FURTHER OBSERVATIONS OF THE ZODIACAL LIGHT FROM A HIGH ALTITUDE STATION AND INVESTIGATION OF THE INTERPLANETARY PLASMA

II. SPECTROPHOTOMETRIC OBSERVATIONS AND THE ELECTRON DENSITY IN INTERPLANETARY SPACE


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Summary

A spectrophotometric method is described for separating the contributions to the zodiacal light of scattering by dust, and by free electrons. A suitably designed photoelectric spectrophotometer has been used to compare the intensities of the two Fraunhofer lines Hβ and Fe I 4384 in the spectra of the zodiacal light (with correction for night sky background) and of sunlight. The results are interpreted as indicating an electron density of $16 \pm 20$ cm$^{-3}$ in interplanetary space at 1 A.U. from the Sun.

1. The principle of the method.—In principle the method is very simple. Any free electrons in interplanetary space will scatter sunlight towards the observer, and if we suppose, to begin with, that the electrons have a high kinetic temperature, Fraunhofer lines will be obliterated and the spectrum of the scattered light will appear essentially continuous. On the other hand, the light scattered by dust particles will have a Fraunhofer spectrum. The two components may therefore be distinguished by comparing the depths of Fraunhofer lines in the spectra of the zodiacal light and the Sun; if an electron-scattered component is present, Fraunhofer lines will be correspondingly weakened. In practice, the measurement is complicated by the multiplicity of corrections that are necessary. We consider these later, together with the effect on the interpretation of the data of the value adopted for the kinetic temperature of the electrons.

In our observations we have compared the effective depths, $D$, of a Fraunhofer line in the various sources by measuring in each spectrum the energy fluxes through three slits, one centred on the line and the other two positioned on nearby parts of the spectrum which are reasonably free from Fraunhofer lines. The effective depth, $D$, we define as

$$D = \int_{v_0-\Delta v}^{v_0+\Delta v} (1 + r_v) \, dv$$

where $v_0$ is the central frequency of the line, $2\Delta v$ is the width of the centre slit and $r_v$ is the depression of the line at frequency $v$. Observations have been made

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of the zodiacal light, the twilight sky and moonlit sky (to simulate the solar spectrum), and the night sky (to correct the observations of the zodiacal light for background night sky light). The method of observation is an adaptation of a technique that has been developed at the Cambridge Observatories, and much used for stellar spectroscopy (1).

2. The theory of the method.—Fig. 1 shows an idealized part of the observed spectrum and the position of the three slits, which are designated 1, 2, 3. The central slit 2 isolates a strong Fraunhofer line; there will necessarily be weak lines in the regions isolated by slits 1 and 3. The component $A$ is a pure solar spectrum and component $B$ is an added continuum which has an intensity equal to $n^{-1}$ of the intensity of the continuous background of the solar spectrum at the position of the Fraunhofer line. In this discussion we assume for simplicity that the central slit 2 is exactly midway between the outer slits; in practice this was not so and account of this has been taken in reducing the observations.

![Fig. 1.—An idealized representation of the part of the spectrum observed, showing the three portions of the spectrum isolated by equally-spaced slits of identical width (see text).](image)

We now suppose an idealized arrangement in which the slits are of equal width and the photomultipliers of equal sensitivity, so that their outputs compare directly the energy fluxes in the three regions of the spectrum. Later in the analysis we remove this simplification. Still considering this simplified apparatus, for each spectrum (i.e. the Sun, the zodiacal light or the night sky) we form the ratio

$$K = \frac{\text{sum of energy fluxes in outer channels}}{2 \times \text{energy flux in central channel}}.$$ 

If $E_1$, $E_2$, and $E_3$ are the energy fluxes through the three slits, we obtain for the solar spectrum,

$$K_s = \frac{E_1 + E_3}{2E_2}. \quad (1)$$
There are weak Fraunhofer lines present in the wavelength regions isolated by slits 1 and 3, and to obtain the fluxes corresponding to the continuous spectra here we must multiply $E_1$ and $E_3$ by the factors $a_1$ and $a_3$. The energy in the continuum at the position of slit 2 is now obtained by linear interpolation and is $(a_1E_1 + a_3E_3)/2$. (In the reduction of the observations we allow for departures from this simplifying assumption.) Hence, for the zodiacal light spectrum, we obtain

$$K_z = \frac{E_1 + \frac{a_1E_1 + a_3E_3}{2n} + E_3 + \frac{a_1E_1 + a_3E_3}{2n}}{2 \left( E_2 + \frac{a_1E_1 + a_3E_3}{2n} \right)}$$

