Tomography of the Solar Corona with Multiple Instruments: First Steps

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Resumen / La tomografía solar rotacional es una técnica observacional de la corona solar que permite la reconstruccion de la distribución tri-dimensional (3D) global de algunos de sus parámetros fundamentales, como por ejemplo la densidad electrónica. Aplicada a imágenes de luz blanca, los resultados de densidad electrónica son de naturaleza absoluta, mientras que utilizando datos en extremo ultravioleta (EUV) los resultados dependen de la abundancia de hierro coronal. La tomografía basada en EUV es aplicada regularmente a datos obtenidos con telescopios espaciales, cubriendo típicamente el rango de alturas heliocéntricas $1.02-1.25$ $R_\odot$. Este rango solapa parcialmente el del campo de visión del coronógrafo de luz blanca K-coronagraph (KCOR), en el High Altitude Observatory (HAO), que cubre el rango $1.05-3.0$ $R_\odot$. En este trabajo presentamos resultados preliminares de la primer comparación de una reconstrucción de la densidad electrónica coronal obtenida utilizando imágenes EUV con la obtenida utilizando imágenes en luz blanca. Este es un primer paso hacia el desarrollo de una técnica de tomografía multi-instrumental. Esta técnica tendrá por objetivo el reconstruir la distribución 3D de diversos parámetros coronales en forma simultánea, a través del análisis conjunto de resultados tomográficos basados en datos provistos por diversos instrumentos, incluyendo coronógrafos de luz blanca, telescopios EUV y coronógrafos de lineas de emisión coronal en el rango visible.

Abstract / Solar rotational tomography is an observational technique of the solar corona that allows reconstruction of the global three-dimensional distribution of some of its fundamental physical parameters, such as electron density. Applied to white light data, density results are of an absolute nature, while applied to extreme ultraviolet (EUV) data they scale with the iron abundance. EUV tomography is routinely applied to data provided by space-borne telescopes, typically covering the range of heliocentric heights $\approx 1.02-1.25$ $R_\odot$. This range partially overlaps that of the field of view of the white light K-coronagraph (KCOR) instrument, at the High Alitude Observatory (HAO), which covers the range $\approx 1.05-3.0$ $R_\odot$. In this work we show preliminary results of the first comparison of a tomographic reconstruction of the coronal electron density based on EUV iages against that reconstructed based on white light images. This is a first step towards implementation of a multi-instrument tomography technique. This method will aim at simultaneously reconstructing the 3D distribution of different coronal parameters through joint analysis of tomographic results based on data provided by multiple instruments, including white-light coronagraphs, EUV telescopes and visible emission line coronagraphs.

Keywords / Sun: corona — Sun: fundamental parameters — Sun: UV radiation — Sun: abundances

1. Introduction

Solar rotational tomography (SRT) was initially developed by Altschuler & Perry (1972) for reconstruction of the three-dimensional (3D) distribution of the coronal electron density based on white light (WL) data. Frazin (2000) and Frazin & Janzen (2002) developed a modern, robust, regularized, positive method for tomographic inversion of the coronal electron density from WL data, used in this work. A thorough review on WL tomography can be found in those references.

More recently, Frazin et al. (2009) developed the differential emission measure tomography (DEMT) technique. DEMT combines EUV tomography in several passbands with local DEM analysis, to reconstruct the 3D distribution of both the coronal electron density and temperature. A recent review by Vásquez (2016) summarizes the existing solar physics literature based on DEMT analysis. More recent DEMT-based works include Lloveras et al. (2017), who carried out a comparative analysis of the coronal structure at the solar minima between solar cycles (SC-) 22/23 and 23/24, and Mac Cormack et al. (2017), who analyzed the energy flux requirements at the coronal base in the quiet sun corona in order to sustain stable structures. The existing DEMT literature has made use of the data provided by several spaceborne EUV telescopes. The latest generation one is the Atmospheric Imaging Assembly (AIA) instrument, on board the Solar Dynamics Observatory (SDO).

