Detection of Alfven modes on tokamak COMPASS

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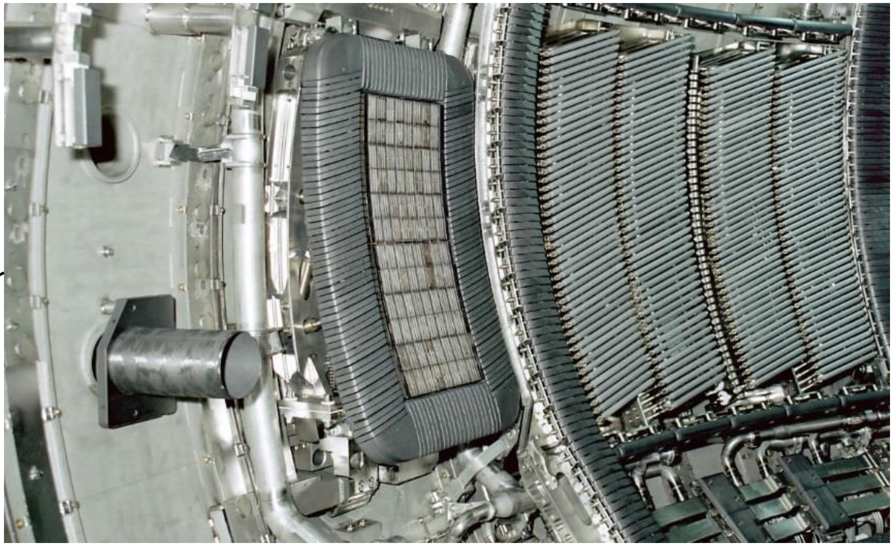
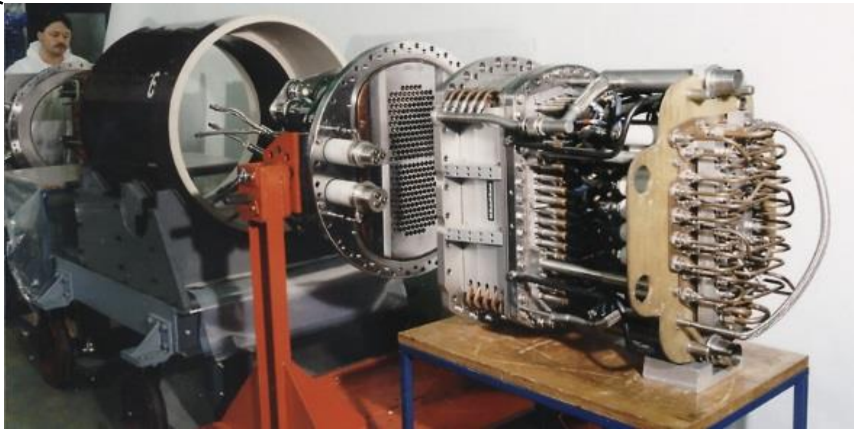
- Alfven modes in tokamak plasmas – motivation.
- Spectral analysis methods:
    - Fast-Fourier Transform
    - Coherence
- Detected plasma modes on COMPASS
- Summary

Motivation

- For successful tokamak operation – RF heating and NBI are essential.

$$Q = \frac{P_\alpha}{P_{external}}$$





- ITER goal – Q = 10
- Reactor – Q > 50
- ‘Uncontrollable’ thermalization of α – MUCH more power than ‘controlled’ systems…

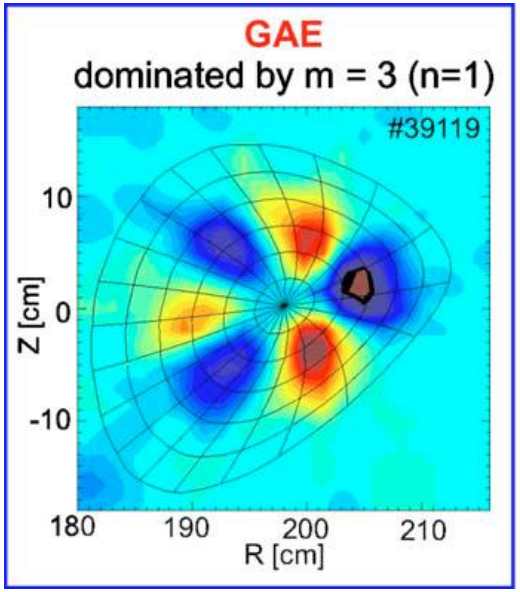
- Consequences of α-particle heating – one of least experimentally investigated phenomena.
  - Even now – no idea how to diagnose α's on ITER!
- Energetic α particles:
  - Affect profiles, stability, etc.
  - Drive *Alfven instabilities*.
- Alfven modes – problematic to understand:
  - Theory – border of MHD and kinetic description.
  - Experiment – modes induced only 'recently'.

- Alfven modes induction – ‘fast’ particles and *grad*(*p*)
- ‘Fast’ → $v_f > v_A = \frac{B}{\sqrt{\mu_0 \rho_0}}$

