INFRARED CORONAL OBSERVATIONS AT THE 1991 SOLAR ECLIPSE

R. M. MACQUEEN
Rhodes College, 2000 North Parkway, Memphis, TN 38112, U.S.A.
and
K-W. HODAPP and D. N. B. HALL
University of Hawaii, 2680 Woodland Drive, Honolulu, HI 96822, U.S.A.

Abstract. Observations of the solar corona in a narrow band filter at wavelength 2.12 μm during the total solar eclipse of 11 July 1991 are described, and compared with results obtained by two observers during the eclipse of November 1966, and shortly thereafter. The lack of any observable signature of thermal emission in the 1991 results suggests that during 1966/67, the near-solar environs were subjected to a locally enhanced dust population, supplied by one or more sungrazer comets. Possible conditions which match the observational circumstances are discussed.

Key words: eclipses – infrared: stars – interplanetary medium – Sun: corona

1. Introduction

We have recently reported the initial analysis of results of near infrared observations of the solar corona obtained at the total solar eclipse of 1991 (Hodapp, MacQueen and Hall, 1992; hereafter referred to as Paper I). In that report, we present observations obtained with a narrow band filter at wavelength 2.12 μm from among observations carried out in the J, H, and K bands.

In this report, we elaborate further on the above observations, compare these current results with some prior results, and discuss possible causes for the differences between observations at the 1966 and 1991 total solar eclipses.

2. Observations

Details of the instrument are presented in Paper I. Particular attention was paid to eliminating any possibility of spurious artifacts which might be interpreted as signatures of thermal emission from circumsolar dust. To address this potential problem we placed an occulting disk in front of the 1-cm diameter CaF_2 objective lens of the *NICMOS* camera. The serrated occulter subtended an angular diameter of 90 arcmin, or 2.5 $R_\odot$ from sun center. Tests of this system were carried out at the time of nearly-full moon, on June 27, 1991 and the results indicated that in the K band, the radiance of diffracted light on the disk periphery was less than 10^{-3} that of the moon. In addition, no artifacts were present in the instrument field to at least a factor of 10^{-2} times the level of the diffracted light. These results held for pointing accuracies of up to 0.4 $R_\odot$; only at the point when extreme offset pointings of about 0.8 $R_\odot$ were carried out could artifacts be identified. These precautions ensured that no spurious instrumental artifacts would be identified as thermal emission features.

Sky conditions during totality, and throughout the day of eclipse, were substandard for the Mauna Kea site. The presence of both Mt. Pinatubo volcanic dust and cirrus clouds limited the quality of observations during totality and quality and

D. M. Rabin et al. (eds.), *Infrared Solar Physics*, 199–203.

quantity of calibrations. The cirrus clouds present during totality drifted rather rapidly through the field of view of the instrument, gradually clearing over this period. As a result, data obtained during the latter portion of totality was less influenced by the effects of the cirrus than that obtained earlier. Thus, initial data reduction has emphasized frames obtained late in the period of totality, especially a 10- second narrow band 2.12 μm filter exposure obtained just prior to third contact.

The 2.12 μm image presented in Paper I exhibits the usual features of the solar K- and F-coronal components. The structured K-corona is dominated by prominent coronal streamers whose bases lie close to the solar east and west limbs, as determined by comparison of eclipse images and High Altitude Observatory K-coronameter maps (Sime and Streete, 1992).

The unstructured F-coronal and background K-coronal contribution is concentrated in (or near) the ecliptic plane. Figure 1 presents equatorial and polar radial scans of the 2.12 μm coronal radiance observed at the 1991 eclipse and, for comparison, near-equatorial radial scans at wavelength 2.2 μm reported from independent observations at the 1966 eclipse (Peterson, 1967; MacQueen, 1968). The latter measurements differ in their absolute radiances by a factor of three. The current 1991 observations more closely agree with the radiances obtained by Peterson, while those of MacQueen (1968) are lower by about a factor of three. As noted in Paper I, the current results have been calibrated by direct observation of α Lyra and α Boo in the 2.12 μm filter, employing the results of Strecker, et al. (1979). This straightforward procedure is inherently more reliable than the calibration procedures required in 1966, and despite sky variations, we adopt the current values.

The comparison of the 1966 and 1991 radial falloffs in Figure 1 vividly shows the relative smoothness of the current results compared to the earlier observations. There is no hint of a signature of thermal emission in the current results. As we have reported, we estimate that the upper limit for such a signature is roughly a factor of twenty smaller than the signature observed in 1966 by MacQueen, and thus about a factor of fifty smaller than that reported by Peterson.

