Bayesian Analysis of Ultrafast Spectroscopy Data for Investigating the Physics of the MAST-Upgrade Super-X Divertor

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Motivations

- **Heat flux** through the exhaust system of a tokamak far **exceeds the material limits** by a factor of 10-100.
- A collection of plasma-atom and molecule interactions are able to greatly reduce these fluxes simultaneously during **detachment**.
- The **Super-X** divertor configuration on MAST-Upgrade (MAST-U) is designed to improve access to plasma detachment and promote plasma-neutral interactions.
- This project aims to develop a fast Bayesian analysis software that will use **hydrogen spectroscopy** to understand power exhaust in the Super-X divertor by inferring the impact of plasma-neutral and molecular interactions on detachment.

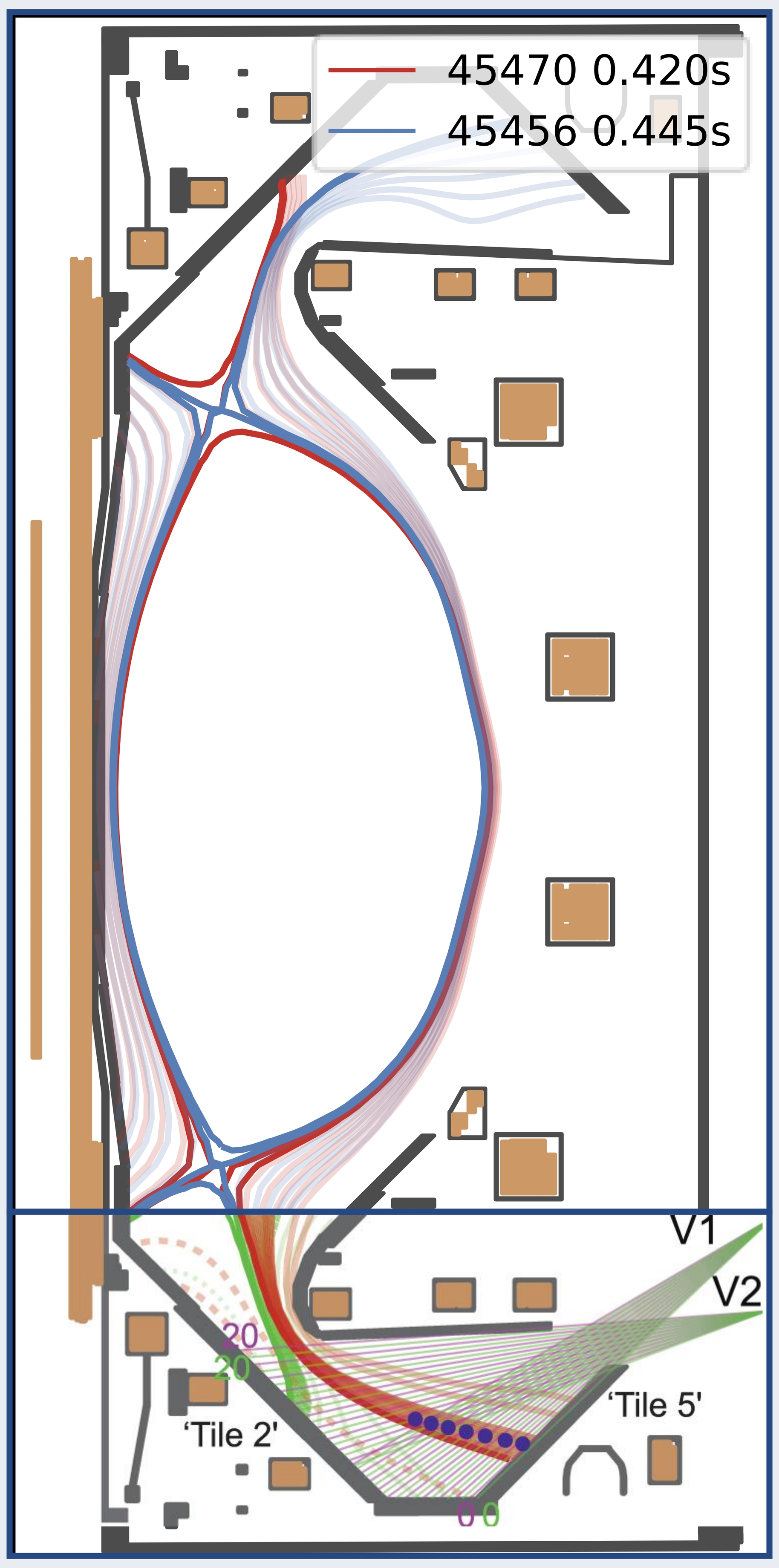

Figure 1: Top: MAST-U configuration featuring the double null Super-X divertor. Conventional divertor flux lines in red, Super-X flux lines in blue. Bottom: The spectrographic lines of sight into the Super-X divertor. V1 composes 40 lines of sight for the conventional spectroscopy. V2 is composed of 10 lines of sight for novel ultra-fast spectroscopy. Conventional divertor flux lines now in green, Super-X flux lines in red. [1]

