Exponential Frequency Spectrum and Anomalous Transport

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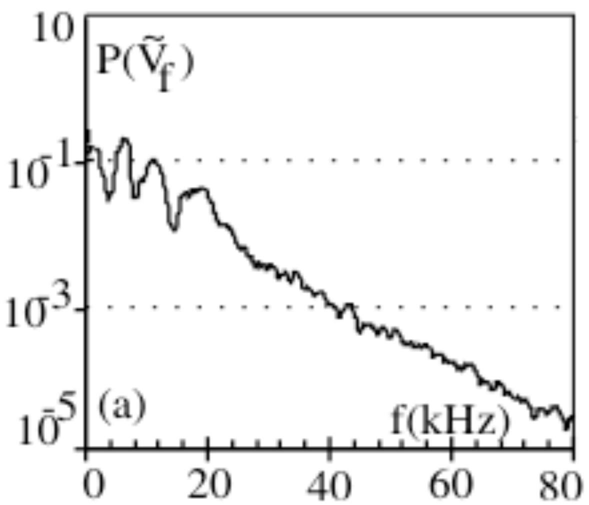
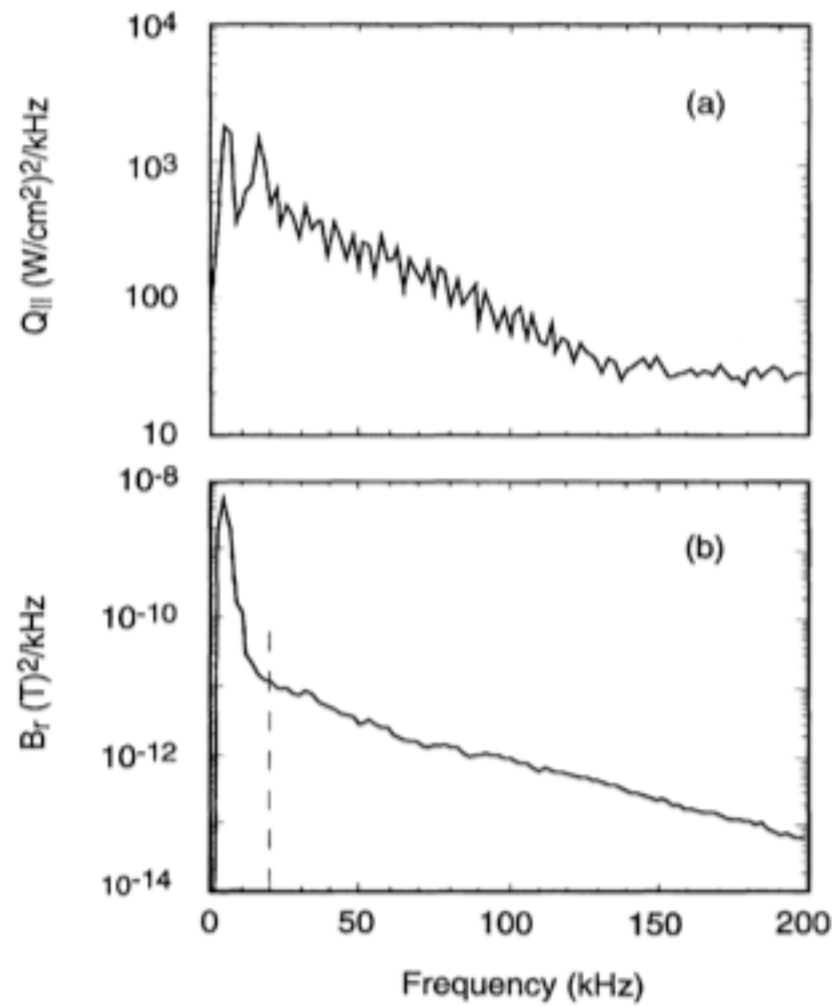
Exponential Spectra Observed in Different Experiments



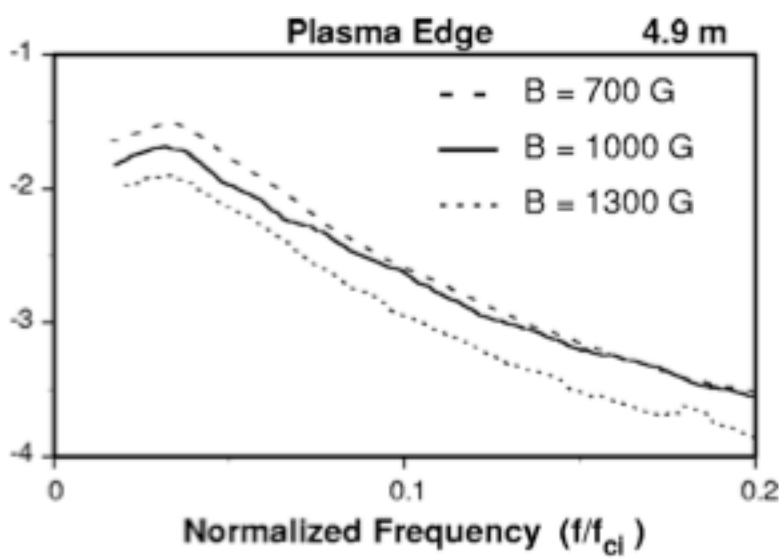
- Floating potential power spectra in the helical device, H1.
- Device demonstrates inverse energy cascade.

Fig. 1a: H. Xia and M. G. Shats, Phys. Rev. Lett. 91, 155001 (2003)



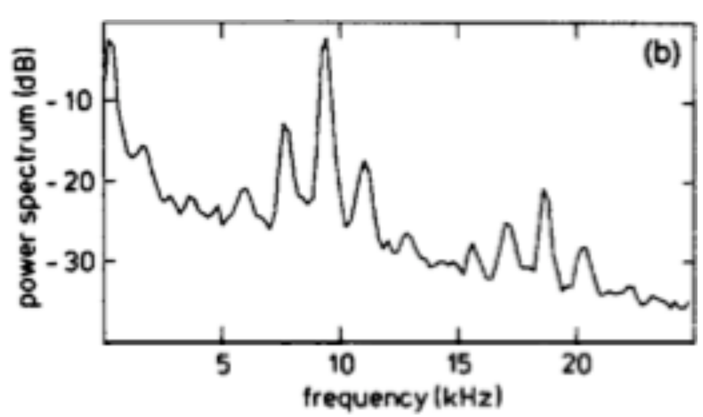
- Parallel electron heat flux in a tokamak, CCT.
- Radial magnetic field.

Fig. 1: G. Fiksel, et al., Phys. Rev. Lett. 75, 3866 (1995).



- Magnetic field fluctuations in the edge of the linear device, LAPD.
- Spontaneously generated, basic turbulence phenomena.

