Interferometric Eclipse Observations of Coronal Fe XIV Emission

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Abstract

An experiment carried out during the February 16, 1980 total solar eclipse to measure velocities and intensity distributions associated with coronal loops is described. The optical instrumentation used consisted of a 30-cm aperture Cassegrain telescope, a solid Fabry-Perot etalon, ancillary optical components and a motor-driven camera. During totality, the green corona was photographed both with and without the etalon in the system; the first maximum of the etalon beyond the limb was recorded on three frames. A preliminary discussion of the data is presented.

INTRODUCTION

The primary objective of our experiment was to determine the mass flux in magnetic loops associated with active regions in the corona, and the February 16, 1980 solar eclipse presented an attractive opportunity to obtain such observations since it occurred close to the maximum activity phase of the solar cycle. A secondary objective was to study the detailed intensity distribution of the corona in the vicinity of the limb, obtained near second and third contacts, to provide further information about where and how the energy contained in the downward mass flow is dissipated. The observations were carried out at the Japal-Rangapur Observatory, operated by Osmania University, Hyderabad, India.

Observations of coronal and prominence loops, in the EUV and at visible wavelengths, have suggested that there is significant mass motion of the plasma along loop field lines (Kopp and Pneuman 1976). Based on an analysis of the energy and pressure balance of coronal loops, Foucal (1976, 1978) has suggested that material flows from the corona, across field lines at the top of loops, and down both sides to the chromosphere, the downflow resulting either from thermal instability or from fluctuations in the deposition of non-thermal energy. His conclusions are based on a relatively small sample of optical spectra obtained at Sacramento Peak Observatory in coronal surveys between the years 1971 and 1976. His suggestions, if valid, would prove extremely interesting for the further development of ideas on mass balance, and our experiment was aimed at checking these suggestions.

Eclipse observations have been carried out using Fabry-Perot interferometers (Jarrett and von Kluber 1955, 1961; Delone and Makarova 1969; Liebenberg et al. 1975; Liebenberg 1975) to obtain emission corona line widths, and the instrumentation used in the experiment described here was similar. A principal difference was that we used a solid Fabry-Perot etalon, which has significantly greater stability than the air-spaced designs used previously. We also were concerned to obtain as high spatial resolution as possible, with interest principally in details of the inner corona. Because of the marked non-uniformities of the corona in this region, reduction of the data is substantially more complex than for data obtained further out in the corona where the distributions tends to be more uniform. We present here details of our experiment and a preliminary summary of the data obtained.

INSTRUMENTATION

The primary imaging system consisted of an f/7.7 field-corrected Cassegrain telescope, 30 - cm aperture. This system was measured interferometrically and found to have a mean wavefront error $\sim \lambda/4$ out to a semi-field angle $\sim 0.5^0$, a value which is almost twice the angular semi field covered in our experiment. Beyond the primary focal plane, a 17.8-cm focal length lens collimated the source rays and formed an image, 23 mm diameter, of the objective aperture which was also the entrance pupil. A solid Fabry-Perot etalon, with a finesse ~ 20 and a free spectral range ~ 2.7Å, was located in this image plane, with a blocking filter positioned between the collimating lens and the etalon. The filter transmission band, 12 Å FWHM, was centred, for normally incident light, at λ 5303 Å, with a peak transmittance of 0.71. The etalon was followed by a 35-mm motor-driven camera, with an f/2.5, 135-mm lens, located to form a telecentric system. The relayed solar image at the film plane was 17 mm diameter. Panatomic-X film, although slow, speed (ASA 32), was used because of its relatively high resolving power (100 - 200 lines / mm, depending on object contrast, exposure and development).

The entire optical train was mounted on a massive, equatorially mounted spar. An auxiliary co-aligned telescope, mounted on another spar face, was used primarily for monitoring the guiding precision. The guiding rate tended to drift, due in part to gear errors, and there is some possibility that a non-negligible drift occurred during the period of eclipse observations, although this is not obvious in the recorded images.

