THE SOLAR CORONA ON 31 JULY, 1981

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Abstract. Various instruments were used to observe the solar corona near or at the time of total eclipse, 31 July, 1981. The High Altitude Observatory (HAO) coronal eclipse camera and the MK-III K-coronameter recorded the lower portions of the corona; the distribution of white light material above 3 $R_\odot$ was observed with the Naval Research Laboratory (NRL) satellite coronagraph on P78-1. These data sets are used to describe coronal structure and to identify coronal active regions. The polar coronal holes, as developed at this time in the solar cycle, were offset from the poles of rotation; both were seen displaced eastward on eclipse day. High latitude streamers appear in all three data sets, extending from the base of the corona outward to at least eight solar radii from Sun center. At least two transients were observed by the NRL experiment on the eclipse day, but it is likely that no transient was in progress during any observation along the eclipse path. A distribution of the white-light corona, derived from synoptic K-coronameter data, is given.

1. Introduction

In an attempt to define the structure of the solar corona at the time of a solar eclipse, an observing effort was undertaken by the High Altitude Observatory which used both K-coronameter observations and an eclipse image. In order to extend this study to high altitudes in the corona, observations from the Solwind coronagraph, developed by NRL, onboard the P78-1 satellite, have been added to the ground-based data. Thus, the eclipse of 31 July, 1981, day of year (DOY) 212, offered a unique opportunity to bring three different, but very powerful experiment systems to bear on the problem of understanding the three-dimensional distribution of the solar corona. A previous study by Hansen et al. (1970) used K-coronameter data with an eclipse observation; the present work extends this technique to greater heights by adding the satellite coronagraph data.

Two points are addressed by the assembled data set; documenting the state of the solar corona as seen from the limb to 10 $R_\odot$ on the day of the eclipse and identifying the changes occurring in the corona during this one particular day. For example, did any transient events occur during the eclipse? Eleven separate coronal features are

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TABLE I
Coronal and chromospheric structure 31 July, 1981

<table>
<thead>
<tr>
<th>Feature</th>
<th>Type</th>
<th>Eclipse image latitude</th>
<th>Mk-III latitude ((h - 1.7 R_\odot))</th>
<th>NRL latitude ((h &gt; 3.0 R_\odot))</th>
<th>Chromospheric association (Hz or (\lambda 10830))</th>
</tr>
</thead>
<tbody>
<tr>
<td>West limb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Helmet streamer</td>
<td>N 58</td>
<td>N 60</td>
<td>N 54</td>
<td>E–W filament channel</td>
</tr>
<tr>
<td>B</td>
<td>Streamer</td>
<td>N 22</td>
<td>N 18</td>
<td>N 26 (active)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Arches</td>
<td>S 01</td>
<td>S 01</td>
<td>S 17</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Transient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Faint arches</td>
<td>S 28</td>
<td>S 28</td>
<td>S 54 (active)</td>
<td>E–W filament channel</td>
</tr>
<tr>
<td>F</td>
<td>Helmet streamer</td>
<td>S 53</td>
<td>S 55</td>
<td>S 54–S 90</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Coronal hole</td>
<td>S 62–85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East limb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Helmet streamer</td>
<td>S 44</td>
<td>S 46</td>
<td></td>
<td>E–W filament channel</td>
</tr>
<tr>
<td>J</td>
<td>Streamer</td>
<td>S 29</td>
<td>S 24</td>
<td>S 29 (active)</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Transient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Coronal hole</td>
<td>N 64–N 96</td>
<td>N 50–N 90</td>
<td>(\lambda 10830) coronal hole</td>
<td></td>
</tr>
</tbody>
</table>

identified and listed above in Table I. These consist of four distinct kinds of large scale structures: coronal hole regions, active region streamers, high latitude helmet streamers, and coronal transients. The northeast limb is neglected in this study, since this region is obscured by the NRL occulting disk pylon.

