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SOLAR MAXIMUM STREAMERS AS THIN TWISTING SHEETS

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Abstract. Images of the corona processed using new techniques reveal detailed fine-scale structure and provide accurate depictions of large-scale structure. Solar maximum streamers which appear at high latitude in white light images are shown to appear and disappear with solar rotation. Carrington-type maps reveal the thin, highly filamentary sheet-like structures of these streamers. Examples of thin sheet structures at very low heights in the corona can also be seen in EIT images, which suggests that some solar maximum streamers exist as twisting sheets from the chromosphere out to the outer corona. This proposition is explored using a structural model of the corona, and the complex appearance of a streamer is well simulated using a twisting sheet topology.

Key words: solar physics, corona

1. Normalizing Radial Graded Filter

The normalizing radial-graded filter (NRGF), and other image processing techniques, are described in detail by Morgan *et al.* (2006). The NRGF is a simple and accurate method to look at the large-scale structure of the corona. It calculates the average and standard deviation of brightness as a function of height within an image, and uses these values to normalize the brightness at each height, therefore viewing the coronal structure seen in a NRGF-processed image is equivalent to comparing a large set of normalized latitudinal profiles simultaneously.

The results of applying the NRGF to images of the solar minimum and maximum corona are shown in Figure 1. These images are composed of observations in He II 304 Å by the Extreme Ultraviolet Imaging Telescope (EIT) (Delaboudiniere *et al.*, 1995), and pB observations by the Mauna Loa Solar Observatory's (MLSO) MKIII (solar minimum) and MKIV (solar maximum) coronameters (Fisher *et al.*, 1981) and the LASCO C2 coronagraph (Brueckner *et al.*, 1995). As can be seen, a useful aspect of the NRGF is the ease it allows to join images from various instruments. The simple normalizing function results in excellent continuity at the boundaries between the instruments'field of views, without interpolation or smoothing. This suggests the correctness of using the NRGF to look at structure.

2. Streamers as Thin Sheets

Figure 2 shows two high-latitude streamers in the north corona labeled A and B. They appear and disappear with a ~7 day interval. When the streamers are seen (left column), the region between the streamers above the North pole is darkest. When the streamers cannot be seen (right column), the same region is brighter and contains some structure. So in the field of view of LASCO C2, streamers A and B are likely

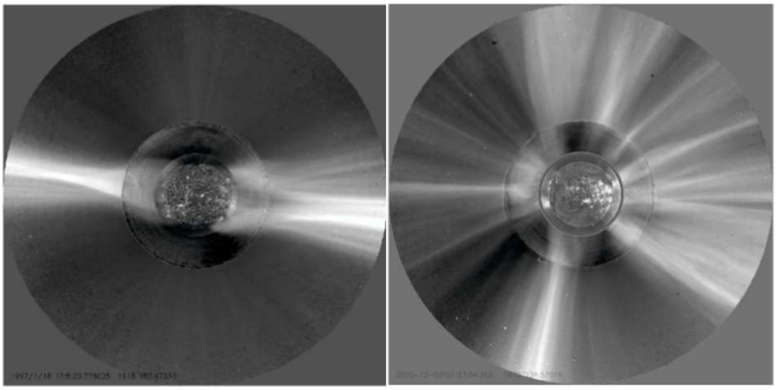

Fig. 1. Composite coronal images processed by the NRGF for dates 1997/01/18 (left) and 2000/12/03 (right).

to be thin sheet-like structures. In the left column, the streamers appear narrow due to being viewed edge-on, and are bright due to their extended contribution along the line of sight. Seven days later the Sun has rotated through a quarter turn and the streamers are viewed face-on above the pole. The bright narrow structures have disappeared and above the North pole their broad and diffuse filamentary structure is revealed. The sheet-like density structure of streamers at heights above $\sim 2.5R_\odot$ is explored in detail by Thernisien and Howard (2006).

