Coronal Emission Line Measurements of the February 16, 1980 Total Solar Eclipse*

D. H. Liebenberg, W. M. Sanders, E. A. Brown, H. S. Murray and R. N. Kennedy

Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545, *U. S. A.*

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Abstract

We have observed coronal emission line profiles at the February 16, 1980 total solar eclipse from an NC-135 aircraft. Very successful observations of a highly active corona near the peak of the 11 year solar cycle show considerable detail. The data from Fe XIV and Ca XV emission lines can be analysed to obtain detailed ion temperature and density with 4 arc-s spatial resolution and extending to beyond 2 solar radii in equatorial regions. Gradients of these parameters are related to cornoal heating and solar wind acceleration processes. This paper describes the observations and methods of data analysis including the planned comparisons with other available data from this time period.

I. INTRODUCTION

Observations of the coronal emission lines are usually limited to small distances above the solar limb (Billings 1966). Ground based coronagraphs proudce high resolution intensity-vs-wavelength observations out to about 1.1 Ro (Ro = solar radius). Integrated emission line studies with a narrow bandwidth filter give observations of Fe XIV distribution out to ~1.4 Ro. X-ray measurements from satellites provide data limited to about this same distance. There is theoretical evidence that energy input to the corona occurs over a larger region, perhaps beyond 3—4 Ro.

The temperature and density structure observed to greater heights is thus of significant interest. Measurements made by us at previous solar eclipses have shown the feasibility of observations to 2-3 Ro (Liebenberg et al. 1975 a, b; Hoffman et al. 1975 a). During this solar maximum we expected to observe specific regions of enhanced corona as well as residual polar coronal holes to develop information of the ion temperature and density. Comparison with hydrogen ion temperatures (Argo and Munro 1980) and electron densities calculated by Keller(1980) and Keller and Mattulca(1979) would provide unique evidence for coronal plasma turbulence and ion excitation conditions as they pertain to solar wind formation in the lower corona. High resolution spectroscopy of solar emission lines has been developed by one of us (DHL), with a Fabry-Perot high resolution interferometer since 1954, and several new results of temperature structure have already been determined (Liebenberg et al. 1975 a, b, 1976). The present eclipse, near the peak of a strong solar maximum, offered an opportunity not available for at least 11 years to study maximum activity in the corona.

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II. INSTRUMENTAL

A 10-inch diameter objective with 80-inch focal length telescope has a prime coronal image of 19.1 mm at 1 Ro. The prime image is collimated and passed through a predispersion interference filter, Fabry-Perot interferometer, and refocussed onto an intensified silicon vidicon (SIT) tube. Data from the pressure-scanned interferometer with free spectral range of about 4 Å is recorded on magnetic tape. Spatial resolution is recorded in each video frame and the time variation of any pixel provides a high resolution intensity vs wavelength scan over a coronal emission line. Both the Fe XIV and Ca XV emission lines were observed. The image is moved to preselected positions by means of a programmed tracking table that offsets the phototracking image. Stabilization of the image to at least 4 arc-s is accomplished with a combination gyro-stabilized, photo-tracked control of a hydraulic positioner. Further instrumental details are given in earlier references (Hoffman et al. 1975 a; Liebenberg 1975).

III. RESULTS

The 7^m 07^s totality obtained from the NC-135 aircraft platform provided a factor of nearly two increase in observation time over the ideal ground location. In addition, sky background scatter and cloud interference were substantially reduced. As noted at previous eclipses, we have observed the corona some 90 s before and after second and third contacts respectively, indicating the low instrumental and reduced sky scatter (Liebenberg 1975).

A series of 10-s spectral scans through three orders of the interferometer was obtained in 10 image positions of the Fe XIV emission line and at 4 positions of the Ca XV emission line.

Less than expected signal strength from the photo tracker lowered the band width of the tracker and manual adjustment was required to follow the programmed tracking offset table. The photo tracker was locked into the image in each position and, generally, tracking accuracy to at least 4 arc-s was obtained. This accuracy matches well the pixel resolution and basic optical resolution of the telescope.

