TIME DEPENDENT TOMOGRAPHIC RECONSTRUCTION OF THE SOLAR CORONA

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ABSTRACT

The distribution of the electron density in the corona is crucial to advance the knowledge in understanding the nature of solar coronal phenomena. The classical reconstruction of the electron density of the solar corona shows some deficiencies, since it considers a corona stationary over time.

Here we present a new time dependent tomography method by adding spatial, temporal and co-rotating regularization into the minimization problem.
(1) We test the method on a simulated 3D MHD model, which includes a temporal evolution.The normalized error between the model and the reconstruction is then computed to estimate the quality of the reconstruction.
(2) We estimate the electron density of the corona using the solar coronagraph LASCO-C2 images.

1. SOLAR DATA

The coronagraph LASCO-C2 onboard the SOHO satellite provides up to 4 sets of polarized images per day. To estimate the electron density of the corona we use the Polarized Brightness images (pB), which are dominated by Thompson Scattering. Caracteristics of the images employed in this work:

- ▶ Field of View: from 2 $R_\odot$ to 6 $R_\odot$.
- ▶ Time Period: from Mar. 15 to 29, 2009 (=14 days).
- ▶ Nb. of images: 53.

These images have been also calibrated and processed to remove noise such as Cosmic Rays.

2. SIMULATED DATA

We use a 3D MHD model of the corona from Nov. 21 to Dec. 04, 2008 (=14 days). A 3D model is produces for each day. Then we build pB images with the same caracteristics than LASCO-C2 images.

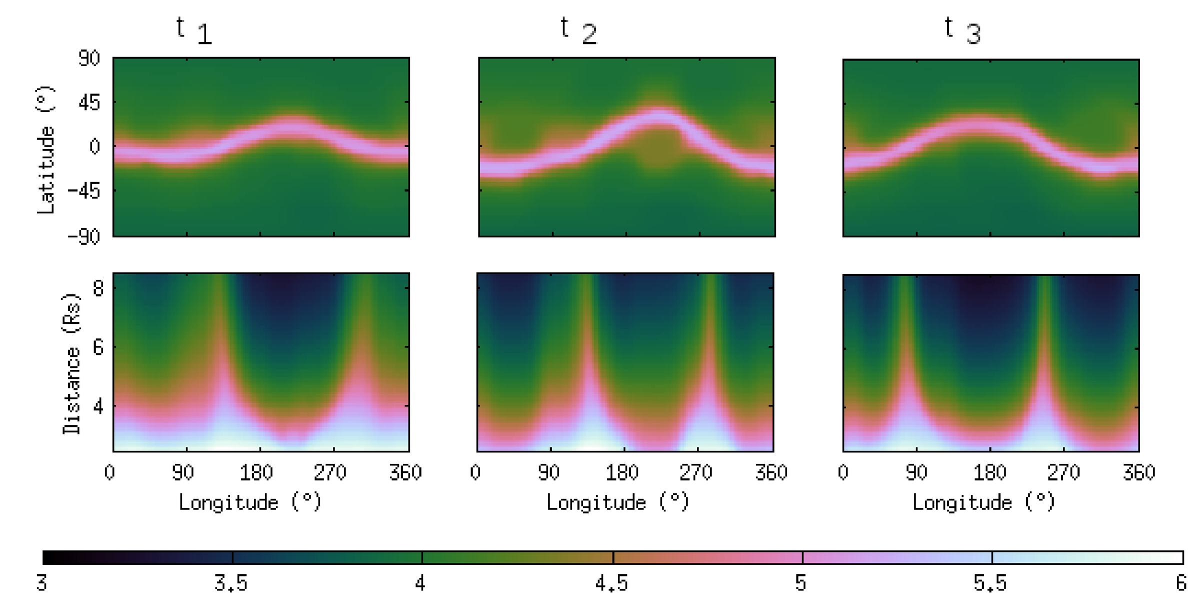

Fig.1: Slices of the model's electron density (N_e in cm^{-3}) in log-scale, for 3 different dates. First row: spherical shell at 4.05 $R_\odot$. Second row: cone at latitude=1.5°.

