Gas Puff Imaging of Edge Turbulence in NSTX

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NSTX Forum 01/01

- Introduction
- GPI measurements (so far)
- Plans

Introduction

- Goals and strategy
- Basic idea of GPI
- GPI setup in NSTX
- Interpretation of GPI
- Why do imaging ?

Goals and Strategy

Goals: Understand physics of edge turbulence as a basis for understanding:

- H-mode transition
- Power and particle flow across SOL
- Effects of wall conditioning
- CHI current penetration (?)
- ICRH wave coupling (?)

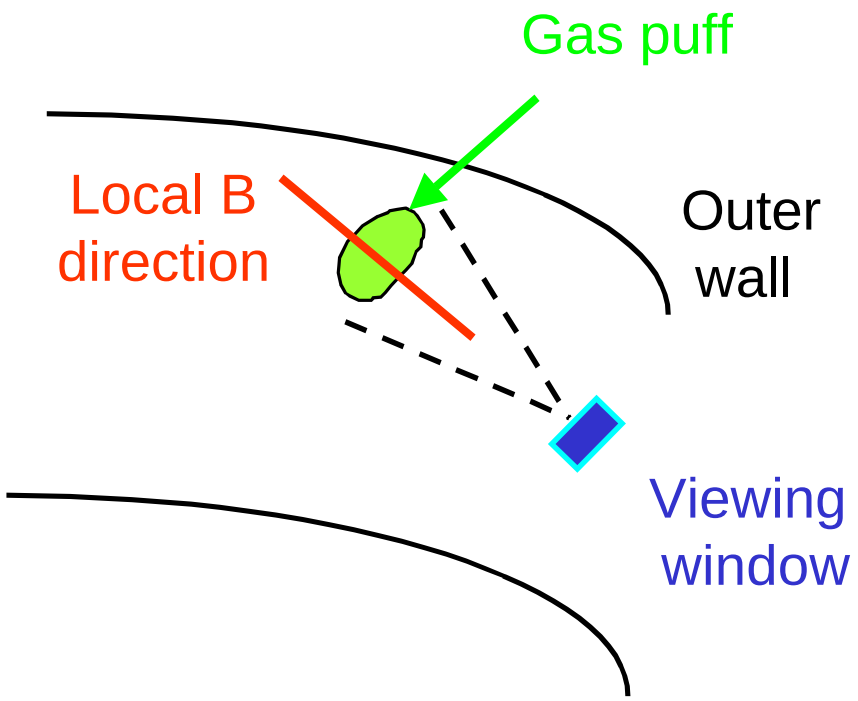
Strategy: Quantitative and detailed comparisons of experiment with theory

- Use "Gas Puff Imaging" to measure 2-D structure of edge density turbulence

- Compare with other diagnostics of edge turbulence, esp. probes

- compare numerical simulations for NSTX (e.g from Maryland, LLNL, Garching...)

Basic Idea of Gas Puff Imaging (GPI)



- Puff neutral gas somewhere at outer wall
- View visible light with gated camera (≈10 μs)
- For radial vs. poloidal structure, view || B
- For poloidal vs. toroidal structure, view ⊥ B

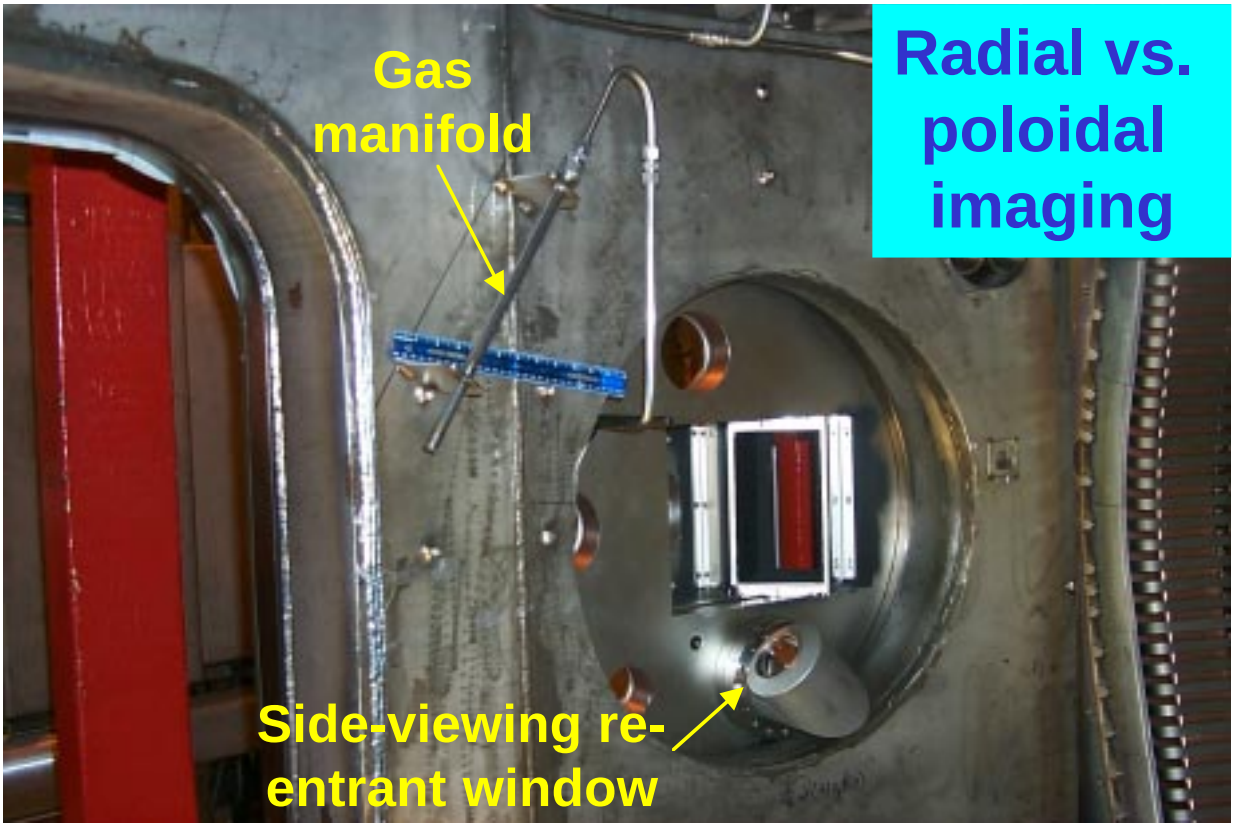
GPI Setup in NSTX (2000)

