Spectral Analysis of Edge Turbulence in NSTX

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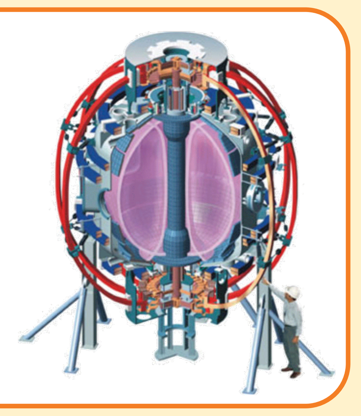
Abstract

This project focuses on calculating the frequency spectrum of edge turbulence in NSTX. This data came from the gas puff imaging diagnostic which makes a 2-D image of the density fluctuation at the edge. Using this data, a spectrum was calculated using the FFT (Fast Fourier Transform) function in IDL. The result is a broad spectrum from approximately 1 to 70 KHz. This demonstrates the turbulent nature of these fluctuations.

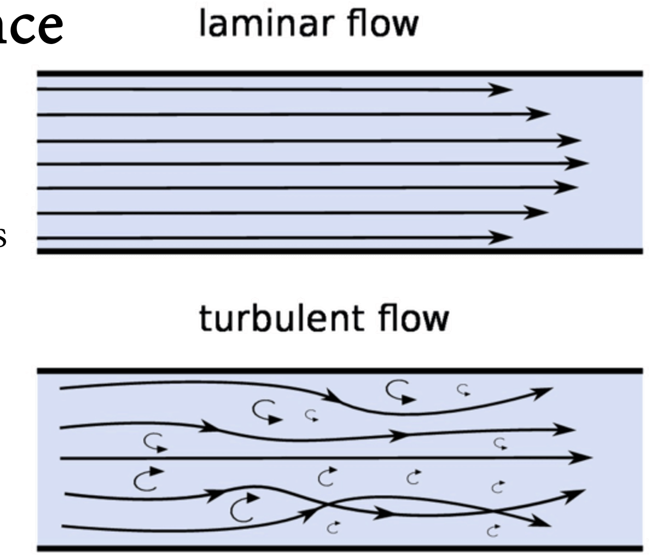
Plasma Fusion in NSTX

- A tokamak is a toroidal shaped device which is like that of a doughnut.
- This device is used to confine hot plasma using a strong magnetic field.
- This strong magnetic field confines this plasma to create fusion where atoms are squished together to release heat.
- In NSTX deuterium is used as fuel



Plasma Turbulence

- Turbulent flow is random and unpredictable
- Turbulent flow occurs at high Reynolds numbers[6]
- "The Reynolds number is a dimensionless number used to categorize the fluids systems in which the effect of viscosity is important in controlling the velocities or the flow pattern of a fluid."[7]
- In plasma the density of the flow is turbulent unlike fluid where the density is incompressible.
- Plasma velocities are generally faster than in fluid causing more turbulent fluctuations

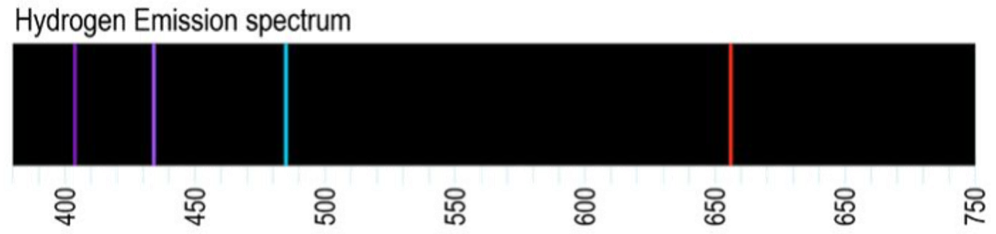


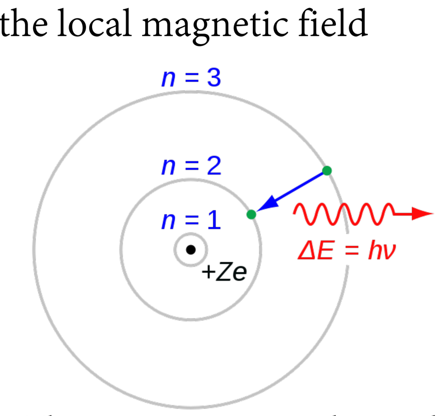
Motivation

- Edge turbulence is important in determining the particle and energy confinement and the plasma-wall interactions in present toroidal magnetic fusion devices.
- The effects of edge turbulence will be important for future magnetic fusion devices such as ITER

