Solar Rotational Tomography of the Corona with Latest Instrumentation

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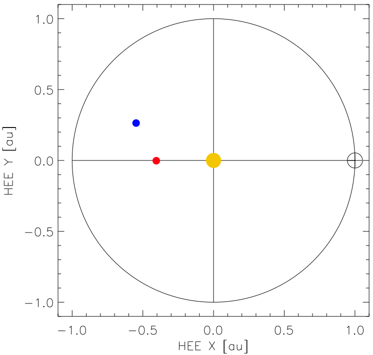
Outline

- **Solar rotational tomography (SRT)** uses sequences of coronal images to determine the 3D distribution of coronal physical parameters (N_e, T_e, see **Poster**).
- WL images are a direct diagnostic of the coronal $N_{\rm e}$ along the LOS. SRT-WL allows determination of the 3D coronal $N_{\rm e}$.
- The **SOLO/Metis** coronagraph records WL and Lyman-α images.
  - SRT can be used for reconstruction of N_e and Doppler-dimming term.
  - Its highly eccentric orbit implies a varying range of observed heights.
  - The synoptic Metis images can be used for tomography during most of its planned orbit **Vasquez et al. (2022)**.
- The **MLSO/UCoMP** coronagraph records images in optical emission lines.
  - SRT can be applied for reconstruction of their 3D coronal emissivity.
  - This can be used for 3D diagnostics, such as line-ratio N_e.
- Here we show first results of SRT applied to both Metis and UCoMP data.

A Superior Conjunction of SOLO and SOHO



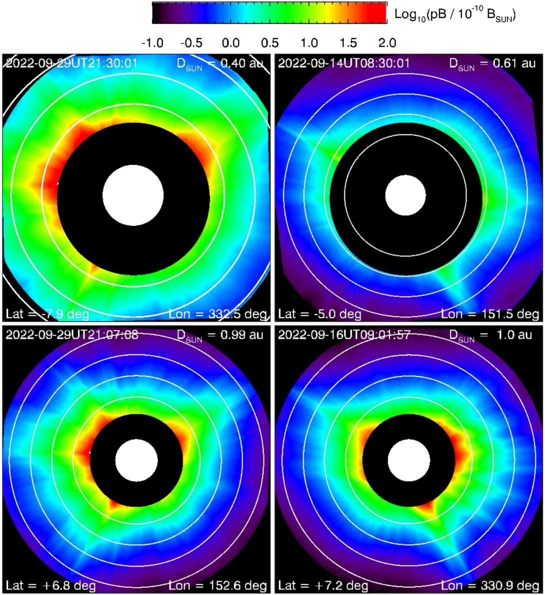
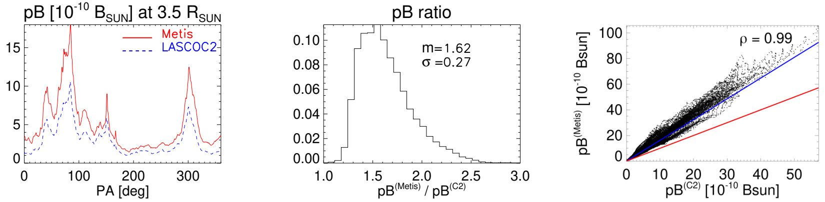


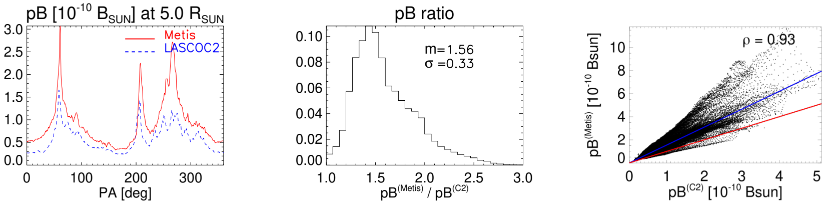
Image Pair Name: Dates (Metis and LASCO-C2)	Δ Lon [deg]	Σ Lat [deg]	Δt [h]
A: 2022-Sep-29 and 2022-Sep-29	−179.9	−1.1	− 0.4
B: 2022-Sep-14 and 2022-Sep-16	+179.4	+2.2	+48.5