- **Radial vs. poloidal imaging:**

  Use “long” gas manifold to produce a 30-cm wide “linear” gas puff, with side-viewing re-entrant window to view puff

- **Poloidal vs. toroidal imaging:**

  Use puff from pumping port or natural recycling, viewing across machine from midplane window



Interpretation of GPI Data

Some Previous results:

ASDEX - fast movies show D_α filaments (~ '82)
Caltech - correlation of D_α and $\tilde{n}$ fluctuations
ASDEX - similarity of D_α and $\tilde{n}$ fluctuations
TFTR - "filaments" in D_α~ along B field line

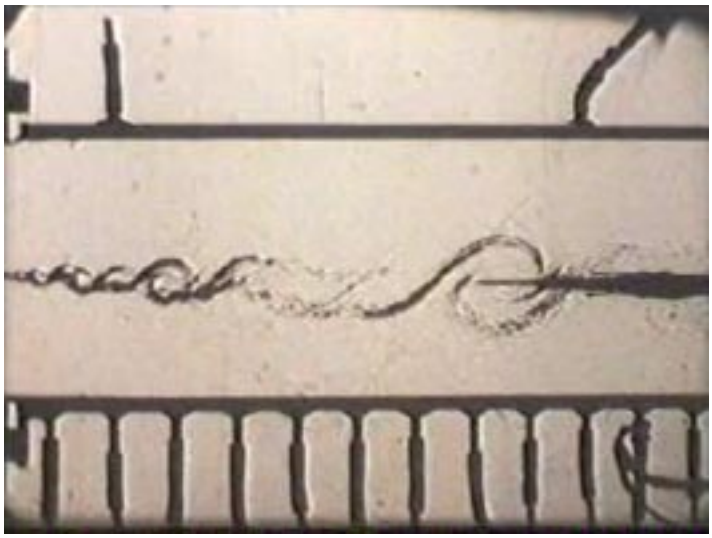
Tentative interpretations:

- Neutral light emission locally ~ $n_o\, n_e\, f(T_e)$
- Excitation and de-excitation times << 1 µsec
- Range of excitation $T_e \approx$ 5-50 eV (roughly)
- Within this range, fluctuations in neutral light emission are mainly caused by local density fluctuations

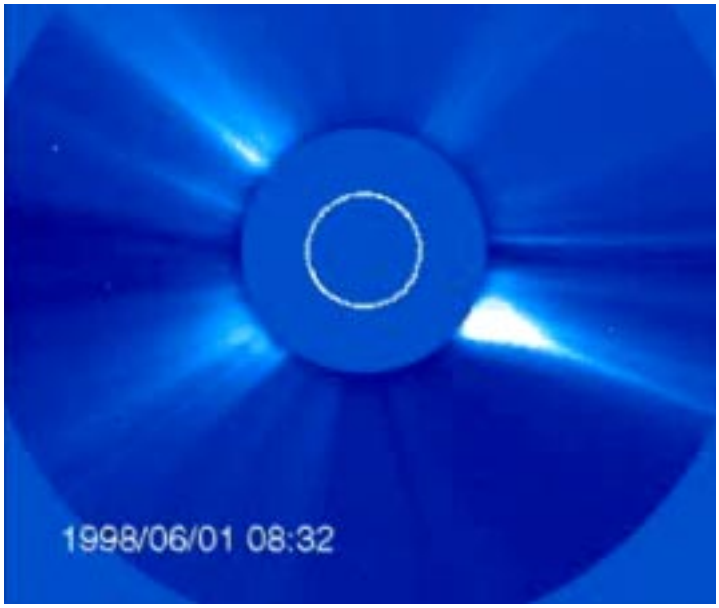
see: Maqueda et al, RSI '00
Zweben et al, EPS '00
Terry et al, J. Nucl. Mat. '00

Why do Imaging ?