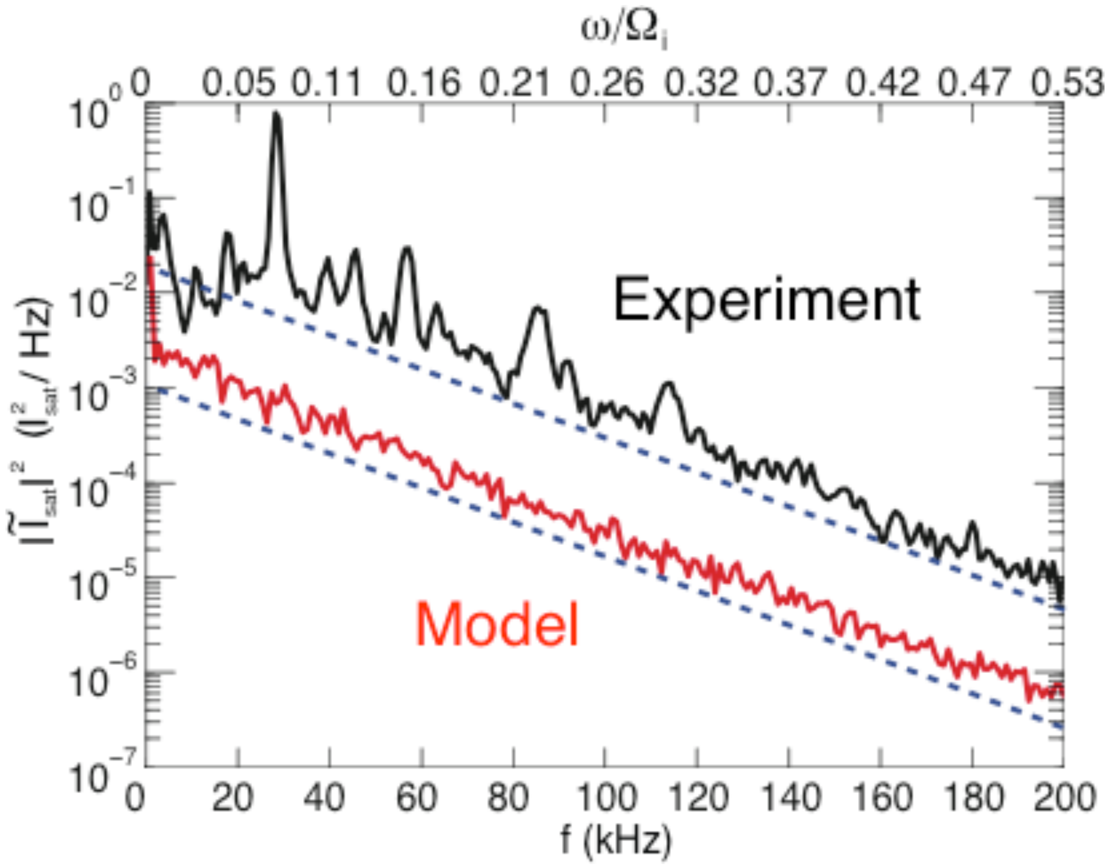
Fig. 7: J. E. Maggs and G. J. Morales, Physics of Plasmas 10, 2267 (2003)



- Ion saturation currents measured in a linear arc plasma device.
- Coherent peaks rise above the baseline exponential spectrum.

Fig. 6b: U. Kauschke, G. Oelerich-Hill, and A. Piel, Physics of Fluids B: Plasma Physics 2, 38 (1990)

LAPD Experiments Exhibit Exponential Spectra

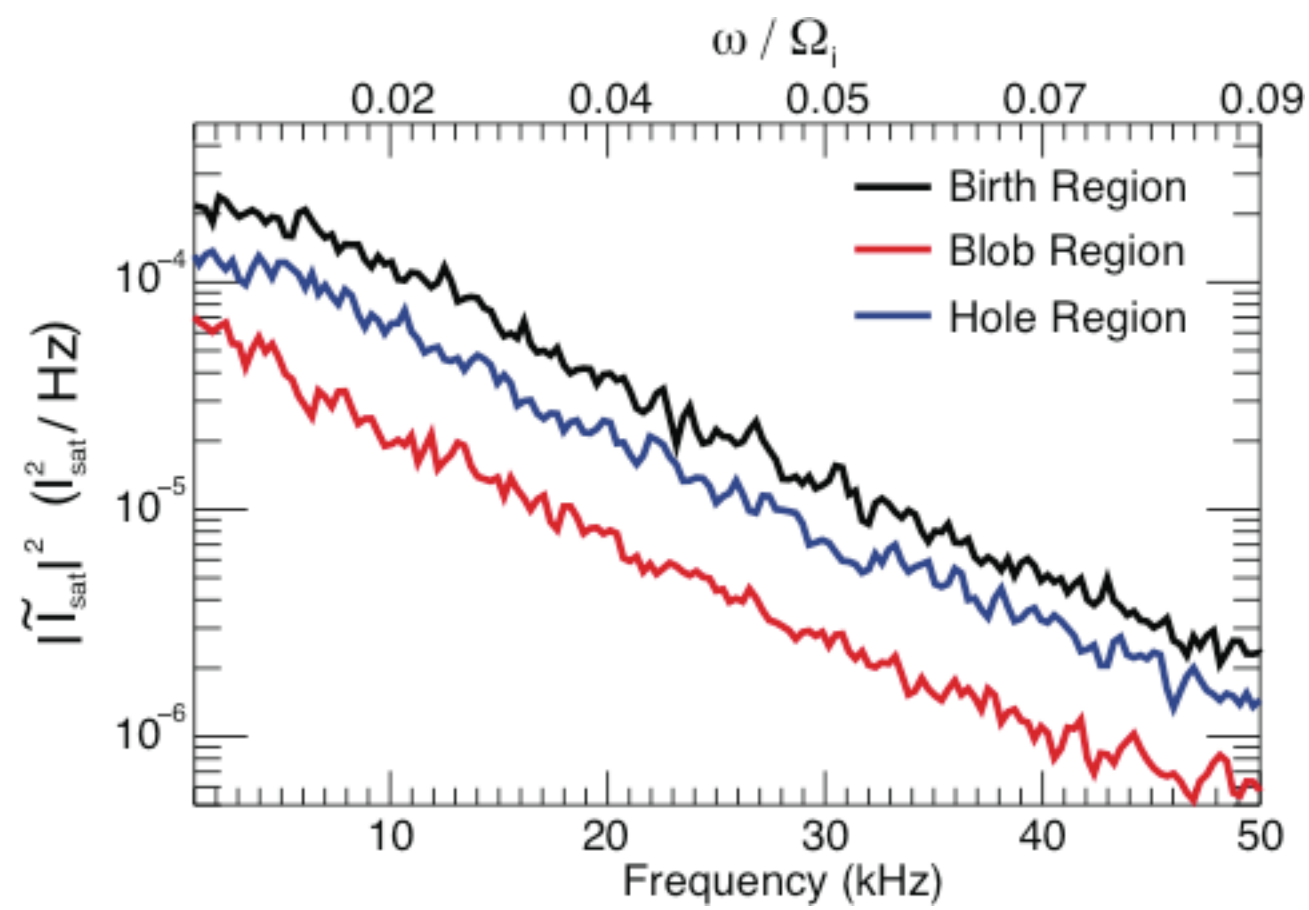


Electron Temperature Gradient Experiment

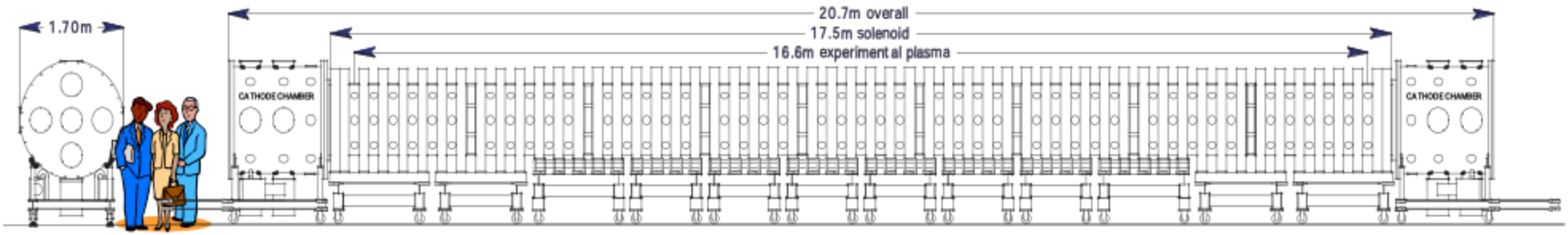
- Coherent modes are observed in addition to the exponential behavior.

