[JP1.100] APS DPP Nov. 1999

Visible imaging of edge turbulence in NSTX

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A diagnostic is being prepared to make 2-D images of the edge turbulence in NSTX by viewing from a direction along the local magnetic field toward the visible light emitted by a local gas puff near the outer wall. This should allow a measurement of the radial vs. poloidal structure of the density fluctuations from edge turbulence and also from any small-scale MHD associated with CHI or beta limits. The 2-D images will be made with a gated, fast-framing, visible camera viewing either Dα or helium lines, with exposure times down to 1 microsec and framing rates of up to 1000/sec. The frequency spectra of these light fluctuations will also be monitored by a linear array of discrete detectors. Of particular interest is the change in the 2-D structure of the edge turbulence between L and H-modes, and the correlation of CHI penetration and edge MHD activity.

Visible Imaging of Edge Turbulence in NSTX

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Goal:

Understand edge radial transport,assuming that edge radial transport is due to edge turbulence

Expected size and timescales of edge turbulence:

- normal measured size scale $k_\perp \rho_s \approx 0.1$, and $L_\perp \approx 1/k_\perp$
- normal measured frequency $\omega \approx k_\perp V_d$, and $\tau_{auto} \approx 1/\omega$

for NSTX outer edge, assume B=1.5 kG / T_e=100 eV

=> $\rho_s \approx 1$ cm, $V_d \approx 3\text{x}10^6$ cm/sec (assuming $\Lambda_\perp \approx 2$ cm)

=> $L_\perp \approx 10$ cm, $\tau_{auto} \approx 3$ µsec

Relative scales of $L_\perp$ and $\Lambda_\perp$ in NSTX seem unusual:

expect from above that $L_\perp \approx 5 \text{ x } \Lambda_\perp$

previous experiments had $L_\perp \leq \Lambda_\perp$

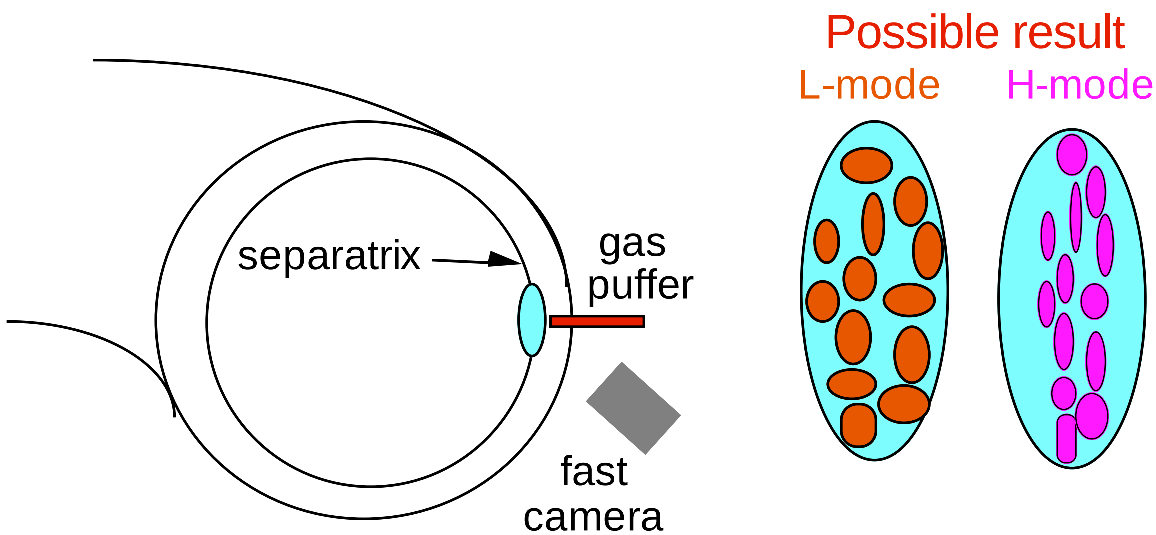
=> NSTX should be interesting

Optical Imaging of Turbulence

- Edge density fluctuations correlated with H_α light fluctuations (Caltech, ASDEX, etc)

- Fast cameras have seen strong filamentation of H_α light due to edge turbulence (DITE, TFTR)

- Try new measurement of 2-D turbulence structure



Camera views along B into localized gas puffer at edge

Should allow local 2-D imaging radially vs. poloidally

Similar diagnostic being set up at C-Mod in collaboration with Terry, LaBomabard, and Pitcher

Edge Turbulence Physics in NSTX

- Physics of edge turbulence & L-H transition in STs

  check scaling of turbulence with ν, β and ρ_s/a

  check with predictions of theoretical models

  look for effects of flow shear on 2-D structure

  look for high-n edge modes near beta limit

  does edge turbulence affect global confinement ?

