Edge Turbulence Imaging on NSTX and Alcator C-Mod

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- Gas Puff Imaging (GPI) diagnostic
- Summary of C-Mod GPI results
- GPI diagnostic set-up in NSTX
- GPI data from NSTX '01 run
- Interpretation of GPI signals
- Tentative conclusions
- Plans for 2002 run

Motivations for Studying Edge Turbulenc

Very likely determines radial power and particle flow throu
SOL onto first wall (“scrape-off length”)

Probably controls L / H transition (turbulence suppressed

Maybe determines density limit (turbulence increased ?)

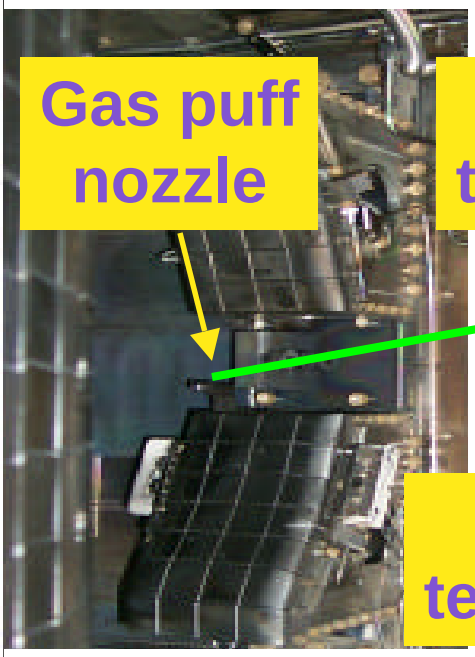
Maybe affects RF power coupling through edge

Good place to study physics of tokamak turbulence, since
both measurements and modeling are *relatively* simple

Gas Puff Imaging Diagnostic

Gas puff imaging (GPI) telescope views neutral line emission from He or D_2 gas puff ≈ along B field at the plasma edge (like BES but uses gas neutrals instead of NBI)

Measures 2-D turbulence structure with fast gated camera, and time dependences at discrete chords (assumes $k_{||} << k$)



Light emission due to electron excitation of neutrals responds to n_e and T_e fluctuations in << 1 μsec, with sensitivity which depends on local n and T_e (as calculated by DEGAS 2)

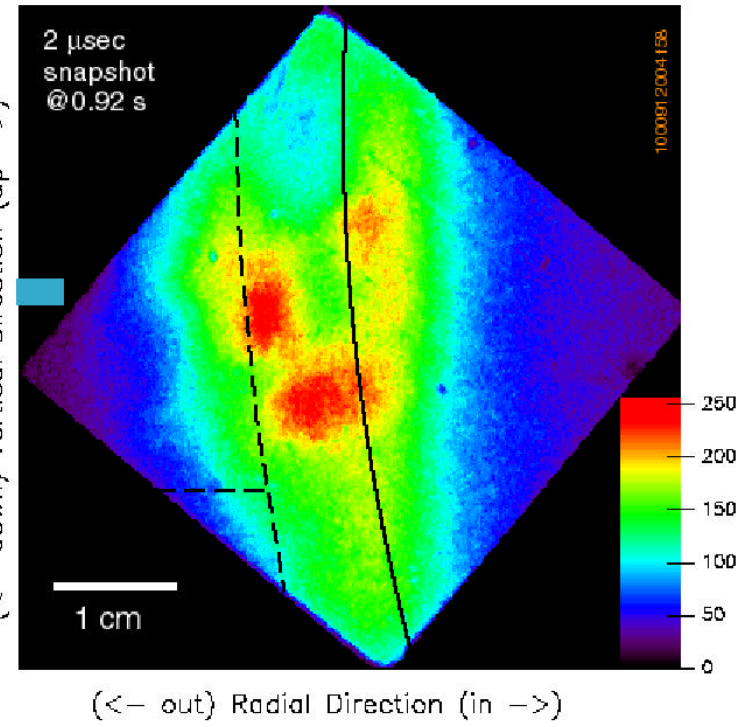
Gas puff changes plasma density by ≈ 1% in C-Mod and ≤10% in NSTX, but this is unlikely to perturb edge turbulence

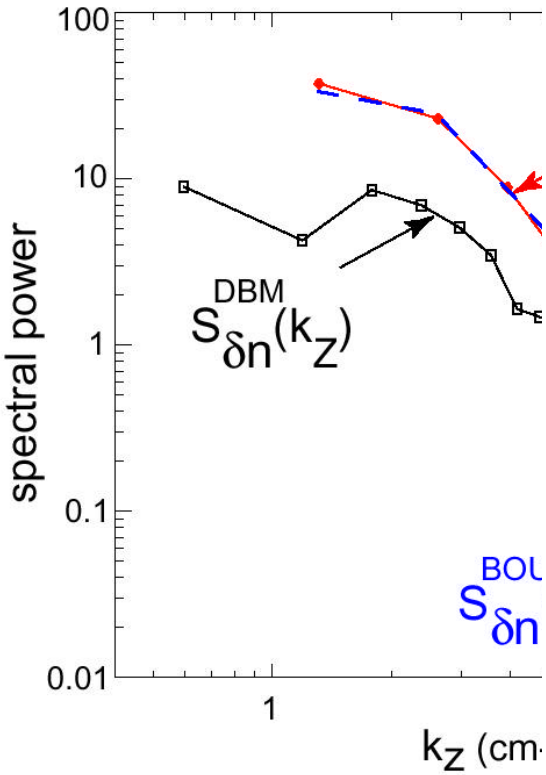
Summary of C-Mod GPI Results

Edge turbulence imaged over region ≈ 6 cm x 3 cm at outer midplane

Poloidal k-spectra compared with DBM code and BOUT for one case

Videos at 250,000 frames/sec often show “blobs” moving radially and poloid

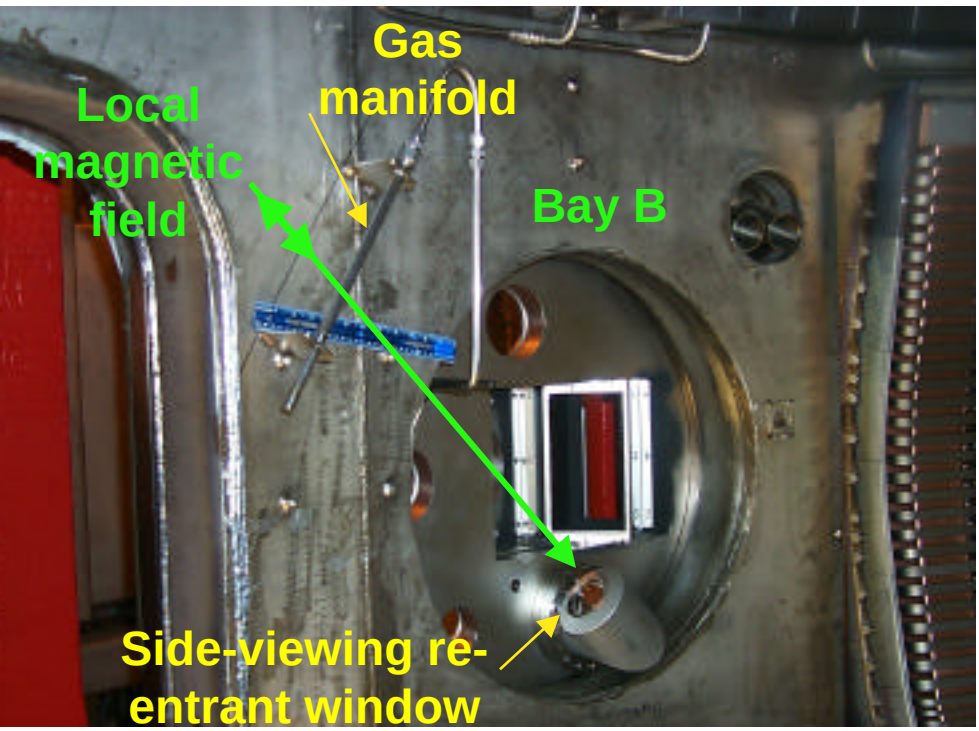


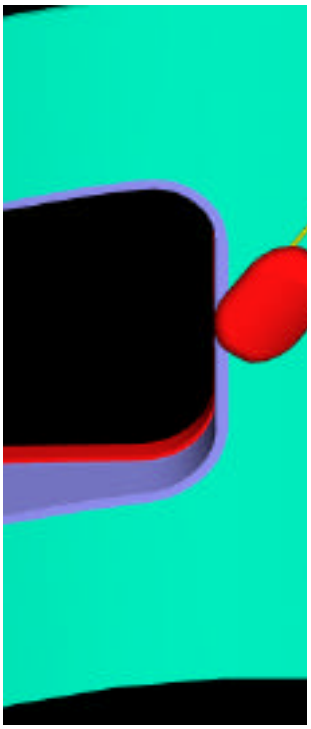


GPI Diagnostic Set-up in NSTX

Similar to C-Mod system but using re-entrant port instead of coherent fiberbun
and elongated gas manifold instead of single-point gas nozzle