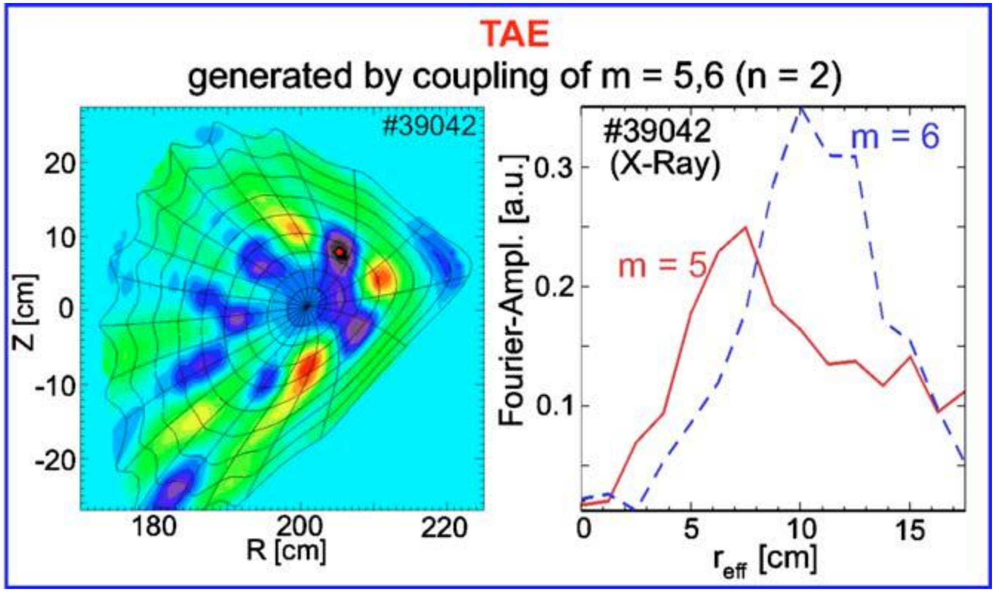
  Diamagnetic velocity of fast particles
- Up until recently – heating too weak.
- First ‘successful’ experiments:
  - NBI – 50 % of beam power expelled and ablated first wall – deposition ruined optics.
  - ICRH – energetic ions caught in ripple wells, escaped and made hole into vacuum vessel…
- Alfven modes→ α’s escape before thermalization.

Alfven mode properties

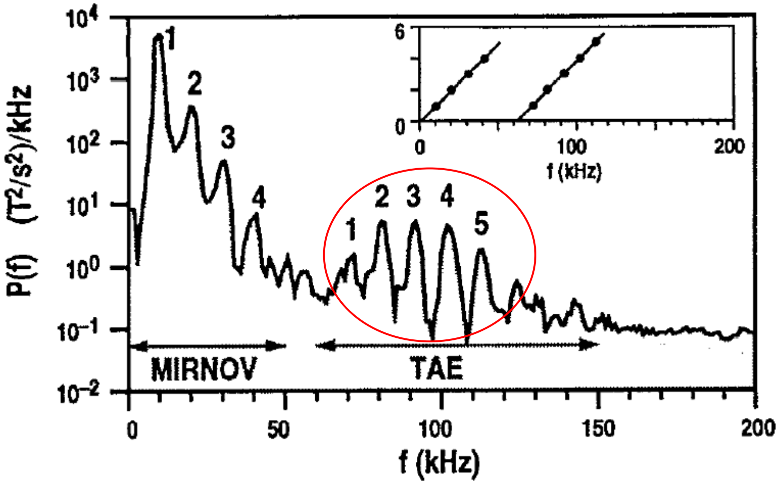
Single-mode ‘Global’



Multi-mode ‘toroidal’