- Interaction of edge turbulence with CHI & HHFW

  what is interaction of CHI and edge turbulence ?

  what is interaction of HHFW and edge turbuence ?

- Explore edge plasma control for ST development

  how to control L-H transition externally (RF ?)

  how to change SOL transport externally (gas ?)

  how to increase edge radiation (effect on δn ?)

NSTX Diagnostic Setup

- LANL intensified, gated CCD camera
  - makes images at 1000 frames/sec at ≥1 μs gate
  - view through midplane window at Bay H
  - view adjusted by moving lens near window
  - initial lens is "fish-eye" for wide field of view

- Gas puffer
  - 1/4" gas line installed inside vessel
  - puff deuterium or helium during discharge
  - view puff with LANL camera for spatial structure

- PM tube linear detector array
  - 8 discrete fibers focused on outer edge
  - bandwidth ≤ 200 kHz digitized at ≤ 500 kHz

=> should give $L_\perp$ and τ_{auto}

Estimated Signal/Noise Level

- Assume local puff strength of 3×10^{19} atoms/sec

  (<< global recycling rate of $\approx 10^{21}$ atoms/sec)

- Assume 30 ionizations/visible photon emitted

  (typical for hydrogen or helium)

- Assume area of puff across B is 10 cm x 10 cm

  => puff brightness is $\approx 10^{16}$ photons/cm^2-sec

- Viewing from 1 m away with 10 cm^2 area front lens

  => camera sees $\approx 10^{12}$ photons/cm^2-sec from puff

- For imaging turbulence in area of 0.1 cm^2 for 1 µs
  using camera with 10% quantum efficiency

  => 10^4 photoelectrons / resolution element / frame

could see $\delta n/n \approx$ 10% turbulence with
0.1 cm^2 x 1 µs resolution with10:1 S/N

Possible Diagnostic Problems

- Gas puffs may locally perturb edge turbulence

  determine how turbulence structure varies with gas puff strength and species

  compare with models of neutral effect on edge turbulence

- Neutrals may not reach last closed flux surface

  move plasma closer to gas puff nozzle

  try viewing ions of carbon, neon, etc

  try supersonic gas nozzle or low energy beam

- Edge turbulence filaments may not be ⊥ B

  scan plasma edge q to find optimum image

  measure angle of filaments at RF antenna

- Atomic physics is too slow to follow turbulence

  radiative rates should all be $>>10^6\ s^{-1}$

  check with different gas species

Potential Diagnostic Improvements

- Add second camera viewing same image

  get time-delayed correlation in 2-D

  view two different gas species in same puff

- Get very high framing rate camera (Kodak, PSI)

  Kodak can do 40,000 frames/sec

  PSI camera can do 10^6 frames/sec

- USX 2-D imaging for seeing deeper inside plasma

  testing UV-sensitive CCD array at Caltech

  coud improve imaging with telescope by JHU

- Develop low energy neutral sheet beam

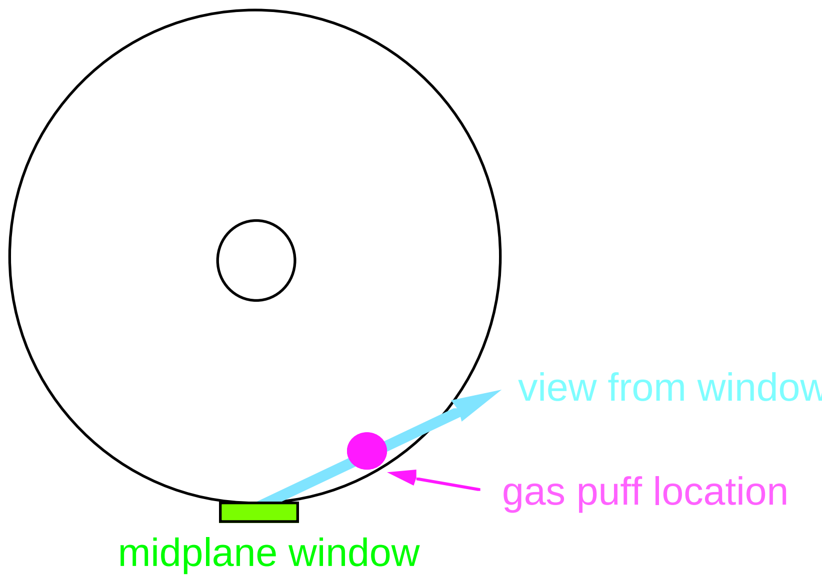
  supersonic gas nozzle developed in Europe

