Nonlinear force-free coronal magnetic stereoscopy

Iulia Chifu[1,2]
T. Wiegelmann[1], B. Inhester[1]

1. Max Planck Institute for Solar System Research, Göttingen
2. Astronomical Institute of Romanian Academy, Bucharest

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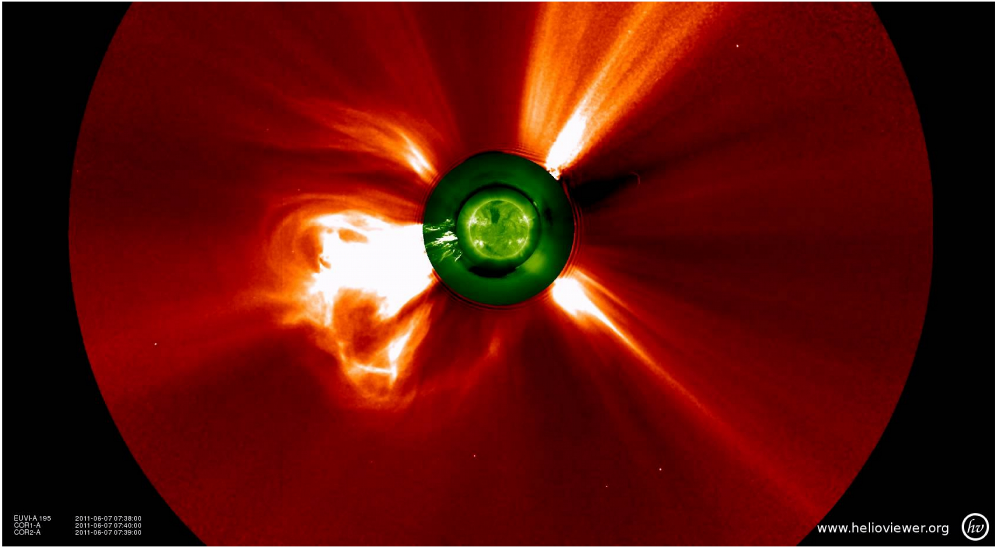
Solar corona



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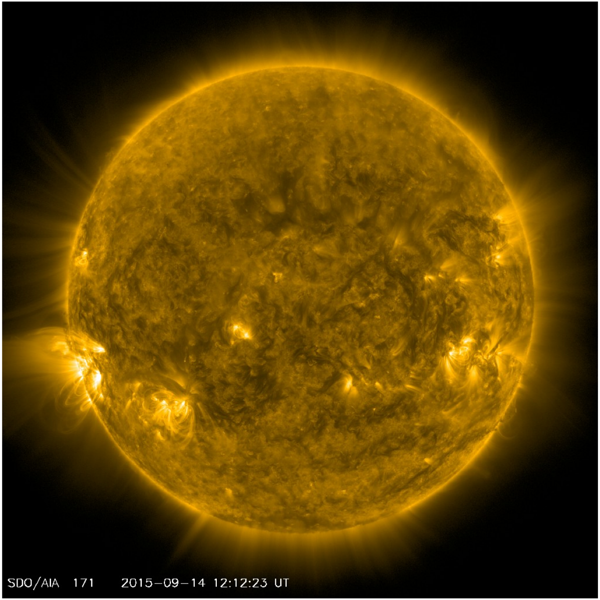

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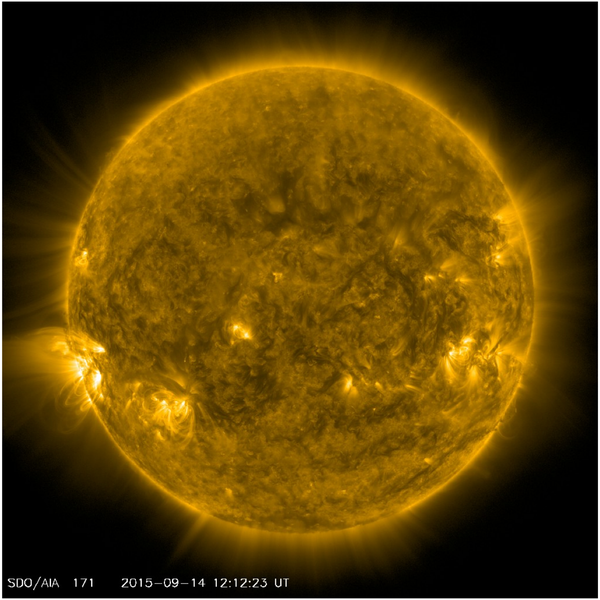

Why magnetic field extrapolation?