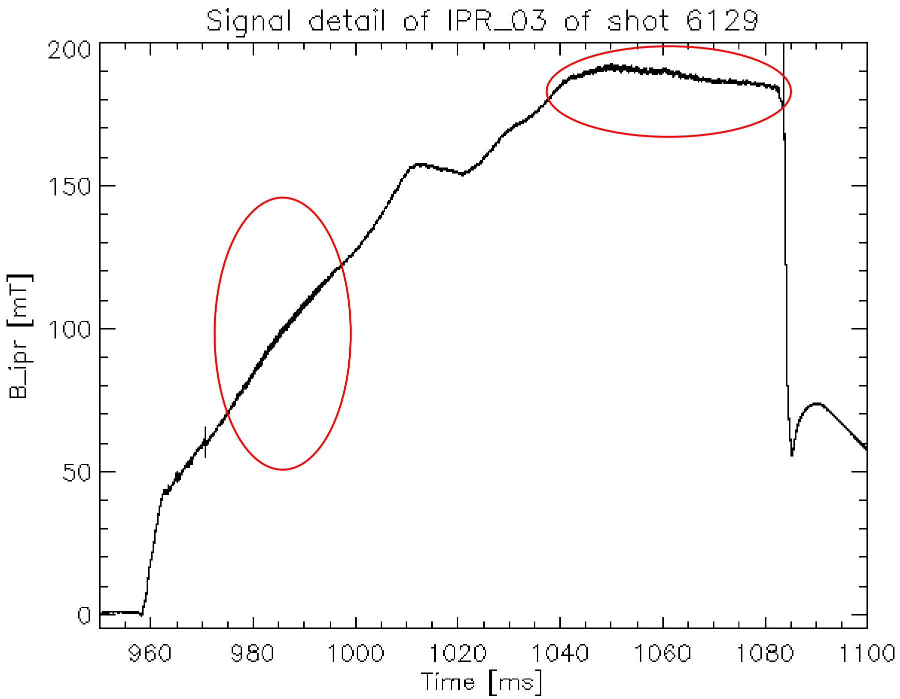


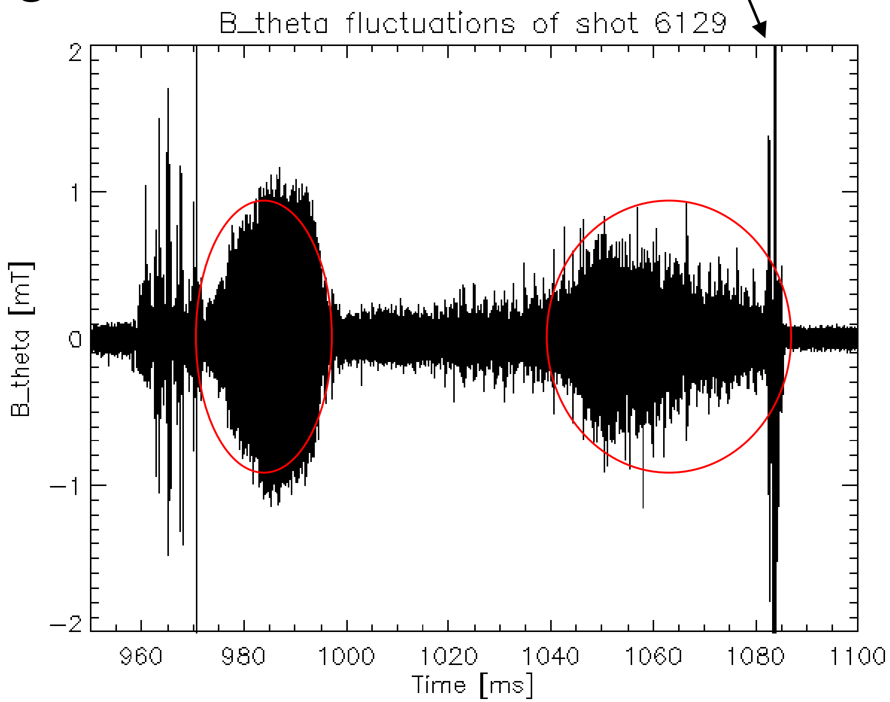
- Many different types.
- Spatially localized high-frequency plasma modes.
- Should follow: $f_A \sim \frac{1}{\sqrt{n_e}}$



- Generally MHD mode is:
    - Perturbation of flux surfaces fluctuation.
    - Rotates toroidally and poloidally.
- I.e. Harmonic perturbation of magnetic field.

Seen by fixed detection coil.





- Such signal – characterized by statistical methods.

Fast-Fourier Transform (FFT)

- Tool for identification of frequencies in signal.
- Transforms B(*t*) into B(*f*):

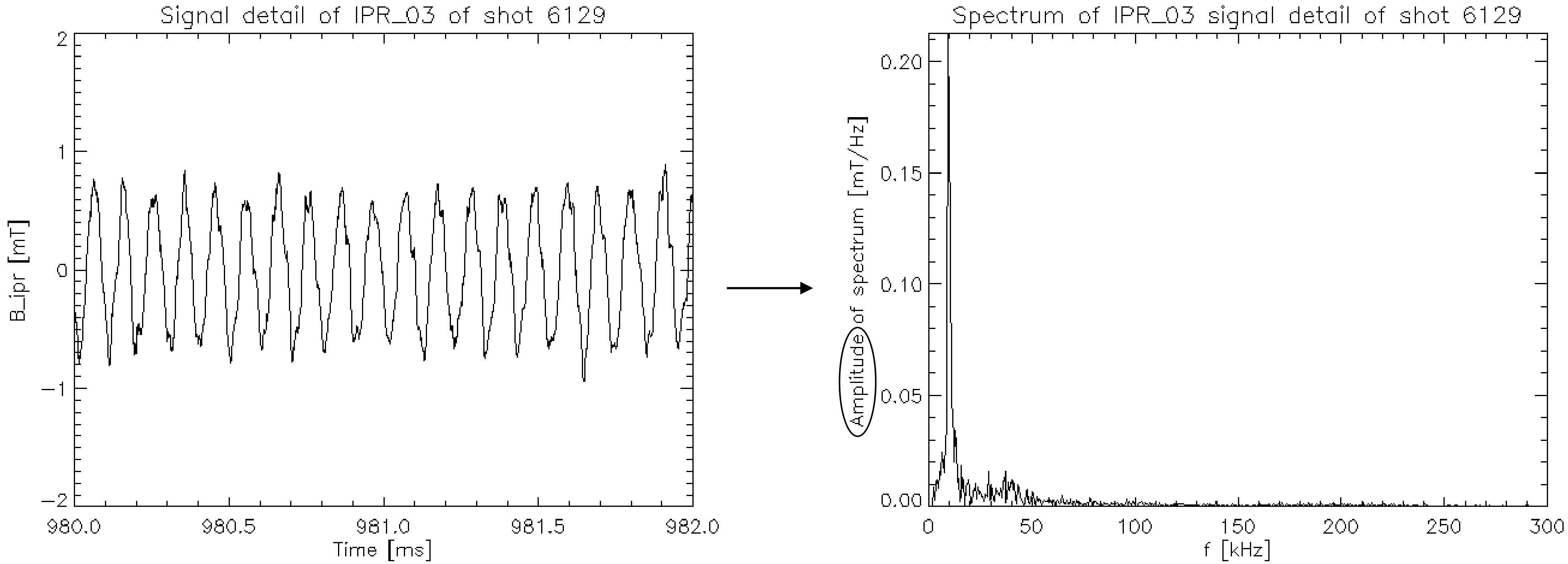
$$B(\nu) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} B(t)\mathrm{e}^{-\mathrm{i}2\pi\nu t}\mathrm{d}t$$

- I.e. for finite data points:

$$F(\nu) = \frac{1}{N} \sum_{x=0}^{N-1} f(x)\mathrm{e}^{-\mathrm{i}2\pi\nu x/N}$$

