Spatial deconvolution of spectropolarimetric data: an application to quiet Sun magnetic elements

Carlos Cristo Quintero Noda
JAXA Aerospace Project Research Associate

May 13, 2015

Outline

I. Introduction. About me.

- I born in Tenerife, Canary Islands, Spain.
- I studied the Physics degree at University of La Laguna
- I did my Master degree in Astrophysics, at University of La Laguna.
  - My project was the development of a Milne-Eddington inversion code under the supervision of Prof. M. Collados
- I did my PhD at Instituto de Astrofísica de Canarias (IAC) during 2010-2014.
  - The title is: "High speed magnetized flows in the quiet Sun"
  - I mainly analyzed data from Sunrise/IMaX and Hinode/SP.
- The main topic of my research is the analysis of Spectropolarimetric data using inversion techniques.

I. Introduction. Some pictures

Figure : Teide Mountain, Tenerife, Canary Islands. Height: 3718 meters.

I. Introduction. Some pictures

Figure : Almond tree flower. February 2015.

I. Introduction. Some pictures

Figure : Sunset in Adeje (Southwest of Tenerife), where I come from.

I. Introduction. Research activities

Scientific papers, as first author, during PhD:

- Temporal relation between quiet Sun transverse fields and the strong flows detected by IMaX/SUNRISE (2013)
- Photospheric downward plasma motions in the quiet Sun (2014)
- High speed magnetized flows in the quiet Sun (2014)

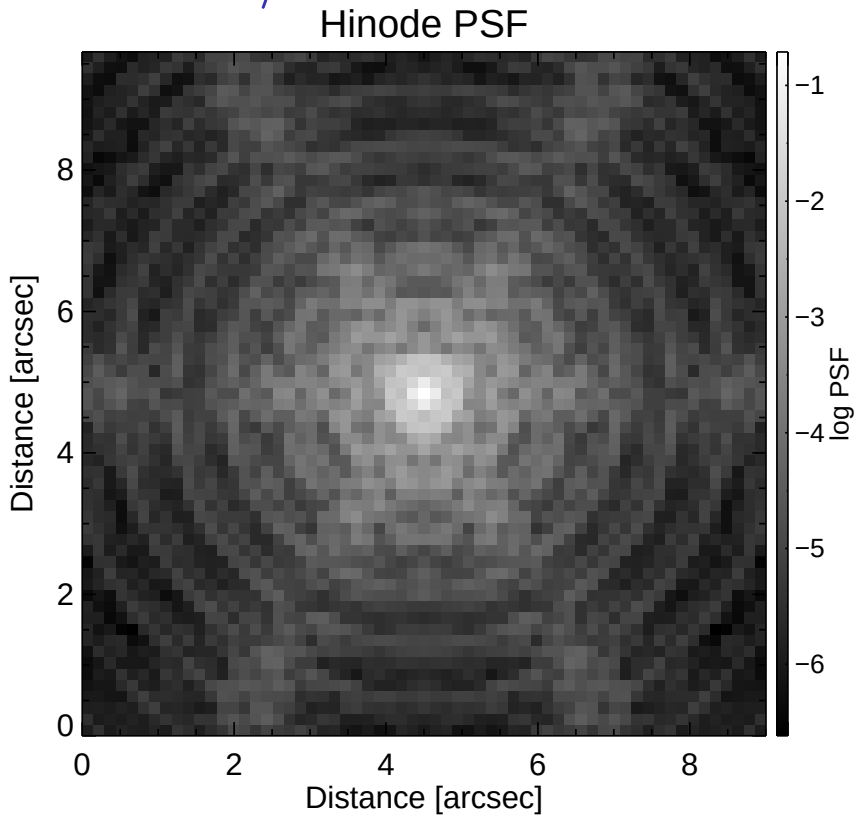
Scientific papers, as first author, after PhD:

- **Spatial deconvolution of spectropolarimetric data: an application to quiet Sun magnetic elements (2015, in press)**
- Spatial deconvolution of spectropolarimetic data: an application to an active region (2015, under revision)
- Spatial deconvolution of spectropolarimetic data: an application to quiet Sun internetwork regions (work in progress)

I. Introduction. Dispersed light.

- A space telescope as Hinode is not affected by presence of the earth's atmosphere.
- However the optical properties of the instruments still limit the observations.
- In the case of diffraction limited observations, the PSF establishes the maximum allowed spatial resolution, defined as the distance between two nearby structures that can be properly distinguished.
- The shape of the PSF also induces a dispersion of the light from different parts of the image, leading to what is commonly termed as stray light or dispersed light.
- As consequence, the contrast of the object measured in the focal plane is typically smaller than the contrast in the original object.

