.

Blob Tracking Software Suite

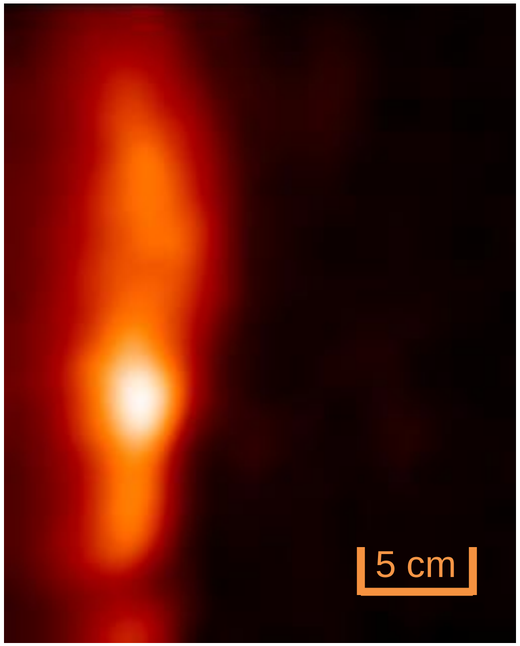
FCplayer: Interactive IDL program for enhancing images, setting blob criteria, and animating data from Phantom camera files with blobs identified.

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

DbAccess: From a database, plots all combinations of blob characteristics with specified constraints.

BlobTrails: From a database, plots blob tracks, with various constraints, and shows tilt, ellipticity, and the position relative to the separatrix.

Normalizing images adjusts for uneven gas puff illumination



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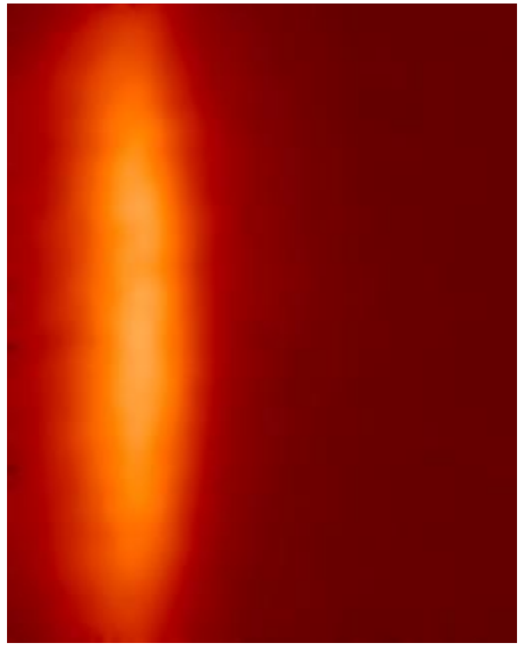

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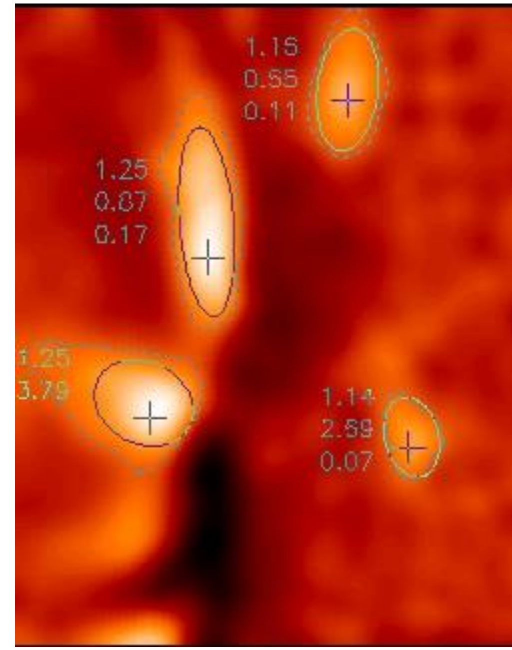