3. 4D TOMOGRAPHIC RECONSTRUCTION METHOD

We estimate the electron density, $\hat{\mathbf{x}}$, of the corona,

$$\hat{\mathbf{x}} = \underset{\mathbf{x} \geqslant \mathbf{B}}{\operatorname{argmin}} \left\| \begin{pmatrix} \mathbf{y} \\ \mathbf{0} \end{pmatrix} - \begin{pmatrix} \mathbf{A} \\ \mathbf{R} \end{pmatrix} \mathbf{x} \right\|_2^2, \quad (1)$$

where $\mathbf{y}$ contains pixels of all the images, $\mathbf{x}$ contains the bins of the electron density, $\mathbf{R}$ is the regularization matrix and $\mathbf{A}$ is the projection matrix determined by the physics (i.e. the Thomson Scattering) and the geometry of the problem.

(1) Classical reconstruction method:
We use a constraint of positivity: $B = 0$; a spatial regularization: $\mathbf{R} = \lambda_s \mathbf{R_s}$ with λ_s the regularization parameter; and a static projection matrix $\mathbf{A}$. Here $\mathbf{x} = \mathbf{x}(r, \theta, \varphi)$ and therefore we obtain one reconstruction for the selected period of time. (E.g., Frazin, 2000).

(2) New dynamic reconstruction method:
We replace the constraint of positivity by a spherical and radius depended minimum background $B = B(r)$. We add a temporal and co-rotating regularization: $\mathbf{R} = \left(\lambda_s \mathbf{R}_s, \lambda_t \mathbf{R}_t, \lambda_c \mathbf{R}_c\right)^{\mathbf{T}}$. We consider a dynamic projection matrix $\mathbf{A}$. In this case, $\mathbf{x} = \mathbf{x}(r, \theta, \varphi, t)$ so that we obtain a 4D time-dependent reconstruction. (Peillon *et al.*, in prep.).

4. ESTIMATION OF THE REGULARIZATION PARAMETERS

We experimentally estimate the values of the three regularization parameters $(\lambda_s, \lambda_t, \lambda_c)$ by minimising the normalized RMS error.

$$\mathbf{RMS}(\lambda_s, \lambda_t, \lambda_c) = \sum_r \sqrt{\frac{\sum_{\theta,\varphi,t} (\hat{\mathbf{x}}_{\lambda_s,\lambda_t,\lambda_c}(r,\theta,\varphi,t) - \mathbf{model}(r,\theta,\varphi,t))^2}{n_\theta\, n_\varphi\, n_t\, var(r)}}, \quad (2)$$

where $var(r)$ is the variance of the model, n_θ, n_φ and n_r are the number of bins of the spherical grid, and n_t is the number of 3D reconstructions. First we estimate the parameters λ_s and λ_t by minimising eq.2 with $\lambda_c = 0$ (see Fig.2). Then we estimate λ_c by minimising eq.2 with the found λ_s and λ_t (see, Fig.3). We obtain $\lambda_s = 2.2\ 10^{-6}$, $\lambda_t = 1.7\ 10^{-6}$ and $\lambda_c = 0.2\ 10^{-6}$.