I. Introduction. Hinode/SOT PSF.



- PSF profile obtained from the pupil specified on Suematsu et al. (2008).
- This PSF has been used by van Noort et al. (2013), Tiwari et al. (2013), Riethmüller et al. (2013), Lagg et al. (2014) and Buehler et al. (2015) in the spatially coupled inversion code (van Noort et al. (2012)).
- Also, in Ruiz Cobo et al. (2013) and Quintero Noda et al. (2015) in a decoupled deconvolution and inversion process.

II. Observations and data analysis. Deconvolution

Deconvolution is carried out in two steps:

- 1. The Stokes profiles of the map are deconvolved from the known PSF using iterative algorithm known as the Gaussian version of the Richardson-Lucy (RL) algorithm.
  - Instead of making the deconvolution wavelength by wavelength we use a principal component analysis PCA.
- 2. The resulting deconvolved Stokes profiles are inverted using standard Stokes inversion codes.

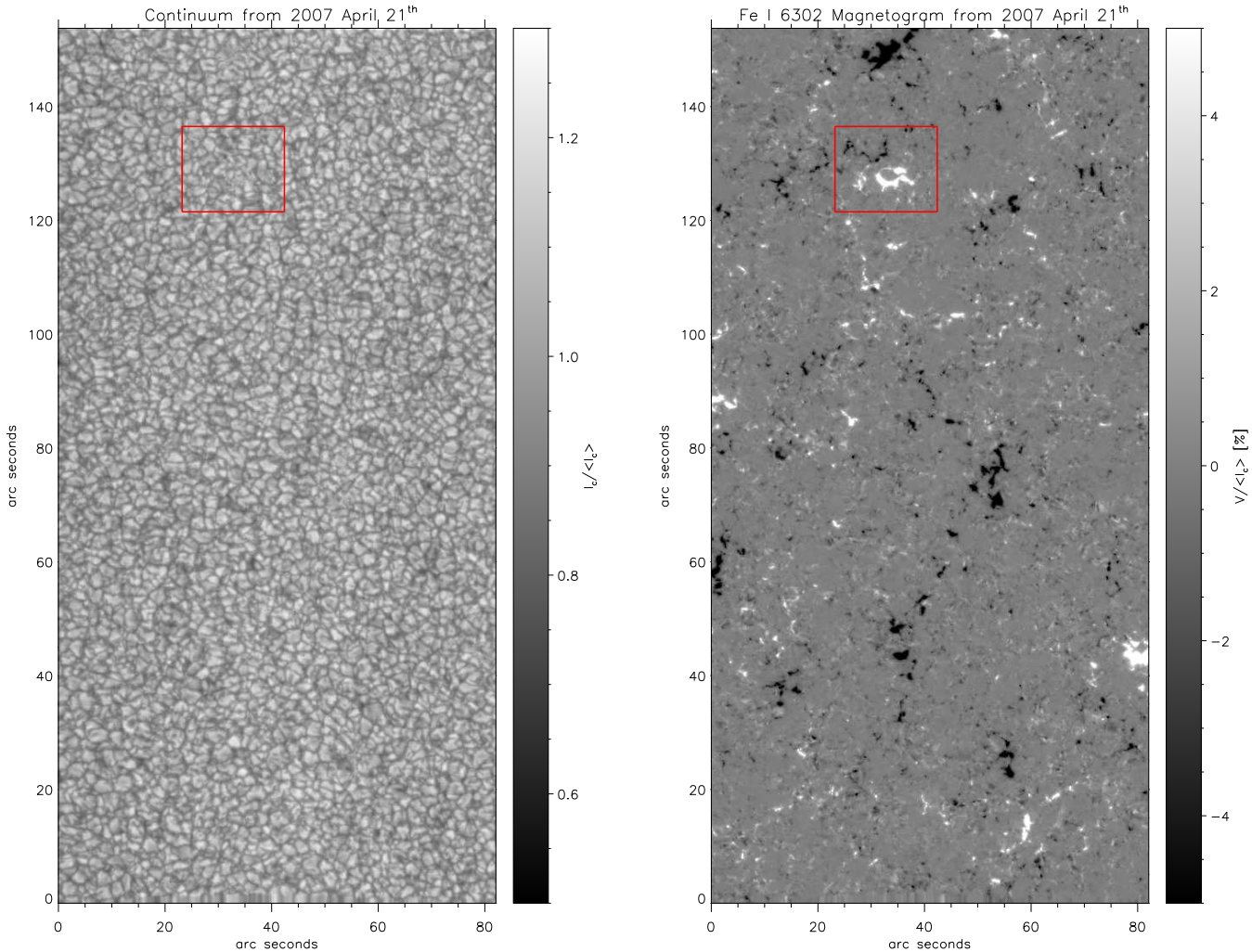
Advantages respect to the spatially coupled inversion code

- Decoupled process. After the deconvolution, any Stokes inversion code can be used.

Limitations

- It is based in a maximum-likelihood algorithm, thus it is sensitive to over-reconstruction produced by the presence of noise.

