A Neural Network and Optimization Framework for the Inversion of Multiline Full-Stokes Stellar Spectropolarimetric Data

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We introduce a novel framework for the inversion of stellar magnetic fields, combining neural network-based synthesis of Stokes profiles with an optimization algorithm for parameter retrieval. This approach aims to reconstruct the global magnetic geometry of stars—particularly dipolar configurations—by fitting synthetic Stokes profiles to observed multiline profiles. The synthesis model is trained on radiative transfer simulations that include full-Stokes (IQUV) polarization, enabling flexible adaptation to different observational setups. A key advantage of this method lies in its efficiency: the neural network facilitates rapid generation of synthetic profiles while substantially reducing the need for extensive retraining when applied to different stellar targets. This is especially beneficial given the high computational cost associated with polarized radiative transfer. We assess the performance of the inversion across a range of scenarios, demonstrating that the inclusion of linear polarization significantly improves the performance and robustness of the inferred magnetic parameters, both for the target star and for other stellar cases. The results shed light on the relationship between polarization profiles and underlying magnetic field structures, paving the way for more precise interpretations of spectropolarimetric data. Furthermore, the framework supports scalable investigations of magnetic field morphologies and their links to stellar structure and activity, helping to connect theoretical models with observational constraints in stellar magnetism.