Indian J. Phys. **76B (5)**, 609–613 (2002)

I J P B
- an international journal

No evidence of circumsolar dust ring during solar activity minimum phase

Debi Prasad Choudhary[1]*, Ashok K Ambastha[1], K R Murali[2] and N G Vashant Kumar[2]
[1]Udaipur Solar Observatory/PRL, Udaipur-313 001, Rajasthan, India
[2]Space Application Centre, Ahmedabad-380 053, Gujarat, India
E-mail : debi@prl ernet.in

Received 13 June 2001, accepted 16 May 2002

Abstract : A circumsolar dust ring is believed to be situated at 4 $R_\odot$ and temporally variable in anti-phase with the solar activity cycle The observable signatures of such a ring is : (i) its thermal radiation in near IR and (ii) a highly polarised scattered solar radiation by the ring constituents During the past attempts the ring signatures were mostly observed at the time of the solar activity minimum phase. Extensive observations at the time of 1991 total solar eclipse did not show any signature of the circumsolar dust ring The 1995 total solar eclipse in India provided a unique opportunity to test the "solar activity dependence" hypothesis for the existence of the dust ring We designed a computer-controlled, laboratory calibrated, wide-field imaging polarimeter to make measurements through three filters centred at 6500, 8100 and 9500 Å for detecting the ring signature The polarimeter was calibrated using various laboratory test facilities at Space Application Centre The experiment was carried out at Kalpi, UP during the 24 October 1995 total solar eclipse The observed coronal polarization and surface brightness were found to be consistent with the overall expected corona at the solar minimum phase We report that no ring signature was observed by our experiment and conclude that the circumsolar dust ring might be a temporary feature

Keywords : Dust ring, interplanetary dust, solar eclipse

PACS Nos. : 95.10 Gi, 96 50 Dj, 96 60.Pb.

1. Introduction

A dust ring is believed to be located around the sun at a distance of 4 $R_\odot$ as a consequence of the dynamics of the interplanetary dust particle (IDP) [1] or due to the tidal disruption of a hypothetical planet inside the Mercury's orbit [2]. The observational signature of such a ring can be thermal emission of the constituents peaking at a wavelength of about 2-micron and enhanced polarization of scattered sunlight by IDP at nearly 90°. During the last 30 years, several experiments have attempted to detect both these components during total solar eclipse and non-eclipse period. These ring signatures were detected during some occasions, whereas during several other observations no such signal was found to exist. During 1991 total solar eclipse over Mauna Kea, many experiments using 2-D IR array detectors were conducted which, did not record the excess infrared radiation due to the dust ring [3,4]. Also during the same eclipse, the optical polarization observations did not show excess polarization attributable to the ring [5]. The negative results from these experiments were thought to be due to the destruction of ring particles by solar activity [6,7]. Consequently, this study also showed that a well-planned experiment during solar eclipse minimum phase might positively show the ring signature. The total solar eclipse of 24 October 1995 occurred during the solar eclipse minimum phase giving an opportunity to test the "solar activity dependence of the dust ring" hypothesis. Therefore, Udaipur Solar Observatory (USO) and Space Application Centre (SAC) to detect both these signatures of dust ring and verify its solar activity dependence, designed an experiment. The analyses of the data from this experiment show that whereas the overall coronal signature was consistent with the solar minimum corona, no significant feature existed, which could be attributed to the dust ring. In this paper,

---

*Corresponding Author

we present the details of experimental set-up, observations and discussion of the results of our 24 October 1995 eclipse experiment. We also re-examine the solar activity dependence of the ring signature and find that out of 13 experiments, during five attempts there were reports of positive detection. These five observations are spread over the entire phase of the solar activity cycle. This might indicate that the ring might not be a permanent feature of the solar system, rather short lived transient phenomena.

2. Experimental set-up and observations

The USO-SAC experiment was aimed at imaging the corona in the near infrared waveband 9500 Å and for measuring the linear polarization of the coronal light at the waveband of 6500, 8100 Å. Accordingly, we designed and fabricated an imaging polarimeter, the schematic layout of which is given in Figure 1. The parameters of the instrument are listed in Table 1. The entire 4° × 6° field-of-view was imaged on a 576 × 384 pixel CCD (Thompson chip Th 7863), using a 8mm f/2.8 Hasselblad objective lens through different Polaroid and lens combinations. The Polaroid filters were mounted on a wheel at polarising axis orientations of 0°, 120° and 124° respectively. The positioning of the desired Polaroid and interference filters in front of the objective lens was achieved with two stepper motors driven by a specially designed electronic unit. Dedicated computer software and hardware performed the complete sequence of operations for controlling the stepper motor rotation and image acquisition. The observing sequence during the totality of the eclipse was such that it required two times change in filter and six time change in Polaroid mounted on respective wheels. The time taken for changing the filter and Polaroid was about five seconds, so that we could get 50 seconds of observing time during the actual experiment.

