Three-Dimensional Tomographic Reconstruction and MHD Modeling of the Low Corona During the Last Solar Minimum

D.G. Lloveras[1], A.M. Vásquez[1], F.A. Nuevo[1], N. Sachdeva[2], W. Manchester IV[2], B. Van der Holst[2], R.A. Frazin[2], P. Lamy[3] and J. Wojak[4]

[1] Instituto de Astronomía y Física del Espacio – CONICET and University of Buenos Aires, Argentina.
[2] Department of Climate and Space Sciences and Engineering – University of Michigan (USA).
[3] Laboratoire Atmosphéres, Milieux et Observations Spatiales, CNRS & UVSQ, Guyancourt, France.
[4] Aix Marseille Université, CNRS, Centrale Marseille, Institut Fresnel, Marseille, France.

Summary

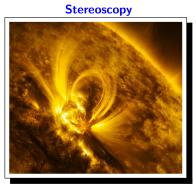
Interest in predicting space weather conditions constantly pushes the advance of state-of-the-art of three-dimensional (3D) magnetohydrodynamic (MHD) models of the solar corona and the solar wind, which need to be validated with observational data. Tomography of the solar corona is the only observational technique that can currently provide a 3D empirical description of the solar atmosphere in a global fashion. In this work we carry out a validation study of the latest version of the Alfvén-Wave driven sOlar wind Model (AWSoM), comparing its results with tomographic reconstructions of physical parameters of the solar corona. For this analysis, we select a rotation from the recent deep minimum of solar activity (CR-2223), between solar cycles 24 and 25, which renews the opportunity to study the Sun-Earth connection under the simplest solar and space environment conditions. Based on narrow band EUV coronal images provided by the SDO/AIA instrument, we carry out tomographic 3D reconstruction of the coronal electron density and temperature in the range of heliocentric heights $\approx 1.0 - 1.25\ \mathrm{R}_\odot$. Based on polarized visible brightness (pB) coronagraph images provided by the SoHO/LASCO-C2 instrument, we carry out tomographic 3D reconstruction of the coronal electron density in the range of heliocentric heights $\approx 2.5 - 6.0\ \mathrm{R}_\odot$. We validate both the reconstructions and the model by computing synthetic images and comparing them with the actual data. We compare the AWSoM model with the tomographic reconstructions and discuss its capability to reproduce the reconstructions.

What is Solar Tomography?

2D versus 3D

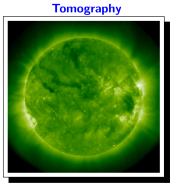
- The corona is optically thin in the UV, EUV, X, WL ranges. Images are thus 2D projections of the underlying 3D emitting structure.
- Advancement of physical models is in need of 3D information of the coronal fundamental parameters **B**, N_e, T_e.

Stereoscopy



By studying the 2D shape of EUV loops from 2 view points it triangulates the 3D geometry of the "frozen-in" magnetic field.

Tomography



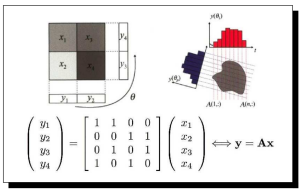
By inverting for the 3D EUV emissivity from time series of images it allows inferring the 3D N_e and T_e of the global corona.

Tomography

Unknown: 3D distribution of a certain quantity $\mathbf{x}_i$ (e.g. N_e) for each cell volume i within an object (e.g. the solar corona), under optically thin regime (e.g. coronal white light)

Knowns:

- Intensity vector $\mathbf{y}_j$: measured in each pixel j of each image in a time series taken from different view angles.
- *Proyection* matrix $\mathbf{A}_{ji}$: depending on the geometry (e.g. solar rotation, telescope orbit) and the involved physical process (e.g. Thomson scattering).

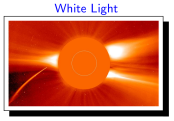


Solar Rotational Tomography (SRT)

The solar rotation provides the needed 360° view angles.

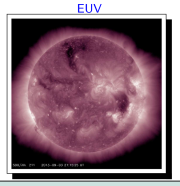
- Corona-K: Thomson scattering of photospheric white light (WL).
- SRT-WL → 3D N_e.
- 1st SRT-WL: Altschuler & Perry (1972)

White Light

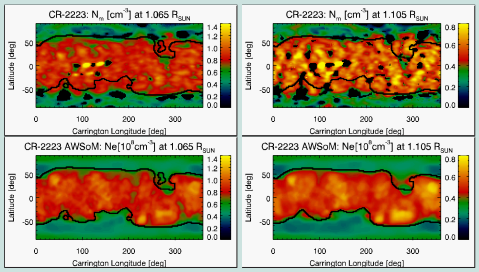


- Corona-E: True coronal emission by ions UV, EUV y X.
- SRT-EUV → 3D EUV emissivity → 3D Differential Emission Measure → 3D N_e y T_e
- 1st SRT-EUV (DEMT): Frazin, Vásquez & Kamalabadi (2009)

EUV

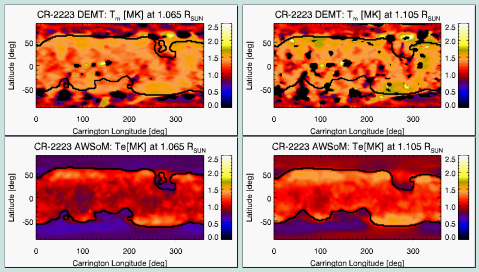


N_e: DEMT versus AWSoM



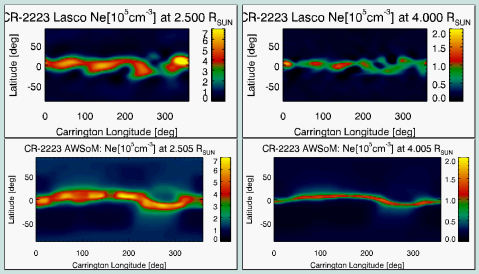
Latitude/longitude maps of N_e at two sample heights from **DEMT** (top) and **AWSoM** (bottom).

