Project title: Artificial Intelligence for Solar Spectropolarimetric Inversions

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Helpful existing knowledge:	Python programming

Project Description:

Recent advances in artificial intelligence, particularly transformer-based deep learning architectures, have revolutionised fields from computer vision to natural language processing. In solar physics, these methods are now being explored as powerful tools for analysing complex, high-dimensional datasets such as spectropolarimetric observations, which encode information about the Sun's magnetic and thermodynamic structure by measuring not just the intensity but also the polarisation state of light.

This project will apply machine learning to the problem of solar spectropolarimetric inversion—the process of inferring physical parameters (temperature, velocity, magnetic field) from observed Stokes profiles. The student will build upon recent progress demonstrating that attention-based, transformer sequence-to-sequence networks could outperform traditional inversion techniques in speed and accuracy by developing the first Vision Transformer model.

Training and validation will be performed using synthetic observations generated from MURaM magnetohydrodynamic simulations of solar convection, where the underlying atmospheric structure is known. The trained model will then be deployed on the first polarimetric observations of the solar poles obtained by the Solar Orbiter mission. This will provide new insights into the relative roles of local versus global dynamos in generating small-scale magnetic fields, a long-standing question in solar magnetism.

The student will use a combination of established inversion codes—including the Stokes Inversion based on Response Functions (SIR) code and its NLTE counterpart DeSIRe—mainly in forward-synthesis mode for model training. The work will combine machine learning and solar physics at the forefront of both fields, with training and inference carried out on the Kelvin2 GPU cluster at Queen's University Belfast.

Useful references

Campbell, R.J. et al., Transformers for Stratified Spectropolarimetric Inversion: Proof of Concept, ApJ, in review (2025), https://arxiv.org/abs/2506.16810.
Sinjan, J. et al., Magnetograms underestimate even unipolar magnetic flux nearly everywhere on the solar disk, A&A, 690, A341.
Ruiz Cobo, B. et al. (2022). DeSIRe: Departure coefficient aided Stokes Inversion based on Response functions, A&A, 660, A37.
Rempel, M. (2014). Numerical Simulations of Quiet Sun Magnetism: On the Contribution from a Small-scale Dynamo. ApJ, 789, 2, id132.
Dosovitskiy, A. et al., An Image is Worth 16x16 Words: Transformers for Image Recognition at Scale, https://arxiv.org/abs/2010.11929.