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OBSERVATIONS OF THE 1963 JULY 20 SOLAR ECLIPSE

I. Spectroscopic Separation of the F and K Components of the Solar Corona at large Distances from the Sun

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Summary

Photoelectric observations were made of the total solar eclipse of 1963 July 20 from an aircraft at an altitude of 30 000 ft. Data are presented for the absolute brightness of the solar corona and for the relative depth of the Hα absorption line in the spectrum of the corona to a distance of $16R_0$; the line depth was measured using interference filters. A separation of the F and K components based on the line depth measurements is given to $16R_0$ from the Sun.

1. *Introduction.* During the last decade several new theories of the solar corona have been proposed, and one at least has received some measure of confirmation from the direct observation of a solar wind at large distances from the Sun by means of interplanetary probes. Following this success, the most urgent task now is to compare the predictions of these theories with the properties of the inner and middle coronas, and particularly with the electron densities in these regions. Hitherto, such a comparison has not been possible because of lack of data. It is the purpose of this, and the following paper, to present data on the electron density at large distances from the Sun (i.e. for $R/R_0 > 5$), observed by a new technique during the total solar eclipse of 1963 July 20. We shall also show in subsequent papers in this series that these data yield new information about the properties of the F corona and the dust particles responsible for it.

2. *Previous measurements of electron density*

2.1. *From optical data.* Measurements of the brightness of the corona may be used to determine the electron density as a function of distance from the Sun. However, it is well known that the light of the solar corona is made up principally of two parts: one is due to the scattering of sunlight by free electrons surrounding the Sun (the K component) and the other (the F component) is due to scattering by dust particles in interplanetary space. In order to obtain the electron density these two components must be separated at each point in the coronal image. Two methods have been used so far, which depend respectively upon measurements of polarization and measurements of Fraunhofer line depth in the coronal spectrum. The principal features of these two methods are described below in order to demonstrate their limitations.

2.1.1. *Measurement of Fraunhofer line depth.* For this method it is assumed that the K component shows a continuous spectrum (because of the high kinetic temperature of the free electrons), whilst the F component shows a Fraunhofer spectrum. Comparison of the depth of a Fraunhofer line in the spectrum of the corona with its depth in the solar spectrum gives the relative proportions of K and F components, according to the following equation,

$$\frac{\text{Depth of Fraunhofer line in coronal spectrum}}{\text{Depth of Fraunhofer line in solar spectrum}} = \frac{F}{K+F}$$

where depth is measured as a fraction of the continuum. The method has been used by Grotrian (**1**), who first proposed it, and by Allen (**2, 3**). Providing proper care is taken (**4**), the interpretation of any observations is unambiguous. However, it is not easy to obtain by photographic means the reasonably high dispersion spectra that the method requires, so that until now the method has been used to only $6R_0$ from the Sun (**3**). As the brightness of the corona decreases rapidly with distance from the Sun there is little likelihood of the method being used at greater distances with a photographic technique; the remarks at the beginning of section 3.2 emphasize this point.

2.1.2. *Measurement of polarization.* If P_F and P_K are the degree of polarization of the F and K components respectively, then the observed polarization at any point in the coronal image, excluding any contribution from a sky background, is given by

$$P_{K+F} = \frac{K}{K+F} P_K + \frac{F}{K+F} P_F.$$

If an assumption is made about P_F, determination of P_{K+F} leads to the evaluation of $K/K+F$. The assumption that is usually made is that $P_F = 0$. This is reasonable as long as $P_F \ll P_{K+F}$ which will be true for smaller elongations, but any deduction about $K/K+F$ from the polarization data must be treated with reserve. Thus, at $R/R_0 = 20$, the polarization is 2·6% (**5**). It is quite possible that the whole of this could be due to the F component alone, especially as at elongation 30° ($R/R_0 = 108$) the polarization of the zodiacal light, due almost wholly to the F component (**6, 7**) is about 22%.

The situation therefore is that whilst the observations required for the polarization method are easily obtained (because the bandwidth, and therefore the available energy, may be large), the interpretation of the data becomes increasingly uncertain at greater distances from the Sun.

2.2. *From radio data.* The existence of free electrons in the outermost parts of the corona has been demonstrated by Hewish (**8**) and Vitkevitch (**9**) from observations of radio emission from the Crab nebula during an occultation by the corona. The measurements extend to very great distances from the Sun, and are of great value in showing that there are indeed free electrons out to such distances. However, numerical data about electron densities can be obtained only by making an assumption about the size of the scattering elements.

2.3. *General conclusion.* Although values for the electron density, derived from polarization measurements, have been published for distances as far as $20R_0$ from the Sun (**10**), it seems unlikely that there are any reliable values beyond about $5R_0$.

3. *General requirements*

3.1. *The nature of the observations.* We have said that an unambiguous separation of F and K components may be achieved only by measurement of the depth of Fraunhofer lines in the spectrum of the corona. At the 1963 eclipse our intention was to measure, by the method to be described later, the depth of a Fraunhofer line in the coronal spectrum at a number of representative points in the coronal image to as great a distance from the Sun as possible. These data will then yield $K/K+F$, and in combination with the measured brightness of the corona, measures of the electron density.

It was also hoped to measure simultaneously with the Fraunhofer line depth the degree of polarization of the corona. The combination of the two kinds of data will yield P_F as a function of distance from the Sun.

3.2. *The technique used.* Whilst we believe that the ratio $K/K+F$ can be obtained optically only through measurements of the depth of Fraunhofer lines, the expected effect is very small. Supposing (**10**) that at $10R_0$ the value of $K/K+F$ is 0·08, we have

$$\frac{\text{Depth of Fraunhofer line in coronal spectrum}}{\text{Depth of Fraunhofer line in solar spectrum}} = 0{\cdot}92.$$

The observed effect will be even smaller than this because the corona must be observed against the eclipse sky background, which also has a Fraunhofer spectrum. It follows that a conventional photographic spectrograph is not suitable for this purpose, partly because it is unable to detect small differences between two large fluxes of energy, but also because it is not fast enough to record the spectra in the short time available during an eclipse.

