Planning Solar Corona Tomography with SolO/Metis

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Summary

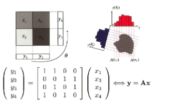
The Metis coronagraph, on board the Solar Orbiter (SolO) mission, records full-Sun images of the solar corona in Lyman-α ultraviolet (UV) radiation and in visible light polarized brightness (pB). The range of heliocentric heights covered by the field of view (FoV) of Metis changes as a function of the SolO position along its highly eccentric orbit. Also, as the angular velocity of SolO around the Sun changes along its orbit, so it does the time required to observe the Sun from different view angles. We explore the use of Metis pB-images for tomographic reconstruction of the three-dimensional (3D) distribution of the coronal electron density. Using the orbital information of SolO we compute synthetic images of the solar corona based on a steady-state run of the 3D-MHD Alfvén-Wave driven sOlar wind Model (AWSoM) model. We use these images as data for tomographic reconstructions. We carry out these simulations for an aphelion and a perihelion. The range of heights of the solar corona that can be tomographically reconstructed ranges from $\approx 2.3-3.2\ \mathrm{R}_\odot$ at perihelion, up to $\approx 5.8-10.2\ \mathrm{R}_\odot$ at aphelion. Also, the required data acquisition period ranges from 13 to 22 days, at aphelion and perihelion, respectively. We conclude that a Metis observational synoptic program of 4 images/day will provide enough data to carry out tomography with Metis images at any point along the SolO orbit.

What is Solar Tomography?

Unknown: 3D distribution of a certain quantity 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 y_j: measurement in each pixel j of each image of a time-series providing different view angles.
- *Projection* matrix A_{ji}: depending on the geometry (e.g. solar rotation, telescope orbit) and the involved physical process (e.g. Thomson scatt.).



- Solar Rotational Tomography: solar rotation provides the view angles.
- A is a very large sparse matrix, *global optimization* of *objective function*:

$$f(\mathbf{x}) = \|\mathbf{y} - \mathbf{A}\cdot\mathbf{x}\|^2 + \text{regularization terms}$$

Visible Light (VL) Tomography and N_e

$$pB \propto \int_{\mathrm{LOS}} \mathrm{d}l\ w(l)\ N_e(l)$$

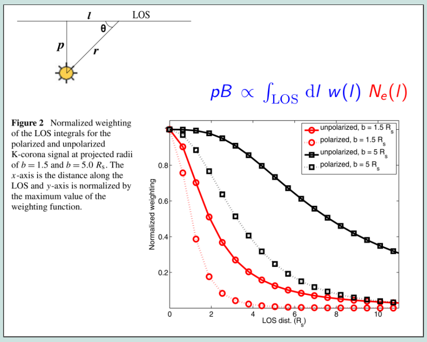
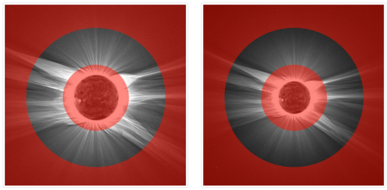


Figure 2 Normalized weighting of the LOS integrals for the polarized and unpolarized K-corona signal at projected radii of $b = 1.5$ and $b = 5.0\ R_s$. The x-axis is the distance along the LOS and y-axis is normalized by the maximum value of the weighting function.

Metis VL Tomography

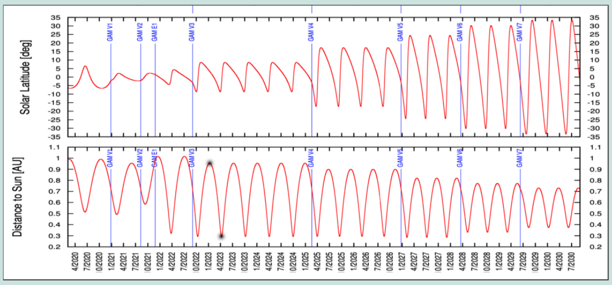
- Highly-eccentric orbit $\rightarrow$ changing radial FoV in the observational sequence.



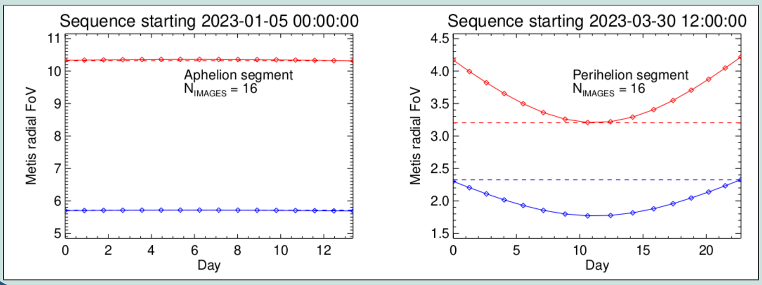
METIS FOV at $D = 0.3$ au (left) and $D = 0.4$ au (right).

