Plans for 2-D Imaging of Edge Turbulence in NSTX and C-MOD

S.J. Zweben, D. Johnson, L. Roquemore et al (PPPL)
R. Maqueda, G. Wurden (LANL)
B. LaBombard, J. Terry (MIT)

TTF Meeting '99

Edge plasma density turbulence has previously been observed in TFTR [1,2] and ASDEX [3] using fluctuations in visible light emission from hydrogen neutrals, which respond mainly to fast variations in electron density. Plans are being made to use the same principle to make 2-D radial vs. poloidal images of the edge turbulence by viewing a localized source of neutrals tangentially along the direction of the magnetic field. The resulting data on the radial and poloidal structure of the turbulence could help to clarify the mechanism of H-mode formation. The diagnostic plans for both NSTX and C-Mod will be described; the main components are a gated intensified camera, a re-entrant coherent fiberoptic bundle, and a gas puffer near the last closed flux surface. Estimates of the signal/noise and potential problems are described.

1) S.J. Zweben and S.S. Medley, Phys. Fluids B1, 2058 (1989)
2) R. Maqueda and G. Wurden, Nuclear Fusion (to be published)
3) M. Endler, H. Neidermeyer et al, Nucl. Fusion 35, 1307 (1995)

Edge Turbulence Measurement in NSTX

Goal:

Understand edge radial transport and H-mode

Assumption:

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 scale lengths of $L_{\perp}$ and $\Lambda_{\perp}$ is not normal

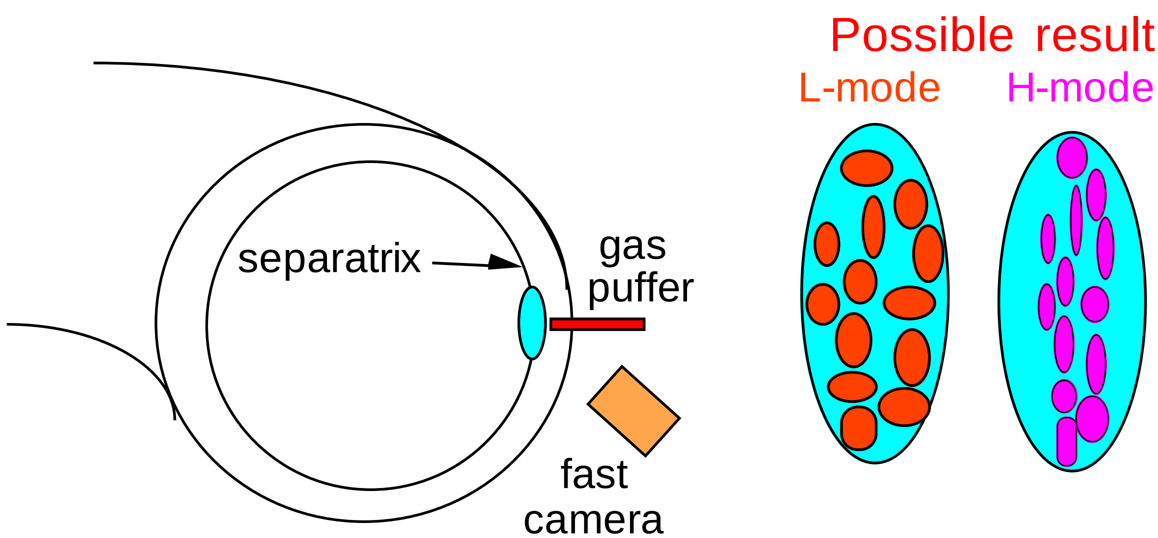
  previous results were $L_{\perp} \leq \Lambda_{\perp}$

2-D Optical Imaging of Edge Turbulence

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

- Fast cameras have seen strong filamentation of H_α light in TFTR due to edge turbulence

- 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 measurement being planned for C-Mod, but with 40 time higher magnetic field and $L_\perp < 1$ cm

Estimated Signal/Noise Level in NSTX

- 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 with 10 cm^2 area front lens

  => 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 with10:1S/N

Diagnostic Planning Details for NSTX

Plans for diagnostic in Summer '99:

- Install midplane window with wide angle view
- Install gas puffer to locally illuminate turbulence
- Install flexible mounting for coherent fiberbundle
- Install array of 8-16 fast photodiodes

