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 **detachment phenomena** and **plasma instabilities**, and search for **links** between the two

2. Background and motivation

Detached divertor plasmas may be essential for the operation of commercially-viable tokamaks:

- Divertor power fluxes estimated to be at least ~15 MW m^{-2} in ITER [1]
- Higher than available materials can handle
- Reduced power flux required to extend divertor component lifetime
- Detachment occurs via volume recombination
- **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 are used for detachment research (e.g. ASDEX [2], MAST-U [3]), 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 which lead to 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 York Linear Plasma Device (YLPD, pictured in Fig. 1) [4]

Aim to continue and extend this work

3. York Linear Plasma Device

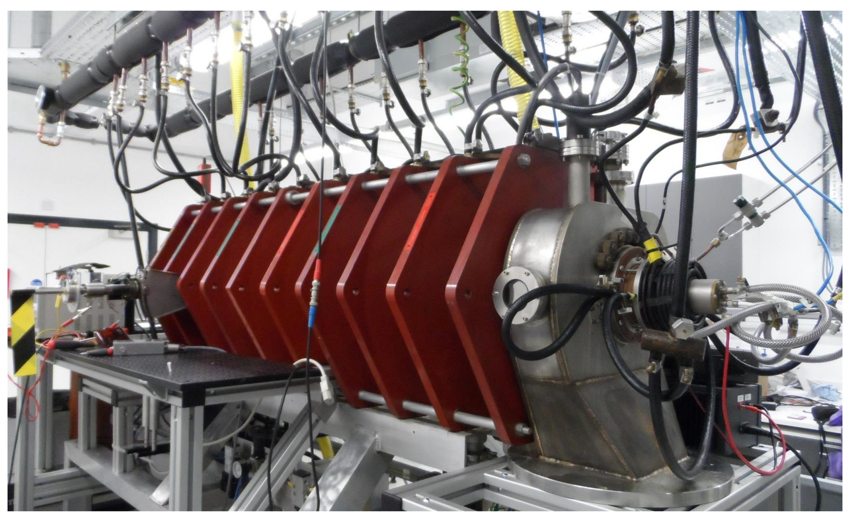

Figure 1: Photograph of the York Linear Plasma Device.

The YLPD, housed at the York Plasma Institute, is a 1.5m long, 24cm diameter stainless steel vacuum vessel. It has a modified duoplasmatron, Demirkhanov-type plasma source, and can operate in hydrogen or helium. The plasma parameters are similar to divertor and scrape-off layer plasmas [5]:

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

4. Preliminary results

- A recent upgrade of the YPLD has doubled the maximum available magnetic field
- Measurements were made across the plasma column using a single Langmuir probe to obtain radial equilibrium profiles of plasma parameters (Fig. 2)