Between 2000/12/02 19:31 and 2001/01/12 23:54 the LASCO C2 coronagraph made over 2400 total brightness observations of the corona. These images are calibrated using the standard LASCO procedures included in the Solar Software package, and processed using procedures described in Morgan *et al.* (2006). From these images we extract horizontal slices of processed brightness at various heights above the North pole. For illustration, the position of two slices are shown as the dotted horizontal lines in the right bottom image of Figure 2. The slices are stacked in time to create maps such as the one shown in Figure 3. Within the map, bright structures at high latitude describe sinusoidal curves with solar rotation. The periodic appearance of the high-latitude streamers labeled A and B in Figure 2 is clearly shown in Figure 3 as an effect of rotation. The approximate alignment of these structures along the line of sight result in the brightenings labeled A and B. The periods of alignment, or brightening can be seen to last for 2 to 4 days. From these synoptic maps, and the face-on appearance of the streamers in LASCO C2 images and movies, we can say that the streamers are thin, high-density filamentary sheets.

The source of streamer B is a narrow but long region of considerable activity seen in EIT 171Å observations, shown in the left image of Figure 4. When this region is centered over the east limb, a bright thin sheet of material can be seen emerging directly from the disk to the corona. Observing the passage of the source region against the limb over the course of many days reveals direct evidence of an extended thin sheet, as shown in the right image. The sheet is also apparent half a rotation later on the west limb. We have established in this section that streamers A and B exist as thin sheets in the corona. EIT observations show that these streamers may

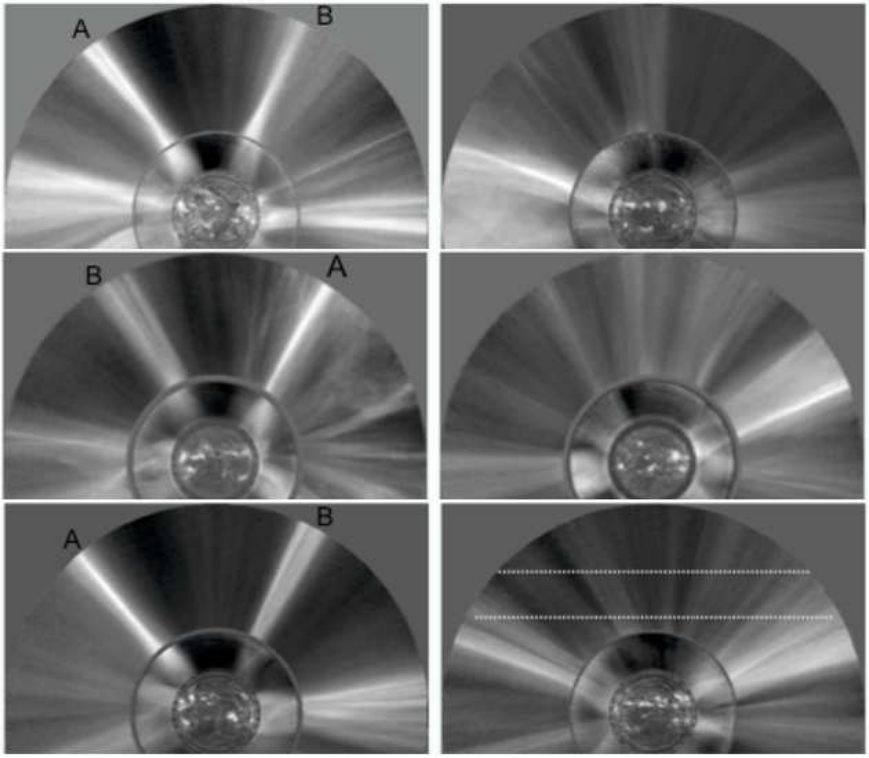

Fig. 2. Composite images of the Sun and corona made during Carrington rotations 1970 and 1971 at approximately 7 day (quarter rotation) intervals. Two high latitude streamers are labeled A and B.

exist as thin sheets at very low heights.