The Gas Puff Imaging Diagnostic

- The GPI diagnostic obtains high resolution data on the space-time structure of the edge turbulence in magnetic fusion devices.
- GPI uses a puff of neutral gas (deuterium) to increase the local light emission level for improved optical imaging of the space-time structure of the edge plasma turbulence.[2]
- The gas puff is used to create a bright source of light in which the brightness depends on the local electron density
- The gas puff localizes the region viewed to a 2-D plane perpendicular to the local magnetic field direction
- The diagnostic looks at the red spectral line (656nm)[4] of deuterium neutral gas excited by plasma electrons
- Limitation, the neutral atoms only emit light near the edge and for temperatures beginning around 3eV and becoming dark around 300 eV.

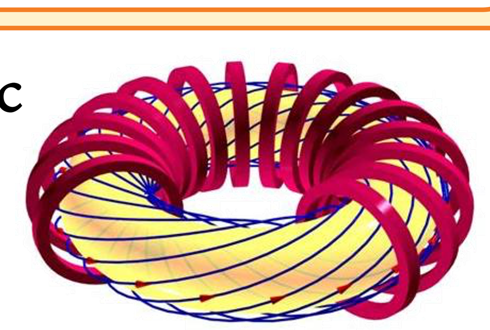




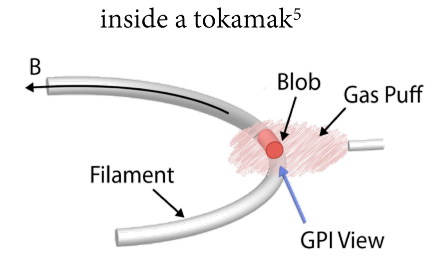
The 3 ⟶ 2 transition depicted here produces a photon of 656 nm in a hydrogen atom

Geometry of the Diagnostic

- The magnetic field lines are in a helical (corkscrew) shape
- B points along the total magnetic field direction and the plasma cannot go very far off that line.
- The GPI diagnostic assumes that electron density does not vary in the B direction
- The geometry is created to look at fluctuations perpendicular to the B field in both the radial direction (left and right) and the poloidal direction (up and down)
- The GPI views along B at the gas puff in order to make and image of the density fluctuations perpendicular to B