Comparison of Metis and C2 Images

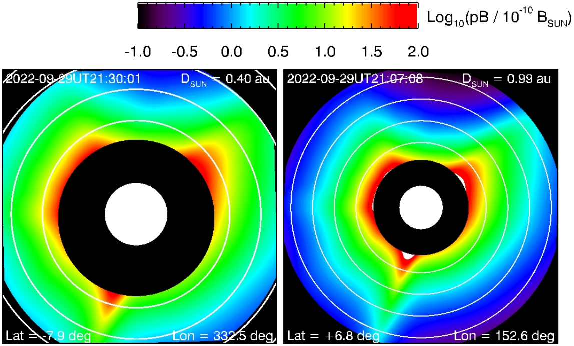
Superior Conjunction: Median $\left(pB^{(\mathrm{Metis})} / pB^{(\mathrm{C2})}\right) \approx 1.62$

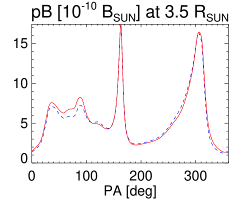


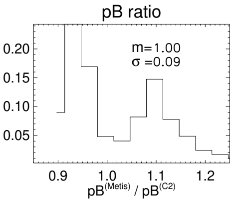
Two Days Apart: Median $\left(pB^{(\mathrm{Metis})} / pB^{(\mathrm{C2})}\right) \approx 1.56$

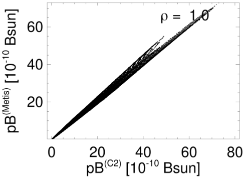


Synthetic Images from 3D-MHD Simulation





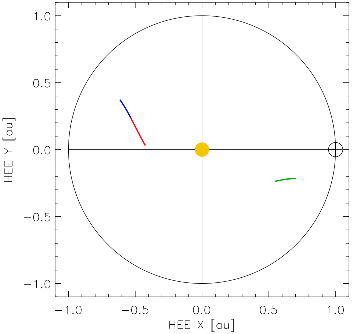




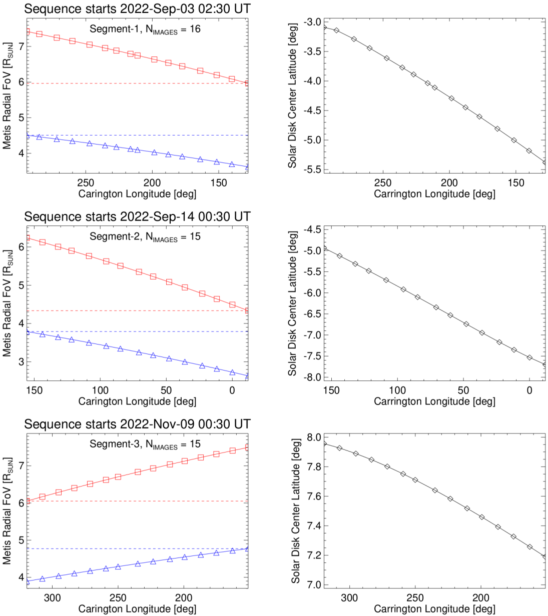
SRT with Metis WL Images

- SRT has been applied to data from both ground-based (e.g. MLSO/KCOR) and space-borne (SOHO/C2) instruments, from $\approx 1\,\mathrm{AU}$ (nearly) circular orbits.
- C2 images (1996-present) with **Lamy et al. (2020)** best-to-date calibration are available at the C2 Legacy Archive (`http://idoc-lasco.ias.u-psud.fr`).
- In the case of Metis, the high eccentricity of the SOLO orbit implies that the FoV of the images is a function of the orbital position.
- Orbital analysis of SOLO/Metis shows that its synoptic program allows for continuous SRT reconstruction of the coronal N_e (**Vasquez et al. 2022**).
- Here we show first tomographic reconstructions carried out with Metis images, and their comparison with C2 tomography.