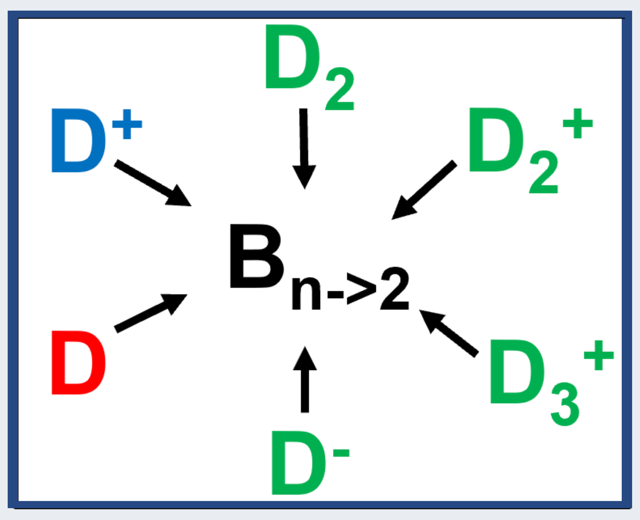

Figure 2: Atomic and molecular processes in detachment giving rise to Balmer lines. Red: Electron Impact Excitation. Blue: Electron-Ion Recombination. Green: Plasma-Molecular Reaction. [2]

Super-X Divertor

- The Super-X configuration **increases the target radius**, decreasing target temperatures & heat fluxes and promoting detachment access.
- There are two spectroscopy systems (V1 and V2 in Figure 1), diagnosing Balmer and Fulcher line emissions.
- Spectroscopy can be used to diagnose detachment as the combination of interactions in the divertor excite neutrals (causing Balmer emission) or result in excited atoms from molecular break up (causing Fulcher emissions) (Figure 2).

Detachment

- Conventionally, ionisation reactions were 'attached' to the target, driving large target particle and heat fluxes.

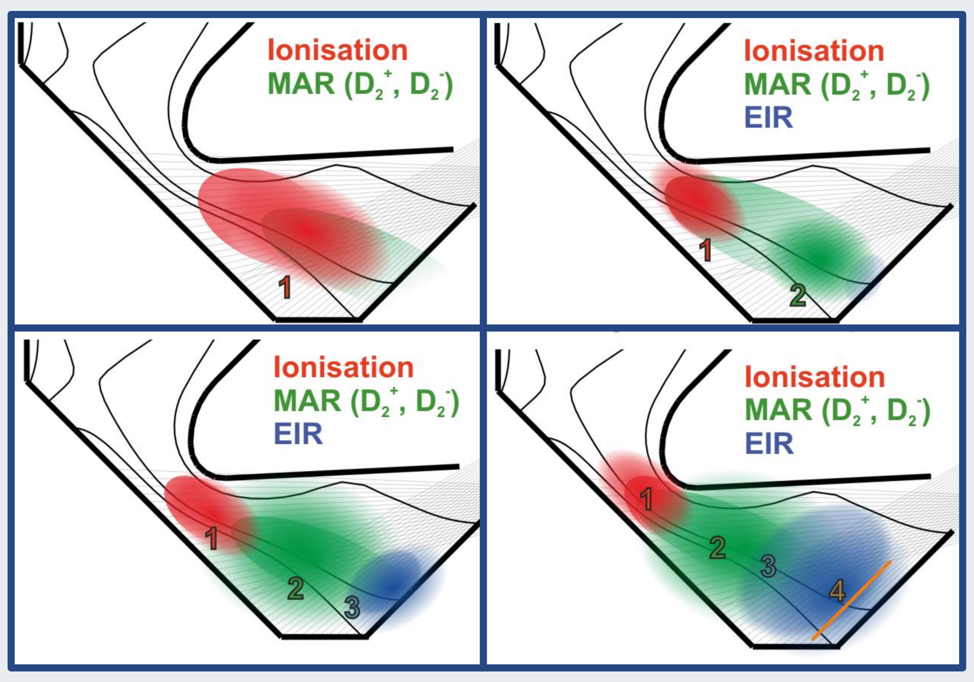

Figure 3: Detachment process in the Super-X divertor. [1]

- The Super-X configuration facilitates detachment which separates the ionisation region from the target, reducing the particle and heat load to the divertor.
- Subsequently, a build up of neutral atoms/molecules and plasma cooling allows several further interactions (such as Molecular Activated Recombination, MAR and Electron-Ion Recombination, EIR) to occur, leading to ion sinks that **reduce the target particle flux**.