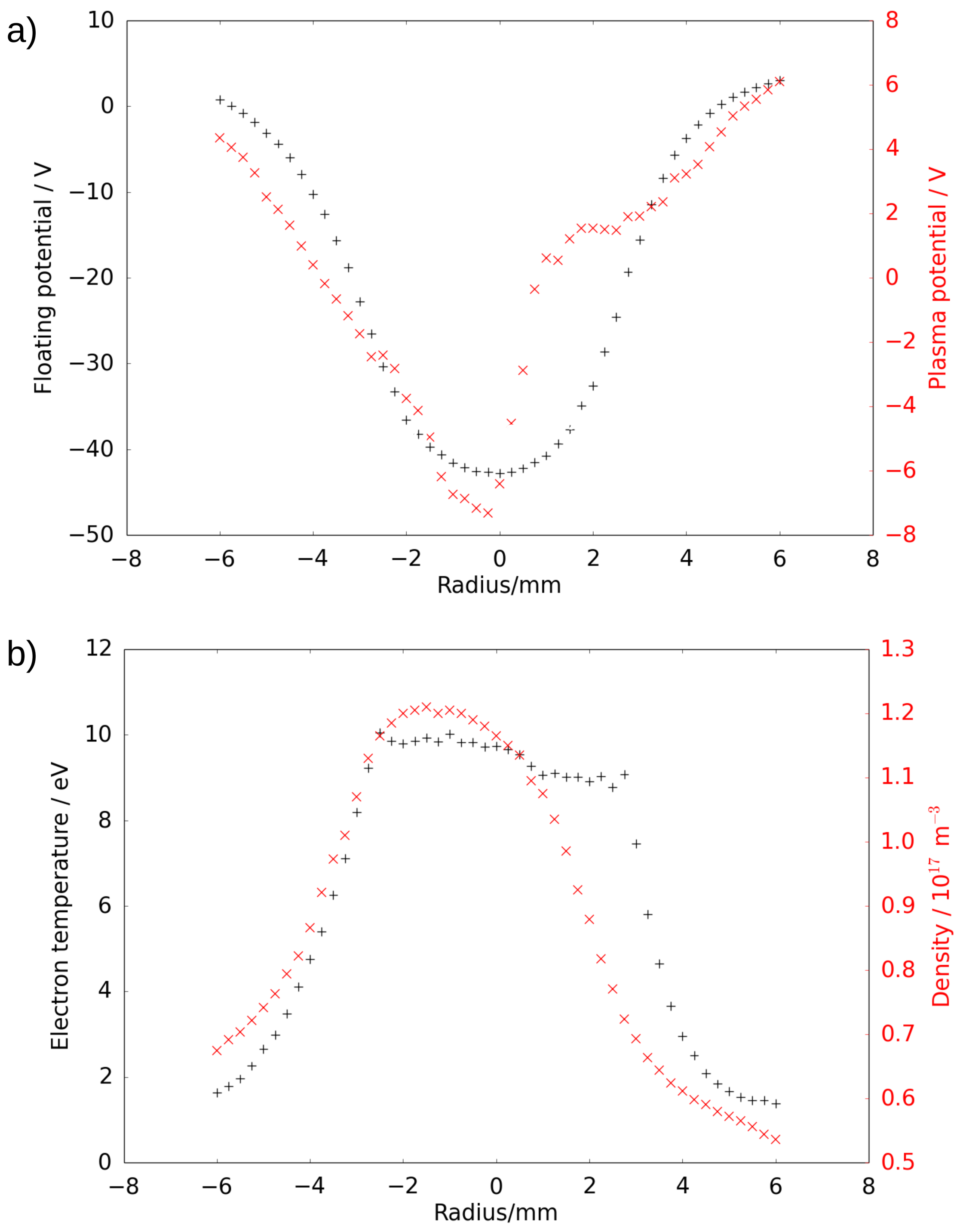

Figure 2: Radial equilibrium profiles of: a) floating and plasma potentials; b) electron temperature and plasma density across the plasma column. Profiles taken using 45mT axial magnetic field strength.

- **Initial observations of EIR detachment have been made in hydrogen plasma:**
  - Photographs of the normal and detached plasmas are shown in Fig. 3
  - Electron temperature of (0.16 ± 0.06) eV from high-n Balmer emission spectrum (Fig. 4)

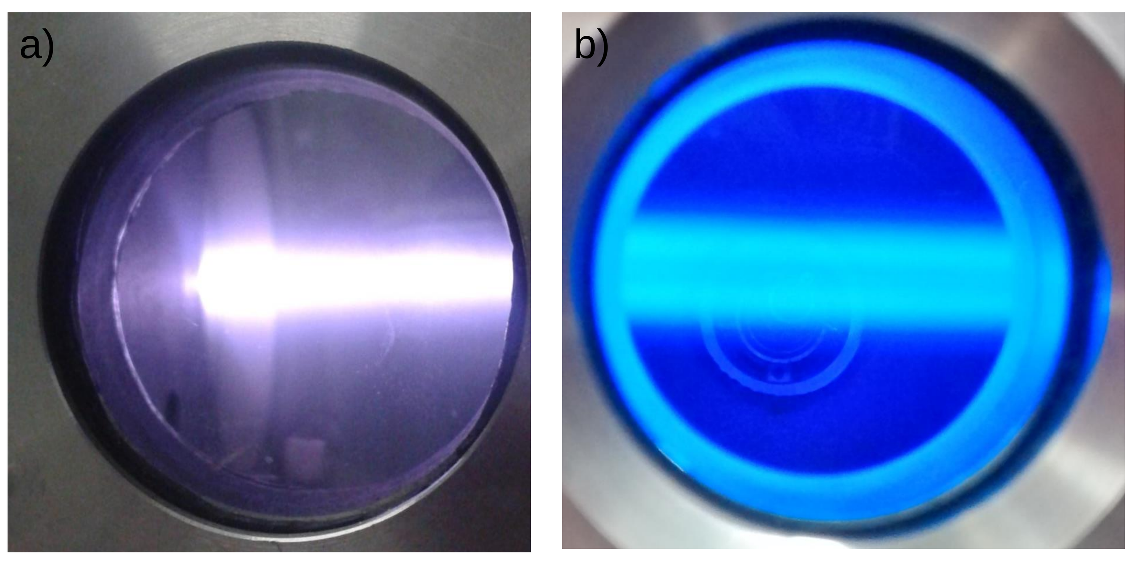

Figure 3: Photographs of hydrogen plasmas in the YLPD in a) the normal state; b) the EIR volume recombination state. The port diameter is 5cm.