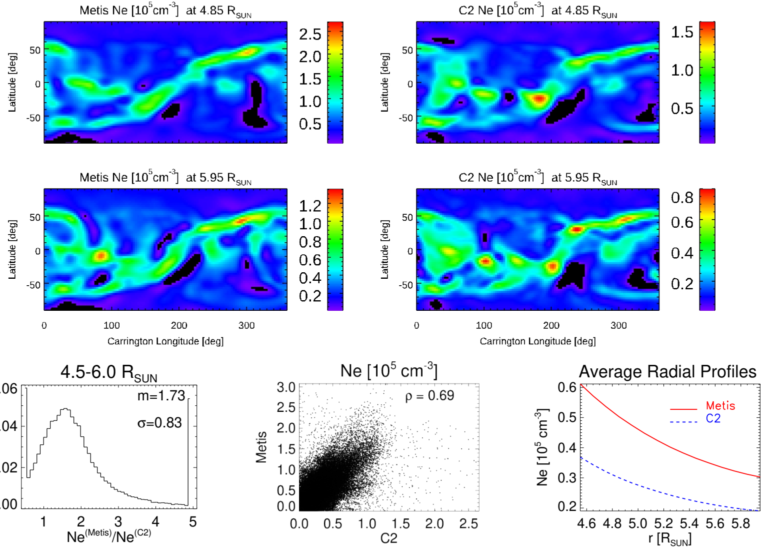
Three SOLO Orbital Segments During 2022



Sequence No.	Date range	Interval [days]	D_{SUN} [AU]	Lat [deg]	ΔLon [deg]	FoV [$R_\odot$]
Metis:						
1	Sep. 03 to 17	13.2	0.73 to 0.57	−3.1 to −5.4	166.5	4.5 – 6.0
2	Sep. 14 to 29	14.4	0.62 to 0.42	−5.0 to −7.7	167.6	3.8 – 4.3
3	Nov. 09 to 23	13.3	0.59 to 0.74	+7.9 to +7.2	168.5	4.8 – 6.0
C2:						
1	Sep. 03 to 16	13.0	1.00 to 1.00	+7.2 to +7.2	178.0	2.3 – 6.3
2	Sep. 14 to 27	13.0	1.00 to 0.99	+7.2 to +6.9	171.6	2.3 – 6.3
3	Nov. 09 to 22	12.8	0.98 to 0.98	+3.5 to +2.0	168.1	2.2 – 6.2

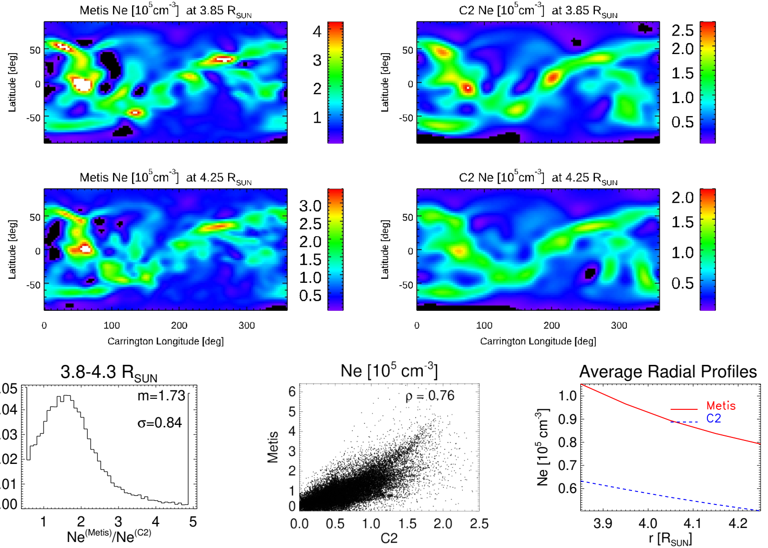


Segment-1: Metis and C2 Reconstructions of N_e



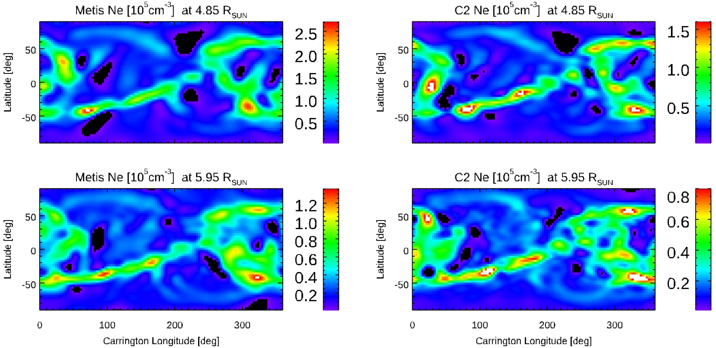
$$\text{Median}\left(N_e^{(\text{Metis})}/N_e^{(\text{C2})}\right) \approx 1.73$$