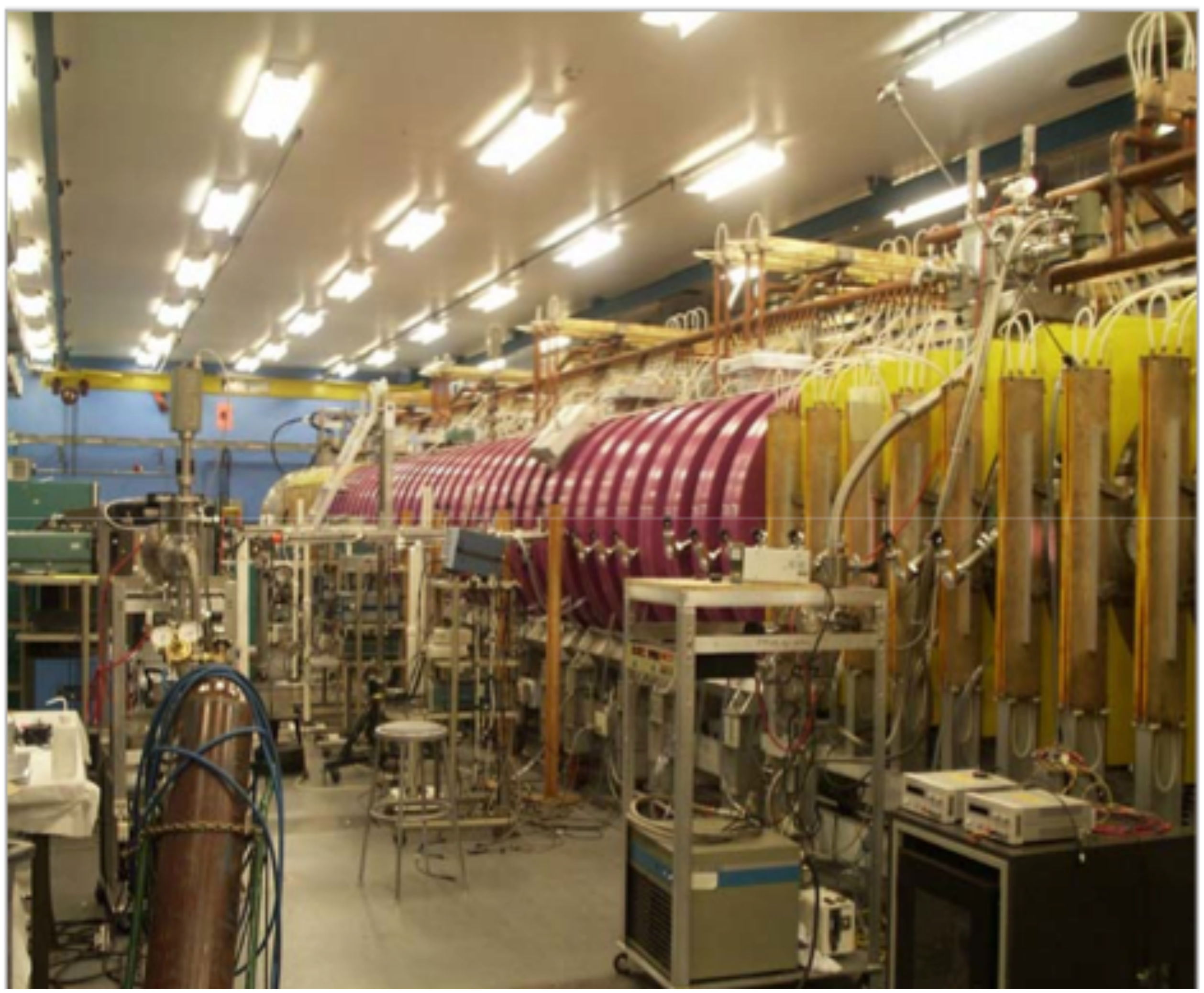
Edge Density Gradient Experiment

- No coherent modes in the LAPD edge plasma.



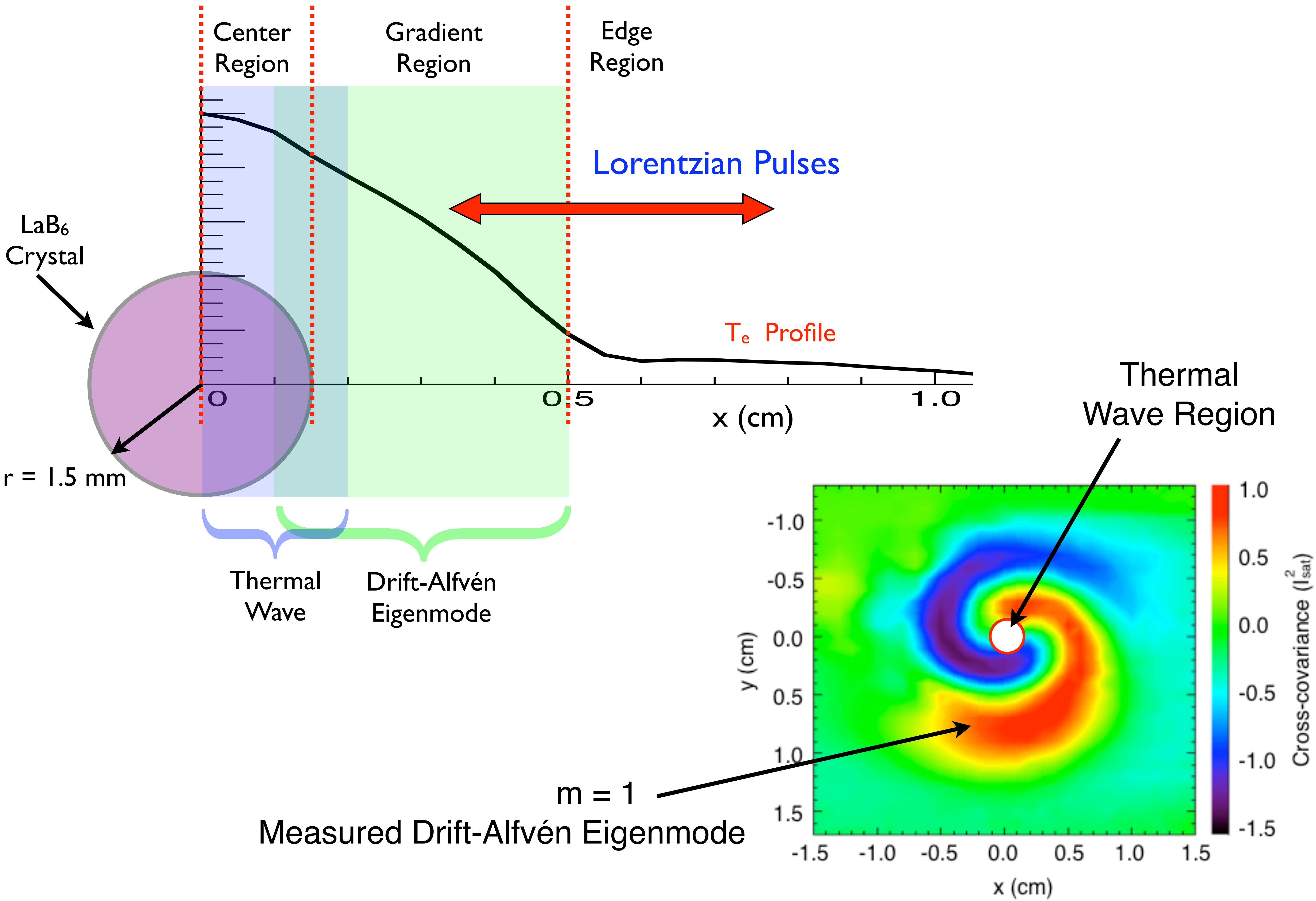
Experiments are Performed in the Large Plasma Device (LAPD)