T_e: DEMT versus AWSoM



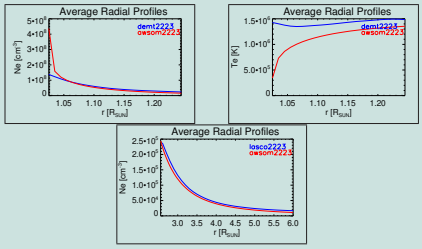
Latitude/longitude maps of T_e at two sample heights from **DEMT** (top) and **AWSoM** (bottom).

N_e: SRT-WL versus AWSoM



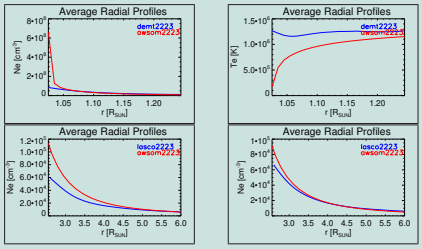
Latitude/longitude maps of N_e at two sample heights from **SRT-WL** (top) and **AWSoM** (bottom).

Streamer Average Radial Profiles



$N_e(r)$ and $T_e(r)$ from **DEMT** and **AWSoM** (top).
$N_e(r)$ from **SRT-WL** and **AWSoM** (bottom).

CHs Average Radial Profiles



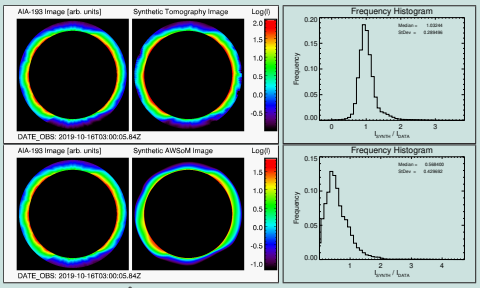
$N_e(r)$ and $T_e(r)$ from **DEMT** and **AWSoM** (top).
$N_e(r)$ from **SRT-WL** and **AWSoM** (bottom),
in the **North CH** (left) and **South CH** (right).

Conclusions

- Using AIA images (in 171, 193 and 211Å) we carried out the tomographic reconstructions of both the coronal N_e and T_e, in the range of heights $\approx 1.0 - 1.25\ \mathrm{R}_\odot$. Using LASCO-C2 images, we carried out the tomographic reconstructions of the coronal N_e, in the range of heights $\approx 2.5 - 6.0\ \mathrm{R}_\odot$. We ran a steady-state simulations using the AWSoM model.
- The characteristic values of N_e and T_e in the AWSoM model are consistent with the tomographic reconstrucions.
- **Streamer:** within the FoV of AIA the model $N_e(r)$ agrees very well with the tomographic reconstructions, while the model $T_e(r)$ is $\approx$ 15% smaller than in the reconstructions. **HCS:** within the FoV of LASCO-C2, the model $N_e(r)$ agrees very well with the reconstructions.
- **CHs:** within the FoV of AIA the model $N_e(r)$ agrees very well with the tomographic reconstructions, while the model $T_e(r)$ is $\approx$ 15% smaller than in the reconstructions. Within the FoV of LASCO-C2, the model tends to over estimate $N_e(r)$ and underestimate its scale height.
- As a test for both the tomographic reconstructions and the AWSoM model, we synthesize images from both and compare them with the AIA and LASCO-C2 data. The tomographic reconstructions are able to reproduce the images with much finer detail than the model.
- An upcoming publication will include a detailed analysis for both CR-2223 and CR-2219, similar to Lloveras et al. (2020), Sol.Phys. 295, 76.

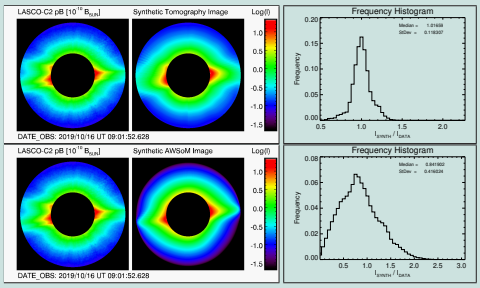
Contact: dlloveras@iafe.uba.ar

EUV Images: Data versus Synthetic



Left: AIA-193Å and corresponding synthetic image from **Tomography** (top) and from the **AWSoM** model (bottom).
Right: Corresponding intensity-ratio histograms.

WL Images: Data versus Synthetic



Left: LASCO-C2 and corresponding synthetic image from **Tomography** (top) and from the **AWSoM** model (bottom).
Right: Corresponding intensity ratio histograms.