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Three-Color Photometry of the Zodiacal Light

Alan W. Peterson

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OF THE
ZODIACAL
LIGHT

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THREE-COLOR PHOTOMETRY OF THE ZODIACAL LIGHT

By

Alan W. Peterson

A Dissertation

In partial fulfillment of the
Requirements for the Degree of
Doctor of Philosophy in Physics

University of New Mexico
1960

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DOCTOR OF PHILOSOPHY

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CHAPTER I

INTRODUCTION

A. THE PHENOMENON OF THE ZODIACAL LIGHT

1. DESCRIPTION OF THE PHENOMENON. The zodiacal light is a readily observable illumination of the night sky. Presumably it has been known and observed in the tropics since antiquity, but only since about 1600 in the temperate zones (1,2). The phenomenon appears at its maximum intensity immediately after the cessation of evening twilight or before the beginning of dawn. The brightest portion of the zodiacal light, roughly triangular in shape, is approximately centered on the ecliptic and extends along the band defining the zodiac. The base of this "light pyramid" is 40 to 50 degrees across. At an angular distance of about 90 degrees from the sun, along the ecliptic, the intensity has fallen to such a value as to be only faintly visible under the best conditions. However, the artifice of averted vision allows the zodiacal illumination to be traced along the ecliptic, through a minimum occurring at an elongation of about 135 degrees, and on to a somewhat brighter region at the antisolar point. The patch of light in this latter region, called the gegenschein, is roughly circular in shape and only slightly brighter than the surrounding sky.

The extension of the zodiacal light across the entire sky is called the "zodiacal band" or sometimes the "light bridge" (3).

The zodiacal light merges gradually with other light sources to either side of the ecliptic and thus has no definite boundaries. On the other hand, the line joining points of maximum intensity, called the "light axis", is rather well defined and usually lies close to the ecliptic. The color assigned to the brighter regions of the light pyramid by visual observers ranges from "reddish" through "greenish". Nevertheless, photoelectrically measured color indices indicate a spectral intensity distribution nearly identical to that of the sun.

2. SEPARATION OF THE ZODIACAL LIGHT FROM OTHER LIGHT SOURCES. Other night-sky luminosities which, of necessity, must be observed along with the zodiacal light are direct star light, the airglow or permanent aurora, the diffuse light originating from unresolved stars of the milky way, light scattered by interstellar matter, and the light of all of these sources scattered by the earth's atmosphere. The peculiar celestial distribution of each light source permits some differentiation as to the origin of the light observed at a given point on the celestial sphere. However, the unambiguous resolution of the night-sky luminosity into its various components, some of which are erratically variable, poses a problem which can at best be only approximately solved. Some of the steps which can be taken to lessen the uncertainty introduced by a specific source of interference are 1) the use of high-altitude observation sites to reduce atmospheric effects, 2) the incorporation of narrow-band

The nodal light merges gradually with the background
either side of the ecliptic and thus has the appearance
On the other hand, the line joining the nodes of the ecliptic
called the "light axis", is rather well defined and nearly
close to the ecliptic. The color assigned to the ecliptic
regions of the light pyramid by various observers is
"redish" through "greenish". However, the color
measured color indices indicate a somewhat different
nearly identical to that of the sun.

2. SEPARATION OF THE LIGHT SOURCES

SOURCES. Other light-ray intensities, of course, can
be observed along with the reddish light and also the light
the airflow or permanent sources, the ecliptic light
from unresolved stars of the Milky Way. Light scattered by
stellar matter, and the light of all of these sources
by the earth's atmosphere. The peculiar character of the
of each light source permits some differentiation as to the
origin of the light observed at a given point on the ecliptic
sphere. However, the unambiguous resolution of the light
luminosity into its various components, some of which are
intrinsically variable, poses a problem which can be solved only
approximately solved. Some of the steps which have been taken to
lessen the uncertainty introduced by a given source of light
ference are: 1) the use of high-altitude observation sites to
reduce atmospheric effects, 2) the use of instruments of high

color filters to observe in spectral regions free of intense airglow emission lines, 3) observation at high galactic latitudes to reduce the milky way contribution, and 4) separation of the total light observed into polarized and non-polarized components with the assumption that of all the contributing sources only the zodiacal light has a polarized component.