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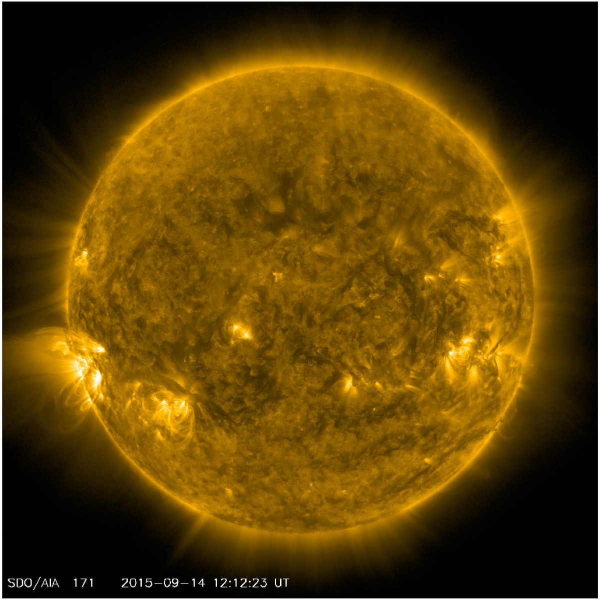


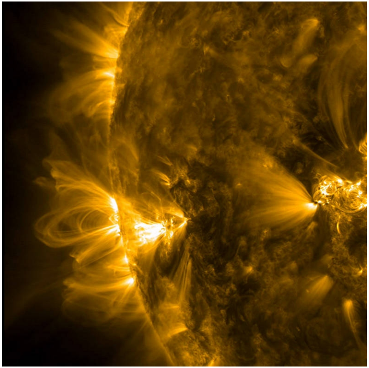
Why magnetic field extrapolation?

Magnetic field measurements

- low magnetic field strength
- corona is optically thin

Active region loops

- Active region loops are considered a good proxy for the coronal magnetic field shape
- Magnetic flux tubes appear bright if filled with sufficient amount of hot plasma



Purpose

$\Rightarrow$ Validation of a nonlinear force-free field (NLFFF) method which extrapolates the magnetic field from the solar photosphere to the corona using observational constraints from the corona.

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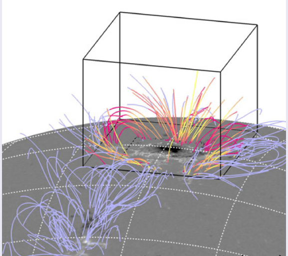

deRosa et al. (2009)

- purple - NLFFF extrapolation
- yellow - misalignment angle $\leq$ 5 deg.
- red - misalignment angle $\leq$ 45 deg.

Stereoscopy

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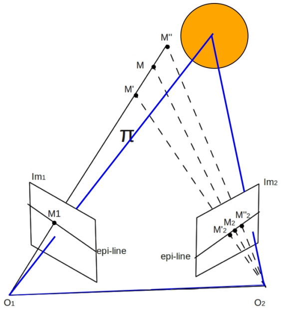
Multi-view B-spline Stereoscopic Reconstruction (MBSR)

- retrieves the 3D information of curve-like objects (coronal loops, prominences, leading edge of the CMEs)
- two & three view directions $\rightarrow$ N views
- reconstructs directly smoothed 3D curves using only tie-point data as input

Multi-view B-spline Stereoscopic Reconstruction

1. The epipolar geometry

- stereo base line, angle, plane
- epipolar plane/line



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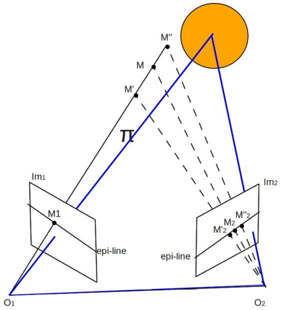
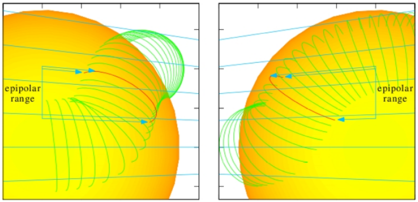