3. Discussion

Although the 1966/67 observations were carried out with single element detectors, it is difficult to picture how the radial scans carried out by the two investigators could have intercepted any extant K-coronal feature whose signature could have been attributed to thermal emission. White light images of the corona at the 1966 eclipse confirm that there were no visible coronal mass ejections (undiscovered until the late 1960's) or anomalous K-coronal features present. And, the presence of a similar (but not exactly identical) feature about 8 weeks after the total eclipse, observed with an infrared balloon-borne coronagraph, lends additional credence to the reality of the feature. Likewise, K-coronameter scans from early 1967 revealed only typical coronal features, and even no bright streamers on the relevant solar limb.

In Paper I we summarize efforts prior to 1991 to observe a coronal dust emission signature. Since the 1966/67 observations remain the most unambiguous detection,

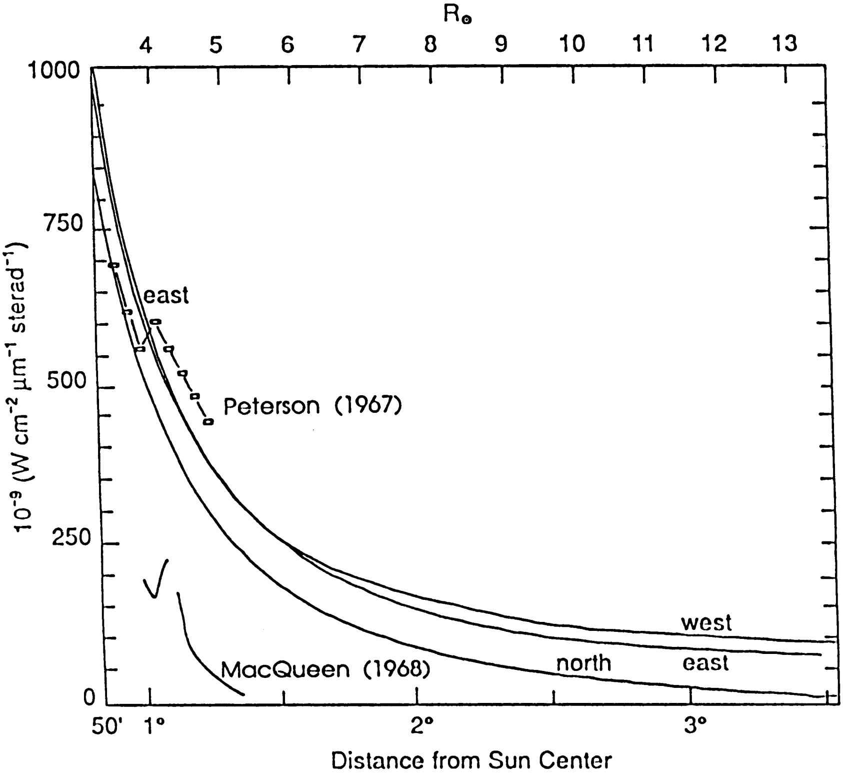

Fig. 1. Radial scans of the near infrared coronal radiance observed on the east, west and north solar limbs at the 1991 eclipse, and equatorial scans by observers at the 1966 eclipse.

we address the question of what variable input to the interplanetary dust population could have been responsible for features at that time, but not later (certainly not in 1991).

The time scale for capture of interplanetary dust is generally far in excess of the several-decade time scale required to explain the variation between 1966/1967 and 1991. However, one possibility of short-term injection of dust into the near-solar environment involves that from sungrazing comets, and we briefly explore this possibility in the following paragraphs.

The appearance of smaller members of the so-called Kreutz group of sungrazing comets is now known to be highly episodic on an annual basis (MacQueen and St. Cyr, 1991). Space-borne coronagraphs have been responsible for the detection of the majority of this class of comet; during a little less than a decade, sixteen sungrazer comets were so observed. To date, no ground-based observing methods have revealed these smaller members, either near the sun, or deeper in space.

The appearance of a Kreutz group member near the sun is similar to that of more usual comets whose perihelion passage is not near the solar surface. However, sungrazer comets apparently do not survive perihelion passage: no such comet has been observed to emerge from the near-solar region occulted by the space-borne coronagraphs. However, using the orbital elements of the Kreutz group, it was shown that these small comets apparently survive perihelion approach down to a distance of about 3 $R_\odot$ without discernable effects (MacQueen and St. Cyr, 1991). With one spectacular exception (Michels, et al., 1982), coronagraph observations do not reveal any visible light effect of the disappearance of the comets near perihelion.

Could a sungrazing comet (or comets) be responsible for the near infrared signatures of 1966/67? This possibility requires at least that (a) such small members of the Kreutz group contain sufficient material to account for the required local enhancement of near-solar dust, based upon thermal emission models of the corona, and (b) such a density enhancement not be apparent in the visible wavelength region, dominated by scattered radiation.

Mukai and his collaborators (Mukai, et al., 1974; Mukai and Yamamoto, 1979; Mukai, 1985) have investigated the dust density enhancement required to approximately match the infrared signatures observed in the 1966/67 period. Following Belton (1966), they have suggested that the circumsolar dust orbits, initially determined by the action of Poynting-Robertson drag, may, upon the onset of sublimation, become stabilized and a locally-enhanced dust region result. Mukai and Yamamoto (1979) suggested that a local enhancement of a factor of 5-10 would be required to match the observed 4 $R_\odot$ signature.