In the method adopted interference filters are used to isolate two regions of the spectrum. One of these is narrow and centred on the Fraunhofer line being measured; it effectively measures the residual intensity in the line. The other filter is wide, and also centred on the Fraunhofer line; it effectively measures the intensity of the continuum. The difference between the energies transmitted by the two filters depends upon the depth of the Fraunhofer line, and is therefore a measure of the proportion of continuous spectrum. When combined with a suitable calibration, the measurements give the value of $K/K+F$ at the point of observation.

There are several criteria for the choice of Fraunhofer line. The most important one is that the line should be of large equivalent width so that the effect of the added continuum is not too much diluted by the inevitably great bandwidth of the narrower filter. Also, the line should be reasonably well isolated so that the continuum may be easily measured with a second, wideband, interference filter. A third criterion is that the wavelength should be as great as possible, so that the sky background, which is due to Rayleigh scattering, should be as dark as possible. In addition, the wavelength should be within the sensitivity range of a tri-alkali photomultiplier, as it is undesirable to use an infra-red photomultiplier, which has a high dark current and low quantum efficiency. The choice of Hα, at 6 563 Å was finally made. Whilst it is true that the inner corona may occasionally show emission in Hα, because of the possible presence of prominences, at $5R_0$ where the measurements began, any emission must be negligible. Photographs of the solar limb in Hα light (**11**) do not show conspicuous activity, neither does the map issued by the Fraunhofer Institute.

3.3. *The need for an aircraft.* Observations of this kind must be made from a high altitude aircraft in order that the sky background should be as dark and as uniform as possible; if it is not uniform an accurate correction for the sky background cannot be made. Even a uniform sky background will increase the noise level of observations appreciably, as has been shown by Blackwell (**12**). There are of course difficulties resulting from the use of an aircraft, which must be considered very carefully. One of these is that wandering of the aircraft makes guiding difficult, although this matters less for the outer coronal regions. Another is that if the aircraft is not open to the atmosphere (and it is becoming increasingly difficult to find an aircraft which can be used open at 30 000 ft), a special window made of optical glass, preferably also bloomed, must replace the ordinary aircraft plastic window; if this is not done, scattering of light from the bright inner corona into the outer corona by the window will be intolerably great. Also, of course, polarization measurements are impossible with a plastic window.

4. *The expedition.* The observations described here were made from a Yukon aircraft at a height of 30 000 ft. The Oxford party were extremely fortunate to be granted space in the aircraft, which was operated by the R.C.A.F. on behalf of Dr C. S. Beals of the Dominion Observatory, Ottawa. They are particularly indebted to the Dominion Observatory for the provision of a special bloomed optical window of diameter 32 cm.

The eclipse was observed over the Great Slave Lake, Canada. Details of it are as follows:

Position of aircraft	117° W 61° N
Duration of eclipse	120 s
Altitude of Sun	49°

There was cloud immediately below the aircraft, but the sky above was of excellent quality.

5. *The apparatus*

5.1. *Optical arrangement.* The arrangement of the optical parts of the apparatus is shown in Fig. 1; the upper section is for the measurement of brightness and Fraunhofer line depth, while the lower part is for the measurement of brightness and degree of polarization. The two sections point at the same place in the corona.

In the upper section, the lens L_1 of diameter 10·0 cm forms an image of the corona on the screen S, and a portion is selected by the aperture A_1. The light is then collimated and split into two beams by the half-aluminized mirror M_1 and the mirror M_2. The two beams pass through a narrow band interference filter F_1 and a wide band filter F_2, and are brought to foci X_1 and X_2 by two more lenses. A chopping disk, rotated by an electric motor, is arranged at these foci so that the two beams are alternately allowed through. The two beams are then recollimated by two more lenses, and re-united by the half-silvered mirror M_3 and the mirror M_4. A further lens focuses an image of the objectiv

