Detachment and instability studies on 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

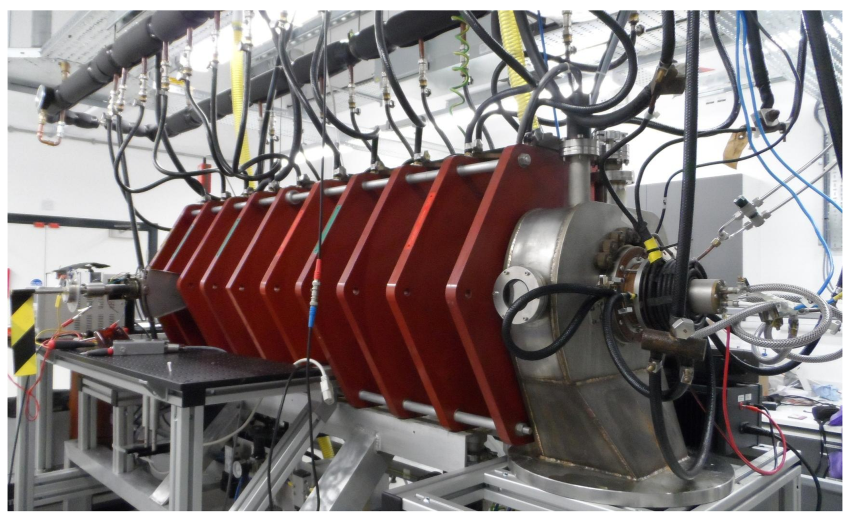

Figure 1: Photograph of the York Linear Plasma Device.

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 all focused onto narrow 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**

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)**

$$H_2(v) + e^- \rightarrow H^- + H \quad \text{then} \quad H^- + H^+ \rightarrow H + H^*$$
$$H_2(v) + H^+ \rightarrow H_2^+ + H \quad \text{then} \quad H_2^+ + e^- \rightarrow H + H^*$$

Evidence for both regimes has been previously observed on the YLPD, pictured in Fig. 1 [5].

Aim to continue and extend this work.