3. THEORIES CONCERNING THE ORIGIN OF THE PHENOMENON.

There have been two main theories to explain qualitatively the source and nature of the zodiacal light phenomena, namely, the "terrestrial" and the "planetary" theories (3). Both theories assume a lenticular cloud of scattering particles but differ in the location and composition of the cloud.

The terrestrial theory postulates a geocentric cloud composed of constituents of the earth's atmosphere or dust particles. The lens-shaped cloud is assumed to lie in the plane of the ecliptic and is thus inclined at a considerable angle to the rotational axis of the earth. The eccentric location of the cloud with respect to the axis of rotational symmetry of the earth requires that some mechanism, such as solar radiation pressure, act on the cloud producing a force sufficient to obtain the observed configuration.

The terrestrial theory, in its many forms, has been championed mainly by non-astronomers. The attempts to bring the zodiacal light phenomena "closer to home" through some novel mechanisms have been given strong verbal support but little

color filters to observe in an optical system two of these
airflow emission lines, 3) experimentally and 4) experimentally
to reduce the Milky Way concentration, and 5) experimentally
total light observed in the polarized and non-polarized components
with the assumption that of all the emission lines only
the scattered light has a polarized component.

3. THEORY CONCERNING THE NATURE OF THE EMISSION

There have been two main theories in relation to the
source and nature of the scattered light phenomenon, namely, 1)
"terrestrial" and the "planetary" theories (2). Both theories
assume a lens-shaped cloud of scattering material and differ
the location and composition of the cloud.

The terrestrial theory postulates a scattering cloud
composed of constituents of the earth's atmosphere or dust
particles. The lens-shaped cloud is assumed to lie in the plane
of the ecliptic and is thus inclined at a constant angle to
the rotational axis of the earth. The rotational velocity of the
cloud with respect to the axis of rotational symmetry of the
earth requires that some mechanism, such as solar radiation
pressure, act on the cloud producing a lateral shift in its
the observed configuration.

The terrestrial theory, in its many forms, has been
championed mainly by non-astronomers. The scattered light
scattered light phenomena "closer to home" (1) and (3) have
mechanisms have been given strong verbal support but little

analytic formulation. The planetary theory, to be discussed next, has found much wider acceptance among astronomers. The zodiacal light, in this theory, becomes visible evidence of an interplanetary medium permeating the solar system rather than some hypothetical appendage loosely attached to the earth.

The planetary theory assumes a heliocentric, ellipsoidal cloud of scattering particles. The major axis of the ellipsoid of revolution coincides with the ecliptic. Dust particles, large compared to the wavelength of visible light are called upon to provide non-color dependent scattering and usually, free electrons are included to produce the rather large polarized component. The particle density is generally taken as proportional to some simple power of the solar distance. The actual number of particles, a few microns in diameter, needed to produce the observed illumination is very small and of the order of one per cubic kilometer.

B. OBJECTIVES OF THIS INVESTIGATION. The major effort of the observational phase of this investigation was placed upon obtaining absolute intensity maps of the zodiacal light in three different colors. Emphasis was also placed upon measurements of polarization and upon photographing the spectrum of the zodiacal light.

Because of the recent peak in solar activity (1957-58), it was desirable to attempt recordings of the zodiacal light during or shortly after a solar flare in order to determine whether or not

analytic formulation. The planetary theory, as we discussed next, has found much wider acceptance among astronomers. The sodical light, in this theory, becomes visible evidence of an interplanetary medium permeating the solar system rather than some hypothetical appendage loosely attached to the earth. The planetary theory assumes a heliocentric, elliptical orbit of scattering particles. The major axis of the elliptical orbit coincides with the ecliptic. Part particles, large compared to the wavelength of visible light are called upon to provide non-color dependent scattering and usually, free electrons are included to produce the rather large polarized component. The particle density is generally taken as proportional to some simple power of the solar distance. The actual number of particles, a few million in diameter, needed to produce the observed illumination is very small and of the order of one per cubic kilometer.