=> This should allow measurements of edge turbulence L_{pol} and τ_{auto}

Midplane Window and View of Edge

- Quartz window on 8" flange at Bay H Midplane
- Mini-CAD model shows that view through this window can see tangent to plasma edge

Viewing Angle /Gas Puffer Location

- Want to puff gas radially into plasma edge at point where view from window is tangent to plasma edge along B field

- Field line angles:

  - Day 0 (Gates): 29º @ ß < 25%, I=0.3 MA
  - Day 1 (Kaye): 35º @ ß = 25%, I=1 MA
    47º @ ß = 40%, I=1 MA

=> choose to look at 35º from window to edge

=> direction of B_T and I are CCW for Day 1

- Use 3-D model to locate point of tangency at plasma edge:

  - this point is 67 cm toroidally from puff port

  - this point is 46 cm above midplane

- Run gas puff line from just above window to location at outer wall at this location

Gas Puffer Design and Installation

- Uses standard components, e.g. PV-10 piezo
- Minimizes volume between valve and plasma
- Can puffs up to ≈ 1 torr-l/sec @ 1 atmosphere
- Minimum opening time ≈ 10 msec
- Gas directed through 1/8" ID, 1 m long s/s tube

Fiberoptic Bundle and Mounting

- Use 6 ft long, 4 mm x 4 mm Schott glass coherent bundle to transfer image to LANL camera (from arc furnace experiment)

- Obtain front end lenses from Computar with horizontal fields of view of 18º, 35º, and 72º

- Mount near window with full manual translational and rotational flexibility, to allow changing within about 10 minutes:

  - front end lens, i.e. width of horizontal field of view

  - field of view, e.g. top, bottom, radial, tangential

- Variable optical filter at camera end of bundle

=> detailed design will be proposed in April/May

=> no vacuum interface, i.e. not needed before pumpdown

Fast Photodiode Array in NSTX

- Add 8-16 channel fast linear photodiode array viewing through Bay H midplane window

  - can use existing lost alpha PM tubes / amps
  - array can be rotatable to determine k_{pol} and k_{tor}
  - can view radially or at tangentially (like fast camera)
  - bandwidth should be in the range 100-1000 kHz
  - variable optical filters

- Measures frequency spectrum of edge turbulence, e.g. to see difference between L- and H-mode

  - needed to evaluate whether the fast camera is capturing most of the turbulence power spectrum

- This will also give an independent measurement of poloidal correlation length

  - perhaps also radial correlation length, if system can be aligned along B at edge

Possible Diagnostic Problems in NSTX

- Gas puffs may locally perturb edge turbulence

  local ionization still less than parallel flow

  interesting to know more about this !

- Neutrals may not reach last closed flux surface

  try supersonic gas nozzle or low energy beam

  could also look at ions of carbon, neon, etc

- Edge turbulence filaments may not be $\perp$ B

  scan plasma edge q to find optimum image

  could imagine movable viewing by bundle

- Turbulence size scale may be too small to see

  localize puff by bringing it closer to plasma

- Atomic physics is too slow to follow turbulence

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

  could change gas species to check

Potential Diagnostic Improvements

- Add second camera viewing same image

  get time-delayed correlation in 2-D

  look at 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 imaging USX telescope by JHU

- Develop low energy neutral sheet beam

  supersonic gas nozzle developed in Europe

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

Some Edge Turbulence Issues in NSTX

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

- check scaling of turbulence with β and ρ_s/a
- check with predictions of Rogers/Drake model
- look for effects of flow shear on 2-D structure

- Interaction between edge turbulence and CHI

- does edge turbulence cause CHI diffusion ?
- do CHI currents form turbulent filaments ?

- Help develop edge controls for ST reactor

- want to control L-H transition externally (RF?)
- want to change SOL transport externally (gas ?)
- want to improve CHI penetration (δB?)
- want to increase edge radiation (effect on δn ?)

Summary

- Plans are being made to measure the 2-D (radial vs. poloidal) edge turbulence on NSTX and C-Mod

- Idea is to look along a magnetic field line at the visible light emission from the edge plasma

- The signal will be enhanced by local gas puffing (e.g. D or He)

- Spatial resolution to be obtained using LANL intensified CCD camera

- Expect to use gating times of 1-10 µs for good mages of edge turbulence

- First results expected:

  - NSTX - summer '99
  - C-Mod - fall '99