SpIN4D aims to develop deep-learning models that rapidly infer the 4D solar photosphere structure from a sequence of spectro-polarimetric observations made by NSF's *Inouye Solar Telescope*. This poster provides an overview of the project.

SpIn4D: Spectropolarimetric Inversion in Four Dimensions with Deep Learning*

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Background

- Solar photosphere are well described by *MHD state variables*: magnetic field ***B***, temperature *T*, density *ρ*, etc.
- Emergent polarized spectra, known as the *Stokes* profiles, can be used to infer the state variables.
- This *inversion* process requires radiative transfer modeling and can be computationally expensive.

Motivation

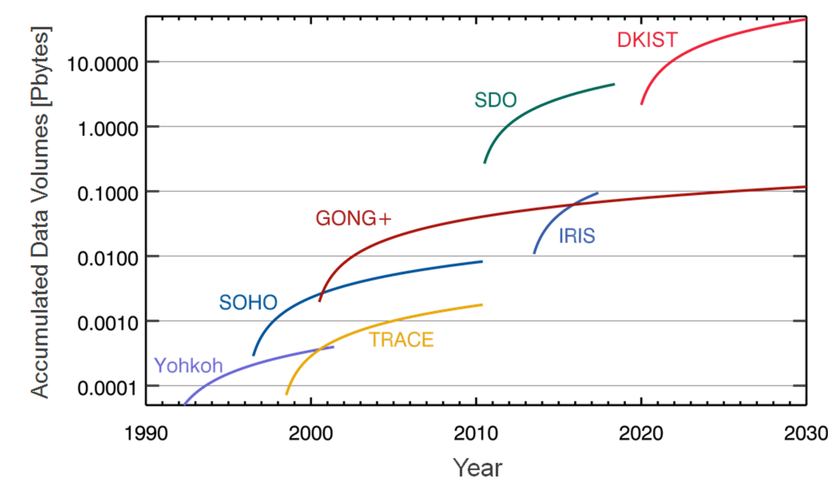

Fig. 1 | Accumulated data volume of NSF/NASA solar observatories. *DKIST*'s data rate averages 20 TB/day. Courtesy K. Reardon.

- NSF's *Inouye Solar Telescope* (*DKIST*) will provide high-cadence, high-resolution, multi-line Stokes data with revolutionary diagnostic potential.
- Owing to *DKIST*'s large data rate (Fig. 1), new computational methods are needed to meet the demands of the "big-data" solar physics.
- Advances in deep learning (DL) and MHD simulations allows for faster and more accurate Stokes inversion algorithm, as demonstrated in [1].

Objectives

A set of DL models will be trained/tested on MURaM MHD simulations [2] of solar plages (Fig. 2). The SIR code [3] will be used for Stokes synthesis/inversion.

- We will use MURaM simulations to create publicly available Stokes data sets that mimic Fe I 630 nm and 1.56 μm observations from *DKIST*/DL-NIRSP instrument [4].
- We will use these data to develop open-source, deep convolutional neural networks that rapidly invert Stokes profiles.
- We will compare our DL models to SIR inversions to benchmark the performance of each.
- We will explore *domain adaptation* methods to reduce potential differences between simulation and observation domains.