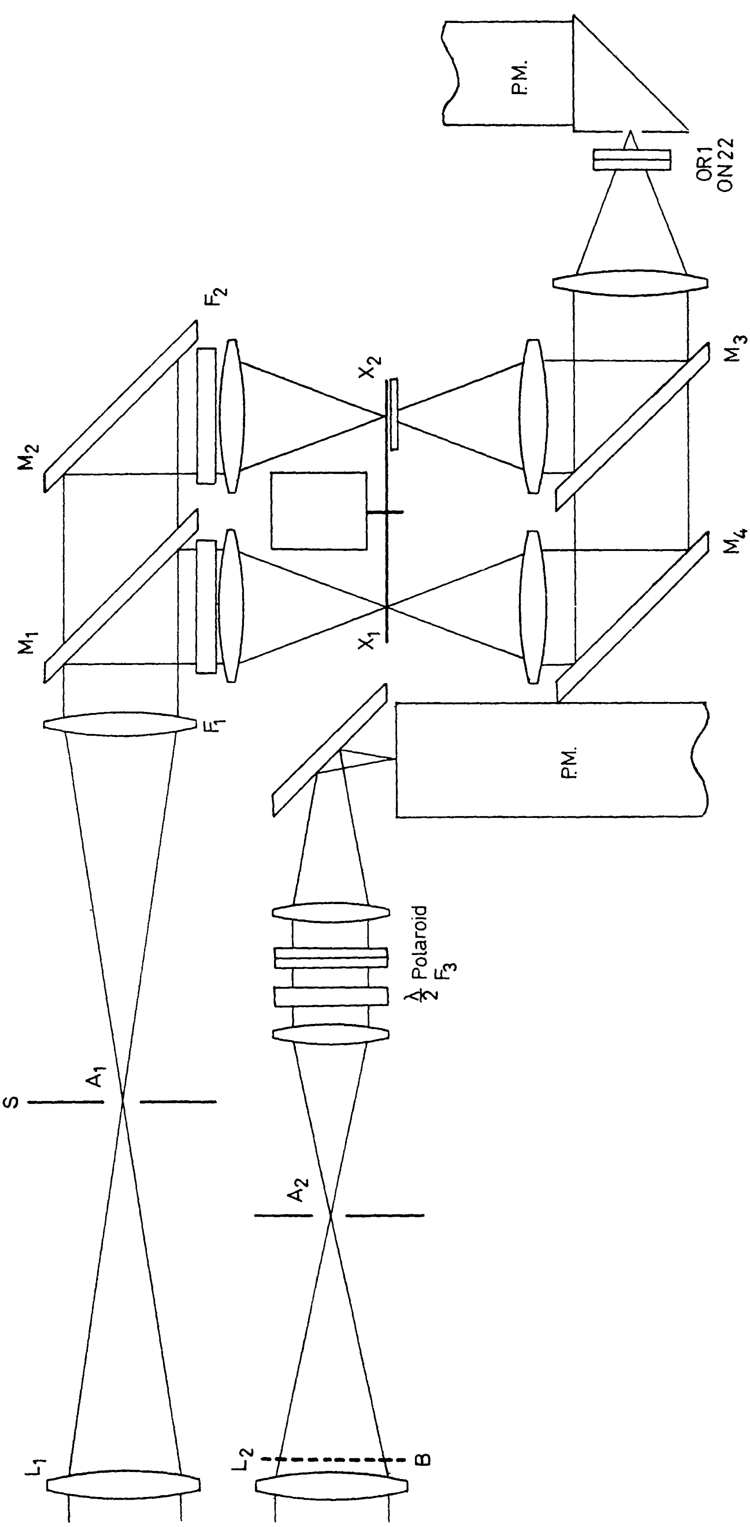

FIG. 1. *Optical arrangement of the apparatus for measuring Fraunhofer line intensity (upper part) and polarization (lower part).*

on to the entrance aperture of an image scrambler (13) attached to an E.M.I. type 9558 tri-alkali photomultiplier. The optical system also contained an OR1 filter, and an ON22 filter to reduce the effect of near infra-red radiation. All lens surfaces were bloomed. The narrow band filter F_1 could be rotated in its mounting so that it could be tuned to Hα; for this adjustment an Hα emission lamp was used.

In the lower section, for the measurement of polarization, an image of the corona is formed by the lens L_2 of diameter 6·2 cm. An aperture A_2 selects part of this image and light is then passed successively through a collimating lens, a $\lambda/2$ plate which is rotated at 1 200 rev/min by an electric motor, a polaroid filter and a wide band interference filter, F_3. A further lens forms an image of the objective on the cathode of a tri-alkali photomultiplier. Light from a standard lamp, suitably reduced by a calibrated neutral filter, could be introduced into the system by means of a screen B, surfaced with white blotting paper, which could be erected in front of the lens L_2.

In both sections the aperture A could be controlled with a solenoid to be $\frac{1}{2}^\circ$ (for the inner corona) or 1° (for the outer corona), or else completely blocked.

Data for the three interference filters are given below.

Filter		Half-width (Å)*
Fraunhofer channel	wide band	128
	narrow band	6·5
Polarization channel		116

5.2. *The electronics.* For both channels, the d.c. and a.c. components of the photomultiplier anode currents were separated by feeding the a.c. through a coupling capacitor to the virtual earth of a feedback amplifier, this capacitor effectively acting as a filter for the d.c. signal, which appeared across a 1 MΩ total switched attenuator. The a.c. signal, amplified to 30 mV/μA in this first amplifier, was further amplified in two stages with gain steps of 1 : 10 : 100 and then, after a high impedance stage to provide a current source, was rectified by a phase-sensitive detector and filtered by a feedback d.c. amplifier. In the case of the polarization signal two detectors in phase quadrature were used in parallel.

The recording system consisted of a Solarton 1010.2 digital voltmeter for each experiment, whose displays were photographed by a cine-camera. The camera shutter had a contact giving 16 pulses/s and this was used as a timing source, being divided in binary stages and used to operate relays which switched the voltmeter inputs between the d.c. and rectified a.c. signals—in the case of the polarization signals alternate a.c. readings were taken of the two detector outputs. Also in the camera field were a number of small lamps showing the attenuator settings and also showing which type of information was being displayed at any moment.

The digital voltmeters have a socket for feeding the reading to a printer, and by means of a diode matrix and transistor logic circuits fed from this output it was arranged that lights on the control panel were energized when the signal in one of the four channels (two d.c. and two a.c.) approached the high or low ends of the voltmeter range (in a range of 1·5999, readings greater than 0·6000 or less than 0·0300 were indicated). The operator could then adjust the appropriate attenuator switch.

* i.e. the whole width at half intensity.

5.3. *Guiding and direction recording*. The optical parts were all attached rigidly to a base plate, to which was also attached a sighting device. This consisted of a 4 in. lens of focal length 3 ft which formed an image of the corona on a ground glass screen. The whole apparatus could be swung about a universal joint so that, using the sighting device, it could be pointed at any part of the corona and guided there against the motion of the aircraft.

A second 16 mm cine-camera, attached to the base plate, operated at 16 frames/s throughout the eclipse to provide a record of the positions of observation in the corona. These positions were linked with the readings of the digital voltmeters by means of mechanical counters. A complete cycle of readings was recorded every quarter second, so that a certain amount of wandering of the point of observation could be tolerated. The integration time was suitably chosen for this rate of recording.