4. Preliminary work

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

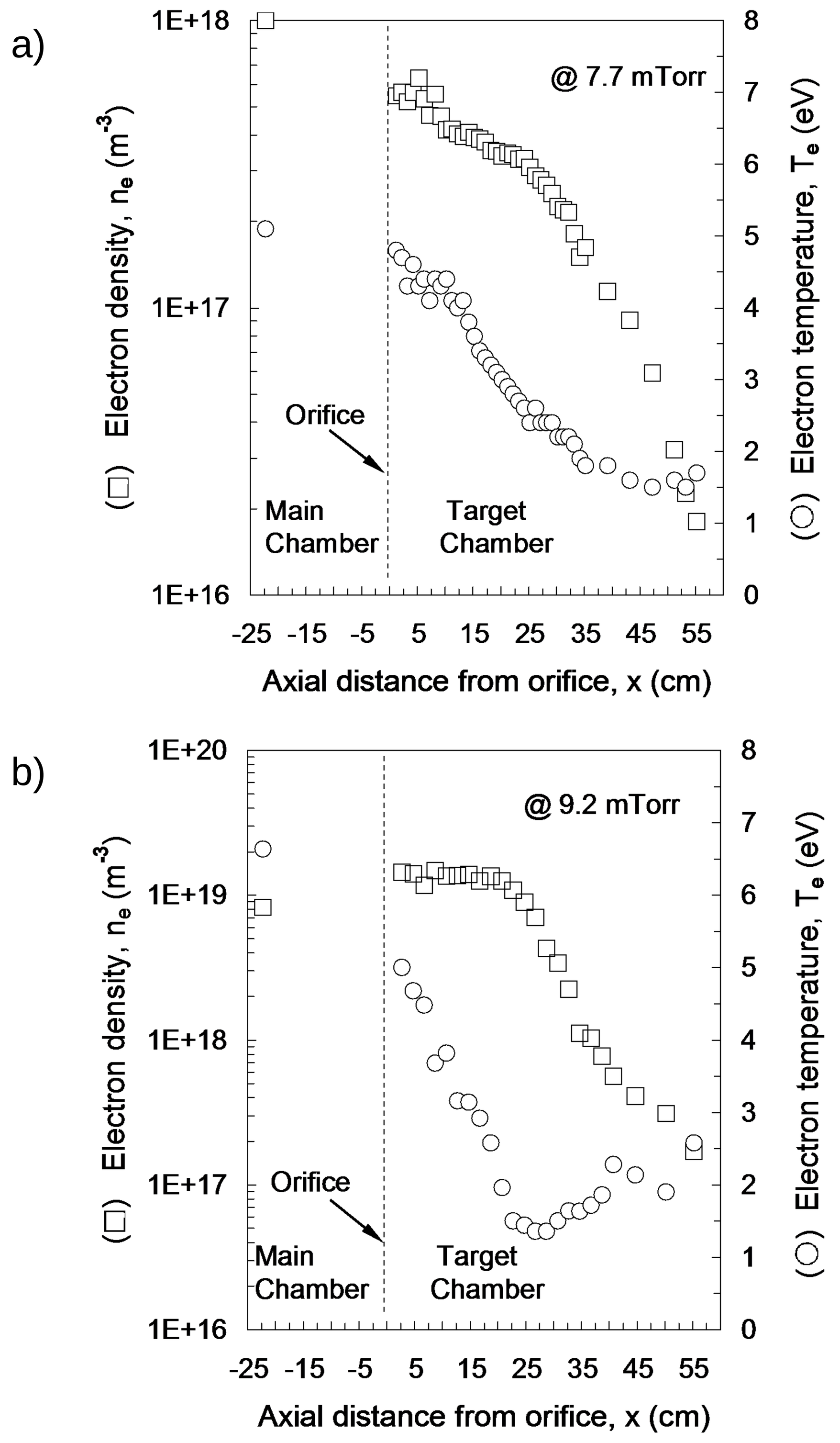

Figure 2: Electron density and temperature profiles in detached plasma in the YLPD, in a) the MAR regime and b) the EIR regime [5].

However, further measurements indicate that the process is not one-dimensional.

Recent images of attached and detached plasmas are shown in Fig. 3. The high-n Balmer emission spectrum yields an electron temperature of **(0.16 ± 0.06) eV** in the detached plasma (Fig. 4).