B. OBJECTIVES OF THIS INVESTIGATION. The major effort of the observational phase of this investigation was aimed upon obtaining absolute intensity maps of the sodical light in three different colors. Research was also placed upon measurements of polarization and upon photographing the spectrum of the sodical light.

Because of the recent peak in solar activity (1957-58), it was desirable to attempt recordings of the sodical light during or shortly after a solar flare in order to determine whether or not

the occurrence of a solar flare had any detectable effect upon the zodiacal light intensity, color, or shape. An atmospheric receiver, which in most cases will give an indication of the occurrence of a solar flare, was constructed to monitor solar activity. Further, since a maximum in geomagnetic activity is associated with peak solar activity it was desirable to obtain recordings during a terrestrial magnetic storm to note any effect upon the zodiacal light intensity or color. An increase in zodiacal light intensity and a color effect has been reported during such a magnetic storm (4).

Further inquiries, although more particular in nature, were made to check upon the reported relationship between the zodiacal light and the solar Fraunhofer corona (5) and to confirm and, if appropriate, to extend previous measurements (6) of an apparent reddening of the zodiacal light with respect to angular distance from the sun. It was desirable to make measurements of this latter effect over the entire zodiacal light pyramid to permit construction of "isochromes" if a color effect proved to be present.

C. OUTLINE OF THE DISSERTATION. The introductory chapter gives a brief, general description of the zodiacal light phenomena. In Chapter II the literature is closely examined and summarized. Descriptions of the methods used in obtaining experimental results are given in an attempt to gain some insight into the reasons for the discordant results, even among reputable

the occurrence of a solar flare, and the resulting increase in the solar light intensity, color, or shape. In addition, the receiver, which in most cases will give an indication of the occurrence of a solar flare, was connected to a solar activity. Further, since a certain amount of activity is associated with peak solar activity, it was desirable to obtain recordings during a continuous period of time to note any change upon the solar light intensity or color. The intensity of solar light intensity and a color effect, as was reported during such a magnetic storm (2).

Further studies, although more extensive in nature, were made to check upon the reported relationship between solar light and the solar-terrestrial connection (3) and to obtain, if appropriate, to extend previous measurements (4) of the apparent reddening of the solar light with respect to distance from the sun. It was desirable to make measurements of this latter effect over the entire solar disk, in order to permit construction of "solar maps" in a color effect, which may be present.

C. OUTLINE OF THE DISCUSSION. The discussion, which gives a brief, general description of the solar flare, is summarized. In Chapter II the discussion is more detailed and summarized. Descriptions of the solar flare are given in some detail into the reasons for the observed changes in the solar light.

observers, which characterize the entire zodiacal light problem. An important byproduct of this chapter is a relatively complete summary of the modern international literature on zodiacal light.

The third chapter deals with a description of the experimental equipment used to make the measurements in this study, along with a detailed description of the entire measurement procedure. The auxiliary equipment necessary to obtain spectra and to record atmospheric noise is also described.

In Chapter IV the sources of atmospheric extinction are considered, and a theoretical expression for the response of the photometer at various elevation angles is evaluated to provide a correction for the resultant light loss. The effective solid angle of acceptance of the photometer is calculated and used instead of the solid angle subtended by the photomultiplier mask at the vertex of the mirror. This is done because the light actually measured by the photometer is less than one would expect from the geometry of the photomultiplier mask only.