To estimate the F-coronal dust mass requires that we specify the dust particle size distribution, space distribution and dust mass density. For the former, we assume the distribution given by Lamy and Perrin (1986): a two-component distribution (Population I and Population II) of large and small particles, each separately with power law falloffs. For the space distribution of dust, we assume that the number of particles per cm^3 varies with distance from the sun as r^{-q}, with the index q equal to 1.0 or 1.3 (Lamy and Perrin, 1986). Finally, we assume a mass density $\rho =$ 2.5 gm cm^{-3}, (Giese, 1961). If we consider a local coronal volume of approximate dimensions 0.2 $R_\odot$ wide, centered on a distance 4 $R_\odot$ from sun center, 4 $R_\odot$ along the line of sight and extending 2 $R_\odot$ in heliographic latitude, that volume would contain approximately 10^6 grams of dust.

This total mass could be easily supplied by even a small member of the Kreutz sungrazer comet group. For example, MacQueen and St. Cyr (1991) estimated that, on the assumption that these comets fully sublimed during perihelion passage, the smallest sungrazing comet was only about 30 meters in diameter. Even such a small member of the Kreutz group could provide roughly 10^{10} grams of material – more than adequate to achieve the above local enhancement of the F-corona, or to enhance a larger volume.

The visibility of such a near-solar dust enhancement depends upon the nature of the scattering properties of the material. Generally, however, dust far from the sun contributes significantly to the F-coronal scattered radiance (forward scattering), while that close to the sun less so (scattering at nearly 90°). To assess the potential contribution of a locally enhanced region of the solar F-corona, we have computed the line-of-sight brightness of an element 4 $R_\odot$ along the line of sight, placed at a distance of about 4 $R_\odot$ from sun center, relative to the total line of sight contribution of all dust. For this computation, we have employed the material properties of pyrrhotite (Perrin and Lamy, 1989) as approximating that relevant to Population II zodiacal cloud material. Population I material has been represented by the complex index of refraction of chondrite (Perrin and Lamy, 1989). The volume scattering functions and line of sight radiance have been computed using the Mie scattering intensities, from a newly developed code (MacQueen and Greeley, 1992).

We find that the 4 $R_\odot$ volume element contributes between 2-3 × 10^{-3} that of the full line of sight F-coronal radiance, and thus a dust enhancement of a factor of 5 would contribute at most roughly 1% to the visible wavelength radiance of the $K+F$ coronal radiance–at or below the limit of detectability of visible wavelength eclipse observations.

As a result, we conclude that it is possible to explain the appearance of an infrared signature of thermal emission of dust at the eclipse of 1966 by injection of an enhanced dust population from a sungrazing comet. However, to explain the presence of the observed features in early 1967, about two months after the eclipse, is more difficult; it is surely unlikely that additional sungrazing comets were responsible for a second transient appearance of a thermal emission signature. Alternatively, the injection of dust provided by a single comet may reside near the sun for an extended period, but as noted in Paper I, we are unaware of any calculations of the dynamics of such dust.

References

Belton, M.J.: 1966, *Science,* **151**, 35-44.

Giese, R.H.: 1961, *Zeits. fur Astrophys.,* **51**, 119-147.

Hodapp, K-W., MacQueen, R.M. and Hall, D.N.B.: 1992, *Nature,* **355**, 707-710.

Lamy Ph. and Perrin, J-M.: 1986, *Astron. Astrophys.,* **163**, 269- 286.

MacQueen, R. M.: 1968, *Astrophys. J.,* **154**, 1059-1076.

MacQueen, R.M. and St. Cyr, O.C.: 1991, *Icarus,* **90**, 96-106.

Michels, D.J., Sheeley, N., Howard, R., and Koomen, M.J., 1982: *Science,* **215**, 1097-1102.

Mukai, T., 1985: in R. Giese and Ph. Lamy (eds.), *Properties and Interactions of Interplanetary Dust,* pp. 59-62.

Mukai, T., Yamamoto, T., Hasegawa, H., Fujiwara, A. and Koike, C.: 1975, *Pubs. Astron. Soc. Japan,* **26**, 445-458.

Mukai, T. and Yamamoto, T.: 1979, *Pubs. Astron. Soc. Japan,* **31**, 585-595.

Perrin J-M. and Lamy, Ph.: 1989, *Astron. Astrophys.,* **226**, 288- 296.

Peterson, A.W.: 1967, *Astrophys. J.,* **148**, L37-L39.

Sime, D. and Streete, J.L.: 1992, (in preparation).

Strecher, D.W., Erickson, E.F., and Witteborn, F.C.: 1979, *Astrophys. J. Supp. Ser.,* **41**, 501-512.