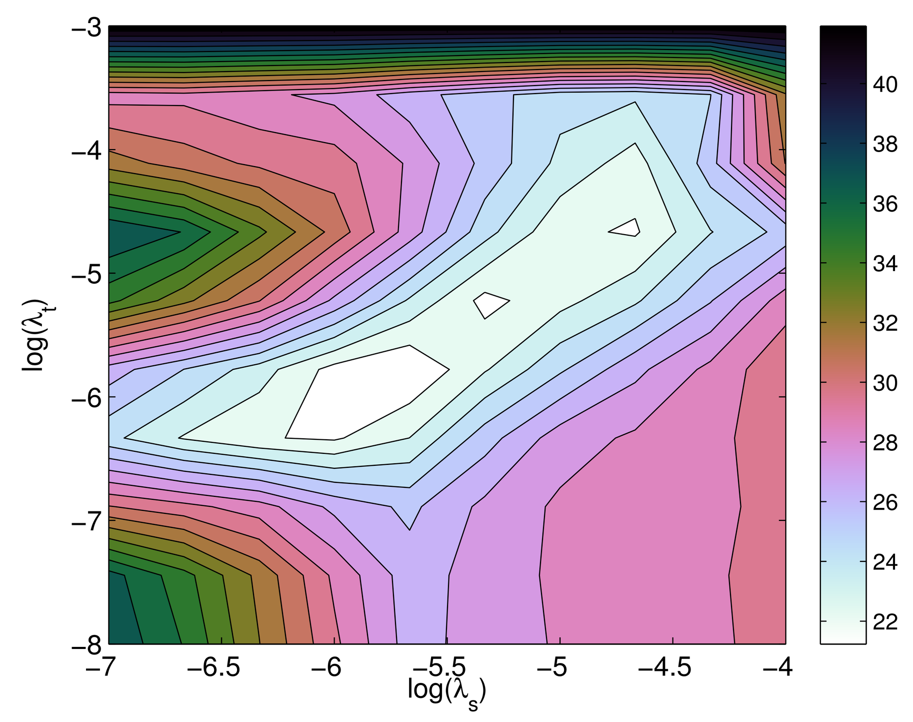

Fig.2: Normalized RMS error estimation (eq. 2) with $\lambda_c = 0$. The minimum is located at $\lambda_s = 2.2\ 10^{-6}$ and $\lambda_t = 1.7\ 10^{-6}$

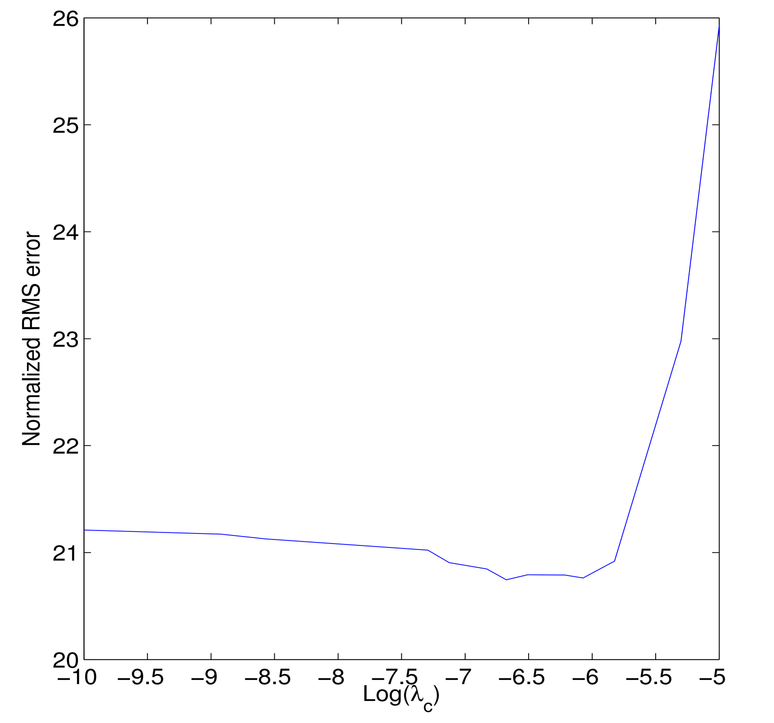

Fig.3: Normalized RMS error estimation (eq. 2) with $\lambda_s = 2.2\ 10^{-6}$ and $\lambda_t = 1.7\ 10^{-6}$. The minimum is at $\lambda_c = 0.2\ 10^{-6}$.

5. TOMOGRAPHIC RECONSTRUCTION FROM SIMULATED DATA

Electron density, N_e, in cm^{-3} of the MHD model is estimated with the classical method and the time dependent method. Fig.4 can be compared with the original model in Fig.1. We see a clear improvement with the new method.