The lengthy procedure employed in the analysis of the intensity recordings is described in detail in Chapter V. The method of correction for extraneous light due to the milky way and the airglow is discussed as well as the source of the data used for these corrections. The color calibration of the photometer, and the conversion of the zodiacal light measurements to absolute intensities is described. The analysis of the polarization measurements is covered also.

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intensities is described. The analysis of the data
measurements is covered also.

The findings of the investigation are presented in Chapter VI and are compared with the experimental results of other investigators. The experimental work is summarized and suggestions for future work, of both an observational and a theoretical nature, are made in Chapter VII.

Light which is of some scientific value consists of brightness and position estimates. Unfortunately, these observations are marred by the eye's inability to distinguish between the various components of the radiation, or to properly account for atmospheric extinction. The strong emission line of neutral oxygen at 5577 Å is a serious source of extraneous illumination to which the night-adapted eye is very sensitive. If this light source happens to be brighter than average, the zodiacal light will appear fainter than usual and only careful study of the situation will keep the eye from being deceived. Similar reasoning applies to the case where the night-sky illumination is weaker than normal, and to variations in atmospheric extinction.

The color estimates by various observers which indicate reddish through greenish tones again illustrate the vagaries of the human eye. According to Roach (7), laboratory tests on the color perception of the normal eye indicate that the brightness of the zodiacal light at an elongation of 30° from the sun is very nearly 100 times too faint for color perception to be possible. Thus, it appears that even the entire light contribution to the eye at small elongation angles near the ecliptic

The findings of the investigation are presented in Chapter VI and are compared with the experimental results of other investigators. The experimental work is summarized and suggestions for future work, of both an observational and a theoretical nature, are made in Chapter VII.

CHAPTER II

REVIEW OF PREVIOUS RESULTS

A. VISUAL OBSERVATIONS OF THE ZODIACAL LIGHT

1. CRITIQUE OF VISUAL OBSERVATIONS. Those naked-eye observations of the zodiacal light which are of some scientific value consist of brightness and position estimates. Unfortunately, these observations are marred by the eye's inability to distinguish between the various components of the radiation, or to properly account for atmospheric extinction. The strong emission line of neutral oxygen at 5577A is a serious source of extraneous illumination to which the night-adapted eye is very sensitive. If this light source happens to be brighter than average, the zodiacal light will appear fainter than usual and only careful study of the situation will keep the eye from being deceived. Similar reasoning applies to the case where the night-sky illumination is weaker than normal, and to variations in atmospheric extinction.

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in not enough to allow a visual determination of the true color. Certainly, this author has never been aware of any significant color impression from the brightest region of the zodiacal light, to say nothing of the very feeble impression made by the light bridge of the gegenschein.

2. EARLY VISUAL OBSERVATIONS. Long and detailed records of the zodiacal light behavior have been kept by several mariners during tropical cruises. The chronicle of Jones (8) contains observations and sketches extending over two years from 1853 to 1855. Many descriptions of variations in shape and intensity are included. Beside the unusual events described by Jones, such as pulsations of the observed light, Hulbert (9), who examined the data about 70 years later claims to have found a good correlation between intensity and magnetic activity. Bayldon (10), on cruises from Vancouver, B.C. to Australia, tends to note the unusual events rather than to record numerous systematic observations. He describes such apparent anomalies as 1) the maximum intensity occurring at an elongation of 105 degrees, 2) the zodiacal band being nearly uniform in width, 3) a contribution to the zodiacal light by the moon when near first and last quarters, 4) the light axis moving toward coincidence with the ecliptic and thence to the south of the ecliptic as the observer travels from northern to southern latitudes. He also observed rapid intensity variations which he ascribed to the presence of thin cirrus clouds which are not otherwise visible.

in not enough to allow a visual determination of the color.
Certainly, this and other observations were made during the
color impression from the bridge and from the observation
to say nothing of the very faint impression from the bridge
bridge of the eye itself.