2. Identification and matching

- automatic
- by visual inspection

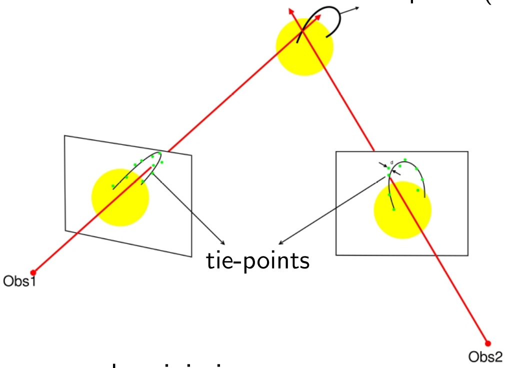


Inhester(2006)

Multi-view B-spline Stereoscopic Reconstruction

3. Reconstruction

loop approximated by a 3D B-spline **c**(s,**q**)



The least– square code minimizes

$$\sum_{\mathrm{images}\ j} \sum_{\mathrm{tie-points\ i}} |P_j \cdot \mathbf{c}(s_{i,j};\mathbf{q}) - \mathbf{x}_{i,j}|^2 + \mu \int |\frac{d^2}{ds^2} \cdot \mathbf{c}(s;\mathbf{q})|^2 ds$$

Nonlinear Force-Free Field (NLFFF) extrapolation

- An indirect approach for deriving the magnetic field in the corona
- It makes use of standard magnetic field measurements in the photosphere $\rightarrow$ full magnetic field vector

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- low plasma beta
- the stationarity of the coronal magnetic field
- Force-free magnetic field

  $\Rightarrow (\nabla \times \mathbf{B}) \times \mathbf{B} = 0$

  $\Rightarrow \nabla \cdot \mathbf{B} = 0$

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Nonlinear Force-Free Field optimization method

$$L = \frac{1}{V}\int_V w_f \frac{|(\nabla\times\mathbf{B})\times\mathbf{B}|^2}{B^2}\, d^3r + \frac{1}{V}\int_V w_f |\nabla\cdot\mathbf{B}|^2\, d^3r + \frac{1}{V}\int_S (\mathbf{B}-\mathbf{B}_{obs})\cdot \mathrm{diag}(\sigma_{\mathrm{q}}^{-2})\cdot(\mathbf{B}-\mathbf{B}_{obs})\, d^2r$$

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L_1 L_2 L_3

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Stereoscopy-Nonlinear Force-Free Field optimization method

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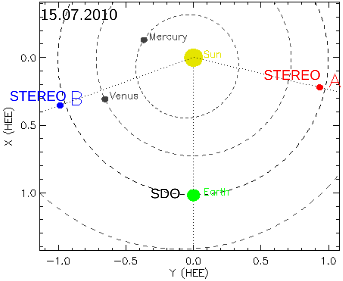
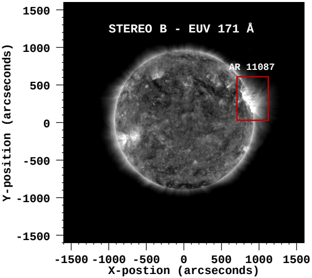
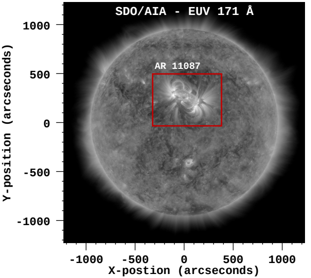
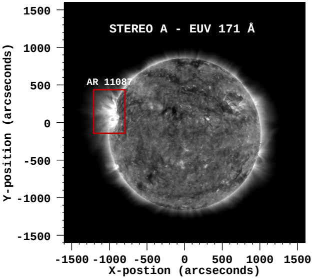
Observations









