Chromospheric Magnetic Field Reconstruction through Neural Field Assisted Spectropolarimetric Inversions

Carlos José Díaz Baso

Rosseland Centre for Solar Physics, Institute of Theoretical Astrophysics, University of Oslo, N-0315 Oslo, Norway

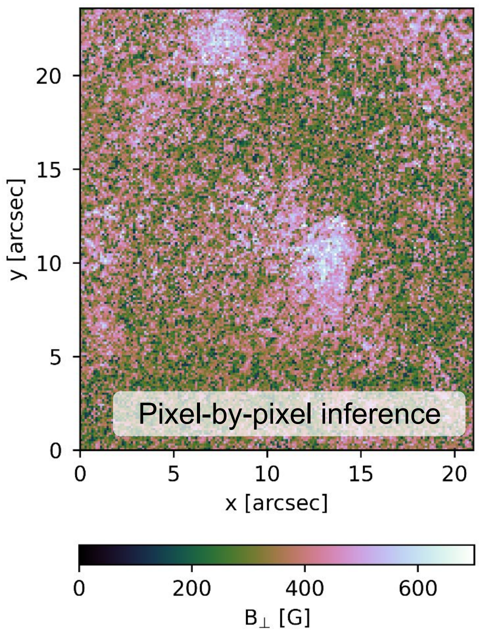
carlos.diaz@astro.uio.no

Collaborators: Andrés Asensio Ramos, Jaime de la Cruz Rodríguez, J. M. da Silva Santos, Luc Rouppe van der Voort

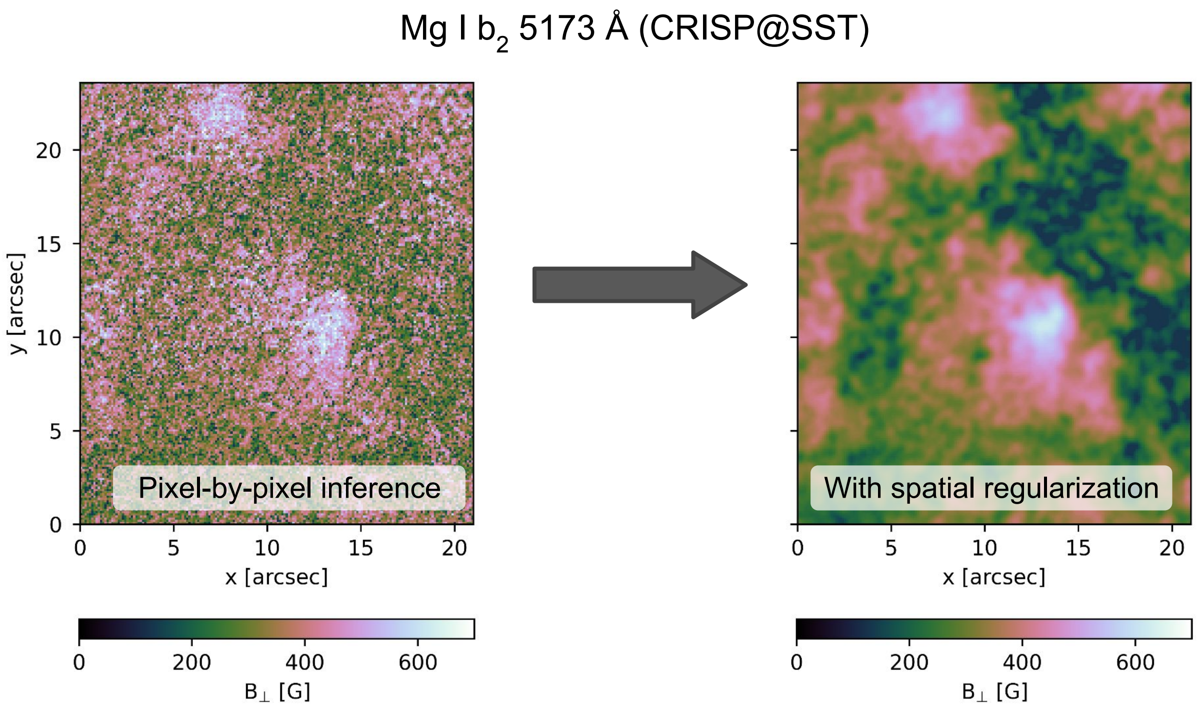
Rosseland Centre for Solar Physics

Magnetic field inference

Mg I b_2 5173 Å (CRISP@SST)



Magnetic field inference



⇒ Imposing coherent solutions improve the estimation, without averaging in space or time.

How do we impose this coherence?

Explicit vs Implicit

$$\mathcal{L} = \sum_{\lambda_i} \left(\frac{S(\lambda_i)^{obs} - S(\lambda_i)^{syn}}{\sigma_i} \right)^2$$

χ^2

Quantity to optimize

de la Cruz Rodríguez 2019, Morosin et al. 2020, de la Cruz Rodríguez & Leenaarts 2024

How do we impose this coherence?

Explicit vs Implicit

$$\mathcal{L} = \sum_{\lambda_i} \left(\frac{S(\lambda_i)^{obs} - S(\lambda_i)^{syn}}{\sigma_i} \right)^2 + \alpha \Big[\left(\mathbf{B}_{\parallel}^{(x,y)} - \mathbf{B}_{\parallel}^{(x,y-1)} \right)^2 + \left(\mathbf{B}_{\parallel}^{(x,y)} - \mathbf{B}_{\parallel}^{(x,y+1)} \right)^2 + \left(\mathbf{B}_{\parallel}^{(x,y)} - \mathbf{B}_{\parallel}^{(x-1,y)} \right)^2 + \left(\mathbf{B}_{\parallel}^{(x,y)} - \mathbf{B}_{\parallel}^{(x+1,y)} \right)^2 \Big].$$

χ^2

de la Cruz Rodríguez 2019, Morosin et al. 2020, de la Cruz Rodríguez & Leenaarts 2024