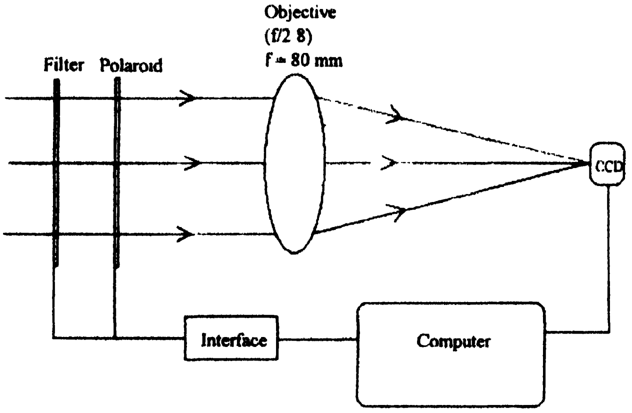

Figure 1. Schematic of the optical lay out of the solar eclipse polarimeter

Table 1. Instrumental parameters.

Parameter	Value
Field of view	4° × 6°
Spatial resolution per pixel	23 arc-second
Filters for polarization measurements	6500 Å and 8100 Å
Filter for imaging	9500 Å
Polarising filters :	
Mean polarization for unpolarized white light	33%
Total transmittance for two in parallel :	20%
Crossed :	0.002%
(*i.e.* Extinction is 1 : 10000 for a degree of polarization of 99.99%)	
Filter changeover time	0.5 second

The calibration of the polarimeter was carried out using various facilities available at Space Application Centre (SAC), Ahmedabad. In order to estimate the noise introduced due to the variation of sensitivity of pixels, the CCD was uniformly illuminated through the filters and Polaroid by an integrating sphere. Images were captured through the frame grabber. The mean and standard deviation of all pixel values of 64 image frames were calculated. The signal to noise (S/N) of the detector is defined as (mean/standard deviation), which is about 90% in IR, 29% in B3 and 55% in B4 through the Polaroid. The absolute flux calibration of the polarimeter was made by using a standard source, integrating sphere (*Photoresearch make*) and a Ground Truth Radiometer (GTR). The output of GTR was recorded for different settings of the standard source. Next, the Integrating Sphere at a given current supply replaced the standard source. Using the standard source GTR output values the Integrating Sphere was calibrated. Without altering the settings of Integrating Sphere the Polarimeter was placed in front of it and calibrated. By adjusting the amplifier gain of the CCD, it was found that the lowest flux that can be measured by the polarimeter, with acceptable noise, is 0.4 erg cm^{-2} μ^{-1} s^{-1} sr^{-1}, which is about three times lower than the flux expected from the dust ring (estimated from earlier observations).

The experiment was successfully performed during the total solar eclipse of 24 October 1995 from Kalpi, UP (Long : 79° 44′, Lati : 26° 7′). The Kalpi site was selected by a pilot USO team for eclipse observations due to its relatively longer totality duration compared to the more populat site, Neem Ka Thana, in Rajasthan. The totality period had perfect weather and clear sky conditions. The expected duration at Kalpi was reported to be around 61 seconds, whereas, at the actual camping site of our experiment, it was only about 55 seconds, which was still sufficient to complete all the steps of our observations. The data was recorded by a video recorder at a rate of 25 frames per second. The video data was digitized by the *Imaging Data Acquisition System* at USO.

3. Data analysis

Each image was corrected for laboratory determined transmission levels of the optical components and the detector efficiency. The linear polarization related Stokes parameters were determined using the well-known transmission matrix of a linear Polaroid [8]. Following simple algebra it can be shown that if I_1, I_2 and I_3 are three images obtained through the Polaroid filters, positioned at the orientations of 0°, 120° and 240° respectively, Stoke's parameters of the transmitted light are :

$I = 2/3\,[I_1 + I_2 + I_3]$ = Total light intensity,

$Q = 2/3\,[2I_1 - I_2 - I_3]$ = Twice the intensity transmitted by a linear polaroid at 0° minus I,

$U = 2/\sqrt{3}\,[I_2 - I_3]$ = Twice the intensity transmitted by a linear polaroid at 45° minus I.