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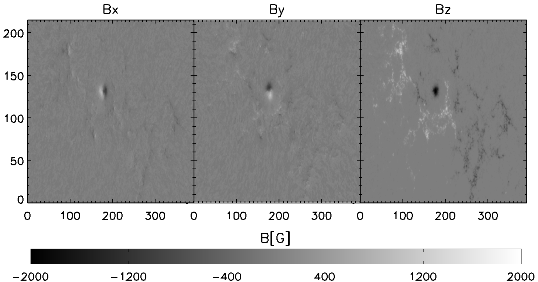
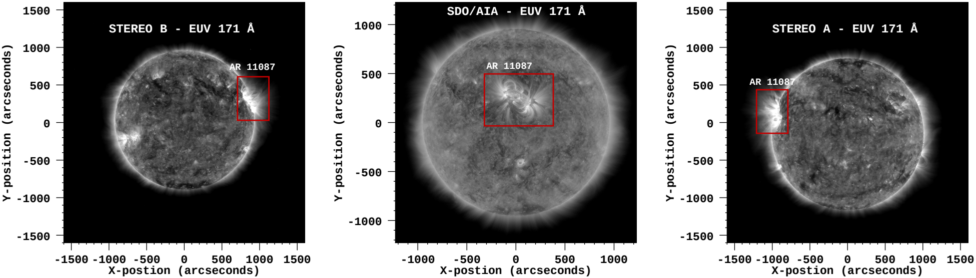
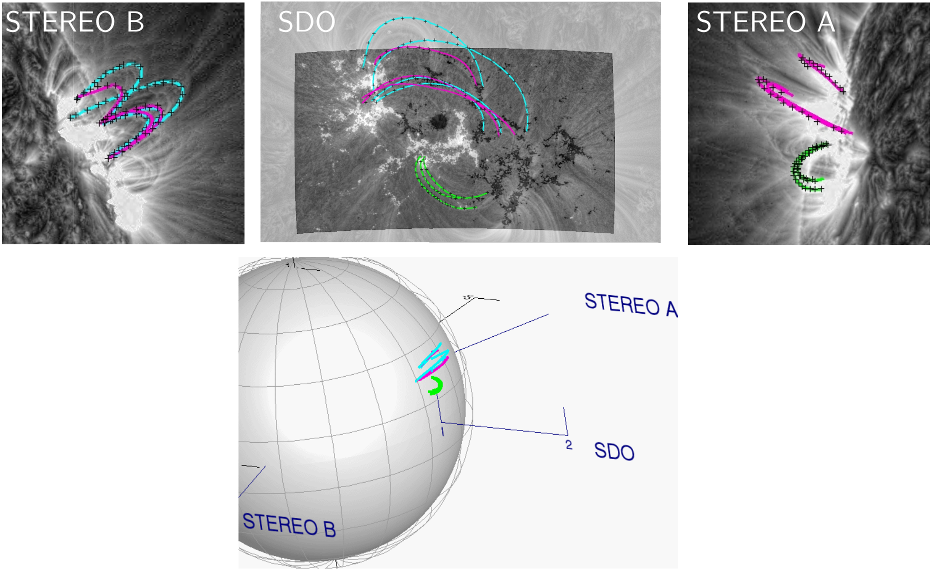




Results

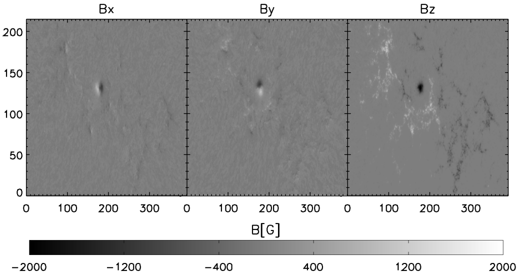
3D loops with Multiview B-spline Stereoscopic Reconstructions



Results

The NLFFF extrapolation

$$L = \frac{1}{V}\int_V w_f \frac{|(\nabla\times\mathbf{B})\times\mathbf{B}|^2}{B^2}\, d^3r + \frac{1}{V}\int_V w_f |\nabla\cdot\mathbf{B}|^2\, d^3r + \frac{1}{V}\int_S (\mathbf{B}-\mathbf{B}_{obs})\cdot \mathrm{diag}(\sigma_q^{-2})\cdot(\mathbf{B}-\mathbf{B}_{obs})\, d^2r$$



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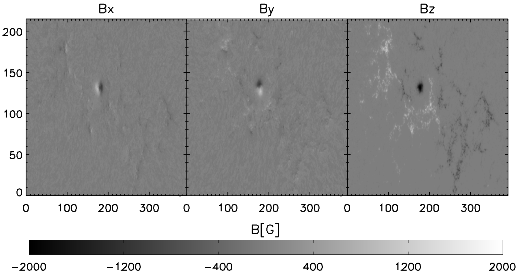
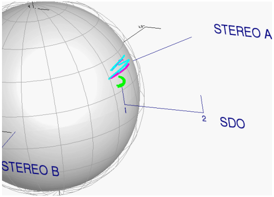
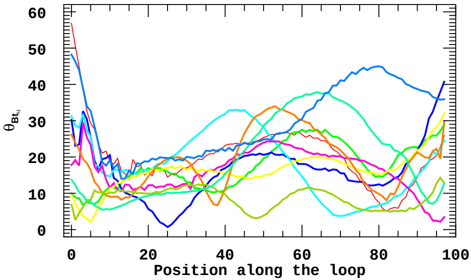




