The role of plasma instabilities in the onset of detachment in the York Linear Plasma Device

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1. Project aim

Use the York Linear Plasma Device as a tool to investigate plasma **detachment phenomena** and, in particular, links to **plasma instabilities** and radial transport.

2. York Linear Plasma Device

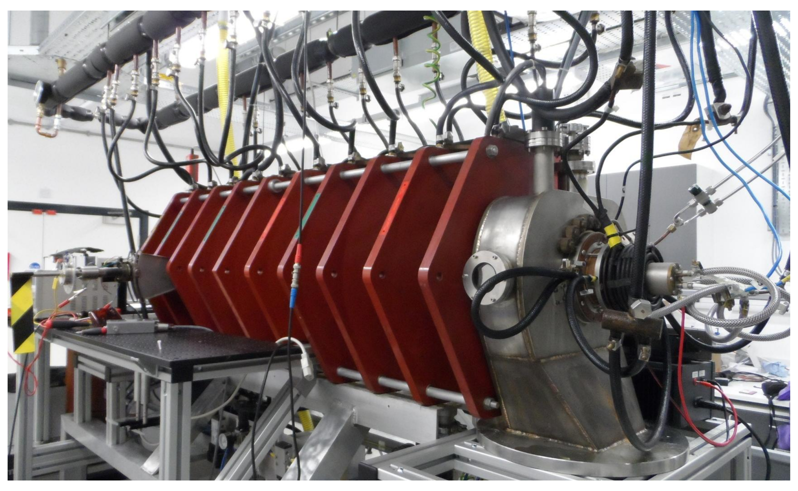

Figure 1: Photograph of the York Linear Plasma Device.

The YLPD, housed at the York Plasma Institute, creates a linear-geometry, magnetised plasma. It has a modified duoplasmatron, Demirkhanov-type plasma source, and can operate in hydrogen or helium. The plasma parameters are of relevance to divertor and scrape-off layer plasmas [1]:

Parameter	Value
Plasma column diameter	~ 2-3 cm
Max. axial magnetic field	~ 90 mT
Ion density	10^{16} - 10^{18} m^{-3}
Max. electron temperature	~ 15 eV

3. Detachment

Detached divertor plasmas are considered to be essential for the operation of tokamak reactors:

- Divertor power fluxes estimated to be at least ~15 MW m^{-2} in ITER [2], higher than available materials can handle
- Reduced power/particle fluxes required to extend divertor component lifetime
- Strong volume recombination particle sinks are associated with detachment
- **Two benefits of detachment:**
    - **Ion flux reduced** – recombination creates neutrals, decreasing ion bombardment
    - **Energy flux reduced** – recombination processes radiate energy into 4π steradians (no longer focused onto divertor strike point)

Experimental tokamaks can be used for detachment research (e.g. ASDEX-U [3], MAST-U [4]), but:

- Diagnostic access is difficult in tokamak geometry
- **Simpler to use linear plasma devices, capable of replicating divertor plasma parameters**

A pre-detached state, in which fluctuations are seen in the soft X-ray emission, has been observed on ASDEX-U [3], but there has been **no detailed study** of the links between **fluctuations** and **detachment**.

Previous work has identified two main recombination regimes associated with detached plasmas:

- **Electron-ion recombination (EIR)**

  $e^- + H^+ \rightarrow H + h\nu$

  $e^- + H^+ \rightarrow H^{**} \rightarrow H + h\nu$

  $e^- + H^+ + \xi \rightarrow H^* + \xi'$

- **Molecular-activated recombination (MAR)**

  $H_2(v) + e^- \rightarrow H^- + H$ then $H^- + H^+ \rightarrow H + H^*$

  $H_2(v) + H^+ \rightarrow H_2^+ + H$ then $H_2^+ + e^- \rightarrow H + H^*$

Both EIR and MAR regimes have previously been observed on the YLPD (e.g. [5]). 1D axial parameter profiles are shown in Fig. 2.

Detachment (cont.)