2. RAWY RIVER BRIDGE. (See also page 100)

Records of the bridge of the bridge and other observations
made during the bridge. The bridge of the bridge
contains observations and a series of observations from
1853 to 1855. Many observations of the bridge in 1853 and
intensity are included. Some of the observations are
Jones, such as bridge of the bridge (1853) and
examined the data about 10 years later. It is found
good correlation between the bridge and the bridge.
Baylor (10), on the bridge of the bridge, found
to note the annual variation of the bridge of the bridge.
the observations. The observations are of the bridge of the bridge
the maximum intensity of the bridge of the bridge of the bridge
2) the bridge of the bridge of the bridge of the bridge of the bridge
tribution to the bridge of the bridge of the bridge of the bridge
last quarter, 4) the bridge of the bridge of the bridge of the bridge
the eclipse and the bridge of the bridge of the bridge of the bridge
observer travels from the bridge of the bridge of the bridge of the bridge
observed rapid intensity variations which are attributed to the
presence of some other object which is not observed.

The many conscientious observations and studies by Schmid (1) again can only be termed unusual. His sketches of the zodiacal pyramid, with the light axis deviating many degrees from the ecliptic at large elevation angles from the horizon, and always coinciding with the ecliptic at the horizon, have not been duplicated by Hoffmeister (11) who, on one occasion, observed from the same site on the same day of the year.

Schmid's claim to have detected a nightly motion of the light axis toward the ecliptic if the earth carries the observer toward the ecliptic plane and away from the ecliptic if the earth carries him away from the ecliptic plane, has not been substantiated. The same is true for the consistent northerly displacements of the gegenschein which he reported. If one accepts atmospheric extinction as the major cause of the displacement of the light axis and its nightly motion, then one would expect a large effect near the horizon where differential extinction would be greatest. But, it is at the horizon where the light axis and the ecliptic always coincide, according to Schmid.

3. THE WORK OF HOFFMEISTER. Hoffmeister (11) made observations from shipboard during early 1929 while cruising from Europe to the Caribbean and back. He used a visual photometer with the comparison spot illuminated by a standard lamp of accurately known brightness. Selected areas of the milky way were used as absolute standards of intensity. Absolute values of zodiacal brightness were obtained which agree well with present

The many common errors observed are as follows:

Bohr (1) again and only the common errors.

The nodal point of the orbit is the point of intersection of the orbit with the line of sight.

From the elliptic orbit the large eccentricity is the distance from the center of the orbit to the focus.

Always coinciding with the elliptic orbit is the distance from the center of the orbit to the focus.

Applied by Holmstrom (1) and, on the other hand, observed.

From the same side as the sun at the time of the year.

Schmidt's observations have been used as a basis for the

light axis toward the elliptic orbit is the distance from the center of the orbit to the focus.

toward the elliptic orbit and away from the elliptic orbit in the same direction.

carries him away from the elliptic orbit, and away from the elliptic orbit in the same direction.

placed. The same is true for one of the other two elliptic orbits.

names of the generations which are the same. It is the same

atmospheric conditions as one of the other two elliptic orbits.

the light axis and the elliptic orbit, and away from the elliptic orbit in the same direction.

large effect near the elliptic orbit, and away from the elliptic orbit in the same direction.

be greatest. But, as the elliptic orbit is the same, the light axis is the same.

the elliptic orbit always coincides with the elliptic orbit.

3. THE WORK OF HOLMSTROM (1) AND

observations from the elliptic orbit, and away from the elliptic orbit in the same direction.

Europe to the German and Danish. He used a special instrument.

with the comparison of the observations with the observations of the elliptic orbit.

accurately known elliptic orbit. The elliptic orbit of the elliptic orbit.

were used as absolute standards of comparison. The elliptic orbit.

of nodal brightness were obtained from the elliptic orbit.

day values for small elongations but, at larger elongations his values become systematically lower. He comments that in this region estimated, systematic errors could make his values low by a factor of two. This would bring his values almost up to the accepted values of today.