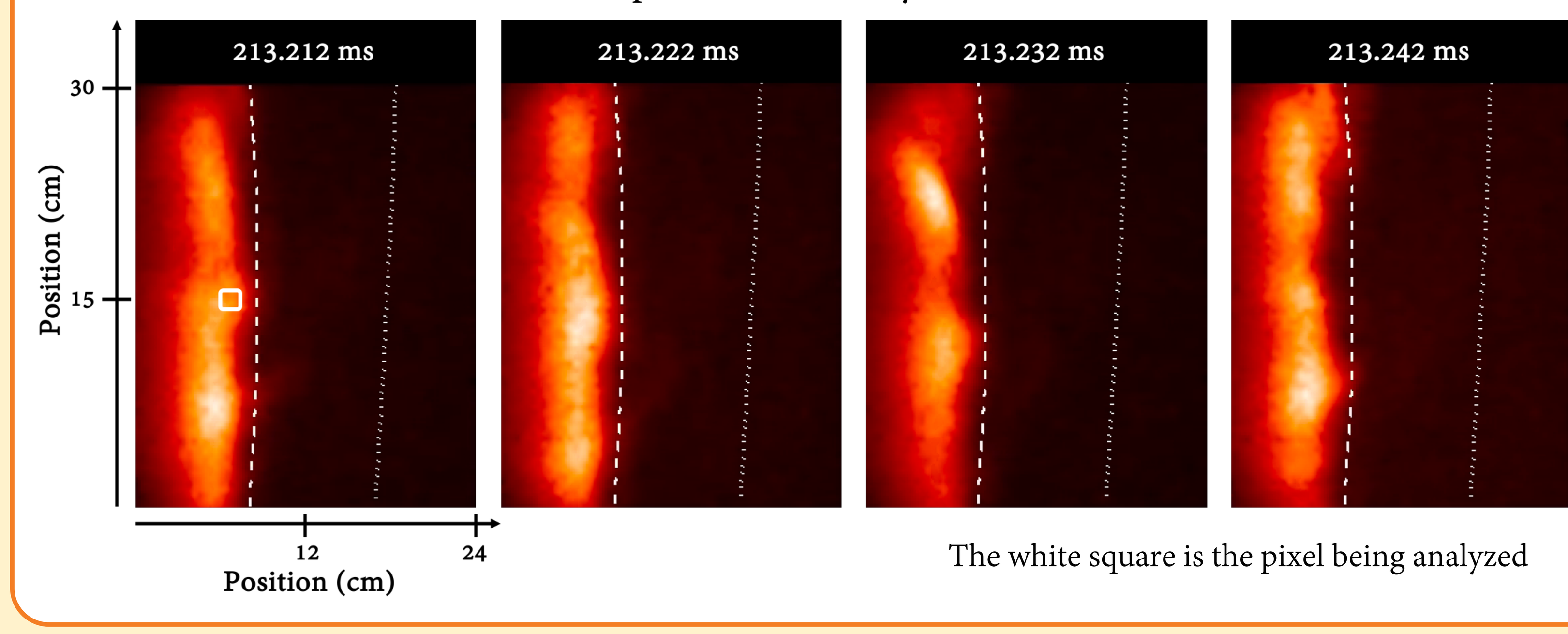


Poloidal coils and magnetic field lines inside a tokamak[5]



