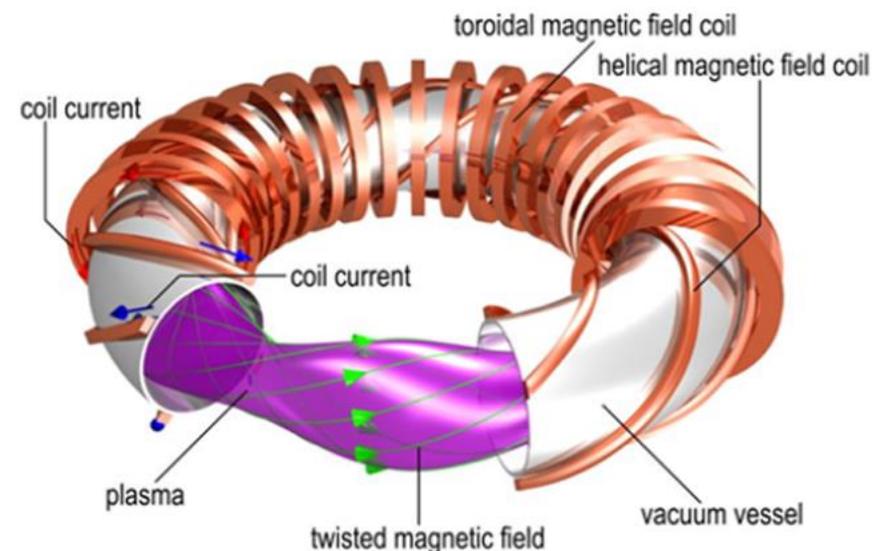
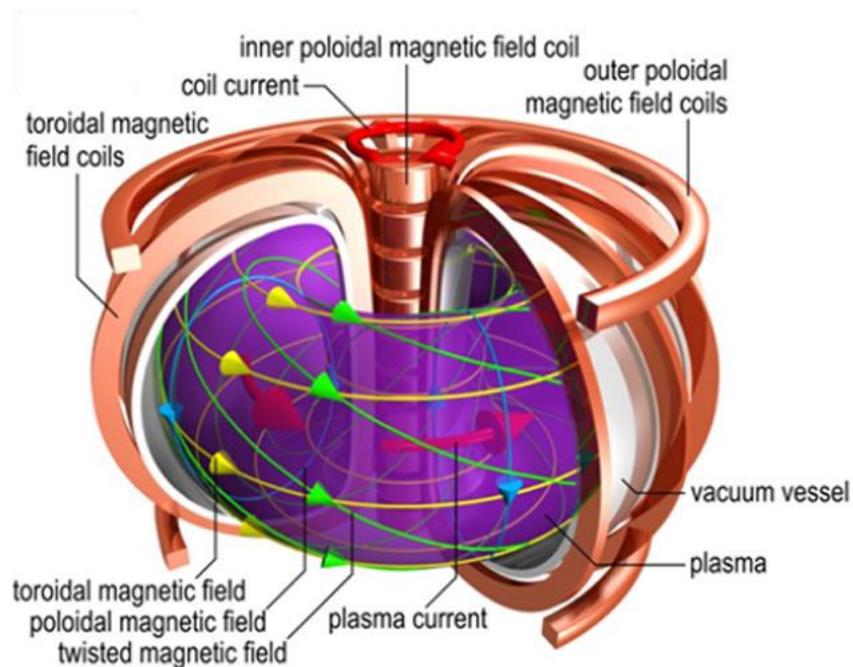


Analysis of perpendicular mean flows and fluctuations for various magnetic field configurations and heating methods

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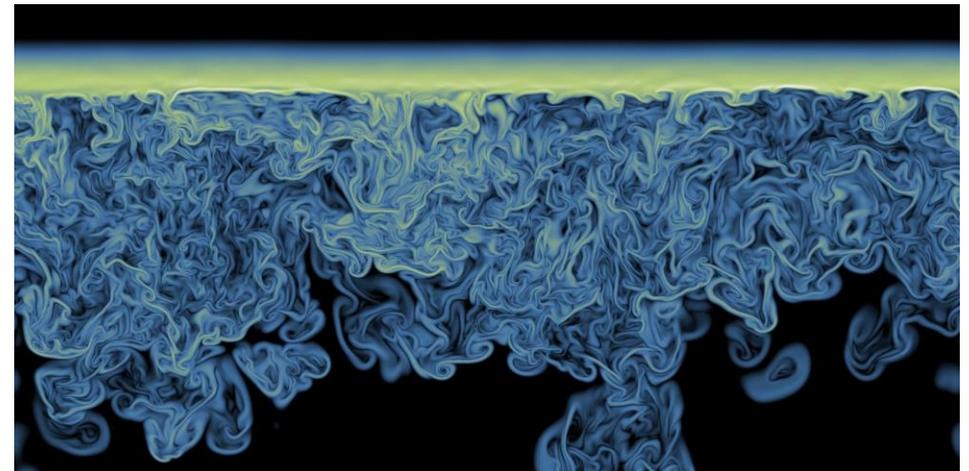
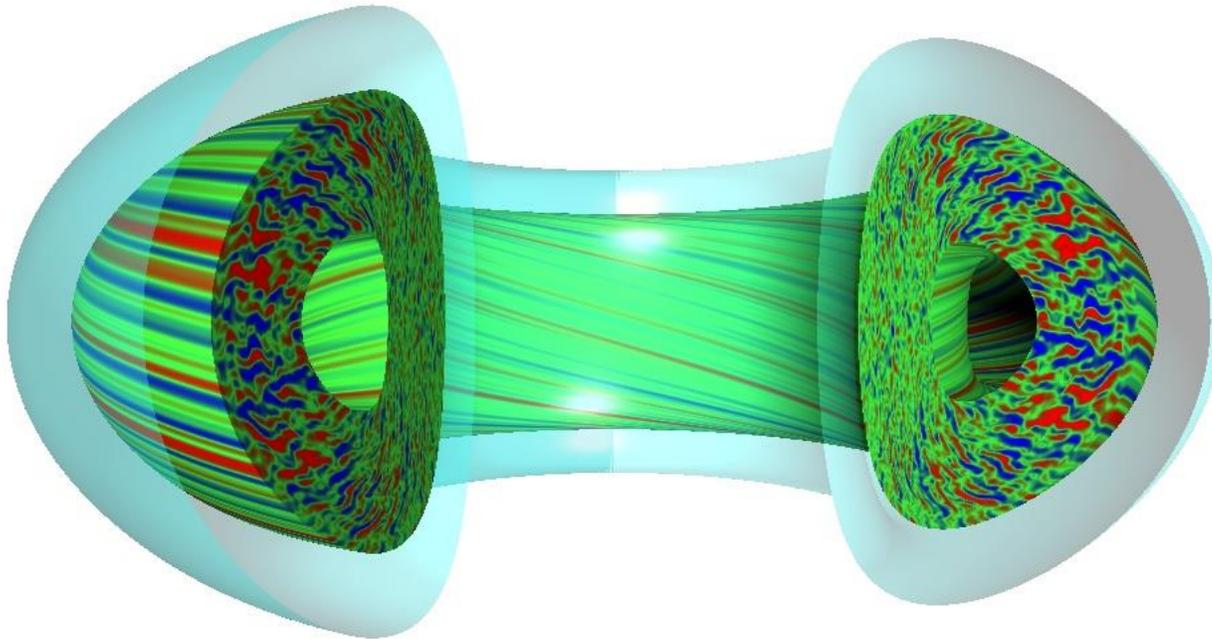
January 28th, 2026