Smoothed Raw Image

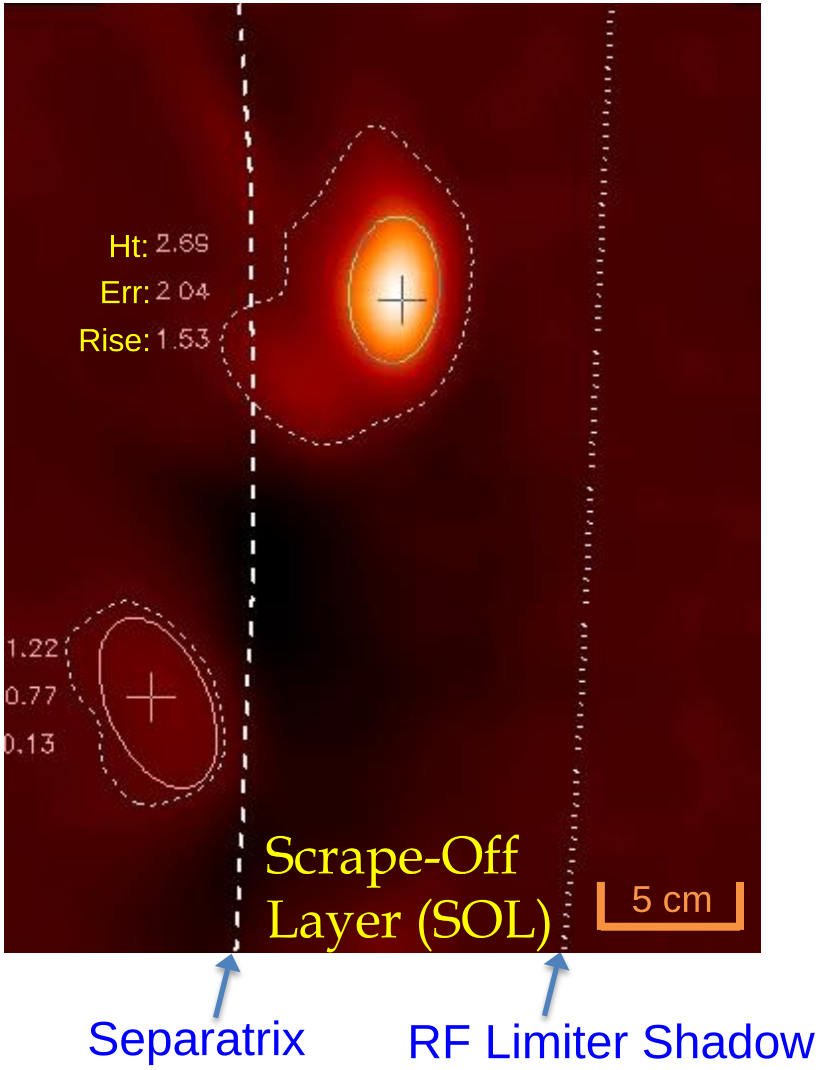
Exposure time:
2.1 µsec/frame

Smoothed Frame averaged over 1 msec

Resulting Normalized Image to which ellipses are fit

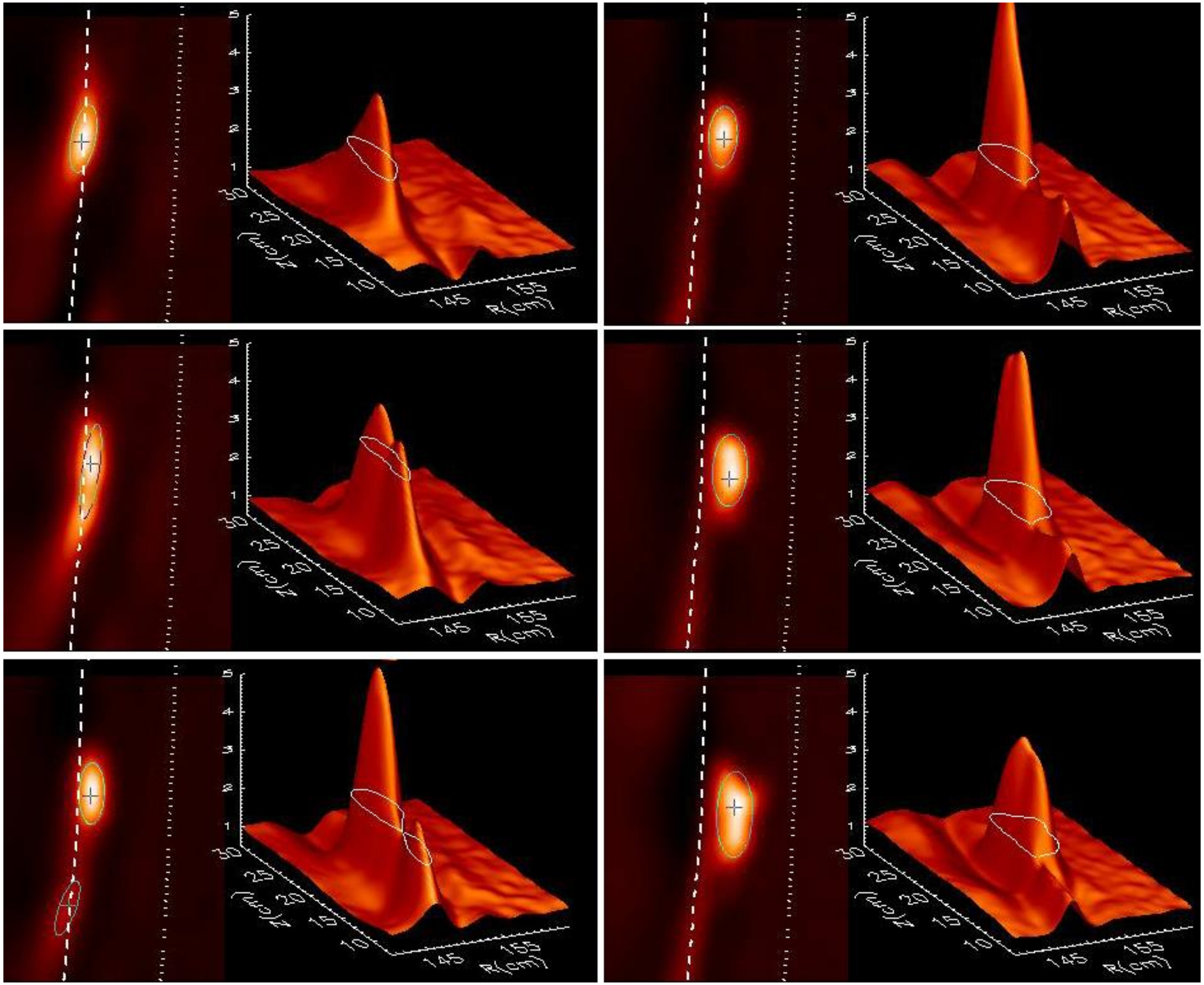
Ellipses are fit to mid-level contours

NSTX Shot 138120, 228 ms



- 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.

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



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

Historical information

- 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

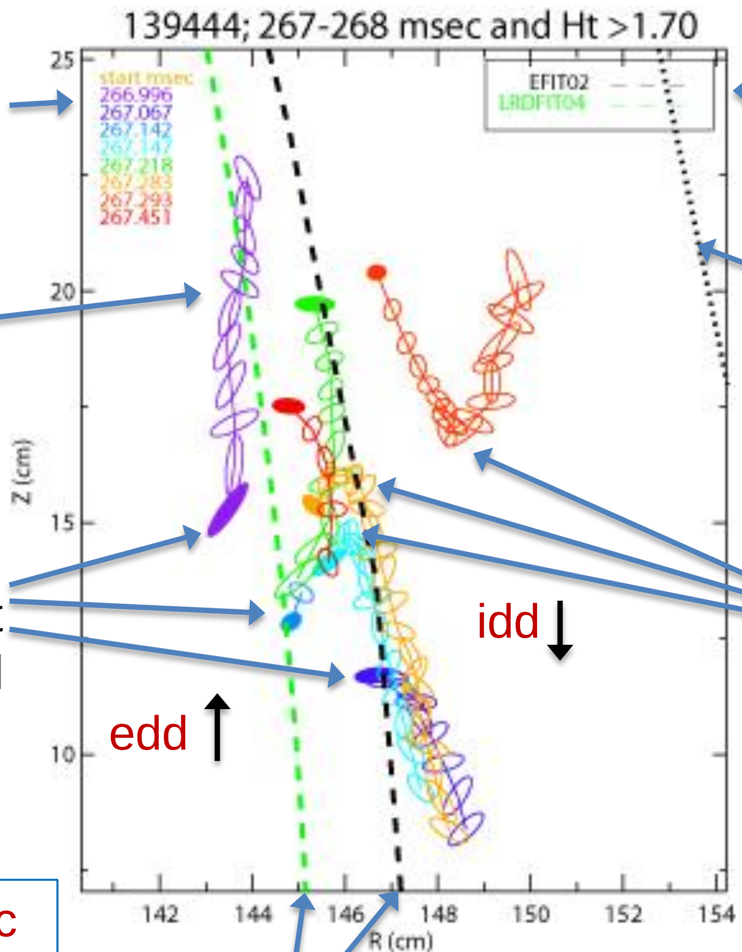
- Time of blob instance
- Radial velocity of blob
- Poloidal velocity of blob