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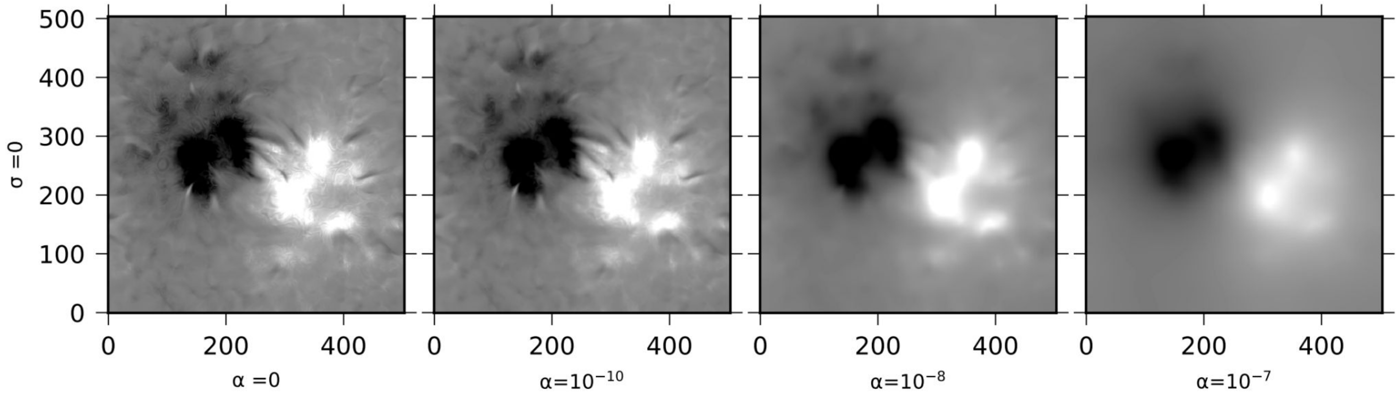

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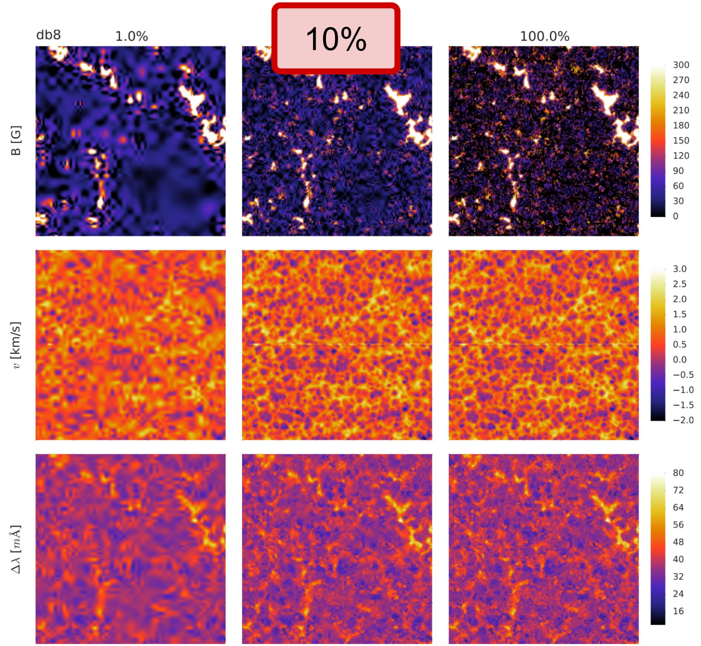


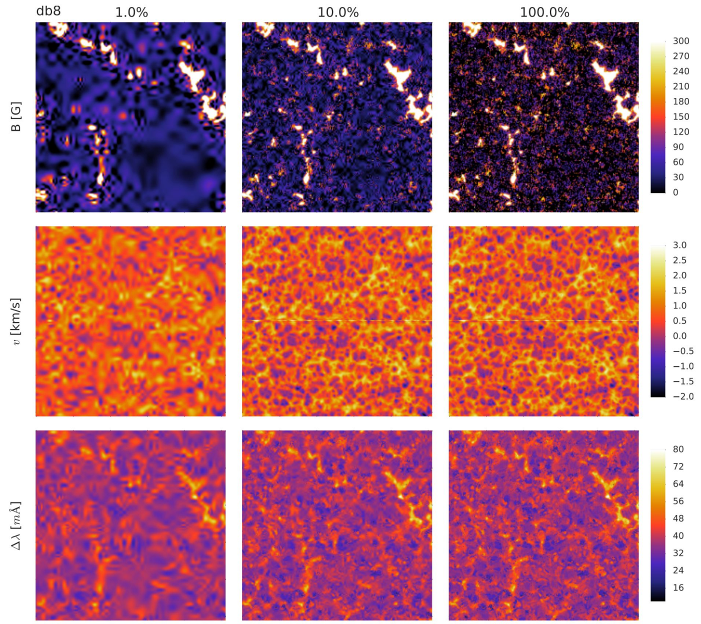
A. Asensio Ramos and J. de la Cruz Rodríguez (2015)

$$\mathcal{L} = \chi^2 + \alpha||g(\mathbf{P})||_0$$

Compact representation in wavelet space

How do we impose this coherence?

Explicit vs <u>Implicit</u>



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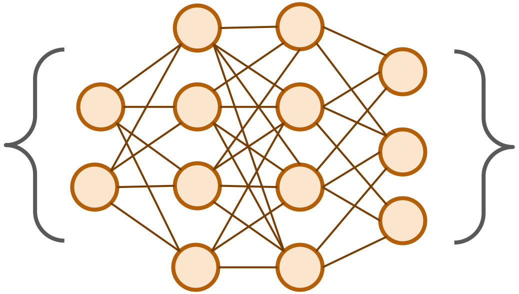
New parametrization: neural fields

$$\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix}$$



$$\mathbf{P}_{x,y,x,t} = f_\theta(x, y, z, t)$$

neural network

⇒ **Compact**, **continuous** and **differentiable** approximation in the whole domain

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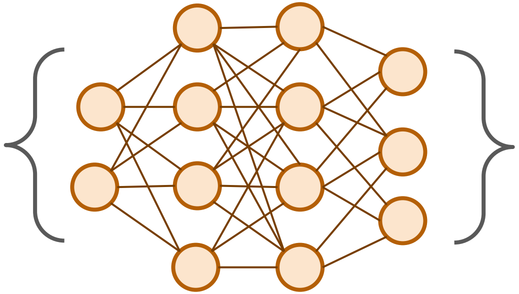

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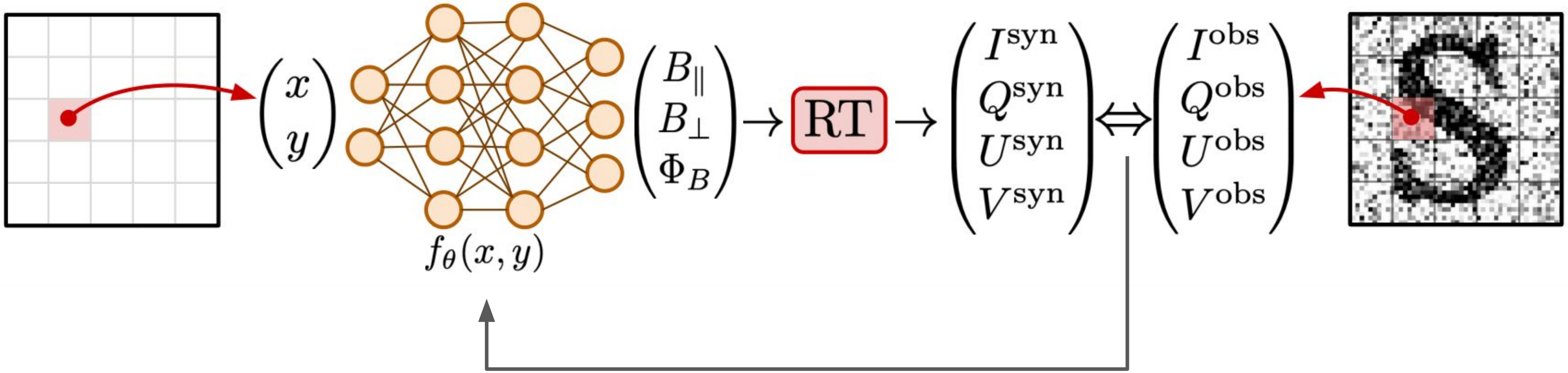
neural network

