Spectroscopic analysis of a plasma for an astrophysical jet experiment

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1. Introduction

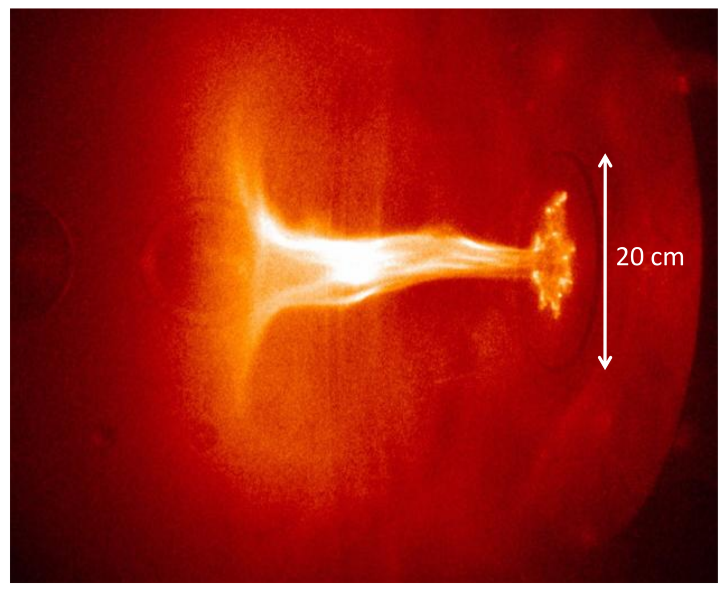


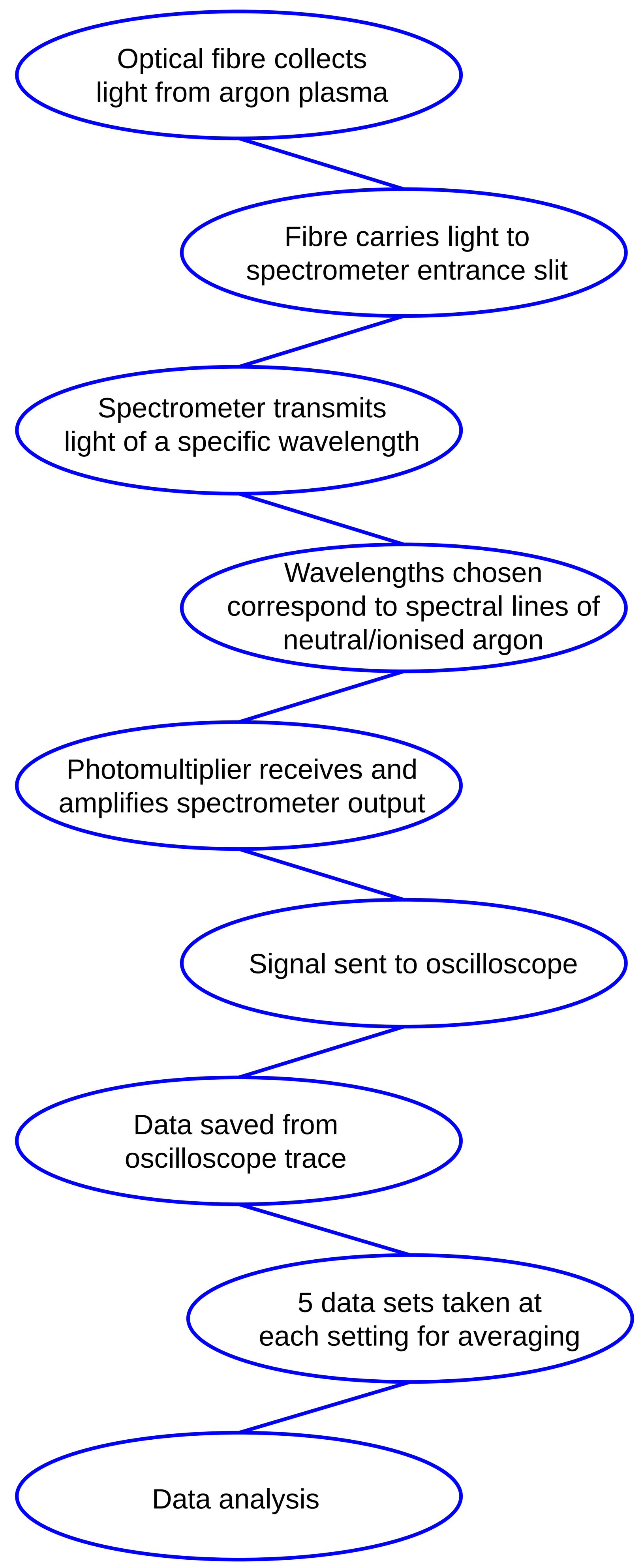
Figure 1: Photograph of a plasma jet produced in the Caltech lab, courtesy of the Bellan Plasma Group