3. Exploring the Structure of Streamers

To explore the structure of coronal streamers from the solar surface to heights above where the corona becomes radial, a density model is constructed which allows the flexibility to incorporate complex structures. The position of high-density structures near the solar surface can be defined by, for example, the position of prominences as observed in Hα, or by bright regions in EIT 171Å images. The position of structures in their final radial configuration at $\sim 3R_\odot$ can be adjusted until images produced from the model agree with LASCO C2 observations. The thickness and position of structures evolve smoothly from the solar surface to $3R_\odot$, then maintain a radial configuration. Synthetic pB images are created from the coronal density model and are compared to observations. No attempt is made to determine the absolute electron density for the background corona or streamers. The background density is zero, and the density of streamers is set at an arbitrary value of 1 at the solar surface, decreasing with the square of the height. The brightness images obtained by line of sight (LOS) integration of the density model are therefore in arbitrary

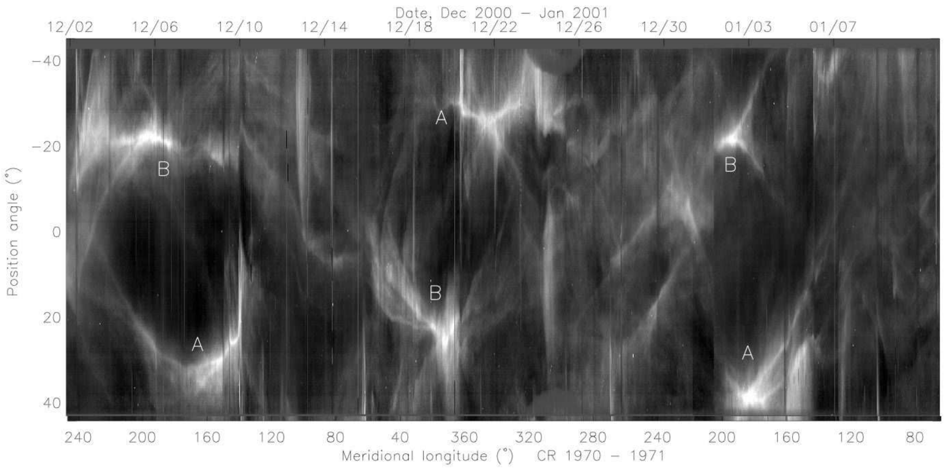

Fig. 3. LASCO C2 synoptic map, showing slices at a central height of $4.5R_{\odot}$. The y axis is position angle (positive is degrees counter-clockwise from North). Periodic regions of higher brightness are labeled A and B, corresponding to the labeled streamers in Figure 2.

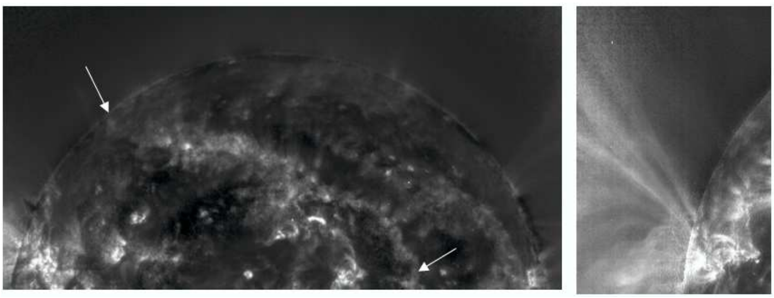

Fig. 4. *Left* - Source region of streamer B seen as an extended narrow region of enhanced activity in an EIT 171Å image. Arrows point to both ends of the region. *Right* - Example of a narrow thin sheet emerging directly from the region shown in the left image.

units, and are zero for any LOS not containing a streamer. The synthetic images are 'flattened' using the NRGF, and compared to observations, also processed with the NRGF. This is a valid and computationally efficient method to explore the large-scale coronal structure.