Magnetic field extrapolations
R. Jarolim et al. (2022)

Coronal tomography
A. Asensio Ramos (2023)

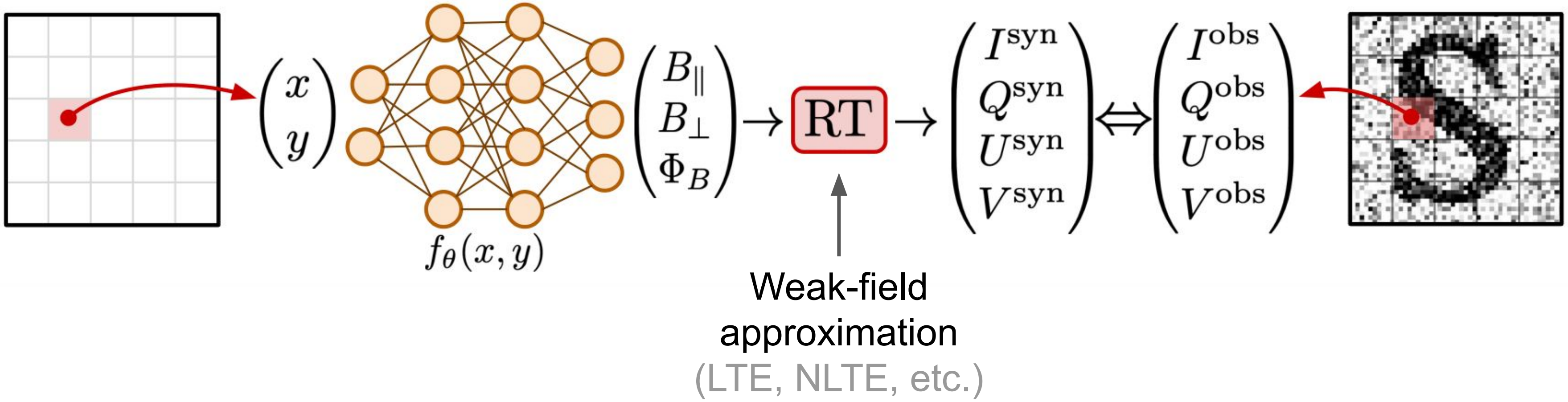
⇒ **Compact**, **continuous** and **differentiable** approximation in the whole domain