Generally have used He puffs in NSTX and Deuterium puffs in C-Mod (althoug
results from both are similar in each machine)

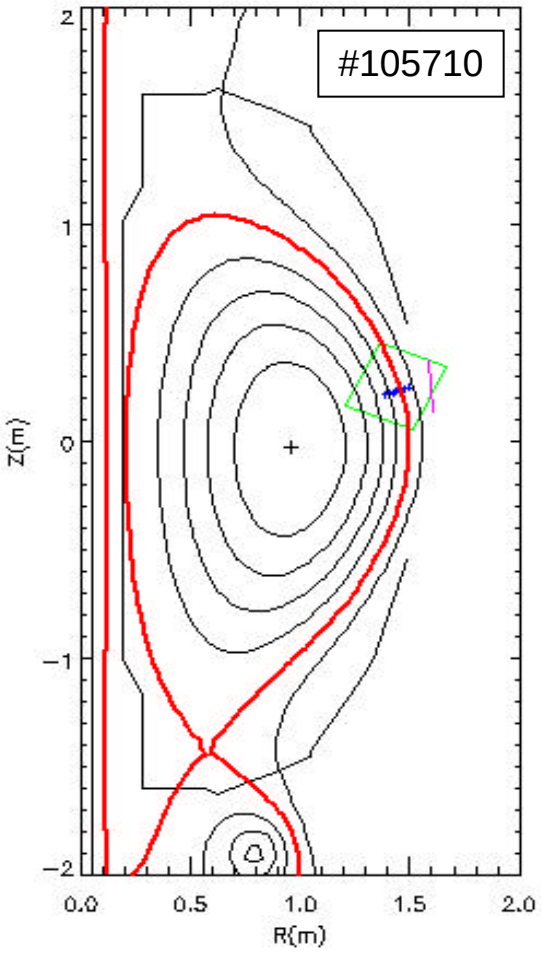


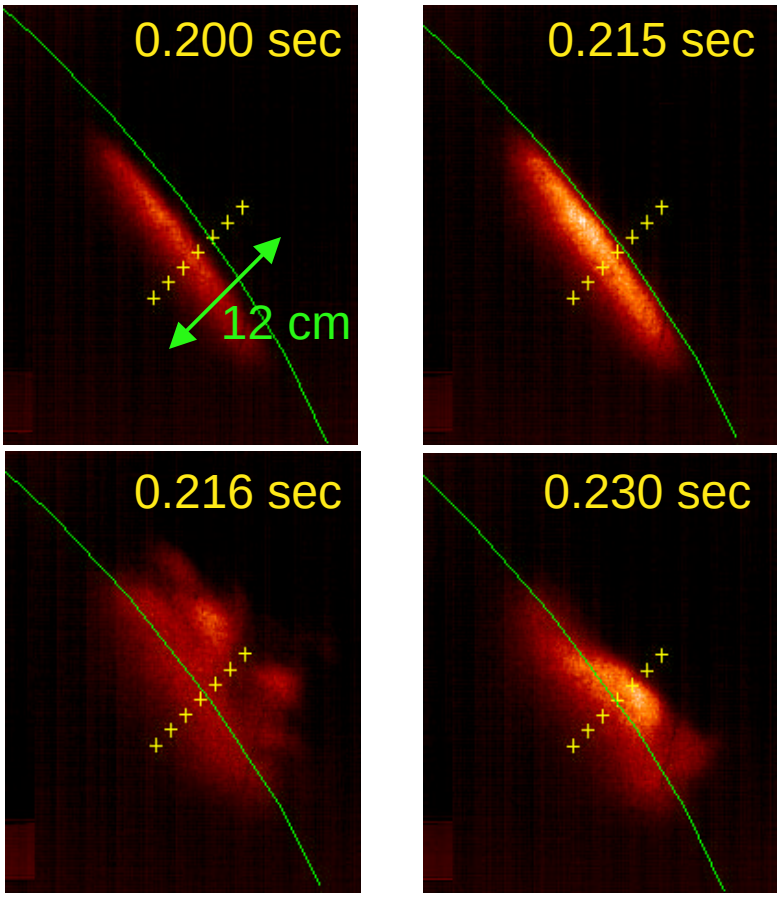


Location of GPI View (2001 Run)

Kodak camera views ≈ 30 cm x 30 cm area just above outer midplane

Fast chords view 2 cm diameter “spots” in 7 channel radial array with PM tub
(bandwidth ≈ 200 kHz, digitized at 500 kHz)





NSTX GPI Diagnostic Issues

He puff itself is unlikely to affect the local edge turbulence

- see similar edge turbulence in natural recycling light
- see same turbulence in GPI over a range of x6 in He puff level
- in C-Mod, see same frequency spectrum in LP (with or without puff)
- search for such an effect in PBX-M was negative (Pedrosa, PoP '95)
- need to compare GPI turbulence signals with LP signals in NSTX

Spatial resolution due to angle between GPI sightlines and local turbulence filaments probably ≈ 2-3 cm (est).

Time resolution set by HeI radiative decay time ≈ 0.014 μse

Relative effect of n_e and T_e fluctuations on GPI not yet know

- in theory these should be in phase and have a similar spectrum, with $(\delta T_e/T_e) / (\delta n_e/n_e) \leq L_n / L_T$, where " < " may be due to parallel electron heat conduction ($\tau_e \approx 1/k_{||}v_e \approx 20$ μsec), depending on magnetic flutter

GPI Results from NSTX in 2001

Typical 2-D GPI images using LANL Kodak Camera

Typical signals from fast chords (#105637, 0.7 MA, 3.0 T)

GPI spectra, fluctuation levels, correlation lengths, etc.

