Eclipse Spectrophotometry of Solar Prominences

Donald A. Landman, John T. Jefferies, and Frank Q. Orrall

University of Hawaii, Institute for Astronomy, 2680 *Woodlawn Drive, Honolulu, Hawaii* 96822, *U.S.A.*

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Abstract

The Institute for Astronomy's Eclipse Spectrograph was used to obtain prominence and coronal spectra throughout the wavelength range from about λλ 3500-7000 at the February 16, 1980 total solar eclipse. The observations were made at the Japal-Rangapur Observatory near Hyderabad. The spectra will be analysed to determine the temperature, density and composition of the prominence plasma, and will also provide tests on recently developed non-LTE, multi-atom theoretical prominence models. Analysis of the forbidden line coronal spectrum too will yield diagnostic data for the coronal plasma.

I. INTRODUCTION

The development of comprehensive non-LTE multi-atom computer codes during the last decade has had a considerable impact on our ability to model the statistical equilibrium of prominences (and other well defined solar features). In principle, this work enables the (over-) determination of the basic physical parameters characterizing the prominence plasma—such as the temperature and density structure—from measurements of the many interdependent spectral lines from the various atomic species. Over the past five or so years, a considerable body of spectra of the principal lines at individual prominence positions has been obtained with the instrumentation at the Mees Solar Observatory, Haleakala (Landman and collaborators), and elsewhere (Stellmacher, Engvold, Kubota, etc.), that is of sufficient photometric quality to critically test the theoretical models. Comparisons of model predictions with observations have led to important refinements in the models, and identified several areas where the discrepancies seem particularly deep-seated, and their sources rather obscure.

The present models are most successful when applied to relatively faint prominences, but even here serious problems persist. In the regime of bright prominence emission, the models appear incapable of describing even qualitatively the observed behavior of many of the principal lines relative to one another. Comprehensive spectral measurements of the type required to investigate this situation—i.e., many lines from different constituents, together with continuum emission, at individual prominence positions, and also emission line and continuum strengths in the surrounding corona which reflect the degree of nearby coronal activity and, thus, the incident UV flux—are difficult to obtain ordinarily owing to scattered light contamination. The major overall purpose of our expedition was to obtain accurate prominence and coronal spectra over a wide wavelength range under-conditions where the scattered light problem is eliminated. A number of specific scientific objective regarding the prominence program are outlined in our proposal to NSF.

The UH IFA eclipse team consisted of J.T. Jefferies, D.A. Landman (Project Leader), D.L. Mickey F.Q. Orrall, and S.J. Walton.

II. APPARATUS

The apparatus, an equatorially mounted telescope-spectrograph unit, was designed by Dr. R.B. Dunn (Dunn, 1966) specifically for eclipse observations. Relatively light weight (68 kg) and straightforward to operate, its successful use on several previous expeditions (e.g., Jefferies, et al, 1971) had demonstrated its ample suitability for field measurements under assorted conditions.

In brief, the telescope is of Newtonian design with a 25 cm aperature and 4.8 effective f ratio. The solar image, about 1 cm dial, is incident on the slightly larger annular entrance slit to the spectrograph, the slit width being nominally 0.003 cm. The spectrograph consists successively of a spherical collimator mirror, a Maksutov corrector lens (to eliminate spherical aberration), a 600 line/mm grating, and a spherical Schmidt camera mirror. A prism assembly immediately behind the entrance slit separates the images of the two solar limbs so that the corresponding spectra are laterally displaced in the final focal surface without overlap. The dispersion is 36 Å/mm in first order, and the spectral and spatial resolution are about 1 Å and 8″, respectively. The entrance slit assembly is polished to permit visual guiding on coronal features during eclipse. The telescope-spectrograph unit moves in right ascension by means of an adjustable battery powered motor; the declination axis is controlled manually with a tangent screw. The film advance and shutter control are also powered by the battery pack.

Because of the relatively short duration of totality, we elected to use only a single film type, and since we were particularly interested in the green region of the spectrum for several scientific objectives, we decided on (35 mm) Kodak Linagraph Shellburst. A Kodak Wratten filter was positioned immediately before a section of the final focal surface to block the second order spectrum from about 3000—3500 Å.

III. CALIBRATION

Two complete calibration runs were successfully accomplished. Each calibration set consisted of a sequence of 10s exposures using a comprehensive assortment of neutral density filters and circular apertures to attenuate the solar disk intensity. Runs were made on 13 Feb 1980 (for backup), and on 16 Feb 1980, eclipse morning. In addition, shorter sequences for absolute intensity and reciprocity calibration were obtained just before first contact and a little after halfway between third and fourth contact. A reciprocity sequence was also taken with the backup calibration run on 13 Feb. The eclipse and 16 Feb calibration data were recorded on the same roll of film and developed together.

