Edge Turbulence Control Experiments in NSTX

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- Test our theoretical understanding of edge turbulence
- Learn how to actively control edge turbulence in NSTX
- Provide additional control for possible ST burning plasma

Background and Motivation

- Edge turbulence determines the edge n and T profiles (except perhaps for ELMy H-mode)
- Edge profiles strongly influence core plasma properties
- Core plasma control becomes increasingly difficult in ST and AT regimes with dominant alpha heating and bootstrap current

⇒ **Edge turbulence control might be a good way to control burning ST and AT plasmas**

- turn on/off H-mode mode for confinement control
- vary SOL thickness for power and particle control

Desirable Properties of Control Scheme

- Low power consumption (<< heating power)
- Fast response time (<< τ_E)
- Reversible, e.g. L-H and H-L (feedback possible)
- Non-invasive (no electrodes, no excessive impurities)
- Localized (e.g. control from outer midplane)
- Consistent with reactor requirements
    - edge helium ash pumping
    - edge power flux limits

Previous Attempts to Control Edge

- DC biased electrodes (UCLA, Textor)
- DC biased divertor (PBX-M, TDV)
- AC driven probes (TEXT, Richards PoP ‘94)
- AC driven electrode array (CASTOR, MIRABELLE)
- DC driven electrode array (Ryutov)
- RI mode (Textor, JT60-U etc)
- Ergodic magnetic divertor (Tore Supra, TEXT)
- Current ramps (Compass, JT-60U, MST ?)

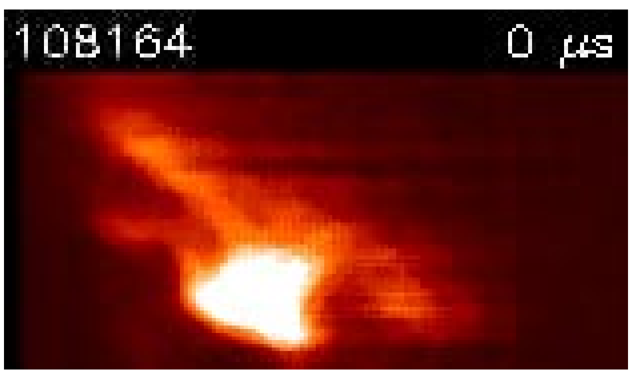
Edge Turbulence in NSTX

- Complex structure and motion with "waves" and "blobs"
- Estimated size scale $\Delta r \approx 4$ cm, timescale $\Delta t \approx 40$ μsec

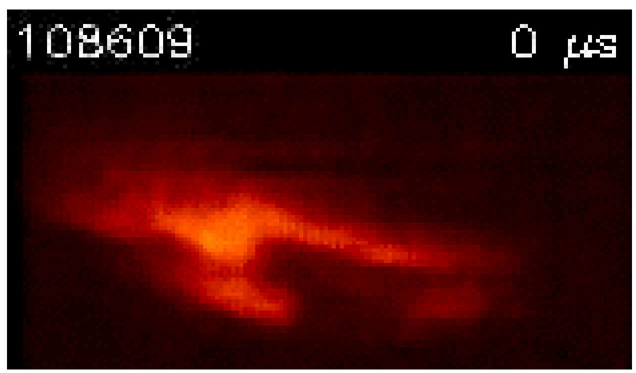
  => $D \approx (\Delta r)^2/4\Delta t \approx 10\ m^2/sec$ from simple random walk

- Edge turbulence always present, even in H-mode, and similar to that in other toroidal magnetic device

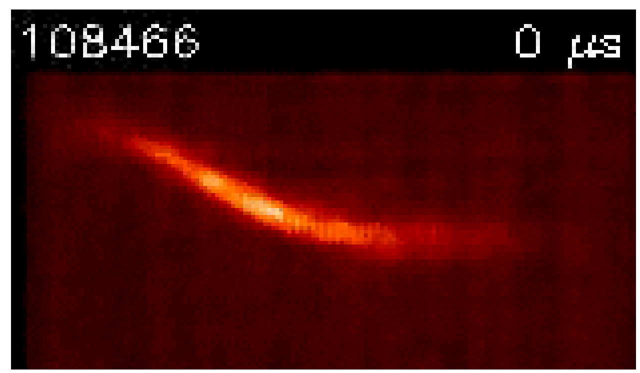
Ohmic



L-Mode



H-Mode



Some Possible Edge Turbulence Control Experiments in NSTX

(not in any order)

- **Shallow NBI (T&T group)**
- **Current ramps (T&T group)**
- **Gap control (T&T group)**
- **Wall biasing (Edge group)**
- **Fueling control (Edge group)**
- **RF-edge interaction (RF group)**

Shallow NBI

Inject low energy beams for which ions are lost to wall and electrons are deposited in edge => change edge E_r ?

