Edge turbulence and flow behavior preceding L-H and H-L transitions in NSTX

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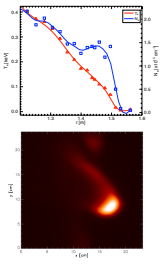
Abstract

Recent Gas Puff Imaging (GPI) observations on the National Spherical Torus Experiment (NSTX) have revealed a quasi-periodic cycle in the plasma edge turbulence preceding the L-H transition in a limited set of neutral beam heated plasmas. These ~3 kHz flow oscillations exhibit both long wavelength and long correlation lengths, suggesting they are zonal-flow-like. The flow oscillations are strongly correlated with modulations of the level of edge turbulence, thus the system appears to undergo a predator-prey type limit-cycle preceding the L-H transition. However, a clear trigger for the L-H transition was not observed. In addition to these results, analysis of the Reynolds stress profiles obtained from image velocimetry for L-mode periods preceding the L-H transition will be discussed.

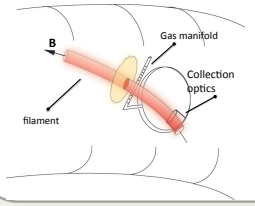
Imaging data from the GPI diagnostic has also captured several L-H and H-L transitions in RF heated plasmas near the L-H input power threshold. These observations show a very distinct ~25 kHz feature present during H-mode that appears to precede ELM events and H-L back transitions. This feature is also seen to grow in amplitude preceding an H-L transition. A detailed characterization of this feature will be presented in addition to the previous results on zonal-flow-like oscillations

Why study the edge?

- L-H transition
  - Confinement improvement likely key to realization of burning plasma
  - Improvements linked to changes in edge (ETB)
  - What are the dynamics of the transition?
  - How are flows and turbulence connected?
- Edge Localized Modes
  - Explosive loss of plasma can degrade plasma facing components, limit reactor life.
  - Linked to stability of edge
  - What modes are unstable?
  - How do modes grow, and what are the nonlinear dynamics?



Gas Puff Imaging

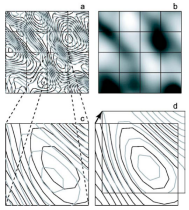


Design
- Gas manifold ~20 cm above midplane on outer wall
- Neutral gas puffed into edge is collisionally excited
- Visible line emission imaged by fast framing camera
  - ~400k frames per second
- View aligned with the local magnetic field
  - ~25cm x 25cm area with 64x80 pix

Goals
- Study edge turbulence and interaction with flows
- Illuminate dynamics of L-H transition
- Examine growth and nonlinear dynamics of ELMs

Velocimetry

- Objective: Take a sequence of 2-D images from a diagnostic (such as GPI), and construct time-resolved 2-D velocity fields of fluid motion
- Hybrid Optical Flow and Pattern Matching Velocimetry
  - Primarily employs pattern matching techniques to derive 2D time resolved velocity fields
  - Uses spatial correlation information opposed to temporal correlation (e.g. TDE)
  - Trades spatial resolution to retain high temporal resolution



Acknowledgments

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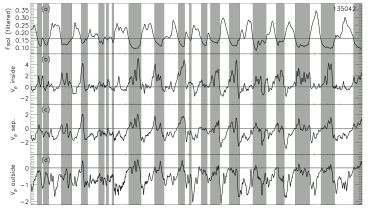
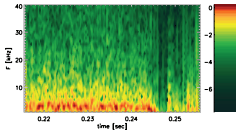
Edge Quiet Periods

Quasi-periodic cycles observed in edge turbulence by GPI diagnostic in L-mode plasmas

- F_{SOL}
  - Measure of Turbulent bursts
  - Fraction of D_α light in the SOL
- Quiet Periods correlated with Flows
  - Poloidal velocities are strongly correlated with F_{SOL} (R≈0.6)
  - Intermittent periodic bursts at ~3 kHz
  - Flow reversals near separatrix correlated periods of high-low F_{SOL}



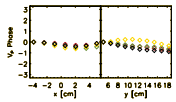


- Strong ~3 kHz feature in turbulence activity
  - F_{SOL} spectrogram
  - Sporadically appears between 2-4 kHz
  - Intermittent with duration of 1-2 ms

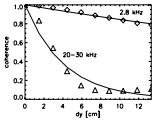
Long wavelength V_{POL} fluctuations

Poloidal velocity exhibits zonal-flow-like features such as long poloidal wavelengths.