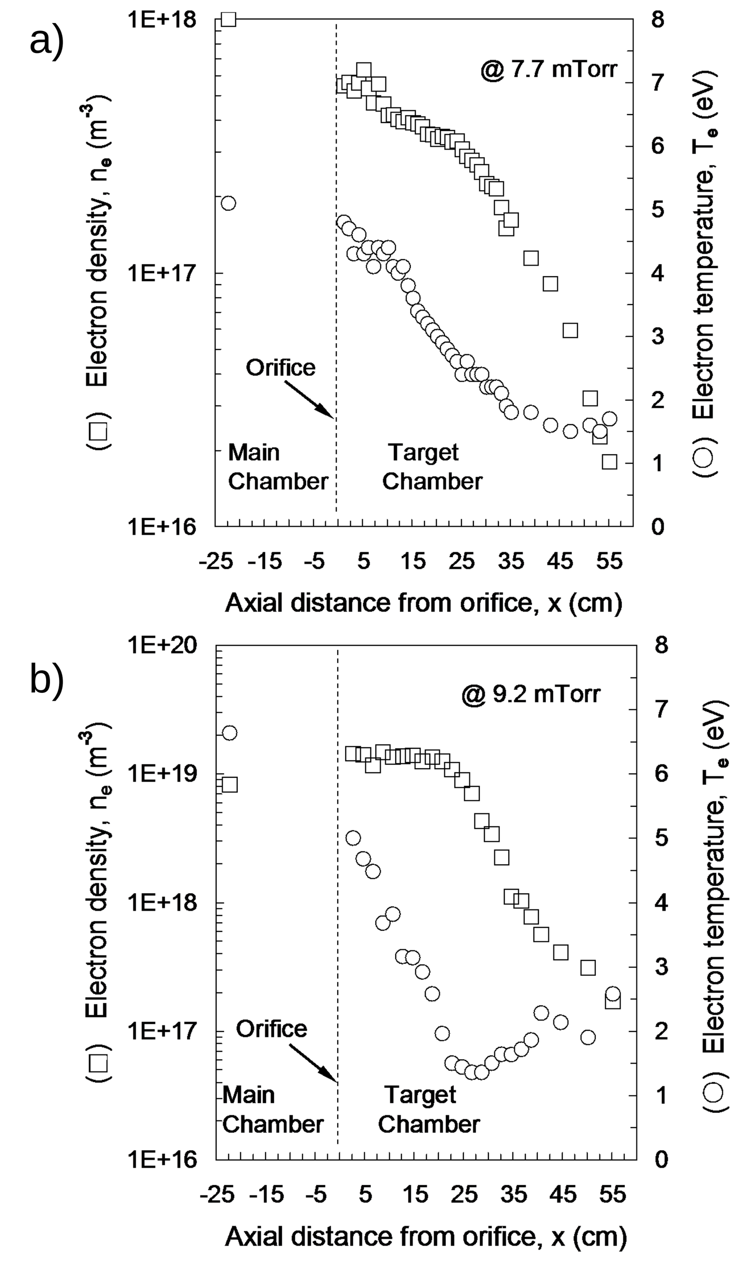

Figure 2: Electron density and temperature profiles in detached plasma in the YLPD, for a) MAR and b) EIR [5].

4. Optical diagnostics

Optical spectroscopy on the EIR-detached plasma in the YLPD shows the characteristic high-n Balmer emission spectrum (Fig. 3). A Boltzmann analysis yields an electron temperature of **(0.16±0.06) eV**.

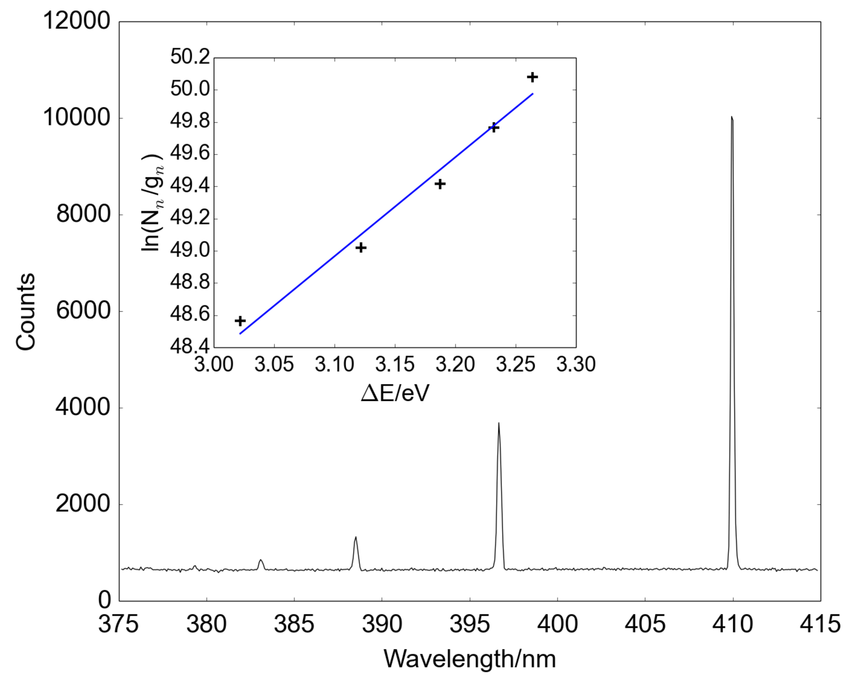

Figure 3: High-n Balmer emission spectrum from the detached hydrogen plasma. *Inset:* Boltzmann analysis results. $T_e = (0.16 \pm 0.06)$ eV.