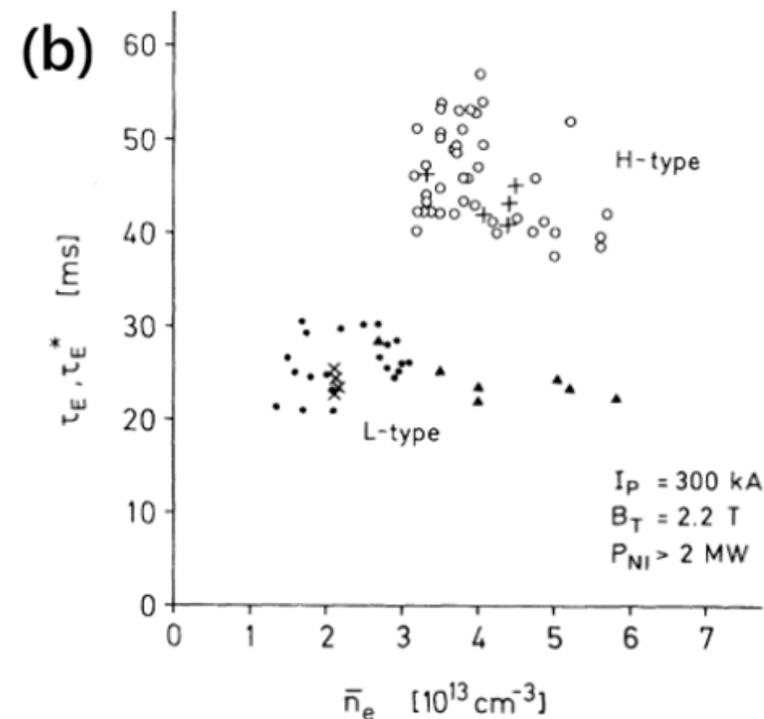
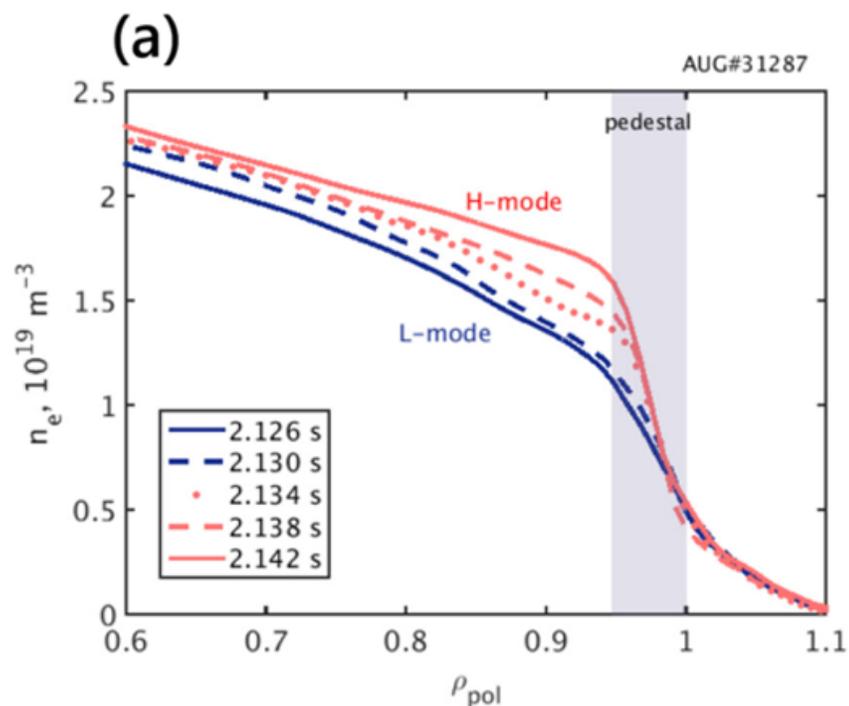
- The reaction process is self-sustainable if the **Lawson criterion** is satisfied:

$$nk_B T \tau_E > 3 \times 10^{21} \text{ keV s/m}^3$$

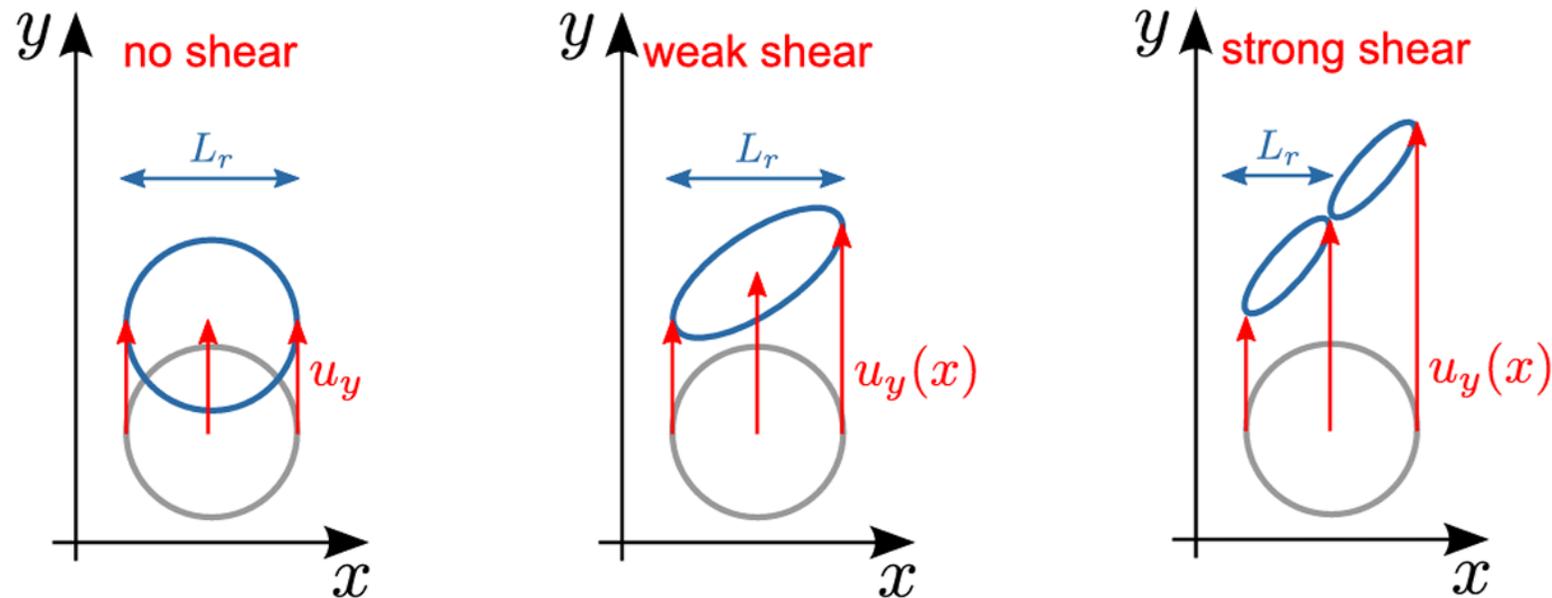
- The energy confinement time, τ_E , is limited by **turbulence** in the plasma:

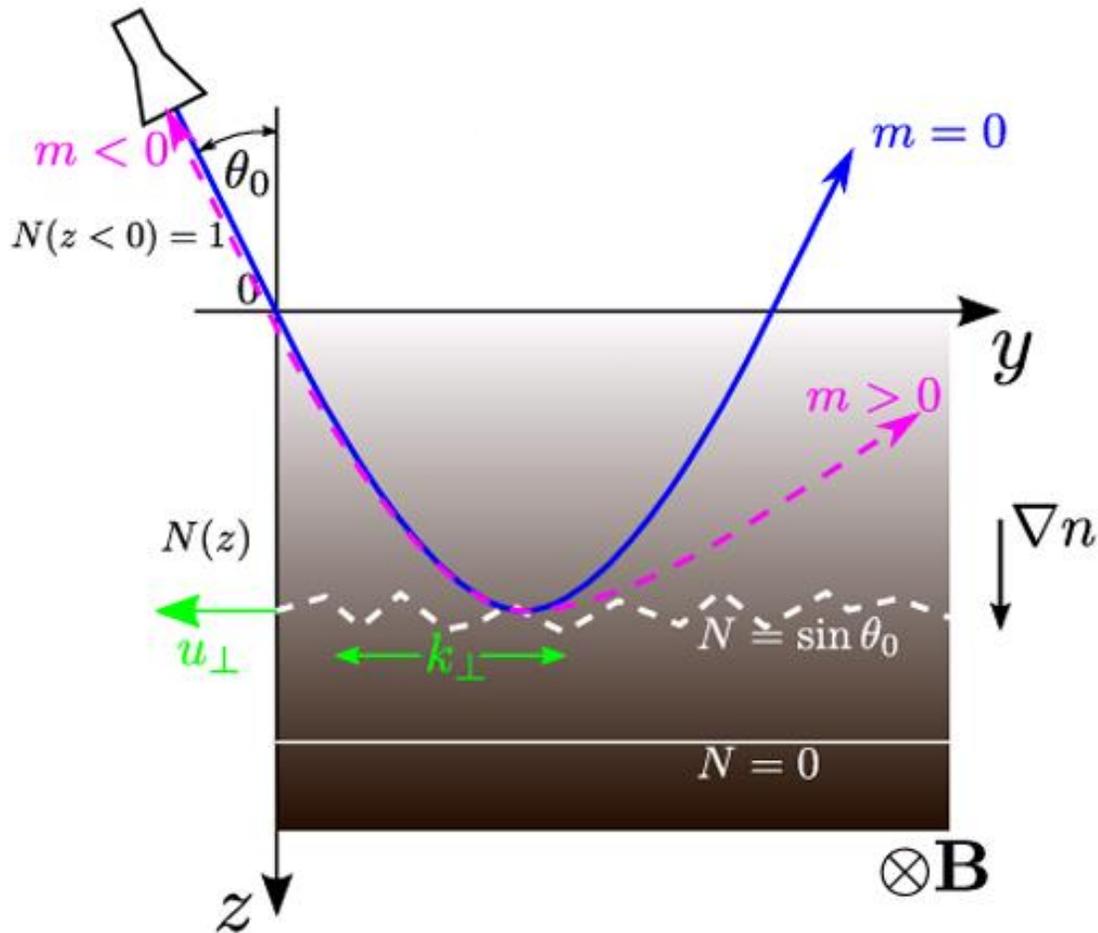


- H-mode:
 - Low turbulence levels;
 - Higher energy confinement times;
 - Steeper density and temperature gradients.