- Used in modern turbulence research to look for "coherent structures"



turbulent gas mixing layer at high Reynolds # (Caltech 1981) from JOT web page



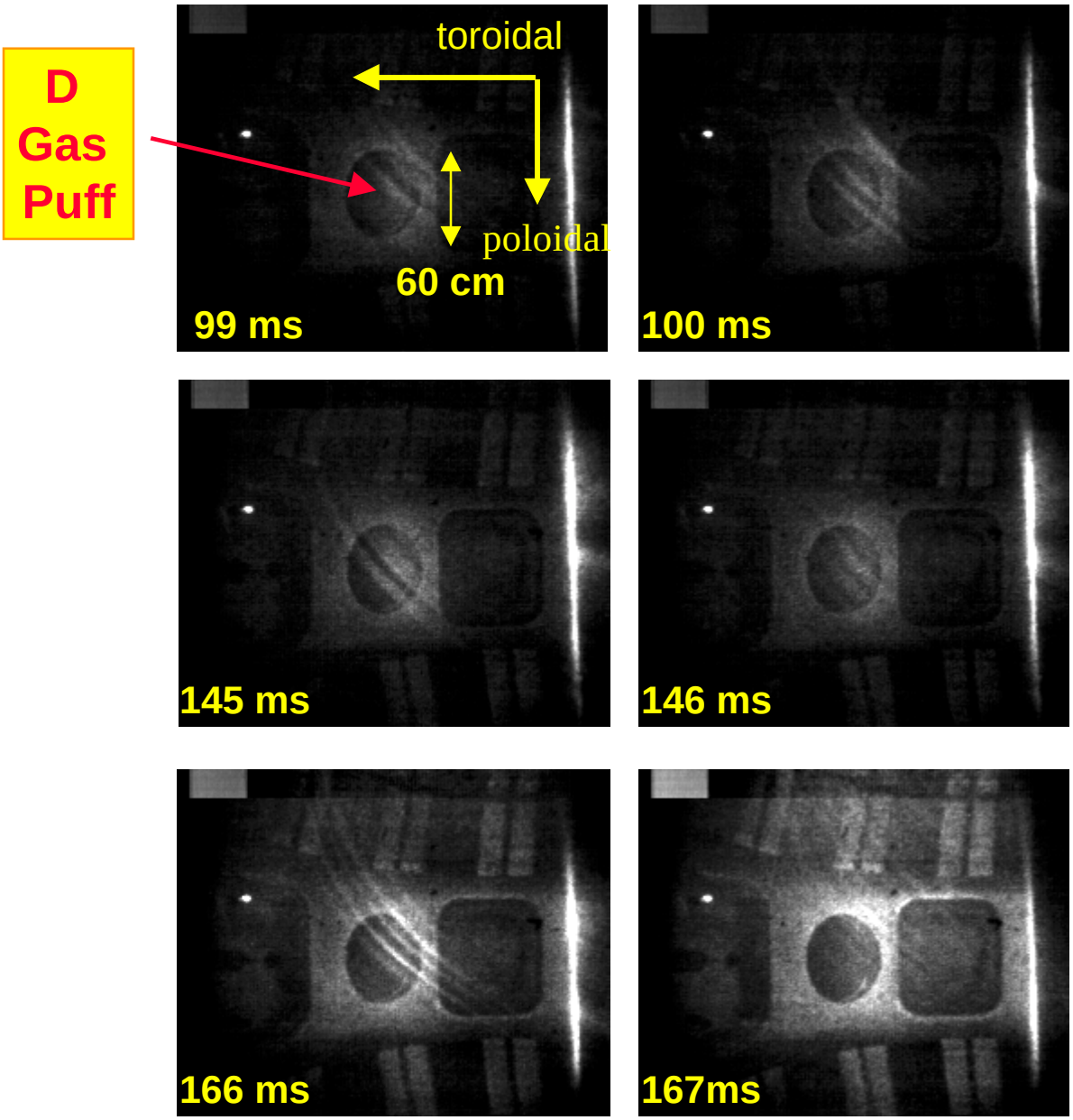
coronal mass ejection from the sun

GPI Measurements So Far (1999-2000)

- Toroidal vs. poloidal "filaments"
- Time series of local fluctuations
- Radial vs. poloidal structure
- Summary of results (so far)