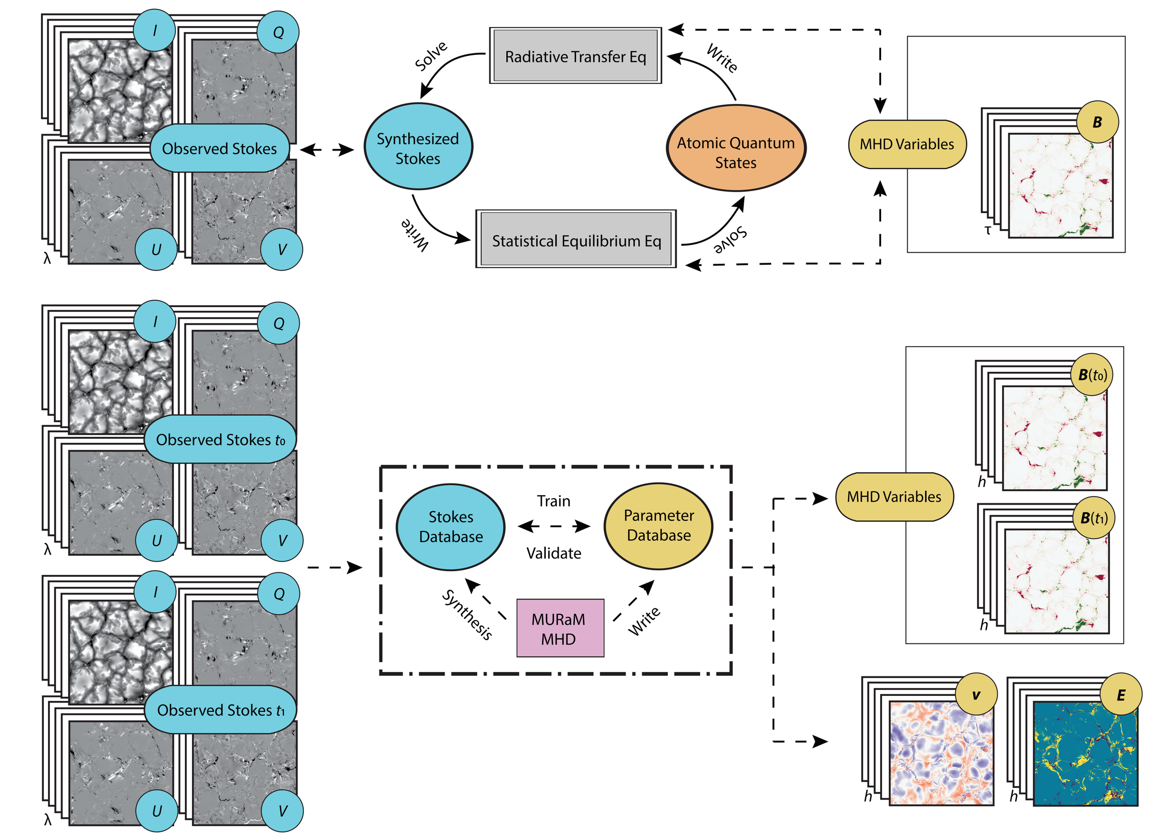

Fig. 2 | Illustration of inversion models. *Top*: traditional methods fit for Stokes profiles (*I*,*Q*,*U*,*V*) at individual pixels. Additional steps are required to derive other parameters (e.g., velocity ***v*** and Poynting flux ***E***). *Bottom*: SpIN4D, trained on a large library of MHD simulations, will take a temporal sequence of Stokes to utilize the spatial/temporal structure. Higher-level parameters in 4D may be directly estimated.

Highlights

- SpIN4D will exploit spatial/temporal (4D) *coherence properties* in observations (Fig. 2), as well as the implicit physical constraints in MHD simulation.
- SpIN4D will address the 180° azimuthal ambiguity resolution *during* DL inversion.
- SpIN4D will provide the uncertainty over the inferred MHD states using the latest DL methods.

Progress

- We performed 10 solar hr of MURaM runs (25 × 25 × 8.2 Mm domain, 16/12 km horizontal/vertical resolution, 40 s cadence) on NCAR's *Cheynne*, totaling 23 TB output, ~20% of all planned.
- We are close to completing the SIR Stokes synthesis pipeline with *DKIST*/DL-NIRSP specs.
- We demonstrated improvement of inversion accuracy using both Fe I lines over a single line with group equivariant neural networks.
- We designed a probabilistic approach to resolving the azimuthal ambiguity.

References

[1] Asensio Ramos, A., & Díaz Baso, C. J. 2019, *A&A*, **626**, A102
[2] Rempel, M. 2014, *ApJ*, **789**, 132
[3] Ruiz Cobo, B., & del Toro Iniesta, J. C. 1992, *ApJ*, **398**, 375
[4] https://nso.edu/telescopes/dkist/instruments/dl-nirsp/

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