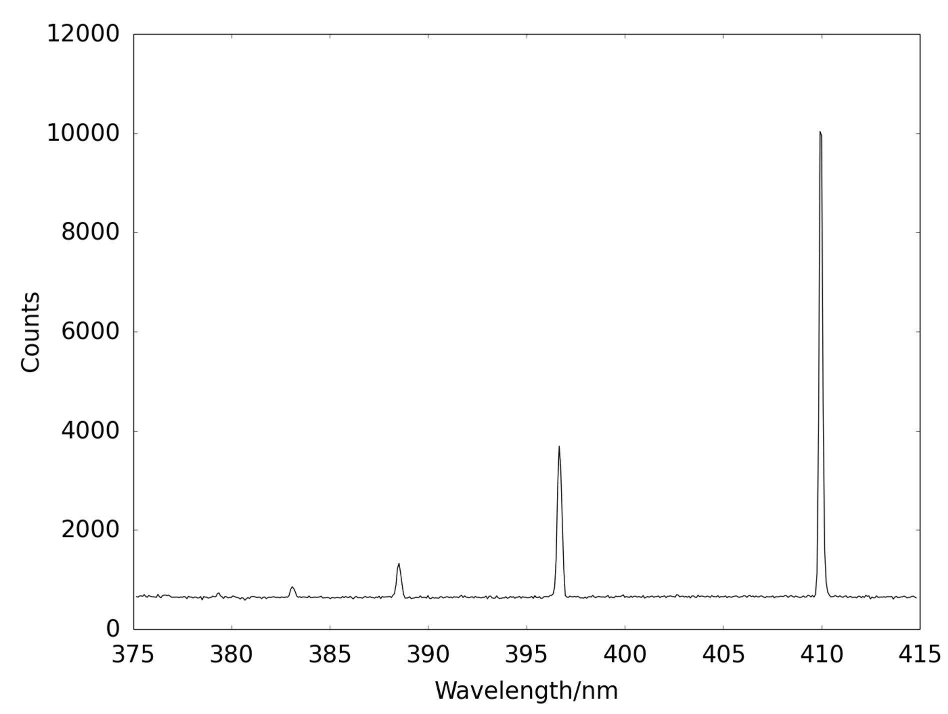

Figure 4: Spectrum from the detached hydrogen plasma, showing the high-n Balmer emission lines characteristic of the EIR regime. $T_e = 0.16 \pm 0.06$ eV.

5. Experimental plan

Previous work has observed EIR and MAR regimes on the YLPD. **However:**

- No measurements were made to look at the negative ion population (a prerequisite for the MAR recombination regime)
- DIVCAM image inversion showed that the EIR 'blue glow' (indicative of detachment) occurred in the outer edge of the plasma column rather than in the central region (Fig. 5) [6]
- 30 kHz fast frame imaging of the plasma showed rotating plasma 'blobs' ejected radially from the plasma column [6]
- These phenomena are yet to be explained

Observations have also been made of fluctuations in the Langmuir probe floating potential, with power concentrated in the edges of the plasma column.

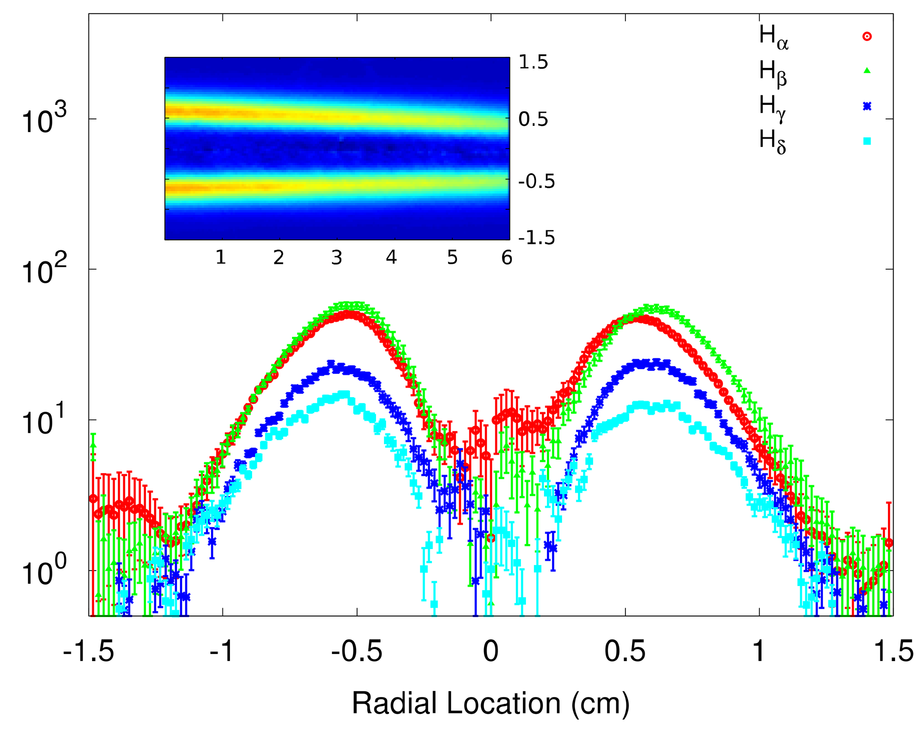

Figure 5: Radial hydrogen emission profiles from EIR detachment in the YLPD [6].

***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.

- Reproduce density and temperature profiles *(Langmuir probe arrays, Thomson scattering)*
- Observe EIR and MAR detachment regimes *(optical spectroscopy, laser photodetachment)*
- Attempt to observe radial flux fluctuations to analyse 'blob' dynamics *(Langmuir probe arrays)*
- Verify experimental results with simulations using the one-dimensional scrape-off layer package SOL1D with 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

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