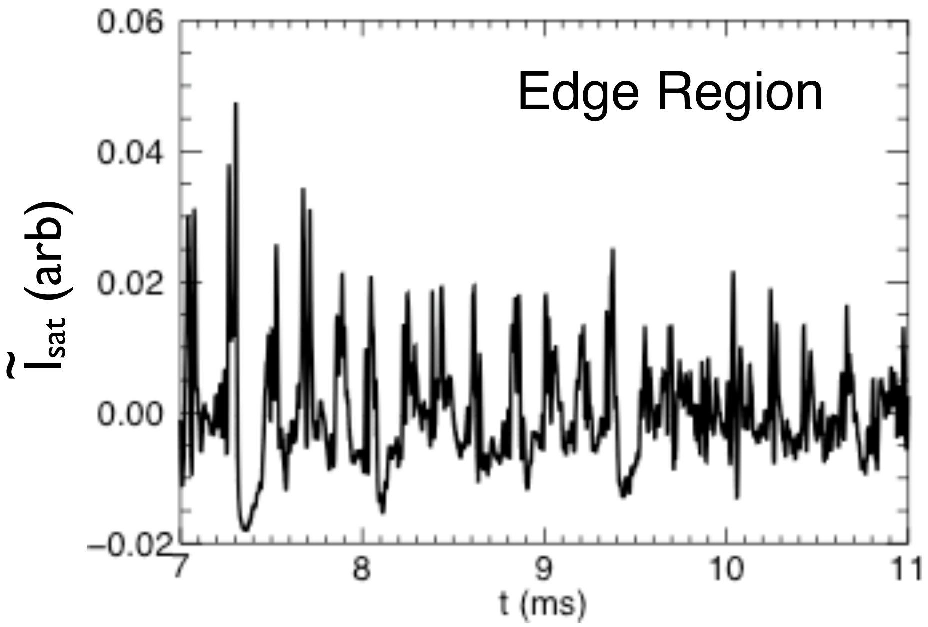


Cathode discharge plasma
Highly Ionized plasmas n ≈ 3 x 10^{12} /cm^3
Reproducible, 1Hz operation
> 4-month cathode lifetime
Up to 2.5kG DC Magnetic Field on axis
Plasma column up to 1000R_{ci} in diameter
Over 450 Access ports, with 50 ball joints
Computer Controlled Data Acquisition
Microwave Interferometers
Laser-Induced Fluorescence
Large variety of probes

Spatial Dependence of Fluctuations in Electron Temperature Gradient Experiment

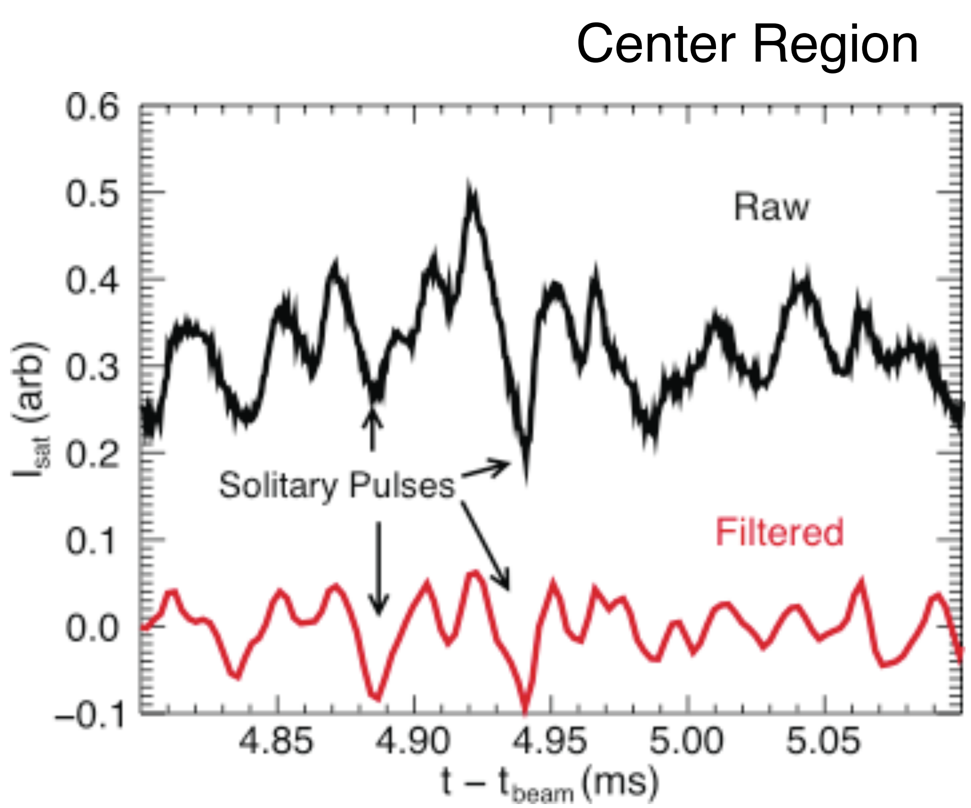


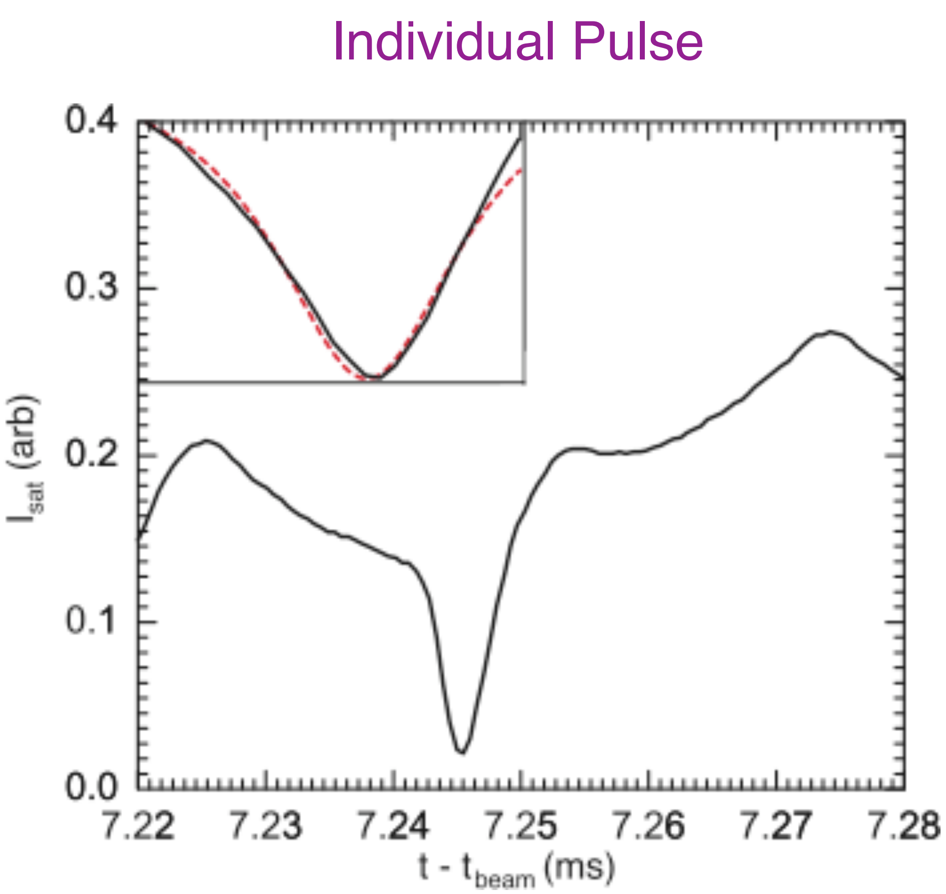
Time Series Contain Lorentzian Shaped Pulses



Electron Temperature Gradient Experiment

- I_{sat} measurements in the filament edge region display positive-going intermittent spikes.
- Spikes appear relatively late in the heating period.
- Signals from near the center of the filament demonstrate spikes of a negative-going character.