H-L transitions from ELM-free case (#105710, 0.7 MA, 4.5

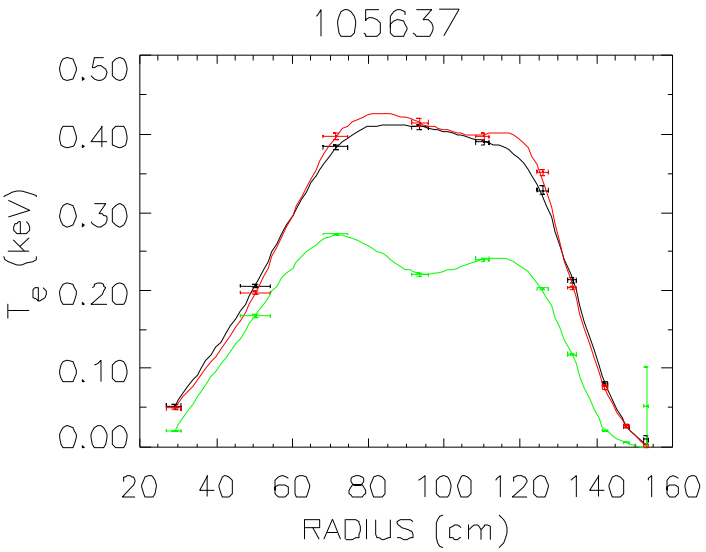
Results from XP#34 (SN vs. DN, I_p / B_T scans) - LATER

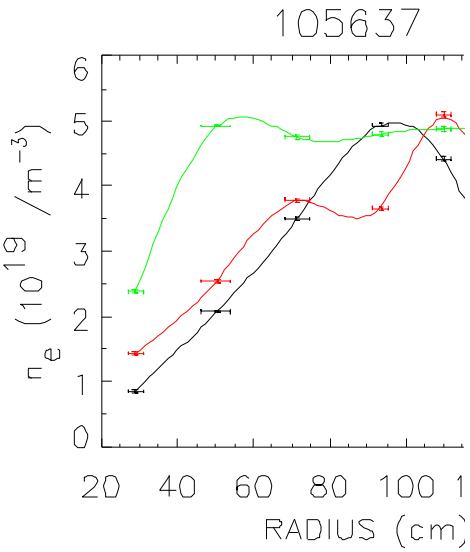
Typical 2-D Images vs. Time from Kodak

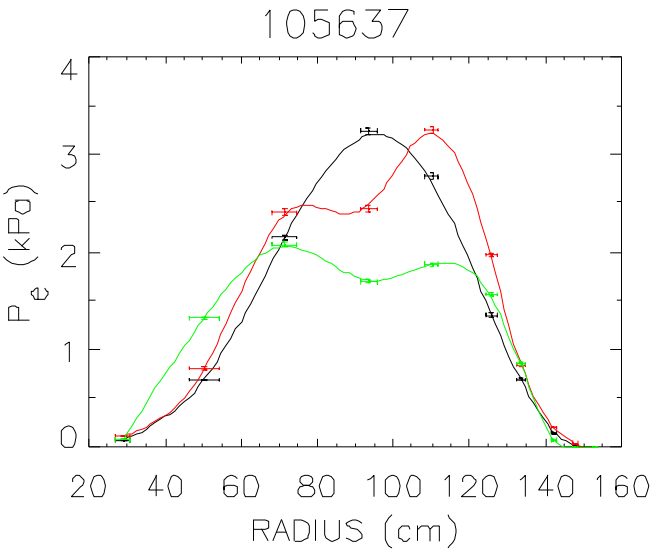
#105724	#105710	#105711
0.7 MA, 3 kG)	(0.7 MA, 4.5 kG)	(0.7 MA, 4.5 k
density scan	H-L transition	no-H mode

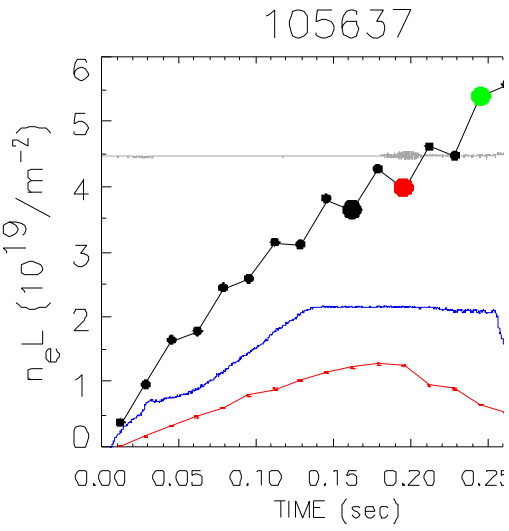
Typical Shot with GPI data

- Moderate density shot from Stan's density scan 7/3/01 (no NBI or ICRH)