Poloidal vs. Toroidal View of Puff Port

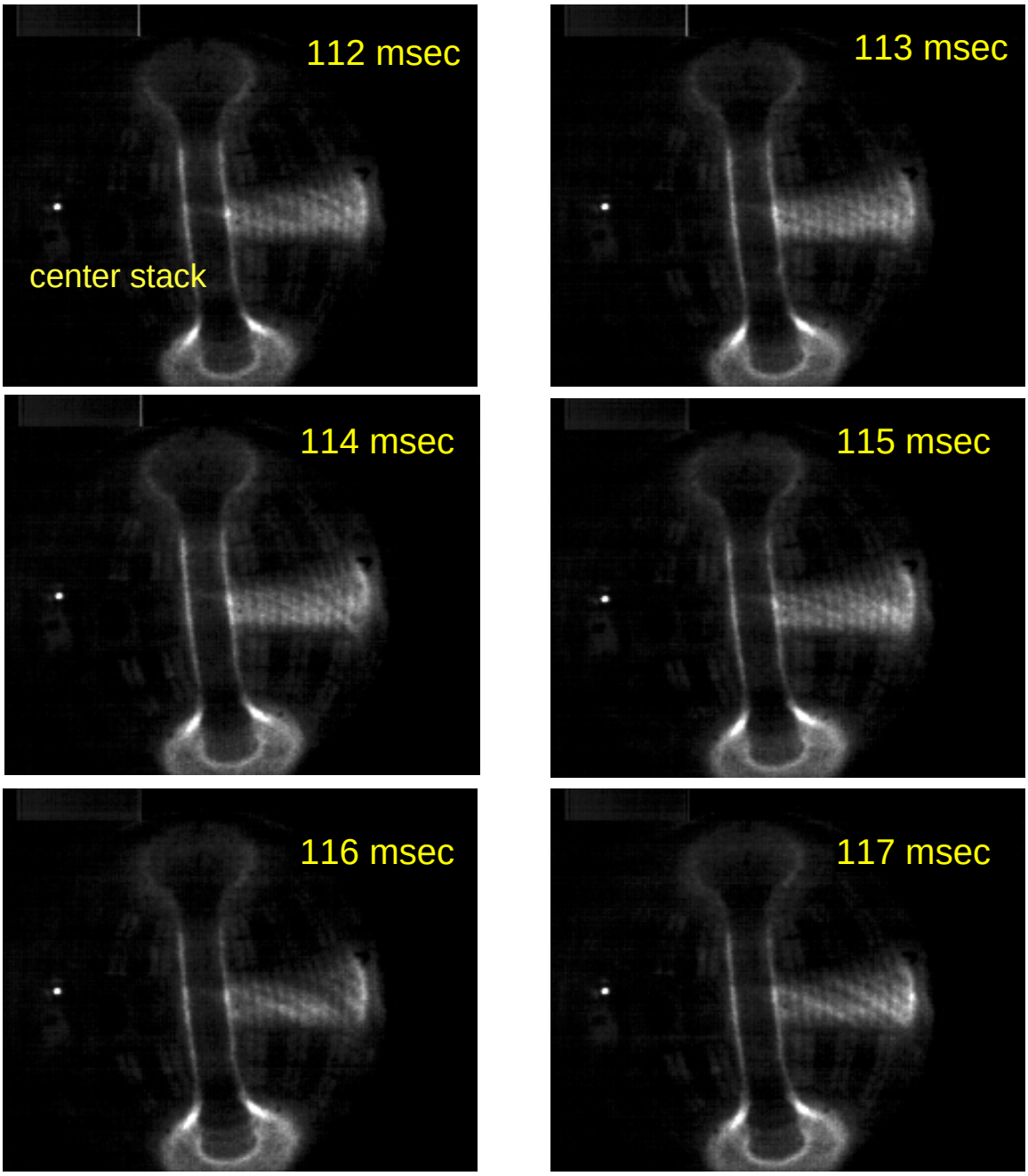
Deuterium gas puff with no filter
10 µs exposure @ 1000 frames/sec



Shot 101533

Images of Turbulence in Recycling Light on ICRF Antenna (no filter)

all Shot 101125, 20 µsec exposure time



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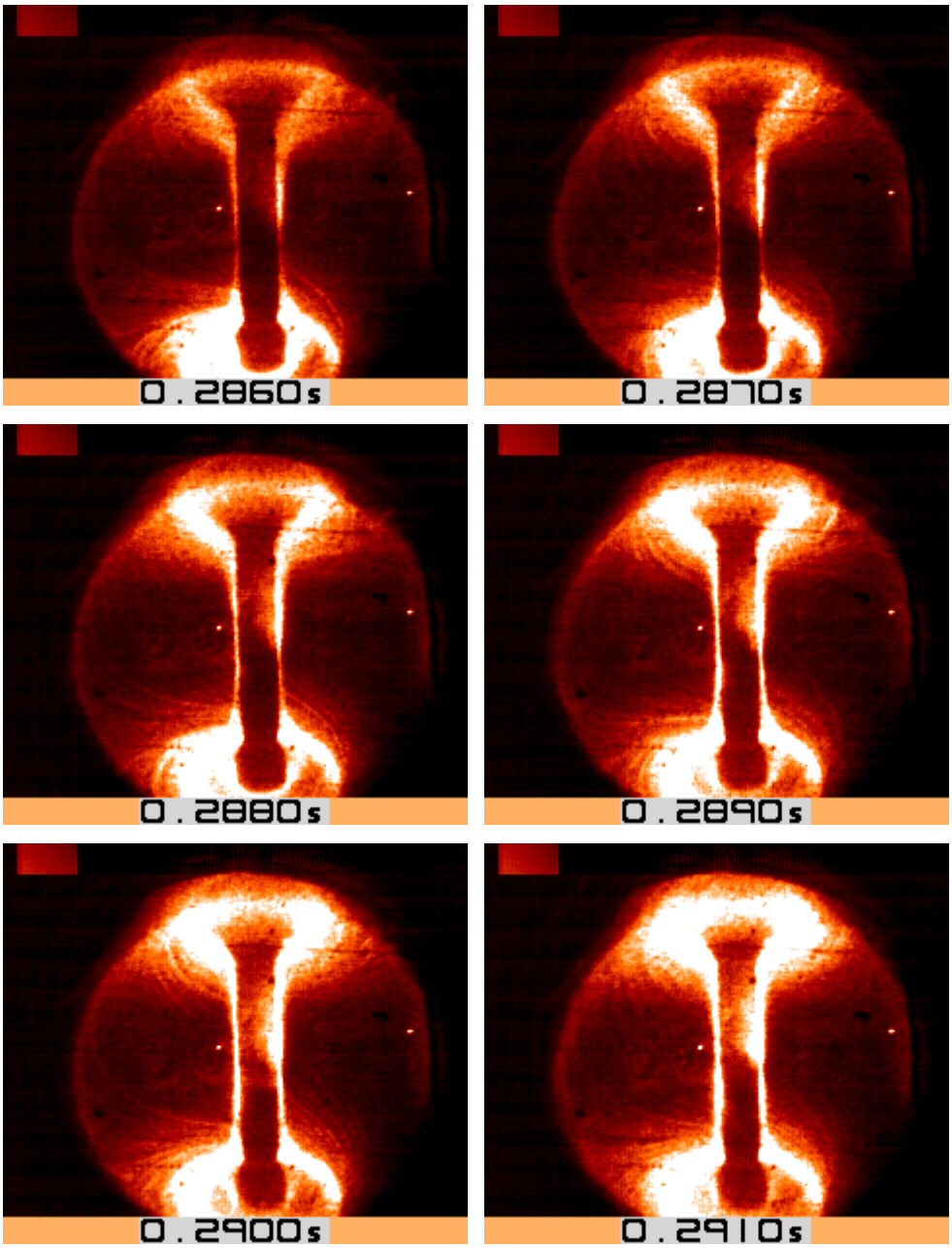
Edge filaments extend to upper and lower divertor regions