- Caltech jet experiment (Fig. 1) makes jets with speeds of 10-50 km s^{-1} – astrophysical jets travel at least 10x faster
- **Increasing jet speed will allow further research**
- At present **neutral gas** is injected into the chamber and **broken down into plasma** by an electrical discharge
- Creating a 'seed' or **pre-ionised plasma** and injecting that into the chamber instead will result in a **lower density, faster jet**
- A **source has been built** to create the seed plasma using **radio frequency (RF) power** sources
- Need to **understand the behaviour of the plasma source** before it can be used in the main experiment

2. Objective

- **Obtain diagnostics for the plasma so that it can be used in the main experiment**
  - Technique: **spectroscopy**
  - Analyse the light emitted from the plasma by looking at the **relative strengths of known spectral lines**
  - Observe **neutral argon** (Ar I) and **singly ionised argon** (Ar II) lines
  - Calculate the **ionisation fraction** and **its response to changes in conditions** in the plasma chamber
  - Use a **magnetic field** to excite **helicon waves** – this should increase the energy transferred to the plasma and hence the ionisation fraction

3. Method



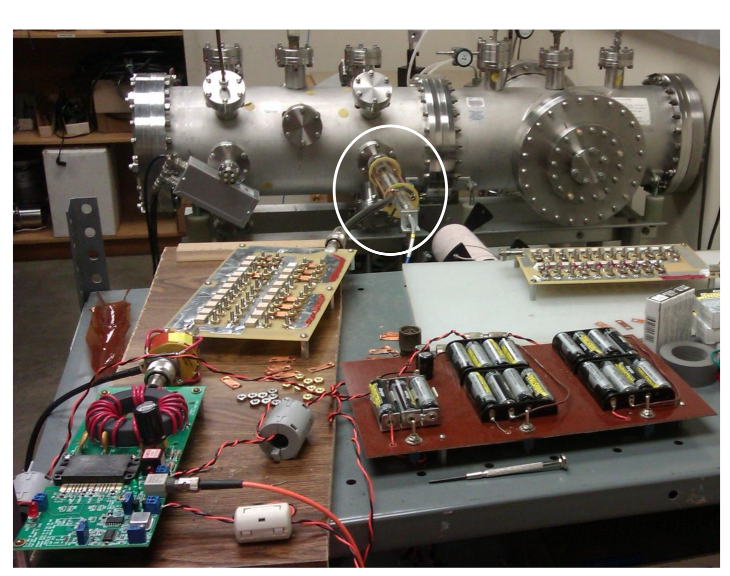


Figure 2: Image of **vacuum chamber** (silver, in the background); **plasma tube** (circled); and **controlling circuitry** (foreground)