II. Observations and data analysis. Data



- Hinode/SP data from a quiet Sun region measured on April 21^{th}, 2007.
- Integration time per slit is 12.8 sec. The signal-to-noise ratio for Stokes Q, U, and V is close to 7×10^{-4}.

II. Observations and data analysis. PCA eigenvectors

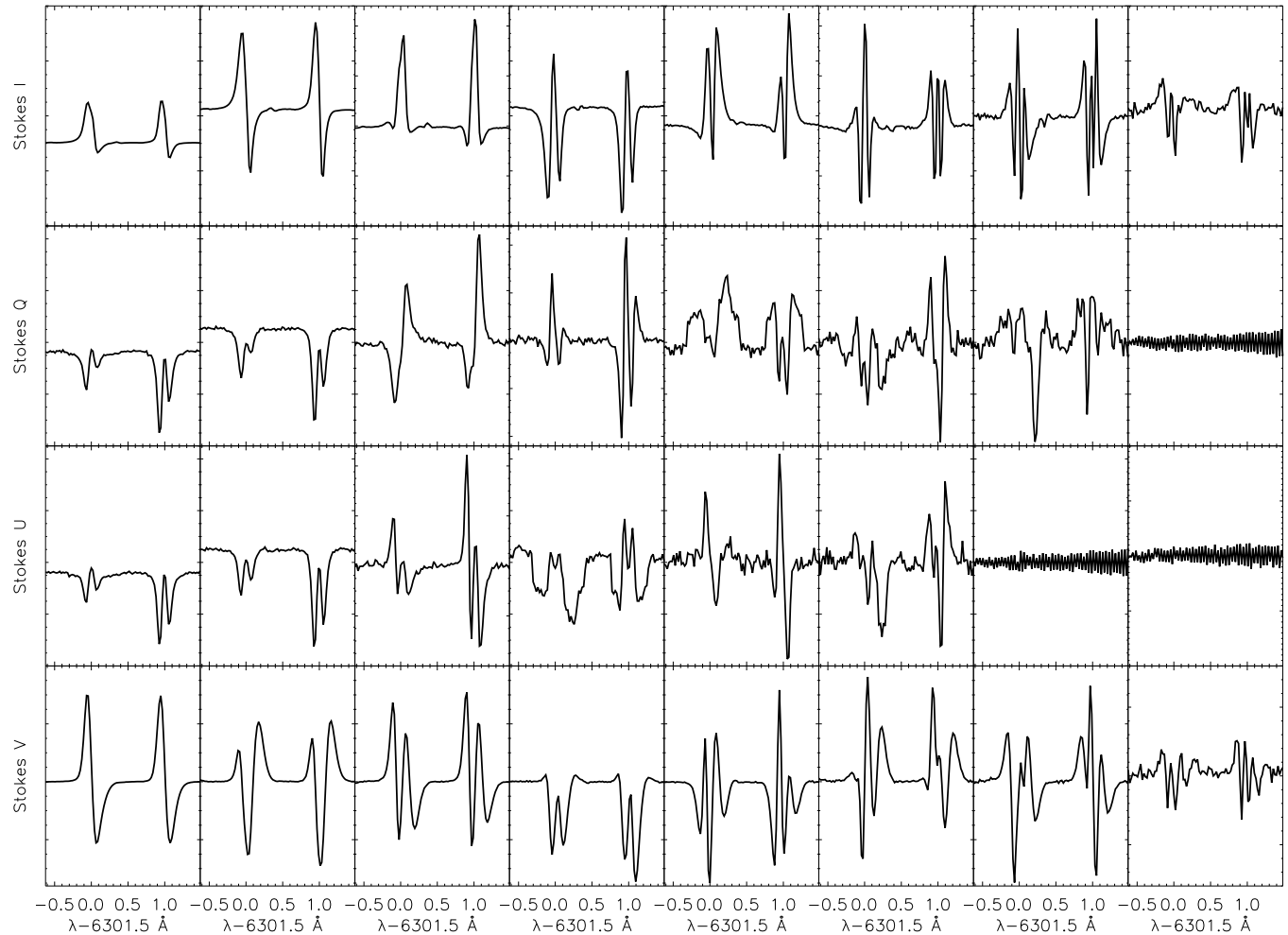


Figure : First eight eigenvectors obtained after the PCA decomposition of the observed Stokes parameters from Hinode/SP map.