(2)

$$= \frac{E_1 + E_3}{2} + \frac{a_1E_1 + a_3E_3}{2n}$$

$$= \frac{E_2 + a_1E_1 + a_3E_3}{2n}$$

$$= \frac{K_s + \frac{K_s}{n}}{1 + \frac{K_s}{n}}$$

(3)

where

$$K_s = \frac{a_1E_1 + a_3E_3}{2E_2}.$$

Solving for $n$ we obtain

$$n = \frac{K_s(K_z - 1)}{K_s - K_z}.$$  

(4)

In practice the quantities that are directly observed are the photomultiplier counts, $N$, which are related to the energy fluxes on the photomultipliers, $E$, by the relation, $N = CE$. If the slit widths are $\Delta \lambda_1$, $\Delta \lambda_2$, and $\Delta \lambda_3$, we may use the expressions derived above if we replace $E_1$ etc., by $N_1/C_1\Delta \lambda_1$ etc. So that, for example,

$$K_s = \frac{E_1 + E_3}{2E_2}$$

$$= \frac{N_1}{C_1\Delta \lambda_1} + \frac{N_3}{C_3\Delta \lambda_3}$$

$$= \frac{2N_2}{C_2\Delta \lambda_2}$$

$$= \frac{1}{2}(R_{12}/S_{12}C_{12} + R_{32}/S_{32}C_{32}),$$

(5)

where

$$C_{12} = C_1/C_2, \quad C_{32} = C_3/C_2,$$

$$R_{12} = N_1/N_2, \quad R_{32} = N_3/N_2,$$

$$S_{12} = \Delta \lambda_1/\Delta \lambda_2, \quad S_{32} = \Delta \lambda_3/\Delta \lambda_2.$$

The quantities $S_{12}C_{12}$ and $S_{32}C_{32}$ are found directly in a separate calibration experiment in which the three spectrometer slits are equally illuminated with light from a distant extended source so that the flux through each slit is proportional.
to its width. If the calibration counts which are then registered are \( N_1^c, N_2^c, N_3^c \) we have,

\[
\frac{N_1^c}{C_1\Delta \lambda_1} = \frac{N_2^c}{C_2\Delta \lambda_2} = \frac{N_3^c}{C_3\Delta \lambda_3}
\]

or

\[
\frac{N_1^c}{N_2^c} = \frac{\Delta \lambda_1}{\Delta \lambda_2} \cdot \frac{C_1}{C_2} = S_{12}C_{12} = B_{12} \quad \text{(say)}
\]

and

\[
\frac{N_3^c}{N_2^c} = \frac{\Delta \lambda_3}{\Delta \lambda_2} \cdot \frac{C_3}{C_2} = S_{32}C_{32} = B_{32}.
\]

Substituting in (5) for \( S_{12}C_{12} \) and \( S_{32}C_{32} \) we get

\[
K_8 = \frac{1}{2} \left( \frac{R_{12}}{B_{12}} + \frac{R_{32}}{B_{32}} \right)
\]

and similar expressions for \( K_z \) and \( K_s \).

The required quantity \( n \) may now be found from equation (4) using the revised values for \( K_8, K_8 \) and \( K_z \). In expression (4) the factor \( (K_z - 1) \) is a sensitivity factor, for if the central line is weak then \( (K_z - 1) \) is small and the method is insensitive.

**Fig. 2.—A schematic vertical section through the spectrometer.** The sky imaging lens forms an image of the sky on the entrance slit: the three slits 1, 2, and 3, in the same vertical plane as the entrance slit, isolate three narrow regions of the spectrum. There is a Fabry lens and photomultiplier behind each slit. (Not to scale; the horizontal dimension is shown much compressed.)