  low energy neutral beam $\approx$ 10 keV, 10 amps

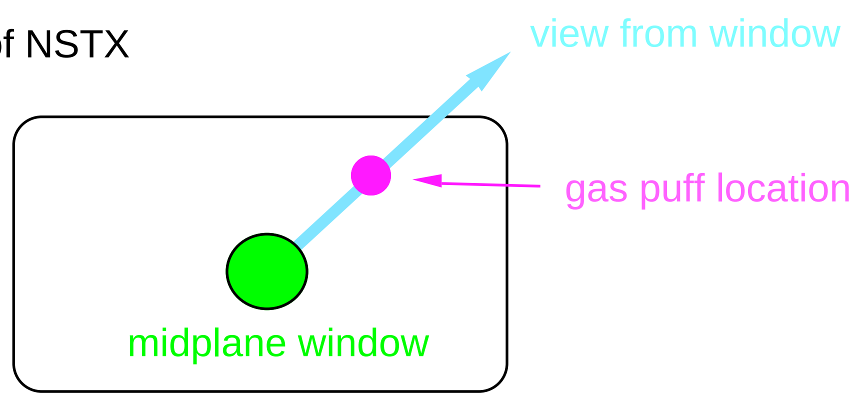
View of Gas Puff in NSTX

- A gas puff line was installed at the outer vessel wall so that. when viewed through midplane window, it was looking along a magnetic field line tangent to the plasma edge, i.e. at a 45-50º angle from the horizontal

Top view of NSTX



Side view of NSTX



Results of View of Gas Puff

- So far have seen deuterium gas puff from midplane window !

- Probably:

  - gas puff was just outside field of view used

  - gas puff was very weak during this run

- Did see He gas puff in Bay L from across plasma, and saw turbulent filaments of visible light

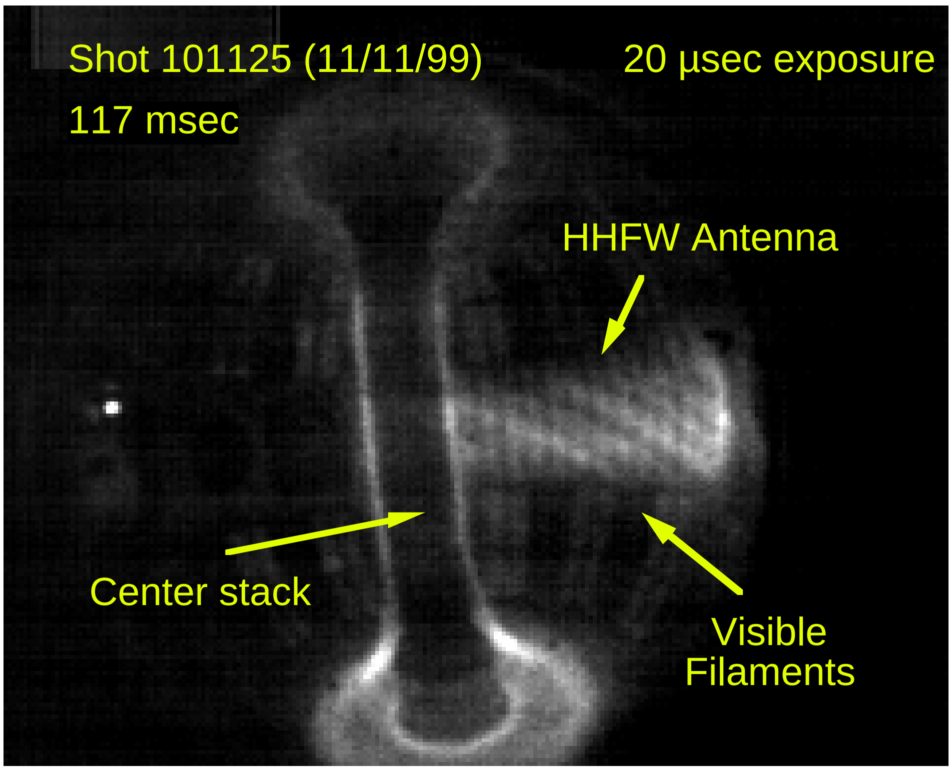
- Did see turbulent filaments in recycling light in front of HHFW antenna