- Sheared plasma flows suppress turbulent transport.
- Turbulent structures can self-organize into generating sheared plasma flows.
- Combining both models, turbulence and sheared plasma flows are coupled!





- Fluctuation wave-number selected:

$$k_{\perp} = 2k_0 \sin(\theta_0)$$

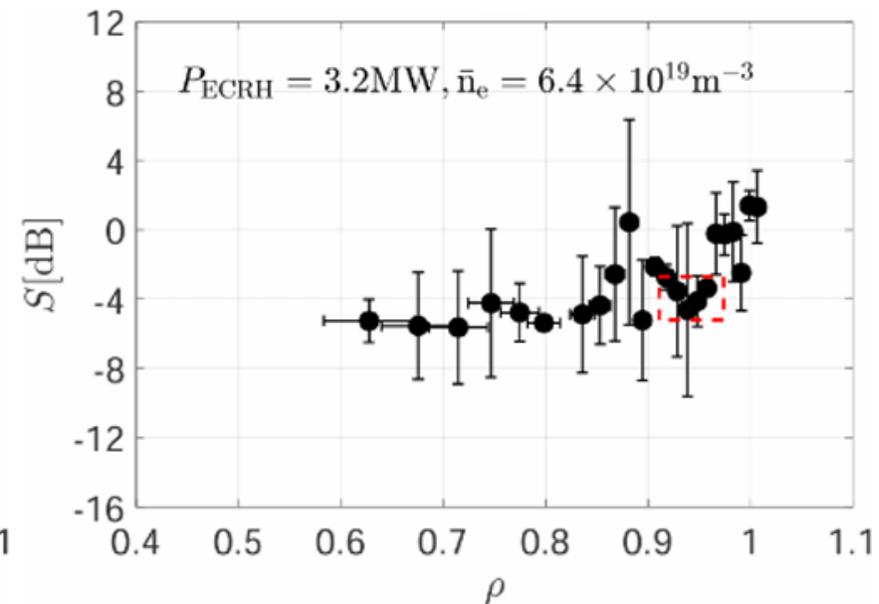
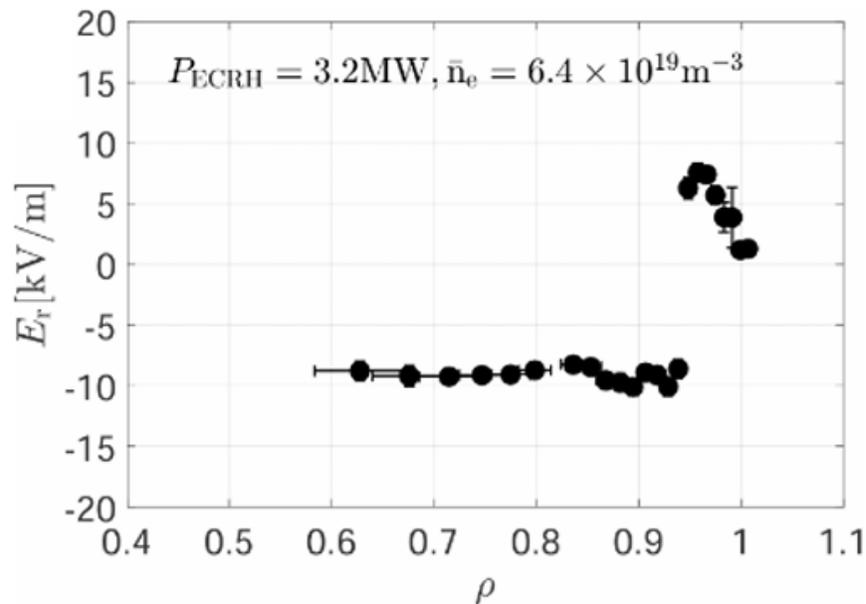
- If the turbulent structures are moving with velocity \vec{u} , the signal will have acquired a **Doppler shift**:

$$\omega_D = \vec{u} \cdot \vec{k} \approx u_{\perp} k_{\perp}$$

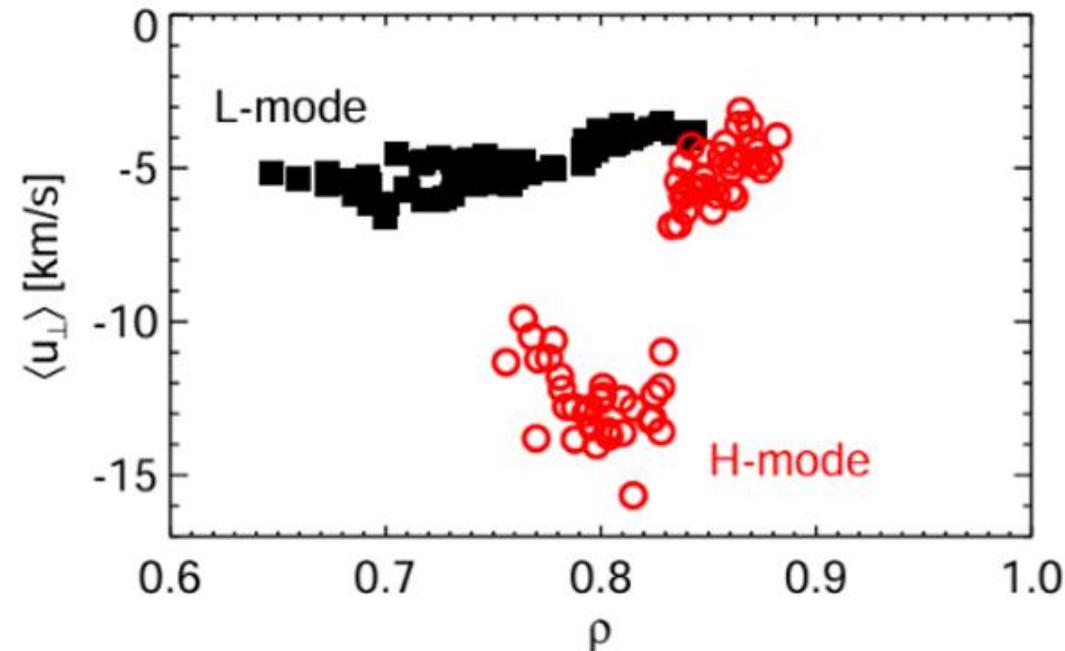
- The reflected power of the wave follows:

$$S \propto (\delta n)^2$$

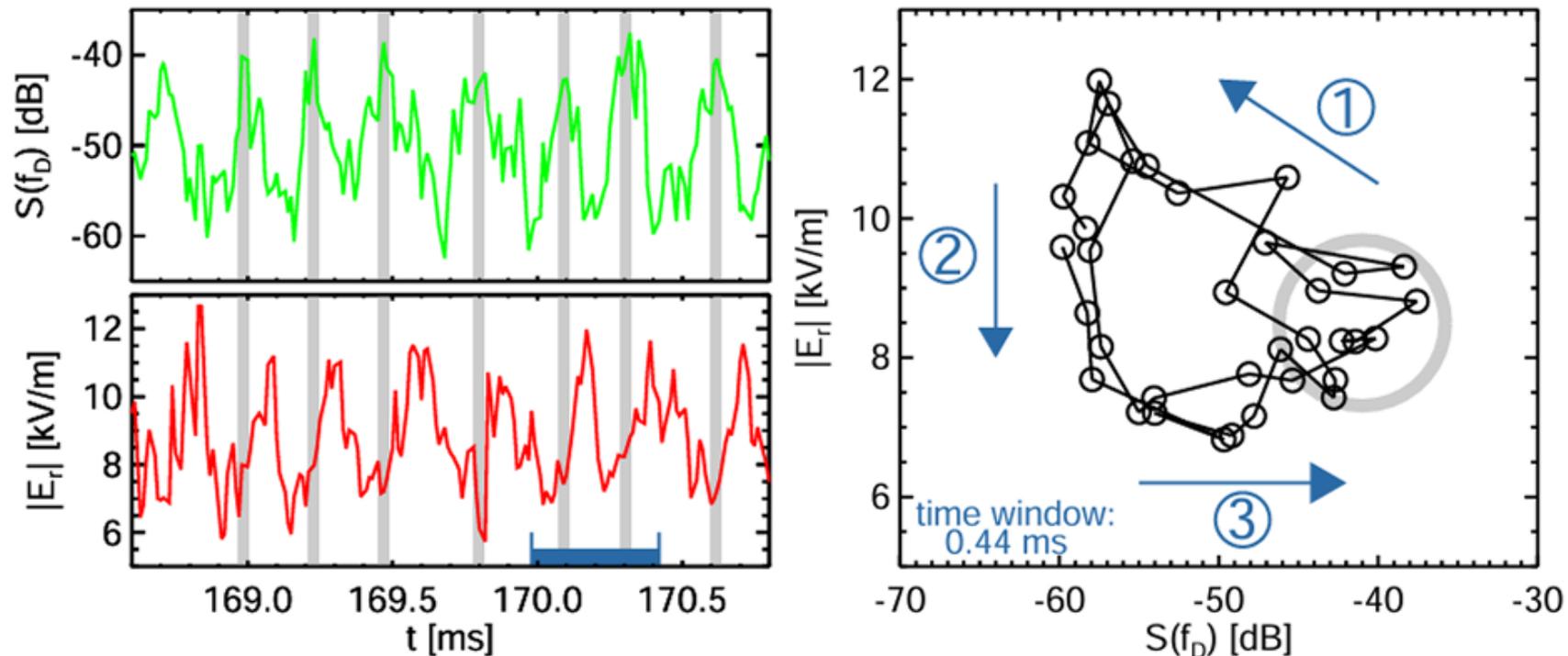
- Doppler reflectometry allows the study of the turbulence suppression mechanisms.
- Sheared profiles in the plasma velocity have been measured in regions close to where the turbulence level reaches a local minimum and also in the H-mode, when in the L-mode the profile is relatively flat.