A preliminary first look at the data has demonstrated the compatibility with the EG & G Division (Los Alamos) digitizer system. Some frames of data have been photographed with this system and provide an initial description of the range and quality of the data.

IV. DISCUSSION OF RESULTS

Figure 1 shows a west-limb single frame of the video interferometer picture. Three orders of the interferometer are illuminated. The occulted Sun is at the left. A rapid decrease of intensity above the limb is seen and is related as

$$I(R) \propto [n_e(R)]^2$$

for a collisionally excited emission line. A variation of $I(R) \propto 1/R$ (Keller 1980) has been measured at an earlier eclipse (Liebenberg et al. 1975b). The intensity shown in Figure 1 is similar to that obtained by a direct photograph (Liebenberg et al. 1975b) with an exposure time of 30-60 s on spectroscopic plates. This frame of video was exposed for about 33 ms at a reduced gain and indicates the significant advantage of SIT tube data. Scattered light into the lunar disk is interpreted as the result of thin high-cirrus colud.

Temperatures of the coronal material could be determined from the intensity vs wavelength profile of a microdensitometer scan of the image. However, the spatial resolution would be larger than a single pixel. From the pressure scan of one order of the interferometer the profile from one pixel may be obtained. In the Figure 1, some 70,000 pixels are illuminated and will provide a detailed map of line widths throughout this region. Above this region, a magnetic bubble has been observed by Keller (1980) and an umbilical connection to the limb is observed at $\sim 280°$ position angle. Thus, the line widths measured in this region should help to determine the extent of temperature perturbations introduced by this coronal bubble motion.

In Figure 2a, the interferometer scan has been stopped at a location to indicate the spatial variation of Fe XIV emission line intensity close to the limb. Using computer generated colour steps to represent different intensity levels, the localized variations are more clearly distinguished in Figure 2b.

One feature of the scanning interferometer technique that we have developed is the use of the data to provide a filtergram in Fe XIV emission line light. Although the full digital analysis can improve the resolution, we have played the television fields through an order of the interferometer and photographed the resulting integral. The result is shown in Figure 3.

The fine scale variations are seen and in addition the base of helmet streamers are marked out in Fe XIV emission. These regions are visible out to 1.5 $R_{\odot}$. At about 20° below horizontal in Fig. 3a, a very bright region of less than 2 arc-min size should be noted. This region also shows up in the continuum observations and is thus identified as a small region of density enhancement.

Figure 4 illustrates the faint emission line corona observed to approximately 3 $R_{\odot}$. The eclipsed Sun was displaced to the left and completely out of the field of view. The gain on the SIT tube was raised and the fringe pattern observed is clearly identified with Fe XIV emission as compared to background continuum.

Ca XV emission was detected by us at the 1973 solar eclipse (Hoffman et al. 1975 b). While previous observers had detected this emission only in very localized and transient regions of higher temperature (Billings 1966), we observed Ca XV emission over much of the inner corona. These new observations indicate the presence again of weak Ca XV emission from a number of locations in this active corona. A photograph of a single video frame is shown in Figure 5. Most of the illumination comes from the continuum or electron scattering. The bright knot mentioned in connection with the Fe XIV line emission is quite distinct and is seen even in the destructive interference condition for Ca XV emission. This is direct evidence for a high density region since the electron scattering intensity is directly proportional to electron density. The size of this knot is of the order 1 arc-min.

For each quadrant of the corona we have obtained a similar set of data. Since a coronal hole was known to be present in the south polar region, we expect to determine the temperature structure and verify our earlier observation (Liebenberg et al 1975 b) that although the density is lower, the temperature remains at about 2 MK in a coronal hole. Newer evidence from satellite observations tends to confirm the higher temperature (Rosenberg et al. 1977).