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

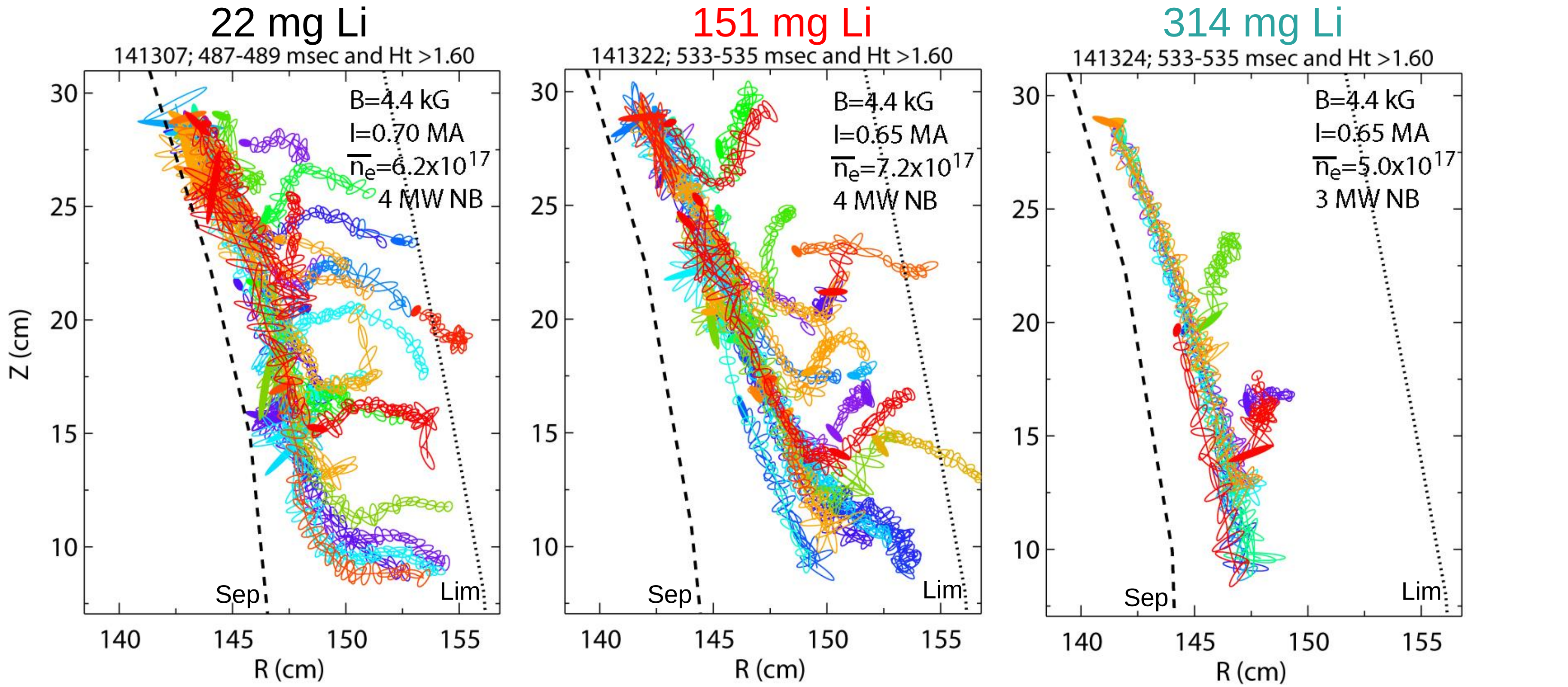
Limiter shadow

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 ∇B)

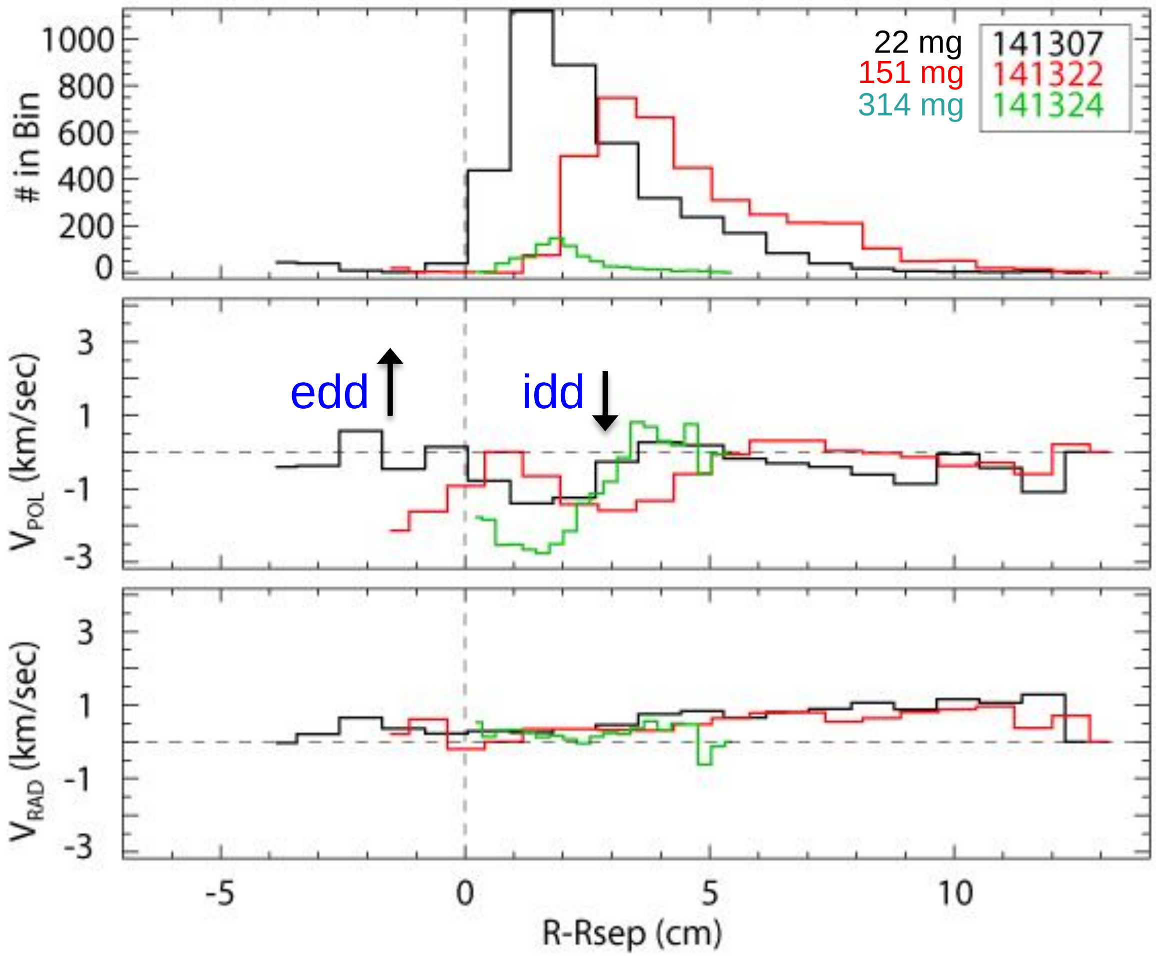
Blob Tracks during a Lithium Scan[3]



- 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).