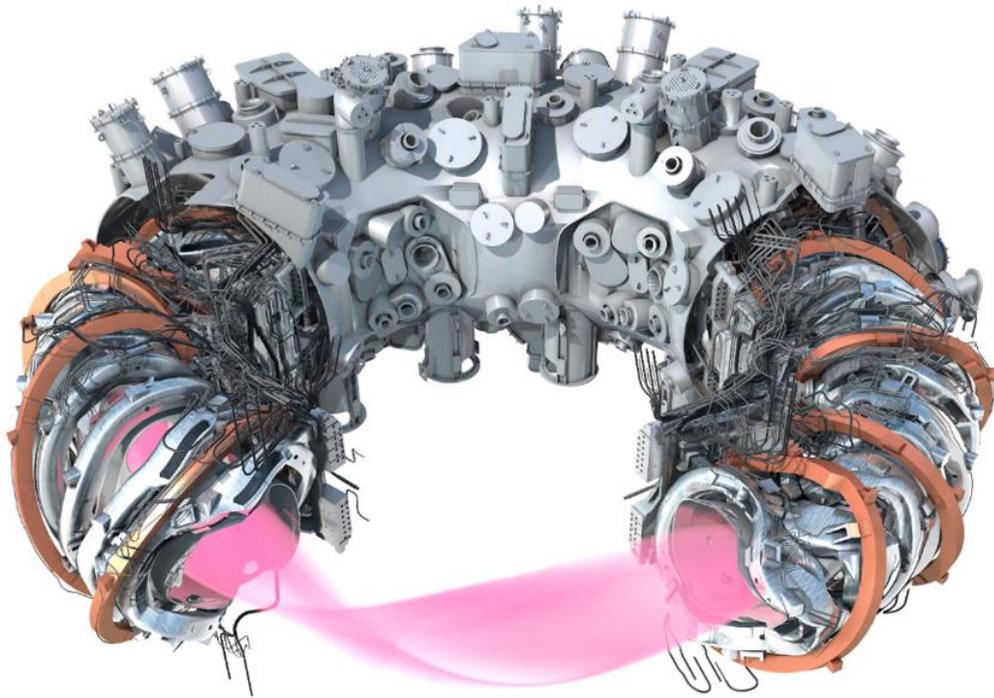
- Doppler reflectometry allows the study of the turbulence suppression mechanisms.
- Sheared profiles in the plasma velocity have been measured in regions close to where the turbulence level reaches a local minimum and also in the H-mode, when in the L-mode the profile is relatively flat.



- Experimental evidence of the coupling between sheared flows and turbulence level has also been observed using Doppler reflectometry, for a time interval during a L-H transition.



- Research work for the thesis to be performed at the Wendelstein 7-X stellarator, of the Max Planck Institute for Plasma Physics (IPP), Greifswald, Germany.

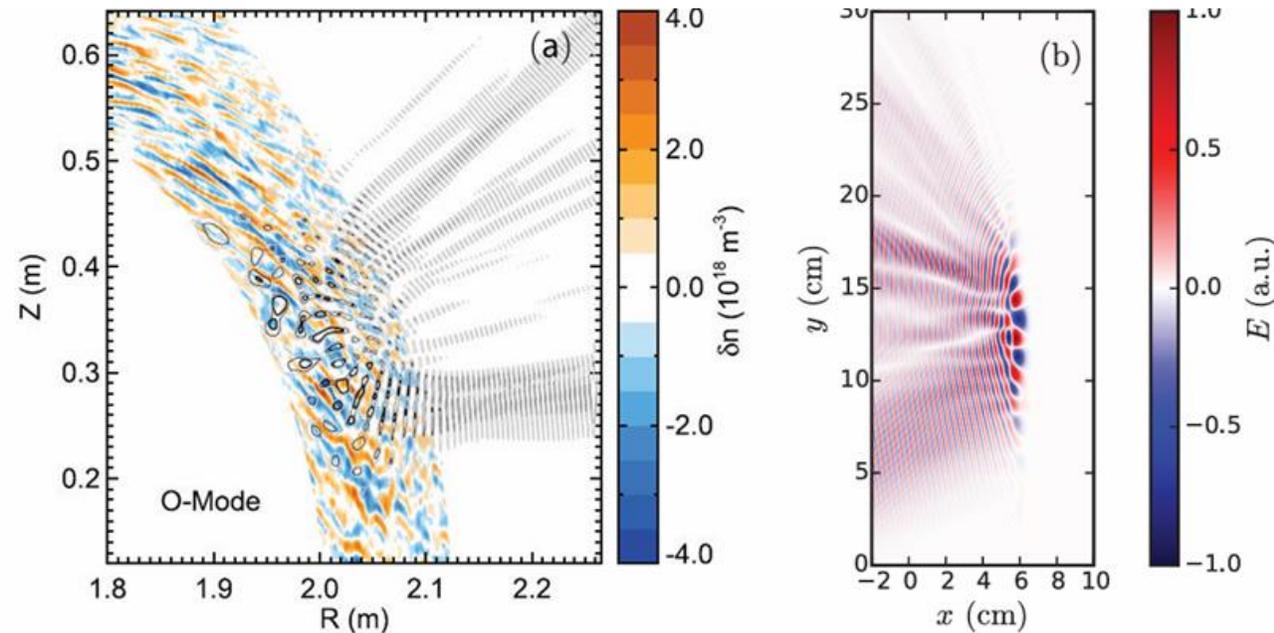


- Plasmas subject to various magnetic field configurations and heating methods will be studied.
- Doppler reflectometry measurements will allow to continue the study of turbulent transport and its interaction with sheared plasma flows.

Extra material

Extracting information from the diagnostic

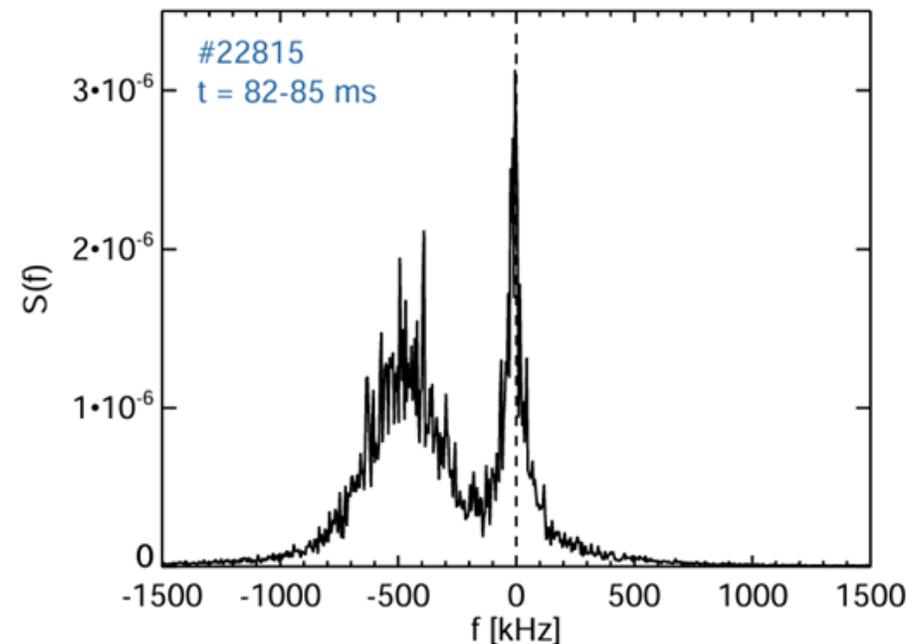
- The turbulence level can be inferred since the scattered power of the wave, S , follows $S \propto (\delta n)^2$, where n is the plasma density.
- In real experiments, to know where the wave will reflect and what wave-numbers of turbulence are selected, simulations are used.