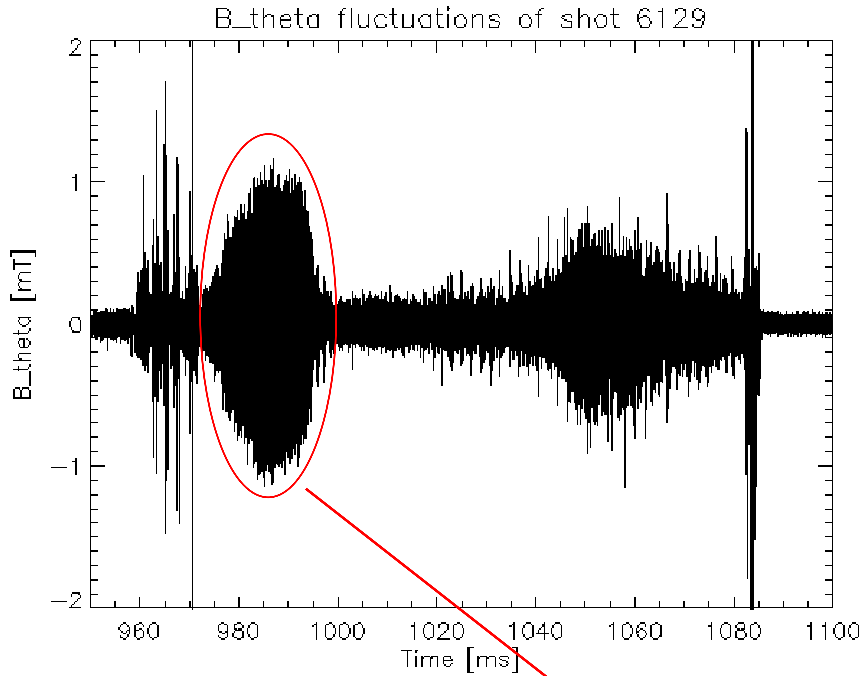
- To represent infinity – the finite interval is assumed to be periodic.

- Upon application:



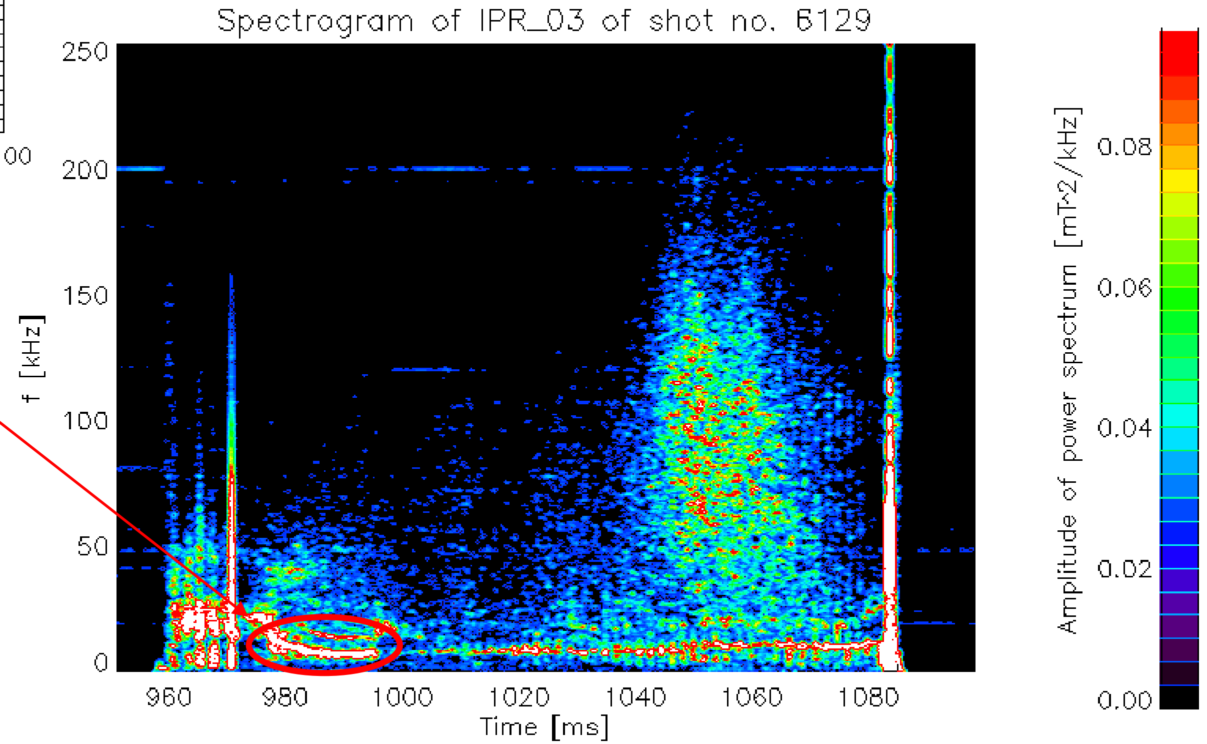
- Actually – output of FFT is complex number.
  - Usually only its magnitude is used. For use of phase see later on.

- Spectrogram – how signal frequency changes with time.
  1. Divide signal into many independent windows.
     - Each corresponds to different moment in time – x-axis.
  2. FFT each window.
     - Frequency – y-axis
     - Transformed *B(f)* as z-axis.

