3D tomography for the solar corona

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Scalar Field Tomography: Regularization

- Problem is badly conditioned, e.g. number of unknown variables exceeds the number of equations
- Random noise in the data

In result, there is possible no unique reconstruction. Problem is ill-conditioned.

\[
F = \sum_{i=1}^{\text{Number of Rays}} \left( I_i^{\text{sim}} - I_i^{\text{obs}} \right)^2 + \mu \cdot F_{\text{reg}} = \\
= |A \cdot X - Y|^2 + \mu \cdot |L \cdot X|^2
\]
Tomography for the Solar Corona

- Problem is badly conditioned, e.g. number of unknown variables exceeds the number of equations
- Noise in the data

\[ \begin{align*}
\text{Regularization should be applied}
\end{align*} \]

- Stationarity of the corona during the observations must be assumed. Coronal observations are restricted to only one-three view direction in ecliptic plane.
Tomographic Reconstruction for the Solar Corona

Input:

- COR1 observations: pB images
- Observations during a half of solar rotation, 2-4 obs per day
- Roll minimum background subtracted
- Starting point for the iterations is flat field (constant density)
- Weighting factor is applied for low intensity pixels

Output:

- 3D Electron Density Distribution: 128x128x128 pixels
Reconstruction of the Electron Density

Reconstruction: CAR 2058

Isosurface: $N_e = 3.6 \times 10^{10} \text{ m}^{-3}$

$\theta = 90.00^\circ$
$\phi = 340.00^\circ$

Isosurface: $N_e = 3.6 \times 10^{10} \text{ m}^{-3}$

Inner spherical boundary is at $1.5 \text{ R}_\odot$
Isosurface: $N_e = 3.6 \times 10^{10}$ m$^{-3}$

Inner spherical boundary is at 1.5 $R_{\text{sun}}$
Reconstruction of the Electron Density

Isosurface: $N_e = 3.6 \times 10^{10}$ m$^{-3}$

Inner spherical boundary is at $1.5 \ R_{\odot}$
Isosurface: $N_e = 3.6 \times 10^{10}$ m$^{-3}$

Inner spherical boundary is at 1.5 $R_{\text{Sun}}$
Reconstruction of the Electron Density

Isosurface: \( N_e = 3.6 \times 10^{10} \) m\(^{-3}\)

Inner spherical boundary is at 1.5 \( R_{\text{sun}} \)
Reconstruction of the Electron Density

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Reconstruction: CAR 2058
Reconstruction of the Electron Density

Reconstruction: CAR 2058

Isosurface: $N_e=3.6\times10^{10}$ m$^{-3}$  

Inner spherical boundary is at $1.5 \, R_{\text{sun}}$
Spherical cross-section at $2 R_{\text{sun}}$

White contour lines are boundary between open and closed magnetic field lines in potential field reconstruction with $SS=2.5 R_{\text{sun}}$.

Black contour line is the magnetic neutral line.

MHD simulation (http://iMHD.net/stereo)

STEREO-B EUVI 195

$\phi_{\text{LOS}}=0.05^\circ$

$\theta_{\text{LOS}}=86.48^\circ$

2007-07-17T18:56
Tomography for the Solar Corona: Errors

Relative Error for the Inversion only

Relative error: $r < 3.6R_\odot$

Rec: MHD_bkg

av. $\mu_{reg} = 0.10E-23$
Reconstructions for the whole year of 2008

Reconstruction No 0

Observation period

Reconstruction No 1

Observation period

Reconstruction No 2

Observation period
Tomography for the Solar Corona: Errors

Relative Error due to non-stationarity of the corona

One day difference

Seven days difference
Reconstructions for the whole year of 2008

Reconstruction No 0

Observation period

Reconstruction No 1

Observation period

Reconstruction No 2

Observation period
Reconstructions for the whole year of 2008
Reconstructions for the whole year of 2008
Reconstructions for the whole year of 2008
CME: June 1\textsuperscript{st}, 2008

Before the CME

After the CME

Mass lost by the streamer: $9 \times 10^{14}$ g

CME mass in COR1 FOV: $\sim 9 \times 10^{14}$ g

(Robbrech et al 2009)
CME: Dec 31\textsuperscript{st}, 2007 & Jan 2, 2008

Before the CME

After the CMEs

Mass lost: $1.1 \times 10^{15}$ g

CME masses:
- $4.3 \times 10^{15}$ g
- $1.1 \times 10^{15}$ g
CME: June 1\textsuperscript{st}, 2008

Before the CME

After the CME

Mass lost by the streamer: $9 \times 10^{14}$ g

CME mass in COR1 FOV: $\sim 9 \times 10^{14}$ g

(Robbrech et al 2009)
CME: June 1\textsuperscript{st}, 2008

Before the CME

After the CME

Next: Vector Field Tomography for the Coronal Magnetic Field
Zeeman/Hanle-effect in the Corona: Observations of Fe XIII

Lin et al. 2004
There is no information about magnetic field strength!
Vector Field Tomography: Regularization

We need additional information about field:

Magnetic field is divergence-free: \( B = 0 \)

\[
F = \sum_{i=1}^{\text{Number of Rays}} D_i^{\text{sim}} - D_i^{\text{obs}}^2 \quad \mu \int_{\text{Corona}} B^2 \, dV
\]

Nice properties of this regularization:

- makes the use of photospheric \( B \) observation as boundary condition
- reproduces standard potential \( B \) if \( \text{div}-\text{term} \) alone is minimized
Conclusion

- We can produce 3D reconstruction of electron density almost for any period of COR1 observations in routine way.

- It was found evidence of streamer blow out during CME event on June 1st 2008 – it is not LOS effect.

- Streamer mass loss for slow CME on 1st June 2008 is $9 \times 10^{14}$ gram which is comparable with the CME mass in COR1 field of view.

- After the CME the coronal magnetic field came to the nearly potential configuration.

- Vector tomography based on spectropolarimetric observations has a possibility to reconstruct the non-potential field that could lead to CME eruption.