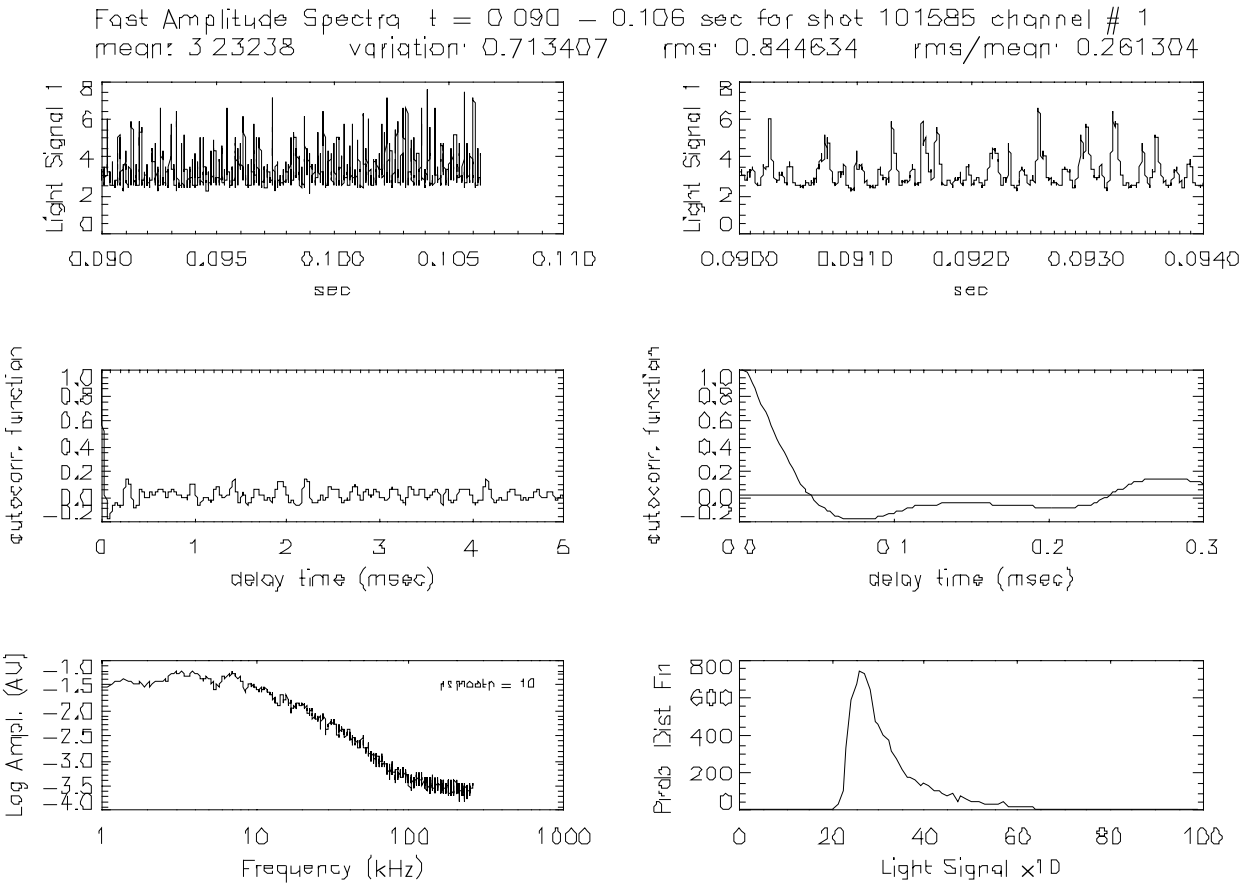
Unfiltered visible light, 10 μs exposure



Shot 103306

Time Series Analysis (Single Channel)

- Looking at gas puff port in D_α light
- Diameter of view ≈ 5 cm at wall
- Digitized at 500 kHz for 8 msec