Neural field for spectropolarimetric inversions

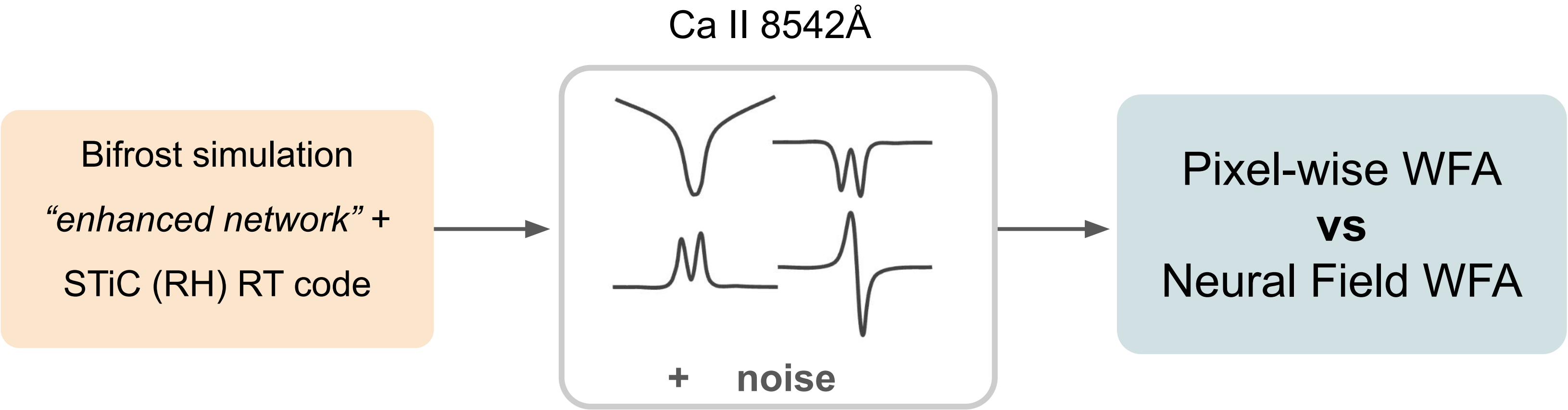


This is not a *predictive neural network*,
but a ***parametric representation***

Neural field for spectropolarimetric inversions

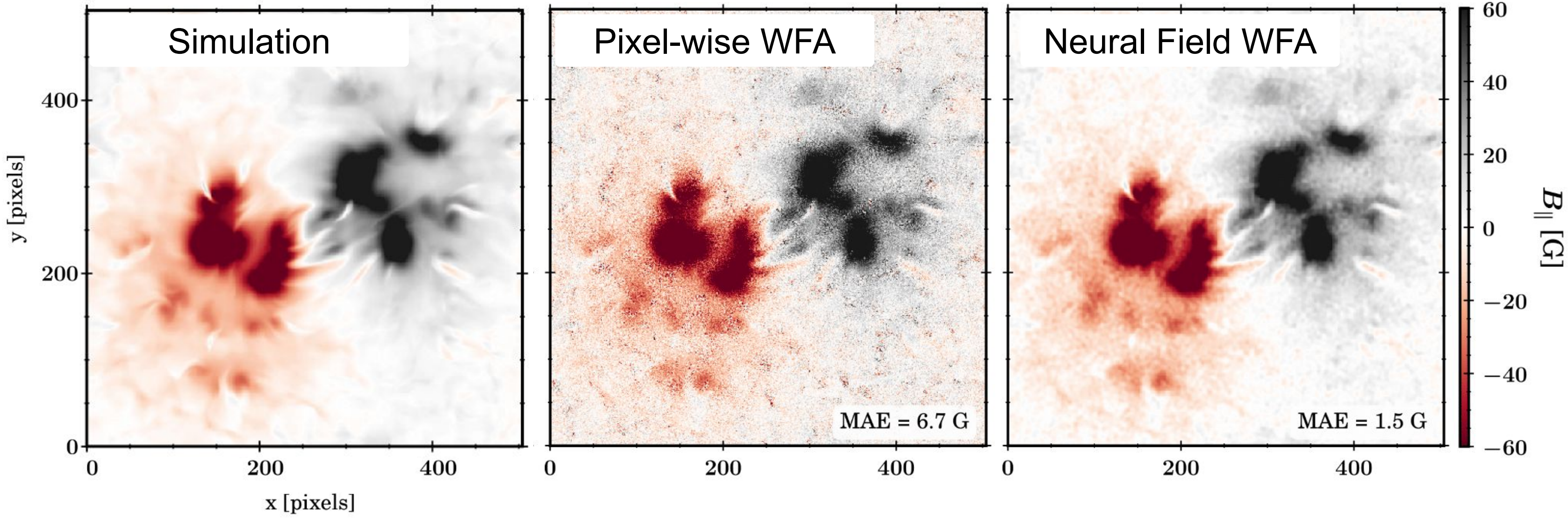


Synthetic scenario



WFA comparison: longitudinal magnetic field

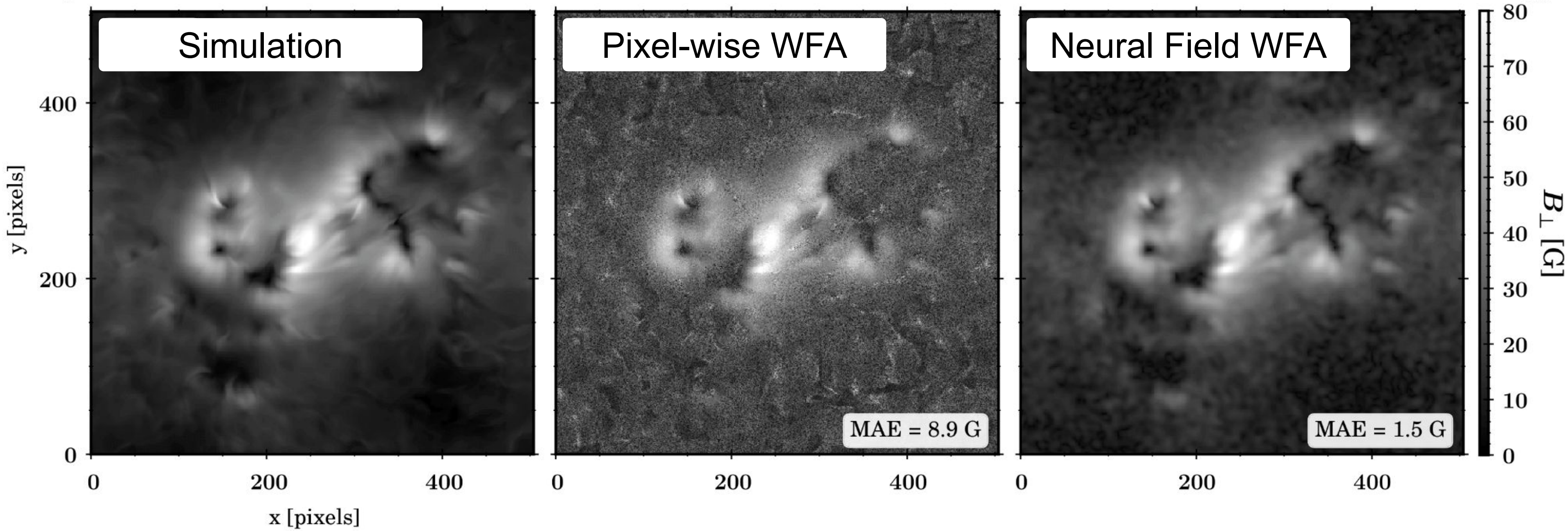
Ca II 8542 Å, noise $\mathbf{10^{-3}}$ **Ic**



⇒ The NF strongly damps the high-frequency components, but the overall structure is very similar.

WFA comparison: transverse magnetic field

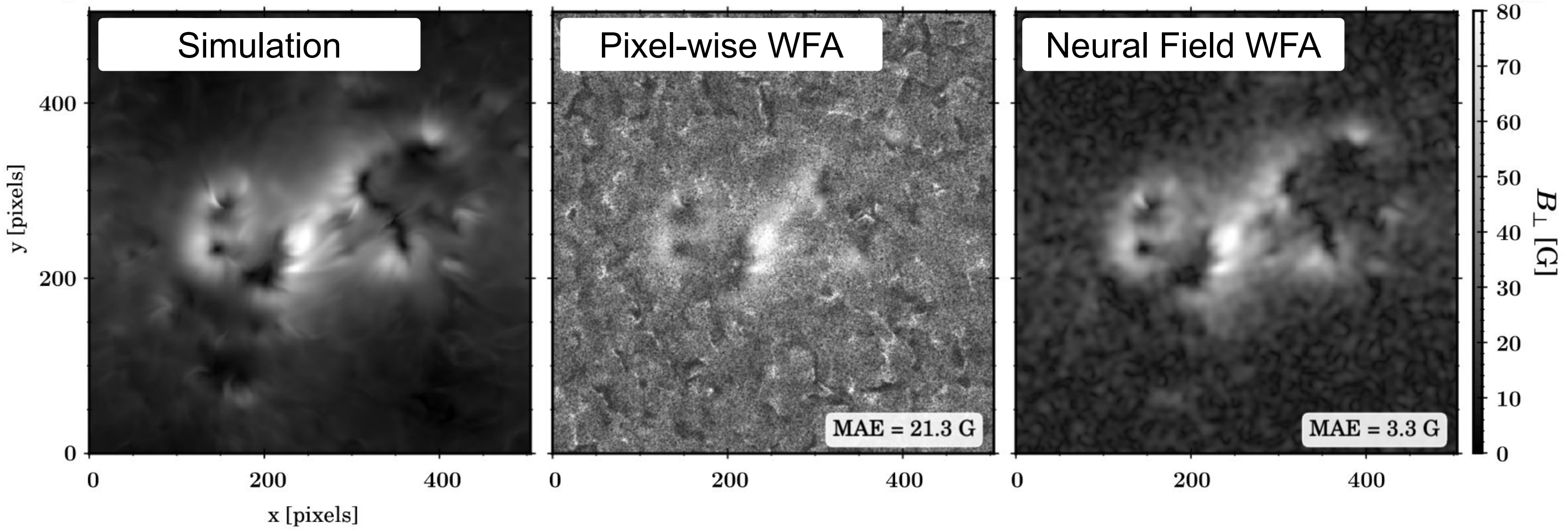
Ca II 8542 Å, noise **10^{-4} Ic**



Mitigates the transverse bias
Martínez González et al. (2012)

