A COMPARISON OF THE INTENSITIES OF INFRA-RED AND VIOLET RADIATION FROM THE SOLAR CORONA AT THE ECLIPSE OF 1952 FEBRUARY 25

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Summary

Measurements made in Khartoum at the total solar eclipse of 1952 February 25 show a considerable excess of infra-red radiation in the solar corona at 2.5R⊙ from the solar centre. The ratio

$$\frac{I(1.9\mu, 2.5R⊙)}{I(0.43\mu, 1.5R⊙)}$$

equals 2.17, where $I(p, q)$ is the intensity of the corona at the wave-length $p$ and distance $q$ from the Sun. The measurements were made with a 20-in. mirror of 45 in. focal length, using a lead sulphide cell and a photomultiplier. It is shown that the infra-red excess supports the current theory of an F-corona caused by diffraction of sunlight by a cloud of interplanetary dust particles. Three models with widely differing distributions of dust are calculated but it is not possible to distinguish between them by using existing infra-red and visible data alone.

Introduction.—It has been supposed by several authors (1, 2, 3, 4) that two scattering mechanisms contribute to the light of the solar corona. The two coronas that they form have been designated F and K, the former being due to diffraction by interplanetary dust particles and the latter to scattering by free electrons at a kinetic temperature of about $10^6$ degrees. The observations made in Khartoum at the eclipse of 1952 were designed to test this theory and provide further data for determining the size and distribution of the dust particles. They consisted of the measurement of the ratio of coronal brightness at $1.9\mu$ to that at $0.43\mu$ at as many positions as possible.

Equipment.—Radiation from the corona was received by an equatorially mounted 20-in. reflecting telescope of 45 in. focal length, at the prime focus of which was the detector unit shown in Fig. 1. In this unit, radiation from a selected portion of the coronal image was focused directly on to a lead sulphide cell by a lens of infra-red transmitting glass. A part of the radiation was also reflected to one side by a partially aluminized glass mirror and focused on to the photomultiplier tube. Although about 15 per cent of the infra-red radiation and 85 per cent of the ultra-violet radiation is lost, this arrangement has the great advantage that almost simultaneous measurements can be made at the two wave-lengths by switching from one detector to the other. The loss of ultra-violet radiation is of no consequence because the limits of the experiment are set by the amount of infra-red radiation available. The radiation entering the detector unit was interrupted at a frequency of about 750 cycles per second, and the signals from the two detectors amplified with a wide band-tuned amplifier, that from the lead sulphide cell passing first through a cathode follower and a pre-amplifier. The amplified signals were fed into a phase sensitive rectifier, the
auxiliary signal for which was obtained from the same chopping disk with a 6-volt lamp and photoelectric cell. The output appeared as a meter reading with a response time of about 1 sec. Both the lead sulphide cell and the photomultiplier tube were used uncooled, but this did not matter because the signal/noise ratio

![Diagram of optical arrangement of detector unit.]

of this particular lead sulphide cell increases very little on cooling and there was ample ultra-violet light for the photomultiplier. A mica infra-red filter was placed before the lead sulphide cell and a Wratten No. 47 filter, with a transmission peak near 0.43 μ, was before the photomultiplier tube. Fig. 2 shows

![Graph of infra-red spectral response.]
the spectral sensitivity of the apparatus to sunlight in the infra-red region, this
curve being a combination of the spectral sensitivity of the cell, the transmission
of the mica filter and the optical components of the detector unit, and the
transmission of the atmosphere; the effective wave-length was taken to be 1.9 \mu.

In order to reduce errors which would arise from a non-linear response, the
detectors were used in a balanced arrangement. The inner corona was measured
first with a diaphragm over the main mirror. This screen, which was pierced
with a number of holes 9.5 mm in diameter and transmitted 11 per cent of the
incident light, had been chosen so that a half-scale deflection would be obtained
with the lead sulphide cell. Then the output from the photomultiplier was
observed and the amplification of the signal from it altered until approximately
the same deflection was obtained: this amplification was not changed again during
the eclipse. In subsequent observations farther from the Sun the screen was
removed. Extensive observations on the Moon before the eclipse had, in fact,
shown the response of both detectors to be linear, but it was thought wise to use
this extra precaution.