Then the degree of polarization P and angle θ in equitorial coordinate system are given by,

$$P = \sqrt{[Q^2 + U^2]}/I \qquad \theta = \tfrac{1}{2}\tan^{-1}[U/Q].$$

4. Discussion

The isophots of the near infrared image taken at the waveband of 9500 Å is shown in Figure 2a. As may be noticed, the shape of the corona is consistent with a typical minimum phase corona-flattened along the poles, while extended in the equatorial direction. We were able to detect the coronal signal up to a region beyond 5 $R_\odot$. The inner corona was saturated up to 1.0 and 0.5 $R_\odot$ in the equatorial and polar directions respectively. The southern side of the image suffered from instrumental scattered light. The overall morphology of the image corresponds to the solar corona of minimum activity phase. The intensity profiles obtained from the image taken through filter at 9500 Å are shown in Figure 2b. This wavelength is closer to the wavelength at which the peak corresponding to the ring was reported earlier [9]. However, in our experiment ring signature was not found at this wavelength. Figure 3a shows isophots of the image taken at 6500 Å. Radial profiles of average

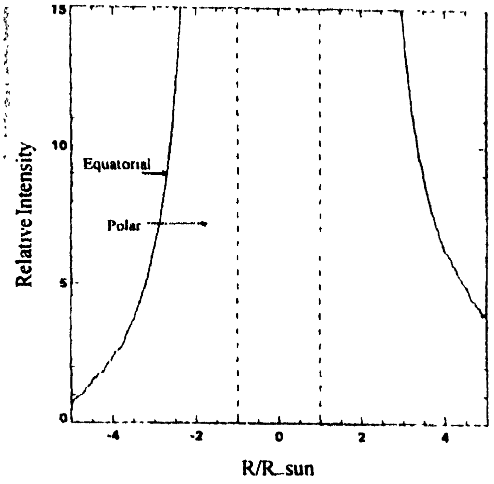

Figure 2b. Radial profiles of the image in 9500 Å The average intensity along the polar (dashed) and equatorial (solid) directions are obtained by averaging the intensities aver 12 pixels lying in the respective perpendicular directions.

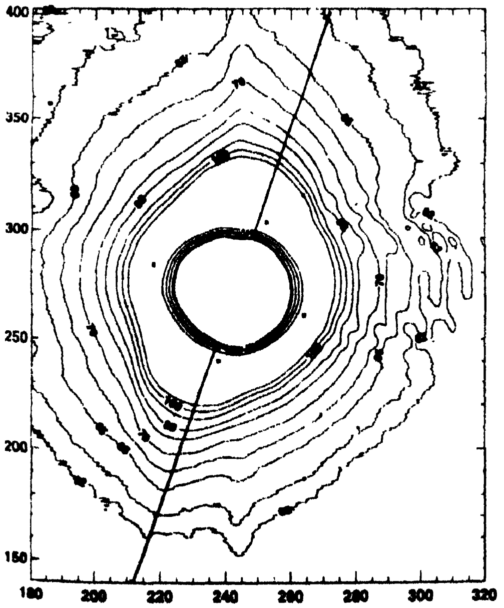

Figure 2a. Contours of equal intensity of the image of the solar corona taken through the filter centred at 9500 Å on 24 October 1995. The contour intensities are as labelled. A thick line shows the ecliptic plane. The ordinate and abscissa are the original pixel numbers of the CCD image.

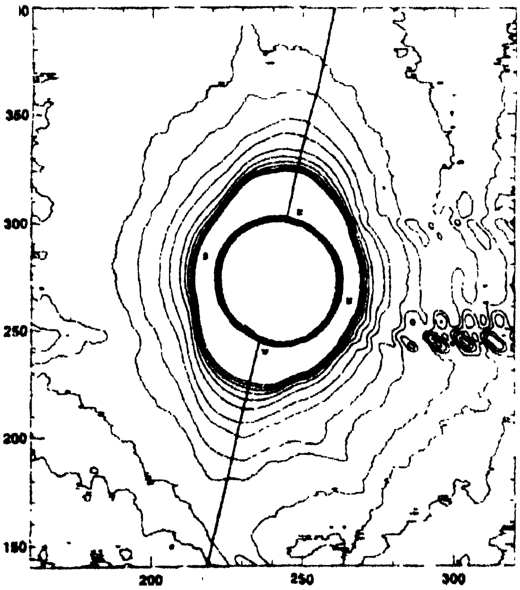

Figure 3a. Contours of equal intensity of the image of the solar corona taken through the filter centred at 6500 Å on 24 October 1995. The contour intensities are same as labelled in Figure 2a. A thick line shows the ecliptic plane. The ordinate and abscissa are the original pixel numbers of the CCD image.