The determination of temperature from these coronal emission line widths depends to some extent upon the magnitude of the turbulence and flow velocity fields. We write the temperature as,

$$T = \int_{-\infty}^{\infty} \frac{m_\alpha (\mathbf{k} \cdot \mathbf{v})^2}{k} f_{\alpha o} \, dv$$

where $f_{\alpha o}$ is the ion distribution. For an equilibrium plasma, it is often a Boltzmann distribution with a superposed macroscopic turbulent velocity v_t, then the line broadening can be written,

$$\frac{\Delta\lambda_{FWHM}}{\lambda} = \frac{1}{c} \left(\frac{3akT}{m} + v_t^2 \right)^{1/2}.$$

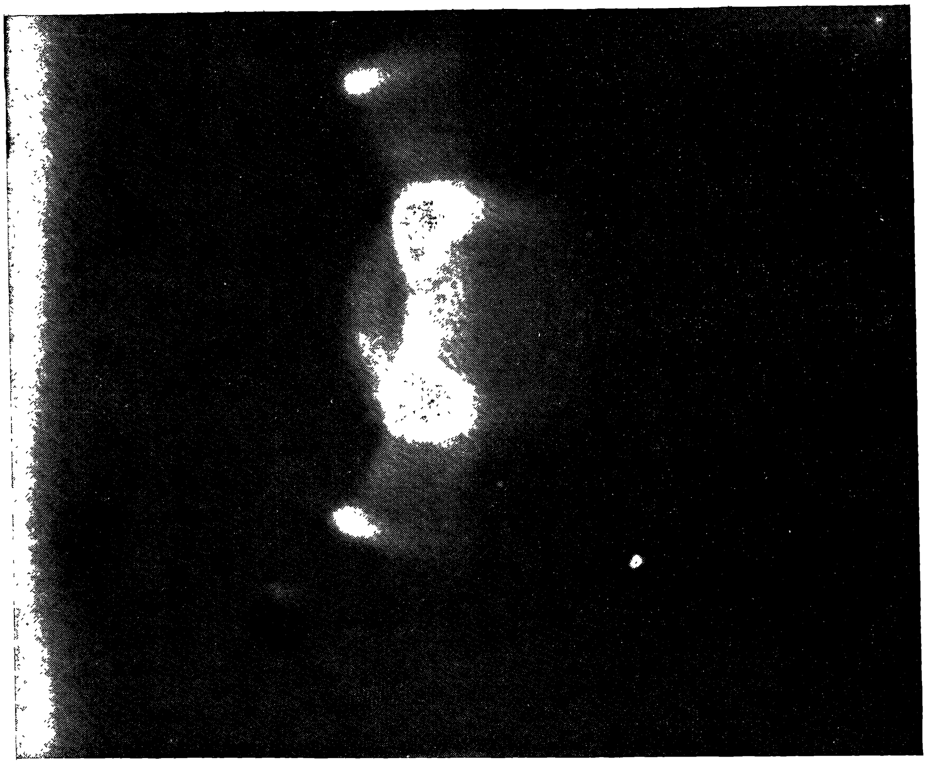

Fig. 1. West limb interferometer photograph of a single video frame in Fe XIV emission line light. Three orders of the interferometer are illuminated.