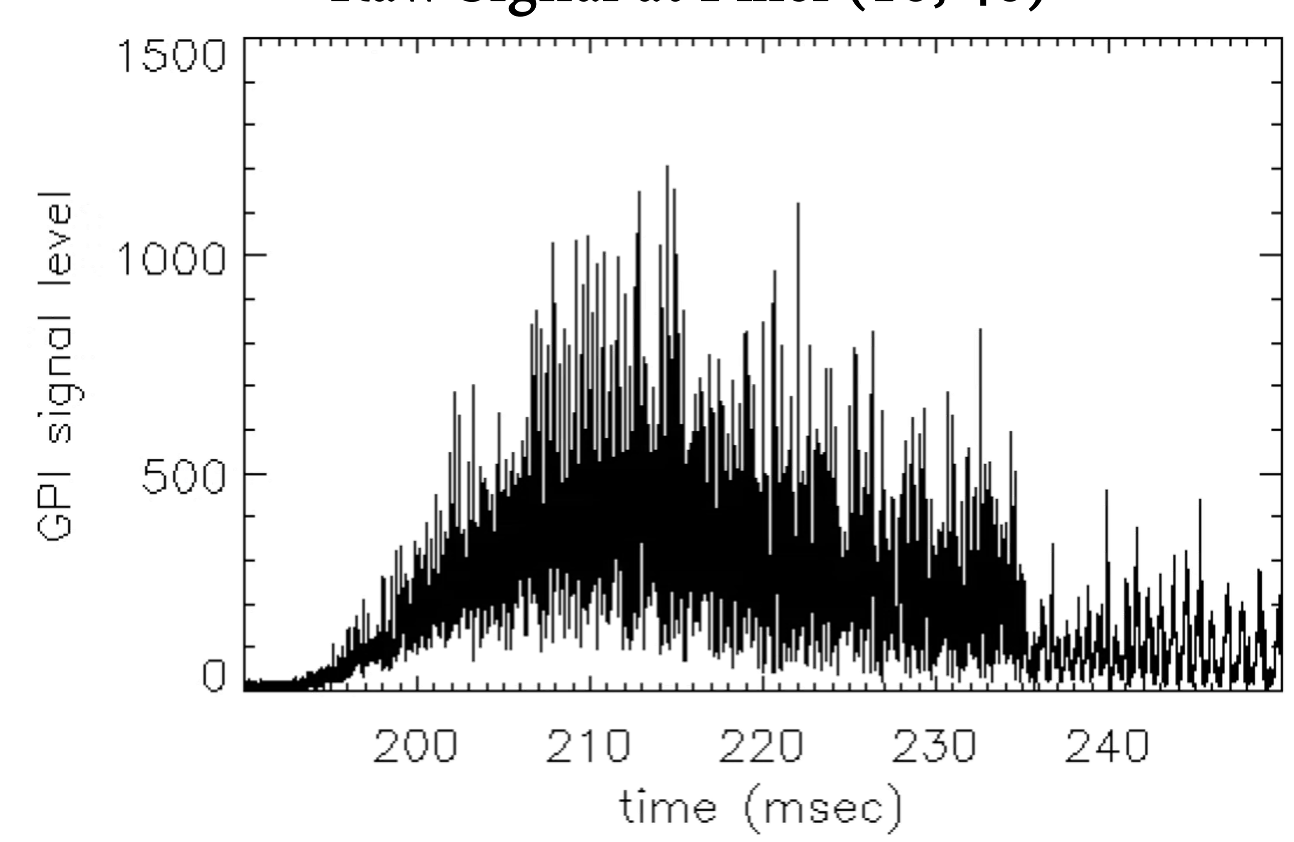
2D Images From Movie

- Each image is 64 by 80 pixels corresponding to the object plane of 24 by 30 centimeters
- These turbulent fluctuations take place at least every 10 microseconds



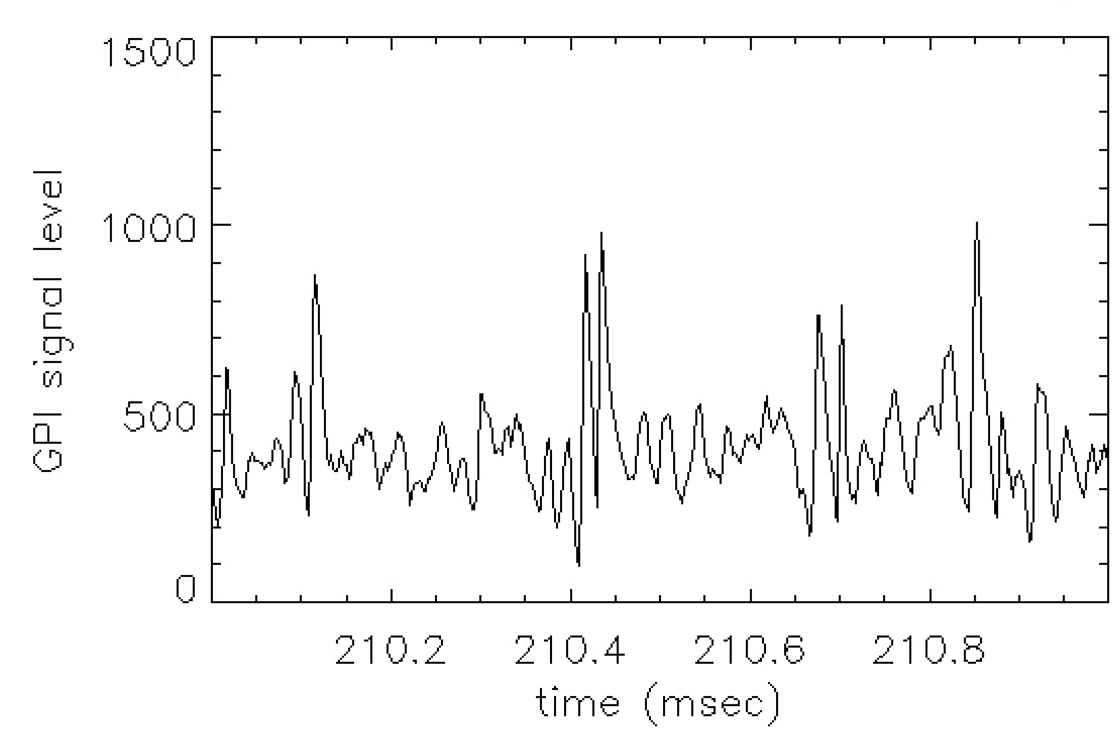
The white square is the pixel being analyzed