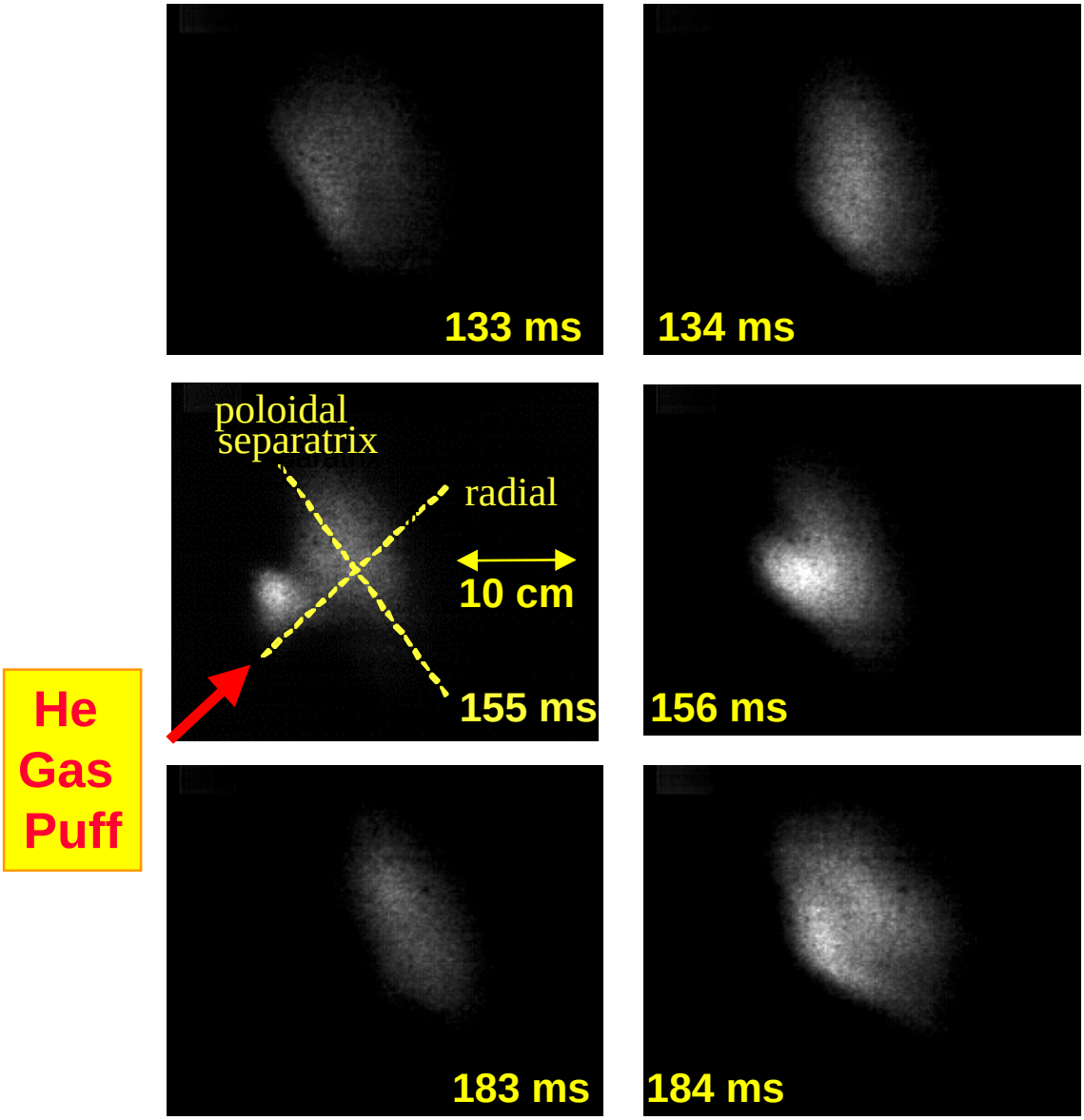


- rms/mean ≈ 25%
- τ(auto) ≈ 30 μsec
- power law f(-2±1)

- no long-time correlations
- tail on probability dist. f'n
- often seems like "bursts"

Radial vs. Poloidal View (point puff)

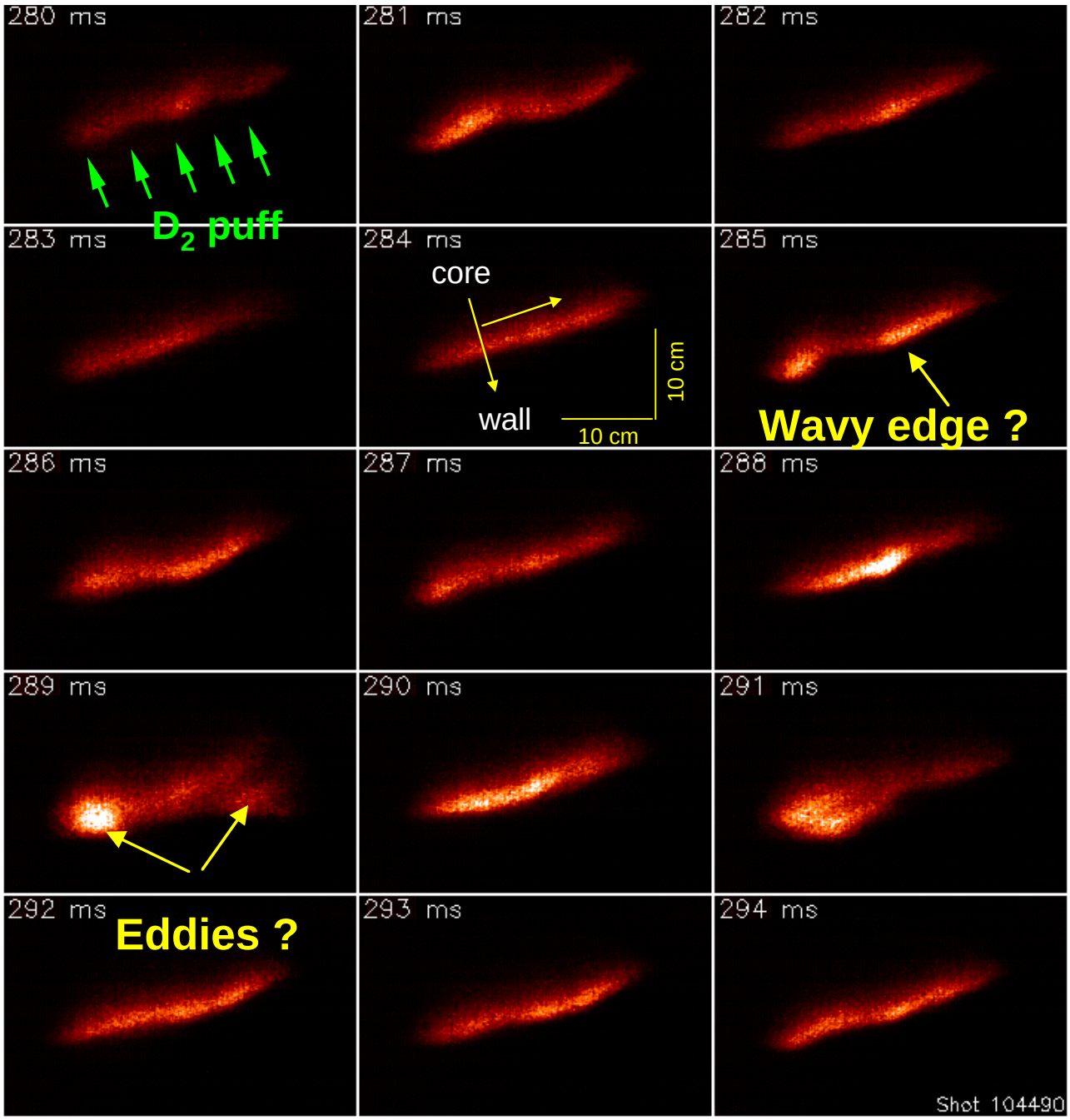
Helium gas puff with HeI filter (587.6 nm)
10 μs exposures @ 1000 frames/sec