From movies made from EIT observations, we can see much dynamic activity in the source region of streamer B (shown in Figure 4), and we believe this causes large changes in the streamer. This makes streamer B very difficult to model. We concentrate our efforts therefore on streamer A. The top plot of Figure 5 shows the source of streamer A as a long filament (or prominence) as observed in Hα, with some active regions associated with the filament at lower latitudes (larger longitudes). This filament lies along a magnetic neutral line in the photosphere, as shown in the photospheric field synoptic map of the bottom plot. We model streamer A as a narrow high-density structure arising directly from the filament. The position of streamer A at the model solar surface is shown as the red region in Figure 5. We adjust the position of streamer A in the higher corona (the model corona becomes radial at $\sim 3R_{\odot}$) until modeled coronal images agree with observations made over the course of half a solar rotation. This position is shown as a yellow region in Figure 5. It is interesting that this coronal configuration has no agreement with the position of the coronal neutral line as calculated by source-surface extrapolation of the photospheric field.

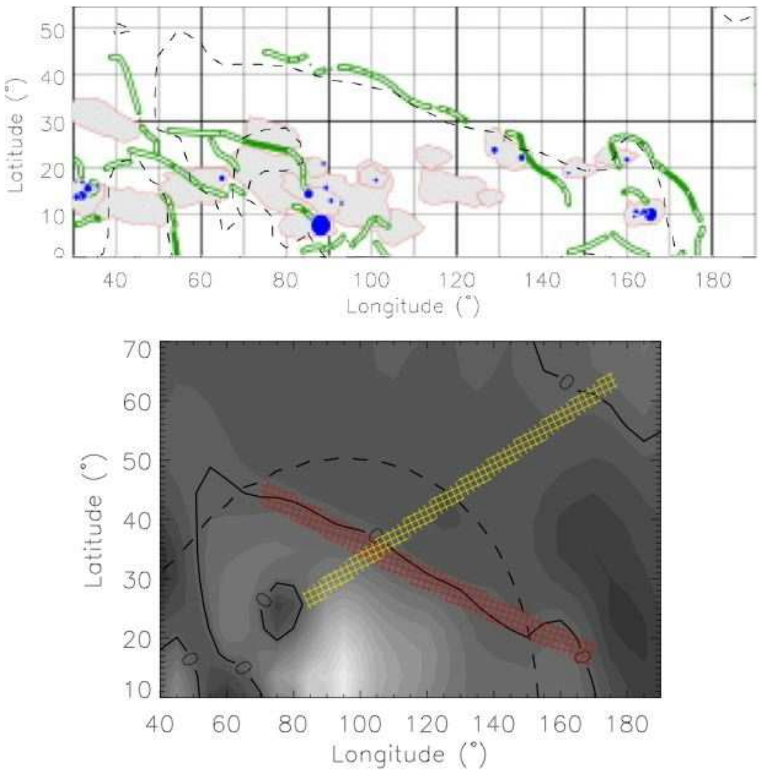

Fig. 5. *Top* - Source region of streamer A as seen in a Paris-Meudon Observatory (PMO) synoptic map. Features shown are filaments observed in Hα (green lines), sunspots as seen in a Ca II line (blue spots) and plage observed in a Ca II line (grey areas). The source of streamer A is the long filament (or prominence) lying from longitude 70°, latitude 50° to longitude 170°, latitude 10°. Also associated with this filament are active regions (sunspots and plage) at lower latitudes. The x-axis gives Carrington longitude for rotation 1970. *Bottom* - Modeled configuration of streamer A overlaid on a synoptic map of the photospheric magnetic field measured by the Wilcox Solar Observatory (WSO). The red and yellow regions show the modeled configuration of streamer A on the solar surface and in the high corona respectively. Brighter regions in the photospheric field map show a stronger positive field. Neutral lines are shown as solid bold contours. The dashed bold contour shows the neutral line at a height of $3R_{\odot}$, as calculated by WSO using a source-surface extrapolation of the photospheric field.

Figure 6 shows that considerable success is achieved in simulating streamer A as a twisting thin sheet. The changing apparent latitude of the main stalk is respected.

The changing shape of the streamer with rotation is also well replicated. The bottom two pairs of images, for rotation 150° and 124°, show replication of a faint structure at one limb (labeled c and d) simultaneously with the main body of the streamer at the other limb - structure which can not easily be associated with streamer A without the support of the model. Note also the appearance of the streamer as a fan-shaped structure in the top image. This is due to the edge-on alignment of the sheet at low heights in the corona. The twisting of the sheet with increasing height gives a diverging, fluted shape to the streamer since it is seen more face-on higher in the corona. The opposite is true in the second image (for longitude 176°). The sheet is seen more face-on low in the corona, and narrows to edge-on with increasing height. This gives a helmet-shaped streamer.