III. Results. Continuum and magnetogram maps

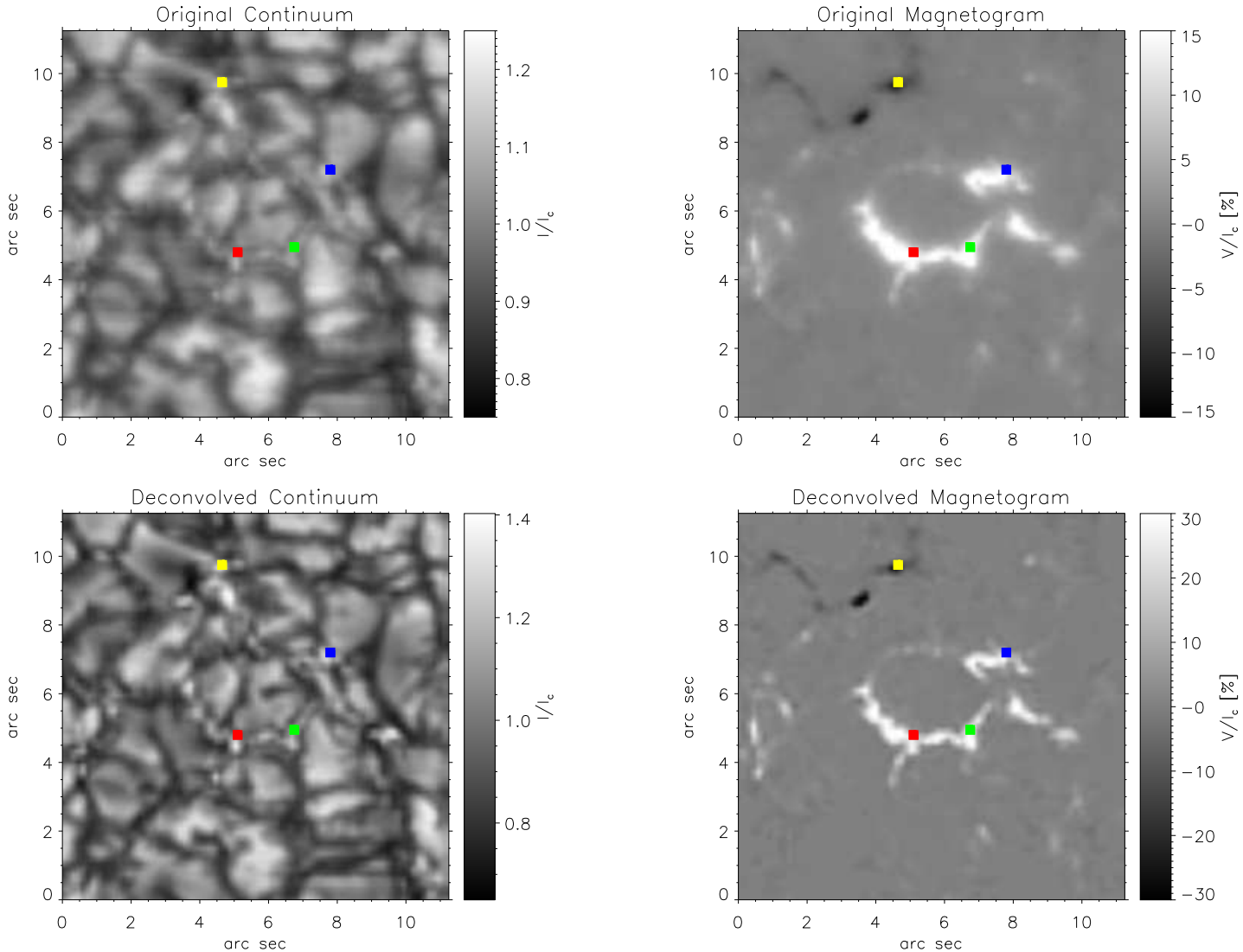


Figure : Comparison between the observed and deconvolved continuum and magnetogram maps.