WFA comparison: transverse magnetic field

Ca II 8542 Å, noise **10^{-3} Ic**



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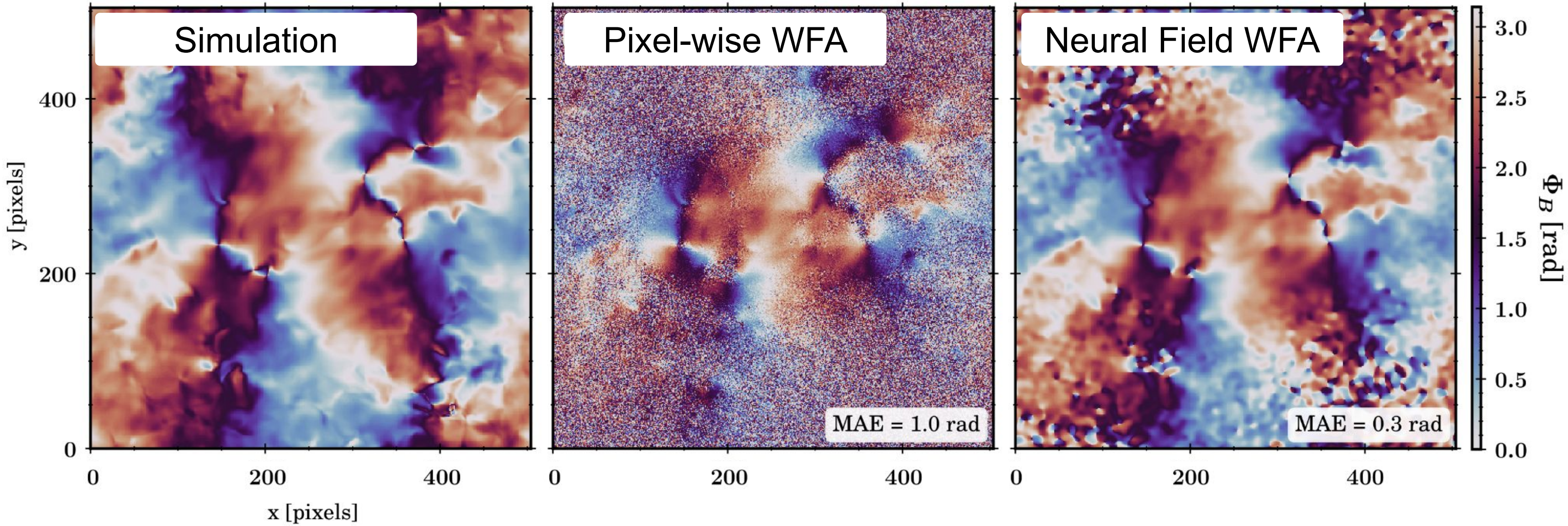
WFA comparison: azimuth angle

