Fast-camera imaging of edge turbulence in Alcator C-Mod and W7-X

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Filament motion in the Alcator C-Mod divertor

The Alcator C-Mod divertor camera imaged edge turbulent filaments at up to 397,100 fps.

A Phantom v710 camera looking tangentially and down at the divertor was used to observe edge turbulent filaments.

Installation of the high speed camera on W7-X

 Phantom camera specs and capabilities

• Phantom v710: records visible light in monochrome up to 397,100 fps at 128x64 pixels, for ~1 second
• Spatial resolution ~2 cm for W7-X
• Able to configure camera settings remotely using MDSticks
• Operated during the OP 1.2a run campaign on W7-X in 2017, recording 641 useful videos. Will operate during OP 1.2b.

Front-end optics presently limit spatial resolution. Total light throughput limits the maximum frame rate to 30k fps.

The LCFS looks very similar in the camera’s view for different magnetic configurations, but edge and divertor emissions appear very different.

W7-X magnetic configurations

W7-X magnetic configurations

Fueling efficiency” analysis

The full plasma cross section view gives us total visible light emission; we relate total emission to number of ionizations/s using an S/XB factor from ADAS calculations:

\[
\frac{S}{X \text{ (excitation rate)}} \cdot \frac{X}{\text{Photon}} = \frac{\text{# ionizations}}{\text{photons}}
\]

We define \( \tau^* \) to quantify roughly the “fueling efficiency”:

\[
\tau^* = \frac{\# \text{ core particles}}{\text{edge ionizations/second}} \cdot \frac{\text{total visible light}}{S/XB}
\]

Plasmas with large \( \tau^* \) require fewer ionizations/s to maintain a given constant core plasma density and are therefore more efficiently fueled than plasmas with lower \( \tau^* \).

We observe that total visible light rises with density, and collapsing/detached plasmas show up as bright outliers.

The 1 kHz quasi-coherent boundary fluctuation

During steady state, quasi coherent fluctuations are often observed in divertor-area emissions.

This quasi-coherent fluctuation is also observed by scanning Langmuir probes for the same shot.

The quasi-coherent fluctuation has only been observed in the divertor in the standard configuration.

Large filaments observed during plasma collapse

Subtracting the previous frame shows where light is increasing (red) and decreasing (blue). This makes it easy to see filaments in the far (a) and near (b) view.

The direction of rotation of the filaments varies from shot to shot, and does not depend on the direction of the magnetic field.


Summary

• Steady-state diverted operation:
  • Distribution of visible light intensity depends on magnetic configuration
  • Resolution is too coarse to see steady-state filaments seen by other W7-X fast-focusing cameras
  • A quasi-coherent fluctuation is observed in divertor-area emissions during the standard magnetic configuration
  • Gas fueling efficiency appears to be relatively lower at high density

• Large, poloidally moving filaments are visible during plasma collapse