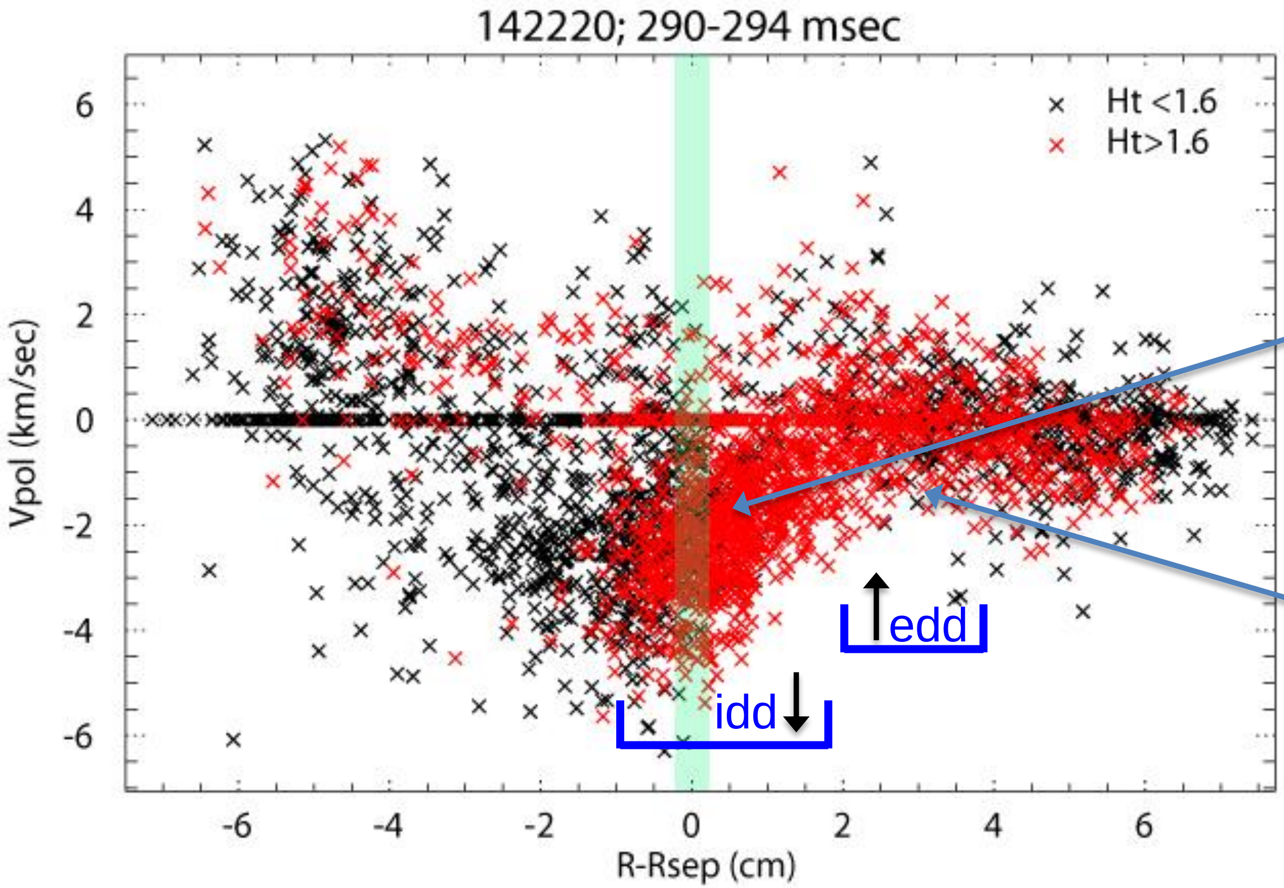
Blob Velocity Averages in Li Scan



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

edd – Electron diamagnetic drift direction
idd – Ion diamagnetic drift direction (ion ∇B)

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) are more likely to be ejected through the separatrix.

Summary and Conclusions

- Fast 2-D cameras can track plasma edge phenomena which are important in understanding energy confinement and interaction with plasma facing components.
- Plasma edge turbulence is prevalent, complex, dynamic, and varies with conditions, so software tools are needed.
- Visualization tools help track blobs and create meaningful statistics of size, orientation, and motion, for comparison with theory.
- Experimental conditions affect blob characteristics, such as Lithium increasing confinement or Neutral Beams inducing poloidal flows.

Backup Slides follow

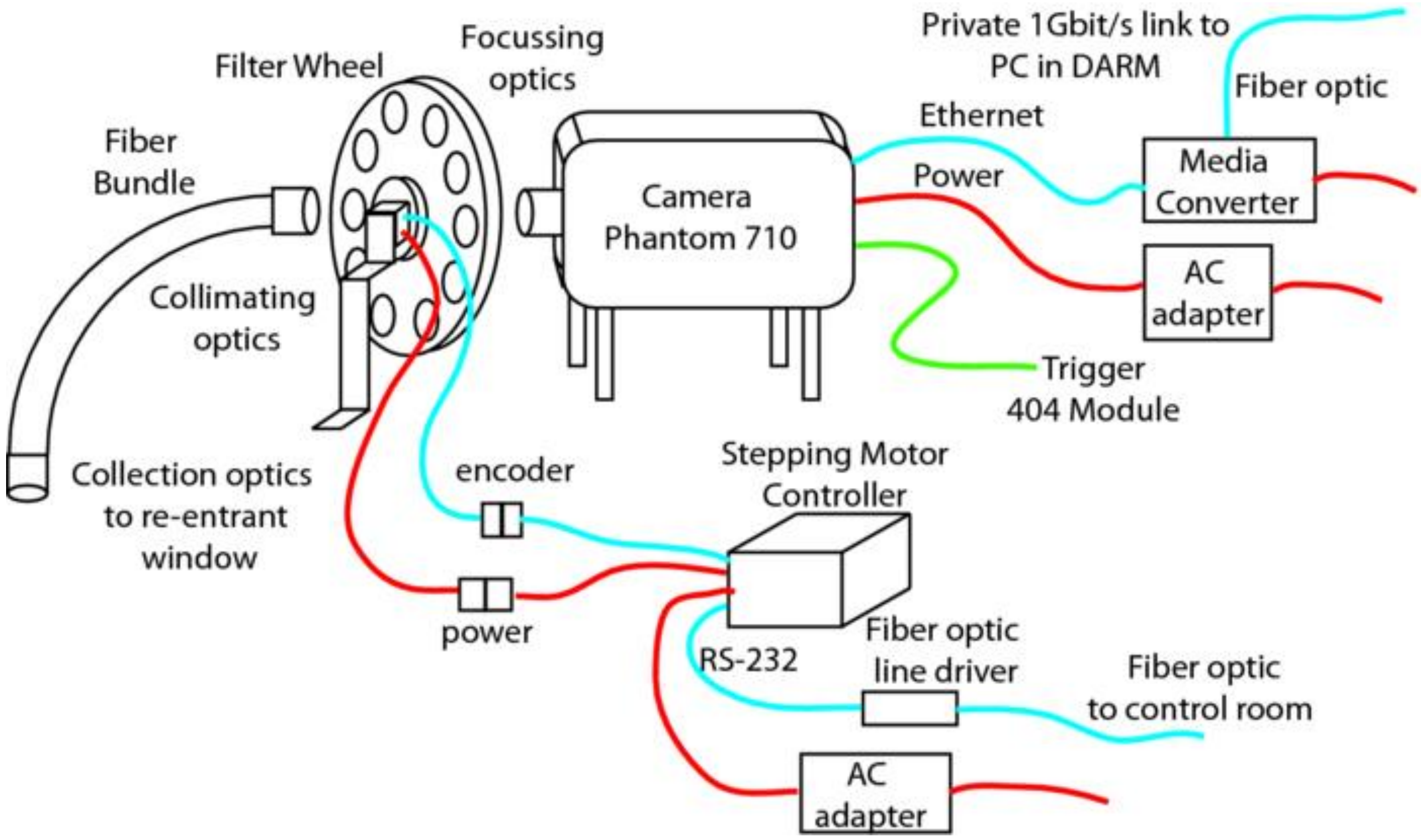
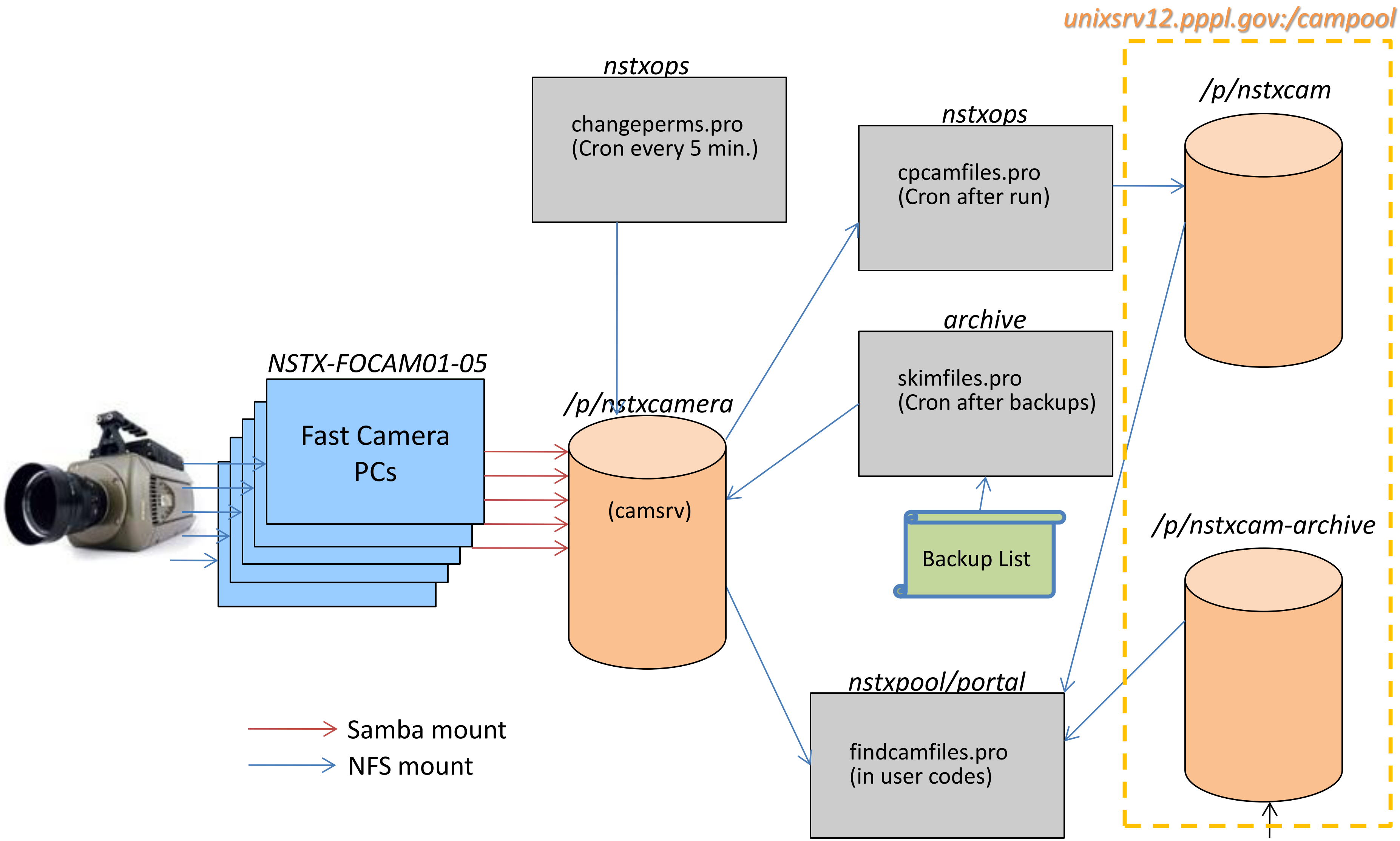