- V_{POL} phase differences at 3 kHz
  - Calculated from 2D v-field derived from imaging
  - Approximately linear phase vs. poloidal position
  - Poloidal wavelengths on the order of 1 m



- V_{POL} poloidal coherence
  - 3 kHz signal maintains high coherence over entire GPI view
  - ~56 cm Coherence length
  - Much greater than turbulent coherence length

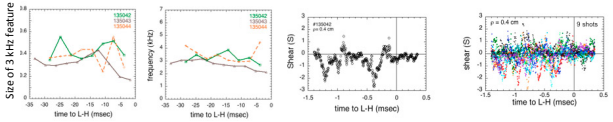


Reminiscent of Drift wave – Zonal Flow interaction

- Quasiperiodic turbulence oscillations
- Turbulence correlated with V_{POL}
- V_{POL} Fluctuations exhibit ZF-like behavior

→ Motivates further studies to probe dynamics close to threshold

No systematic changes observed preceding L-H



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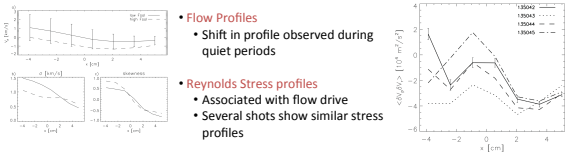
Other Results...

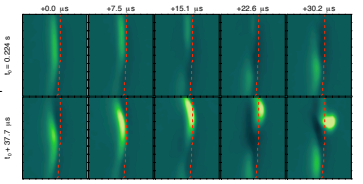


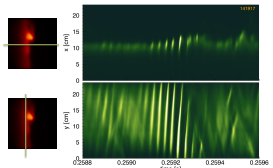
- Flow Profiles
  - Shift in profile observed during quiet periods
- Reynolds Stress profiles
  - Associated with flow drive
  - Several shots show similar stress profiles

ELM Precursors

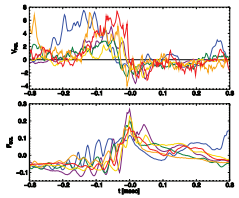
The GPI diagnostic has been used to observe ELM precursors in RF-heated plasmas near L-H threshold power. So far, these precursors have only been observed in RF-heated plasmas

- Clear wave-like edge intensity precursor
  - Observed with GPI
  - drift radially and deform edge shape
  - Filament forms as structure passes into SOL



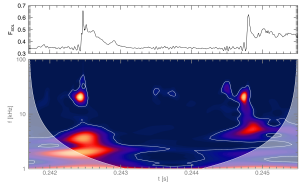


- Precursor is coherent intensity fluctuations
  - Two dimensional cuts, x(radial) vs. time and y(poloidal) vs. time
  - observable radial drift of precursor
  - tilt of intensity structures in y vs. t indicates poloidal velocity in +y



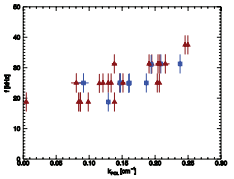
- Average poloidal velocity reverses during ejection
  - V_{POL} measures average velocity near sep.
  - Precursor travels in +y (electron diamagnetic) at 2-8 km/s
  - Filaments travel in –y (ion diamagnetic)
  - Filaments ejected explosively into SOL with radial velocities peaking as high as 8 km/s

Wavenumber and Frequency analysis



- Poloidal Wavenumbers range from 0.1 to 0.25 cm^{-1}
  - Short time windowed FFT cacluation
  - Poloidal variation of intensity fluctuation phase yields wavenumber estimates
  - Calculations done for fluctuations leading to ELMs (red) and without ELM event (blue)

- Precursor activity around 20-30 kHz
  - Continuous wavelet transform shows Increase in power preceding ELM events
  - Low amplitude fluctuations seen intermittently throughout H-mode
  - ELM induced H-L dither visible near 0.245 s



Magnetics signature

- ~20 kHz activity preceding elm
  - Measured by mirnov coils on vessel wall
- Low frequencies strongly correlated with edge intensity
  - Black lowpass filtered < 200 kHz
  - Red bandpass filtered near 20 kHz
  - N ~10 estimated from coil array