III. Results. Stokes profiles

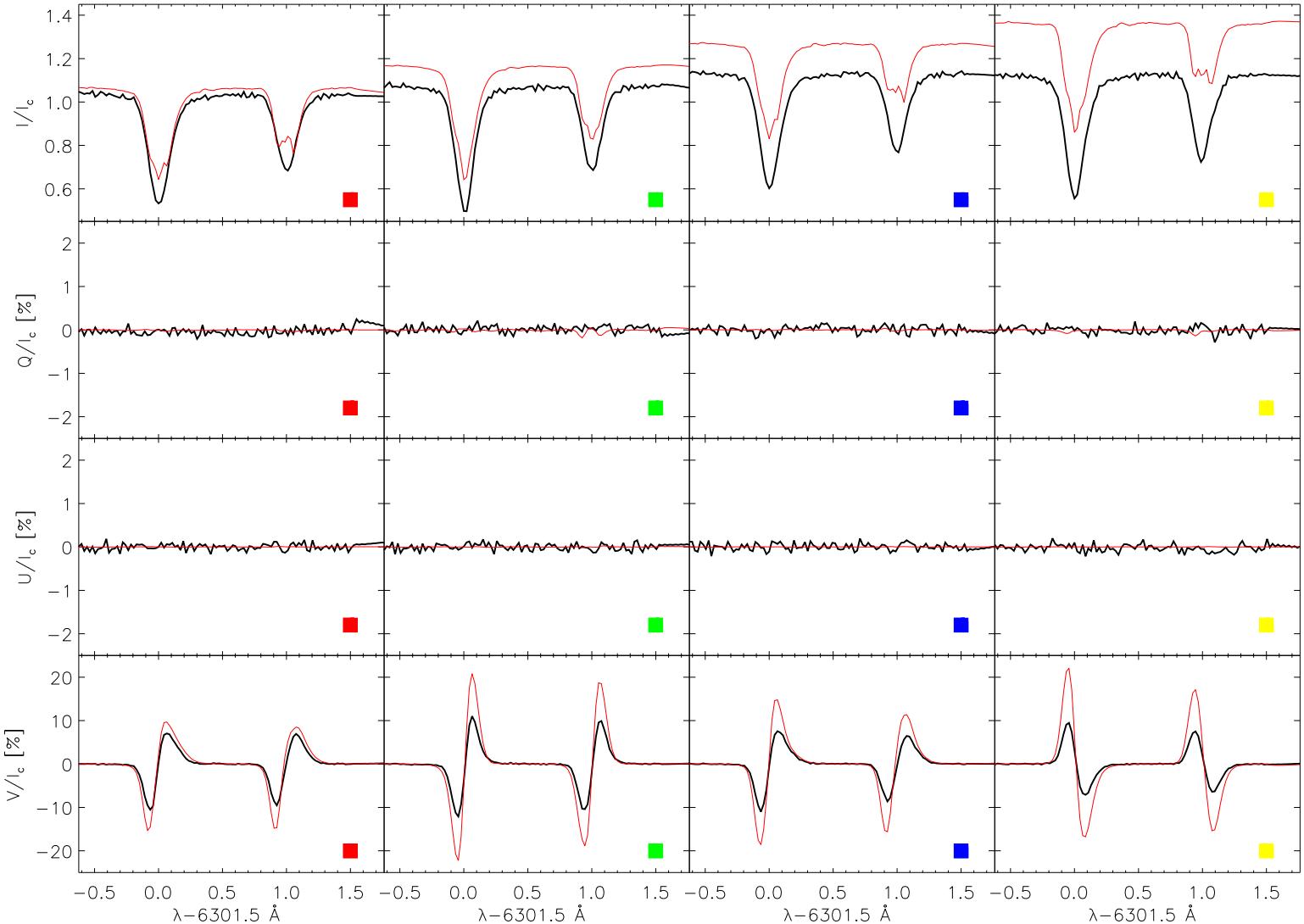


Figure : Each panel shows the original profile in black and the corresponding deconvolved profile in red.