6. *The observing programme*. At the beginning of the eclipse the apparatus was pointed to a position in the corona at a distance of about $4R_0$ on the west side of the Sun. An attempt was made to guide for 5 s at a time on parts at successively greater distances from the Sun to about $16R_0$; then at about half-time, to observe the sky background at about 10° from the Sun and at the same altitude. After this the scanning procedure was reversed. Presumably the sky brightness varies a little during the eclipse, being smallest at mid-eclipse, and this kind of programme ensures that those observations which are most heavily dependent upon an accurate knowledge of the sky background are made near the time that the background is being measured.

The results of this procedure can be judged by Fig. 2, which shows part of the returning scan. It seems quite feasible to guide for periods of several seconds to an accuracy of $\pm 0 \cdot 5R_0$. However, we do not rely upon accurate guiding of the coronal image because intensity gradients in these outer regions of the corona are quite small, and the time constant of the electronics is short. As we have an accurate correlation between the outputs of the electronics and position in the corona, practically every point in a diagram such as Fig. 2 is useable.

7. *The measurement of brightness*

7.1. *The solar corona*. The d.c. outputs of the two sections are each proportional to the brightness at the position of observation. The outputs were satisfactorily great; for example, the polarization channel when used to observe the corona at a distance of $6R_0$ with an aperture of diameter ½ degree gave an output of 0·3 μA; the corresponding dark current of the photomultiplier was 0·01 μA.

In Fig. 3 we show a plot of each measurement of the d.c. output of the polarization channel (less dark current) against the position of the point of observation in the solar corona. Corresponding data from the Fraunhofer channel agree to within 1%. The brightness of the sky background has been found from the observations made at 10° from the Sun, making a small allowance for the likely proportion of solar corona there; this brightness is also given on the diagram. The values of the coronal brightness found by subtraction have been further corrected for the finite size of the scanning aperture (0°·5

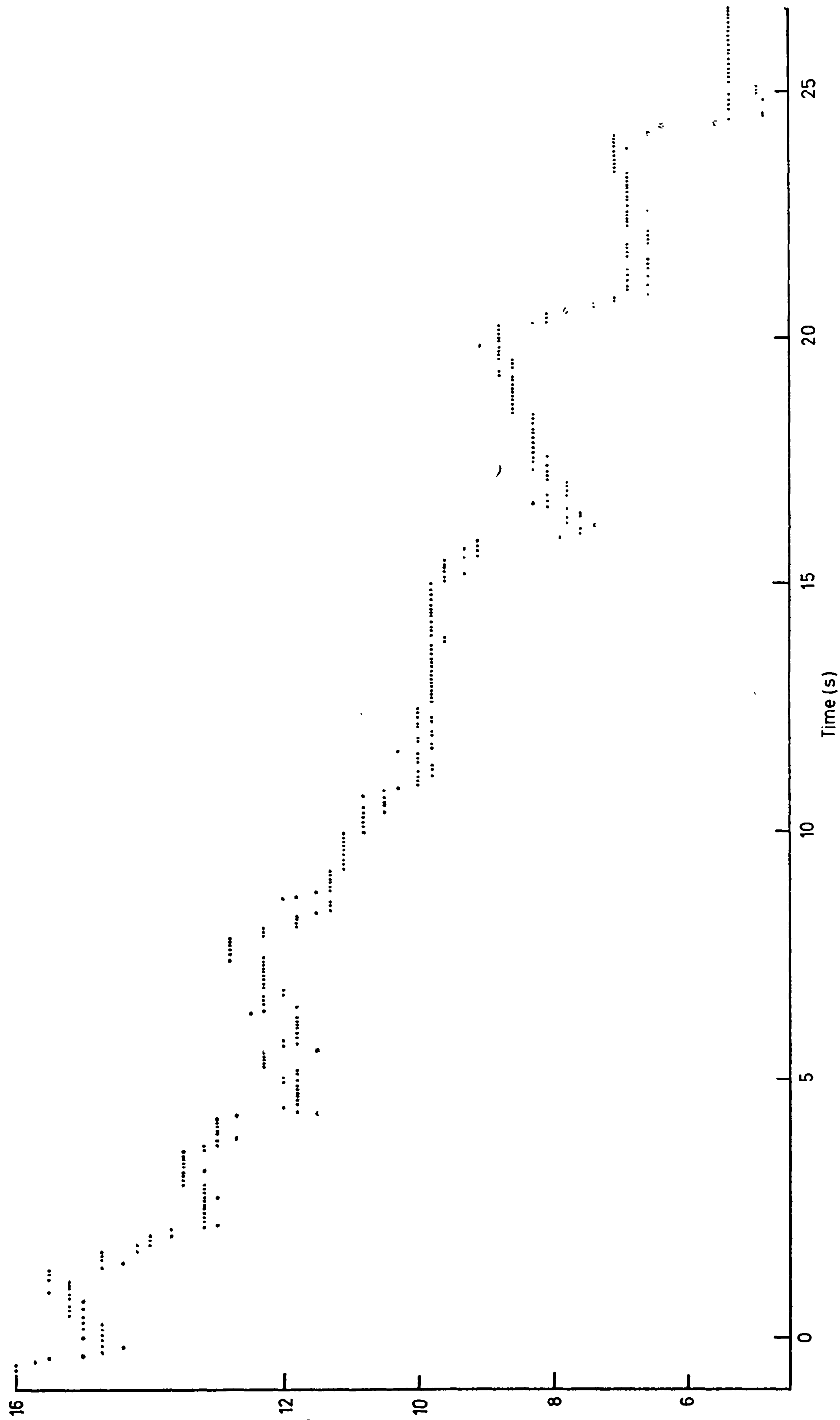

FIG. 2. *Plot of position of scanning aperture along equator against time for part of the returning scan, showing attempts to guide.*