Bayesian Analysis

Posterior Probability ∝ **Likelihood** × **Prior Probability** (Eq. 1)

Posterior Probability	Likelihood	Prior Probability	
Probability that the hypothesis is true in light of the data.	Modifies the prior using experimental data.	Probability that the hypothesis is true based on existing knowledge.	[3]

- This project will use an **adaptive gridding approach** with dimensions in each parameter of interest and use equation 1 with spectroscopic data to obtain **probability distribution functions** (pdf) for the combination of said parameters.
- The algorithm will randomly evaluate the hypercube of parameters to find high posteriors and then adaptively evaluate only these areas.

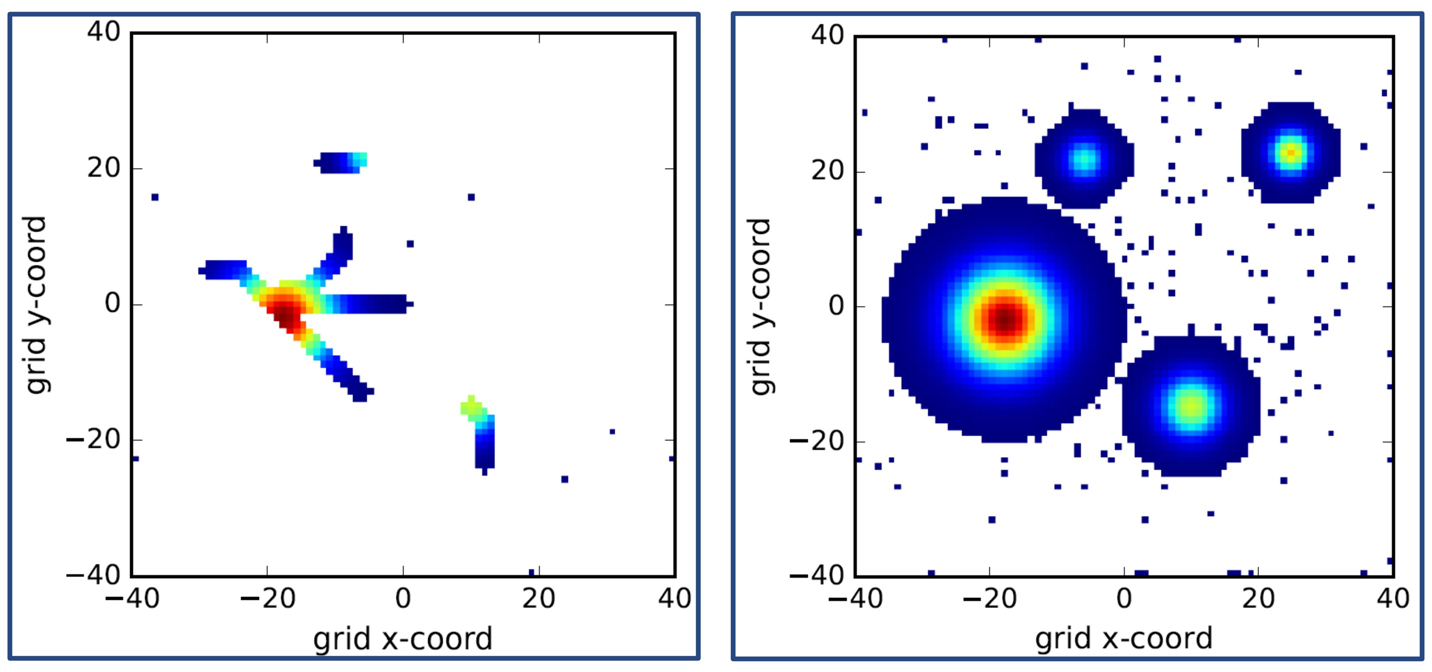

Figure 4: 2D example of the algorithm used to calculate the posterior probability. The colour indicates the posterior value at that location. [4]