III. Results. Asymmetries

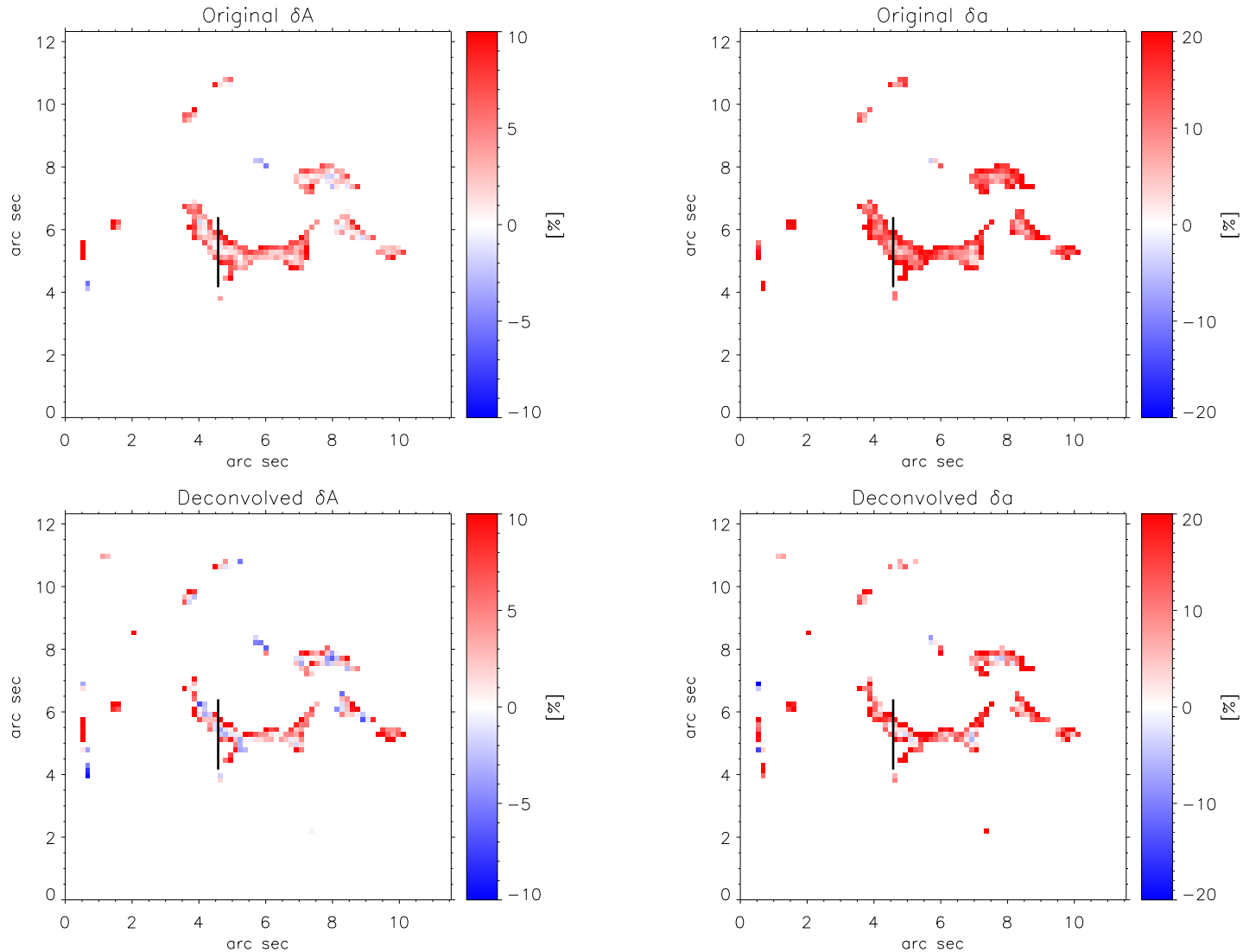


Figure : Comparison between the original and deconvolved area and amplitude asymmetry.

IV. Inversion. Configuration

- SIR (Stokes Inversion based in Response functions, Ruiz Cobo et al. 1992) code allows to infer the optical depth dependence of the physical parameters.
- We use a single magnetic component to reproduce the Stokes profiles of each pixel.
- We set as free parameters the temperature, LOS velocity, magnetic field vector, and microturbulence.
- Number of nodes, T=7, V_{LOS}=5, B=5, γ=3, ϕ=1, microtubulence=3.
- The total number of free parameters is 24.
- We also invert each pixels 100 times using random initializations in order to avoid local minima.