FIG. 2. Schematic of camera setup.

F. Scotti, Rev. Sci. Instrum. 83, 10E532 (2012)

Software to manage NSTX fast camera data acquisition and archiving



for top-level directories, see
http://w3.pppl.gov/~bdavis/swdoc/Fast_Camera_Dirs.txt

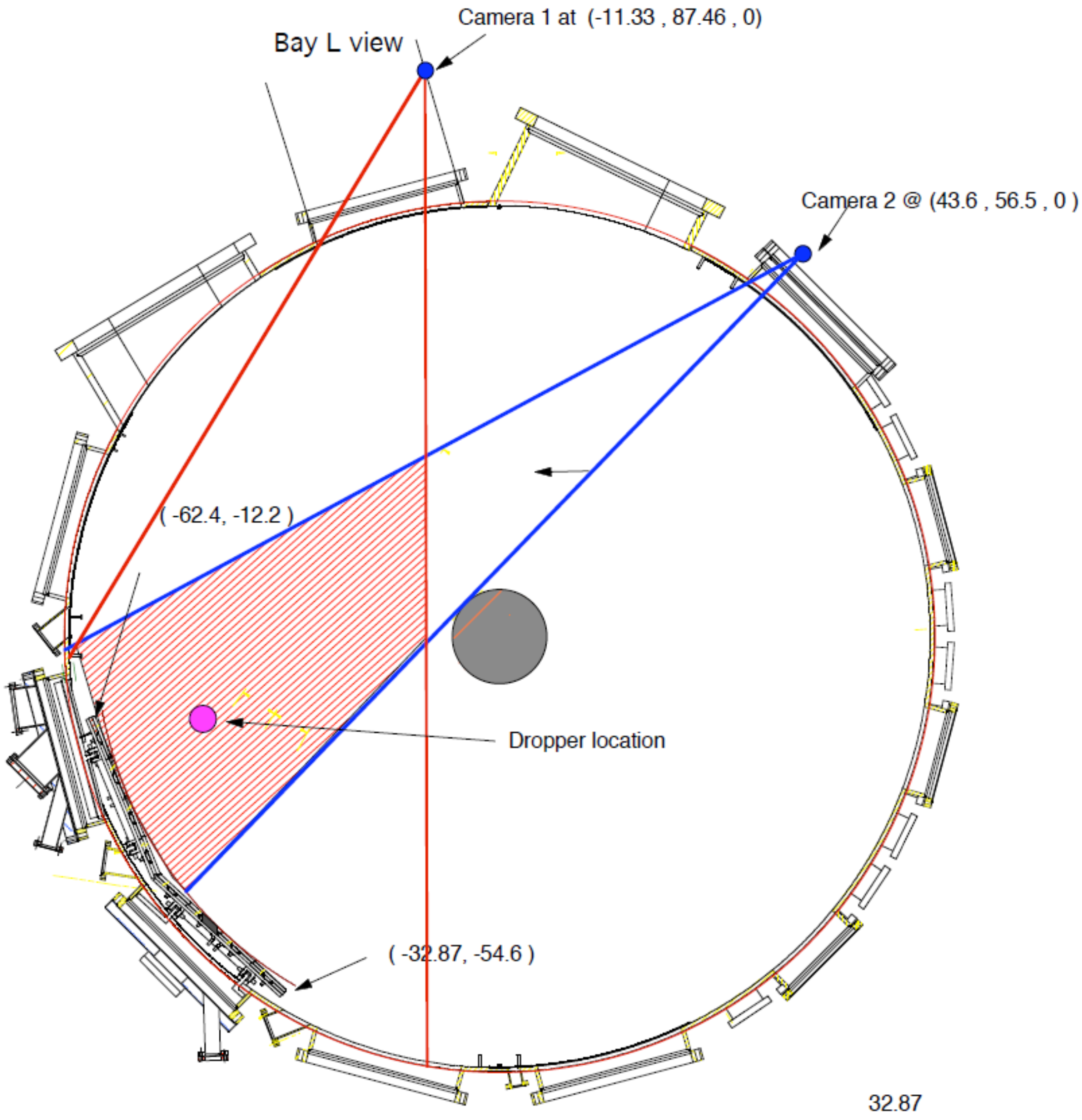
Last Edit: 29-Jul-2011 by Bill Davis

A global view of an NSTX plasma showing flux tubes

MDSplus Nodes for Fast 2-D Camera Data

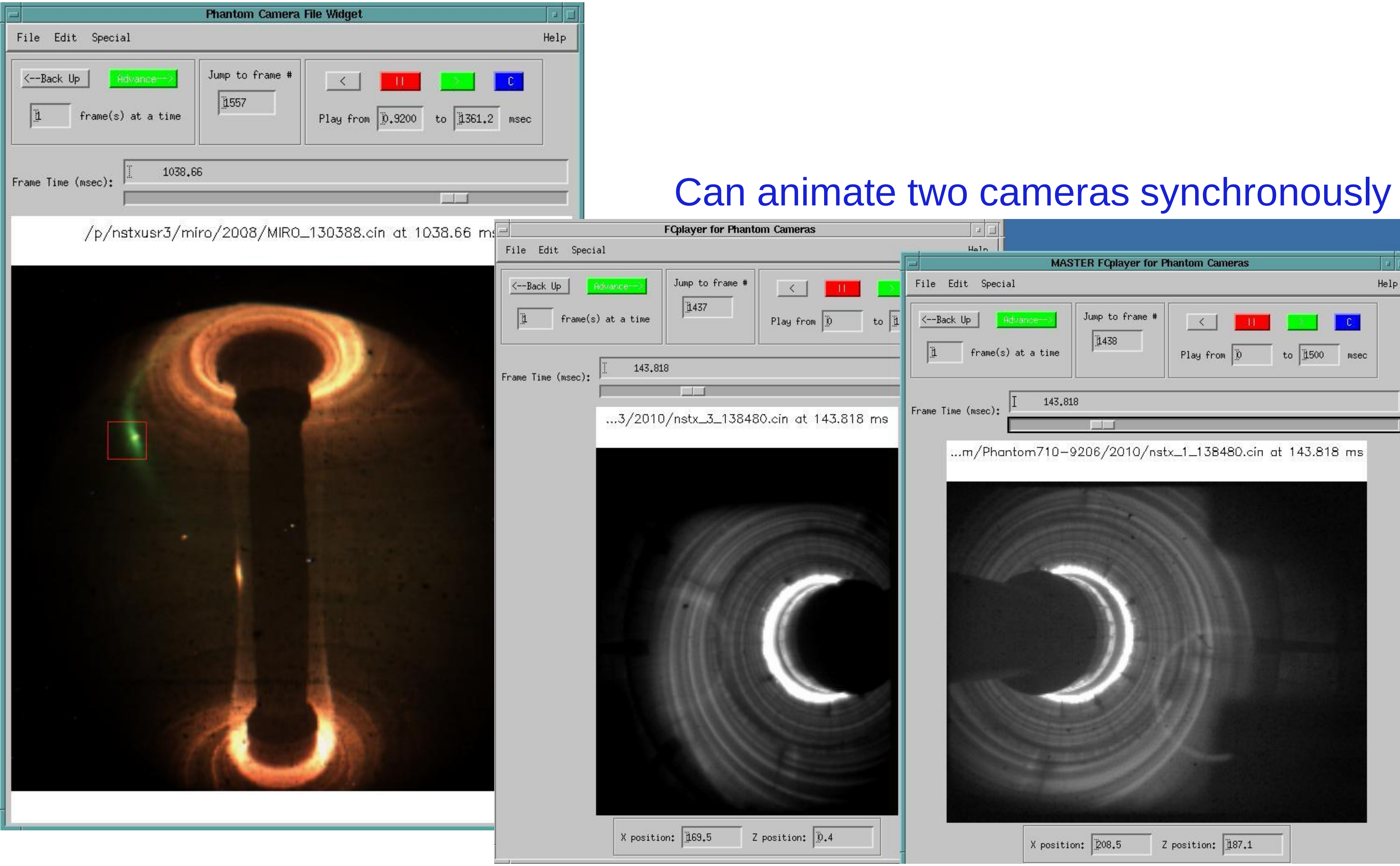
Required:	Frames	Signal	3-D Signal [x,y,t] with axes and units specified
	Frame_rate	Numeric	(int) frames per second
	Exposure	Numeric	(float) seconds shutter open for a frame
	Xpixels	Numeric	(int) # of horizontal pixels
	Ypixels	Numeric	(int) # of vertical pixels
	Nframes	Numeric	(int) # of frames
	Description	Text	text describing diagnostic, location, etc.
	Camera_type	Text	text with camera type, e.g., "Phantom 7.3"
	Cognizant	Text	Person who knows about this system
If Relevant:	Trigger_time	Numeric	(float) seconds after T0 when capture triggered
	Filter	Text	description of filter in place
	Gain	Numeric	(float) # to divide into values
	Offset	Numeric	(float) # to subtract from values
	Npretrigger	Numeric	(int) # of frames taken before trigger
	VersionInfo	Text	desciption of any version information
	Dark_image	Numeric	a 2-D array (or pointer) for background subtraction
	Gamma	Numeric	(float) gamma correction (between 0.0-1.0)
	Thumbnails	Signal	3-D signal of reduced size and/or rate