While the electron density determined by WL tomography is of an absolute nature, that obtained from EUV tomography is dependent on the assumed iron coronal abundance. Also, while EUV tomography is affected by the so-called coronal flling factor, the WL tomographic results are not. No comparison had been

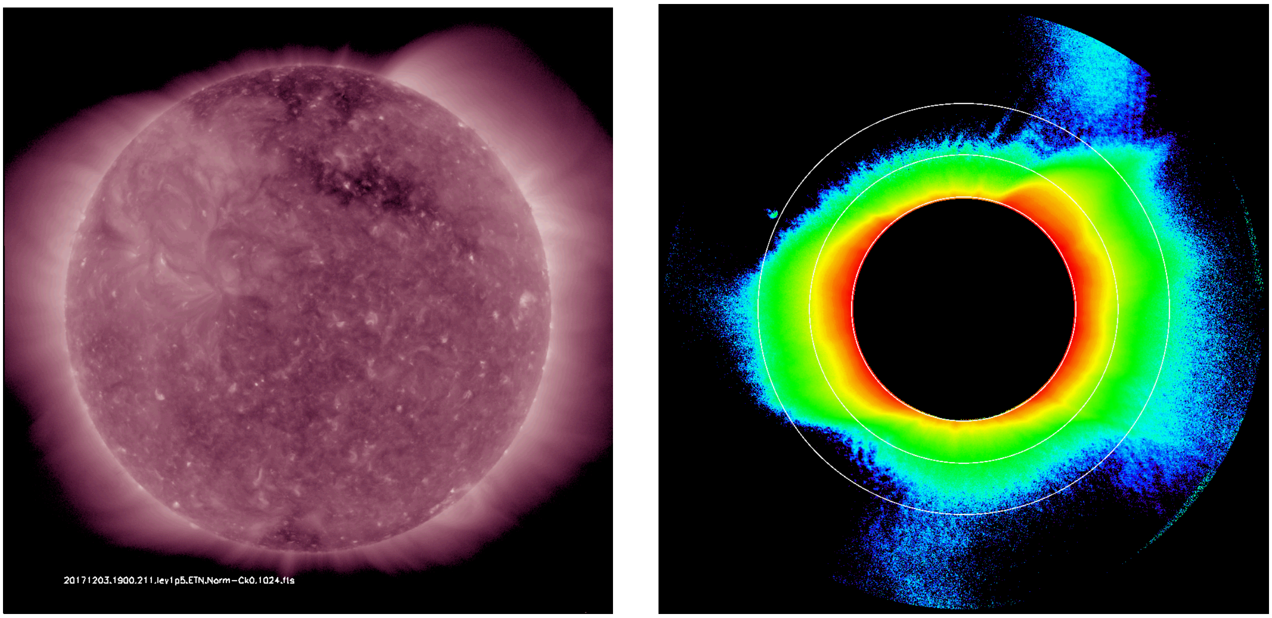

Figure 1: Example of images used for tomographic reconstruction of the coronal electron density of CR-2198 (see text), both corresponding to 2017 December 03 UT 18:00-19:00. Left panel: SDO/AIA coronal EUV image in the 211 Å band. Right panel: HAO/KCOR coronal pB image, with white rings indicating heliocentric heights $1.09, 1.50, \text{and}\, 2.0\ \mathrm{R}_\odot$.

yet carried-out between results obtained with both techniques. In this work, and for the first time, the tomographic reconstruction of the coronal electron density for a given period is carried out using both methods and their results are compared.

2. Data and Methodology

Carrington rotation (CR-) 2198 (2017, December 03 UT 14:37 through December 30 UT 22:25) was selected as target for analyis. This was a relatively quiet rotation in the declining activity phase of SC-24. Low latitudes were dominated by the equatorial streamer belt, high latitudes by polar coronal holes (CHs), and a complex of several ARs was located in the longitude range $\approx 80^\circ - 200^\circ$.