The selecting aperture was 30 minutes of arc long by 5 minutes of arc broad
and was maintained constant in size throughout the experiment. Such a large
aperture was needed only for examination of the outer corona, but it was kept
the same for the inner and outer corona because a change in size during the
experiment might have caused a spurious result through variations of sensitivity
over the receiving areas of the detectors. For convenience in setting, the aperture
was placed perpendicular to the celestial equator on the E. side of the Sun.

Observations.—At the time of the eclipse the sky was fairly transparent and
almost free from cloud. Owing to the climate and the nature of the surrounding
country, dust deposits formed very easily on the optical parts and were a great
nuisance, but they have not interfered with the observations.

It was not possible to make observations at many points during the three
minutes of the eclipse. Sixteen readings are needed to make a reliable comparison
between only two points of the corona—two for each wave-length in the two
positions and eight zeros—and in addition to this a balance point must be found
and the telescope directed in turn to two measured places in the corona. Also,
if the points are not in an intense part of the corona a further eight readings are
needed to measure the sky background. In this experiment thirty readings
were taken at distances from the solar centre of up to 4.5 R\odot (all quoted distances
are measured from the solar centre), but the last two sets of readings must be
rejected. The last set, which was intended to give a measure of the sky brightness,
is rejected because the sky was beginning to brighten when they were taken;
the preceding set because they show a brightness only a little greater than that
of the sky and are unreliable without an accurate knowledge of the sky background.
The readings that are left compare the colour of the corona at 2.5 R\odot from the
centre with the colour at distance 1.5 R\odot from the centre. The fact that no
photoelectric measures of sky brightness are available is not of great importance
because the corona at these places is many times brighter than the sky and an
estimate only of the sky brightness is needed. An estimate of the brightness
at 0.43 \mu was obtained from a coronal photograph, taken by Dr von Klüber, giving
a value of 1/3 of the coronal brightness at 2.5 R\odot. The sky brightness at 1.9 \mu
was assumed to be zero, an assumption supported by measurements made
previously on the daylight sky and the region of the night sky near the full Moon.
If \( I(0.43\mu, 1.5R_\odot) \) is the observed intensity of the corona, in arbitrary units, at a distance of \( 1.5R_\odot \) from the solar centre and at a wave-length of \( 0.43\mu \); then the mean of the two sets of observations gives

\[
\frac{I(1.9\mu, 2.5R_\odot)}{I(0.43\mu, 2.5R_\odot)}/\frac{I(1.9\mu, 1.5R_\odot)}{I(0.43\mu, 1.5R_\odot)} = 2.17,
\]

the individual measurements being 2.20 and 2.13. This means that the corona is considerably reddened at increasing distance from the Sun.

In general, one of the difficulties of photometric observation of the outer parts of the corona is to correct satisfactorily for light scattered by the instrument from the intense inner corona. Experiments on the full Moon in a clear sky before the eclipse showed that in this particular case such scattering was negligible at both wave-lengths, nor would much scattering be expected because there was only one optical surface and a diaphragm to exclude all but the radiation actually measured. If scattering of this kind had occurred it would have caused an excess of blue in the outer corona, not the observed great excess of infra-red.

Another difficulty is the elimination of the atmospheric background, which is particularly difficult for the fainter parts of the corona. But such errors should not affect these observations appreciably, for if the intensity of the background brightness were in error by 10 per cent, the corresponding error in colour could be no more than 1 per cent. The magnitude of the infra-red excess is a sufficient argument against the supposition that it originates either in the Earth's atmosphere or in instrumental scattering.

**Other observations.**—These are the first coronal observations to be made with a lead sulphide cell, but other observations of a similar nature have been made with photoelectric cells, thermocouples and photographic plates. Abbot (5), Stetson and Coblentz (6) and Pettit and Nicholson (7) have all made measurements of the infra-red radiation from the parts of the corona near to the limb, with conflicting results. Allen (2) has made photographic observations of the variation of colour with distance from the limb. Allen finds

\[
\frac{I(0.65\mu, 2.4R_\odot)}{I(0.40\mu, 2.4R_\odot)}/\frac{I(0.65\mu, 1.2R_\odot)}{I(0.40\mu, 1.2R_\odot)} = 1.49.
\]

Both Ludendorff (8) and Grotrian (9) find no change of colour with change of radial distance, but their measurements were over a smaller range of wave-lengths and radial distance. It will be shown later that these last three results are not incompatible with the present observations.