IV. ECLIPSE SPECTRA

The eclipse program consisted of the following sequence of 13 exposures starting just after second contact and continuing to shortly beyond third contact: (in seconds) 1, 1, 1, 2, 4, 10, 25, 30, 10, 4, 2, 1, 1. The Sun was completely free of clouds, as it was also for the calibration sequences, and we were able to execute our entire program successfully.

Figures 1 A-D are prints of the four longest eclipse exposures: 10, 25, 30 and 10 s, respectively. In each case the upper half corresponds to the west limb and the bottom half to the east limb. North is at the top for both limbs. Wavelength increases from right to left. The first order spectrum is on the right and extends about 60 percent of the full length up to the vertical break, beyond which is the second order spectrum. The line pair visible in both orders around most of the west limb corresponds to Ca^{+} H and K. The line in the middle of the first order spectrum extending around both limbs is the coronal line Fe^{13+} $\lambda 5303$. The dark horizontal trace running along the center of each print is the shadow of a retaining wire holding the film against the focal surface.

Unfortunately, the prominence activity at the limb at eclipse time was rather mediocre. The situation is reasonably well illustrated by the filtergram shown in Figure 2, which was taken about twelve hours before totality with the H coronagraph at the Mees Solar Observatory, Haleakala. The many emission lines along the tops of Figures 1 A-D are from the low-lying prominence in the north west. Though possibly not suitable for studies involving the ordinarily fainter prominence lines, these spectra should still be useful for several aspects of prominence spectrophotometry (such as the behavior of the middle-high Balmer decrement, e.g.), and we plan to make a thorough photometric reduction of the data. The high-temperature coronal line and continuum emissions, clearly evident throughout the spectra, will also be analysed as a function of position angle around the limb. At present, glass mountings for the individual eclipse and calibration frames are being prepared, preparatory to a comprehensive reduction program using the IFA microdensitometer system in Manoa.

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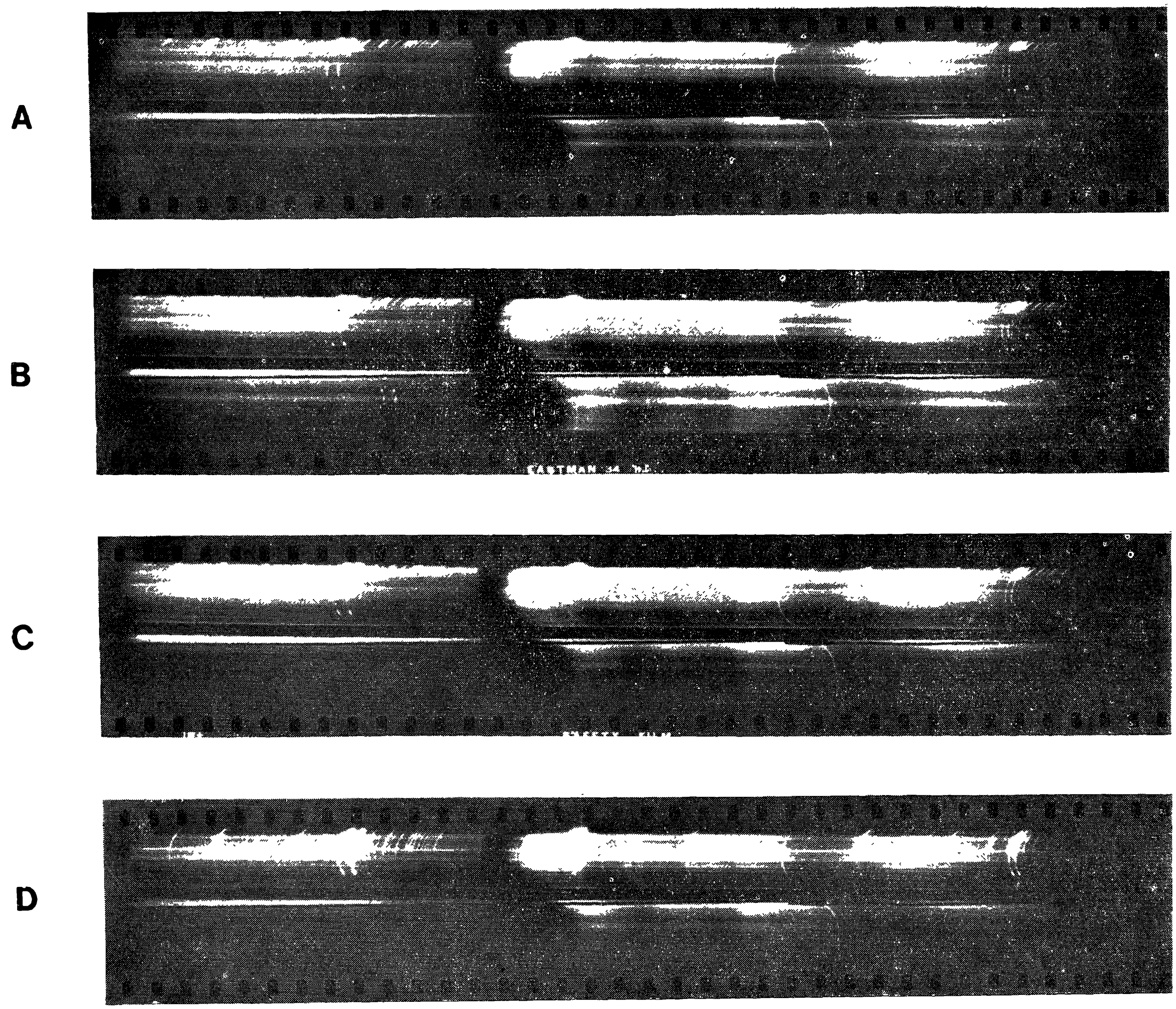