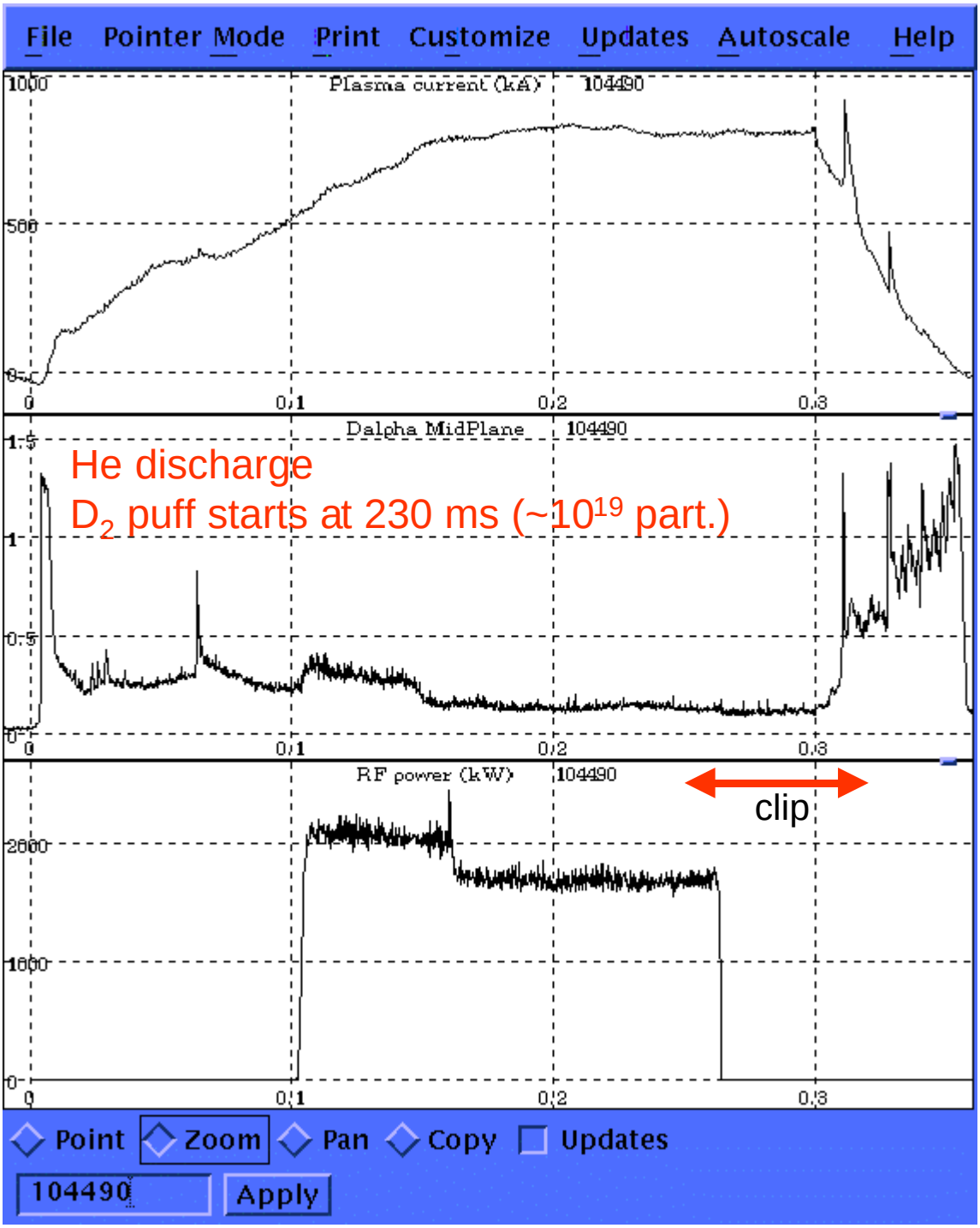
Shot 101989

Radial vs. Poloidal View (line puff)