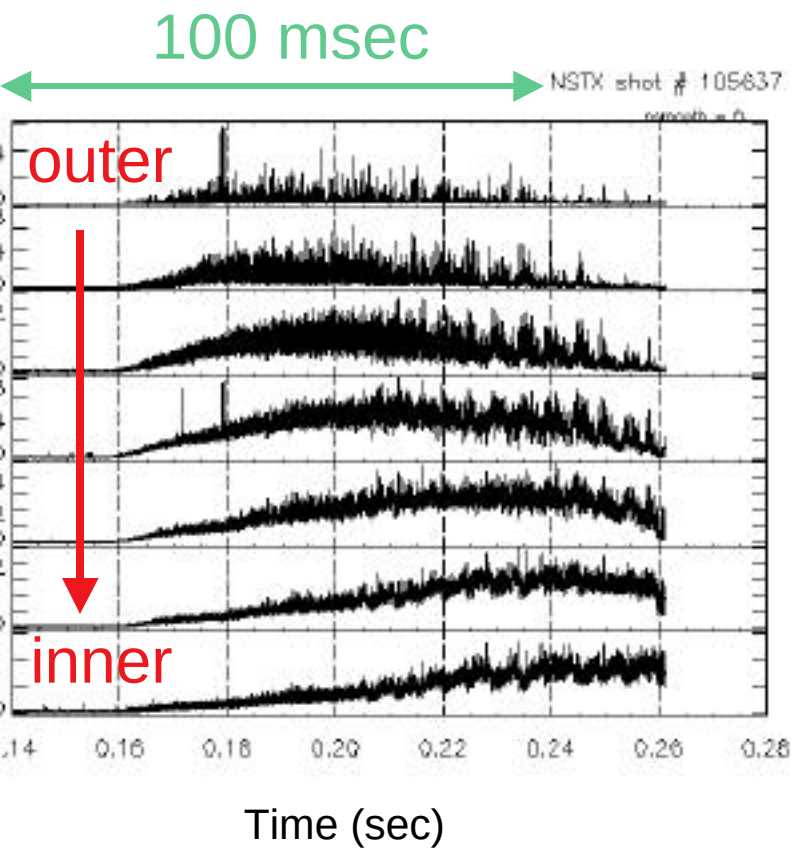


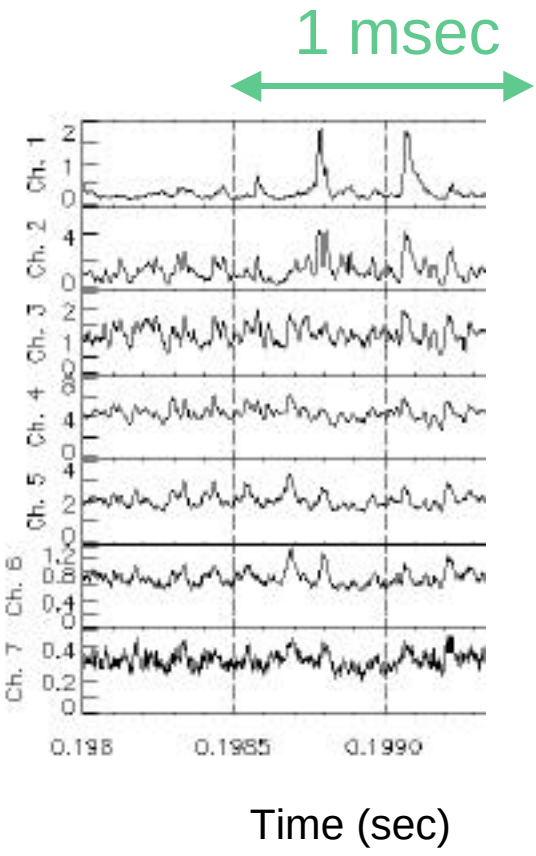




Typical Signals from Fast GPI Chords

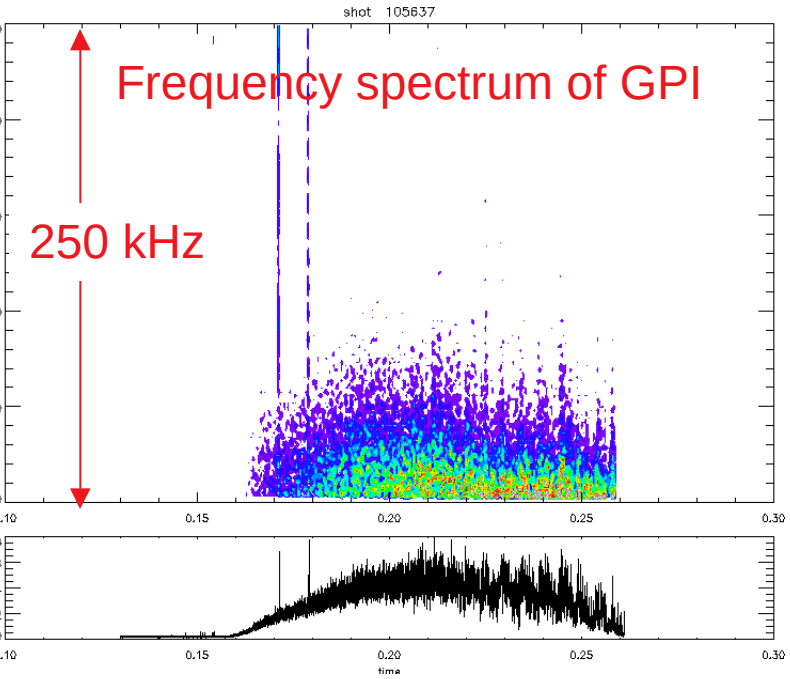
- Fast GPI chords are 7 channels vs. radius with ≈ 200 kHz bandwidth
- Near outer wall see “intermittant” fluctuations with ~ 100% modulation
- Nearer center, see “Gaussian” fluctuations with ≈ 20% modulation



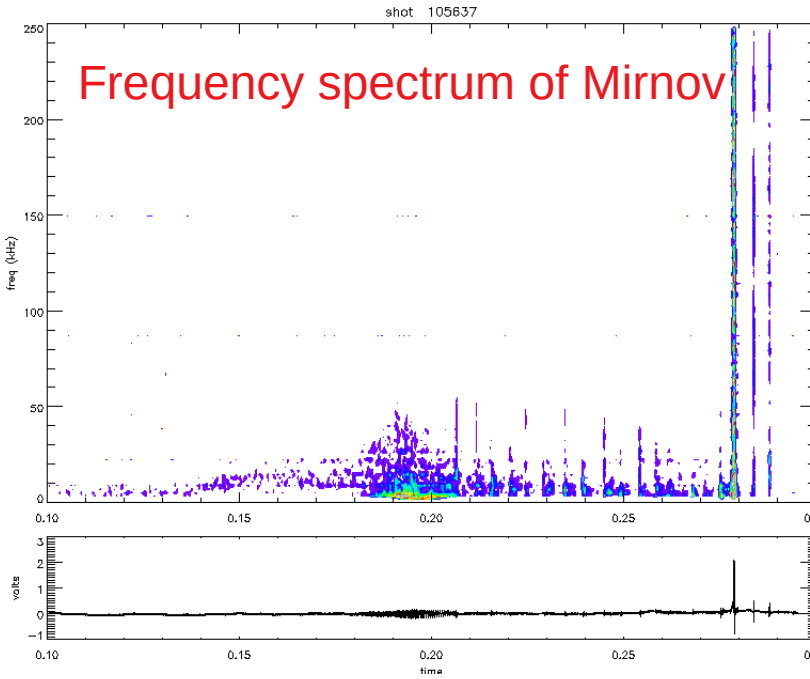


Comparison of GPI and Mirnov Data

- Broadband turbulence exists without coherent MHD on Mirnov coil
- Coherent MHD or sawteeth generally cause only a relatively small modulation of edge turbulence