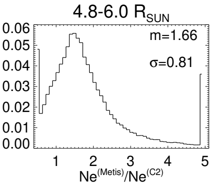
Segment-2: Metis and C2 Reconstructions of N_e

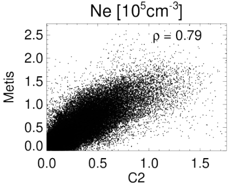


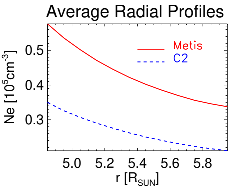
$$\text{Median}\left(N_e^{(\text{Metis})}/N_e^{(\text{C2})}\right) \approx 1.73$$

Segment-3: Metis and C2 Reconstructions of N_e







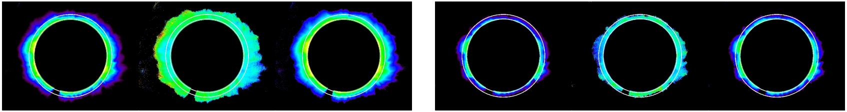


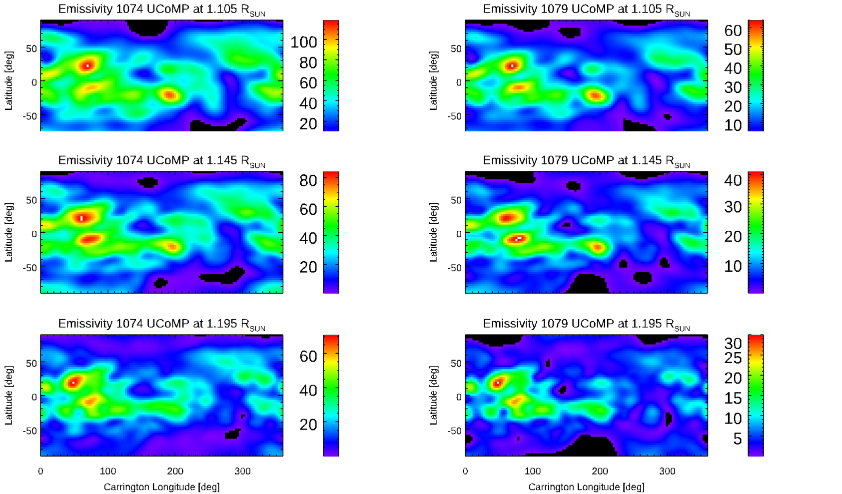
$$\text{Median}\left(N_e^{(\text{Metis})}/N_e^{(\text{C2})}\right) \approx 1.66$$

Comments on Metis versus C2

- The Metis FoV varies from $\approx 5.8 - 10.2\ R_\odot$ at its maximum aphelion ≈ 1 AU, down to $\approx 1.7 - 3.0\ R_\odot$ at its minimum perihelion ≈ 0.28 AU, nearly always overlapping siginificantly the C2 FoV ($\approx 2.5 - 6.0\ R_\odot$).
- Comparison of Metis and C2 WL images: Median $\left(pB^{(\mathrm{Metis})} / pB^{(\mathrm{C2})} \right) \approx 1.6$.
- Comparison of Metis or C2 tomography: Median $\left({N_\mathrm{e}}^{(\mathrm{Metis})} / {N_\mathrm{e}}^{(\mathrm{C2})} \right) \approx 1.7$.
- The systematic discrepancy is not due to lack of perfect opposition and/or simultaneity, nor different distances to Sun, but to calibration procedures. A thorough comparison analysis is under way (**Burtovoi et al. 2024**).
- Tomography may aid instrumental intercalibration: while the images obtained by an instrument greatly depend on its location, the reconstructed density does not.
- This research was recently submitted to *Solar Physics* (**Vasquez et al. 2024 a,b**).