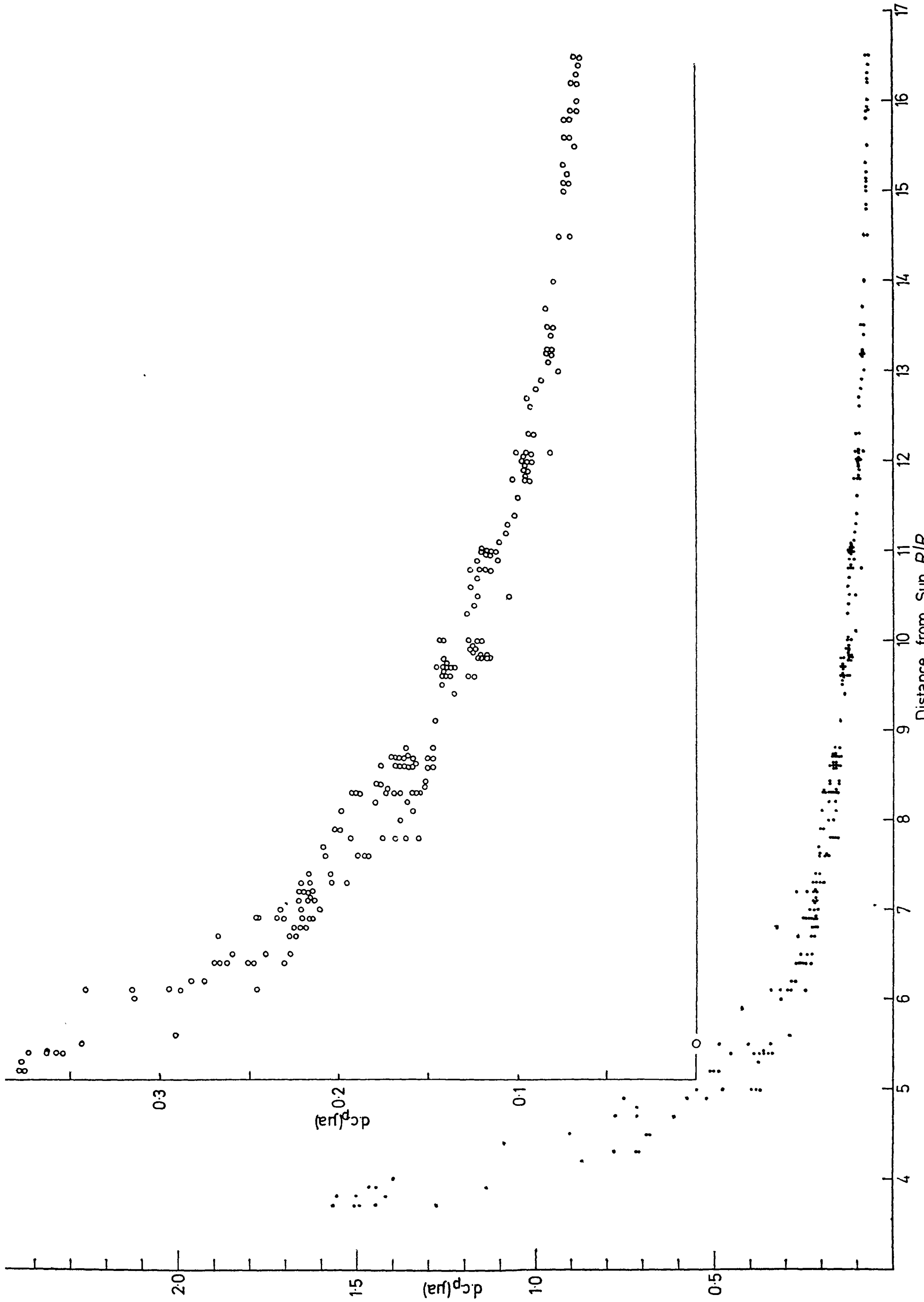

FIG. 3. *Output (d.c.) from polarization channel plotted against radial distance from Sun in the equatorial region. The distance scale is uncorrected for collimation error.*

for distances less than $10R_0$, and 1°·0 for greater distances); this correction is rather great for distances less than $5R_0$, and so we restrict ourselves to distances greater than this. Conversion to absolute units has been made using an absolute calibration for the standard lamp provided by the National Physical Laboratory, Teddington; in doing this we have made a measurement of the reflectivity of the blotting paper screen used in the apparatus by substituting for it a screen coated with magnesium oxide, of known reflectivity. Finally, we have converted the brightness relative to that of the mean solar disk using the value of solar flux at Hα of $0{\cdot}160 \times 10^4$ W/cm^{-2} (100 Å)$^{-1}$ (**14**). A small correction has been made for the transmission of the relevant optical parts and for the Earth's atmosphere at 30 000 ft.

In connection with some observations by Blackwell (**5**) of the polarization of the outer corona, Ney (**15**) has drawn attention to the possibility of uncertain correction for sky background. We shall consider this matter in a later publication, and only state now that we believe that the correction for the sky background that has been made in these reductions is satisfactory.

TABLE I

Observed photometric model of the corona

R/R_0	$K+F$*	$k=K/(K+F)$	K*	F*
5	7·5	0·14	1·05	6·5
6	5·0	0·13	0·65	4·4
7	3·7	0·11	0·41	3·3
8	2·9	0·093	0·27	2·6
9	2·3	0·077	0·18	2·1
10	1·8	0·069	0·124	1·7
11	1·45	0·061	0·089	1·36
12	1·20	0·056	0·067	1·13
13	1·02	0·048	0·049	0·97
14	0·90	0·043	0·039	0·86
15	0·81	0·040	0·032	0·78
16	0·72	0·038	0·027	0·69

Wavelength region Hα;
Eclipse 1963 July 20;
Equatorial region;
Sunspot minimum;
Relative sunspot number for 1963 July (Zurich) : 19·0.