2. K-Coronameter Data

The MK-III K-coronameter is an internally occulted, photoelectric polarimeter which uses an \(f/11\), 23 cm diameter singlet objective lens. This instrument is described by Fisher et al. (1981). Data are recorded onto magnetic tape; when required, digital images of the polarized radiance of the corona are produced at the NCAR computing facility in Boulder, Colorado. This instrument has a limiting resolution of approximately 20 arc sec. The field of view extends from 1.2–2.3 \(R_\odot\). The synoptic data collection program was begun with the MK-III in August 1980, and this program has continued until the present. A synoptic map of the distribution of polarized radiance has been constructed using a smaller data set collected over a period beginning DOY 203 to DOY 219, centered on the eclipse data, 31 July, 1981 (DOY 212). The synoptic plot is shown in Figure 1 for altitudes of 1.3 \(R_\odot\) and 1.7 \(R_\odot\). A synodic rotation period of 28.0 days was chosen for this synoptic map, since this synodic period best approximates the rotation rate of the white light corona at this particular time of the solar cycle (Fisher, 1982). Data are used from both east and west limbs, and a best approximation was estimated for the overlap at the center of the map, discounting effects of rapid evolution. In Figure 1, DOY is plotted along the horizontal axis, and solar latitude is plotted along the vertical axis. The units of \(pB\) used in Figure 1 are \(10^{-8}\) (per cent polarization \(\times B_0\) erg cm\(^{-2}\) s\(^{-1}\) sr\(^{-1}\)).
Fig. 1. Synoptic maps of coronal polarized brightness, $pB \times 10^{-8} B_\odot$, for a period of observation centered on the total solar eclipse of 31 July, 1981. Two heights are plotted, the upper figure refers to a height of $1.3 R_\odot$, the lower refers to daily azimuthal values of $pB$ at a height of $1.7 R_\odot$. Time (and longitude) increase to the left; data from both the east and west limbs were used for to construct these two plots.
Fig. 2. Polar projection of $pB$ values for a height of $1.3 R_\odot$. Azimuth is indicated so that $0^\circ$ is toward the earth on eclipse day, $90^\circ$ and $270^\circ$ refer to the east and west limbs on 31 July, 1981. The units are in $pB$ values of $10^{-8} B_\odot$. 
Fig. 3. Polar projection of $pB$ values for the 1.7 $R_\odot$ height. Note that in both this diagram and those of Figure 2, the polar coronal holes are offset to the east of the pole of rotation as viewed from the Earth on 31 July, 1981.
In order to visualize both the north and south polar distribution more accurately, data from Figure 1 have been replotted on the polar maps. These are shown in Figures 2 and 3. Higher density regions are indicated by the shaded areas, and the high latitude coronal hole structures are shown enclosed with a solid line at the 0 \( pB \) contour level.

3. Eclipse Camera Observations

A program of high resolution photography of the solar corona has been carried out by the High Altitude Observatory at total eclipse over the last fifteen years. The first successful use of the HAO coronal camera, developed by G. A. Newkirk, was at the 12 November, 1966 eclipse in Bolivia. The HAO coronal camera is a photographic system which uses an \( f/15 \), 11.1 cm diameter, four-element objective lens; this instrument is described by Newkirk (1966). For the work herein reported, the camera was taken to a point on the center line of the eclipse path, located near the village of Tarma (near Bratsk) Siberia. Two minutes prior to second contact, the planned observing program was abandoned in favor of a cloud contingency program. A single long exposure of 104 seconds in duration was obtained using a radially-graded filter. This exposure was taken through cirrus clouds, but yielded an observation satisfactory for the morphological study; the image is shown in Figure 4.

4. P78-1 Satellite Coronagraph Observations

The Naval Research Laboratory Solwind coronagraph, carried on the U.S. Department of Defense Space Test Program Satellite P78-1, is capable of producing coronal images extending from approximately 2.5 \( R_\odot \) to 10 \( R_\odot \) at a rate of one image every 5 or 10 min. The characteristics of this experiment system have been described by Sheeley et al. (1980). Data are recorded in analog form and played back through a digital image processing system. Both direct coronal images and differenced images are available for the eclipse day; data for this discussion extend over a period of about 22 hr beginning at 01:11 UT on DOY 212. The spatial resolution is 1.25 arc min. The off-centered annuli caused by polarizers are located in the field of view at 5.0 \( R_\odot \) and 8.0 \( R_\odot \) over the west limb. These are used to quantify the radial polarization of sources passing through the field of view. A set of nine images and difference images were extracted from a larger data set obtained on DOY 212, 1981 and used for this study. These are shown in Figure 5.

The variable nature of the solar corona, as seen at this phase of the solar cycle is dramatic and obvious from Figure 5. Over the eclipse day numerous changes are observable in the streamer structures, and two major coronal transient events were detected. The changes in coronal features are most easily observed when a difference technique is used on sequential images. A base frame is subtracted from an image obtained at a later time. The difference is displayed as either bright (an enhanced density) or dark (a depleted volume). The difference images were selected for the demonstration of coronal changes during the day of the eclipse: the base frame for these difference images is shown in the upper left-hand corner of Figure 5.
5. Discussion

Three helmet streamers were observed at high latitudes. These are positioned in Figure 4 at N 57 (A) and S 53 (F) on the west limb and S 44 (H) on the east limb. The west limb streamers, as seen in the synoptic maps obtained with the K-coronameter, are extended in longitude. These structures appear to be associated with the high latitude boundary between the old and new cycle polar fields. The exact longitude of the streamer seen on the east limb is hard to pin-point, but it is associated with the boundary between old cycle and new cycle polar fields. A section of the filament that marks this boundary in the chromosphere is seen at the base of the streamer in the eclipse image.