- edge deposition probably requires < 30 keV beam energy
- ion gyro-orbit loss occurs over ≈10 cm at 30 keV
- difficult to make full energy NBI below 50 keV
- available current at 1/3 energy=30 keV ≈ 10 amps in ≈ 1 m^2
- thermal particle loss ≈ 10^{22}/sec ≈ 1000 amps in ≈ 10 m^2

=> NBI loss current << thermal ion loss current

Possible Next-run Experiments:

- look for subtle changes in edge turbulence at start/end of NBI
- compare with counter-NBI (Kaye) and gas puff fueling

Current Ramps

Change loop voltage to control edge current density, which could change edge turbulence via edge magnetic shear or $j_{||}$

- Edge RBM and DW do **not** depend directly on either s or $j_{||}$
- Edge MHD stability probably does => good for ELM control ?
- Mixed history: e.g. reduction in voltage improved H-mode access in Compass but not in JT60-U (PPCF '02)

$\Rightarrow$ Can probably do small voltage modulations in "piggy-back" and calculate changes in edge s and $j_{||}$ with TRANSP/TSC

Possible Next-run Experiments:

- Look for changes in edge turbulence vs. dI/dt in normal shots
- Make scan of loop voltage increments (+/-) in steady-state

Gap Control

Change distance of LCFS or separatrix to inner/outer wall or divertor, changing local edge flows and ion losses

- Ion gyro-orbit loss current increases when gap ≈ $\rho_{i,th}$ ≤ 1 cm
- X-point transport may dominate the neoclassical ion loss
- SOL flow increases to M ≈ 1 ≈ 10^6 cm/sec near wall (sheath)

=> significant shear flow and edge turbulence stabilization might be expected near regions of small gaps, although parallel flow might also destabilize edge turbulence

Possible Next-run Experiments:

- Look for changes in edge turbulence vs. gap (in/out/up/down)
- Use dedicated scans to distinguish gap from other effects

Wall Biasing

Imposing DC electric field along or across B can generate flow or ion loss which could affect edge turbulence

- Inner vs. outer wall biasing can create various electric fields:
  poloial E with single-null: $E_{||} \approx 1000$ V/10 m ≈ 1 V/cm
  radial E with double-null: $E_{rad} \approx 1000$ V/10 cm ≈ 100 V/cm

=> Normal phase speed of edge turbulence $\approx 2 \times 10^5$ cm/sec corresponds to $E_{\perp} \approx 4$ V/cm, so radial biasing should be able to significantly change phase speed of edge turbulence

Possible Next-run Experiments:

- Look for changes in edge turbulence in CHI + OH experiments
- Vary gaps in association with wall biasing to vary local E

Fueling Control

Edge source variations can change neutral effects, edge n and T profiles, and edge poloidal or toroidal flows

- local D fueling can change edge neutral density significantly
- local impurity fueling (e.g. Ne) can change edge temperature
- not clear whether local fueling can change edge n,T or edge flows without significantly changing core density

=> systematic experiments will be necessary to distinguish "cause and effect" between fueling and edge turbulence

Possible Next-run Experiments:

- vary poloidal location of D gas puff (Maingi)
- use edge impurity puffing (e.g. Ne) to change edge radiation

RF-Edge Interaction

RF wave at the edge could potentially modify the edge plasma profiles or the edge turbulence directly

- RF waves have oscillating E,B fields >> plasma edge fields
- create DC potentials near antenna (e.g. fast particle loss)
- create AC "near- fields" at f ≈ 10-100 kHz by 2-freq. beatwave
- create oscillating ExB drifts to modulate turbulence
- create oscillating Er to generate zonal flows (capacitively ?)

⇒ many possible mechanisms with HHFW, EBW, LH (C-Mod)

Possible Next-run Experiments:

- measure effect of normal RF heating/CD on edge turbulence
- try to generate turbulence-frequency RF by beatwaves

Tentative Conclusions

Methods of edge turbulence control:

- **Shallow NBI - too weak to expect any effect**
- **Current ramps - no direct link to edge turbulence**
- **Gap control - possibly large wall power loads**
- **Wall biasing - possibly impurity influx**
- **Fueling control (Edge) - possibly too perturbing**
- **RF-edge interaction (RF) - best bet ?**
- **???**