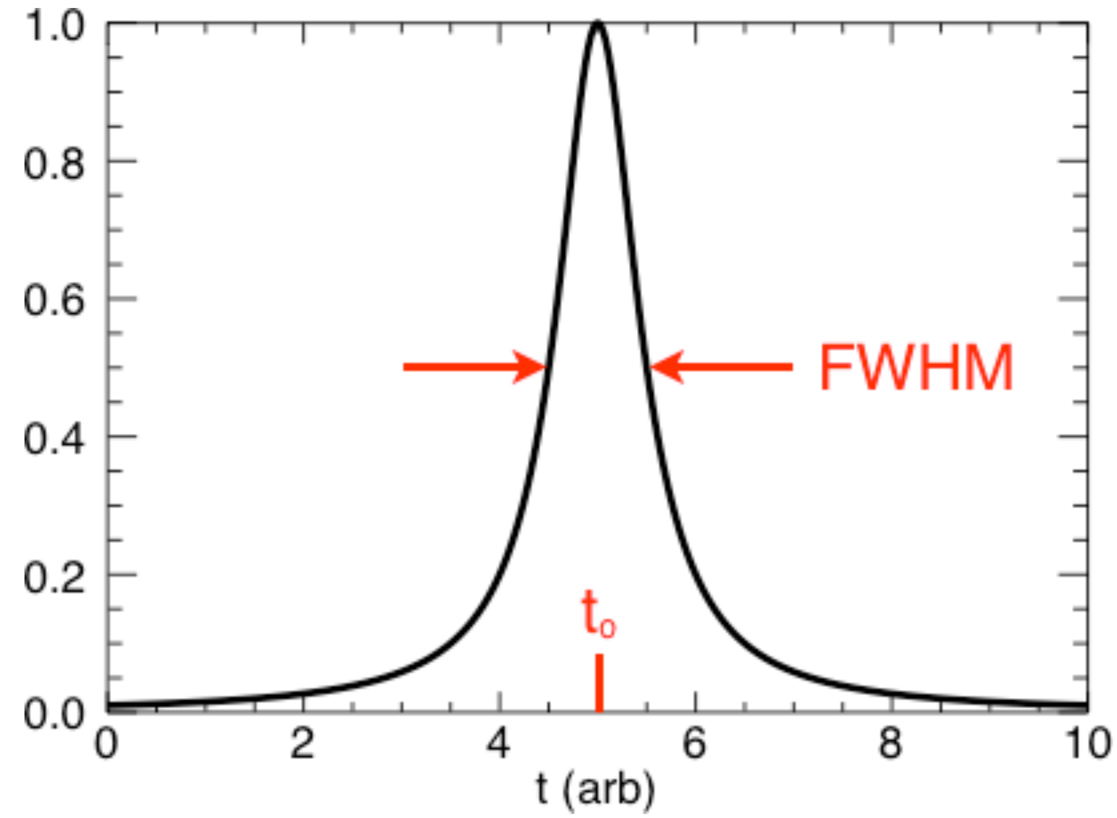
Exponential Spectra Arise from Lorentzian Pulses