IV. Inversion. Nodes location

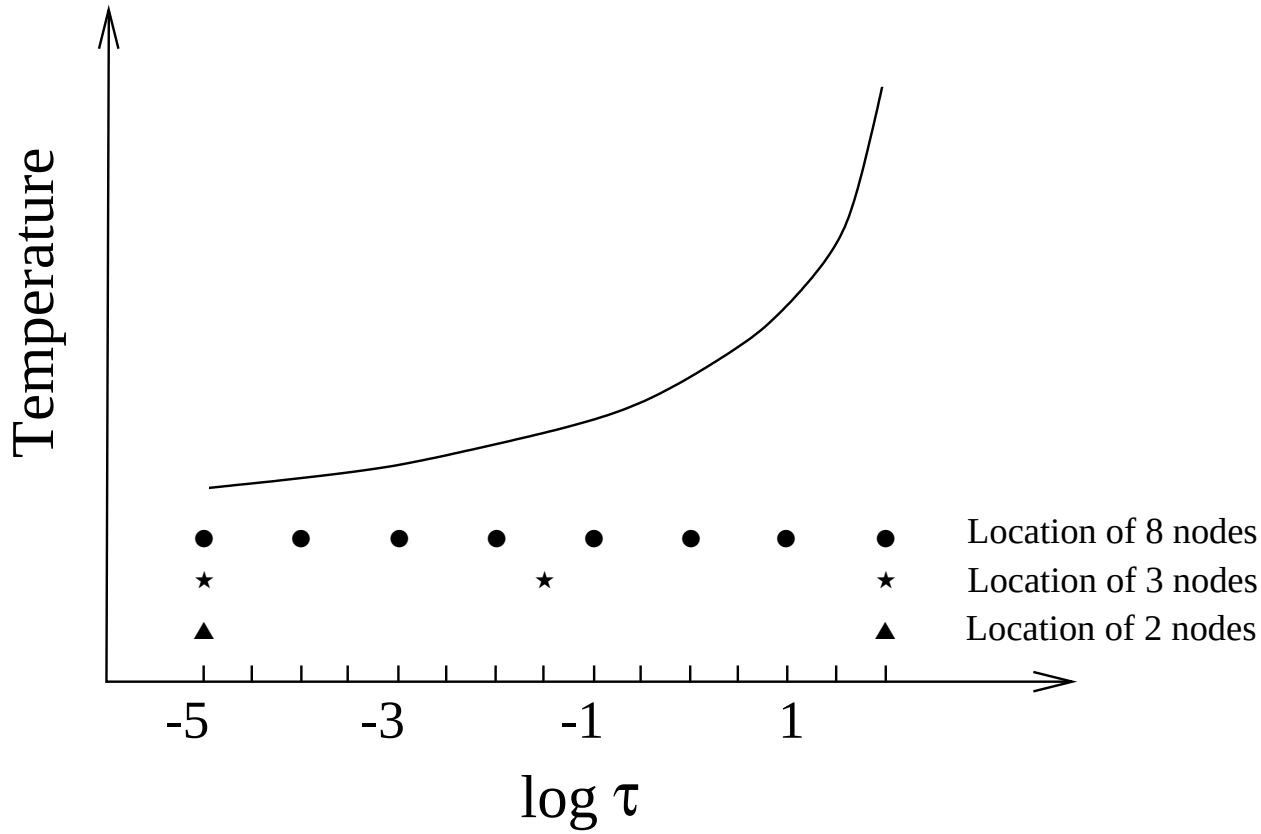


Figure : Different node positions in SIR code, always equidistant. Other codes are different.

IV. Inversion. Stokes profiles

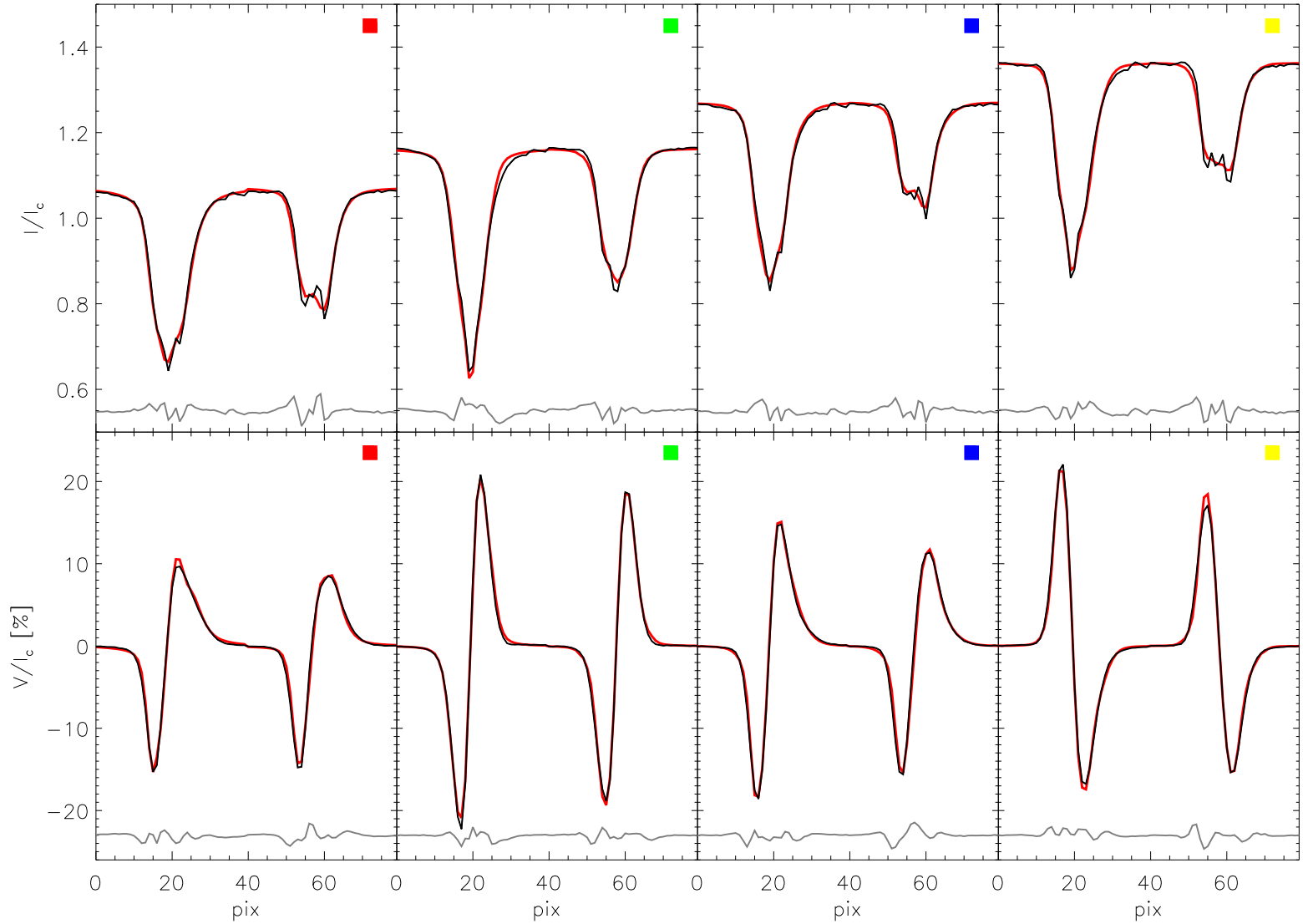


Figure : Results from the inversion of the deconvolved Stokes profiles. Deconvolved profiles are in black, while the results from the inversion are in red.