- From the backscattered wave, an I/Q detector gives the signals:

$$I(t) = A(t)\cos(\phi(t)) \quad Q(t) = A(t)\sin(\phi(t)).$$

- $\phi(t)$ contains $\omega_D t$ because of the Doppler shift. Combining $I(t)$ and $Q(t)$ into the complex signal $V(t) = I(t) + iQ(t) = A(t)e^{i\phi(t)}$, that shift will be present as a peak in the spectrum of $V(t)$.



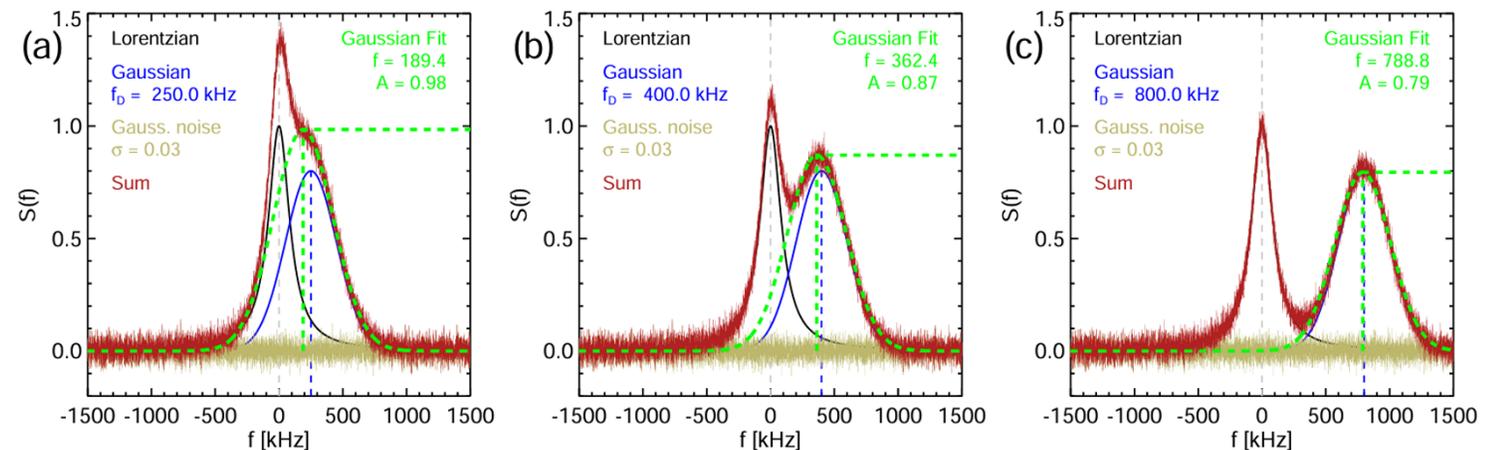
- The detected signal may contain a component from the zero-order reflection, centered at $f = 0$ Hz, so one must be careful when analysing the spectrum of $V(t)$ to obtain the Doppler Shift f_D .
- A few ways of making that measurement are:

- **Center of Gravity (COG):**

- Takes the Doppler shift to be the asymmetry measure:

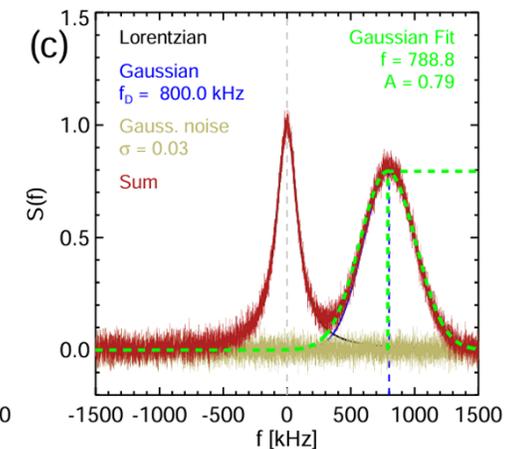
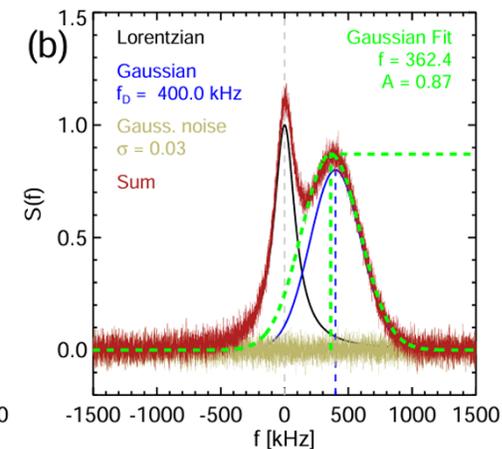
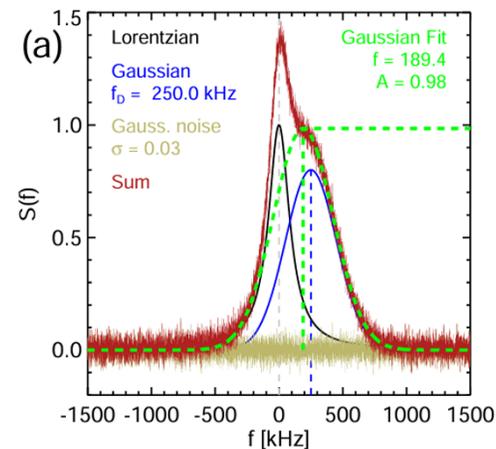
$$f_D = \frac{\int_{-\infty}^{\infty} fS(f)df}{\int_{-\infty}^{\infty} S(f)df}$$

- Yields the correct value if there's no zero-order reflection.