Lorentzian pulse in time, $g(t)$, given by,

$$g(t) = \frac{\tau^2}{(t - t_o)^2 + \tau^2} \ ,$$

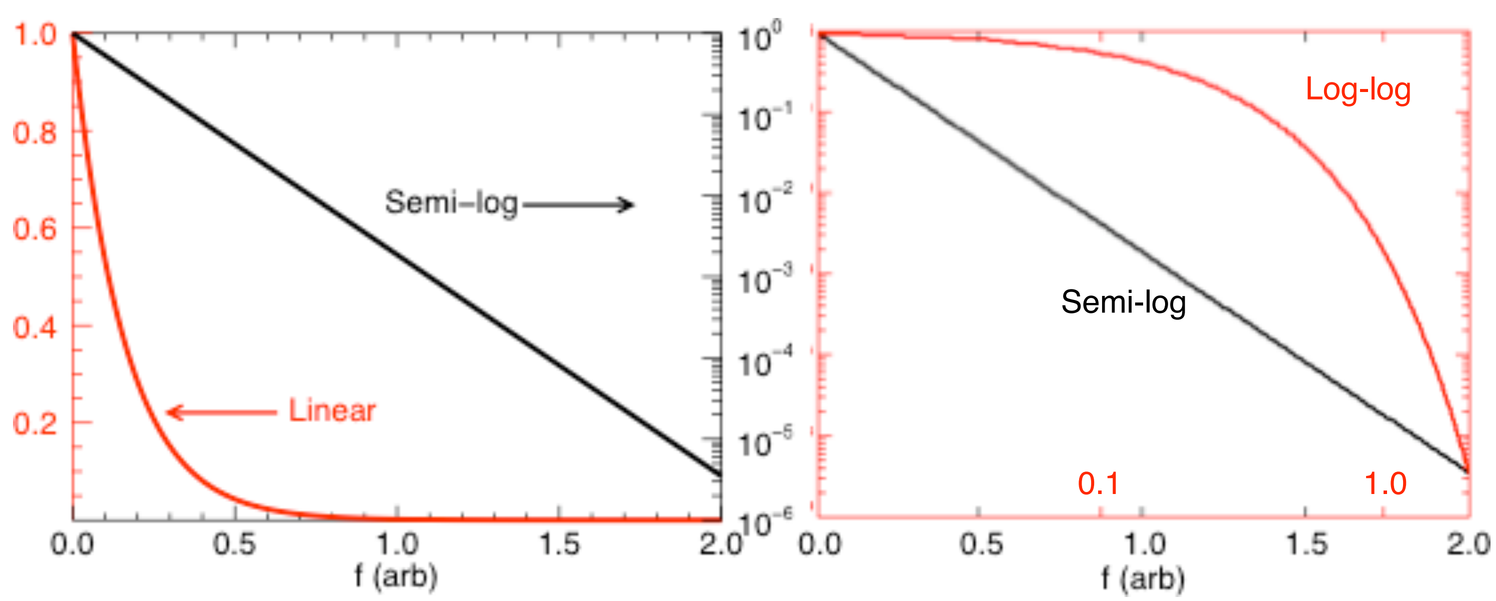
t_o = Initial Time

τ = Time Width
= ½ FWHM



with corresponding Fourier transform,

$$\tilde{g}(\omega) = (\pi\tau)\exp\left(-\omega\tau + i\omega t_o\right) \ ,$$

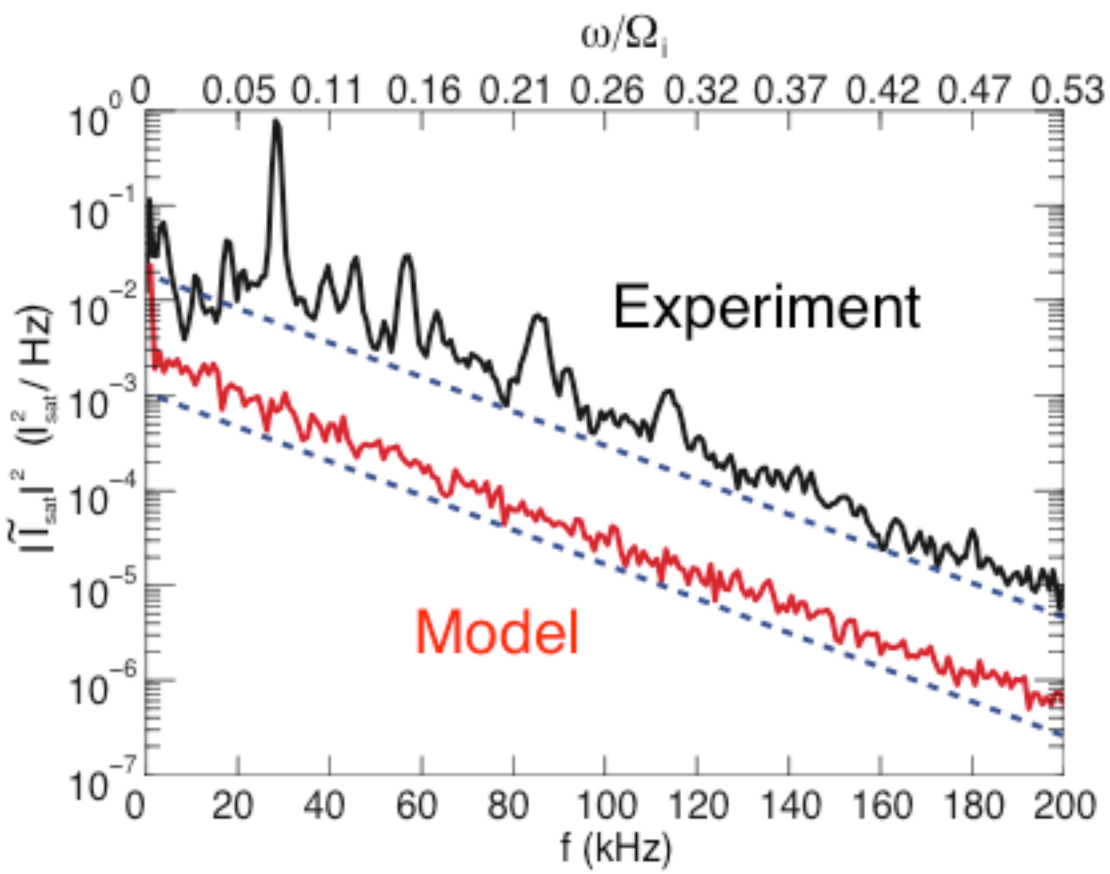


and resulting power spectrum,

$$|\tilde{g}(\omega)|^2 = \left(\frac{2\pi^2}{f_s}\right)^2 \exp\left(\frac{-2f}{f_s}\right)$$

$$f_s = \frac{1}{2\pi\tau}$$ = Scaling Frequency

Exponential Slope is Consistent with Pulse Width



Electron Temperature Gradient Experiment

- Experiment power spectrum is computed from an ensemble of time series.
- Average pulse width is computed by fitting Lorentzians to individual pulses in the time series.
- Slope of exponential spectrum agrees with measured average pulse width.

Pulse Fits, $\langle \tau \rangle = 4.0\ \mu s$

Exponential Slope, $\langle \tau \rangle = 3.5\ \mu s$

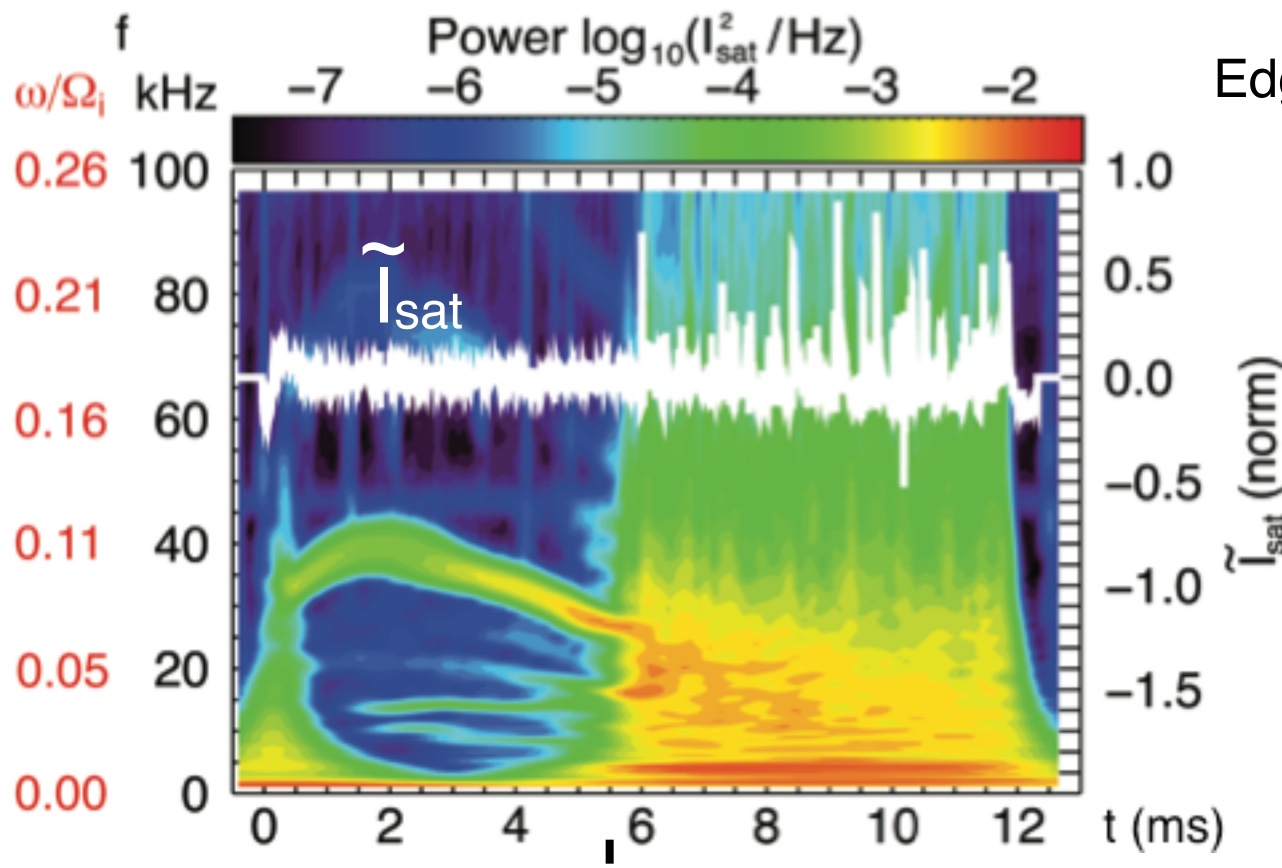
Model

- Ensemble of randomly distributed Lorentzian pulses.
- Uniform distribution of widths consistent with data, 2.5 - 4.5 μs.

