ON THE CORONAL AND PROMINENCE STRUCTURES OBSERVED AT THE TOTAL SOLAR ECLIPSE OF 11 JULY 1991

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Abstract. Coronal images were taken in the light of the He I 10830 Å line, the 10000 Å continuum, and the Fe XIV 5303 Å line, with the aim of studying the thermal structure of the corona. In addition, spectroscopic observations were made in the violet wavelength region (3760–4060 Å) and near-infrared (10745–10835 Å), to obtain details of physical conditions of the corona, especially of its cool part. The data obtained do not show any distinct cool structures other than ordinary prominences. Some preliminary results concerning the corona and prominence structures are given.

Key words: eclipses – He I 10830 Å – infrared: stars – Sun: corona – Sun: prominences

1. Introduction

The solar corona is generally known to have temperatures in the million-degree range. However, several types of features of relatively low temperature exist in the low corona such as spicules, prominences ($T = 10^4$ K) and EUV-jets ($T = 10^4$ K, Dere *et al.*, 1983; $T = 10^5$ K, Brueckner and Bartoe, 1983). Since some of these cool features are transient, they should at least in part interact with the hot corona through mass and energy transfers. For instance, spicules ascend from the chromosphere into the corona, and then some of them fade out, others fall back to the chromosphere (Beckers, 1972). Wagner *et al.* (1983) showed that a coronal rain prominence forms underneath a coronal void, using eclipse white-light pictures. Hence, it is probable that material having temperatures between 10^4 and 10^6 K exists in the vicinity of the well-known cool features or could even spread over the entire corona.

Some authors have reported the existence of cool material other than the well-known features in the corona. From eclipse observations, Deutsch and Righini (1964) obtained a surprising Ca II H and K emission spectrum up to one solar radius above the limb; the intensity ratio of K to H was much larger than 2. They drew the conclusion that material with a characteristic temperature of 10^5 K existed over a wide region of the corona (Cavallini and Righini, 1975). Bappu *et al.* (1972) also obtained a strange metallic-line emission spectrum, which seemed not to arise from normal prominences, although they did not carry out an analysis of the data.

Outside of eclipses, Leroy (1972) found many small-scale faint features in Hα filtergrams from coronagraph observations (*cf.* Öhman, 1972), while Gnevishev and Gnevisheva (1963) reported such features in He I D_3 filtergrams. Furthermore, it is interesting to note that the weakening of the EUV line emission with wavelengths shorter than 912 Å could be caused by Lyman continuum absorption due to unknown cool material in the corona (*e.g.*, Kanno and Suematsu, 1982).

However, there has been criticism directed at the validity of the evidence for cool material mentioned above, because of its strange properties. Some of the emissions might come from atmospheric or instrumental scattering of the chromospheric or prominence radiation (*e.g.*, Caccin *et al.*, 1971). Our main purpose in these eclipse observations was to confirm the existence or non-existence of cool material other

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than the ordinary cool features, and further, to study the origin of such material if it exists.

We used the He I 10830 Å line for this purpose because this line suffers less atmospheric scattering than visual or violet lines. In order to know the spatial distribution of cool material, He I 10830 Å filtergrams were taken with a CCD camera. Moreover, He I 10830 Å spectra, including the well-known Fe XIII 10747/10798 Å lines, were taken to understand the detailed physical conditions of both cool and hot material, although this did not yield a useful result. In addition, spectra of metallic lines in the violet region (3760–4060 Å), including the Ca II H and K lines, were taken because these lines give much more information on the physical conditions of cool material. Fe XIV 5303 Å filtergrams were taken in order to study the hot corona and the relationship between the cool and hot structures. As a matter of course, we were also interested in the thermal structure of the corona, especially the regions surrounding prominences, and in the physical conditions in the faint parts of prominences.

The observations were carried out under good sky conditions, at the campus of Universidad Autonoma de Baja California Sur (UABCS), La Paz, Mexico.

2. Instrumentation and Observing Procedure

A 3-channel telescope was used consisting of three tubes mounted on a single equatorial mount and was designed to obtain three different monochromatic images of the corona. Two of the three tubes had apochromatic lenses of 76 mm diameter ($f/7.9$), telecentric lens systems, filter boxes, camera lenses, and CCD cameras (TAKENAKA TM-840N). A He I 10830 filter (passband of 6 Å) was used in one filter box and a 10000 Å-continuum filter (passband of 200 Å) in another. The solar image diameter at the CCD camera was about 5 mm. The image data from the CCD were stored on a VCR with S-VHS mode, as well as on a hard disk of a personal computer through a 512 $\times$ 512 pixel image-processor with 8-bit precision. The image processor automatically integrated video images up to the saturation level.

The third tube consisted of an apochromatic lens of 100-mm diameter ($f/8$), a relay lens system, a Fe XIV 5303 Å filter (passband of 3.5 Å) , and a 35-mm camera (Nikon F3, with 250 exposure capability). The solar image diameter on the film was about 25 mm. Kodak TMAX400 emulsion was used. Camera exposures were controlled by a note-type computer; the exposure time was changed between 1/2000 second and 64 second during the eclipse observation. The telescope was pointed to the east solar limb before mid-totality and to the west limb after mid-totality.