D_2 puff on He discharge, D_α filter, 10 μs exposure



Plasma Behavior for this Shot



Radial vs. Poloidal View - Movies

Summary of NSTX GPI Results So Far

- Toroidal vs. poloidal structure

  - Strong poloidal vs. toroidal filamentation is seen in all images of edge neutral light emission with exposure times ≤ 30 μsec or so (blurs at ≥ 100 μsec exposure)

  - These filaments are aligned nearly along the total B field direction at the edge (typically ≈ 45º in NSTX), with poloidal wavelength of the observed filaments:

$$\lambda_{pol} \approx 10\text{-}15 \text{ cm, i.e. } k_{pol}\, \rho_s \approx 0.1\text{-}0.2 \text{ @ } T_e \approx 25 \text{ eV}$$

- Time series of local fluctuations

  - The filament structure does not stay the same from frame-to-frame at up to 4000 frames/sec

  - Frequencies spectrum of local light fluctuations is broad (≈ 1-100 kHz), autocorrelation time ≈ 30 μsec

- Radial vs. poloidal structure

  - Radial vs. poloidal structure seems to be a combination of large-scale "waves" and small-scale "eddies"

Plans

- Potential diagnostic improvements
- Analysis of images and time series
- Interpretation of GPI fluctuations
- Plan for experiments / data taking
- Comparison with theory / modeling
- Needs for other measurements

Potential Diagnostic Improvements

- Multi-point time series from an array of discrete fibers viewing puff (should have 8 channels in '01)
- Higher framing rate camera (tried PSI million-frame/sec camera in Dec. '00, continue in '01)
- Try different gases and compare results (e.g. Ne, Ar), especially to look at neutral vs. ion light
- Improve gas nozzle to increase speed or directionality of puff

Analysis of Images and Time Series

Goal: analyze space-time structure of raw data

- Poloidal vs. toroidal structure
  - have code to compute k_{pol} spectrum (Maqueda)
  - have code to compute filament statistics (Davis)
  - need code to find $k_{||}$ spectrum by comparing w/ EFIT
- Radial vs. poloidal structure
  - almost have code to evaluate k_{pol} and $_{kr}$ spectra
  - need code to search for "coherent structures"
- Time series from discrete detectors
  - have code to do spectrum/correlation analysis,
  - need code to do fractal dimensionality, avalanches, etc.

Interpretation of GPI Fluctuations

Goal: interpret GPI light fluctuations in terms of local density or temperature fluctuations

- Neutral codes

  - determine region where light is emitted f(n,T...)
  - evaluate level of neutral density fluctuations
  - evaluate possible effects of neutrals on turbulence
  - evaluate possible effect of turbulence on neutrals

- Atomic physics code

  - calculate light emissivity as f(n,T, ...)
  - evaluate frequency response to fluctuations
  - look for variations with species / atomic state

- 3-D geometry code

  - evaluate geometrical wavelength sensitivities
  - evaluate alternate viewing/puffing geometries

Plan for Experiments / Data Taking

- Dedicated experiment (XP-10)
  - vary gas puff strength and gas species
  - make systematic density / power scans
  - look at L -> H and H -> L transitions

- Routine data taking on other experiments

We would like to take both imaging and time series data on all plasmas, but we need a small puff of gas during each shot !

  - look at effects of ICRH and CHI on turbulence
  - look for MHD ballooning modes at high beta
  - look for correlations with global confinement

Comparison with Theory / Modeling

Realistic edge turbulence models have only been developed in the past few years !

- Types of models:
  - Rogers et al - drift-ballooning slab fluid code
  - Xu et al - many modes with 3-D fluid code
  - Myra, D'Ippolito - linear code for surveys
- Comparisons can be made with GPI on:
  - radial and poloidal correlation lengths
  - coherent structures and zonal flows (?)
  - changes at density limit and H-mode
- Relevant dimensionless parameters:

$\alpha = -R\, q^2\, \beta/L_p \propto nT$ (MHD ballooning parameter)
$\alpha_d = \rho_s c_s t_o/[1+\tau)L_n L_o] \propto T/n^{0.5}$ (diamagnetic parameter)
Edge plasma: ρ_s/R, β, $L_\perp/\rho_s$, $L_\parallel/\rho_s$, s, ν, etc.
Neutrals: n_o/n_e, λ_o^*, ν_{cx}/ν_b , etc.

Needs for Other Measurements

- Wall conditions
  - surface coatings on walls and limiters
  - heat loads on walls and limiters
  - electrical conduction paths
- Neutral and impurity influx
  - 3D emissivity of D_α, esp. fraction in/out of LCFS
  - 3D visible emissivity of carbon, oxygen, etc
  - bolometry for edge power balance
- Edge plasma parameters
  - density, electron and ion temperatures, Z_{eff}
  - current density and plasma flow speeds
  - magnetic flux surfaces & electrostatic potential
- Edge fluctuations
  - electrostatic fluctuations (n, φ, T_e)
  - magnetic fluctuations (probe and at wall)
  - low frequency structures (convective cells ?)