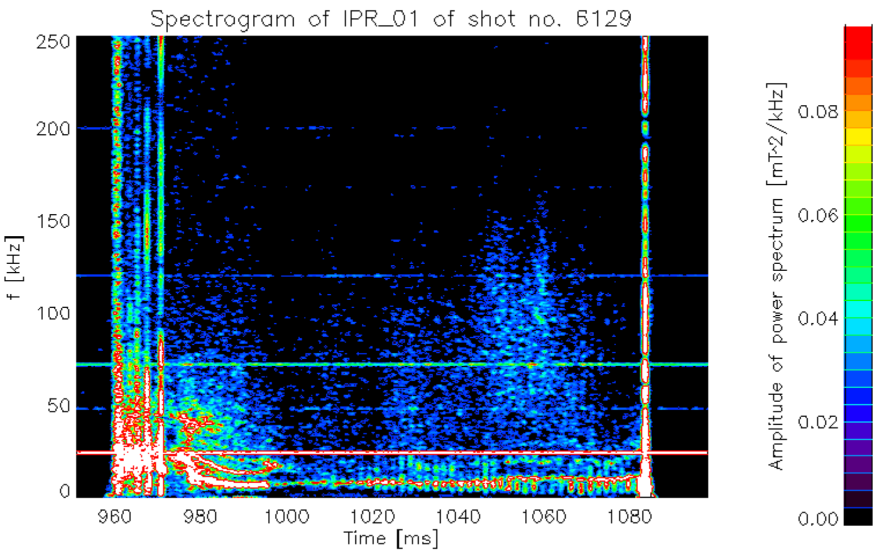


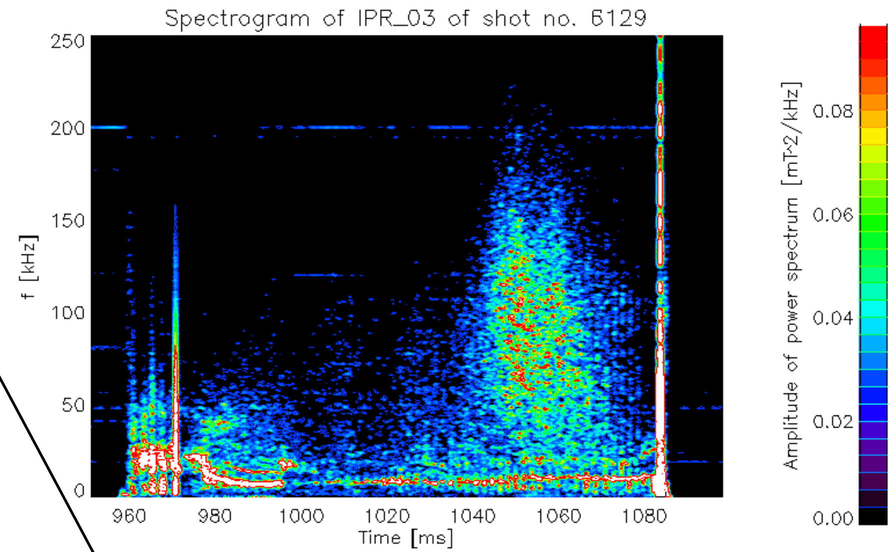
Spectrograms are very useful to detect and track time evolution of coherent events.

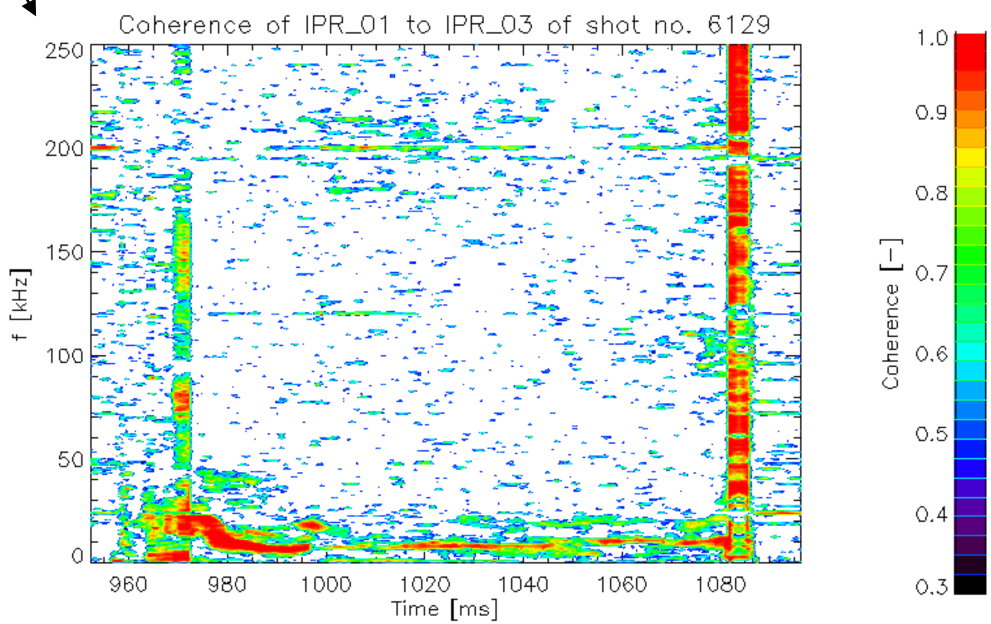
Especially useful to characterize multiple-mode events, such as Alfven modes.