MAST tokamak DIVCAM image inversion has shown that this emission originates from the **outer edge** of the plasma column (Fig. 4) [6].

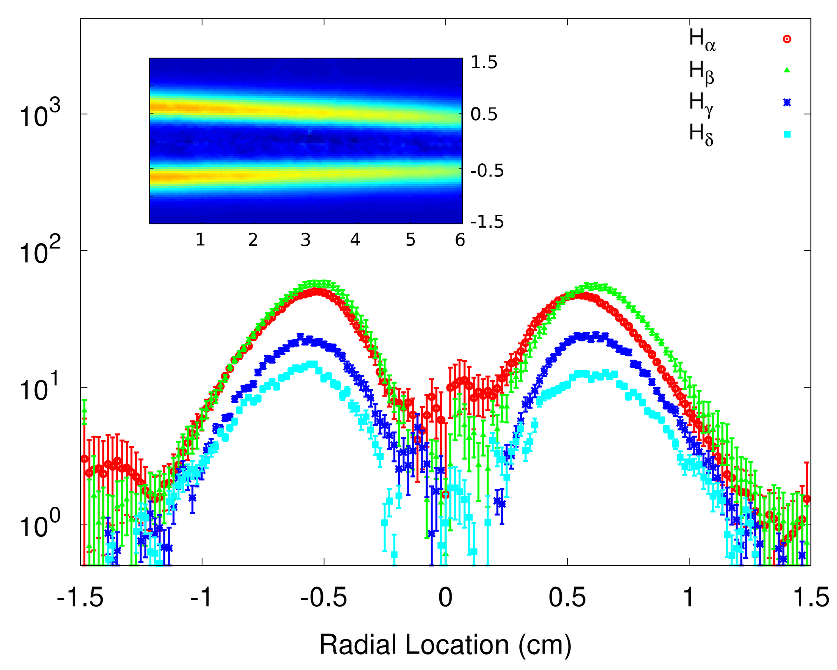

Figure 4: Radial hydrogen emission profiles from EIR detachment in the YLPD [6].

Fast-frame imaging of the detached plasma reveals the presence of **radially-transported filamentary structures** that are ejected from the column (Fig. 5).

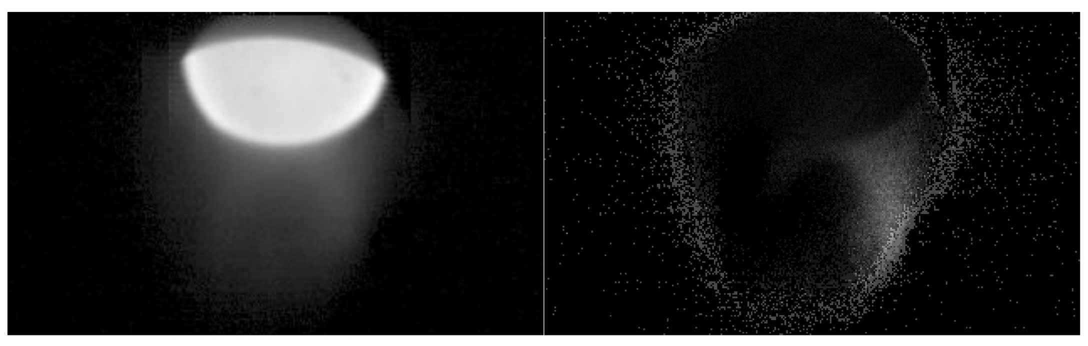

Figure 5: Raw (left) and background-subtracted (right) stills from axial fast-frame imaging of the EIR plasma (50 kHz).