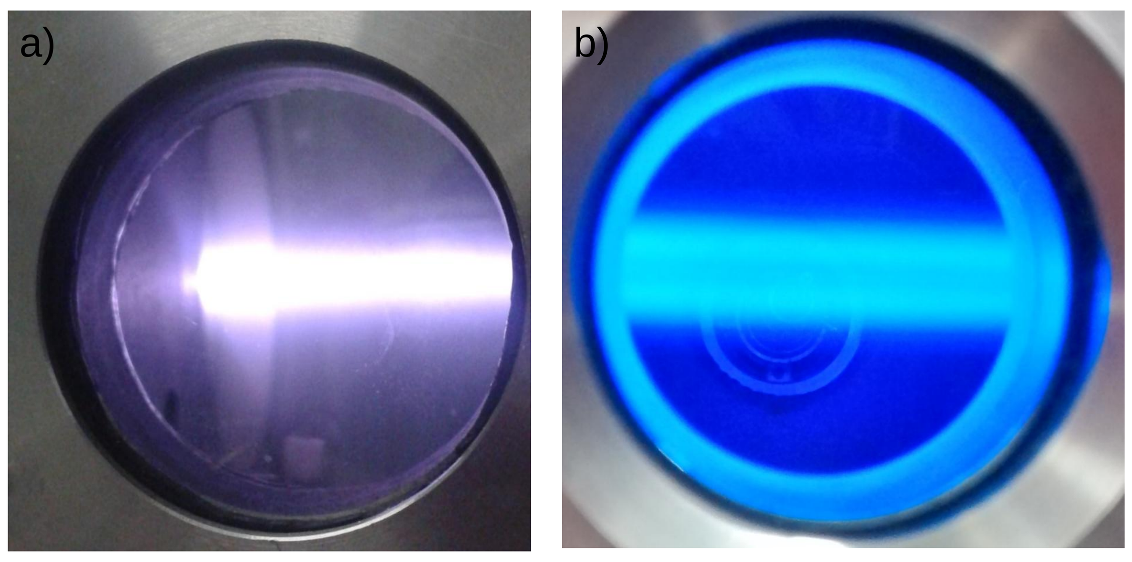

Figure 3: Photographs of hydrogen plasmas in the YLPD in a) the attached state; b) the EIR volume recombination state. The port diameter is 5cm.

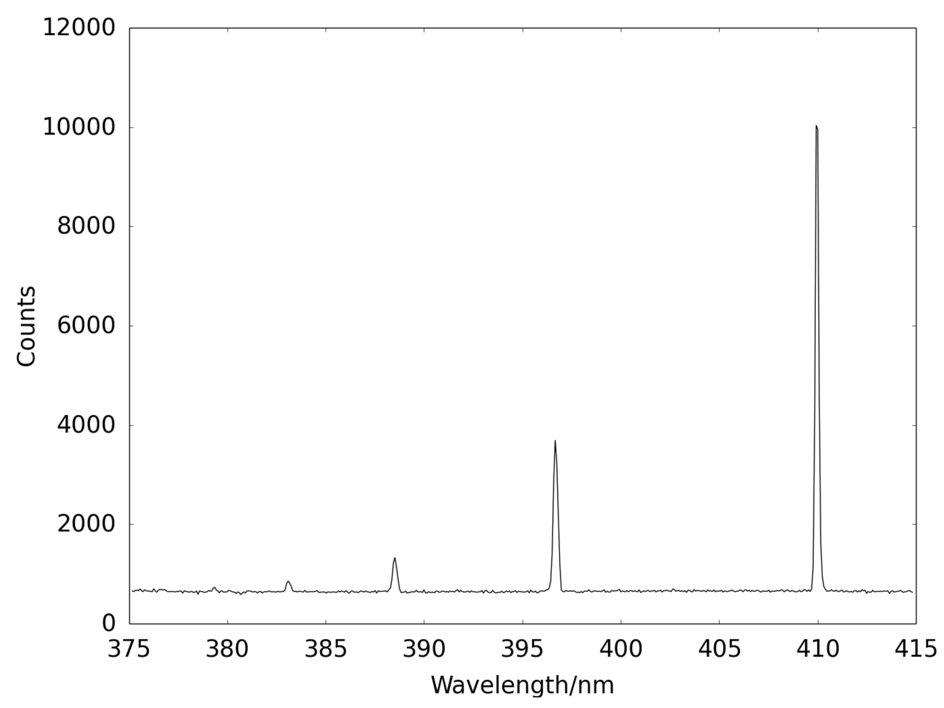

Figure 4: Spectrum from the detached hydrogen plasma, showing the high-n Balmer emission lines characteristic of the EIR regime. $T_e = (0.16 \pm 0.06)$ eV.

Fast-frame imaging of the detached plasma reveals the presence of **radially-transported blob-like or filamentary structures** that are ejected from the column *(video data displayed during poster session)*.

Preliminary work (cont.)

MAST tokamak DIVCAM image inversion has shown that the EIR 'blue glow' (indicative of detachment) occurs in the **outer edge** of the plasma column, where the blob-like structures are observed (Fig. 5) [6].