intensity along the polar and equatorial directions were obtained by averaging the intensities over 12 pixels lying in the respective perpendicular directions as shown in Figure 3b. It is seen that the average flux in the equatorial direction is larger than that in the polar direction at any given distance from the centre of the sun's disk. Furthermore, it is observed that there is an asymmetry in coronal flux along the east-west direction. We notice a conspicuous peak at around 5 R⊙ towards the west in the equatorial intensity profile. A careful examination revealed that this feature is due to instrumental artefact. Therefore, we conclude that no significant enhancement over the general coronal intensity was observed at around 4 R⊙, which could be attributable to the circumsolar dust ring.

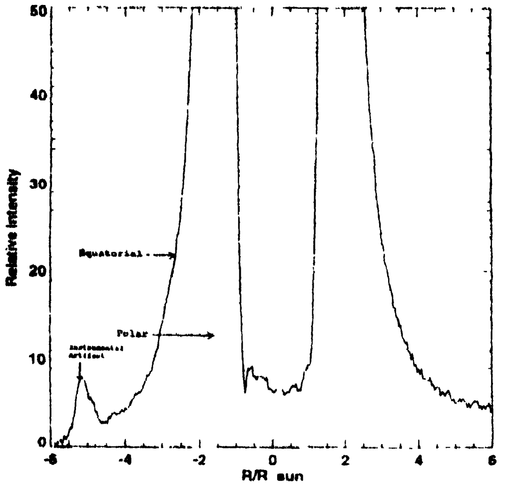

Figure 3b. Radial profiles of the image in 6500 Å The average intensity along the polar (dashed) and equatorial (solid) directions are obtained by averaging the intensities aver 12 pixels lying in the respective perpendicular directions. The peak seen at –5 R⊙ in the equatorial plot is due to the instrumental defect explained in the text.

Figure 4 shows the polarization map of the corona. The contours correspond to the degree of linear polarization and the line-segments represent the magnitude and direction of the polarization. It may be noticed that the polarization along the equatorial direction is stronger than in the polar direction. In general, our polarization measurements are consistent with the previous observations. There are some areas of large polarization away from the regions enclosed by contours. It is to note that the signal at these locations was considerably weaker leading to large errors in the measurements. In the inner region the typical error is about 1%. The present aim, however, is to illustrate that in addition to the intensity map at 9500 Å the polarization map also does not show any enhanced polarization corresponding to the dust ring at the expected locations marked by the circles. Our observations, therefore, show that no signature of the circumsolar dust ring was present during the 24 October 1995 total solar eclipse at λ = 6500, 8100 and 9500 Å. It would imply that at least during this period, the observable signals due to dust particles were not significant.

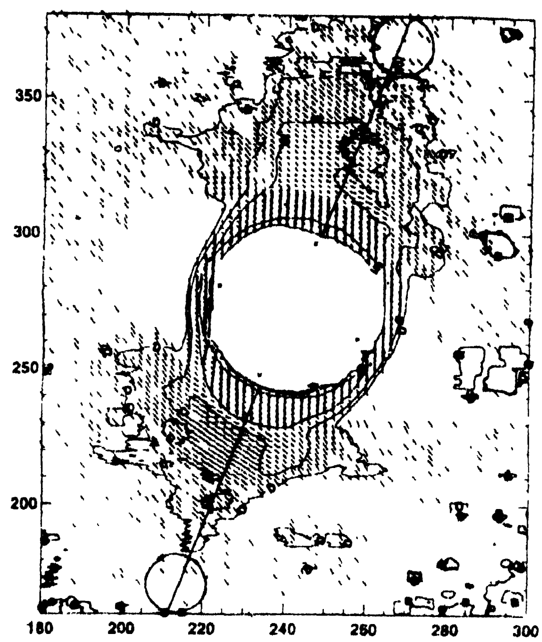

Figure 4. The polarization map of the corona. The contours correspond to the degree of linear polarization and the line segments represent the magnitude and direction. The hatched region is saturated inner corona The two small circles along the equatorial plane are the expected positions of the dust ring. The contours A, B, C and D are the degree of linear polarization in the descending order. The bars represent the magnitude and direction of polarization The value of the polarization at the longest bar is 10% The ordinate and abscissa are the original pixel numbers of the CCD