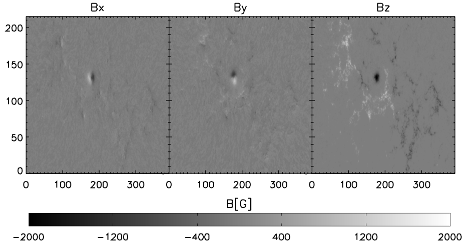


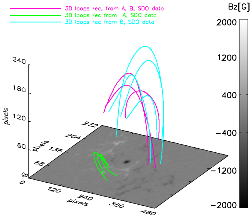
$\theta_{\mathbf{B},\mathbf{t_i}}$ → the angle between the magnetic field vector $\mathbf{B}_{\mathbf{NLFFF}}$ and the loop tangent $\mathbf{t_i}$

Results

The S-NLFFF extrapolation

$$L = \frac{1}{V}\int_V w_f \frac{|(\nabla\times\mathbf{B})\times\mathbf{B}|^2}{B^2}\, d^3r + \frac{1}{V}\int_V w_f |\nabla\cdot\mathbf{B}|^2\, d^3r + \frac{1}{V}\int_S (\mathbf{B}-\mathbf{B}_{obs})\cdot \mathrm{diag}(\sigma_{\mathrm{q}}^{-2})\cdot(\mathbf{B}-\mathbf{B}_{obs})\, d^2r + \sum_i \frac{1}{\int_{\mathbf{c}_i} ds}\int_{\mathbf{c}_i}\frac{|\mathbf{B}\times\mathbf{t}_i|^2}{\sigma_{c_i}^2}\, ds$$





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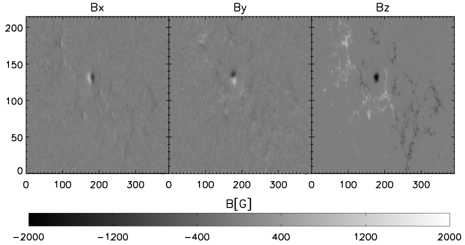

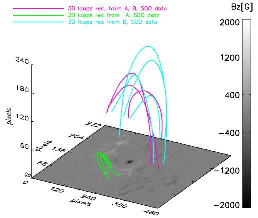

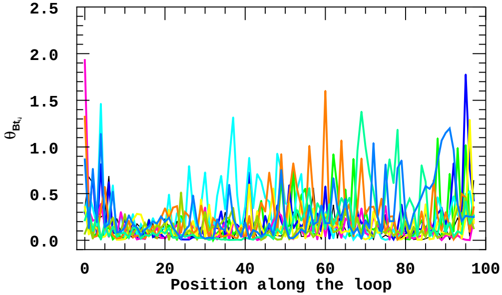

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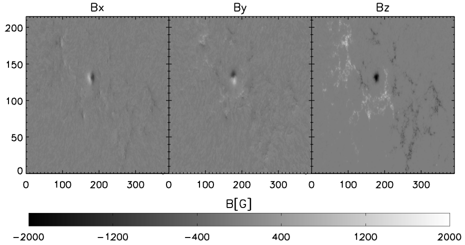

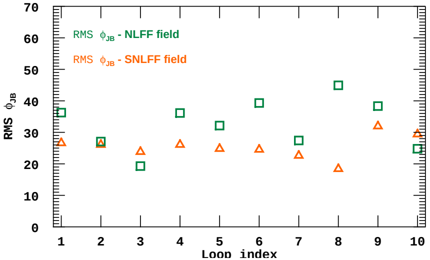

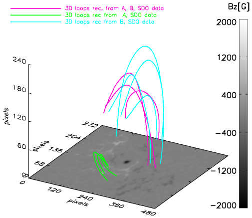

$\phi_{\mathbf{B},\mathbf{J}}$ $\rightarrow$ the angle between the magnetic field **B** and the current **J** for each loop

Summary and conclusions

- Two indirect approaches of deriving the 3D shape of the coronal magnetic field.
- For the same observational data, the computed 3D coronal magnetic field did not coincide.
- We present the performance of the S-NLFFF method using ten 3D coronal loops as a constraint for modeling the coronal magnetic field.
- We show that the S-NLFFF method can obtain a good agreement between the modeled field and the coronal loop observations.
- The S-NLFFF method can also obtain a better alignment between the magnetic field and the current $\rightarrow$ better field in terms of force-freenes.

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Thank you for your attention!