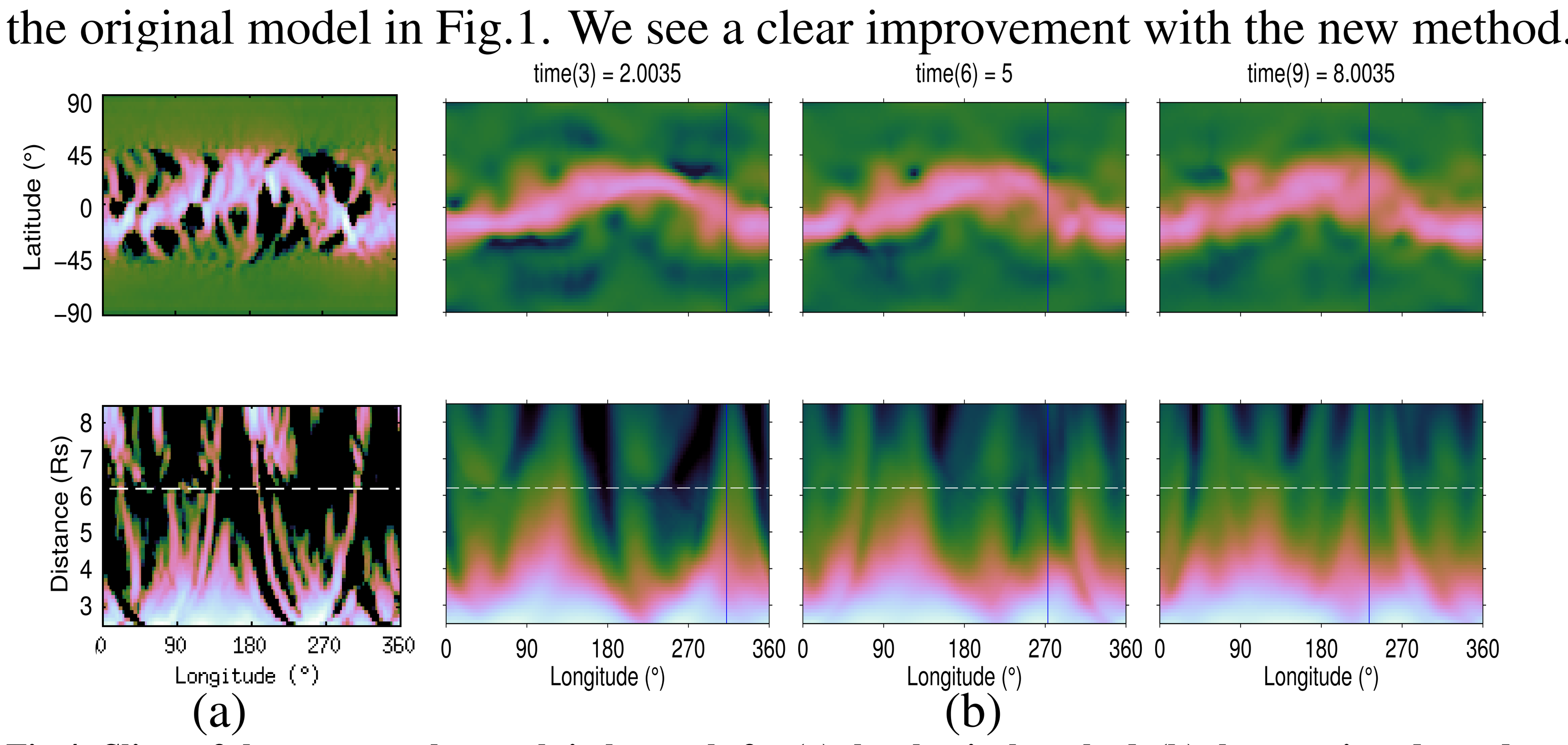

Fig.4: Slices of the tomography result in log-scale for (a) the classical method, (b) the new time dependent method. First row: spherical shell at 4.05 $R_\odot$. Second row: cone defined by latitude=1.5°.

6. TOMOGRAPHIC RECONSTRUCTION FROM SOLAR DATA

Estimation of coronal N_e from LASCO-C2 data with the time dependent method. We can observe that the density maximum is concentrated close to the equator as it is expected for a period of time of low solar activity.