* unit: $10^{-10} \times$ mean brightness of solar disk.

The values for the coronal brightness are given in Table I; we estimate that they are reliable to within 5%. These values follow those given by Gillett *et al.* (**16**) for the same eclipse but at $10R_0$ are about 5% less. They are also in reasonable agreement with the model of Allen (**17**)†.

7.2. *The sky background.* The value of the sky brightness at the effective wavelength of 6 640 Å is $0{\cdot}71 \times 10^{-10}$ B_0, where B_0 is the mean brightness of the solar disk: it is equal to the brightness of the corona alone at a distance of about $16R_0$ from the Sun. The sky was therefore much darker than it was at the 1954 exclipse as observed from a height of 30 000 ft, when it was $2{\cdot}6 \times 10^{-10}$ B_0 at wavelength 6 300 Å (**5**). If we suppose that the brightness follows the λ^{-4}

† A more detailed examination of published data concerning the properties of the corona will be made in a later publication.

Rayleigh law, the brightness at the 1954 eclipse reduced to wavelength 6640 Å was $2 \cdot 1 \times 10^{-10} B_0$, i.e. three times brighter than at the 1963 eclipse.

8. *The determination of $K/(K+F)$*

8.1. *The principle of the method.* The method is very similar to one already used by Beggs *et al.* (7) for separating the K and F components of the zodiacal light. In that method three slits were placed in the spectrum of the zodiacal light, the central one measuring the Fraunhofer line and the two side ones measuring the continuous spectrum; each slit was used with its own photomultiplier. The arrangement used for the eclipse is superior to this in at least two ways. One of these is that the Fraunhofer line and the continuum are measured over bandwidths which have the same central wavelength. In this way possible effects due to a change in the distribution of energy in the spectra (for example as between the sky background and the corona) are reduced to a minimum. The other advantage is that only one photomultiplier is used so that drift of a balance point due to changes of sensitivity are avoided.

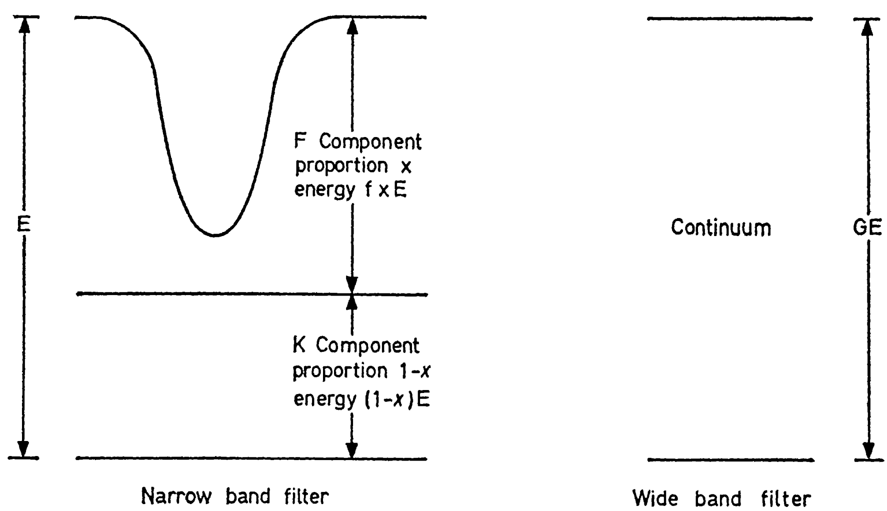

FIG. 4. *Diagram showing the principle of the method, with the appropriate energy fluxes. The two bandpasses are shown of rectangular form and separated for the sake of simplicity; they are actually centred on the same wavelength.*

The principle of the method is described with the aid of Fig. 4. The spectrum of the source being observed (in this case, the corona and the sky background) consists of a pure Fraunhofer component and a continuous component. These are present in the following proportions;

Pure Fraunhofer spectrum	x;
Continuous spectrum	$1-x$.

The photomultiplier alternately views a narrow region in the spectrum which contains the Fraunhofer line, and a wide region. The Fraunhofer line reduces the energy of the continuous spectrum over the region of spectrum being considered by a factor f. A neutral filter reduces the flux from the wide band filter to the flux E, which is the flux passed by the narrow band filter in the continuum. The flux from the wide band filter is then further reduced by a factor g so that it is equal to the flux from the narrow band filter when the narrow band is occupied by a Fraunhofer line of normal depth. In practice perfect equality will not be achieved, so that

$$g = f + \Delta f.$$

The a.c. component of the photomultiplier output is proportional to the difference between the energies transmitted by the two filters, i.e.

$$E(fx + 1 - x) - gE,$$

while the d.c. component is proportional to the sum of these two fluxes, i.e.

$$E(fx + 1 - x) + gE.$$

The ratio a.c./d.c. is proportional to

$$\begin{aligned} &\frac{fx + 1 - x - g}{fx + 1 - x + g} \\ &= \frac{fx + 1 - x - f - \Delta f}{fx + 1 - x + f + \Delta f} \\ &= \frac{(1 - f)(1 - x) - \Delta f}{1 + f - x(1 - f) + \Delta f} \\ &= B(1 - x) + D, \end{aligned}$$

where B and D may be taken to be constants if $x \ll (1 + f)/(1 - f)$, which in this case is true.

With a suitable calibration the observed ratio a.c./d.c. now leads to the ratio x. To obtain the corresponding quantity for the corona alone we must correct for the presence of the sky background.