Time

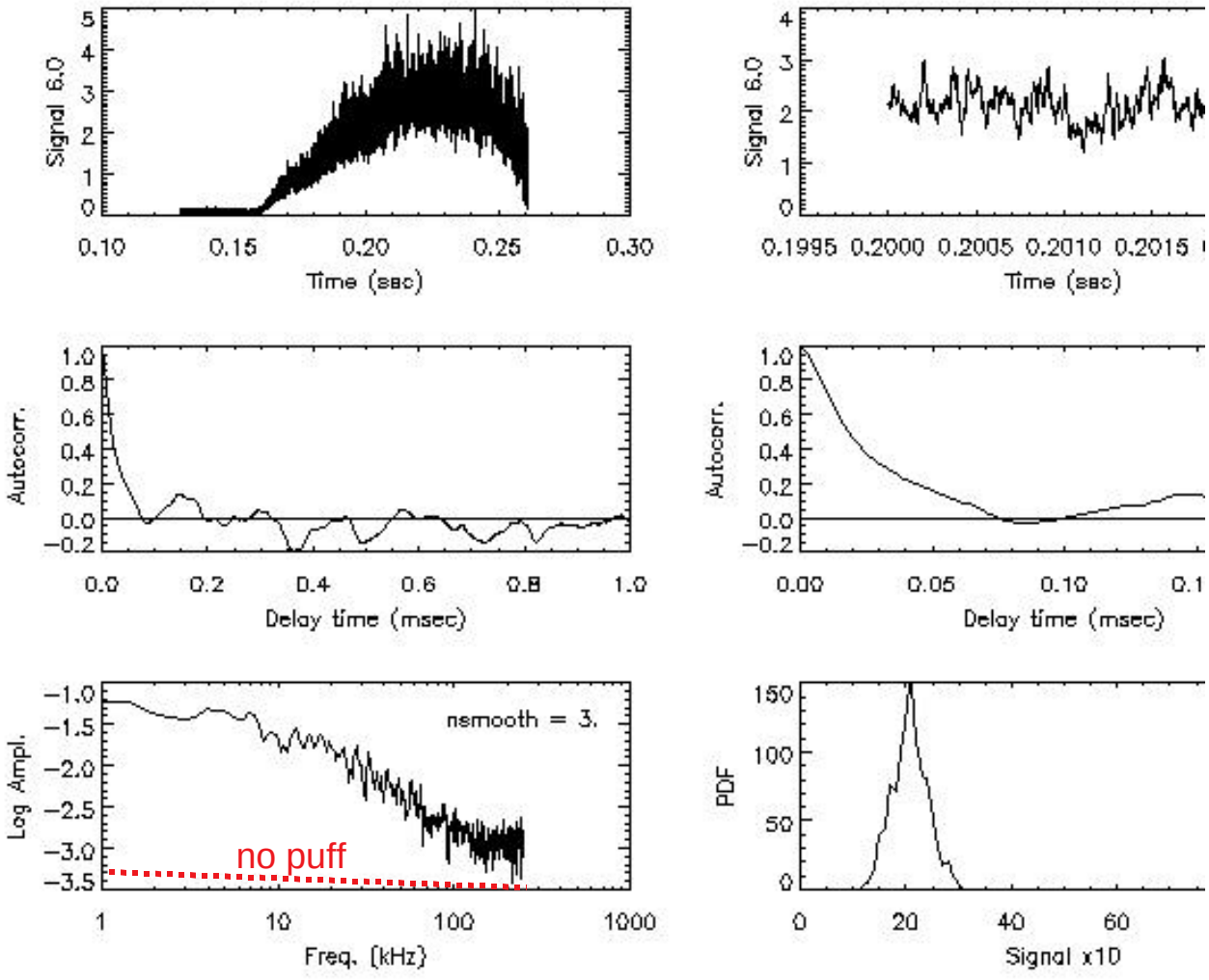


Time

E. Fredrickson

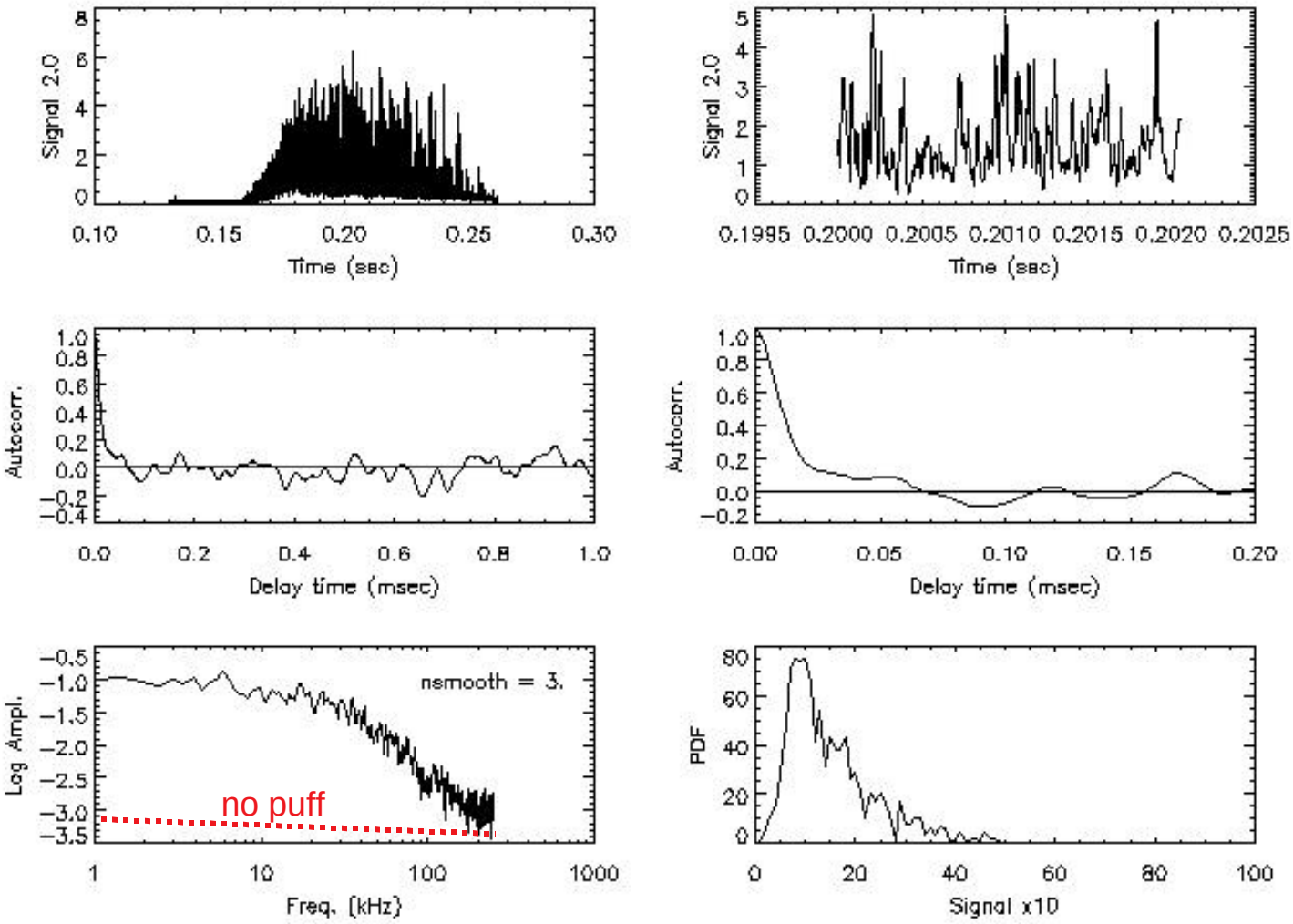
Statistics of Inner GPI Chord

- Looks like the usual “Gaussian” plasma turbulence



Statistics of Outer GPI Chord

- Looks like the usual “intermittent” SOL turbulence



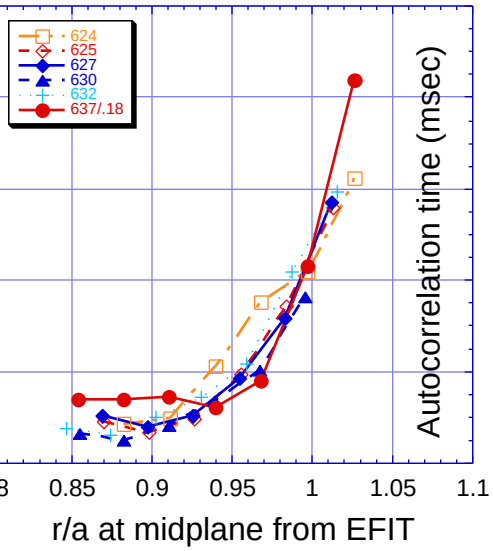
Radial Profile of GPI Fluctuations

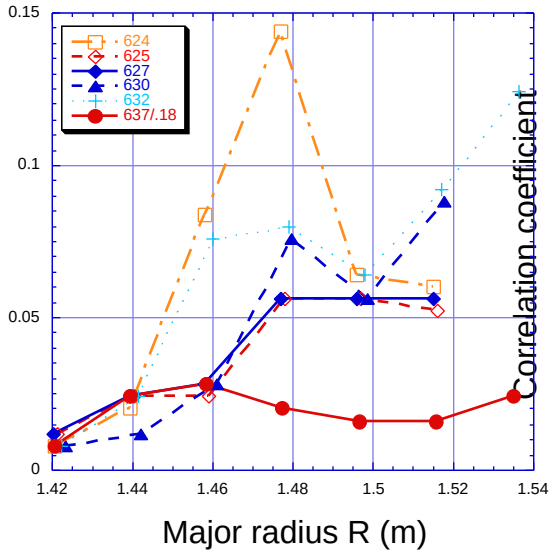
elative fluctuation level goes from ≈10% @ r/a≈0.85 to ≈100% outside separa

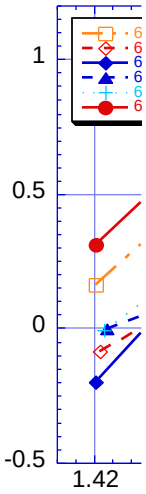
utocorrelation times ≈10-20 μsec @ r/a≈0.85 to ≈30-100 μsec outside separa

adial correlation lengths ≈ 4-7 cm in all cases (FWHM)