If it is the case that high latitude streamers may be represented by a simple model, in which a column is radially oriented to the surface of the Sun and rotates rigidly, it should be possible to see a change in apparent latitude of the streamer as a function of time. At the time of limb transit the position angle is at the point of closest approach to the equator, either descending from, or rising toward, a polar region depending upon the limb and hemisphere of the streamer. If the structure does not evolve over the period of observation, difference images of a corona made up of such model streamers, such
Fig. 5. Coronal images and difference images from the Solwind P78-1 coronagraph taken on 31 July, 1981. Brightness images are shown as the first and last frames, all other images are difference images made by subtracting the first coronal brightness observation 01:11 UT from subsequent data frames taken at the indicated times. Enhanced regions with respect to 01:11 UT are seen as brighter areas, depleted regions are darker areas.

as those images seen in the middle row of Figure 5, will show streamers as pairs of bright and dark structures. In the case of a west limb streamer, a dark edge toward the equator will imply that the streamer is on the back of the Sun; a bright edge toward the equator implies just the opposite condition, the streamer is on the front of the Sun toward the observer. Streamers seen at the east limb should give just the opposite signature.

Figure 5 does show paired bright and dark structures corresponding to features A, B, F, and H. Using this simplified model, streamers A and F were on the side of the Sun away from the Earth on eclipse day; B and H apparently were on the front of the Sun.
In the case of the structures $A$, $B$, and $F$ this seems to be consistent with the information obtained from the $K$-coronameter as shown in Figure 1. There is no easily identified feature in the synoptic map which may be associated with streamer $H$. This may indicate that the model of a time-stationary, radially-oriented, rigidly-rotating column is inappropriate in this case.

The location and shapes of the high latitude coronal holes are of interest. There are two hole regions seen in both the $K$-coronameter and eclipse observations, both holes are near the east limb; these are features ($G$) and ($L$). These low density regions are offset from the poles of rotation, both on the eastern side of the Sun. This situation is shown in detail in the polar plots of $K$-corona data seen in Figures 2 and 3. In these plots 0° is directed toward the observer in eclipse day, 90° and 270° are the east and west limb, respectively. Waldmeier (1981) has shown that a similar offset coronal hole configuration occurred for a region near the south pole in 1947, as detected in Fe XIV radiation. He suggests that this high latitude hole configuration is typical of a time near solar maximum. This differs from the situation, described by Hundhausen et al. (1981), that was seen near the minimum of sunspot cycle 20. These authors have shown that the polar coronal holes were offset from the pole of rotation, but one was approximately 180° of longitude from the other giving the white light corona the so-called tilted dipole appearance.

Changes in streamers were observed in both the NRL and $K$-coronameter data sets. One such streamer appeared on the west limb at a latitude of N 26 ($B$) and the other was on the east limb at S 22 ($J$). By inspection of the difference images shown in Figure 5, it is clear that major evolution took place during the day of the eclipse; however, it must be remembered that solar rotation is responsible for some portion of the change observed in the difference images. The streamer on the east limb at S 26 became thicker during the eclipse day, and exhibits a change which seems consistent with mass ejection along the streamer. That is, as time progresses, there appears to be an outward propagation of coronal matter.

A small system of closed arches is seen at S 01 ($C$) on the west limb of the eclipse photograph. This structure was seen in the $K$-coronameter as late as 22:00 UT on DOY 211, but this feature was absent from the 18:00 UT image the next day. While it might seem possible that a transient was occurring during the eclipse, inspection of the NRL difference images does not confirm the occurrence of transient activity at this particular period of time. A west limb transient was detected in the NRL data in the 04:25 difference image (the 01:11 UT image was used as the base frame), but it is located at a different latitude, S 17 ($D$). Using the NRL sequence of difference images, it is possible to estimate an upward velocity, in the plane of the sky, of $47 \pm 20$ km s$^{-1}$ for this transient. A second transient region is noted in the NRL data at the opposite limb, on the east side of the Sun, at S 11 ($K$). This event occurred late in the observing period, and is seen in the last image of Figure 5. The appearance of bright material above the occulting disk with large surrounding arch structure marks the last major change recorded during this period. There is no corresponding structure at this position angle observed in the eclipse image.
In conclusion, attention is drawn to the distinction between high and low latitude structures. The high latitude structure of the corona is similar in both the northern and southern hemispheres, showing coronal holes offset from the pole. The bright high latitude regions are associated with areas of opposite magnetic polarity separated by an east-west oriented filament. In general, it is difficult to relate the low latitude streamers to specific chromospheric or photospheric features. The circumstance of the offset coronal holes represents a considerable change in the large-scale distribution of the corona from solar minimum, the model of a tilted dipole is inappropriate for this particular moment in solar cycle 21.

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