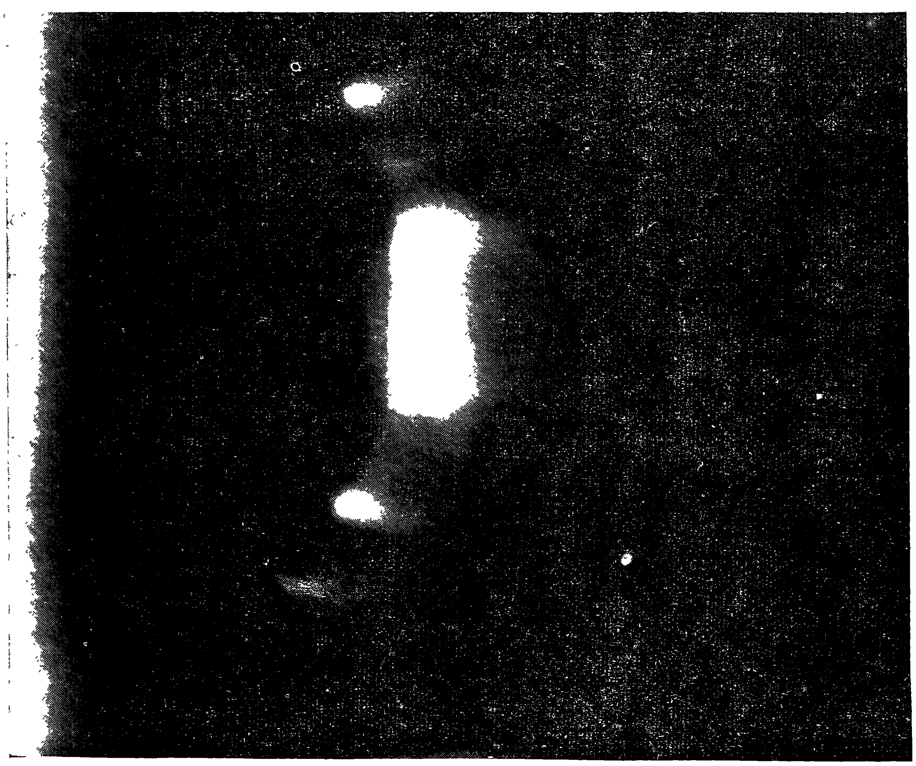

Fig. 2a. West limb interferometer photograph of a single video frame in Fe XIV emission line light. The interferometer scan is stopped with first-order interference at the limb.

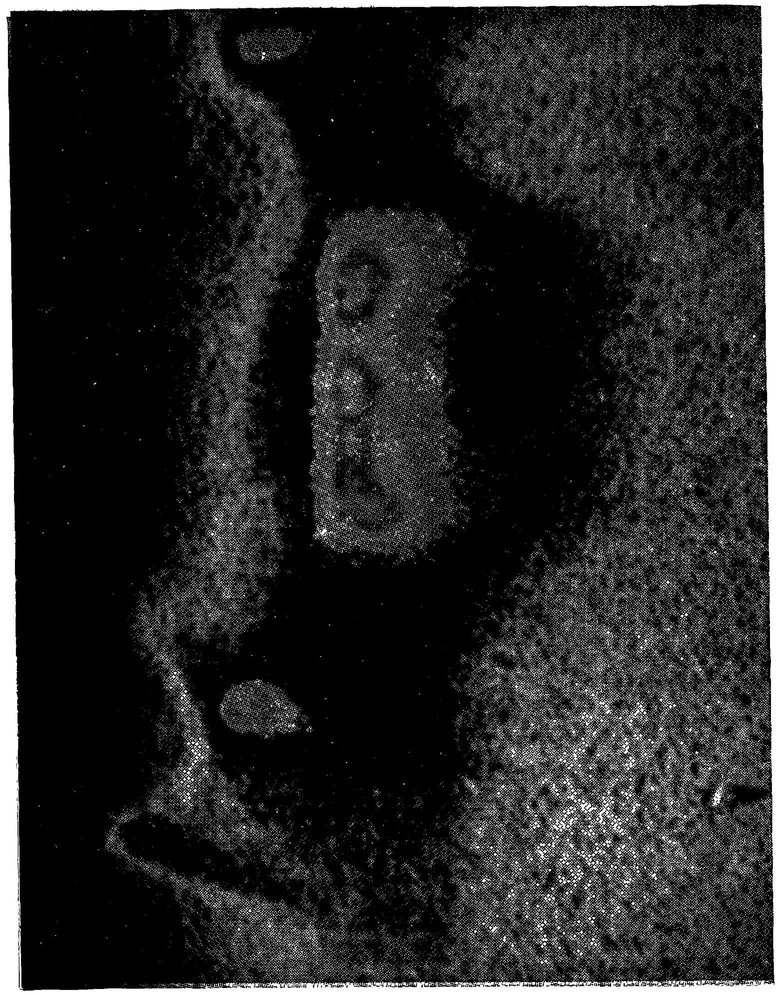

Fig. 2b. Enhanced version of Fig. 2a, colors indicate intensity levels and provide direct evidence of the fine scale variation of Fe XIV intensity. One pixel is ∕ 4 arc-s square.