3. The apparatus.—The spectrum of the sky or zodiacal light was formed by a Littrow spectrograph (Fig. 2) with a Bausch and Lomb grating of ruled area 204 cm × 152 cm and of 600 lines mm\(^{-1}\). The collimator was a simple plano-convex lens of focal length 299 cm giving a dispersion of 2.7 Å mm\(^{-1}\); the direction of dispersion of the spectrograph was vertical. Three horizontal exit slits, each of length 9 cm, were positioned in the plane of the spectrum, and behind each slit was a Fabry lens. This formed an image of the uniformly illuminated grating on the cathode of an E.M.I. type 9502 photomultiplier. An image of the sky was focused upon the horizontal entrance slit by a simple lens of focal length 38.6 cm. Whilst it was realized that the flux of energy through the spectrometer is independent of the presence of this lens, its provision ensured that light from only a sharply defined area of the sky in a narrow
range of altitude entered the spectrometer. As the normal entrance slit width was 1 mm, the area of the sky examined was of size $15^\circ 4 \times 6^\circ 15$ with the longer side horizontal. The photomultipliers were supplied from a power unit with a stability of 0·1 per cent and their outputs fed to a three channel pulse-counting system. Because of the low light levels encountered, the overall resolving time could be kept long and was determined by the first decade scaler, a single-pulse Dekatron unit of resolving time 50 $\mu$s. This permitted counting rates up to 200/sec for a 1 per cent loss.

The whole spectrometer, about 4 m long, could be moved within a small range of azimuth and altitude. It was mounted in an upper laboratory at the Cosmic Ray Observatory at Chacaltaya, and adjusted so that at about 19·30 hours Zone Time it pointed to a position in the western sky near to the ecliptic, and at an altitude of about 10$^\circ$.

4. The observations.—Two Fraunhofer lines, Fe I at 4384 A and H$\beta$ at 4861 A were used. They were chosen because of their prominence in the solar spectrum and because there are no obvious night sky emission lines near to them. Table I gives the arrangement of the spectrometer for these observations. The wavelengths of the comparison slits were in each case selected to be as close as possible to that of the central slit, whilst being as free as possible from Fraunhofer lines.

| Table I |
|------------------|------------------|------------------|
| Line Fe I 4384 A | Dates of observation: July 1, 2, 3, 5. |
| Comparison slits set at 4168 A and 4610 A |
| Widths of comparison slits 7·9 A each |
| Width of central slit 2·1 A |
| Line H$\beta$ 4861 A | Dates of observation: July 7, 8, 9, 10, 11. |
| Comparison slits set at 4683 A and 5099 A |
| Widths of comparison slits 7·8 A each |
| Width of central slit 2·1 A |

On each of these nights observations were made of the zodiacal light at elongations between $27^\circ$ and $38^\circ$, of the twilight sky in the evening and sometimes in the following morning, and of the night sky and moonlit sky whenever these were possible. The purpose of the twilight sky and moonlit sky observations was to simulate the solar spectrum, as direct observation of the Sun is clearly impracticable. The observations of the brighter twilight sky were made through a neutral filter mounted over the sky lens, so that there was not too great a difference between the zodiacal light and the twilight sky counts. Because the energy fluxes to be measured were so small, the strictest precautions were taken to prevent entry of stray light into the spectrometer.

In spite of the low intrinsic efficiency of the optical arrangement the observed energy flux was satisfactory. Typical counts over a period of 4 minutes are given below in Table II.

| Table II |
|------------------|------------------|------------------|
| Channel | Count on zodiacal light ($\epsilon = 29^\circ$) | Count on night sky | Dark count |
| 1 | 10000 | 2600 | 980 |
| 2 (Fe I line) | 2600 | 600 | 350 |
| 3 | 26000 | 4500 | 2160 |

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All counts were for a period of 4 minutes, so that with the necessary inter-
spersed dark and calibration counts, six 4-minute counts on the zodiacal light
could be made every evening. The photomultipliers were selected by E.M.I.
from their stocks, and were used uncooled at a temperature near 0°C; the one
used in the important central channel was of a remarkable quality and contrib-
uted greatly to the success of our work.

5. Reduction of observations.—In this and the following section we describe
the method of reducing the observations to give a value for the percentage of the
continuum in the spectrum of the zodiacal light, and the several corrections that
are necessary at various stages.

5.1. The sensitivity factor.—The sensitivity of the method depends upon the
central intensity of the Fraunhofer line as observed by the spectrometer. The
central intensity was found by rotating the grating and scanning the spectrum
of the daytime sky across the middle slit, recording the output with a D.C.
amplifier; such a scan for the Hβ line is shown in Fig. 3. If the measurement
is made from the continuum, the observed central depression of the line is
37.5 per cent. The value of $K_z$ used in expression (4) has been found by
combining the value of this central depression with the Fraunhofer line absorption
at the wavelengths of the comparison slits, found from the Utrecht Atlas.