Raw Signal at Pixel (16, 40)



- At the beginning of the shot, once the deuterium gas is puffed in, the signal begins to ramp up as the gas manifold puffs gas in for about 20 milliseconds.
- In the middle of the shot the gas peaks, and the signal is high and turbulent.
- At the end of the shot, the plasma suddenly changes around 235 milliseconds called the L-H mode transition where the turbulence level goes down and the confinement goes up.

1 Millisecond of Raw Signal

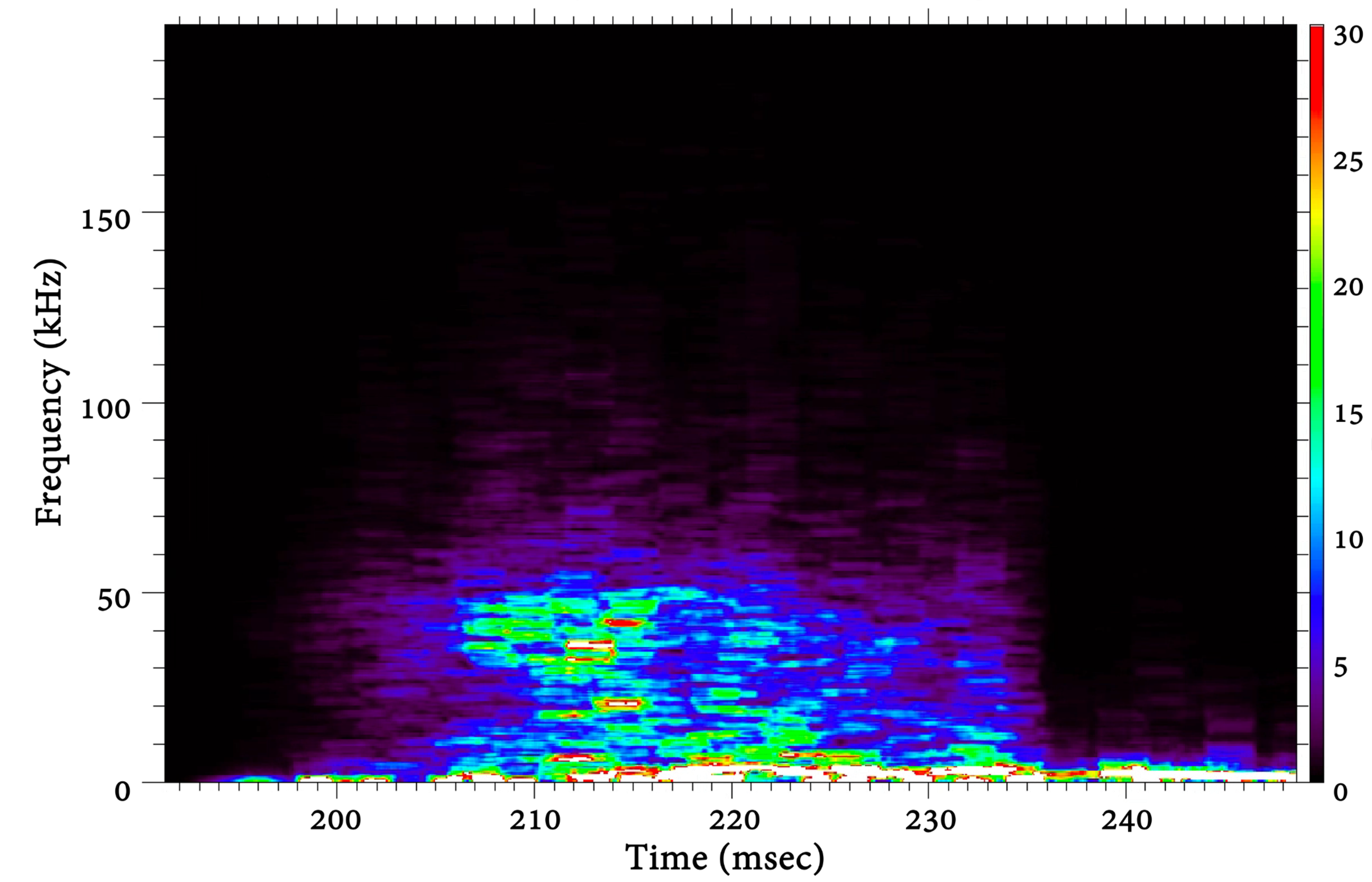


- This millisecond is in the middle of the time series where the signal is highest, and you can most clearly see the fluctuations.
- By looking at this small increment of time, there is no true pattern in these fluctuations.

Fourier Analysis

- Fourier analysis is the study of the way general functions may be represented or approximated by sums of simpler trigonometric functions.
- By using Fourier analysis we can breakdown the GPI signal into its frequency components
- Turbulent nature is demonstrated by a broad frequency spectrum
- The limitation to Fourier analysis is that there is a compromise between frequency and time resolution

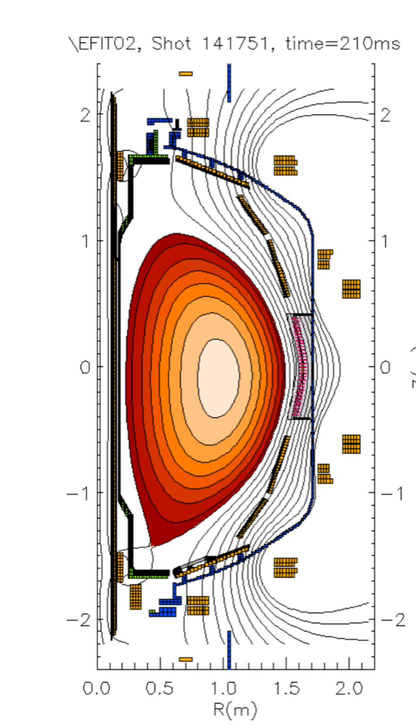
Frequency vs Time Spectrogram



- This spectrogram contains information on how the power, or square of the amplitudes, of different frequencies changes as a function of time.
- Each time is an average of 1000 frames of data.
- The highest power levels of the spectrum are shown in red consistent with the color bar to the right of the figure.

Findings

- There is a broad spectrum opposed to alternatives of dominant peaks
- Using diffusion $D=\Delta x^2/\Delta t$ we can estimate confinement time of approximately 1 millisecond
  - Using a step size in space Δx of 5cm and a step size in time Δt of .01ms, D is approximately 250 m^2/s
  - Then, estimate the distance from the plasma center to the wall to be around .5 meters
  - To find the confinement time you can rearrange the diffusion equation to solve for Δt, $\Delta t=\Delta x^2/D$
  - So, Δt is approximately 1 millisecond
- This one millisecond estimate is much lower than the 50-millisecond global confinement time. This is because the plasma is more turbulent at the edge than in the center



Cross section of shot 141751

Future Work

- Look at different pixels from the same shot. By looking at a pixel closer to the edge of the plasma and comparing it to a pixel a few centimeters closer to the center of the plasma, it may be possible to look at how the turbulent transport changes as a function of radius from the center of plasma.
- Compare the same pixel in multiple shots to get a better understanding of edge turbulence
- Look more carefully at whether the signals are random or not

References

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