Figure 1. Eclipse spectra for our four longest exposures:—(A) 10s, (B) 25s, (C) 30s, and (D) 10s. The spectral format is described in the test.

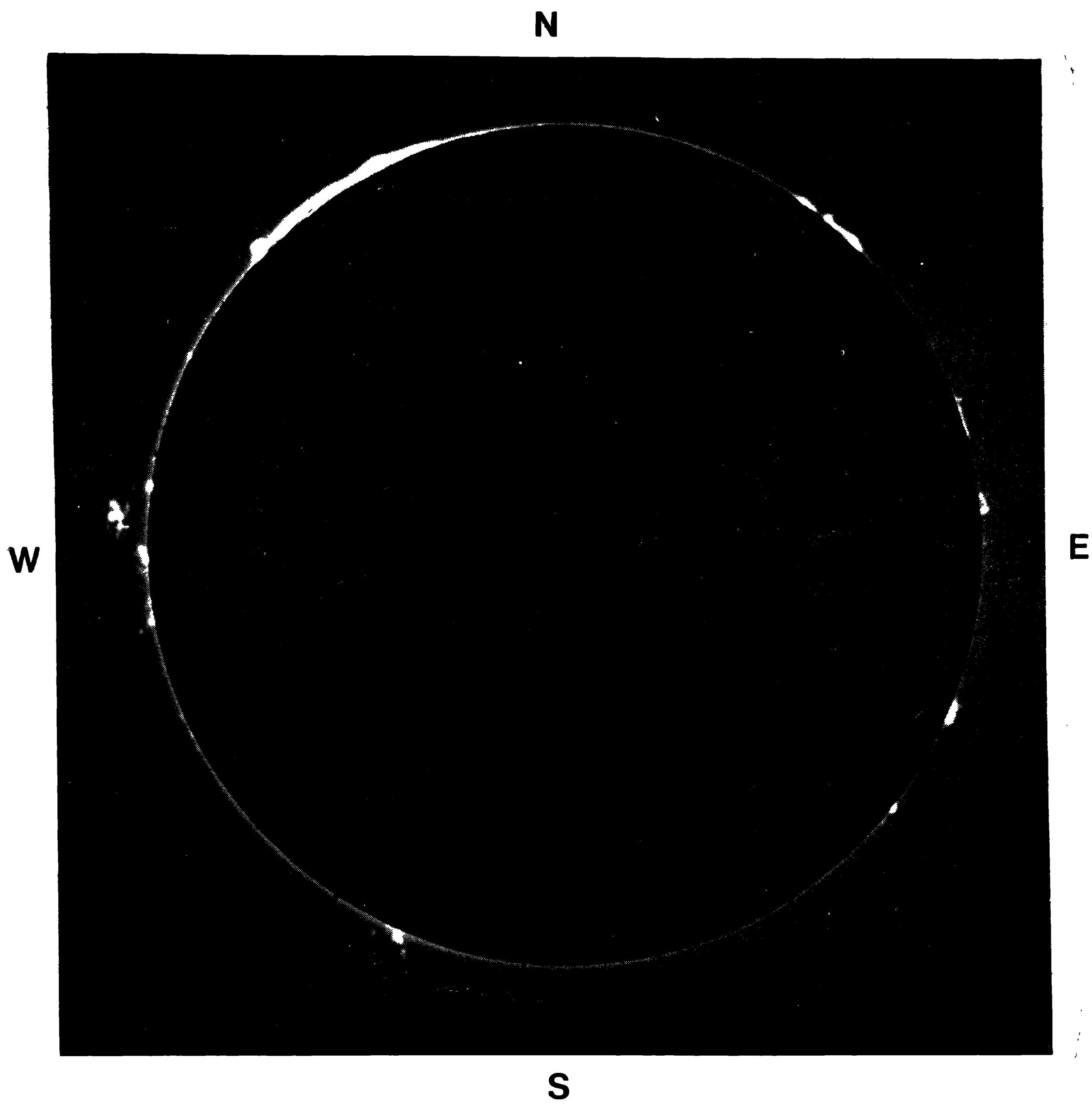

Figure 2. Hα coronal filtergram from Haleakala, taken about 12 hr. prior to totality. The extensive sets of emission lines in the upper parts of Figures 1 A-D correspond to the low-lying prominence material located on the NW limb.