Views of 2 Fast Cameras on NSTX

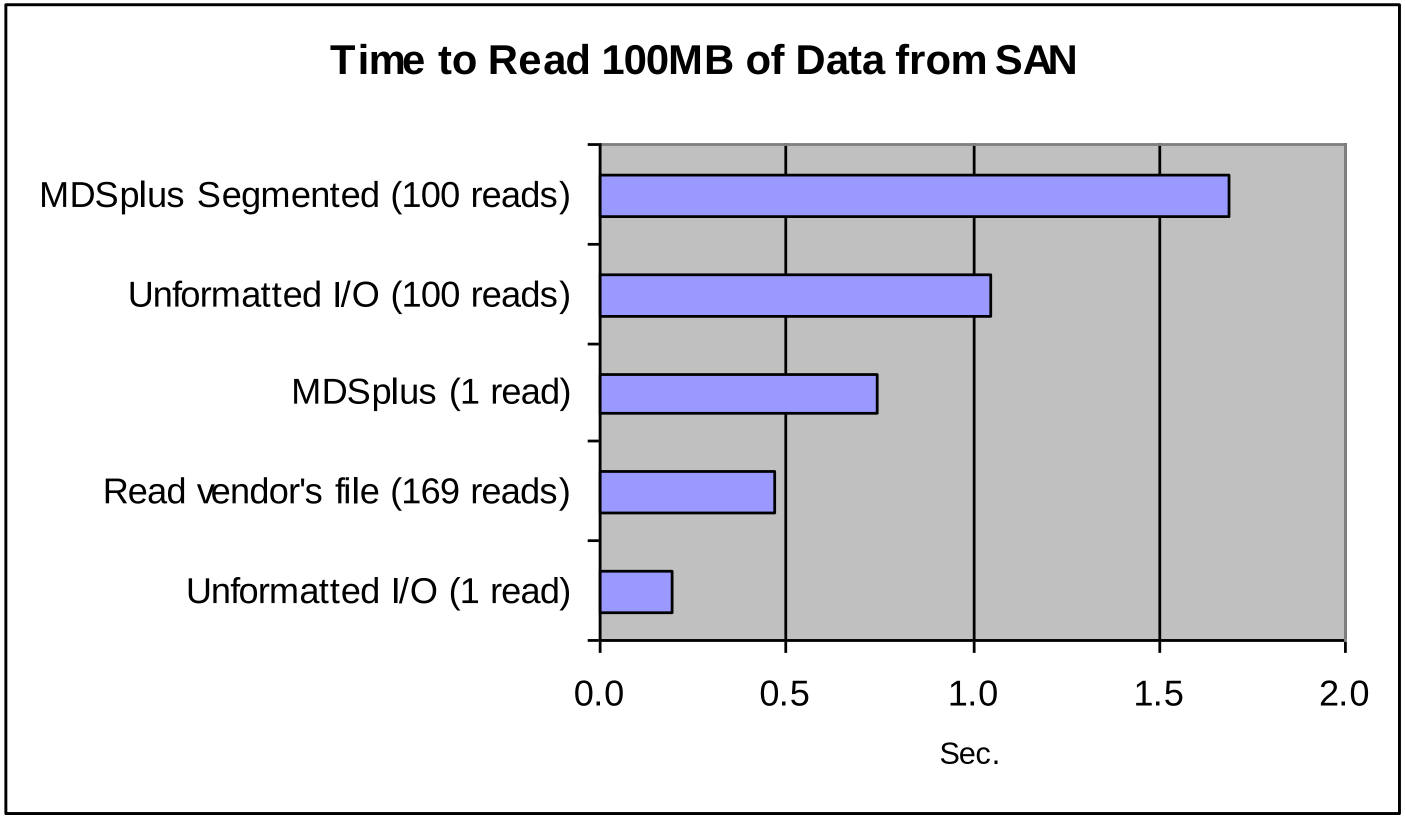


IDL application for displaying fast camera output and for tracking particle or blob positions

Can animate two cameras synchronously



Times to read 100MB of data



- *Run on an 2.60 GHz, 8-processor Linux computer with 10GB of memory*