**Discussion of results.**—Allen (2) and van de Hulst (3) have summarized the evidence for the existence of the F-corona and shown how it may be accounted for by diffraction of sunlight by interplanetary dust particles. The strongest evidence so far has been the existence of Fraunhofer lines in the coronal spectrum, and the falling off of the percentage polarization below the value predicted by a model consisting solely of free electrons. In both these discussions it is assumed that the F-corona can be identified with the zodiacal light, and this assumption is used in the reduction of the observations because otherwise there would be insufficient data to determine both the size of the diffracting particles and their spatial distribution. A more satisfactory proof of their identity would be the calculation of the zodiacal light intensity from data provided by observation of the corona alone, and it was originally hoped to achieve this, but there are still insufficient data.
In the following analysis we show how it is possible to account for the infra-red excess on the basis of diffraction of the continuous solar spectrum by interplanetary dust. We neglect the contribution from infra-red emission lines, but this seems reasonable because their contribution in the visible region is less than 1 per cent.

According to Allen, the total amount of sunlight diffracted into unit solid angle by one particle of radius \( \rho \) is

\[
10I_\lambda \Omega \rho^4 \frac{I}{\lambda^2 \left(1 + \frac{4\pi^2 \rho^2 \theta^2}{\lambda^3}\right)},
\]

where \( I_\lambda \) is the surface brightness of the Sun expressed as the rate of radiation of energy by unit area into unit solid angle, \( \Omega \) is the solid angle subtended by the Sun at the particle, \( \lambda \) is the wave-length of light and \( \theta \) the angle between the directions of the observer and the Sun at the particle.

![Figure 3](https://example.com/figure3.png)

Hence the intensity of the light diffracted by a cloud of particles, of concentration \( N(L) \) per unit volume per unit solid angle viewed from the Earth, is

\[
\frac{10\rho^4 I_\lambda}{\lambda^2} \int_D^{4\pi \rho^2} \frac{N(L)}{r^2} \frac{dL}{1 + \frac{4\pi^2 \rho^2 \theta^2}{\lambda^3}},
\]

where \( L \) is the distance of a particle from the Earth, \( D \) is the distance between Sun and Earth, and \( s \) the radius of the Sun (see Fig. 3, which has been taken from Allen's paper). The upper limit is chosen to be 4\( s \) because within this limit all particles are vaporized by solar radiation.

Putting \( dL = -dr \) and \( \theta = R/r \) this expression becomes

\[
\frac{10\pi \rho^4 I_\lambda s^2}{\lambda^2} \int_D^{4s} \frac{N(r)rdr}{r^3 + \frac{4\pi^2 \rho^2 R^3}{\lambda^3}},
\]

where \( N(r) \) is the number of particles per unit volume at a distance \( r \) from the Sun, and \( R \) is the projected distance of the line of sight from a surface element of the Sun. To a good approximation, \( I_\lambda \) is the rate of radiation from the solar surface in the direction of the observer, so that it is necessary to make a correction for limb darkening as well as for the finite size of the Sun. Putting in these two

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corrections we find that the radiation from the dust corona at a distance $R$ from
the centre of the Sun is

$$
\frac{10\pi r^4 s^2}{\lambda^3} \int_A \int_D \frac{r N(r) I_\lambda(s) \, dr \, dA}{r^3 + \frac{4\pi^3 r^3 R^3}{\lambda^3}},
$$

the first integration being taken over the projected area of the Sun.

It is convenient to define an effective scattering coefficient $\sigma_{R,\lambda}$ which gives
the brightness of the dust corona, at distance $R$ from the solar centre, in terms of
the mean brightness of the Sun.

$$
\sigma_{R,\lambda} = \frac{10\pi r^4 s^2}{\lambda^3} \int_A \int_D \frac{r N(r) I_\lambda(s) \, dr \, dA}{r^3 + \frac{4\pi^3 r^3 R^3}{\lambda^3}} \frac{\int_A I_\lambda(s) \, dA.}
$$