CALIBRATION

Photometric : A telescope cover containing four holes, each 16 mm diameter and covered with neutral density glass filters, produced an attenuation of 2.8 x 10^{-5} of the light transmitted by the uncovered aperture over the spectral range of the interference filter. By recording a range of exposures of the solar disk with the cover in place, exposure values appropriate for typical brightness level of the inner green-line corona were obtained. As well, a neutral density calibrated step wedge was positioned at the primary image and the image recorded, which provided additional calibration data not only as a check of the method just described, but also to give the characteristic curve of the film.

Interferometric : Provision was made to insert a mercury lamp, together with a condensing lens, diffusing screen and an appropriate filter for the mercury green line, into the optical system such that the screen was located in the primary focal plane. This allowed the circular Fabry-Perot fringes characteristic of the etalon parameters and the illumination geometry, at λ 5460.7 Å, to be recorded over an angular field identical dimensionally with that of the coronal field, apart from the negligibly small aberration introduced by the Cassegrain telescope. The etalon was designed to produce the first maximum beyond the solar limb (two maxima within the image of the solar disk) at an angular radius of 17.84′, for a wavelength of λ 5460.7 Å. The value measured was 17.93′, the difference presumably due to the phase change on reflection at the dielectric films of the etalon. Any possible dispersion of phase shift between the calibrating and operating wavelengths has not yet been measured.

Spatial resolution : The entire optical system was bench tested using an illuminated resolution traget at the focus of a collimating mirror that was coaligned with the optical axis of the Cassegrain telescope. Measurements of the recorded image showed a resolution limit <1 second of arc, consistent both with the independent measurements of the telescope wavefront aberration, and with the scale of 0.018 mm at the film plane corresponding to a 1 arc sec field angle. Hence with extremely good atmospheric seeing and an object of modest contrast, we would expect to detect detail down to 1 arc sec.

OBSERVATIONS AND PRELIMINARY ANALYSIS

Both photometric and interferometric calibration records were obtained before first contact and in the partial phases before and after totality. During the total phase, which lasted 128s, a sequence of exposures were obtained according to a set program, triggered by a remotely located photographic timer. Exposures were obtained immediately following second contact and just prior to third contact, without the etalon in the optical path. The angular resolution in the recorded images is estimated to be between 2 and 3 arc sec, and some loop structures are clearly evident. One isolated single loop, extending to a height of 2.7 x 10^4 km, is clearly recorded in the exposure obtained just prior to third contact and is close to the position angle of the first part of the disk to be exposed at the end of totality. Although microdensitometer tracings are required for confirmation, a visual inspection indicates that one leg of the loop disappears, or almost so, before reaching the limb.

In the intervening period which represented the major part of totality, the main experiment was carried out with the etalon inserted in the optical path. Exposures at 15s, and 45s reveal the first maximum in the etalon transmission function. Although not crucial to the experiment, it was hoped to record also the next maximum further out in the field. Apparently a much longer exposure time would have been required for this, since the images obtained without the etalon indicated that the green-line corona was less extensive than usual for this phase in the solar cycle.

One of the images obtained with the etalon in the optical path is reproduced in Fig.1. To highlight the maximum region, an image of the corona without the etalon has been subtracted from one with it. This subtraction is poor however, due primarily to the different contrast ratio in details in the two images. Although the optical system was adjusted such that the interference pattern was precisely concentric with the solar disk prior to first contact, Fig. 1 reveals an eccentric location of the maximum fringe. Of several possible explanations (tracking error, a systematic variation of radial flow with position angle, or an instrumental effect), we consider the last most likely at this time.

Finally, while the eclipse records are rich in structure detail, precise information cannot be simply extracted, since this detail itself complicates the reduction. Therefore, to deduce accurate line profiles and line shifts, especially in the vicinity of loops, requires microdensitometer scans and computer processing of the data. This work is proceeding.

