Zeeman-Tomography of a quiet sun region

Method & Application

Thorsten A. Carroll & Markus Kopf

Astrophysikalisches Institut Potsdam (AIP)

The Idea

Retrieving 3D information about the atmospheric structures from remotely sensed data

Z-Magnetic Field

Z-Velocity

Magnetocconvective Simulations

Temperature
The Approach

Using MHD Simulations to find the underlying mapping between observed Stokes profiles and the stratification of atmospheric parameters

Some Technical Details

• Synthesizing Stokes spectra from high resolution MHD-Simulation
  mixed-polarity, non-gray, <22G>, <50G>, <140G>, Simulation-Box : 6000x6000x1400 km
  576x576x100 grid points, resolution ~10 km horizontal, ~14 km vertical
  (MURAM-Code, Vögler & Schüssler)

• Spectral lines FeI 6301.5 Å & FeI 6302.5Å
  $g_{eff} : 1.67 & 2.5$, log($g^*f) : -0.718 & -1.235$, $\chi : 3.654 & 3.686$, iron abundance $\epsilon : 7.43$

• Spatial degradation of Profiles and averaging of atmospheric parameters
  PSF (Airy with central obscuration) , aperture 0.5 m, CCD pixel size 0.16"x0.16", spectr. resol. 30mÅ

• LTE radiative transfer
  stratified atmosphere taken from the simulation , temperature, electron pressure, magnetic field, velocity;
  quadratic DELO
Some Details About The Networks

Three ANNs (MLPs) to retrieve the:
- LOS Temperature Stratification
- LOS Velocity Stratification
- LOS Magnetic field Stratification

Some More Details About The Networks

Three ANNs (MLPs) to retrieve the:
- LOS Temperature Stratification
- LOS Velocity Stratification
- LOS Magnetic field Stratification

Temperature Network
- Input: PCA decomposed Stokes I of FeI 6301 and FeI 6302 (10+10 components)
- Output: PCA decomposed depth stratification (5 components), depth range ~500 km

Velocity Network
- Input: PCA decomposed Stokes I of FeI 6301 and FeI 6302 (10+10 components)
- Output: PCA decomposed depth stratification (5 components), depth range ~500 km

Mag. Field Network (Z-Comp.)
- Input: PCA decomposed Stokes V of FeI 6301 and FeI 6302 (10+10 components)
- Output: PCA decomposed depth stratification (5 components), depth range ~500 km
The Synthetic Case: Temperature

Zeeman Tomography of a MHD-Simulation Box: \( \mathbf{B} = 22 \, \text{G} \)

6000x6000x510 km; 52x52x37 grid points; 510 km = \( \log(\tau_{\text{lower}}) = 0.6 \) – \( \log(\tau_{\text{upper}}) = -4.0 \)

Error: 65.34 K per grid point

Max. Temp.: 10500 K; Min. Temp.: 2730 K

The Synthetic Case: LOS Velocity

Zeeman Tomography of a MHD-Simulation Box: \( \mathbf{B} = 22 \, \text{G} \)

6000x6000x510 km; 52x52x37 grid points; 510 km = \( \log(\tau_{\text{lower}}) = 0.6 \) – \( \log(\tau_{\text{upper}}) = -4.0 \)

Error: 188 m/s per grid point

Max. upflow: 7240 m/s; Max. downflow: 6270 m/s
The Synthetic Case: Long. Magnetic Field

Zeeman Tomography of a MHD-Simulation Box: \( \langle B \rangle = 22 \text{ G} \)
6000x6000x510 km; 52x52x37 grid points; 510 km = \( <\log(\text{lower})> = 0.6 \) - \( <\log(\text{upper})> = -4.0 \)
Error: 5.32 G per grid point

Max. Mag. Field: 406 G; Min. Mag. Field: -848 G

3D-Structure from Tomography 3D-Structure from MHD-Simulation

The Real Case:

Zeeman Tomography of a Quiet Sun Region with Hinode (SOT/SP) data

Quiet Region: Scanned on March 10 2007
FOV 164"x307"

App. Flux Density: \( |B_{\text{app}}| \approx 20 \text{ G} \)

100x100 pixel
16" x 16"
\(~11.600 \times 11.600 \text{ km}\)

164"x164"; 1024x1024 pixel
The Real Case: LOS Velocity

Zeeman Tomography of a Quiet Sun Region with Hinode (SOT/SP) data

Max. downflow: 6500 m/s; Max. upflow: 7500 m/s

100x100x37 grid points, ~ 11,600x11,600x500 km

SPW5, Ascona - Switzerland, September 17 – September 21

The Real Case: Temperature

Zeeman Tomography of a Quiet Sun Region with Hinode (SOT/SP) data

Max. Temp.: 11,300 K; Min. Temp.: 3030 K

100x100x37 grid points, ~ 11,600x11,600x500 km

SPW5, Ascona - Switzerland, September 17 – September 21
The Real Case: Magnetic Field (Long.)
Zeeman Tomography of a Quiet Sun Region with Hinode (SOT/SP) data

Max. Mag. Field: 697 G; Min. Mag. Field: -686 G
Isosurfaces: ~ -300 G

100x100x37 grid points, ~ 11,600x11,600x300 km

SPW5, Ascona - Switzerland, September 17 – September 21
Summary:

• A Tomography is possible (combining 1D inversions on a geo. height scale)

• If MHD-Simulations are realistic and cover the entire variety of possible realizations, ANNs are a good method to model the inverse mapping (ANN-Inversions can retrieve even complicated depth stratifications)

• Linear polarization components must/will also be included

• Noise has to be taken into account (PCA & robust ANN training)