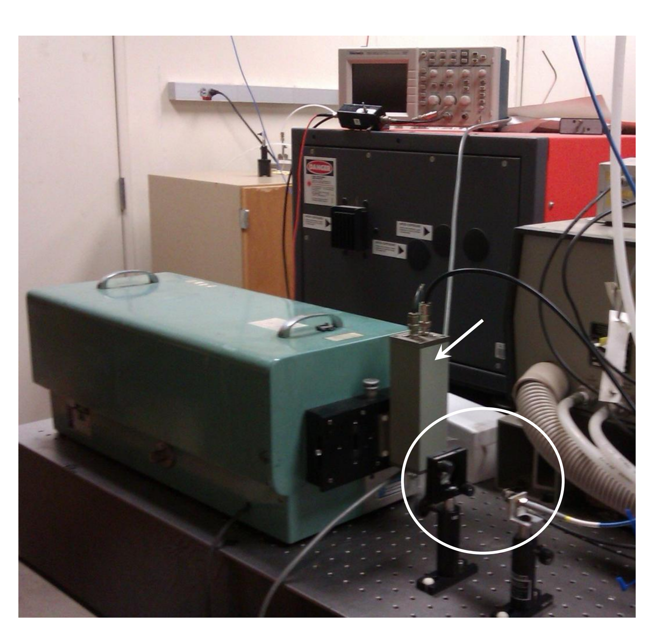


Figure 3: Image of **optical fibre and lens** (circled); **spectrometer** (blue box); **photomultiplier** (indicated by arrow); and **oscilloscope** (top)

4. Results so far

Error bars on all graphs show the standard deviation of the five averaged data sets for each point.

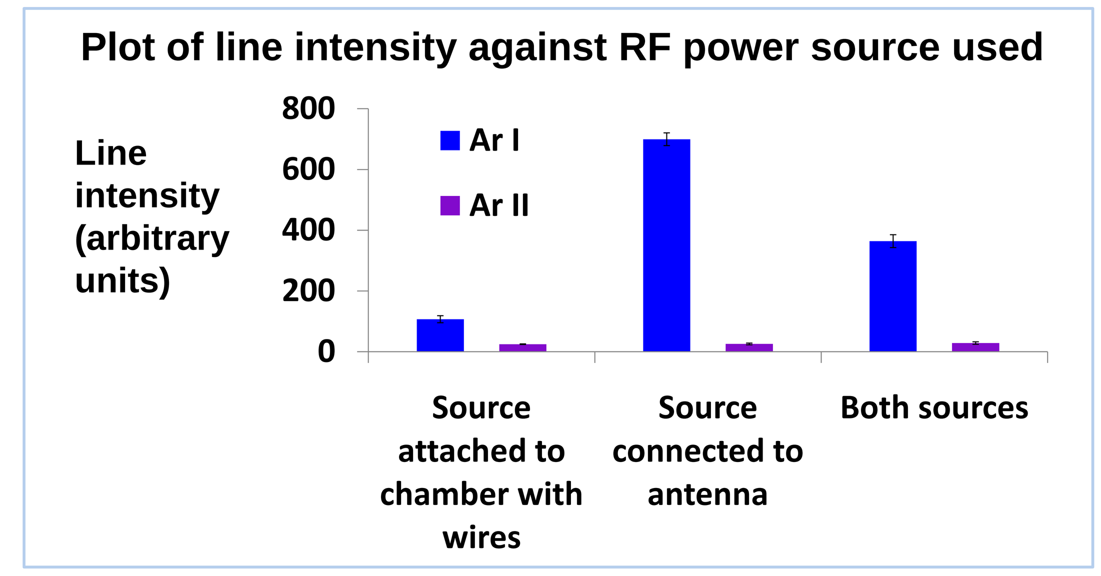


Figure 4: Plot showing the effect of changing the RF source powering the plasma on the brightness.
Lines used: Ar I 696.5nm; Ar II 611.5nm

