Photoionized plasmas in the laboratory

Research Groups: CPP and ARC

Supervisors: Professor David Riley and Dr Steve White, Prof. F Keenan

In this project you will work in an experienced experimental team to pursue laboratory astrophysics experiments, mostly relating to photo-ionised plasmas. Such plasmas are thought to be regularly associated with accretion-powered astrophysical objects, where the radiation field is sufficiently intense that photoexcitation and ionization rates are high relative to electron collisional excitation and ionization rates [1,2,3]. The distribution of ionization is characterised by the photoionization parameter ξ , where this is given by $\xi = 4\pi F/n_e$ where F is the flux of X-rays and n_e is the electron density and this parameter may reach $\simeq$ 1000 erg cm s^{-1} or greater. There have been several attempts to create such photoionized plasmas in the laboratory, to allow plasma modelling codes to be benchmarked against well-diagnosed experimental data. However, as the electron density is generally much larger than the astrophysical counterpart, so too must be the X-ray flux to generate high values of ξ. This can be attempted by the use of large laser facilities to generate extremely intense, nanosecond duration X-ray sources. Currently, we are planning for experiments at the much larger Omega-EP laser system in Rochester, NY in September 2022 and at the Orion laser in 2023. We also plan a series of subsidiary experiments using the in-house laser at QUB to explore and identify emission lines of lower ion stages of heavy elements that may be of interest in astrophysical contexts.

The experiments are demanding, requiring detailed planning and understanding of X-ray spectroscopy, laser-plasma interactions and the experimental hardware such as vacuum systems, CCD cameras and imaging X-ray crystals. Over the course of your PhD these are skills you will develop working within our team, alongside the Astrophysics Research Centre (ARC) to implement experiments where we create intense X-ray sources and drive the X-rays into a plasma and recorded the self emission of the plasma. Our goal is to take data that can be compared to spectral modellling codes such as e.g. FLYCHK [4] and GALAXY [5] which are used extensively by the laser plasma communities in the UK and elsewhere.

Our initial experiments used a technique proposed by Hill and Rose [6] that replaces a broad band source with an intense L-shell line-group radiation source. This technique has allowed us, in initial experiments to generate ξ=45 erg cm s^{-1}, plasmas in the laboratory [7], allowing us to investigate plasma kinetic processes in a hard X-ray regime that has proved elusive, and can lead to benchmarking plasma modelling codes used in the analysis of laser- produced plasmas. This is very competitive with other experiments such as those by Foord et al [8] who created a photo-ionised plasma using X-rays from the Z Machine pinch at the Sandia National Laboratories, the X-ray flux acting both to heat and decompress the original foil and to subsequently bathe the resulting plasma in a radiation field. They achieved values of ξ ~25 erg cm s^{-1}.

[1] Rice et al 2015, J. Phys. B, 48, 144013

[2] Barbato et al 2015, Phys. Procedia, 62, 84
[3] Keenan et al 1991, Phys. Rev. A, 44, 3831
[4] Chung et al 2005, High Energy Density Physics, 1, 3
[5] Rose 1998, J. Phys. B, 31, 2129
[6] EG Hill and SJ Rose HEDP 7 377-382, 2011
[7] S. White et al Phys. Rev E **97** 063203, 2018
[8] Foord et al 2004, Phys. Rev. Lett., 93, 055002