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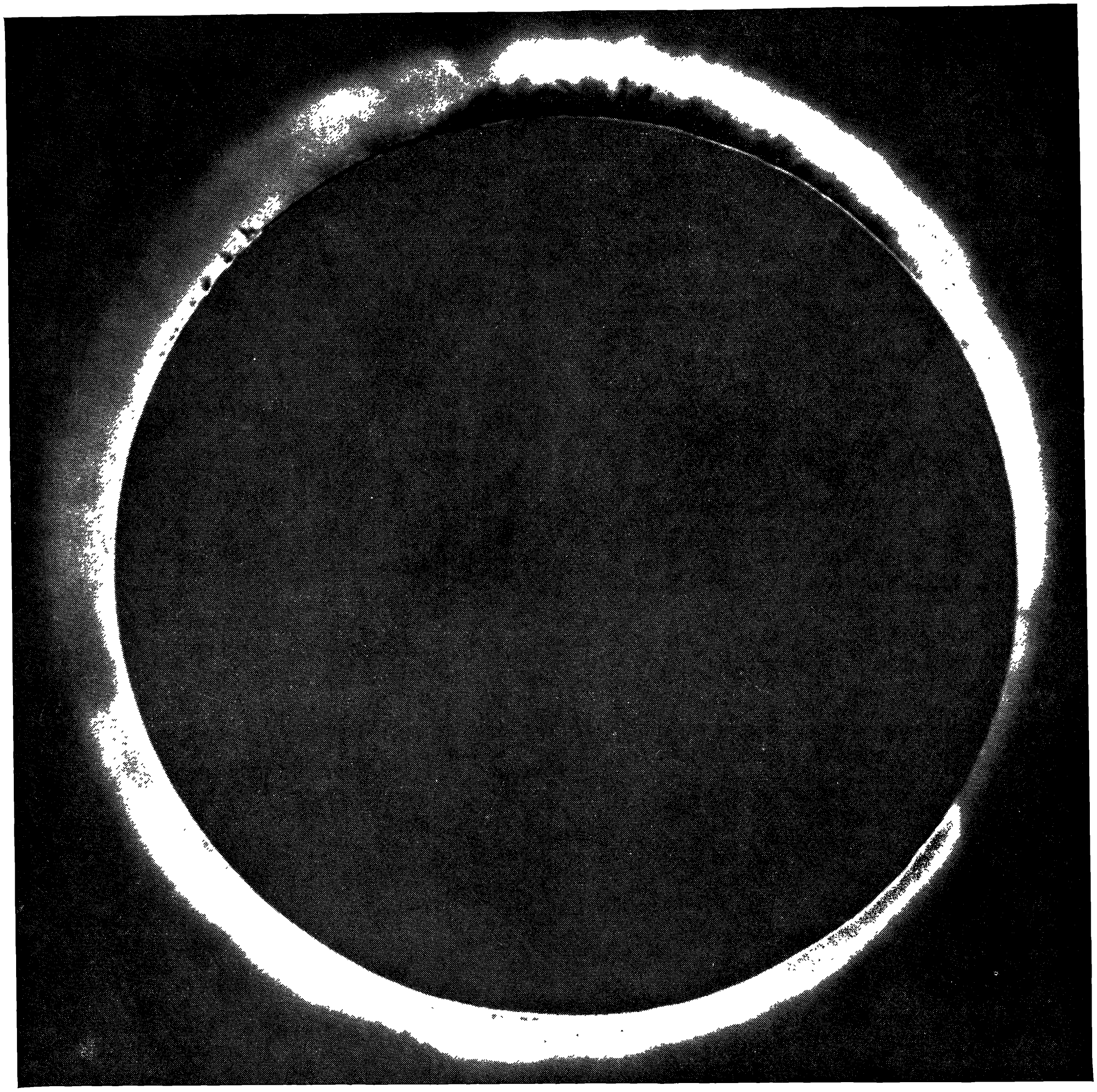

Fig. 1: Eclipse image of the Fe XIV coronal emission convolved with a Fabry-Perot etalon circular transmission function.

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