=> no 2-D radial vs. poloidal imaging data obtained yet using gas puff

=> but do have 2-D poloidal vs. toroidal imaging data using recycling from HHFW antenna

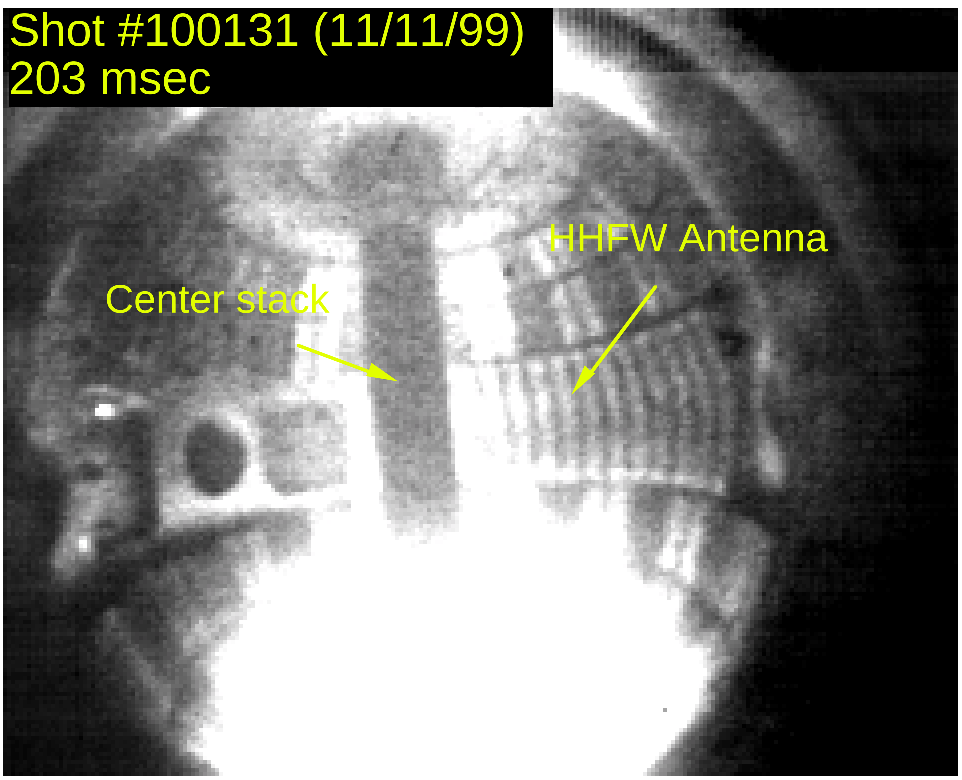
Fast Camera Images of Edge Visible Light Filaments in NSTX

- LANL Kodak fast-framing visible camera is used to observe whole cross-section of NSTX
- Fast moving "filaments" of visible light are seen in the recycling light from HHFW antenna (with no ICRF)
- Filaments move to different locations from frame-to-frame at framing rate of 1000 Hz



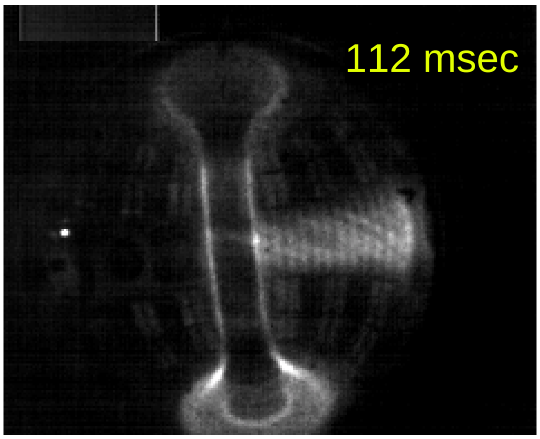
Field of View of HHFW Antenna

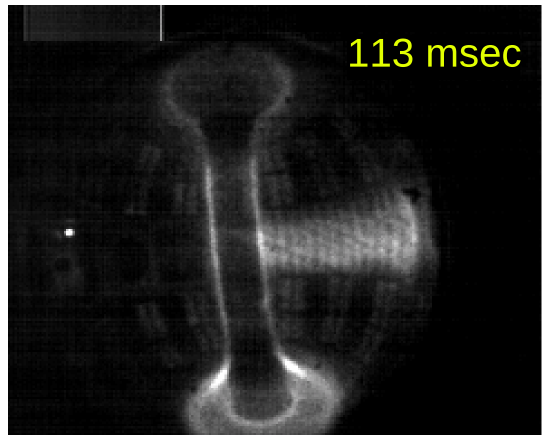
- This frame had a large amount of light
- Same view as other frames
- HHFW antenna is ≈ 90 cm high