Figure 5 shows the summary of circumsolar dust ring observations during last 30 years as a function of the phase

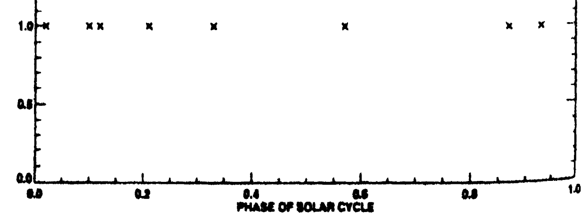

Figure 5. Detection of the circumsolar dust ring as a function of the solar activity cycle derived from experiments conducted over last 30 years The maximum phase is represented by one and minimum phase by 0 We represent the positive detection of ring feature during a particular experiment '+' sign and negative detection by 'x' sign (weighted by 1 0 and 2 0 respectively).

of solar activity. The maximum phase is represented by one and minimum phase by 0. We represent the positive detection of ring feature during a particular experiment '+' sign and negative detection by 'x' sign (weighted by 1.0 and 2.0 respectively). The figure shows that the numbers of experiments are well spread over the entire solar activity phase. During 8 of the 13 experiments the ring feature was not observed, whereas during 5 experiments there was positive detection of the ring feature on the solar activity cycle is not apparent. Assuming that the positive reports of the detection of the ring feature are real, we may conclude that the circumsolar ring is highly transient. The dust released by moderately sized comets falling on to the sun [10] perhaps could generate such rings, with a very short lifetime.

5. Summary and conclusions

We have successfully conducted an experiment during 24 October 1995 total solar eclipse for imaging the solar corona at 9500 Å and measured the polarization of circumsolar radiation at 6500 and 8100 Å. We have detected the coronal signal up to 5 $R_\odot$ in the equatorial direction. The following conclusions have been derived from this experiment.

1. The observations do not show the enhanced signal in 6500, 8100 and 9500 Å at 4 $R_\odot$.
2. The polarization map of the inner corona was found to be consistent with other previous measurements without enhanced polarization at 4 $R_\odot$.

Therefore, the present study does not support the existence of a circumsolar dust ring, which is made up of the interplanetary particles and is variable depending on the solar activity cycle. However, we can not completely rule out the possibility of the existence of such a ring structure, which might be transient in nature, and may be generated due to the break up of the sun grazing comets.

Acknowledgments

We acknowledge the keen interest shown by Dr. K Kasturirangan in this experiment. The encouragement from Dr. A Bhatnagar, Dr. George Joseph, Dr. Kiran Kumar and Dr. K S Dasgupta is acknowledged. Thanks are also due to P Khekale, B K Sharma of SAC and S K Gupta, Naresh Jain and B L Paneri of USO/PRL for their help in integrating the hardware and software.

References

[1] M J S Belton *Science* **151** 35 (1966)

[2] K Brecher, P Morrison and I Wasserman *Nature* **282** 50 (1979)

[3] P Lamy, J R Kuhn, H Lin, S Koutchmy and R N Smartt *Science* **257** 1377 (1992)

[4] H Klaus-Werner, R M MacQueen and D N D Hall *Nature* **355** 1992 (1992)

[5] T Tanabé, F Tsumuraya, N Baba, M Alvarez, M Noguchi and S Isobe *Publ Astron. Soc Japan* **44** L221 (1992)

[6] C Debi Prasad *Sol Phys* **159** 181 (1995)

[7] S Isobe and A S Kumar *Astrophys & Space Sci* **205** 297 (1993)

[8] K Serkowski in *Planets, Stars and Nebulae Studied with Polarimetry* ed T Gehrels (Arizona Tucson : The University of Arizona Press) p 145 (1974)

[9] M Mizutani, T Maihara, N Hiromoto and H Takami *Nature* **312** 134 (1984)

[10] K Hodapp, R M MacQueen and D N B Hall *Nature* **355** 707 (1992)