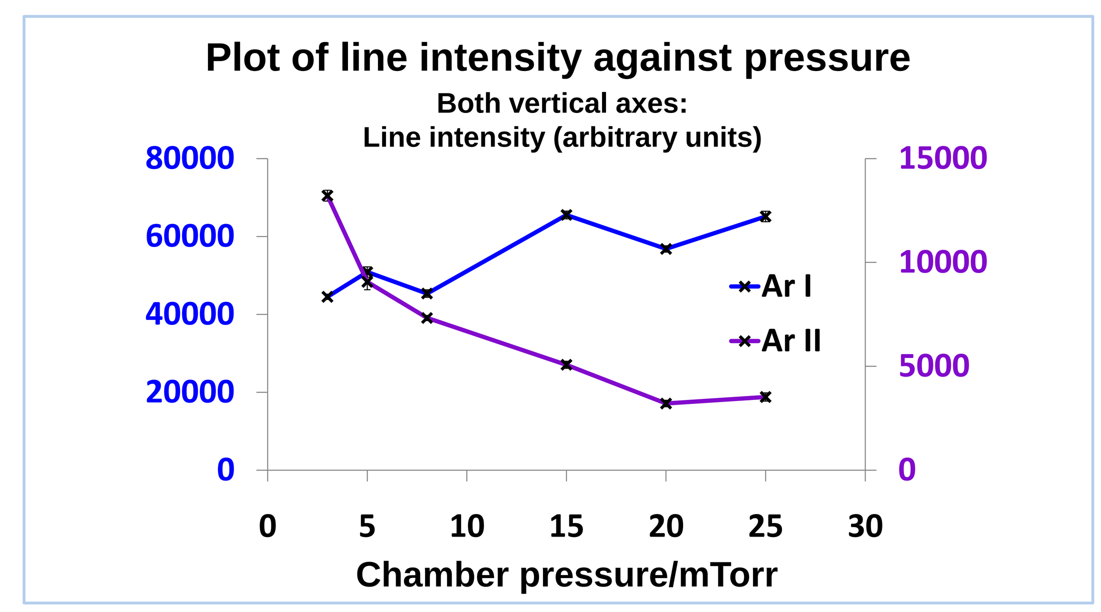


Figure 5: Plot showing the effect of changing the pressure in the plasma chamber on the brightness.
Lines used: Ar I 696.5nm; Ar II 434.8nm

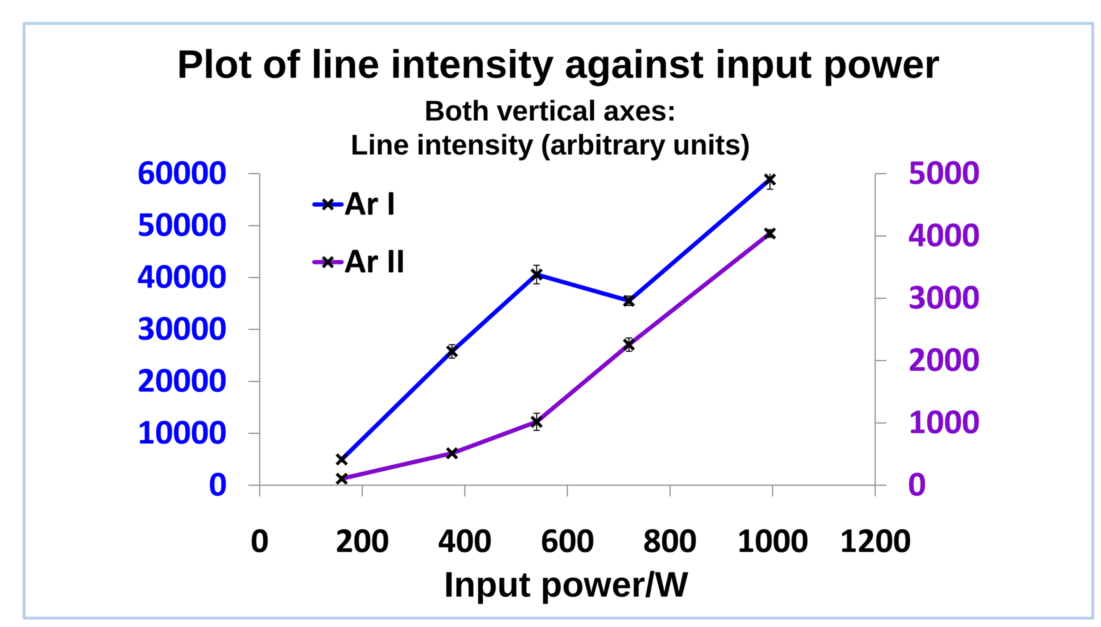


Figure 6: Plot showing the effect of changing the input power on the brightness.
Lines used: Ar I 696.5nm; Ar II 434.8nm