For the selected rotation, KCOR and AIA images were obtained for the period 2017, December 03 through December 17, allowing to observe the off-limb corona at all Carrington longitudes. In the case of AIA, images for all the coronal bands $171, 193, \text{and} 211$ Å are obained every 1 hr, and processed with our own tomography-preprocessing tools, which make use of the SolarSoft AIA software in its latest version. In particular, images are averaged over 6 hr long bins, so that a total of about 55 images are used in the end. In the case of KCOR we requested to the HAO team one 10-minute average coronal polarized brightness (pB) image for each day, obtained using its best observational window.

Figure 1 shows examples of the coronal images used for this work. The left panel shows an AIA coronal EUV image taken in its 211 Å band. The right panel shows a KCOR coronal pB WL image. Both images were taken nearly-simultaneously on 2017 December 03 UT 18:00-19:00. This is roughly the beginning of CR-2198, so the longitude of the disk center in these images is $\approx 0^\circ$, and the ARs aforementioned is not seen here, and the images are dominated by the quiet sun streamer belt and the CHs.

3. Results

Figure....

4. Conclusions and future efforts

- $E_{\rm EUV} \propto \left\langle N_e^2 \right\rangle = f\ \left\langle N_e \right\rangle^2$, where filling factor is defined as $f \equiv \left\langle N_e^2 \right\rangle / \left\langle N_e \right\rangle^2$
- $E_{\rm WL} \propto \left\langle N_e \right\rangle$
- Then: $\left\langle N_e \right\rangle_{\rm WL} / \left\langle N_e \right\rangle_{\rm EUV} \propto \sqrt{f}$
- If differences in the results are solely attributed to filling factor:
  $f \sim 2$ in subpolar open region, and $f \sim 4$ in quiet sun closed region.
- Note that: $\sigma^2_{Ne} \equiv \mathrm{VarN_e} = \left\langle \mathrm{N_e^2} \right\rangle - \left\langle \mathrm{N_e} \right\rangle^2 = \left\langle \mathrm{N_e} \right\rangle^2 (\mathrm{f}-1)$
- So that: $\sigma_{Ne} / \left\langle N_e \right\rangle = \sqrt{f-1}$.
- With this interpretation, where f is larger (quiet sun closed region) the electron density probability distribution has larger variance.

This work is a first step towards implementation of a new technique dubbed multi-instrument tomography (MIT), currently under development. MIT will aim at simultaneously reconstructing the 3D distribution of different coronal parameters through joint analysis of tomographic results based on data provided by multiple instruments, including white-light coronagraphs, EUV telescopes and visible emission line coronagraphs. In particular, MIT will attempt to combine KCOR and

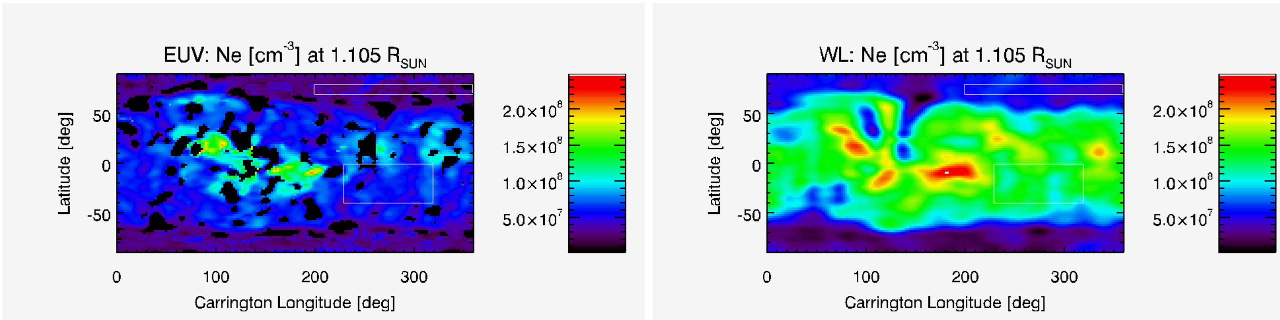

Figure 2: Example of results of the tomographic reconstruction of the electron density of the solar corona for CR-2198. Carrington maps of the reconstructed electron density are shown at heliocentric height $r = 1.105$ $R_\odot$. Left panel: reconstruction based on EUV data. Right panel: reconstruction based on WL data. The white boxes indicate two ranges of longitudes and latitudes selected for quantitative comparison. The region in the Southern hemisphere is a high-density quiet Sun region within the equatorial streamer belt during this rotation. The region in the Northern hemisphere is a lower density region at subpolar latitudes in the northern CH.