8.2. *Correction for the sky background.* The light from the place of observation in the corona contains the three components,

Sky background	=	S		
Corona	=	C		
Continuous component	=	C_K	=	kC
Fraunhofer component	=	C_F	=	$(1 - k)C$.

Hence the *observed* ratio of continuous component to total is given by

$$\begin{aligned} 1 - x &= \frac{C_K}{C_K + C_F + S} \\ &= \frac{kC}{C + S} \\ &= kR, \end{aligned}$$

where $R = C/(C + S)$ i.e. the ratio of coronal brightness to total brightness of corona and sky.

Hence, $$k = (1 - x)/R.$$

This equation relates the ratio of continuous to Fraunhofer spectrum in the corona to the ratio which is observed in the mixture of corona and sky background.

8.3. *Calibration.* We adopt a differential method of calibration which is based upon observations of the inner corona at $5R_0$. At this distance from the Sun we judge that $P_F \ll P_{K+F}$ and hence we may use observations of polarization

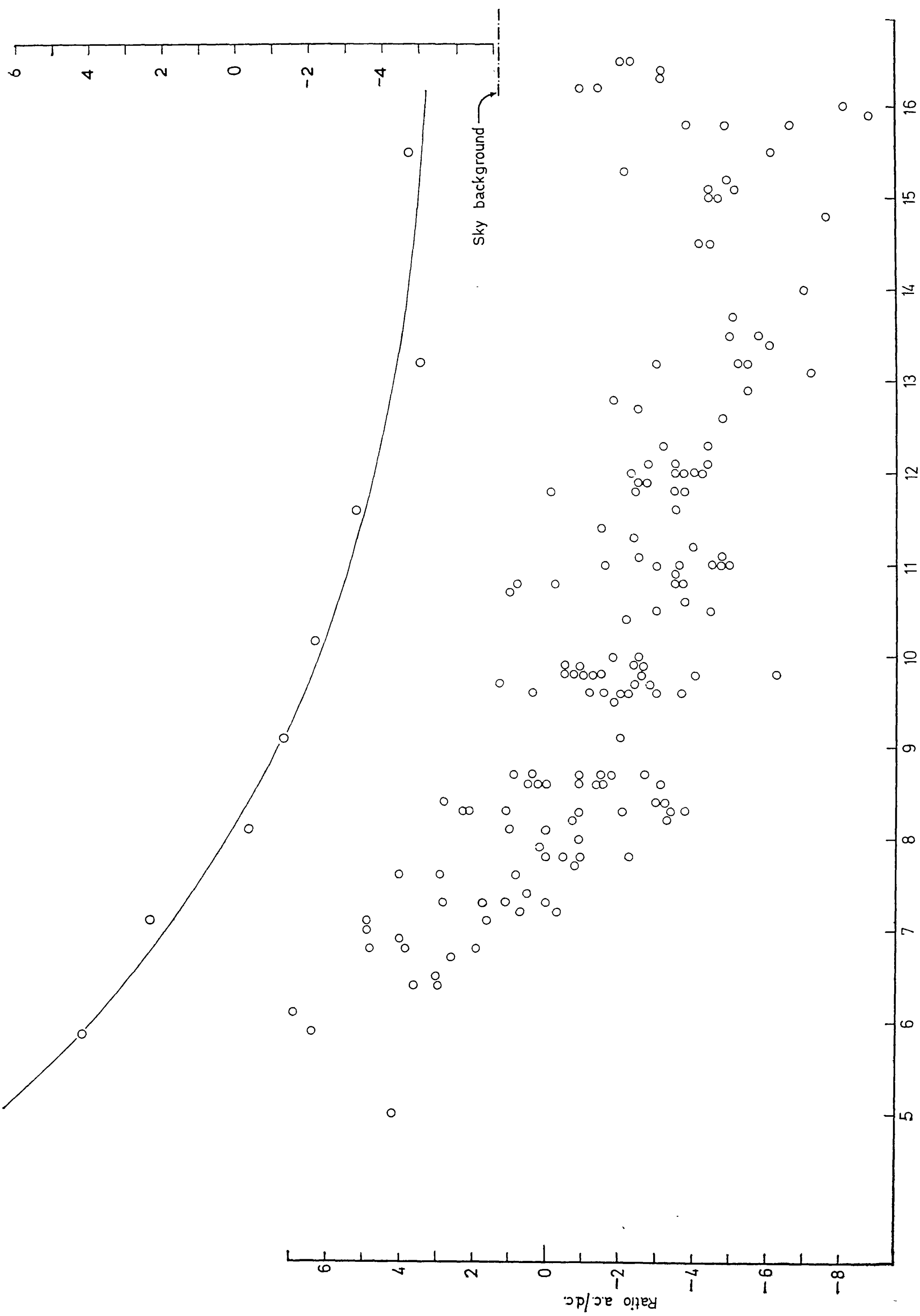

FIG. 5. *Ratio a.c./d.c. output from the Fraunhofer line channel plotted as a function of distance from the Sun.*

to obtain the proportion of continuous component in the light from the corona at this point. We also know the proportion of sky background light at this distance, and hence can determine the quantity x. Similarly, far from the Sun we observe the quantity x for the sky background, which has a nearly pure Fraunhofer spectrum. The accuracy of our reductions does not greatly depend upon an assumption that the distant sky background has a pure Fraunhofer spectrum; for instance, even if the background has a continuous component which amounts to 10% of the whole (which we believe to be unlikely) an error of only 10% is introduced into the final results. These two measurements give two points on the straight line relating a.c./d.c. to $(1-x)$, and hence we are able to calculate x for any observed a.c. output. This method has the advantage that no knowledge of the properties of the interference filters is needed. It also has the advantage that there are no undesirable effects due to any difference in colour between the corona and the calibrating source such as would exist if we were to use an incandescent lamp for calibration. This point is considered further in section 10 below.