SRT with UCoMP 1074 & 1079: 3D Emissivity

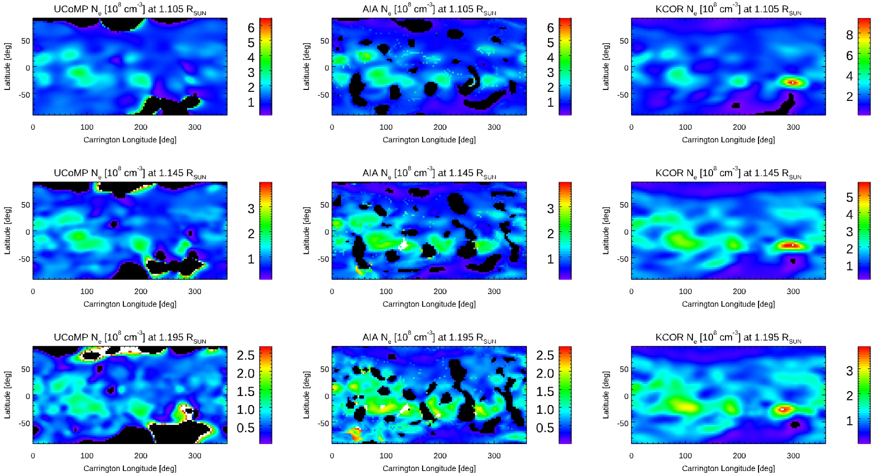




3D-Density Reconstruction with Three Diagnostics

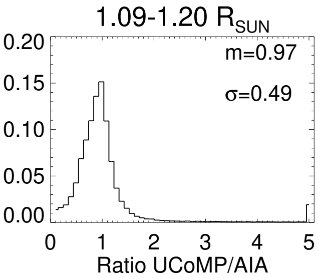
September 2022 Simultaneous Tomography with three different instruments

UCoMP 1074/1079 | SRT-AIA | SRT-KCOR

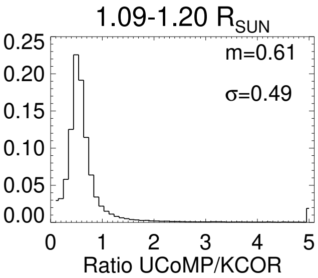


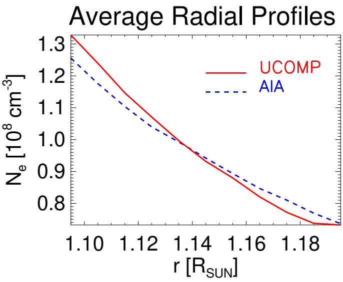
Comparison of Reconstructed Density

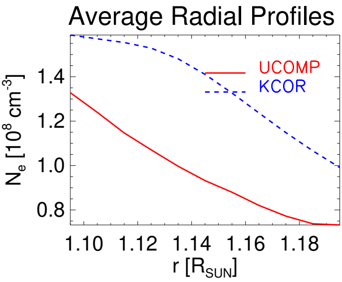
UCoMP versus AIA



UCoMP versus KCOR







Comments on UCoMP versus AIA versus KCOR

- Emission lines to which UCoMP and AIA are sensitive are produced by Fe ions.
- The UCoMP-SRT N_e is independent of $[\mathrm{Fe}]$, while SRT-AIA $N_e \propto 1/\sqrt{[\mathrm{Fe}]}$. Comparison of their reconstructed N_e can in principle provide constraints on the 3D distribution of $[\mathrm{Fe}]$, as well as the coronal filling factor affecting emission lines.
- The significantly larger SRT-KCOR N_e compared to SRT-AIA N_e has been consistently found for other periods (**Lloveras et al. 2019**). Discrepancy can be due to calibration issues, coronal $[\mathrm{Fe}]$, and/or coronal filling factor.

Final Remarks

- As new coronagraphs becomes available, opportunities for development and application of SRT arise.

- Metis simultaneously records WL and Lyman-α. Their combined SRT products can provide 3D constraints on the wind speed. The concept was probed with synthetic images from 3D-MHD simulations of the solar corona (see **Poster**).

- UCoMP images expand SRT 3D diagnostics. Multi-instrument tomography with:
  - ▷ **SDO/AIA** $\rightarrow$ 3D filter band emissivity in $1-4$ MK EUV bands.
  - ▷ **MLSO/KCOR** $\rightarrow$ 3D N_e.
  - ▷ **MLSO/UCoMP** $\rightarrow$ 3D emissivity in $1-3$ MK visible Fe lines.

  Joint analysis of all SRT products over common FoV $\approx 1.1-1.2\ R_\odot \rightarrow$ 3D $N_\mathbf{e}, T_\mathbf{e}, \sigma_N, \sigma_T, [\mathrm{Fe}]$.

Thanks so much for having me!