5. Langmuir probes

Ongoing work employs Langmuir probes to study the **time-variation** of the floating potential of the plasma. An example of a spectrum from the centre of the attached plasma column is shown in Fig. 6:

- Coherent feature (~60 kHz) varies in frequency with axial magnetic field, and **disappears** when plasma is detached
- Low-frequency **broadband** region (up to ~30 kHz) remains as plasma detaches

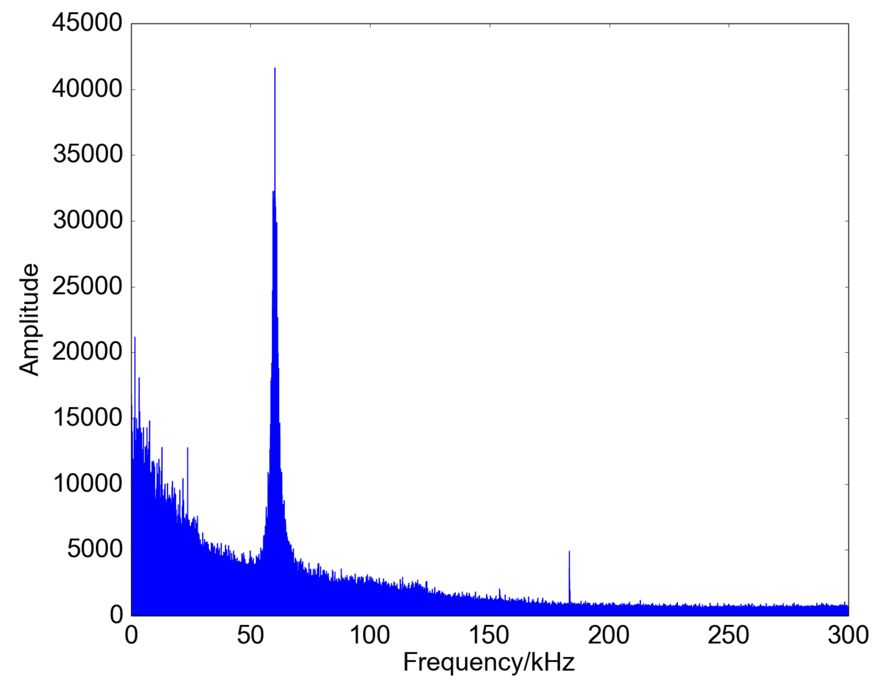

Figure 6: Frequency spectrum of the floating potential at the centre of the attached YLPD plasma.

The radial profile of the skewness of the low-frequency broadband region has been studied for the attached plasma (Fig. 7):

- Locations at which the skewness is negative **coincide** with the position of both the maximum EIR emission and the location of the filaments seen in the fast-frame imaging

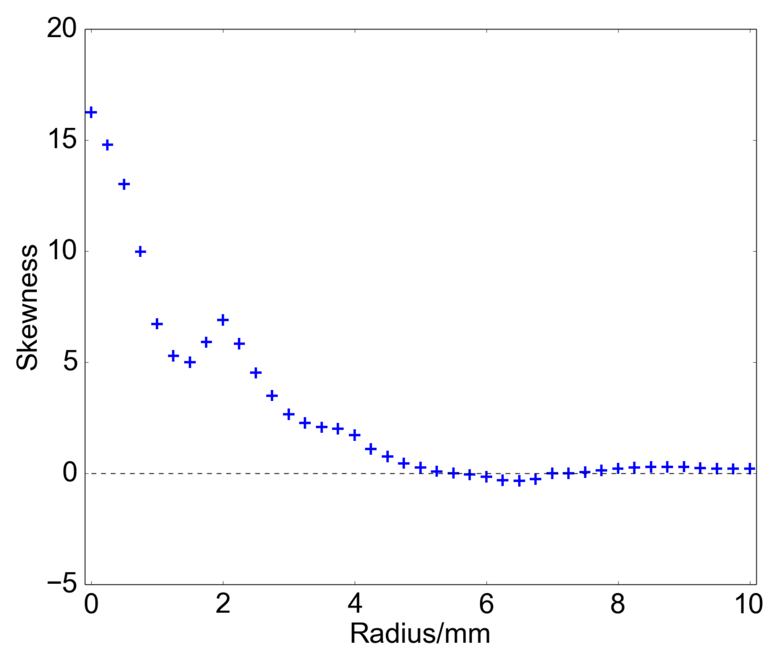

Figure 7: Radial variation of the skewness of the low-frequency broadband component of the floating potential.

6. Conclusions

These observations suggest that **fluctuations in the plasma may influence the process of EIR detachment**.

Ongoing work includes:

- Further development of Langmuir probe and optical diagnostics
- Thomson scattering diagnostic (improved temperature and density measurements)
- Laser photodetachment diagnostic (explore MAR regime through negative ion populations)
- Verification of experimental results with simulations using the BOUT++ tokamak edge turbulence code [7]

Detachment physics research is essential for success of commercial tokamak reactors.

7. References

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