9. *Results.* We plot in the lower part of Fig. 5 each observation of the ratio of a.c./d.c. against the distance of the place of observation from the Sun. A separate investigation has shown no systematic effect depending upon the size of the scanning aperture. The points in the diagram have been divided into groups, and the centre of gravity of each group found. The results of this procedure are shown in the upper part of Fig. 5, from which it is apparent that the curve is reasonably well defined.

For the calibration point at $5R_0$ we need the polarization of the corona here. In the absence of direct observation we take the polarization from a new model of the corona (**18**) which is based upon observations made at eclipses since 1952, and on the models of van de Hulst (**19**) and Allen (**17**). For this model, $P_{K+F}=9{\cdot}0\%$ and $P_K=62{\cdot}7\%$. This new model will be discussed in detail elsewhere, but we here remark only that the values of P_{K+F} in it are greater than those in the van de Hulst model, and less than those in the Allen model. At this distance from the Sun during the eclipse, $R=0{\cdot}911$.

The values of $k=K/(K+F)$, K and F are given in Table I. These are the first direct measurements of k to so great a distance from the Sun. It is our intention to devote a second paper to the interpretation of these values of k in terms of electron densities in the corona and the properties of the F component.

10. *Errors.* As the change of balance point which must be observed is so small it is very important to guard against spurious effects. The most important of these is the effect of a 'leak' in the infra-red in the transmission of the narrow band interference filter, for if the filter transmits only 1% at wavelengths greater than its pass-band the total flux over these wavelengths will be comparable with that in the region of $H\alpha$. Clearly, only a leak that is much smaller than this can be tolerated, but even a very small leak may be undesirable because it will lead to a dependence of a.c. output on the colour temperature of the source being examined. This is an important consideration because there is a considerable difference between the distributions of energy with wavelength for the inner corona and the sky background.

In order to reduce this undesired effect we have taken particular care over the selection of the narrow band filter. The one chosen was made by Spectrolab Inc. and is blocked to 10 000 Å with a small peak of transmission at 9 500 Å. As an additional precaution, an ON22 filter was also used. The presence of a small infra-red leak is shown by a small change of balance point between the inner corona, when this is a source, and an incandescent lamp (which contains a large excess of infra-red radiation). However, this was not sufficiently large to affect the comparison between the inner corona and the sky background. The wide band is not sufficiently wide to be affected by the colour difference between corona and sky.

It is clear from the spread of points in Fig. 4 that the accuracy of the method cannot be great, although we emphasise again that the large spread is due to the short time constant (0·25 s). We now seek the origin of this noise.

The root-mean square fluctuation about the mean curve in the diagram is equivalent to 0·7% of the flux through either channel. The total photon flux through the apparatus from the corona at a distance of $10R_0$ from the Sun is about 7×10^4 photons in 0·25 s, so that if the quantum efficiency of the photomultiplier cathode is 25% the photon-electron flux in the same time is $1{\cdot}8 \times 10^4$ photoelectrons, which we call n_e. This may be expected to fluctuate by $100 \times \sqrt{n_e}/n_e\%$, i.e. by 0·75%. It therefore seems that the whole of the observed noise may be attributed to photon fluctuation. None can be due to the photomultiplier itself because the dark current, which was observed to have a shot noise spectrum, is considerably less than the observed photoelectron flux. This calculation shows that it will be very difficult to extend the electron density data beyond $16R_0$ from the Sun.

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References

(1) W. Grotrian, 1934. *Z. Astrophys.*, **8**, 124.
(2) C. W. Allen, 1946. *Mon. Not. R. astr. Soc.*, **106**, 137.
(3) C. W. Allen, 1956. *Mon. Not. R. astr. Soc.*, **116**, 413.
(4) M. Waldmeier, 1958. *Z. Astrophys.*, **46**, 17.

(5) D. E. Blackwell, 1955. *Mon. Not. R. astr. Soc.*, **115**, 629.
(6) D. E. Blackwell & M. F. Ingham, 1961. *Mon. Not. R. astr. Soc.*, **122**, 129.
(7) D. W. Beggs, D. E. Blackwell, D. W. Dewhirst & R. D. Wolstencroft, 1964. *Mon. Not. R. astr. Soc.*, **127**, 329.
(8) S. Gorgolewski & A. Hewish, 1960. *Observatory*, **80**, 99.
(9) V. V. Vitkevich, 1958. *Astr. Zh.*, **2**, 45.
(10) D. E. Blackwell, 1956. *Mon. Not. R. astr. Soc.*, **116**, 56.
(11) D. E. Trotter, 1963. *High Altitude Observatory Report*, No. HAO-59.
(12) D. E. Blackwell, 1962. *Space Sci. Rev.*, **1**, 612.
(13) D. E. Blackwell, A. D. Petford & S. H. McCrea, 1965. *Observatory*, **85**, 21.
(14) L. Goldberg & A. K. Pierce, 1959. *Handbuch der Astrophysik*, **42**, 17.
(15) E. P. Ney, W. F. Huch, P. J. Kellogg, W. Stein & F. Gillett, 1961. *Astrophys. J.*, **133**, 616.
(16) F. C. Gillett, W. A. Stein & E. P. Ney, 1964. *Astrophys. J.*, **140**, 292.
(17) C. W. Allen, 1962. *Astrophysical Quantities*, p. 176. Athlone Press.
(18) D. E. Blackwell & D. W. Dewhirst (in preparation).
(19) H. C. van de Hulst, 1953. *The Sun*, Ed. G. P. Kuiper, p. 262. University of Chicago Press.