Fig. 3

West limb Fe XIV emission line intensity distribution integrated through a scan of one order during the photographic exposure.

Fig. 4. West limb interferometer photograph of a single video frame in Fe XIV emission line light. The base of the corona is displaced to the left and out of the field of view.

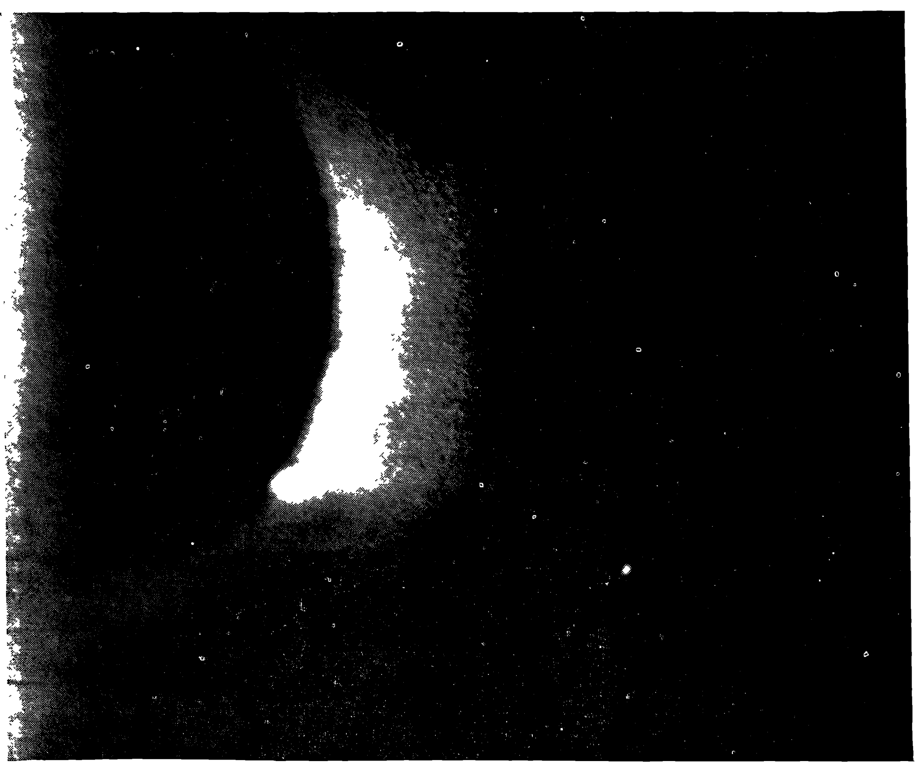

Fig. 5. West limb interferometer photograph of a single video frame in Ca XV emission line light. The Ca XV emission is so weak that the electron scattered continuum is the primary contribution to the intensity.

The thermal velocity of an Fe XIV ion at 2 MK is about 37 km s^{-1} and we have determined (Liebenberg et al. 1975 b) turbulent velocities of 10-15 km s^{-1} in agreement with measurements closer to the limb by Rosenberg et al. (1977). Measurements of the thermal broadened hydrogen line Ly α by Argo et al. (1980) will permit a more precise determination of these non-thermal velocities. At 2 MK the hydrogen ion velocity is several hundred kilometres per second. Thus the turbulent velocity will have a smaller effect on the total broadening. Comparison of the two data sets will provide new information on nonthermal velocities in the corona.

V. SUMMARY

We have observed the Fe XIV and Ca XV coronal emission line profiles with a pressure scanned high resolution interferometer through a 10 inch diameter telescope. Spatial resolution to 4 arc-s was achieved from the U. S. Air Force NC-135. The Los Alamos Scientific Laboratory expedition attained an extended totality duration of $7^m 07^s$. Our observations at the February 16, 1980 eclipse show considerable spatial variation of Fe XIV emission line intensity in this active solar corona and we will be able to determine temperatures, densities, and turbulent velocity structure of the coronal plasma.

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