$\sigma_{R,\lambda}$ has been evaluated graphically for a range of particle sizes, wave-lengths
and values of $R$, taking $N(r)$ to be a constant between $r = 4s$ and $r = D$, with the
results shown in Figs. 4, 5, 6. In these curves the ratio $\sigma_\lambda/\sigma_{0.43}$ has been plotted
as a function of $\lambda$ for various values of $R$. This ratio is a measure of the colour
of the corona in terms of the colour of the Sun, a value of unity meaning a colour
equal to that of the Sun averaged over its apparent disk. In interpreting these
diagrams we bear in mind that they refer to the dust corona only; the real corona
has an admixture of electron scattering for which $\sigma_\lambda/\sigma_{0.43}$ is equal to unity
independent of wave-length and distance from the limb (neglecting a small effect
due to limb darkening). A striking feature of the diagrams is the strong dependence of colour, in the wave-length interval 0.43 μ - 1.9 μ, upon the size of particle. With a particle radius of 10^{-3} cm there is an infra-red excess at 3.5R_☉ and an infra-red deficiency at 2.5R_☉ and closer to the Sun, although at wave-lengths shorter than 1.2 μ there is a slight infra-red excess at 2.5R_☉. Passing to particles of size 2 x 10^{-3} cm there is an overall increase of reddening, and at 10^{-2} cm radius there is a reddening at all distances from the Sun. The last diagram shows the way in which the curves for all distances tend to converge to a limiting curve as the particle size increases. Fig. 7 demonstrates the superiority of 1.9 μ radiation over 0.65 μ radiation for the determination of particle size.

As we have reliable infra-red data for only two places in the corona it is not possible to calculate the particle size without recourse to other data. The other data that have to be used are determinations of Fraunhofer line intensities in the coronal spectrum, for these give directly the relative proportions of dust diffraction and electron scattering at short wave-lengths, and a measurement of the surface brightness of the corona in terms of the brightness of the Sun. We also make the initial assumption that the radiation from the inner corona, distant 1.5R_☉ from the solar centre, is identical with solar radiation. This is a reasonable assumption because the Fraunhofer lines are weak in comparison with the continuous spectrum here, and the reddening of the dust corona near to the solar limb is slight.
Let \( \sigma_r \) and \( \sigma_b \) be total effective scattering coefficients at red and blue wavelengths respectively. Each scattering coefficient is the sum of two scattering coefficients, \( \sigma_d \) due to dust and \( \sigma_e \) due to free electrons.

Thus

\[
\frac{\sigma_r}{\sigma_b} = \frac{\sigma_{d,r} + \sigma_{e,r}}{\sigma_{d,b} + \sigma_{e,b}}
\]

\[
= \frac{\sigma_{d,r} + \sigma_{e,r}}{\sigma_{d,b} + \sigma_{e,r}} \quad \text{(because } \sigma_{e,r} = \sigma_{e,b})
\]

\[
= 2.17 \quad \text{(by observation).}
\]

Hence

\[
\left( \frac{\sigma_d}{\sigma_b} \right) = 1.17 \left( \frac{\sigma_{d,r}}{\sigma_{d,b}} - 2.17 \right)
\]

and

\[
\sigma_{d,b} = 1.17 \frac{\sigma_{d,b} + \sigma_{e,b}}{\sigma_{d,r}/\sigma_{d,b} - 1}.
\]

\( \sigma_{d,b} \) at a distance of \( 2.5R_\odot \) from the solar centre can be calculated in terms of the particle concentration from the expression already given, \( (\sigma_{d,b} + \sigma_{e,b}) \) is the brightness of the corona at this point in terms of the brightness of the solar disk—according to Allen this is \( 0.078 \times 10^{-6} \)—and \( \sigma_{d,r}/\sigma_{d,b} \) can be read off for various particle sizes from Fig. 7. In this way there can be constructed the relation between particle size and concentration which is shown in Fig. 8, a curve which ends at the particle size \( \rho = 2.3 \times 10^{-3} \) cm because particles smaller than this size give a reddening at \( 2.5R_\odot \) of less than 2.17. This does not give the distribution.
of particle sizes in the interplanetary dust, for so far these have been assumed to be of one size only, but if the particle size can be fixed it will give the concentration. The particle size can be determined from the measurements by Allen and Grotrian of the Fraunhofer line intensities, these giving directly \( \frac{\sigma_d}{\sigma_d + \sigma_e} \) from which \( \frac{\sigma_d}{\sigma_e} \) and then \( \rho \) can be calculated. The results are given in Table I. The \( \rho, N \) curve slopes steeply in this region so that the large uncertainty in the intensity of the Fraunhofer lines does not cause a large difference between the two estimates of the particle radius. Indeed, as will be clear later, all the uncertainty arises from the choice of model and not in the choice of supplementary data.