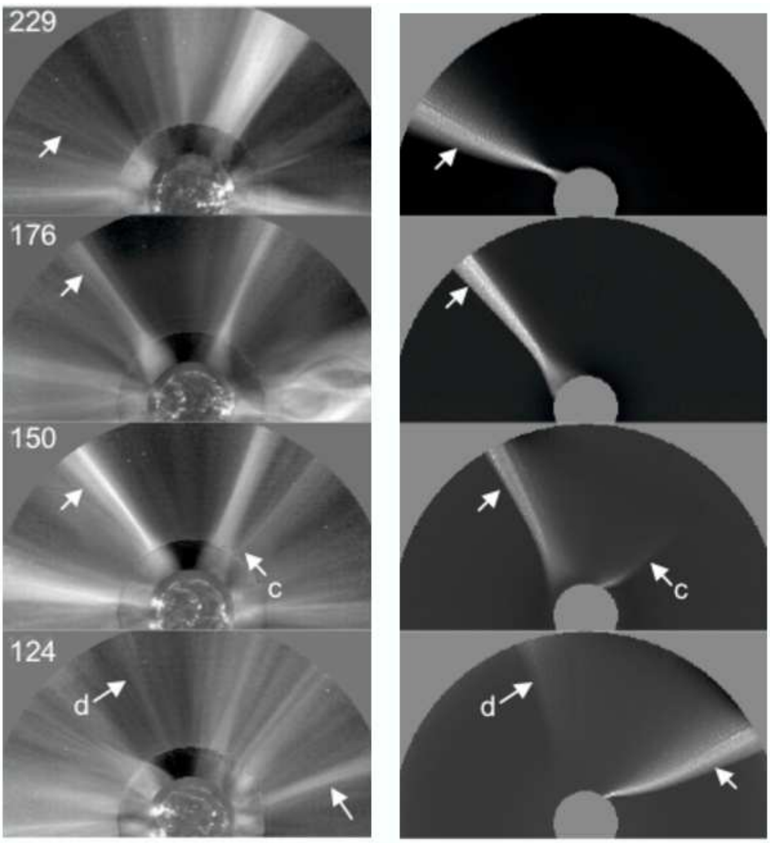

Fig. 6. Four comparisons of the observed north corona (left) and the appearance of streamer A modeled as a twisting sheet (right column). The numbers in the top left give the Carrington longitude . From top to bottom, the observations correspond to dates 2000/12/03, 07, 09 and 11 respectively. Arrows help identify features formed by streamer A. Two faint features are labeled c and d.

4. Summary

The comparison of synthesized and observed coronal images processed by the NRGF is a simple and efficient method to explore the structure of the corona without concern for the absolute coronal density, or density as a function of height. It allows the quick exploration of structure and the testing of ideas against observation. It can also be used as a basis for calculating absolute densities, since once the structure is 'fixed' in the model, and a background density found for a streamerless region of the corona, the density of structures may readily be found by inversion.

The main points of this work are:

- LASCO C2 images and synoptic maps show the thin sheet topology of two high-latitude solar maximum streamers.
- Direct observations of thin sheets at low heights are often seen in solar maximum EIT images. These sheets are not part of large closed-field structures, since they are seen to extend into the corona and form the base of streamers.
- Simulating streamers as thin twisting sheets closely replicates the appearance of complex structures in the solar maximum corona, and their changing appearance with solar rotation.
- We show that twisting sheets can give the appearance of helmet streamers. At other alignments, they can appear as fan streamers. So a simple topology gives an elegant interpretation for two categories of streamers with a very different appearance.
- In successfully simulating streamers in the solar maximum corona, we find no agreement between the position of the modeled streamers in the corona and the position of the coronal neutral line calculated by source-surface extrapolation of the photospheric field.

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