A spectrograph was designed to observe the violet (3760–4060 Å, dispersion $= 8.5$ Å mm^{-1}) and near-infrared (10745–10835 Å, dispersion $= 10.3$ Å mm^{-1}) wavelength regions simultaneously, consisting of a straight mirror slit, a collimator (off-axis paraboloid), grating (50$\times$50 mm^2, 1200 grooves mm^{-1}), and two camera lenses. The solar image was focused on the mirror slit by a Cassegrain-type telescope (objective of 100 mm diameter; $f/12.4$ system). The spectrograph and the feed telescope were equatorially mounted.

The width and the length of the slit were 30 μm and 15 mm, respectively, for the chromosphere and low corona, while the width was changed to 200 μm during the observation of the high corona. The direction of slit axis was always north-south in the sky: the slit was positioned tangentially to the solar east or west limb. In order to examine linear polarization of the light, a Gran-Taylor prism, which is effective for both infrared and violet wavelengths, was placed in front of the mirror slit. The prism was rotated around its axis in 60-degree steps.

An improved CCD camera (National CD-55) was used with an evacuating and cooling device for the infrared observation. A film-camera (Nikon F-3, with 250 exposure capability) was used for the violet region. Another personal computer was employed to control the exposure of both the CCD and film cameras, the rotation of the polarizer, and the fine settings of the spectrograph slit. The telescope-spectrograph was moved so that the slit was set to the extreme east solar limb around the time of second contact, and moved higher above the east limb (up to 100 arcseconds) by 90 seconds before third contact. Finally, the telescope was manually pointed to the west just above the lunar limb until third contact.

We used Kodak TMAX400 emulsion for the violet observations and exposure times of 1/15, 1, 4, 8, and 180 s, synchronizing with the rotations of the polarizer, for the east corona, and a fixed value of 8 s for the west corona. For the cooled CCD camera, we selected exposure times of 1/15 and 180 s for the east corona, storing the data on a VCR. This CCD did not operate for the west corona.

White-light slit-jaw images, which were also linearly polarized because of the Gran-Taylor prism, were also recorded on a VCR through a CCD camera (Sony XC-77RR) with a neutral density filter and f55 mm camera lens (Micro Nikkor).

Finally, large-scale coronal images in white-light were taken with a film-camera (Kodak TMAX100 emulsion and Fuji Color HRII 100) and a video camera.

3. Preliminary Results and Discussion

During this eclipse, we observed three outstanding streamers: two extended in the northeast direction and the other in the southwest. Also, prominent coronal plumes (ray-like structures), *not always polar plumes* in this case, were observed in the north-to-west region. Two large prominences were evident: one was at the east limb and another at the west.

White-light coronal pictures were analyzed to study the width-variation of the plumes as a function of distance along them. Although we can see both bright plumes and dark extended voids, the result presented here is for seventeen plumes. It is found that most of the plumes expand linearly with distance: the expansion rate is 10–70 arcsec per solar radius. The widest and most prominent plume seems to connect to the large west prominence and hence to be abnormal. When the widths are extrapolated to the solar surface, we obtain values of 10–40 arcsecond. These values suggest that the narrow coronal plumes may be related to the enhanced unipolar magnetic fields emanating from the supergranulation network boundaries, whose typical cell diameter is about 40 arcsecond (*cf.* Newkirk and Harvey, 1968).

In the Fe XIV 5303 filtergrams (Figure 1) we can see many fine-scale structures such as loops, threads and rays. In the long exposures filtergrams, we can even

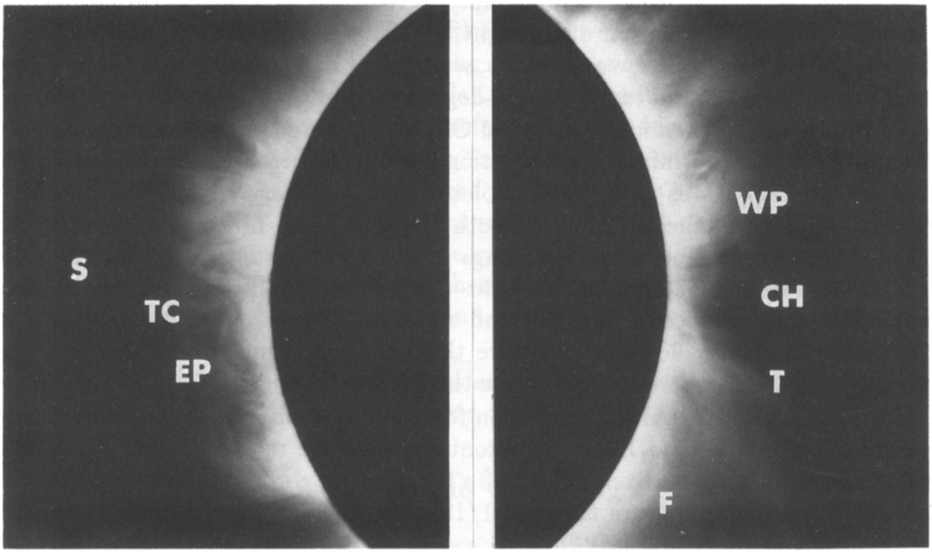

Fig. 1. The east (left) and west (right) corona in Fe XIV 5303 Å line. The exposure times were 32 s. North is at the top. The symbol TC indicates the twin cavity, S the east streamers, EP the location of the east prominence, CH the coronal hole, T the thread, WP the location of the west prominence, and F the location of the faintest prominence (see Figure 2).