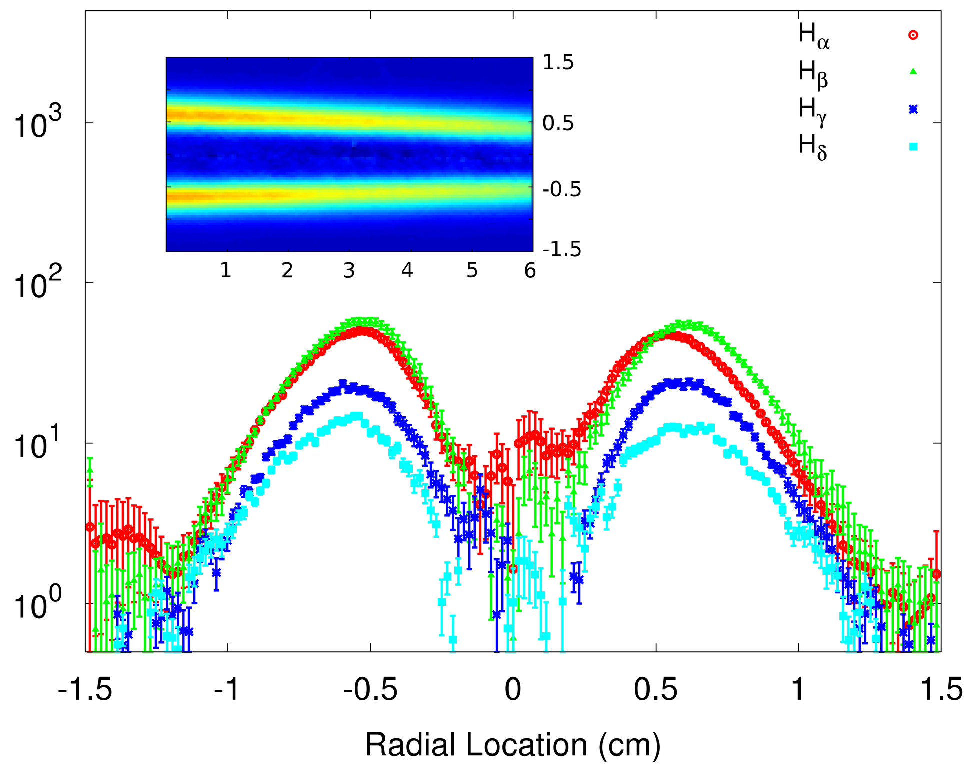

Figure 5: Radial hydrogen emission profiles from EIR detachment in the YLPD [6].

A 12-tip Langmuir probe system has been built:

- Will **measure fluctuations** in the plasma, complementing the high-speed imaging data
- Initial observations indicate differences in the frequency spectra of the floating potentials in detached and non-detached plasmas

Fluctuations have also been observed in a pre-detachment state in ASDEX-U [3], but **these phenomena are yet to be explained**.

5. Hypothesis

Instabilities in the plasma column cause recombination to occur in the edge region.

Aim to investigate links between radial transport of plasma (due to instabilities) and location of recombination processes.

Ongoing and future work includes:

- Measurement of radial flux fluctuations to analyse 'blob' dynamics *(Langmuir probe arrays, fast-frame imaging)*
- Further observation of EIR and MAR detachment regimes *(optical spectroscopy, laser photodetachment)*
- Verification of experimental results with simulations using the BOUT++ tokamak edge turbulence code [7]

6. Summary

- Detachment physics research essential for success of commercial tokamak reactors
- Previous studies on the York Linear Plasma Device have observed two detachment regimes
- Aim to replicate and extend results using additional diagnostic techniques and simulations
- Look for **links between detachment and turbulent transport**, building on preliminary measurements of instabilities in the YLPD

7. References

[1] Rusbridge et al., *Plasma Phys. Control. Fusion*, **42**(5), 2000
[2] Alvarez et al., *Fusion Eng. Des.* **86**(9-11), 2011
[3] Potzel et al., *Nucl. Fusion*, **54**(1), 2014
[4] Havlíčková et al., *Contrib. Plasma Phys.*, **54**(4-6), 2014
[5] Mihaljčić, PhD thesis, University of Manchester, 2004
[6] Browning, Lisgo, Trojan, Private Communication, 2014
[7] Dudson et al., *Comput. Phys. Commun.*, **180**(9), 2009

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