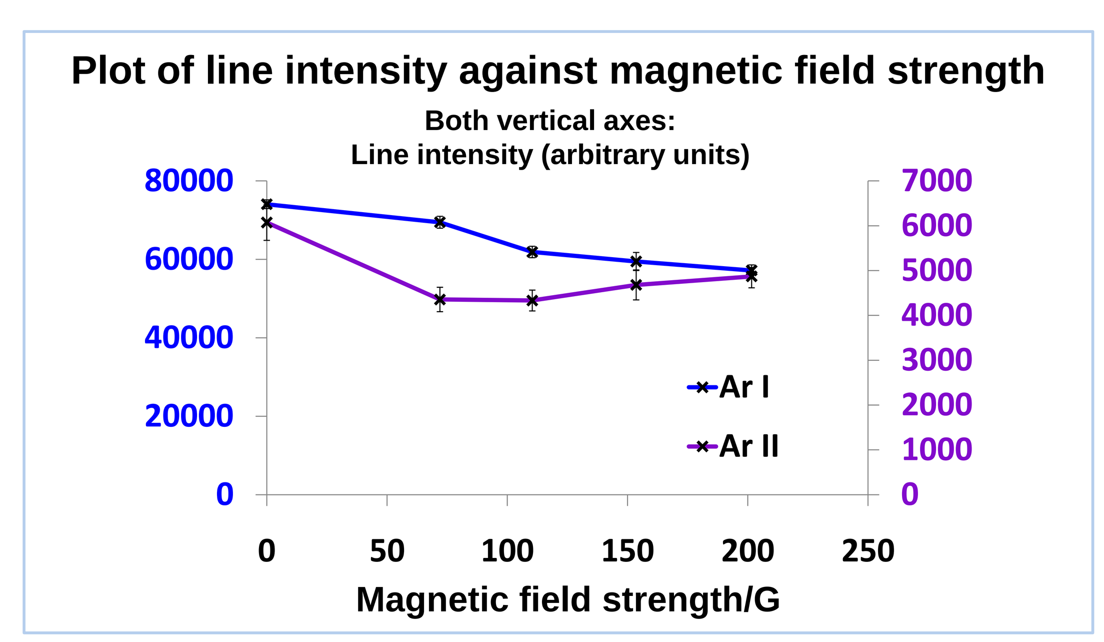


Figure 7: Plot showing the effect of introducing a magnetic field on the brightness.
Lines used: Ar I 696.5 nm; Ar II 434.8nm

Results cont.

- Have also:
  - Investigated the **background continuum radiation**:
    - Appears to be strongest in the 400-500nm region
    - Very little in the region of the strong Ar I lines
  - **Tested** and **rejected** the **local thermodynamic equilibrium model** for the plasma (see Table 1, section 6)

5. Conclusions

- Found the **set-up** that **makes the plasma most ionised** so far (using Figures 4-6)
- Introducing a **magnetic field appears to excite helicon waves**
  - Figure 7 shows the amount of Ar II increasing with field strength
- **Apparent 400-500nm background continuum** is likely to be **broadened Ar II lines merging together** as their density is high in this region
  - Will still take this into account when taking measurements

6. Further work

- Currently working on a **better model** for the plasma to calculate the ionisation fraction:
  - **Coronal equilibrium** may apply to **ions**
  - **Collisional-radiative** model should apply to **atoms and ions**
- Will take **more data** for **higher magnetic field** strengths to investigate presence of helicons
- **Aim to have a working model and good estimates of the ionisation fraction for different plasma conditions**

Model	Electron density	Includes electron collisional processes?	Includes radiative processes?
Local thermodynamic equilibrium	High (greater than our estimated density)	✓ excitation/ionisation and de-excitation/ recombination	X
Collisional-radiative	Applies to most densities (including our plasma)	✓ excitation/ionisation and de-excitation/ recombination	✓ de-excitation/ recombination only
Coronal equilibrium	Low (our value estimated to be on the borderline)	✓ excitation/ionisation only	✓ de-excitation/ recombination only

Table 1: Overview of the features of the three plasma models under investigation. The model most likely to apply to this experiment is highlighted.