![Graph](image)

**Table I**

<table>
<thead>
<tr>
<th>Observer</th>
<th>( \frac{\sigma_d}{\sigma_d + \sigma_e} )</th>
<th>( \rho )</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grotrian</td>
<td>0.71</td>
<td>2.78 \times 10^{-3} cm</td>
<td>15.6 \times 10^{-18}/cm^8</td>
</tr>
<tr>
<td>Allen</td>
<td>0.61</td>
<td>3.07 \times 10^{-3} cm</td>
<td>12.0 \times 10^{-18}/cm^8</td>
</tr>
</tbody>
</table>

As this corona model depends upon only one infra-red comparison it is desirable to check it with other observations. Suitable observations are those of Allen, Grotrian and Ludendorff on the variation of corona colour with distance from the Sun, those of Allen on the variation of the Fraunhofer line intensity...
with wave-length, and those of Öhman and Allen and others on the variation of polarization with wave-length. Results of the calculations are given in Table II, together with the observations.

### Table II

<table>
<thead>
<tr>
<th>Radius of particles</th>
<th>( \sigma_{0.85}/\sigma_{0.45} )</th>
<th>Ratio of Fraunhofer line intensities at 0.60μ/0.40μ</th>
<th>Polarization at 4600Å</th>
<th>Polarization at 6250Å</th>
</tr>
</thead>
<tbody>
<tr>
<td>at 2.4R⊙ Measured by Allen : 1.48</td>
<td>2.4</td>
<td>1.42</td>
<td>0.30</td>
<td>1.03</td>
</tr>
<tr>
<td>at 1.2R⊙ Measured by Allen : 1.35</td>
<td>1.28</td>
<td>1.35</td>
<td>1.28</td>
<td>1.11</td>
</tr>
</tbody>
</table>

| Measured by Grotrian : 0.9 | | | 0.93 | 0.93 |

The agreement with observation is, at first sight, fair. However, Allen’s measurement at 2.4R⊙ is almost certainly too high because he obtains a 10 per cent variation of colour between 1.2R⊙ and 1.6R⊙, even though at 1.6R⊙ the F-corona contributes only 10 per cent to the combined F- and K-coronas. It is not easy to make a comparison with Allen’s measurement in the third column as he has averaged the intensity ratios over all distances from the Sun. In making
the comparison we have supposed that this is equivalent to a measurement at $1.5R_\odot$. Although the calculated result is 30 per cent higher than the measurement, it is fair to say that a result of 1.3 would fit Allen's observations as well as, or better than, a result of 1.0 (see Fig. 7 of Allen's paper). The fourth column shows that the colour effect to be expected is very small near the limb and that such measurements can give little information about the F-corona.

![Colour curves for model No. 5, particle size $\rho = 0.25 \times 10^{-3}$ cm](image)

**Fig. 9.**—Colour curves for model No. 5, particle size $\rho = 0.52 \times 10^{-3}$ cm.

Ordinates: Intensity ratio $\sigma_{\lambda 3} / \sigma_{\lambda 4}$.

Abscissae: Wave-length in microns.

It is also possible to obtain an estimate of particle size from the decrease in polarization of the corona below that calculated from the pure electron scattering model, assuming that the F-corona is unpolarized. It is well known that the results do not agree well, and van de Hulst has already given a discussion of possible causes for the discrepancy. But the fact that there is no detectable change of polarization with wave-length (4,10) has to be explained on the basis of our model. Some effect would be expected because a dust corona with a particle size of $3 \times 10^{-3}$ cm is strongly reddened. The effect can be easily calculated from the data of Figs. 4–6 and knowledge of measured polarization, with the result that for a distance of $1R_\odot$ from the limb and a wave-length range of 4600 A to 6250 A (corresponding to the experiments of Allen in 1940) there is a variation of no more than 4 per cent in the polarization. This is smaller than the scatter of all polarization measurements so far made, and it would be difficult to measure it with certainty. The change of polarization with wave-length increases with increasing distance from the limb, becoming 6 per cent at $2.5R_\odot$ from the solar centre, but already at this distance there are great difficulties in allowing for the
polarization of the background radiation—which must really be the background radiation and not simply the dust corona.