IV. Inversion. Vertical cut

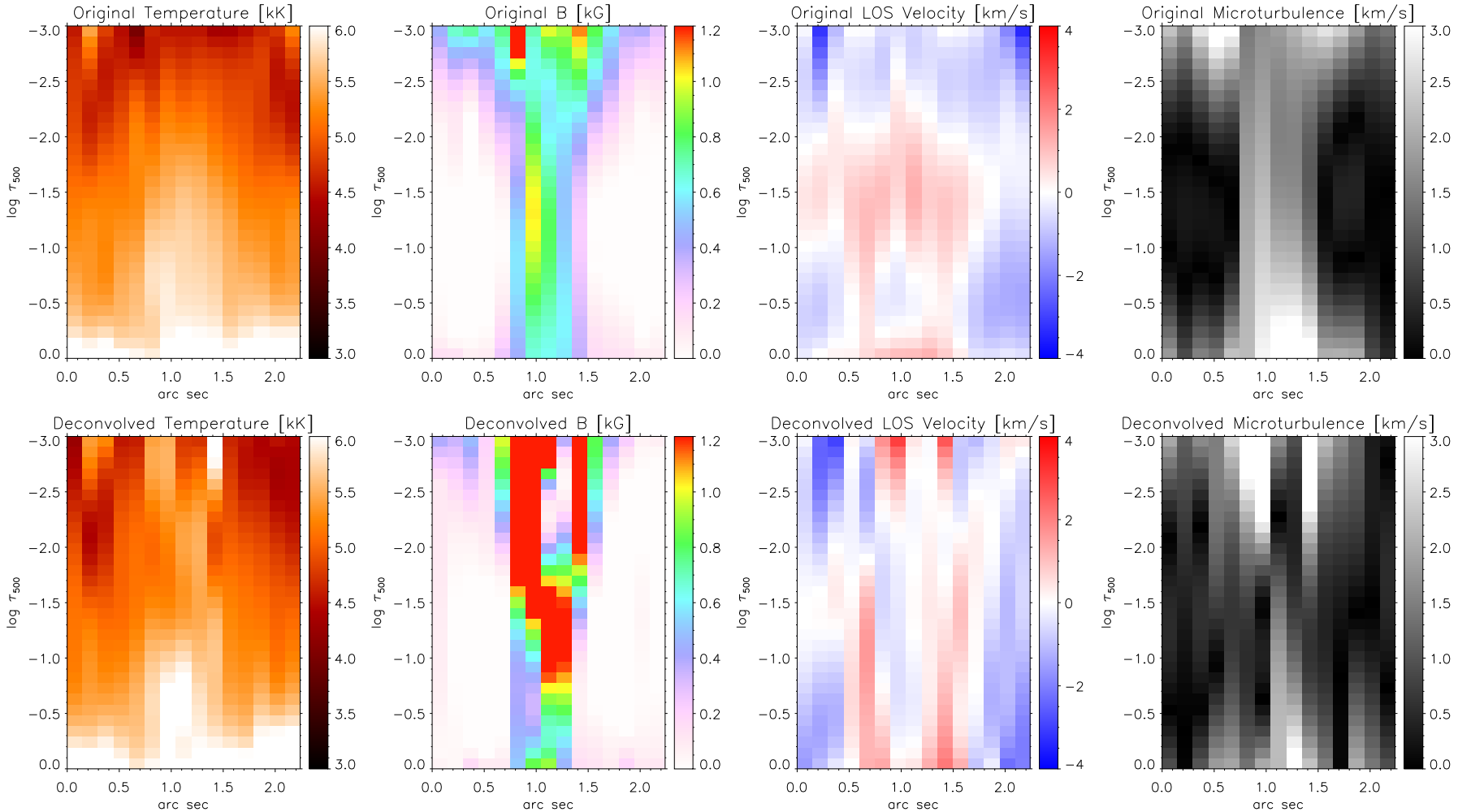


Figure : Results of the inversion. Vertical cut.

V. Summary

- The process of spatial deconvolution produces some changes in the Stokes profiles:
  - The continuum contrast increases from 7.6% to 11.9% accompanied by a reduction of the size of the structures.
  - The Stokes I profiles show the Zeeman splitting, σ-components, in regions of strong longitudinal field.
  - Some pixels show a strong increase of the Stokes V amplitude.
- From the results of the inversions:
  - We found the same magnetic flux structure but with less continuity between pixels.
  - The inferred magnetic field intensity is larger in the deconvolved data.

V. Conclusions

- This is the first time that a deconvolution code is used in noisy data. Strong magnetic elements display enough signal to reliably reconstruct the information perturbed by the PSF and do not introduce many artifacts.
- The decoupled deconvolution process allows the user to choose the inversion code.
- In addition, it allows to pursue a trial-and-error study due to the low demanding computational time.
- We can conclude, then, that the spatial deconvolution of 2D spectropolarimetric data prior to the inversion of the Stokes profiles is the way to proceed in the near future.

Thanks!