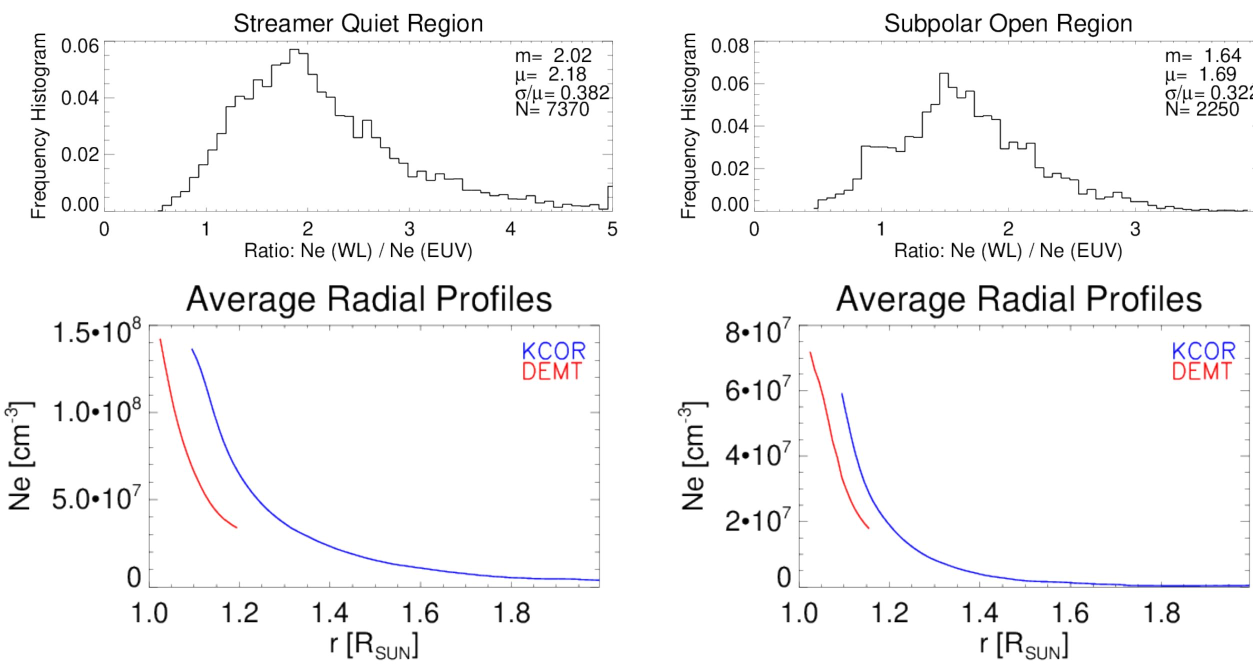

Figure 3: Quantitative comparison between the results of the two tomographic reconstructions of the coronal electron density of CR-2198. Results are shown here for the two selected regions indicated in Figure 2. Left panels show the results in the quiet sun region of the southern hemisphere within the streamer belt, and right panels show the results in the subpolar open region within the northern CH. For each region, the top panel shows the frecuency histogram of the ratio of the electron density value obtained in each computational voxel from WL and EUV tomographies. For each region, the bottom panels show the average radial profile of the electron density based on the EUV (red) and WL (blue) tomographies.

AIA data, with that to be provided by the, soon to be opperative, Upgraded Coronal Multichannel Polarimeter (UCoMP) instrument (Landi et al., 2016).

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