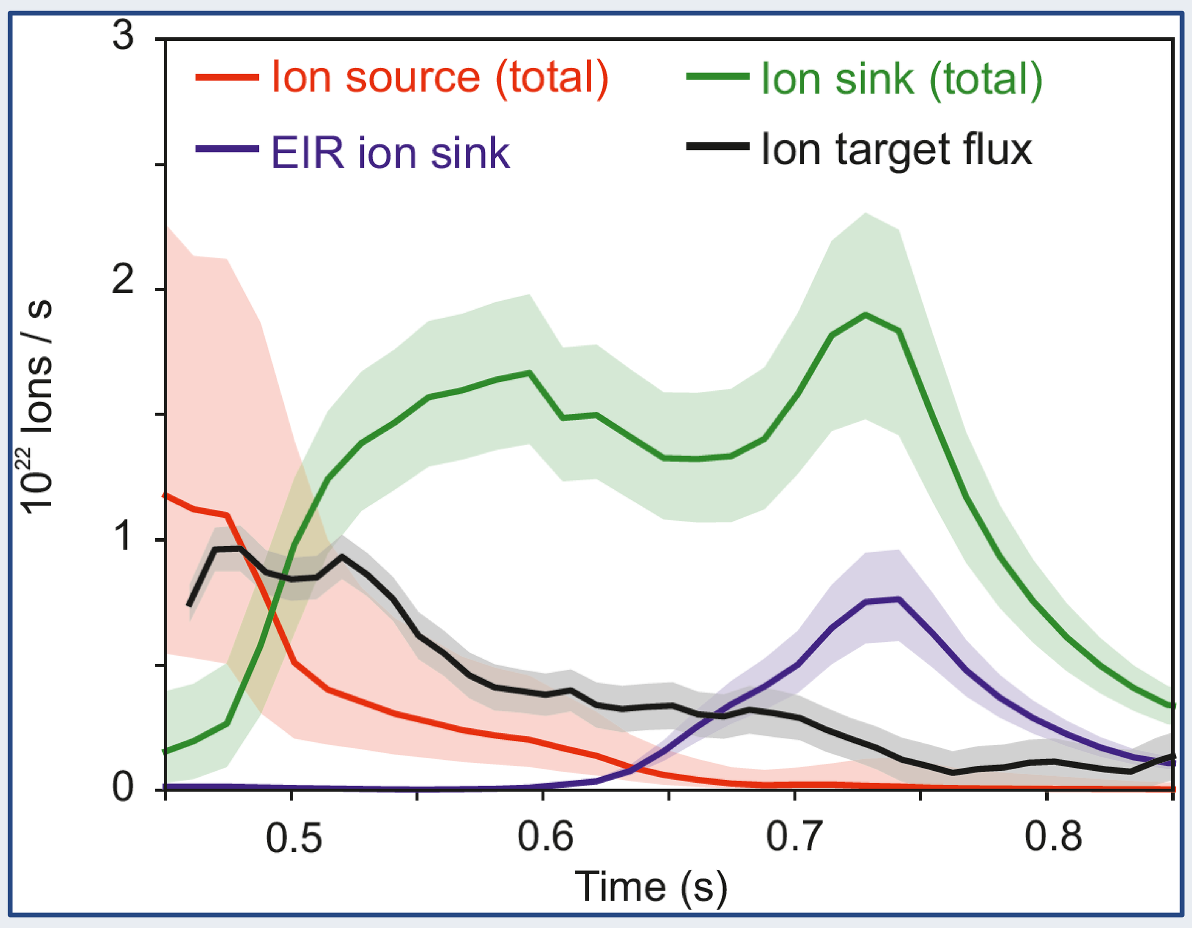

Figure 5: Particle (and subsequently power) balance within the Super-X divertor. Ion sources: Ionisation. Ion sink: MAR and EIR. [5]

Analysis Outcome

- Determine the pdf for parameters in the divertor such as; path-length, number density, neutral fraction and temperatures.
- Infer the impact of plasma-neutral interactions on power and particle balance in the divertor (as shown in Figure 5) with more speed and robustness.

Project Plan

1. Develop/optimise the fast spectroscopic analysis software in Python.
2. Test the software using synthetic data from existing SOLPS-ITER simulations.
3. Apply analysis tool on conventional and ultrafast spectroscopic MAST-U data.
4. *Apply the analysis software to international fusion devices (time permitting).*

References

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