5.2. The factor $B_{12}$ etc.—These were obtained by placing, in front of the
Littrow lens, a white card of the same shape as the ruled grating area and illumi-
nating it with a lamp. The determinations show that the system is electronically
very stable, the ratios varying by little more than 1 per cent throughout a night's
observing.
5.3. The value of $K_s$.—As previously mentioned the twilight sky observations were made through a neutral filter. A small correction for departure from neutrality has been made, together with an allowance for the presence of a small zodiacal light component. In reducing the observations of the moonlit sky, allowance has been made for the presence of a night sky background.

The comparison channels were set as close as possible to the centre channel, but a correction has been made to the observations of both of these sources for the strong variation of the energy with wavelength which they show, as both are due to Rayleigh scattering. For a $\lambda^{-4}$ law of scattering the correction to the ratio $K_s$ is 1.7 per cent, and for a $\lambda^{-3}$ law the correction is 1.0 per cent; we have assumed a correction of 1.5 per cent.

6. Corrections

6.1. Correction for the night sky background.—The contribution of the night sky background has been found by using the photoelectric scans of the zodiacal light already described in Paper I of this series. Before making allowance for this, four correction terms, (a) to (d), must first be applied as follows:

(a) Conversion from wide band to monochromatic ratios. The photometric scans were made with appropriate wide band filters as described in Paper I. These must be converted to monochromatic scans at H$\beta$ and Fe I 4384. In doing this we assume the energy distribution in the zodiacal light to be that given by Blackwell and Ingham (2) modified by atmospheric absorption. By chance, the numerical value of this correction is zero.

(b) An allowance for the presence of Fraunhofer lines in the spectrum of the zodiacal light. The zodiacal light is assumed for this purpose to have a solar type spectrum. The night sky is assumed, in the region of all three slits, to have a smooth spectrum with no prominent features. This requirement was borne in mind when selecting the wavelengths of the comparison channels. Neglect of this correction will lead to an error of 10 per cent in the required ratio of zodiacal light brightness to that of the night sky background.

(c) An allowance for the field of view of the spectrometer. Since the projected length of the spectrometer slit on the sky is 13°.4, an allowance is necessary, and has been made, for the variation of brightness of the zodiacal light with distance from the ecliptic.

(d) An allowance for the deviation of the axis of the spectrometer from the ecliptic. Because it was essential to maintain its precise adjustment, it was impossible to move the spectrometer to keep it pointing exactly at the ecliptic. The deviation of the spectrometer from the ecliptic was calculated for each observation of the zodiacal light. The deviation from the ecliptic of the axis of symmetry of the zodiacal light was taken from Blackwell & Ingham (2). The total correction to the ratio of zodiacal light brightness to that of the night sky background resulting from the terms (c) and (d) together depended upon the date and time of observation. The correction was usually between 9 and 12 per cent, but occasionally reached 25 per cent.

After making these four corrections, we now allow for the night sky background. For simplicity we again suppose that the slits are of equal width and the photomultipliers of equal sensitivity. Then we have for the combined zodiacal
light and sky background

\[ K_{z+b} = \frac{E_{1z} + E_{1b} + E_{3z} + E_{3b}}{2(E_{2z} + E_{2b})} \]

where, for example, \( E_{3b} \) refers to the flux through slit number 3 from the sky background.

\[ K_{z+b} = \frac{K_z + \frac{I}{Q}, K_b}{1 + \frac{I}{Q}} \]

where

\[ K_z = \frac{E_{1z} + E_{3z}}{2E_{2z}} \]
\[ K_b = \frac{E_{1b} + E_{3b}}{2E_{2b}} \]
\[ Q = \frac{E_{2z}}{E_{2b}} \]

and

\[ K_z = K_{z+b} \left( 1 + \frac{I}{Q} \right) - \frac{I}{Q}, K_b. \]

This relation shows how we obtain \( K_z \) from the observed values \( K_{z+b}, K_b \) and \( Q \), which is related to the observed ratio of zodiacal light to night sky brightness.