- *Writing to SAN disks via 1GB/s fibre channel; no TCP/IP connections involved*
- *All calls from IDL; "reads" means calls to read routines.*

NSTX Computing Environment

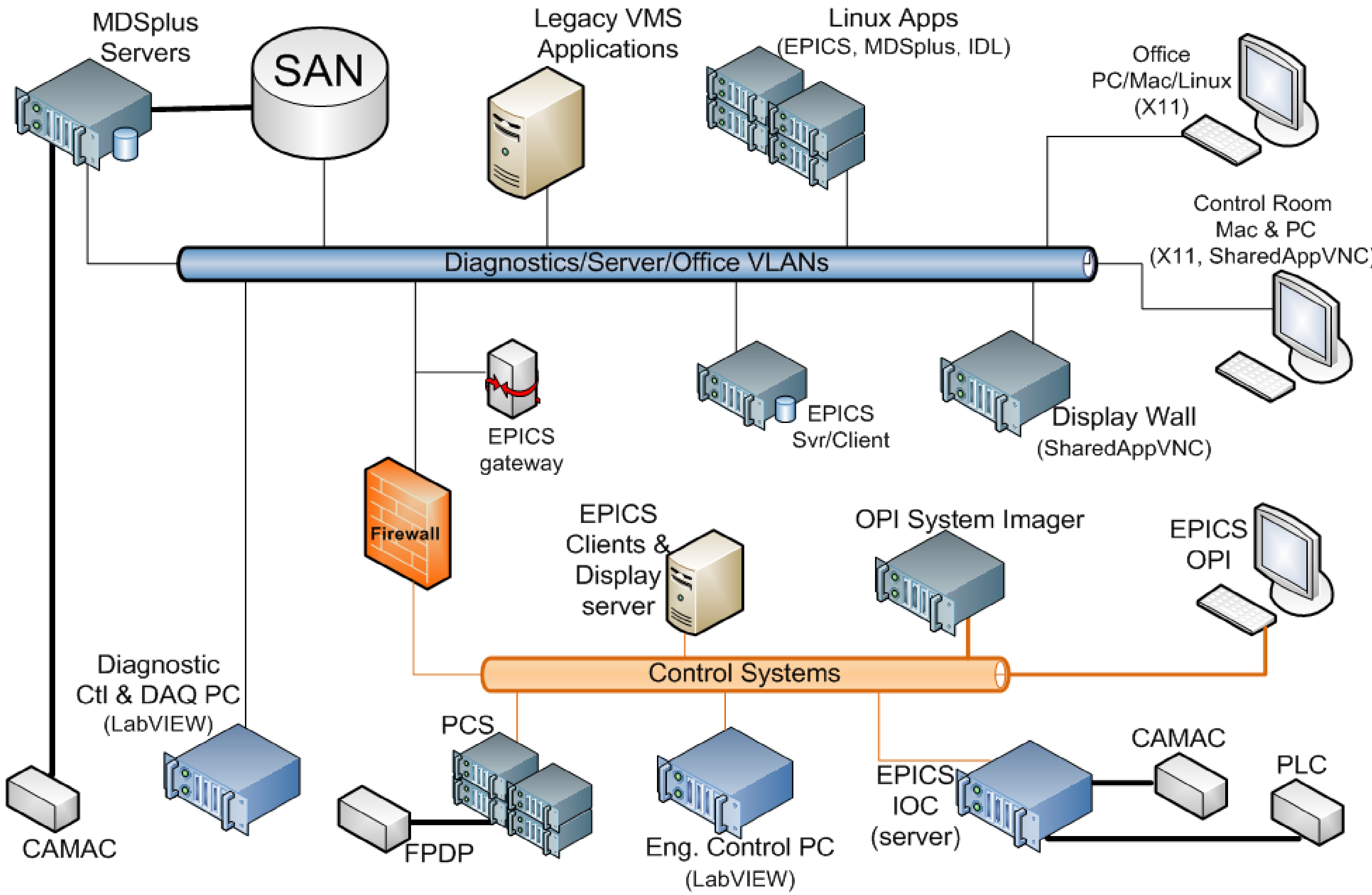
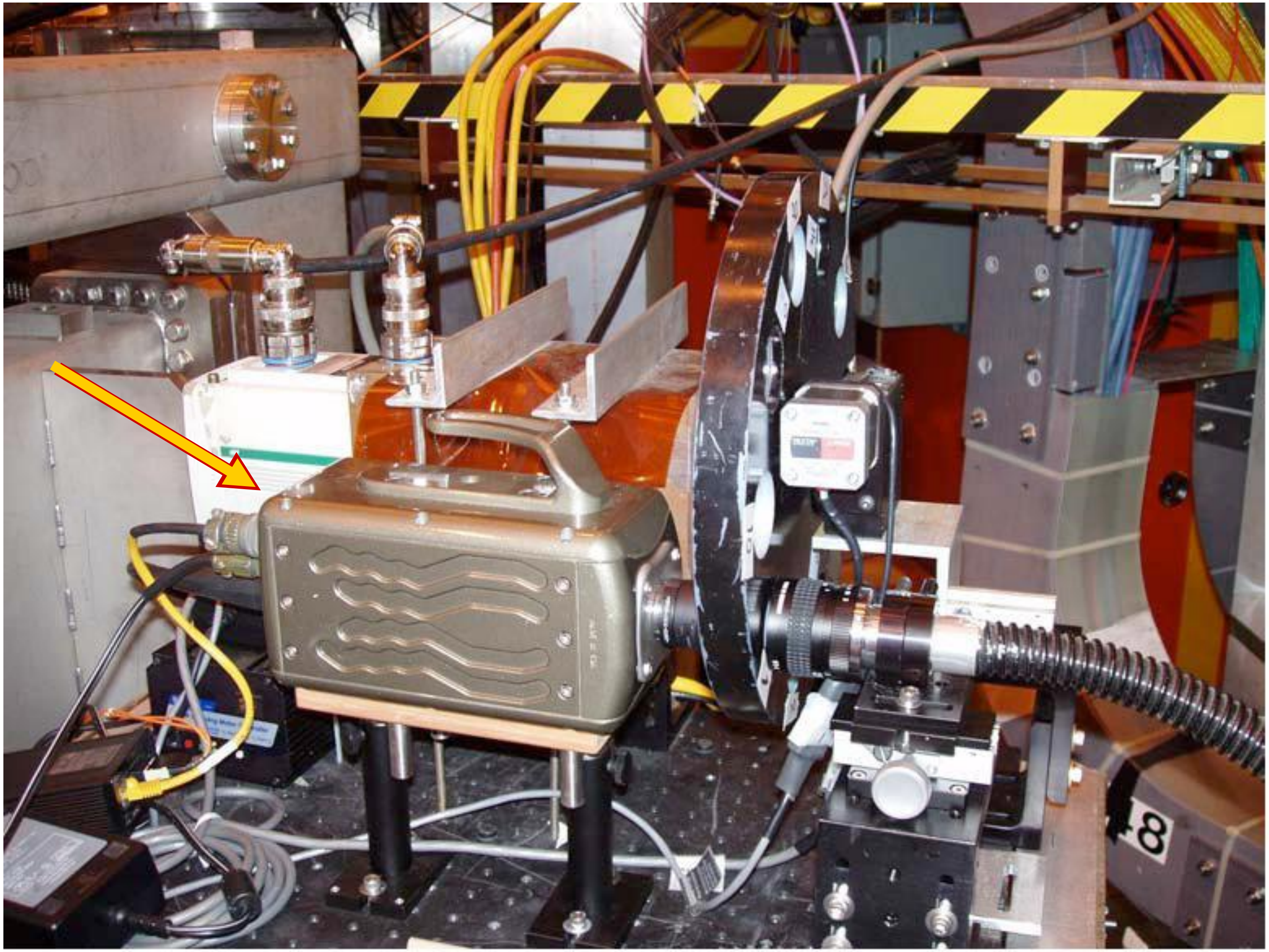