These are all at least qualitatively similar to edge turbulence measured elsew

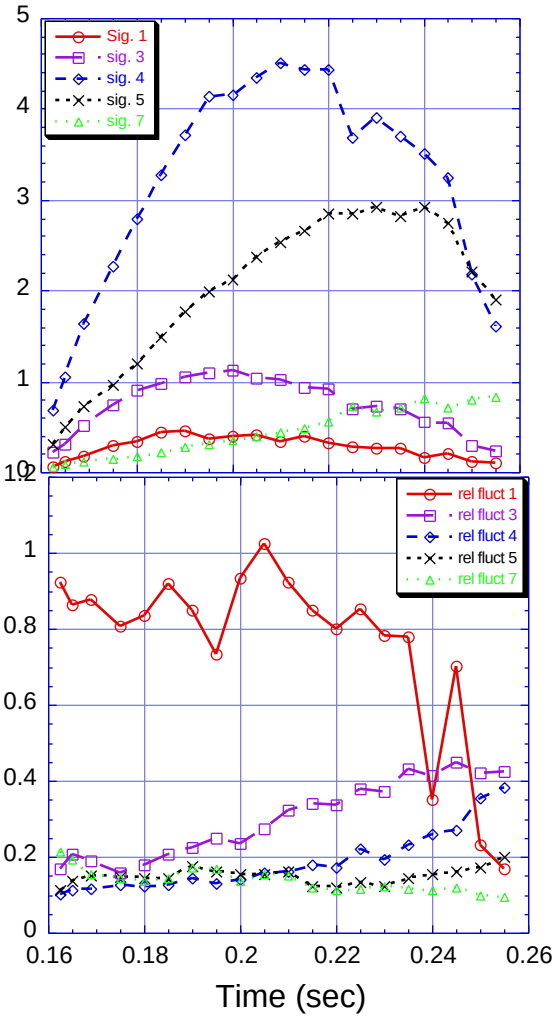


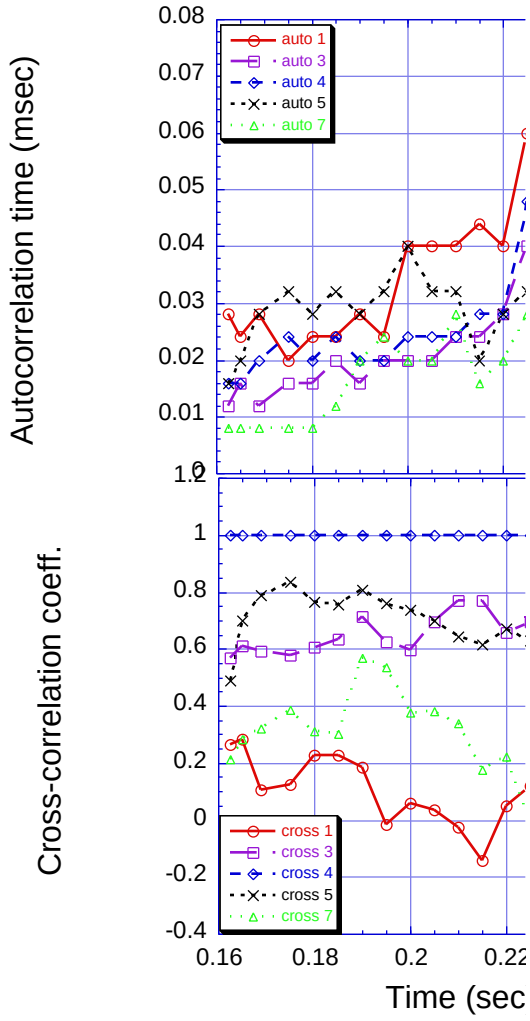




Fluctuations vs. Time (shot #105637)

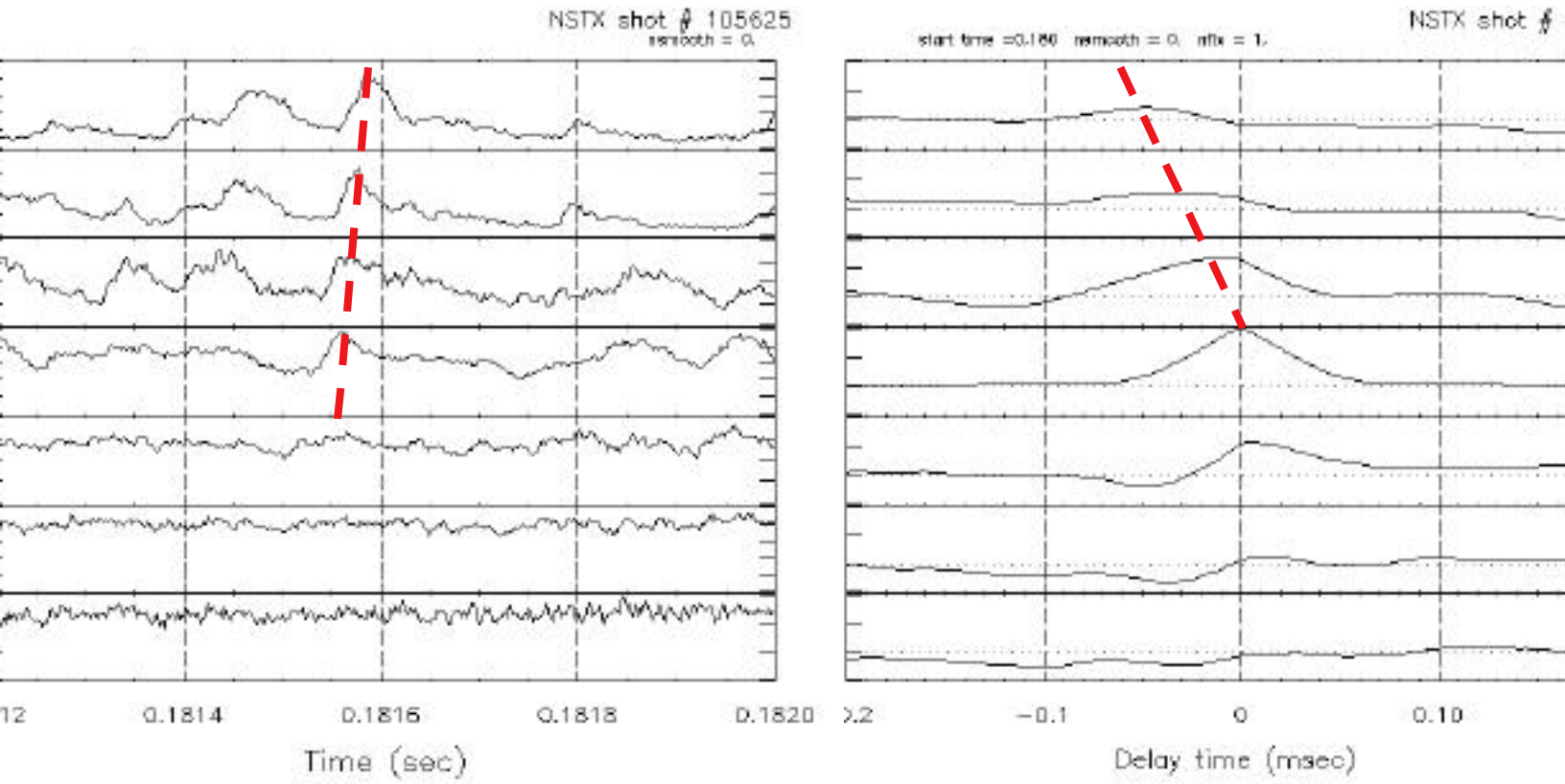
- Relative fluctuation levels and cross-correlation coefficients approx. constant over 0.16-0.22 sec (while signal levels rise by up to x6)
- Autocorrelation times seem to increase over time as density increases





Radial Propagation of Edge Turbulence

- Often (not always) a radially outward group velocity, especially in the outer channels, at $V_g \approx 10^5$ cm/sec (seen with LP in many machines)
- Also consistent with radially outward “blob” motion seen in GPI in C-Mod S