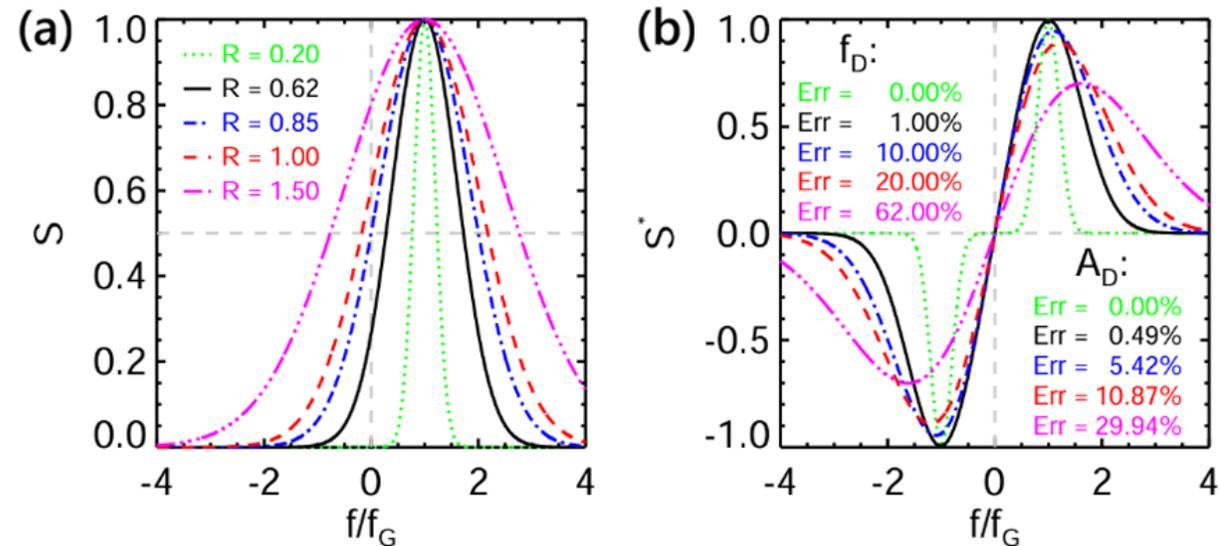
- The detected signal may contain a component from the zero-order reflection, centered at $f = 0$ Hz, so one must be careful when analysing the spectrum of $V(t)$ to obtain the Doppler Shift f_D .
- A few ways of making that measurement are:

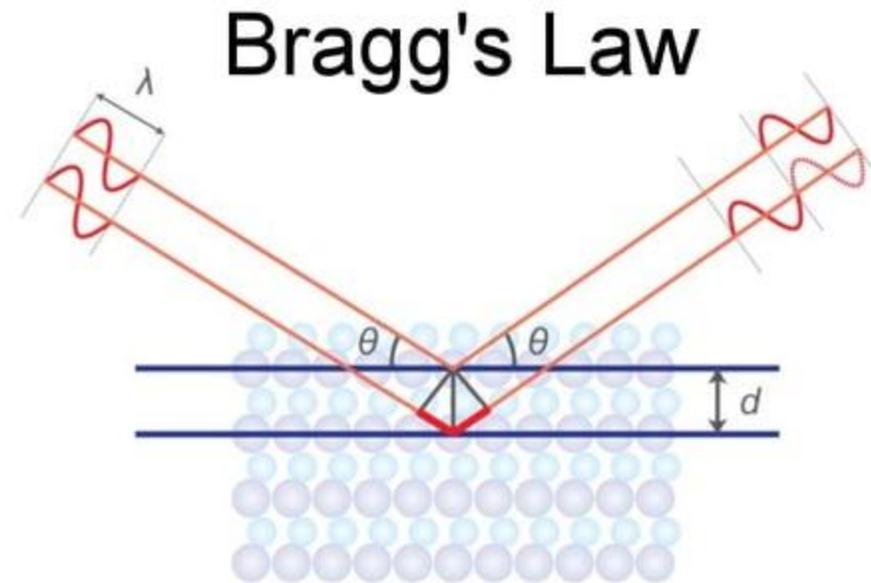
- **Fit to the Power Spectrum (SFIT):**
 - Fits selected points on the spectrum to a gaussian and takes its peak frequency and amplitude.
 - Yields the correct value if there's a significant level of separation between the two reflection components.



- The detected signal may contain a component from the zero-order reflection, centered at $f = 0$ Hz, so one must be careful when analysing the spectrum of $V(t)$ to obtain the Doppler Shift f_D .
- A few ways of making that measurement are:

- **Fit to the Asymmetric part of the Power Spectrum (AFIT):**
 - Filters the symmetric part of the spectrum.
 - $S^*(f) = S(f) - S(-f)$
 - Yields the correct value if the Doppler peak is far from the origin.





$$n\lambda = 2d \cdot \sin \theta$$

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- **(12)** A. Medvedeva et al. “Density profile and turbulence evolution during L–H transition studied with the ultra-fast swept reflectometer on ASDEX Upgrade”. In: Plasma Physics and Controlled Fusion (2017).
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