Fig. 1 Simplified depiction of NSTX Computing system The diagram indicates the principal scientific software that runs on the computer.

•From P. Sichta, SOFE, 2009

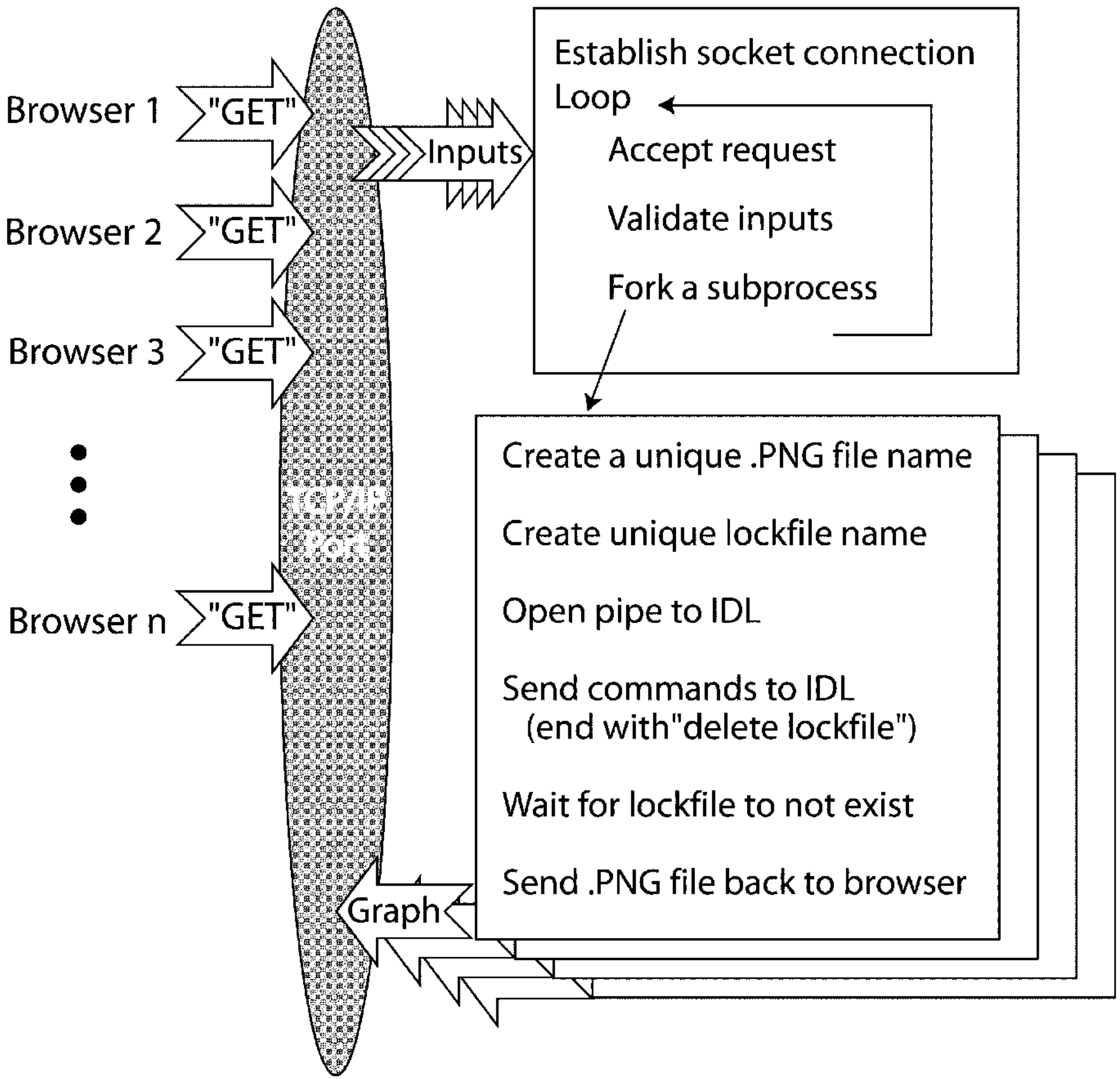
Phantom 7 Fast Camera and Filter Wheel on NSTX



NSTX Fast 2-D Camera Specs for Edge Studies

Camera type	Typical MB/shot	Max MB/shot	GigaPix /sec	Max Resol.	Max Rate (KHz)	Max Rate Resol.	Bits
Phantom 7.3 (2@)	350	3500	3.0	800x600	500	32x8	14
Phantom 710 (2@)	350	3500	7.0	1280x800	680	128x32	12
Miro 4	350	3500	0.6	800x600	111	32x16	10
Miro 2 (color)	50	2000	0.3	640x480	105	32x16	10

Data flow of MDSplots.html and the Perl server



Distribution of radial velocity with blob height (brightness)