Transition from Coherent to Exponential Spectra

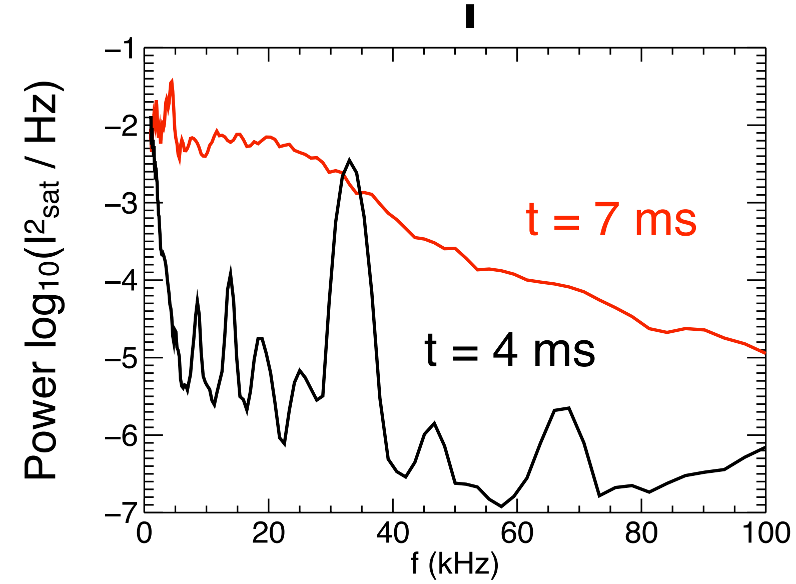
Electron Temperature Gradient Experiment

Edge Region



Classical Transport ← → Anomalous Transport

- Coherent modes at early times, no Lorentzian pulses.



- Transition to exponential spectra is simultaneous with appearance of Lorentzian pulses.
- Thermal wave appears with exponential spectra.

Edge Density Gradient Experiment

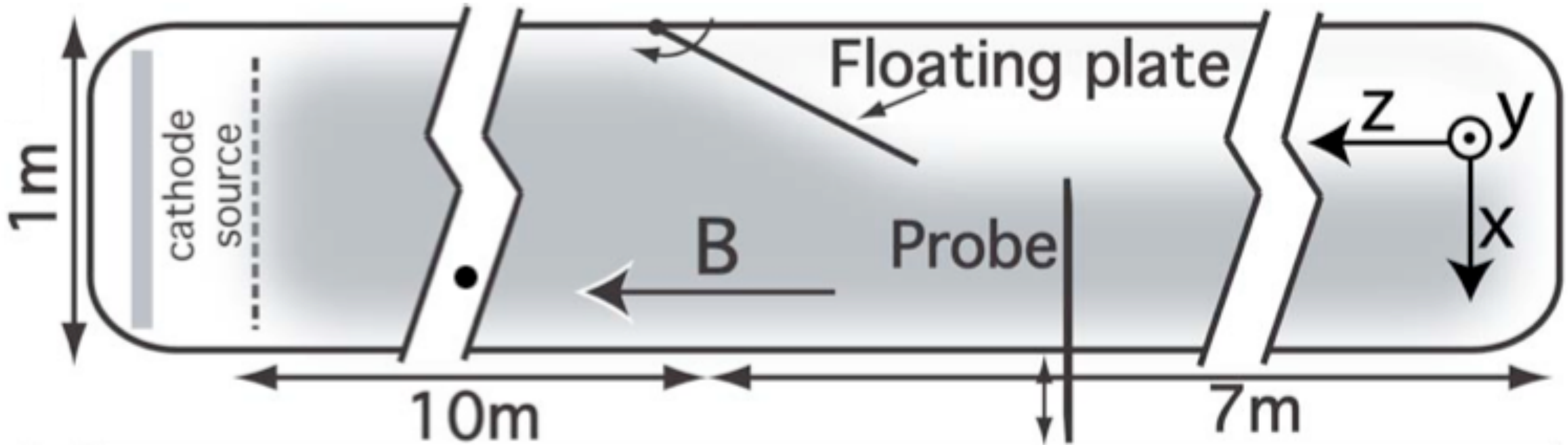
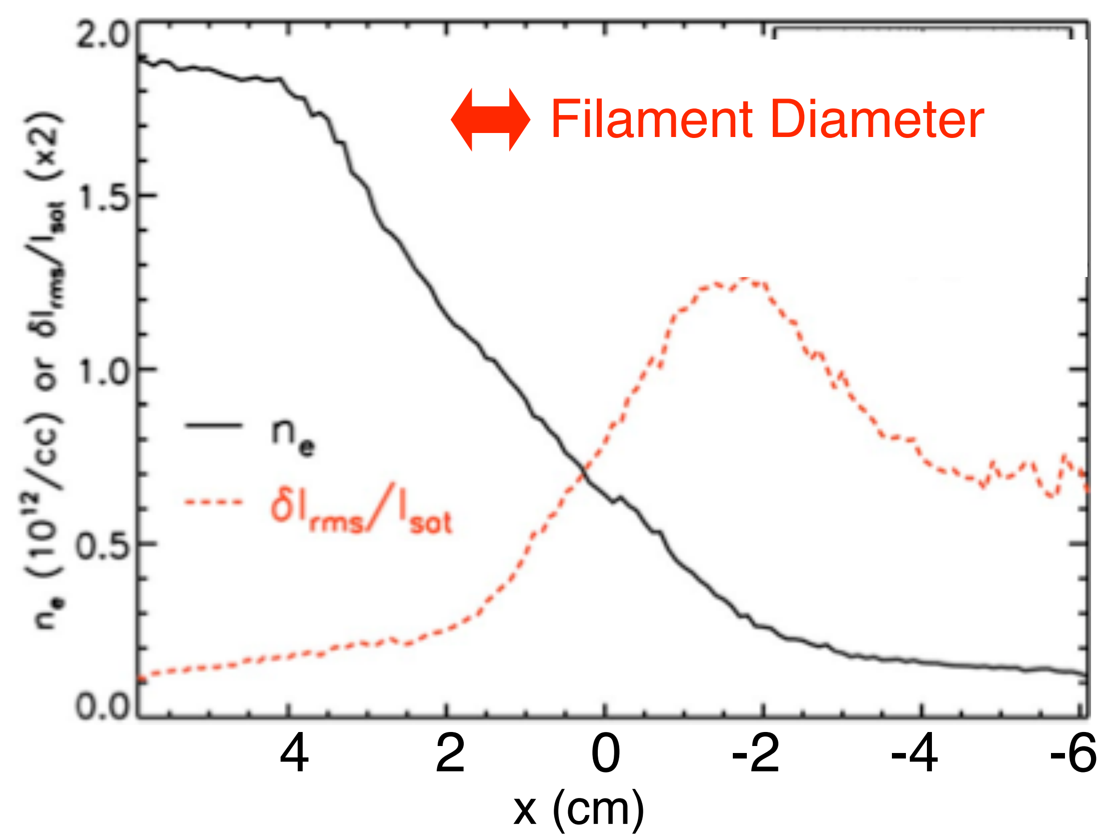


Fig. 1: T. A. Carter,
Phys. Plasmas, 13, 010701 (2006)

Electron Temperature Gradient Experiment
$L_T \sim 0.63$ cm

Edge Density Gradient Experiment
$L_n \sim 3.46$ cm



Adapted from Fig. 1: T. A. Carter,
Phys. Plasmas, 13, 010701 (2006)