We now consider the derivation of the factor \( Q \) from the photoelectric scans of the zodiacal light. We obtain from each scan the ratio \( E_{cz}/E_{2b} \), where \( E_{cz} \) refers to the continuum of the zodiacal light spectrum, and \( E_{2b} \) to the energy in the central channel from the night sky. The factor \( Q \) is calculated from the relation

\[ Q = \frac{E_{2z}}{E_{2b}} = \frac{E_{cz}}{E_{2b}} \times \frac{E_{2z}}{E_{cz}} \]

where the factor \( E_{2z}/E_{cz} \) is taken from the scan of the spectrum of the daytime sky (assumed for this purpose to be the same as that of the zodiacal light; as we are considering the magnitude of a correction only, any slight difference between the zodiacal light and daytime sky will show itself as a second-order term).

6.2. Correction for orbital motion of dust.—We may expect the wavelength and the profile of the Fraunhofer line in the spectrum of the zodiacal light to differ slightly from those of the line in the solar spectrum because of the motion of the dust relative to the Earth. The effect has been investigated quantitatively for H\( \beta \), and for various models of the zodiacal dust cloud, by Ingham (3). If the dust is co-rotating with the Earth, the effect will be to increase the quantity \( D \) (as defined on p. 329) by about 0.1 per cent; for contra-rotation the reduction would be about 2.3 per cent. Still smaller corrections would be expected for the narrower Fe I line. The correction appropriate to co-rotation has been made throughout.

7. Reduction to percentage of continuum.—The observational material collected during the expedition is extensive. For each night it consists basically of the readings of the Dekatron counters for each of the three channels on the zodiacal
Observations of the zodiacal light, II

light, together with the similar observations of the twilight or moonlit sky and the night sky. These are bracketed and interspersed with dark and calibration counts in the usual way. The photometer scans described in Paper I, made continuously throughout each period of zodiacal light observation, are required for the principal correction for the night sky background. We considered reproducing the observations in extenso so that the interested reader might make an independent reduction of the data to determine the electron density, but they are useless for this purpose unless accompanied by a further extensive body of data on the line intensity scans, filter transmissions, dimensions of the spectrometer to give the vignetting function, etc. To be of value this material must also be described in detail and altogether the length of the paper would have been increased by an amount that we have thought unjustifiable. The original observations can be made available for study by writing to The Director, the University Observatory, Oxford.

Fe I $\rightarrow$ H$\beta$

**Fig. 4.**—The mean value of the percentage of added continuum in the spectrum of the zodiacal light (interpreted as due to electron scattering). Each point is a mean of one night's observations.

The results of all reductions are given in Fig. 4, which shows the mean value of the percentage of continuum obtained for each night's observations. In determining these mean values we have taken account only of observations of the zodiacal light made before 20h Zone Time, covering elongations $28^\circ < \epsilon < 37^\circ$, as the errors increase rapidly with the elongation. The results show no systematic variation of percentage continuum with elongation. The mean value of the percentage continuum for the whole observing period is 1.4 per cent, and the standard error of the mean is 1.7 per cent.

8. Errors. We have assumed that both the twilight sky and the moonlit sky have spectra identical with that of the Sun. Recent work by Grainger & Ring (4) throws some doubt on this assumption, for they have observed that small areas of the Moon show a continuous component in their spectra (possibly due to luminescence). However, we think it unlikely that the whole surface of the Moon shows a luminescent component stronger than 1 per cent. These authors have also suggested that the daytime sky contains a small additional component too.
The analysis of our observations shows no significant difference between the spectra of the twilight and moonlit sky.

The uncertainty due to lack of knowledge of the orbital motion of the dust, i.e. whether it is co-rotating or contra-rotating, is not unimportant in comparison with the errors due to other causes.

We here draw attention to anomalous results obtained when observing the Hβ line on the two nights of 1961 July 9/10 and July 11/12. On the first night, and less markedly on the second, the values of K alike for the zodiacal light, twilight and night sky were significantly smaller than usual, although the calibration values showed no change. We have been unable to attribute these anomalous results to any plausible natural or factitious cause, and the observations of these two nights have not been included in the analysis. It may be remarked that there was no notable geomagnetic activity during our period of observation (maximum Kp=6+ on July 5). The active spot group (Mt Wilson 15353) that crossed the Sun’s central meridian on July 14 had an associated Class 3 flare on July 11 at 17h U.T. Otherwise there were only minor flares during our period of observation: the three major 3+ flares of 1961 July occurred on dates after July 11 when moonlight had brought our observations to an end.