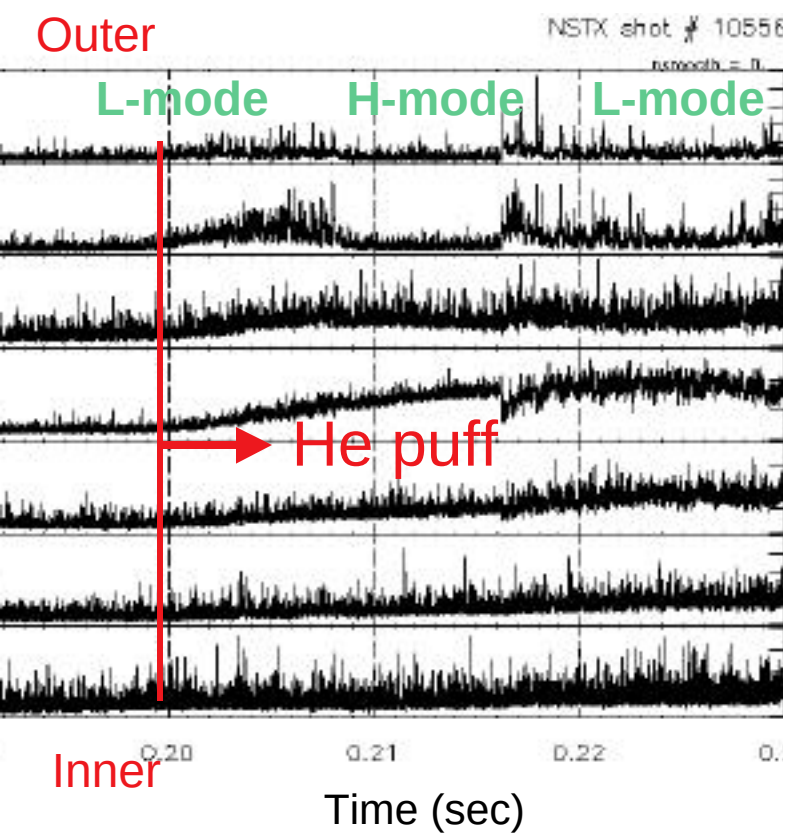


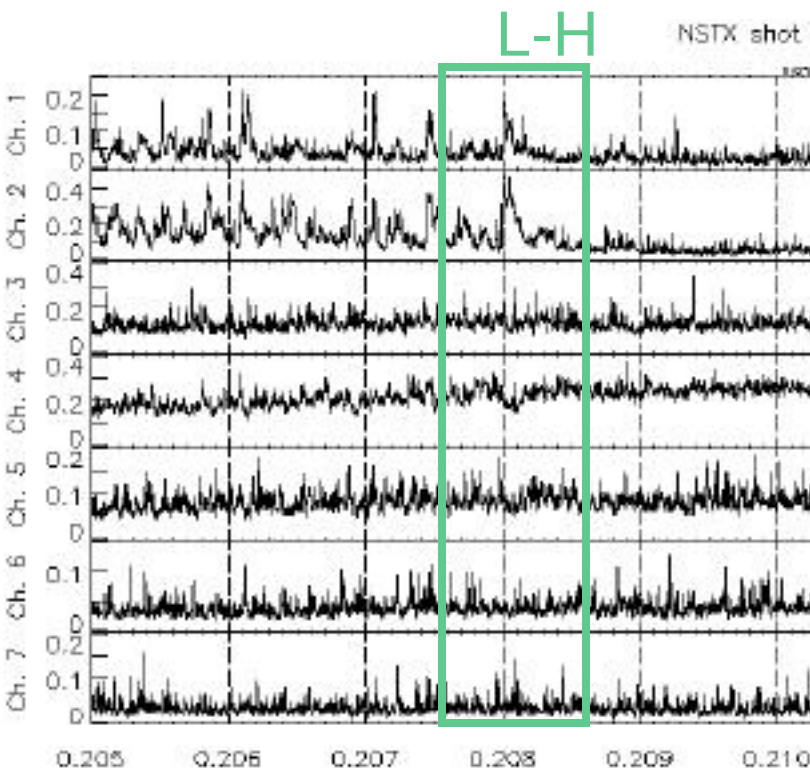
Edge Turbulence Signals at L-H Transitio

L-H transition occurs within ≈ 1 msec on most channels

Perhaps preceeded by large “bursts” in outermost channe

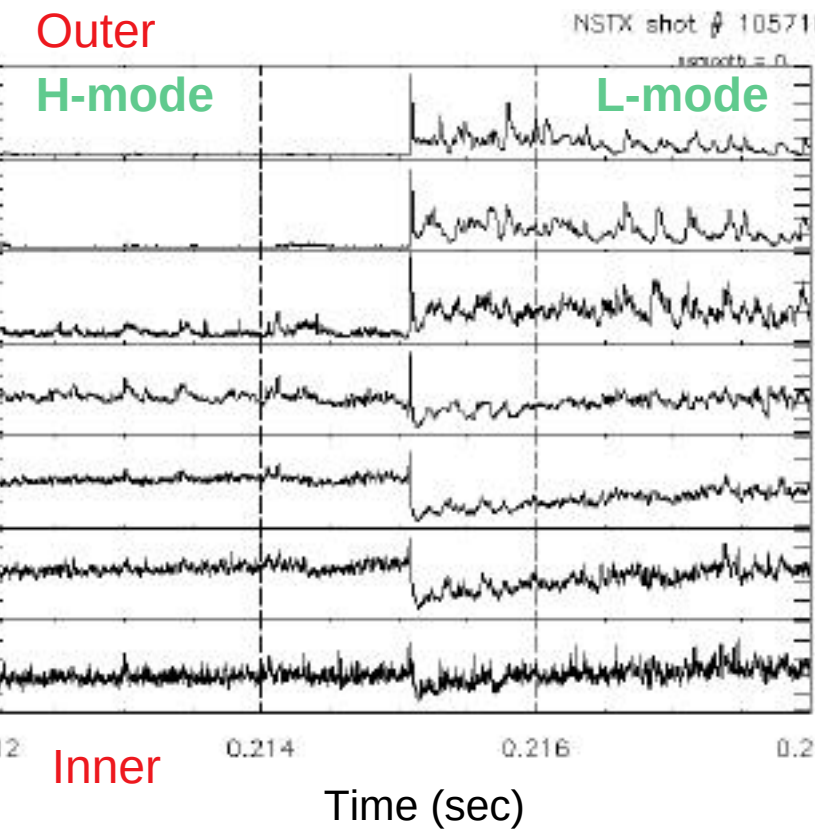
Data quality for L-H transitions is poor due to low signal le

