



A Self-Supervised CNN for Joint Spectropolarimetric Inversion and Magnetic Field Disambiguation

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CONTEXT

Spectropolarimetric diagnostics typically involve two separate procedures: inversion and resolving the 180° azimuth ambiguity inherent to the Zeeman effect. Despite its importance, disambiguation is mostly performed and evaluated using synthetic test cases, and is rarely validated against magnetohydrodynamic (MHD) simulations or real observational data. We seek to reliably retrieve the full magnetic field vector while testing the *feasibility of combining* inversion and ambiguity resolution into a simultaneous procedure.

METHODOLOGY

The inversion is performed with a specifically designed convolutional neural network with extended spatial context, which is *essential* for disambiguation. The disambiguation is guided by the acute-angle method, applied to the evolving azimuth. Using a fully differentiable Milne-Eddington forward model, we fit the observed Stokes profiles directly, without labels or a training set, while the ambiguity is resolved within the same optimization.

$$\mathcal{L} = \sum \frac{1}{N} \sum_i \left(\frac{S_i^{\text{obs}} - S_i^{\text{syn}}}{\sigma_S} \right)^2 + \nu_{\text{acute}} \left\langle \frac{\text{ReLU}(-\vec{B}_{\perp,i} \cdot \vec{B}_{\perp,i}^p)}{\|\vec{B}_{\perp,i}^p\|} \right\rangle_i$$

Eq. (above): A noise-weighted least-squares Stokes data term plus a flux-weighted acute-angle regularizer that penalizes the transverse field pointing anti-parallel to its potential reference, resolving the 180° ambiguity. Fig. 1 (to the right): Azimuth for the MHD ground truth (top), classical pyMilne + minimum-energy disambiguation (middle), and our CNN-PINN (bottom), at a representative noise level, recovering the azimuth structure as well as the classical pipeline.

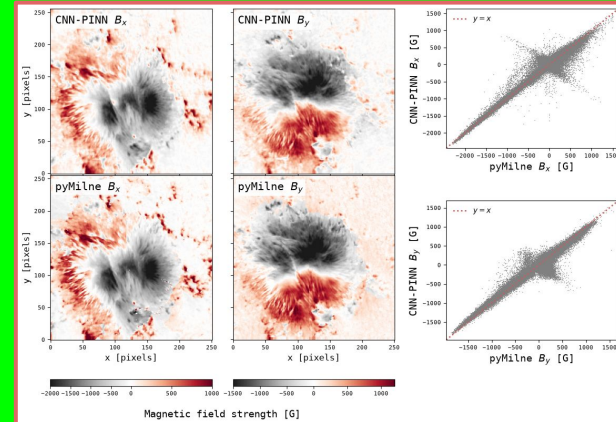
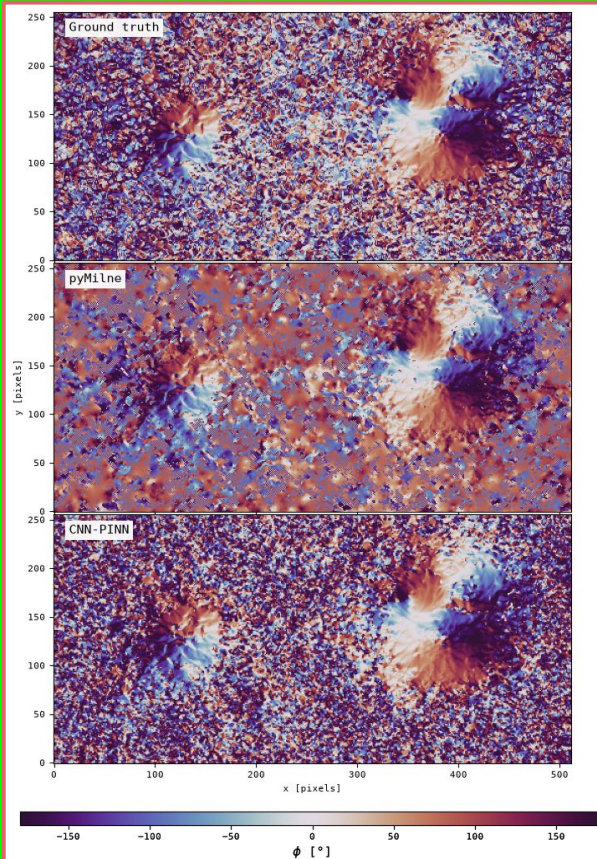


Fig. 2 (above): Transverse field components over a Hinode/SOT-SP sunspot from our CNN-PINN and classical 2-step approach, with scatter plots.

RESULTS & CONCLUSIONS

We validate on MHD simulations by synthesizing their Stokes parameters and comparing the inferred field to the ground truth across several noise levels. We then apply the method to Hinode/SOT-SP data, comparing against the standard two-step approach (here, pyMilne for the inversion and the minimum energy method for the disambiguation). Our field is disambiguated over a *similar* spatial extent as the 2-step result, and in the MHD case, where the ground truth is known, resolves the azimuth *at least as accurately*. Inversion and disambiguation *can therefore be done in a single procedure*, with strongly non-potential regions the main limitation, to be attacked in future work.