9. Interpretation in terms of electron density.—In our model we assume that the electron density at distance r from the Sun is given by \( N_e = A r^{-2} \), for values of r greater than \( 91R_\odot \) (corresponding to the elongation \( \epsilon = 25^\circ \)). We find that at elongation \( \epsilon \) the ratio

\[
\frac{\text{brightness of zodiacal light}}{\text{mean brightness of solar disk}} = \frac{3\sigma A \Omega}{32\pi R \sin^3 \epsilon} \left\{ \frac{5\pi}{4} - \frac{5\epsilon}{4} + \frac{1}{2} \sin 2\epsilon + \frac{1}{16} \sin 4\epsilon \right\}
\]

where \( \sigma \) is the Thomson scattering coefficient

\[
\sigma = \frac{8\pi}{3} \left( \frac{e^2}{mc^2} \right)^2,
\]

\( \Omega \) is the solid angle subtended by the Sun at the Earth, and \( R \) is the distance of the Earth from the Sun.

We take the brightness of the zodiacal light at \( \epsilon = 40^\circ \) to be \( 3.86 \times 10^{-13}B_\odot \) (Blackwell & Ingham (2)), putting in a colour correction from Fig. 6 of that paper, and evaluate the brightness at other elongations from Blackwell and Ingham (2). The results of the calculation are given in Fig. 5 which shows the electron density at 1 A.U. from the Sun, supposing that 1 per cent of the zodiacal light is contributed by electron scattering, at various elongations.

The law \( N_e = A r^{-2} \) is a reasonable one which is in accord with present ideas. A less steep slope of electron density leads to a higher value for the electron density at 1 A.U., but the effect of choice of model is hardly significant.

The mean elongation of the position of observation is about 30°, so we interpret our observations of the intensity of the continuous component as showing that the electron density at 1 A.U. is

\[ 16 \pm 20 \text{ cm}^{-3}. \]

This final result is in satisfactory agreement with the null result obtained in 1958. However, there is the important difference that the 1958 result was based upon one spectrum photograph, whereas the present result is based upon the mean of 30 individual determinations. Schmidt & Elsasser (5) are right
to criticize the 1958 result in so far as it is based on the one spectrogram, but the present results are quite incompatible with their suggested density of $400 \text{ cm}^{-3}$. This is equivalent to a continuous spectrum component of 33 per cent, and reference to Fig. 4 shows that this is completely outside our errors.

![Graph showing electron density at 1 A.U. from the Sun corresponding to 1 per cent of added continuum, as a function of elongation.]

10. The assumption of a "high" kinetic temperature.—So far we have assumed that the sunlight scattered by the free electrons has a continuous spectrum. However, the method is still valid even for quite low kinetic temperatures. The sensitivity of the method ultimately depends upon the difference between the electron scattered spectrum and the dust scattered spectrum. For example, if the kinetic temperature is such that a line in the electron scattered component has a depth equal to half of that in the dust component, the sensitivity is halved. As the dust scattered light contains Fraunhofer lines that are infinitely sharp for all practical purposes, and the instrumental half-width is about 4 A, then the electron component will show, with this spectrometer, lines with a depth of half of that of the dust component if the natural width is also about 4 A. This happens for a kinetic temperature of $770^\circ K$. So that if the kinetic temperature were $770^\circ K$, then the limiting density might be $72 \text{ cm}^{-3}$ instead of $36 \text{ cm}^{-3}$. In Fig. 6 we show qualitatively the way in which the sensitivity changes with kinetic temperature. As the kinetic temperature is at least $10^4$ degrees K we see that the effect of any reasonable uncertainty of temperature is negligible.

11. Problems and future work.—We are satisfied that the electron density of the interplanetary plasma is so low that it does not make a significant contribution to the zodiacal light. Certainly, there seems no possibility that the density is as
great as the 300 cm\(^{-3}\) suggested by Giese & Siedentopf (6) from polarization data. Hence, most of the observed polarization of 34 per cent must be attributed to scattering by interplanetary dust particles and the mechanism by which this high polarization is produced is now the central problem of the zodiacal light.

![Graph showing sensitivity vs kinetic temperature.]

**Fig. 6.—Influence of assumed kinetic temperature on the sensitivity of the method.**

Although in principle the method we have used to determine the electron density in interplanetary space is a very simple one, the practical difficulties of measuring and interpreting the very low energy fluxes have proved to be very great. We feel that although a slight improvement may yet be made, the accuracy of the observations described here is close to the limit attainable from a ground station.

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