Lorentzian Pulses also Present in Edge Density Gradient Experiment

Hole Region Birth Region Blob Region

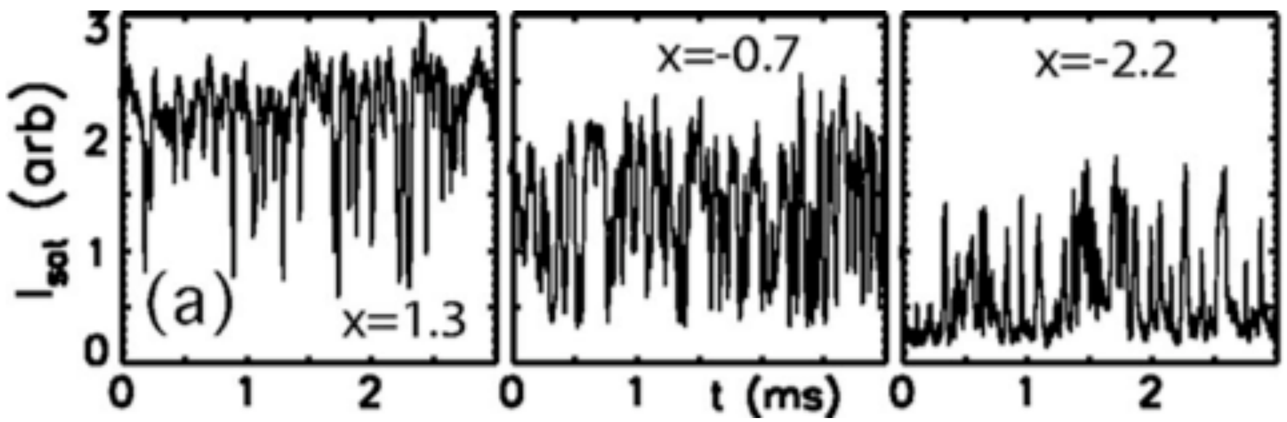
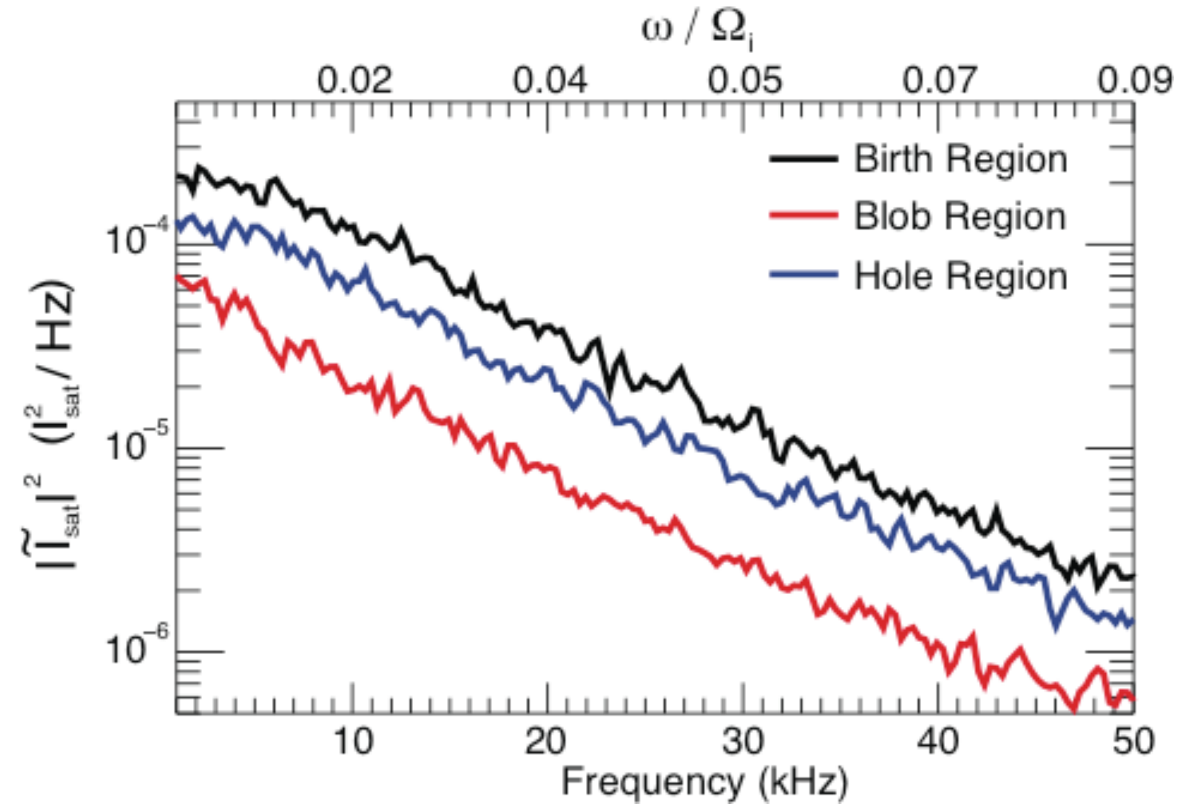
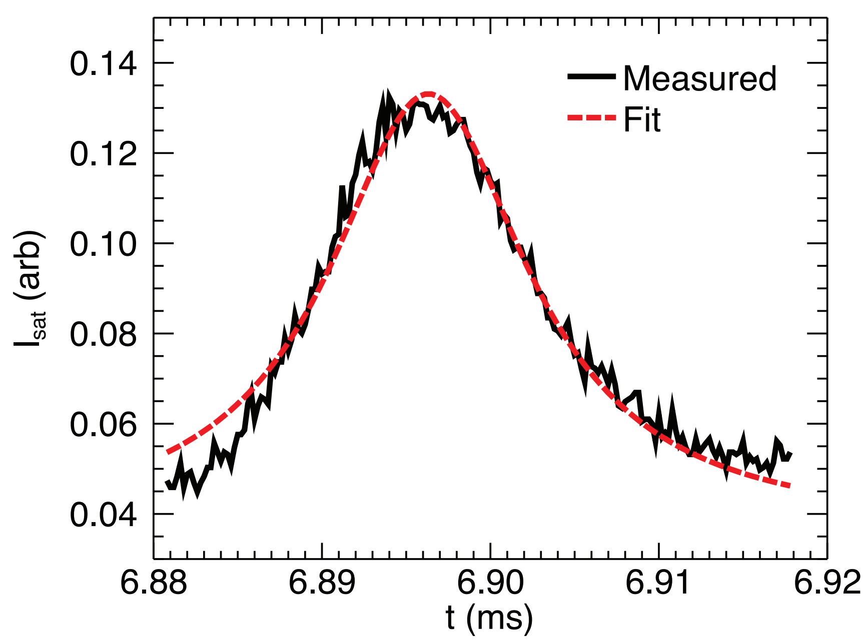


Fig. 2: T. A. Carter,
Phys. Plasmas, 13, 010701 (2006)



Individual Pulse, Blob Region



- Spectral slope is consistent with Lorentzian pulse width,

  Pulse Fits, $\langle \tau \rangle = 7.2\ \mu s$

  Exponential Slope, $\langle \tau \rangle = 7.0\ \mu s$

Conclusions

- Electron temperature gradient experiment exhibits transition from coherent drift-Alfvén waves to an exponential spectrum.
- Exponential spectrum arises from individual Lorentzian pulses.
- Temporal widths of individual Lorentzian pulses are a fraction of a cycle of the drift-Alfvén wave.
- Pulse generation is associated with modulation of the drift-Alfvén waves.
- Similarity of the phenomenon in the electron temperature and edge density gradient experiments, together with observations of exponential spectra in other devices, strongly suggests a universal behavior of magnetized plasmas.