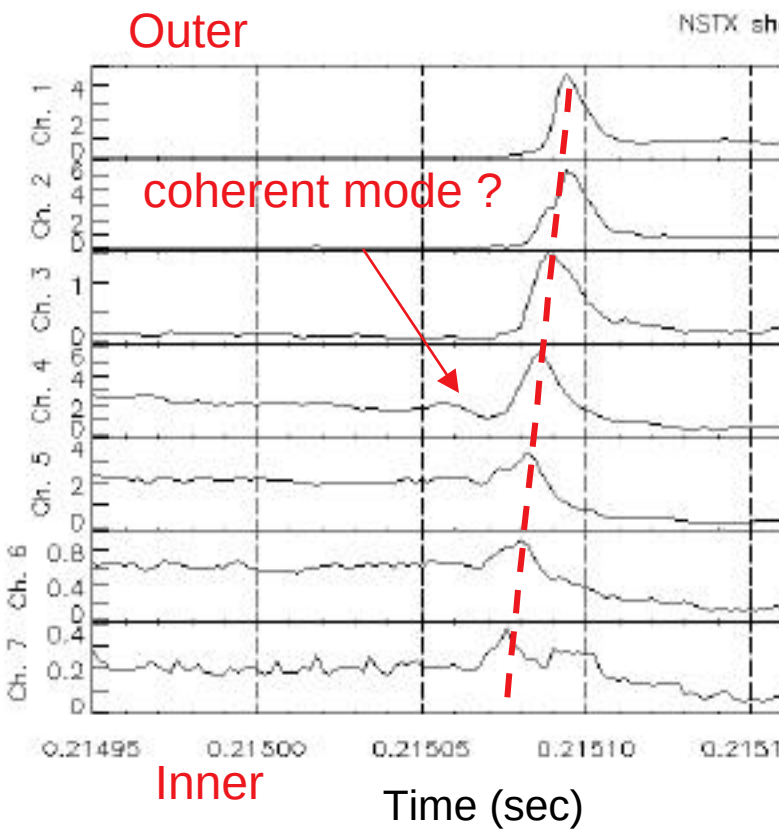




Edge Turbulence Signals at H-L Transitio

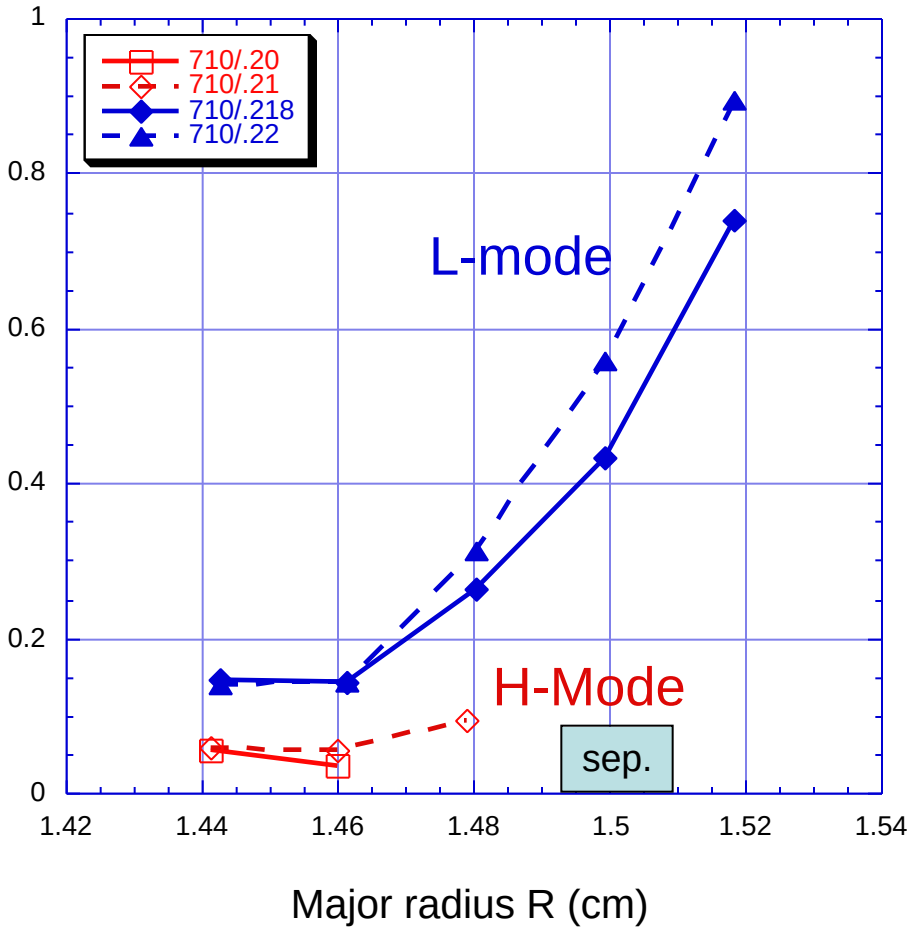
- H-L transitions occurs within ≈20 μsec in most channels
- Transition seems to propagate outward at ≈10^6 cm/sec
- Transition seems to start with coherent mode (ELM ?)

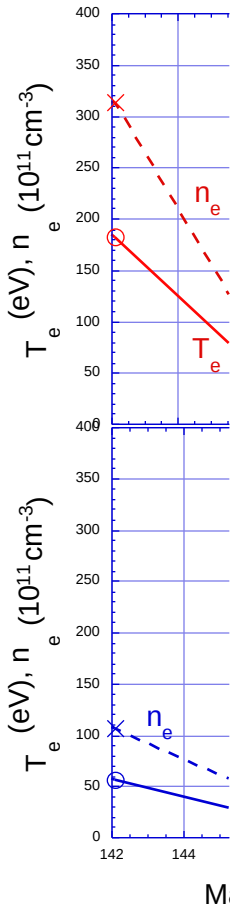




Fluctuation Profiles in H- vs. L-mode

- Fluctuation level seems to be lower in H-mode (but non-zero) in #105710 e
- Only one Thomson Scattering point within range of GPI data



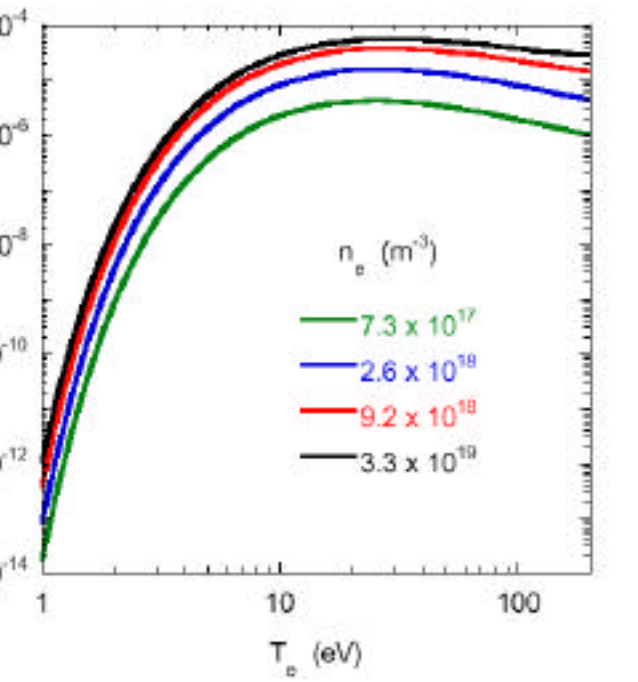


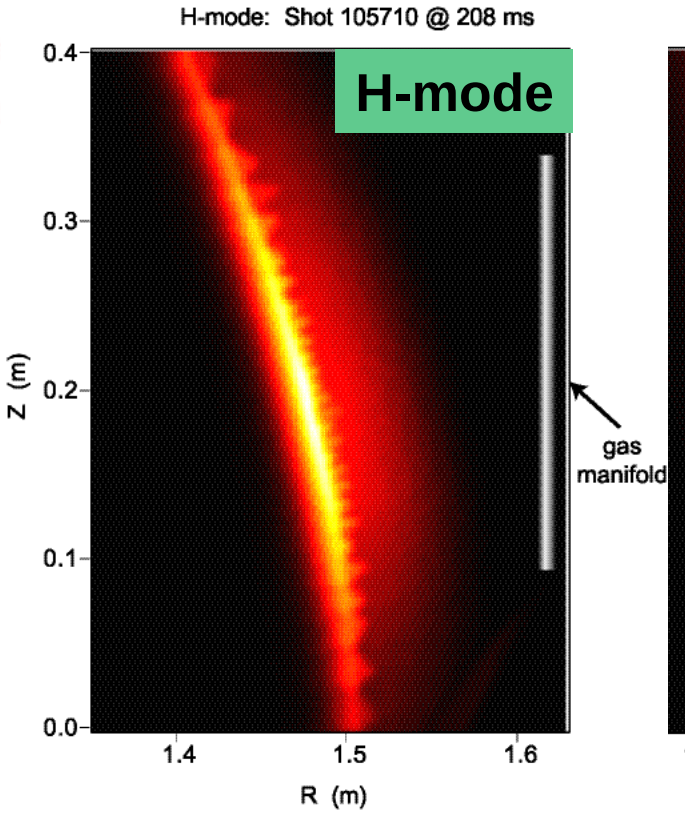
T_e=13.3 eV
n_e=1.1x10^{12} cm^{-3}

T_e=8.9 eV
n_e=2.2x10^{12} cm^{-3}

DEGAS-2 Simulation of GPI in NSTX

- Average HeI emission cloud can be simulated given edge profiles
- For $T_e \approx 10$ - 50 eV, HeI line emission $n_e^{0.5 \text{ to} 1.0}$ and $T_e^{1.5 \text{ to } -0.5}$
- H-mode emission is narrower due to narrower edge profiles





L-mo

D. S

Tentative Conclusions

Edge turbulence in NSTX looks similar to that in tokamaks, at least near outer midplane where we can see with G

Most dramatic variation comes with H-mode, where edge turbulence level seems to be reduced where we can see with GPI (just inside separatrix)

Quantitative interpretation of GPI fluctuations needs to be done in conjunction with edge profile measurements and modeling of neutral light emission (as in BES)

Plans for 2002

Add fast channels to make simultaneous 7 radial x 7 poloidal array D

Set up new Phantom fast camera for GPI imaging @ 1000 frames/se
(more sensitive and more pixels than Kodak camera) DONE

Swap Phantom with Princeton Scientific Instruments camera @ 1 mill
frames/sec for about 1-2 months (SBIR with PSI) EST. MID-APRIL

Get GPI data for the “Edge Characterization” XP along with good edg
profiles (TS, LP, reflectometry), and cross-check GPI data with other
edge fluctuation data (LP, reflectometer, USXR, etc.) MAY ?

Feed edge profiles to BOUT and DEGAS 2 to calculate expected GP
signals from theoretical simulations and compare with GPI data

Repeat (4)-(5) for other conditions, especially L/H mode and density li