Ca II 8542 Å, noise **10^{-4} Ic**



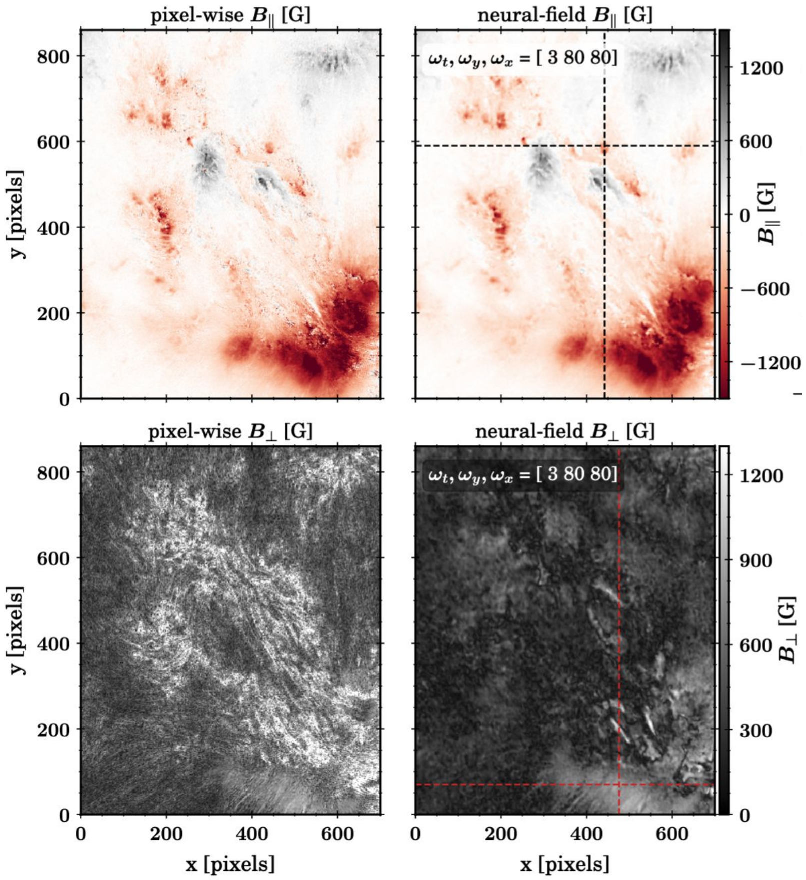
Spatiotemporal regularization

Region: NOAA 12593

Duration: ~30 min long

Observatory: CRISP @ SST

Spectra line: Ca II 854.2 nm



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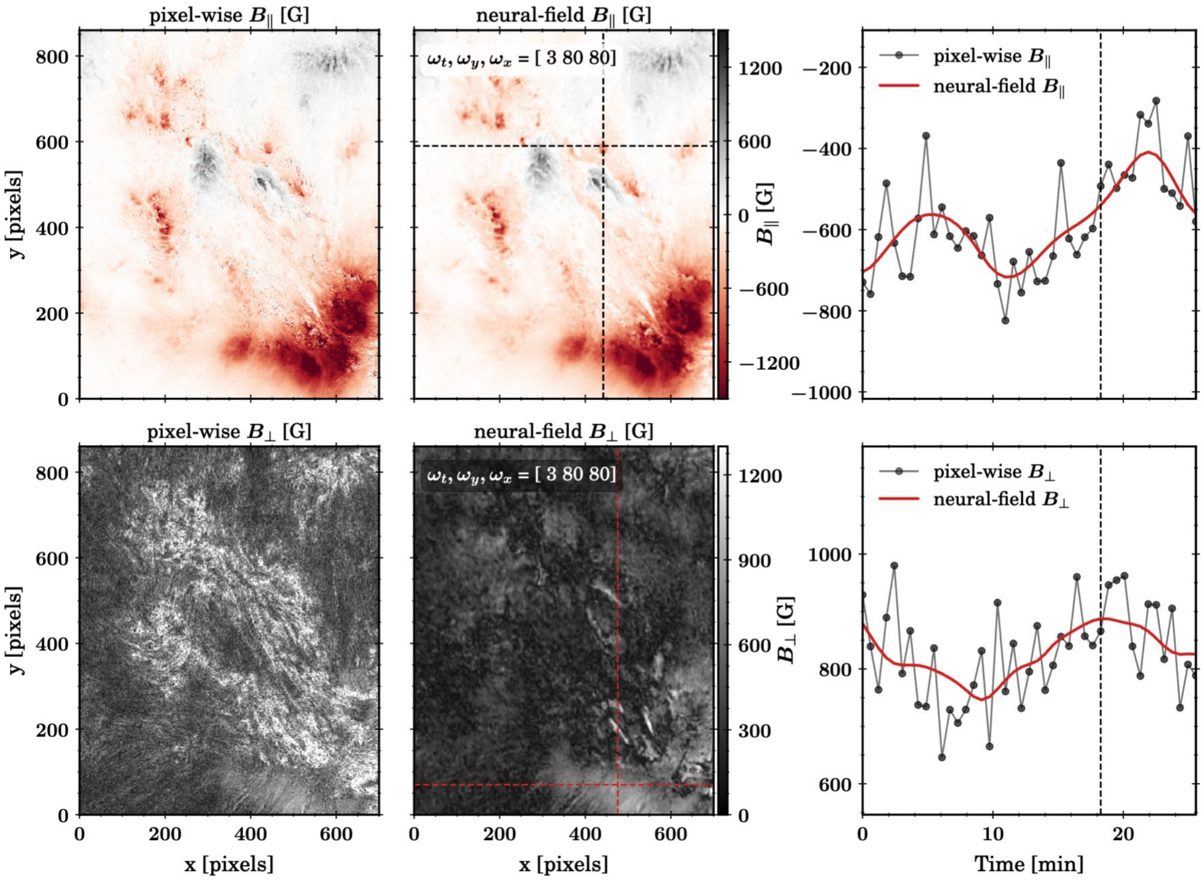

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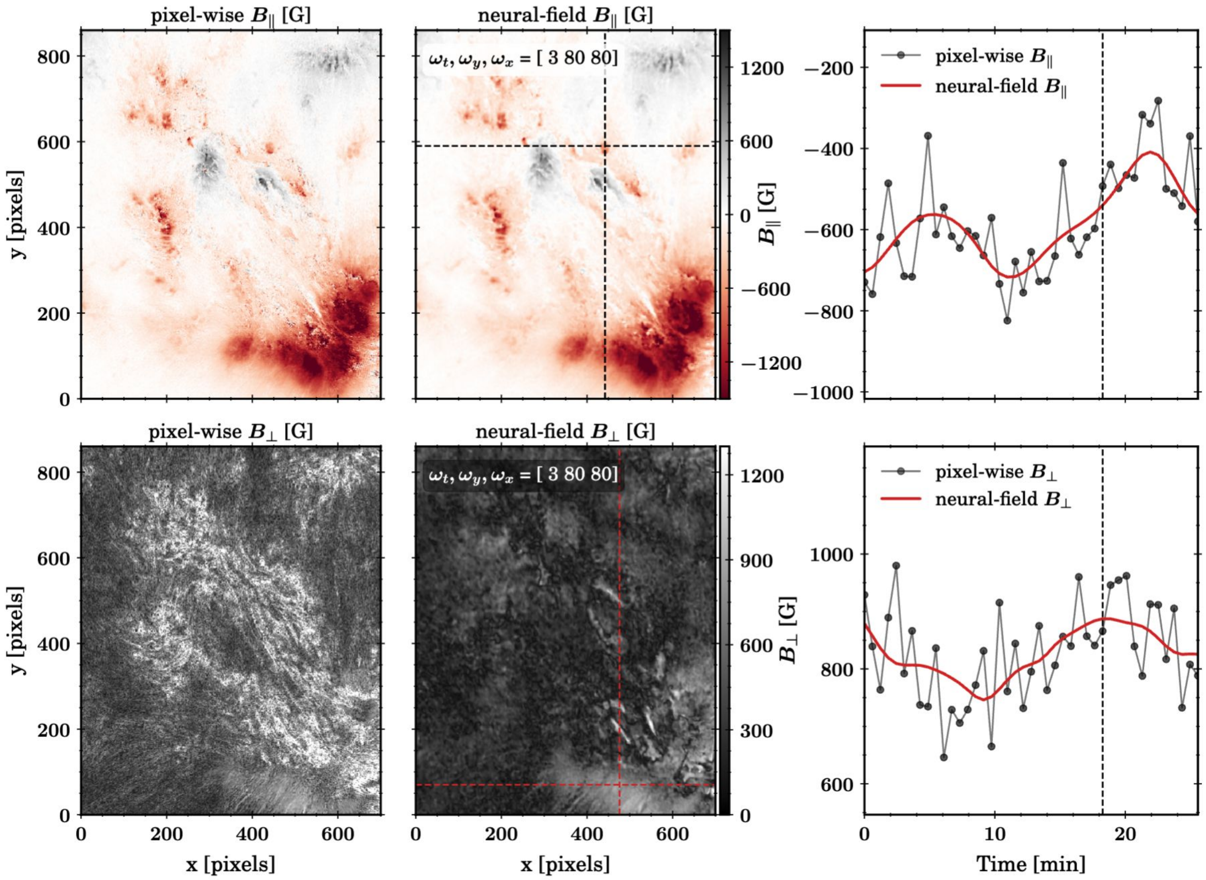


