Study of Ar Photoionisation Physics using VULCAN

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Introduction

Photoionised plasmas are of great importance in astrophysics as they are ubiquitous in astrophysical environments. They can be found in accretion powered X-ray sources, such as Seyfert galaxies. Their ionisation can be described by the photoionisation parameter ξ, where

$$\xi = \frac{4\pi F}{N_e}$$

F is the flux incident on the plasma in ergs cm^{-2} s^{-1} and N_e is the free electron density in cm^{-3}.

Figure 1 – Circinus Galaxy, a Type II Seyfert galaxy [1]

Objectives

The aim of the experiment was to photoionise Argon gas to produce a photoionised plasma, using a X-ray line radiation field produced by a laser irradiated tin(Sn) foil target. Then, to characterise the Sn emission spectrally and spatially, while also aiming to obtain a higher value for the photoionisation parameter, ξ, than has been achieved previously in this type of experiment.

Previous experiments creating photoionised plasmas have found it difficult to generate high values of ξ. Fujioka *et al* [1], using the GEKKO-XII laser facility, and Foord *et al* [2], using Z-pinches at Sandia, only achieved ξ = 6erg cm s^{-1} and ξ = 25erg cm s^{-1} respectively, whereas typical astrophysical plasmas have values of ξ greater than 100 erg cm s^{-1}.

Experimental Setup

The experiment was carried out using the VULCAN laser at the Rutherford Appleton Laboratory in August 2016.

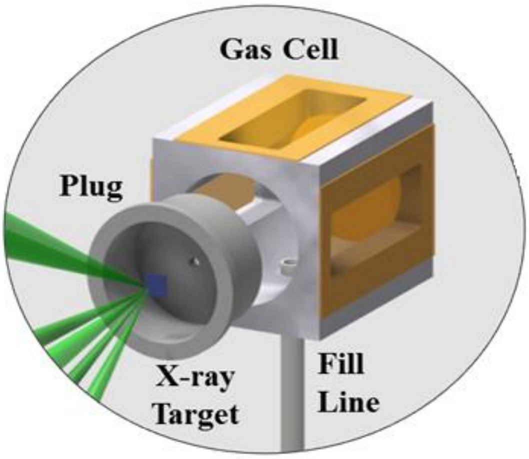

Figure 2 - Schematic of the gas cell and 6 laser pulses incident on the target

The target was a gas cell, as shown in figure 2, constructed from aluminium with a window on each face. Once the chamber had been placed under vacuum the gas cell was filled in-situ to a predetermined pressure of Argon (Ar) gas. Six long-pulse laser beams (527nm), delivering up to 850J in a 300-500µm focal spot, were incident on the east window of the gas cell, which consisted of 18.8µm of polypropylene coated with 218nm of Sn. This created the line radiation required, at 3-4 keV, to photoionise the Ar gas. The south window was made from kapton, allowing the k_α and k_β emission from the Ar gas to be imaged by a mica crystal spectrometer.

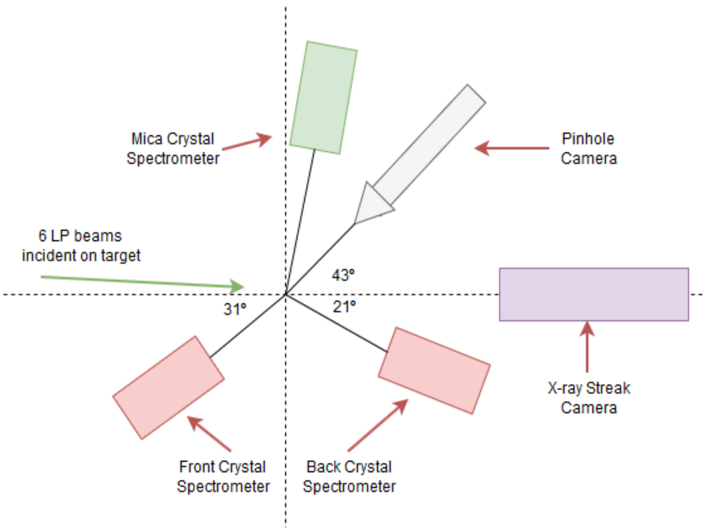

Figure 3 – Schematic of diagnostics setup

The diagnostics setup is shown in figure 3. Two silicon flat crystal spectrometers were used to provide characterisation of the Sn spectrum. One observed the laser irradiated side of the target, and the other, the L-shell emission through the target. A mica crystal spectrometer detected the k_α and k_β emission from the photoionised Ar gas, while a pinhole camera was used to observe the spatial distribution of the Sn. In addition, an X-ray streak camera coupled to a HOPG crystal provided temporally resolved images of the Sn X-ray spectrum.

Results

Figure 4 shows raw CCD images from the mica crystal spectrometer, both with a Sn foil target and when it is replaced with an Al target, at a gas pressure of 496mBar.