perceive the coronal streamers (the symbol S in Figure 1) seen in the white-light pictures, although they are very faint. Of special interest in the east corona is a twin cavity structure (TC) underneath the east streamer – two cavities that are in close proximity. The large east prominence (EP) is sitting inside one of these cavities. The 1966 eclipse showed such twin cavity structure too: Two adjacent cavities were enclosed by a helmet-streamer structure and each contained a prominence (Tandberg-Hanssen, 1979). In the west corona, a coronal hole (CH) is seen and a thread (T) at the south edge of this coronal hole seems to be twisted. We cannot see a distinct cavity above the large west prominence (WP).

We cannot detect any cool structures other than the ordinary prominences for the He I 10830 line and the Ca II H and K lines to the limit of the detector sensitivity which is about 10^{-2} of the ordinary prominence intensity for He I 10830 filtergrams (Figure 2), and 10^{-4} for Ca II H and K line spectra. Unfortunately, the coronal parts of the Ca II H and K line spectra are contaminated by atmospheric scattered light from the prominences: False emission lines are seen in the regions neighboring the prominences. This negative result might not necessarily mean that cool material other than that of ordinary prominences does not exist in the corona at all. Our

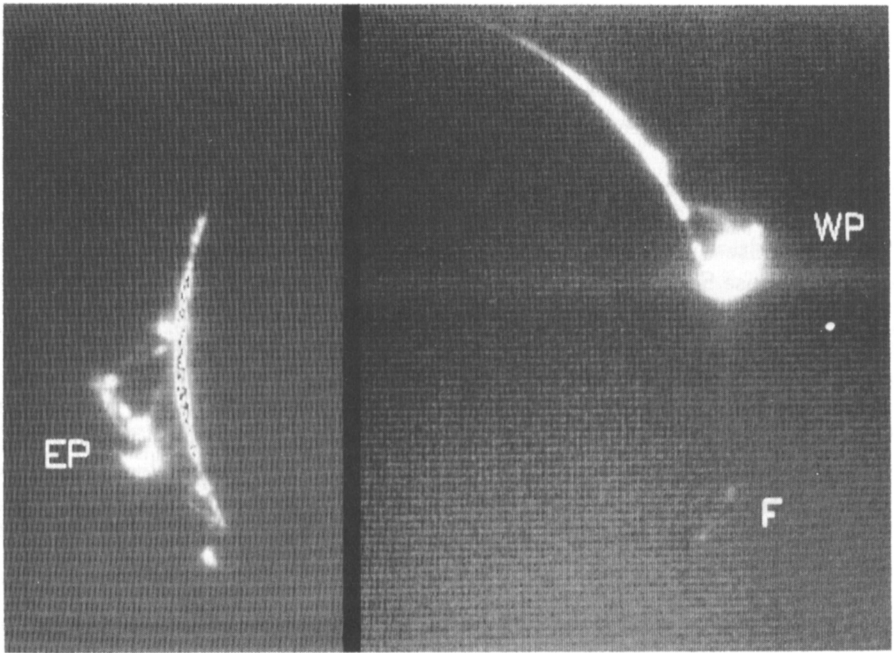

Fig. 2. The east (left) and west (right) corona/prominence in He I 10830 line. A total of six images and nine images were summed up for the east and the west, respectively. In order to enhance faint regions, bright regions are saturated. North is at the top. The symbol EP and WP indicate the large east and west prominences, respectively, and the symbol F indicates the faintest prominence we could detect.

detector sensitivities were insufficient for this purpose, and one might find such cool material in other eclipses. This problem will need further investigation in the future.

The faintest prominence (F in Figure 2) in our observations is in the southwest quadrant. Its intensity is a few hundredths that of a normal prominence in He I 10830. This is a nearly horizontal bar shaped prominence and shows highly-shifted line spectra in Ca II H and K, corresponding to a velocity of 100 km s^{-1}. However, the prominence is barely seen in higher Balmer or metallic lines. This might imply that the temperature of this prominence is higher than that of more typical ones (see, *e.g.*, Alikayeva, 1975).

We can see tilted line spectra in the violet at the extreme top of the large east prominence. This tilting probably indicates the rotational motion of the prominence material. At the leg part of this prominence, between the prominence body and the chromosphere, we have highly-shifted Ca II H and K line spectra, corresponding to a line-of-sight velocity of several tens of km s^{-1}.

In the violet spectra, in addition to the chromospheric/prominence lines, we can detect three coronal lines; Co XII 3800.7, Fe XI 3987.1, and Cr XI 3998.0, which are formed in plasma of about one million degrees. With these lines, as well as the Fe XIV 5303, we can estimate the temperature structure in the corona in the future.

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