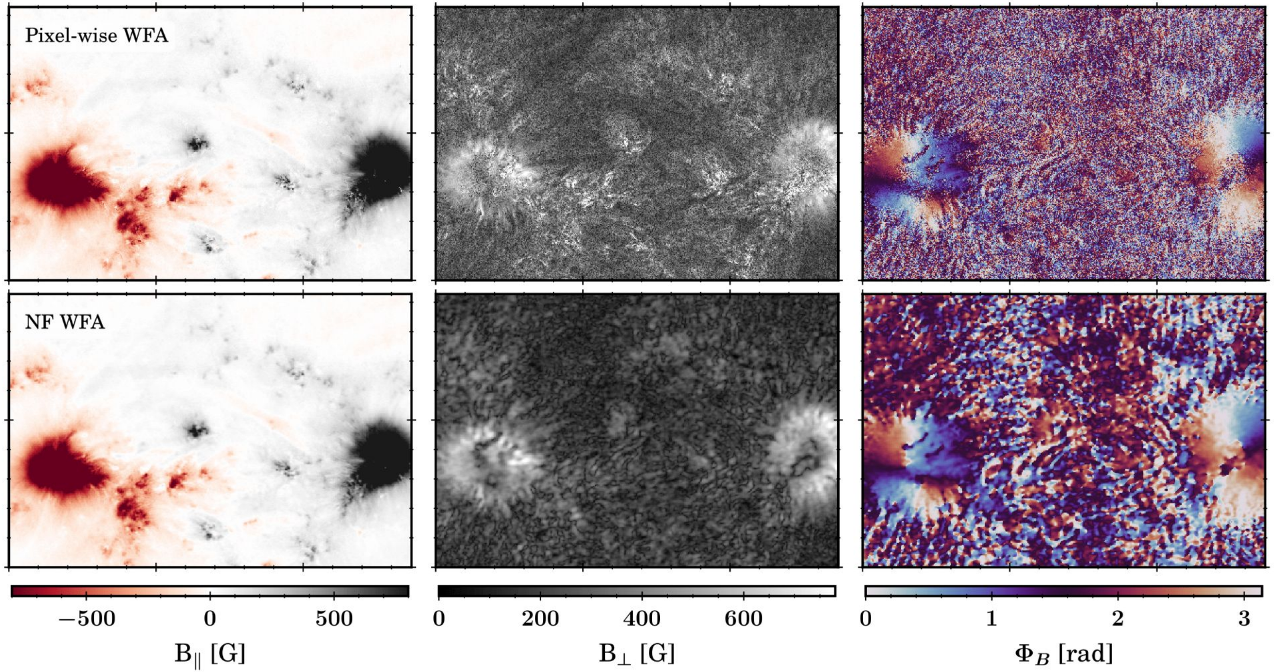
⇒ Hot magnetic canopy produces line profiles with a shallow line core, increasing the bias.

Challenging case

Region: NOAA 12723

Observatory: CRISP @ SST

Spectra line: Ca II 854.2 nm



Challenging case

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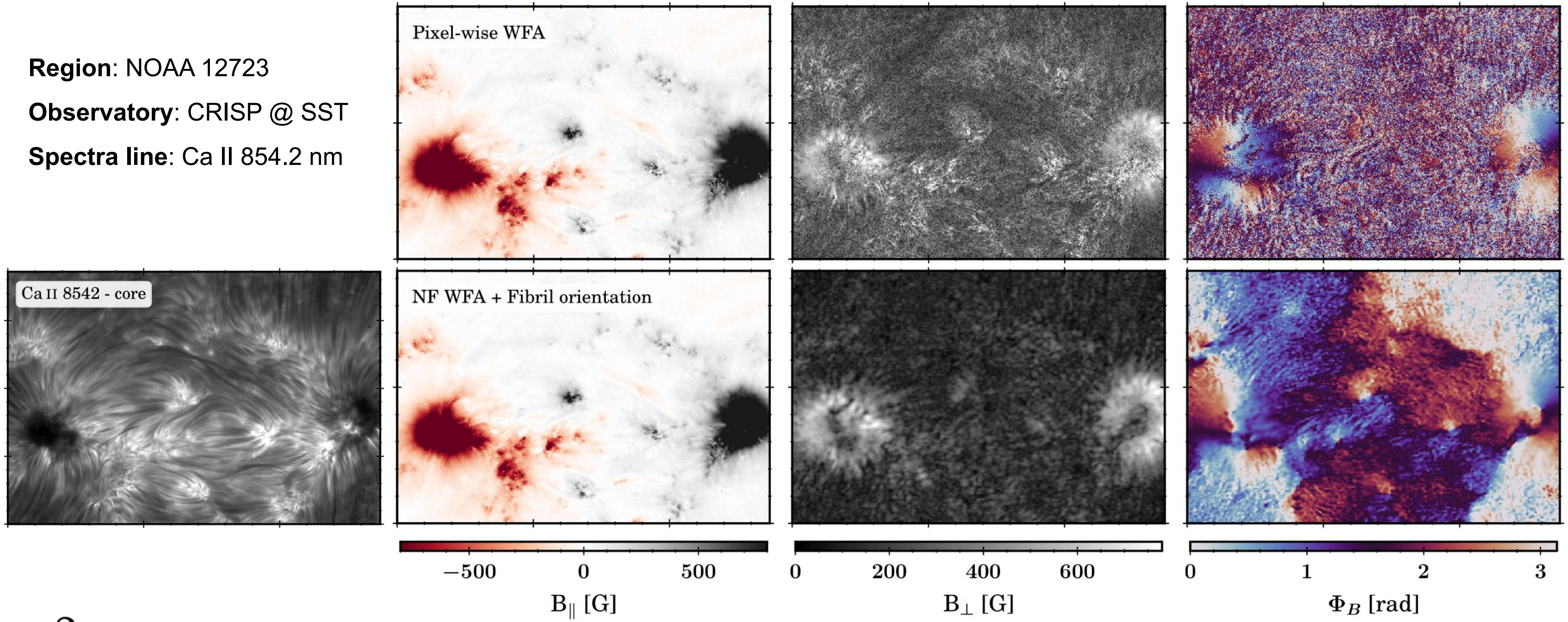

$$\mathcal{L} = \chi^2 + \alpha \mathcal{L}_{\text{reg}}$$

… regularizing with **orientation of the chromospheric fibrils**

Summary and conclusions

- **Compact representation:** reduce complexity of the problem

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- **Continuous controllable scales:** excellent for noisy scenarios

Morosin et al. 2020
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Summary and conclusions

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- **Continuous controllable scales:** excellent for noisy scenarios
- **Speed:** using DL frameworks we have GPU support

Morosin et al. 2020
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Summary and conclusions

- **Compact representation:** reduce complexity of the problem
- **Continuous controllable scales:** excellent for noisy scenarios

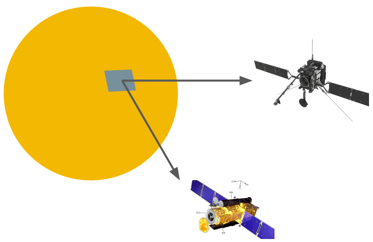
Morosin et al. 2020
de la Cruz Rodríguez & Leenaarts 2024