- Non-constant cadence is required to achieve a $\approx$ uniform Carrington longitude step between consecutive images.

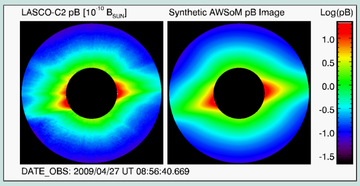
SolO Orbit



Aphelion and Perihelion Image Time-Series: FoV-versus-Time

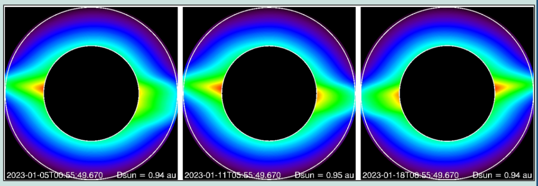


Model Validation



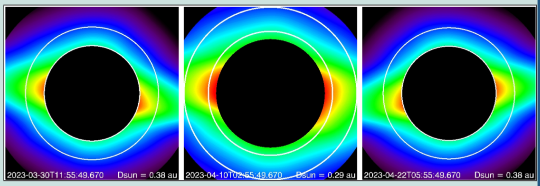
LASCO-C2 versus Synthetic Image.
Based on the AWSoM model for CR-2082.

Aphelion Metis Synthetic Images



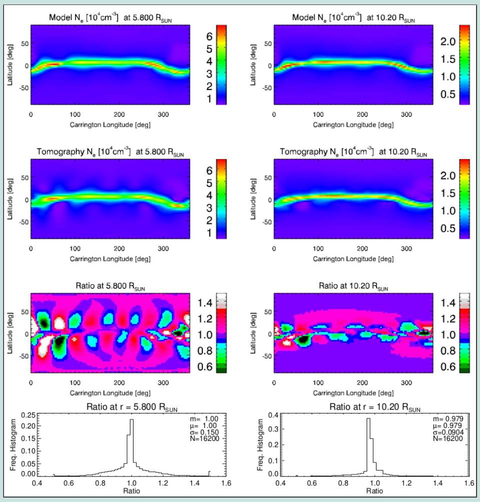
First, middle and last image of the aphelion time-series.
The white circles indicate the radial FoV $5.7-10.3\ \mathrm{R}_\odot$.

Perihelion Metis Synthetic Images



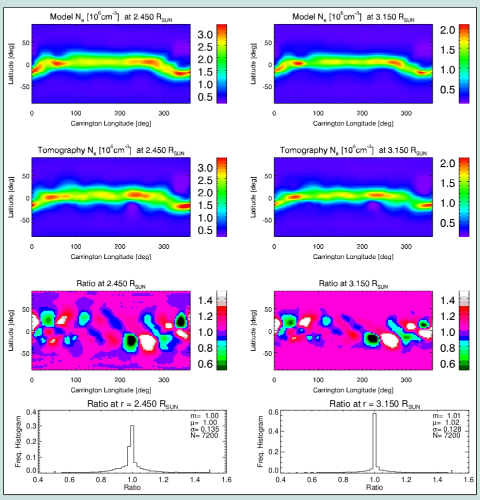
First, middle and last image of the perihelion time-series.
The white circles indicate the radial FoV $2.3-3.2\ \mathrm{R}_\odot$.

Aphelion Tomography



Latitude/longitude maps of the N_e of the model and the tomographic reconstruction (and their quantitative comparison) near the inner and outer heliocentric height of the radial FoV of the aphelion image sequence.

Perihelion Tomography



Latitude/longitude maps of the N_e of the model and the tomographic reconstruction (and their quantitative comparison) near the inner and outer heliocentric height of the radial FoV of the perihelion image sequence.

Conclusions

- Aphelion segment: image sequence is gathered over a period of ≈ 13 days. The range of heights over which N_e can be reconstructed is $\approx 5.7-10.3\ \mathrm{R}_\odot$.
- Perihelion segment: image sequence is gathered over a period of ≈ 22 days. The range of heights over which N_e can be reconstructed is $\approx 2.3-3.2\ \mathrm{R}_\odot$.
- The mean observational cadence in these simulations ranges from ≈ 1.2 images/day (aphelion segment) to ≈ 0.7 images/day (perihelion segment).
- Over the ranges of height specified above, the reconstructed density differs from the model by less than 10% throughout $\approx 80\%$ of the coronal volume.
- Based on our results, a Metis observational synoptic program of 4 images/day should provide enough data to carry out tomographic reconstructions of the solar corona along the full orbit of SolO. These results are soon to be published in Solar Physics.
- As a next step we plan to implement tomography based on Metis HI Lyman-α images. In combination with Metis VL tomography, this will in principle allow to derive 3D maps of the Lyman-α Doppler dimming term.

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