Other corona models.—This is a naïve model and we should neither complain if it does not fit the facts nor be content if it does. A completely general model would have a distribution of particle sizes, and the space distribution of each size would vary in a specified way with distance from the Sun. As more data accumulate it may be possible to elaborate the model, but at the moment we can only calculate other models to see if they agree with the scanty data better or whether they can be rejected by reason of complete disagreement. Two other models have been examined: model 3 in which the particles are nearer the Earth, extending with uniform concentration from distance $\frac{3}{5}D$ to distance $D$ from the Sun, and model 5 in which the particles are near the Sun, extending from distance $4s$ to $\frac{1}{10}D$ from the Sun. The representative curves of Figs. 9, 10 show that to obtain the required reddening a larger size is needed for particles near the Earth than for particles near the Sun. The calculated data for these two models are given in Table III.

It is clearly impossible to distinguish between these widely differing models by appealing to data relating to the inner part of the corona and a short wave-length region, although this comparison with observation makes it likely that there is an increase of concentration towards the Sun rather than a decrease. We lack sufficient information at this stage to discuss models having a range of particle sizes.
Further experiments.—The problem is largely solved if by an independent method we can measure the effective particle size without appealing to zodiacal light observations. The curves given show that observations near the Sun using visible light can contribute little more. But from simultaneous measurements of the infra-red excess at three or more points and the polarization in the infra-red, which gives directly the ratio $\sigma_{\alpha r}/(\sigma_{\alpha r} + \sigma_{\alpha r})$, both the particle size and the spatial distribution may be deduced. The latter measurement can be made with an infra-red quarter-wave plate, infra-red polaroid and a lead sulphide cell. The problem is simplified in the intermediate portion of the corona, extending for several degrees beyond 6$R_\odot$ from the solar centre, because this is a dust diffraction pattern without the complication of the electron corona. However, the interpretation is not easy because as it is necessary to integrate over a large range of diffraction angles, the rate of decrease of intensity is not sensitive to the choice of particle size.

Table III

<table>
<thead>
<tr>
<th>Model</th>
<th>Observer</th>
<th>Radius of particles (cm)</th>
<th>$[\sigma_{0.65\mu}/\sigma_{0.40\mu}]^{2}4R_\odot$ Measured by Allen : 1.48</th>
<th>$[\sigma_{0.65\mu}/\sigma_{0.40\mu}]^{2}2R_\odot$ Measured by Allen : 1.45</th>
<th>$[\sigma_{0.65\mu}/\sigma_{0.40\mu}]^{2}1.25R_\odot$ Measured by Allen : 1.39</th>
<th>Ratio of Fraunhofer line intensities at $\sigma_{0.60\mu}/\sigma_{0.40\mu}$ Measured by Allen : 1.31</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Allen</td>
<td>4.04 x 10^{-3}</td>
<td>1.45</td>
<td>1.45</td>
<td>1.45</td>
<td>1.35</td>
</tr>
<tr>
<td>5</td>
<td>Allen</td>
<td>3.74 x 10^{-3}</td>
<td>1.39</td>
<td>1.39</td>
<td>1.39</td>
<td>1.32</td>
</tr>
<tr>
<td></td>
<td>Grotian</td>
<td>4.31 x 10^{-3}</td>
<td>1.38</td>
<td>1.38</td>
<td>1.38</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Grotian</td>
<td>0.28 x 10^{-3}</td>
<td>1.34</td>
<td>1.34</td>
<td>1.34</td>
<td>1.22</td>
</tr>
</tbody>
</table>

Acknowledgments.—I should like to express my gratitude to Professor Redman, leader of the Cambridge Observatories Expedition, for his help and encouragement; to Mr Colville-Stewart of the Civil Secretary’s Office in Khartoum and the officers and men of Fort Stanley for their invaluable assistance in very many ways; and to Dr P. B. Fellgett for the loan of a mica filter and assistance with electronics. The expedition was financed by a grant from the Joint Permanent Eclipse Committee. The apparatus was built in the Observatories’ workshops by Mr J. Hignell.

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Cambridge:
1952 September 23.

References