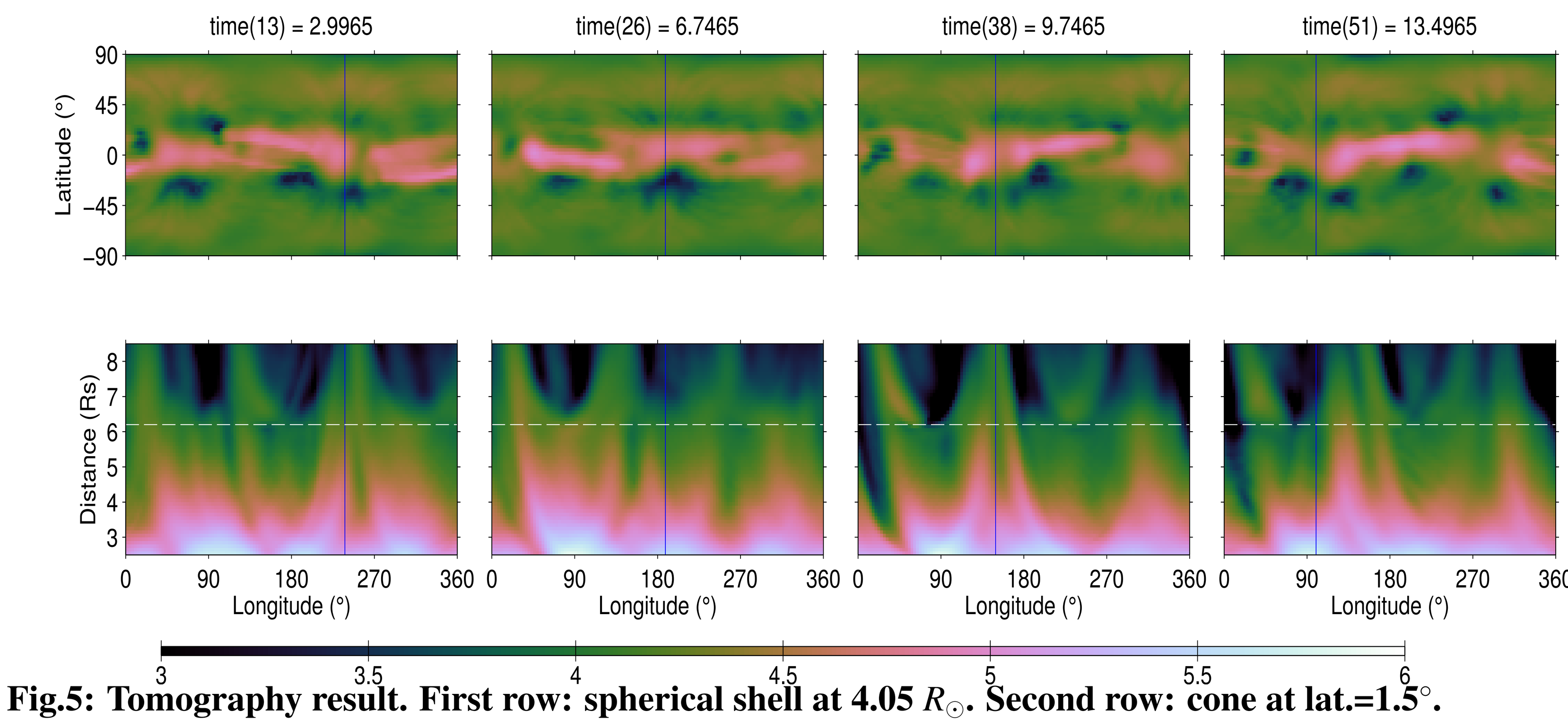

Fig.5: Tomography result. First row: spherical shell at 4.05 $R_\odot$. Second row: cone at lat.=1.5°.

CONCLUSION & REFERENCES

Conclusion: We have established a new time dependent tomographic reconstruction method of the solar corona with a temporal, spatial and co-rotating regularizations, and the minimum background. The regularization parameters have been choosen experimentally by minimising the error between the reconstructed model and the original MHD model. We have shown that for the MHD model, the time dependent reconstruction gives better results than the static reconstruction. Finally We have performed the optimum method on LASCO-C2 images. The results are consistent with a typical corona during the minimum of solar activity.

References:

- ▶ Frazin, R. (2000). *Astrophysical Journal*, 530, 1026-1035.
- ▶ Peillon, C. *et al.* (2014). *Solar Physics*, in prep.

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