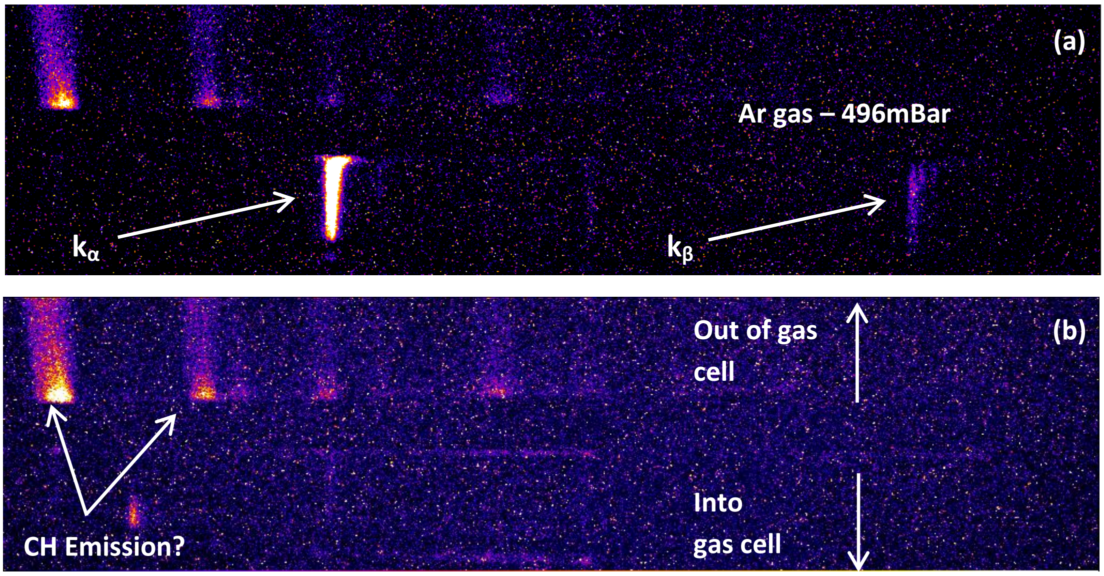

Figure 4 – Images obtained using Mica spectrometer
a) With Sn target b) With Al target

The k_α and k_β emission are evident in 4a and are known to have energies of 2957eV and 3190eV [4] respectively. In 4b the Sn has been replaced with Al and there is almost no evidence of k_α and k_β emission, which indicates that the emission is driven by radiative heating from the Sn plasma. The other emission observed in both cases is believed to be due to CH or another contaminant in the adhesive used on the targets.

Figure 5 shows lineouts taken close to the source at z = 0.5mm (orange) and far from the source at z = 5.66mm (blue). The red squares illustrate the anticipated positions of the $k_{\alpha 1}$ lines from different ion stages. These results show, as expected, that as one moves closer to the source there is a greater range of ion stages and more ionisation occurs where the flux is greater.

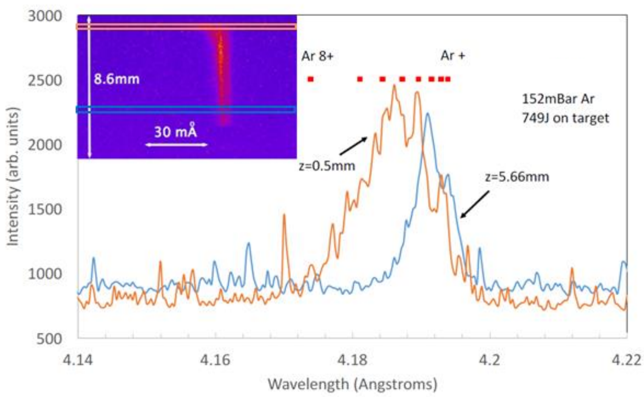

Figure 5 – Lineouts for shots with 152mBar gas pressure and 749J on target. The spectra shown are close to the source at z=0.5mm (orange) and far from the source at z=5.66mm (blue). Where the lineouts were taken from is illustrated at the top left of the figure.

During this experiment significantly higher values for the photoionisation parameter, ξ, were achieved, as high as ξ = 45erg cm s^{-1}.

Summary

The values achieved for the photoionisation parameter (ξ) are, to our knowledge, the highest to be achieved in the laboratory. This will benefit future understanding of the physics of numerous astrophysical bodies such as Seyfert galaxies. A possible future experiment would be to try to achieve a higher value for ξ at a larger laser facility such as GEKKO, NIF or OMEGA, and to extend the study to other gases such as Neon.

References

1. *https://en.wikipedia.org/wiki/Seyfert_galaxy* [Accessed on 28/03/17]
2. Fujioka, S. et al. *X-ray astronomy in the laboratory with a miniature compact object produced by a laser-driven implosion*, Nat. Phys. 5, 821 (2009).
3. Foord, M. E. et al. *Charge-State Distribution and Doppler Effect in an Expanding Photoionized Plasma*, PRL. 93, 5 (2004).
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