A Transformer-Based Approach to Spectropolarimetric Regression

R. Campbell[1], M. Mathioudakis[1], and C. Quintero Noda[2,3]

[1] Queen's University Belfast[1]
[2] Instituto de Astrofisica de Canarias[2]
[3] Dept. Astrofisica, Universidad de La Laguna[3]

contact e-mail: *rjcampbell.research@outlook.com*

Inverting the Stokes vector to retrieve physical conditions in the solar atmosphere is a fundamental tool for probing solar magnetism. However, traditional inversion methods remain computationally expensive and can suffer from convergence issues, especially when applied to complex, multi-line, full-Stokes datasets. We present the first implementation of a Transformer-based model for spectropolarimetric inversion. Transformer architectures, which have revolutionised natural language processing through their ability to capture long-range dependencies in sequences, are well suited to handling spectropolarimetric data. Our model takes full-Stokes spectra across multiple spectral lines as input and predicts stratified atmospheric parameters—temperature, magnetic field strength, inclination, azimuth, and line-of-sight velocity—as a function of optical depth. It incorporates an attention mechanism that enables the inversion to dynamically focus on the most informative spectral regions for each parameter, and uses positional embeddings to preserve spectral ordering. We benchmark its performance against a multilayer perceptron (MLP) baseline using synthetic spectra from realistic 3D MHD simulations spanning 15 photospheric and chromospheric lines. The Transformer achieves both lower absolute errors and higher correlations with the ground truth than the MLP, while producing physically bounded and regularised atmospheric profiles. Performance remains robust across noise levels typical of real observations. This approach provides a fast, accurate, and interpretable method for full-Stokes, multi-line inversion, and we outline plans to apply the method to datasets from DKIST and SUNRISE III. Our open-source Transformer-based model can also be adapted for other inversion codes.