Coherence





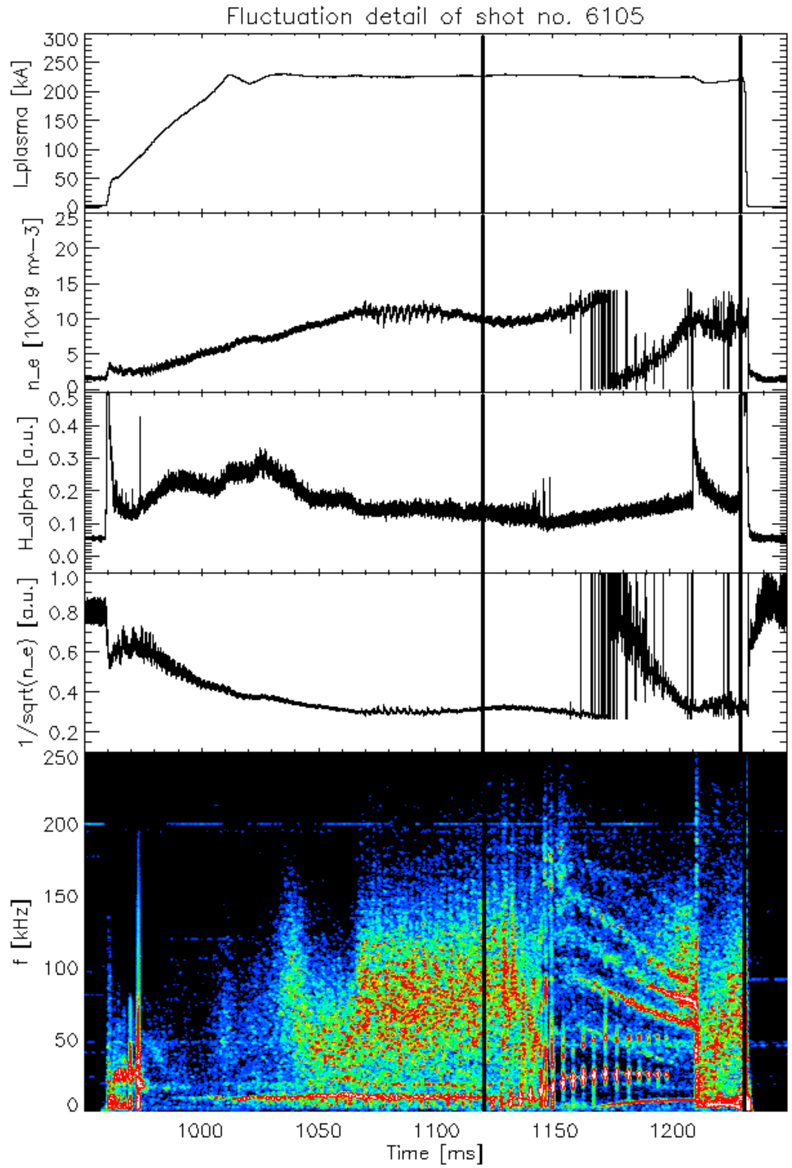


By definition – correlation of spectrograms:

$$\mathrm{Coh}_{xy} = \frac{S_{xy}^2}{S_{xx}S_{yy}}$$

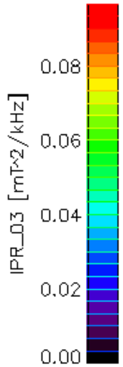
Useful for elimination of random noise and DAQ cross-talk

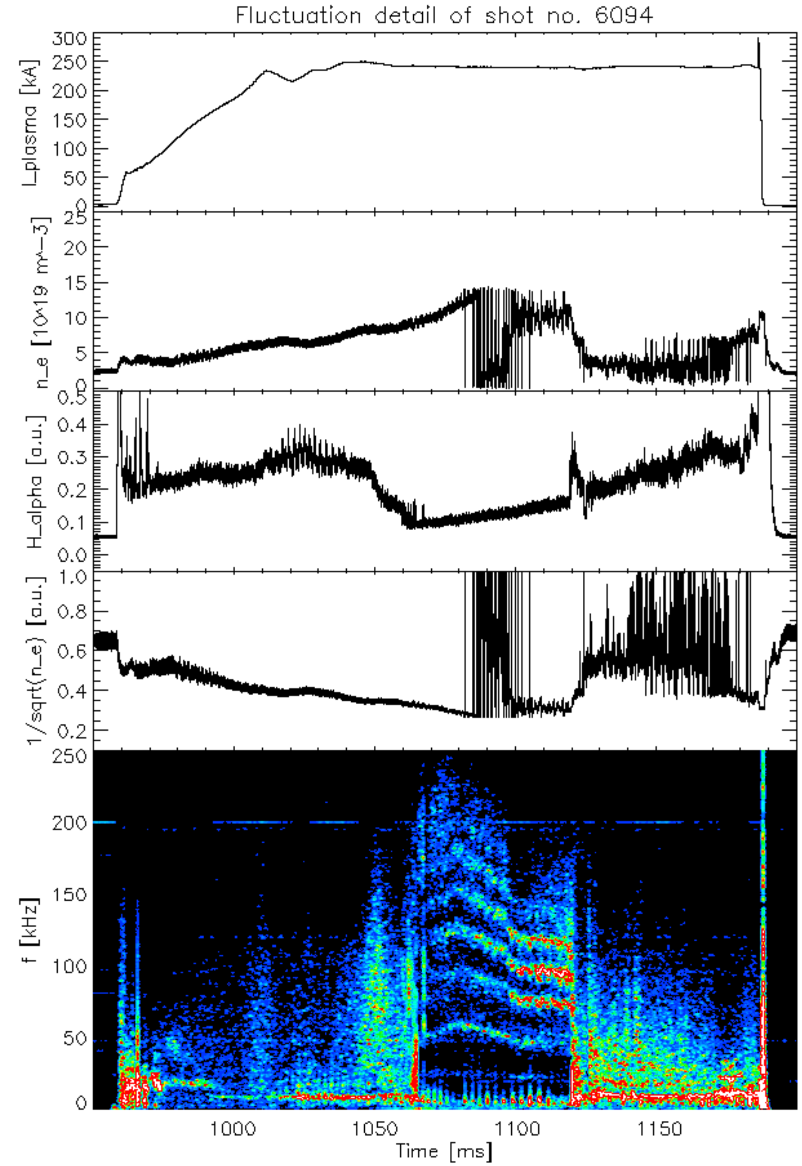
Discussion – modes on COMPASS



Arguments for and against AE:

1. Density
2. Frequencies
3. Drive
4. Localization
5. Structure





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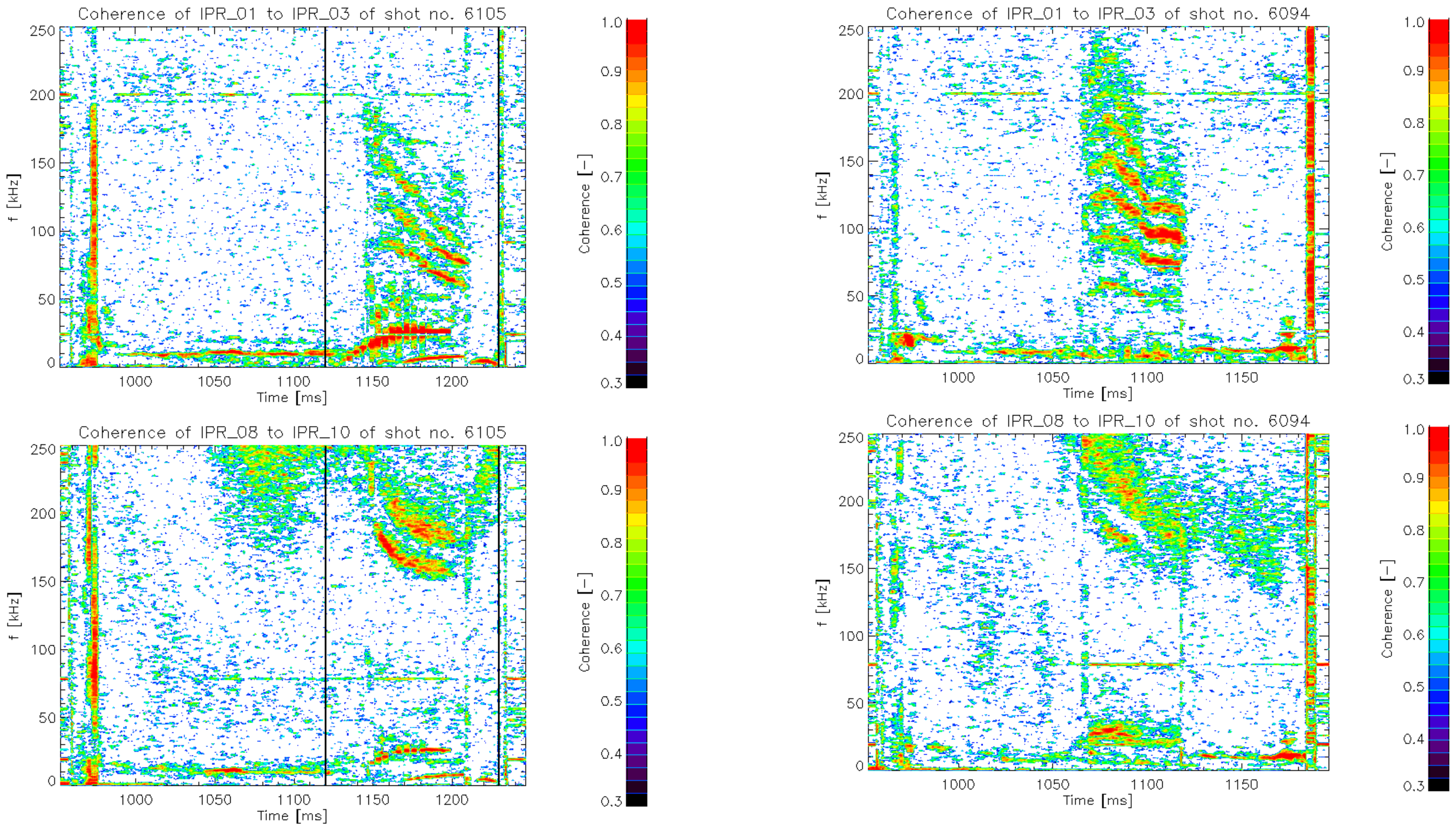
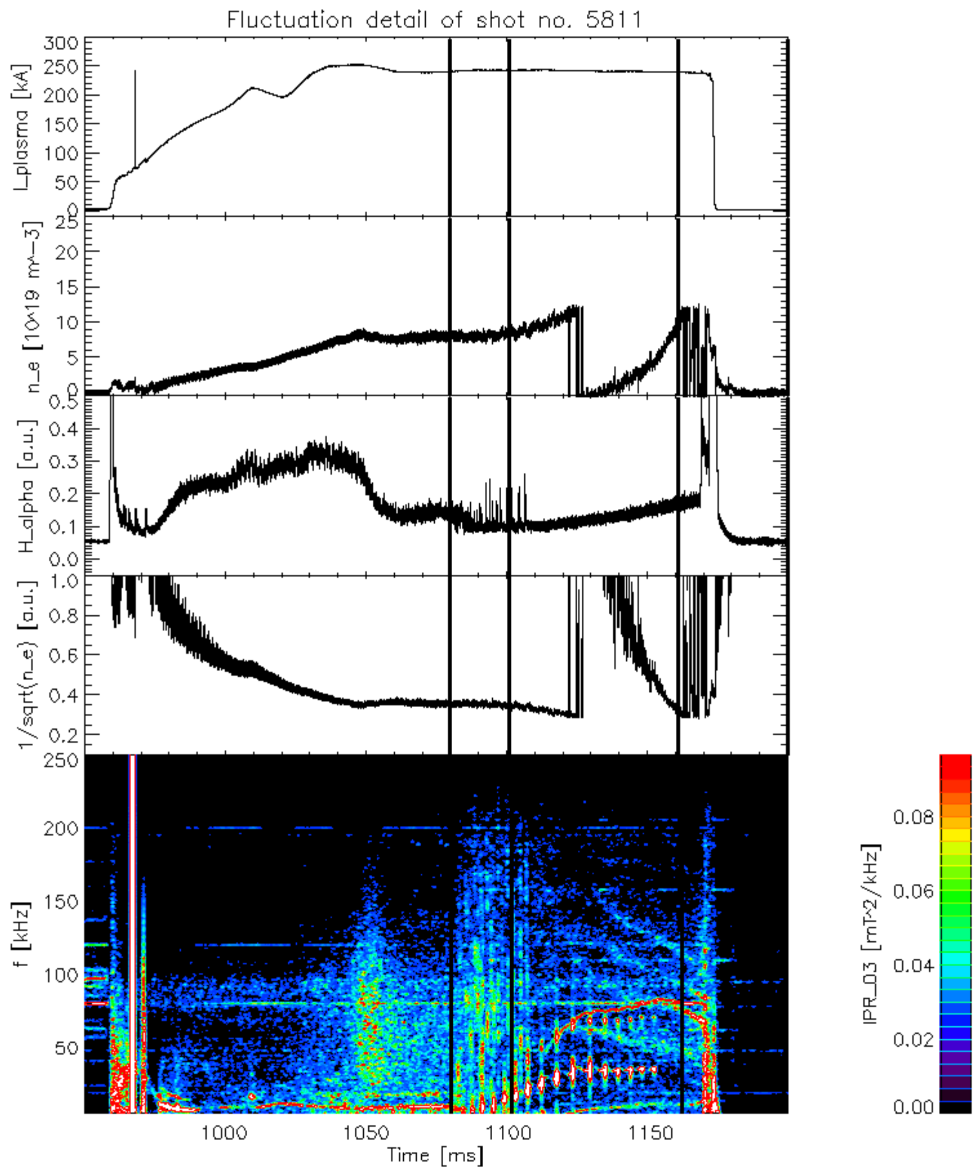
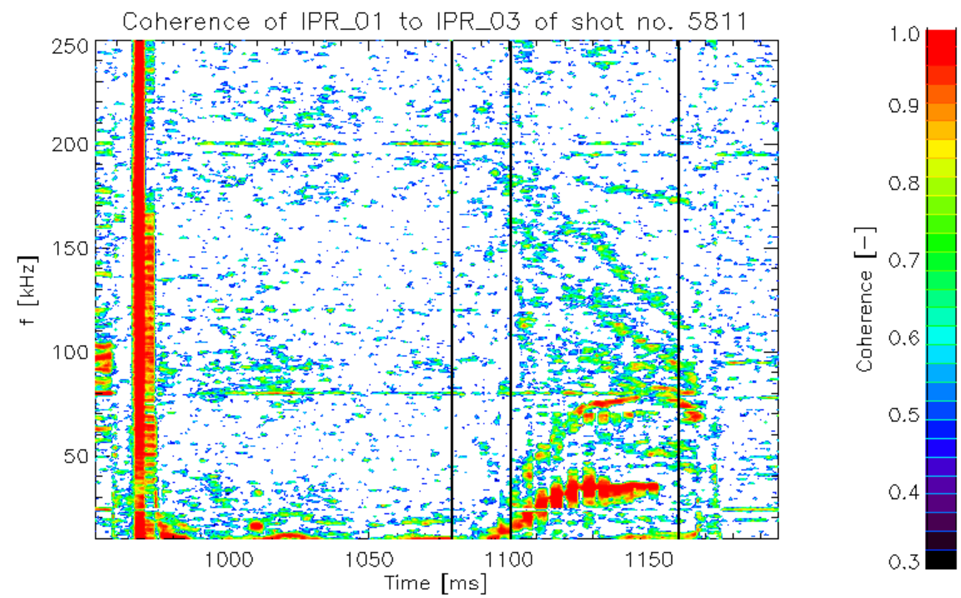
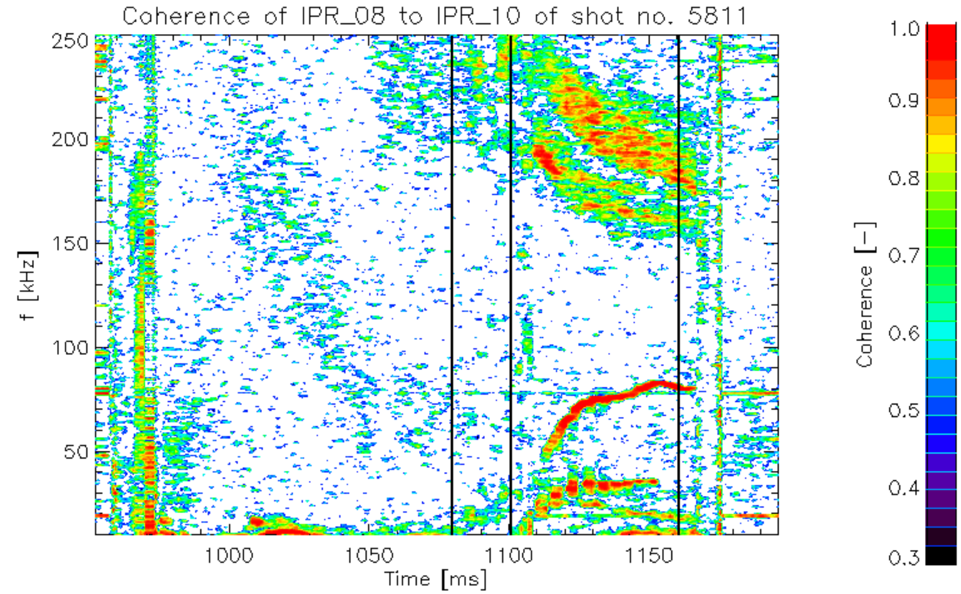


- Alfven eigenmodes:
  - Significant for future tokamak operations.
  - Still many open questions.
- Possible to detect by spectral methods – like any quasi-coherent mode.
- Tokamak COMPASS – inconclusive for now.
  - Large quantities of data yet to be analyzed.
  - More experiments planned.

Bonus – NBI modes







Bonus – Global modes