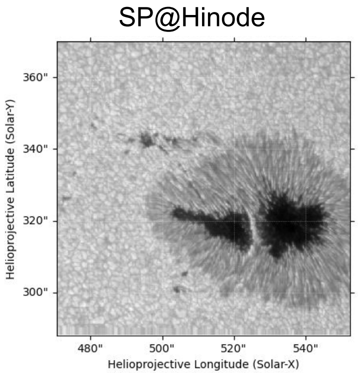
- **Speed:** using DL frameworks we have GPU support
- **Differentiable:** promising for NLTE inversions, other constraints like divergence-free (solve the Zeeman-180 azimuth ambiguity), etc

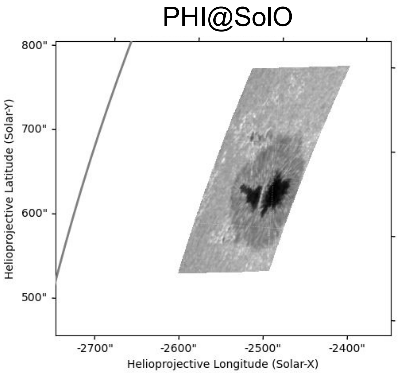
Štepán et al. 2022, 2024

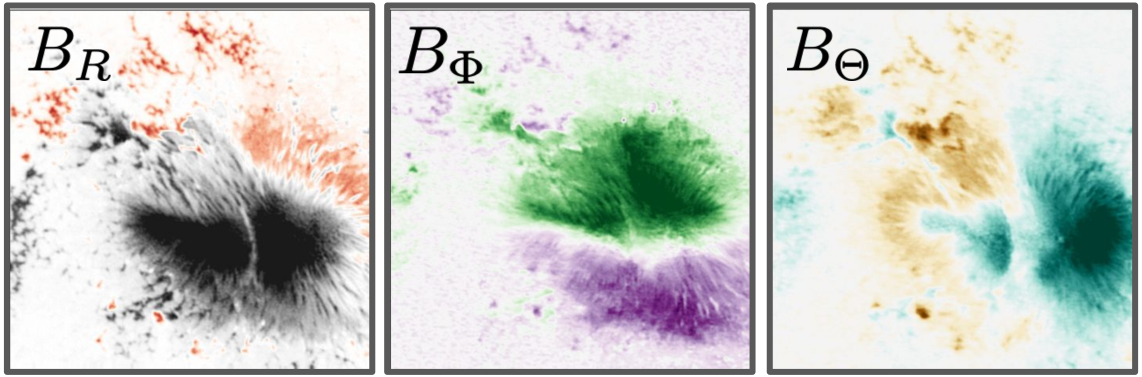
More details in the published article: http://arxiv.org/abs/2409.05156
Contact: carlos.diaz@astro.uio.no

Stereoscopic magnetic field reconstruction (ME)



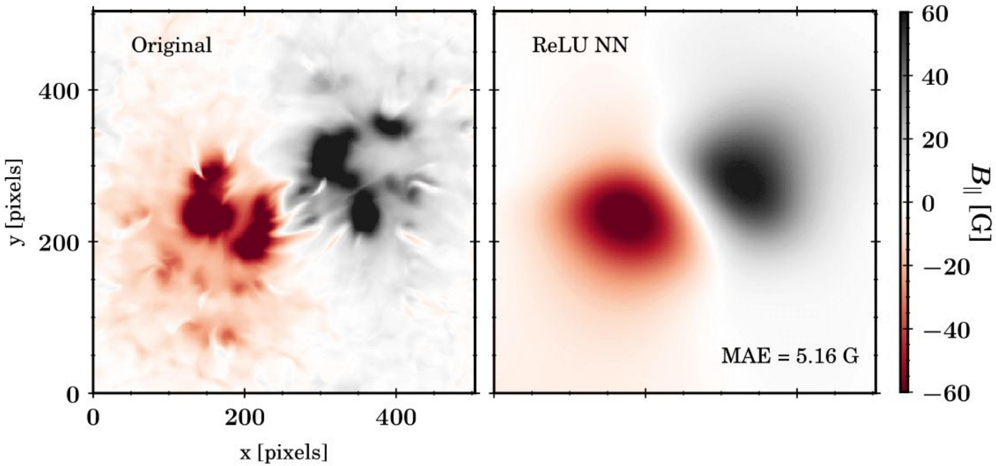






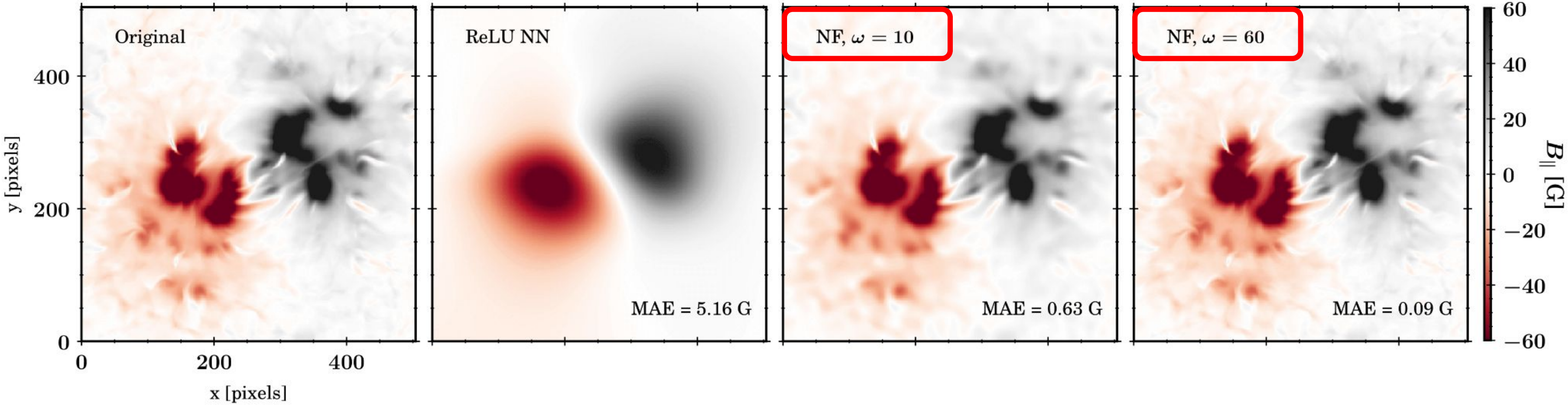
Díaz Baso et. al (in prep)

Controllable implicit bias



$$\mathbf{x} \longrightarrow \mathrm{NN}(\mathbf{x})$$

Controllable implicit bias



$$\mathbf{x} \longrightarrow \mathrm{NN}([\cos(2\pi\boldsymbol{\omega}\mathbf{x}), \sin(2\pi\boldsymbol{\omega}\mathbf{x})])$$

⇒ This <u>nonlinear</u> extension of Fourier series allows us to control the spatio-temporal coherence