Experimental Plasma Spectroscopy: meeting data needs for astrophysics

Maria Teresa Belmonte*, Pratyush Ranjan Sen Sarma, Santiago Mar

University of Valladolid, Department of Theoretical and Atomic Physics and Optics,
Paseo de Belén 7, 47011 Valladolid (Spain)
(*) mariateresa.belmonte@uva.es

The vast majority of the information we have about astronomical objects comes from analysing the radiation they emit. In this context, plasma spectroscopy becomes an extraordinarily powerful tool, allowing us to decipher the physical and chemical properties of stars, nebulae and galaxies from their spectra. The widths and shifts of the spectral lines tell us about the electron densities and temperatures of the plasmas in which the radiation was produced, and the speeds at which they were moving. However, this decoding depends critically on the availability of accurate atomic parameters such as wavelengths, transition probabilities, Stark parameters, and hyperfine and isotope structure constants for many different neutral and ionised species.

These data are not only fundamental to astrophysics, but also play a key role in applications ranging from the lighting industry to plasma diagnostics in fusion research and benchmarking of theoretical and semi-empirical atomic calculations. Despite very impressive technological improvements in telescopes and spectrographs, studies of chemical composition are still held back by the lack of quantity and quality of the atomic data available. Thousands of transitions across the periodic table remain poorly characterised, highlighting the urgent need for sustained experimental efforts.

At the Atomic Spectroscopy Laboratory of the University of Valladolid (Spain) we have more than 40 years of experience in the measurement of accurate atomic parameters. Our current focus is on the measurement of rare earth parameters [1], which are urgently needed by astronomers for the study of kilonovae emitted by neutron star mergers [2]. We also put a lot of effort into determining the uncertainties of our newly measured data, which is essential to provide data users with a guide and a way to obtain the uncertainties of their own measurements and calculations. We have produced new open-source code for the determination of transition probability uncertainties from fitted spectra for plasmas that satisfy the assumption of partial local thermodynamic equilibrium [3].

The primary goal of this talk is to bridge the gap between experimental plasma spectroscopy laboratories and the users of atomic data. I will present the capabilities of our laboratory and discuss the challenges we face in measuring atomic data. I will also provide examples from our previous work on noble gases and our current research on rare earth elements. By promoting a better understanding of how these data are produced, we hope to strengthen the collaboration between the producers and users of atomic data, and help to fill this critical gap in the data.

Acknowledgements: M. T. Belmonte thanks the Ministerio de Ciencia, Innovación y Universidades of the Spanish Government for her Beatriz Galindo Fellowship and acknowledges funding from MICIU/AEI /10.130 39/501100011033 and by FEDER (UE) under project PID2021- 127786NA-100 P. R. Sen Sarma thanks the University of Valladolid for his Ph.D. grant.

References

[1] P. R. Sen Sarma, M. T. Belmonte, S. Mar, Eur. Phys. J. D 78:76 (2024)
[2] D. Kasen, B. Metzger, J. Barnes *et al.*, Nature, **551**, 80-84 (2017)
[3] M. T. Belmonte, S. Mar, S. Djurović *et al.*, Spectrochim. Acta B. **229**, 107190 (2025)