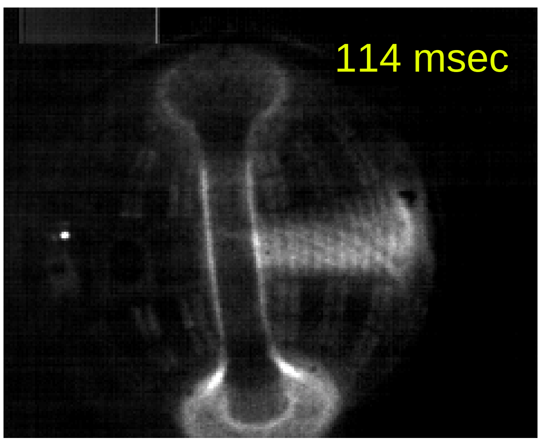


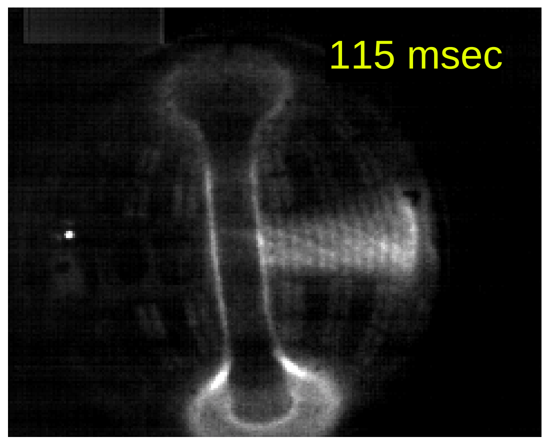
Edge Visible Filaments vs. Time

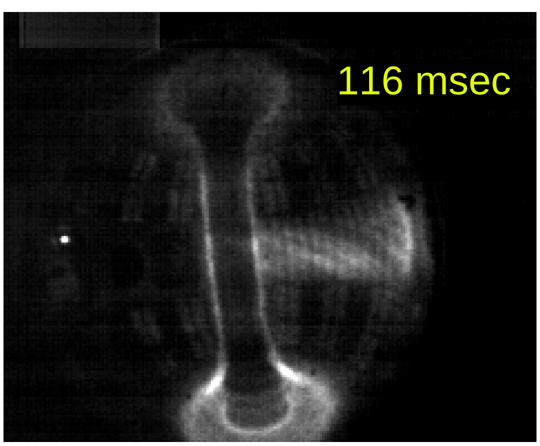
all Shot 101125, 20 μsec exposure time

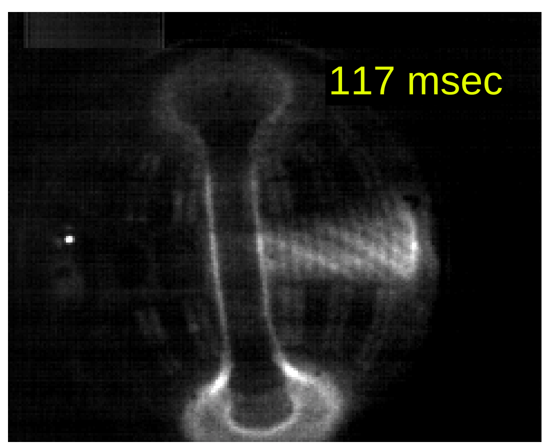












Edge Filament Characteristics

- Similar filaments seen in D-alpha and in He neutral light
- Qualitatively similar to filaments seen in TFTR and ASDEX

Assuming these filaments are the illumination of edge density turbulence (as for TFTR and ASDEX), the NSTX edge turbulence charactersistics are:

- horizontal angle ≈ 23±5º ≈ B field line angle in NSTX
- poloidal wavelength ≈ 15±5 cm at edge (T_e ≈ 25 eV)

  => $\rho_s \approx 0.5$ cm (B=1.5 T) => $k_\perp \rho_s \approx 0.2$

- frequency ≤ 1/(2π exposure time) ≤ 20 kHz

- This is most likely only the largest-scale, lowest frequency part of the edge density turbulence spectrum, since:
  - Smaller scale structure is averaged over radial H-alpha emission region (few cm ?)
  - Faster structure is averaged over 10 μsec camera exposure time