In a later theoretical study of these and other results Hoffmeister (12,13) concludes 1) no earth-centered cloud of scattering particles can reproduce the observed intensity distribution, especially in the region of the gegenschein, 2) neither the Lambert nor the Seeliger phase laws hold for the particles constituting the scattering cloud, but, the phase law of the moon approximates the observations well, 3) no heliocentric ellipsoidal distribution of mass can reproduce the observed intensities, especially at large elongations. Hence, he postulates two regions of maximum particle density, one inside and one outside the earth's orbit. He also finds the light axis to be affected by the nearer planets and to deviate away from the ecliptic into coincidence with their orbital planes. Taking the orbital plane of Jupiter as the plane of symmetry of the zodiacal light, he obtains a parallax for the outer cloud of 2.4 astronomical units, which puts the maximum particle density in the asteroid belt.

Pursuing the question of the plane of symmetry of the zodiacal light and gegenschein, Hoffmeister (14) summarizes about 5000 visual estimates of the position of the light axis. These data were carefully corrected for the shift in position of

day values for small elongations but, at larger elongations the values become systematically lower. The observed errors in the region estimated, systematic errors being about 10% in the region by a factor of two. This would mean that the values are about the accepted values of today.

In a later theoretical study of the case of a realistic distribution (12,13) (conclusion 1) it was found that the scattering particles can reproduce the observed distribution, especially in the region of the maximum density. The Lambert law for the scattering phase law is also consistent with the scattering of light, and the observed distribution approximates the observed distribution well, (3) as mentioned in the distribution of mass can reproduce the observed distribution, especially at large elongations. Hence, the observed distribution of maximum particle density, one would expect the observed distribution of light to be affected by the scattering of light and to deviate away from the observed distribution with their orbital planes. Taking the orbital plane of Jupiter as the plane of symmetry of the nebula, the observed distribution is parallel for the outer cloud of 2.4 astronomical units, while the maximum particle density in the nebula is about 10%.

Pursuing the question of the plane of symmetry of the nebula, (14) and (15) and Gegenheimer, (16) and (17) found that about 5000 visual magnitudes of the nebula are observed. These data were carefully corrected for the effects of the

the light axis to be expected from extinction and airglow. His results again indicate that the plane of symmetry of the zodiacal light is affected by the nearer planets. A parallax of 2.98 astronomical units is obtained for the outer ring with indications that little dust exists between the earth and Mars. The gegenschein is found to follow a sine wave path with respect to the ecliptic; the amplitude is one to two degrees and the ascending node is at approximately 100 degrees ecliptic longitude. These results however, have been challenged by his contemporary and by later investigators; see, for instance, Schoenberg (15). Hoffmeister's assumption that the major contribution to the observed intensity can be localized in space at "photometrische Hauptpunkte" due to a concentration of scattering particles near planetary orbits does seem rather arbitrary, but in the recent work of Beard (see section F-2-d) such a view is given theoretical support.

Elvey (16) reduced the visual observations made by Japanese observers during the early 1930's to a uniform intensity scale. He corrected for scattered light, for extinction of the region of observation, and for extinction of the comparison regions. These comparison regions were especially selected portions of the milky way. He found a sharp yearly maximum for both the morning and evening zodiacal light, the intensity variation being about two to one. The evening maximum occurs in mid-January and the morning maximum in October.

the light axis to be expected from astronomical observations. The results again indicate that the plane of symmetry of the observed light is affected by the nearer planets. Astronomical units is obtained for the outer planets. The results that little dust exists between the earth and Mars. Gegenstand is found to follow a path that is perpendicular to the ecliptic; the amplitude is one to two degrees and the ascending node is at approximately 10 degrees celestial longitude. These results however, have been developed by the contemporary and by later investigators, for instance, Scheubert (19). Hoffmeister's assumption that the contribution to the observed intensity can be identified in some "photometrische Hauptpunkte" due to a concentration of particles near planetary orbits does not seem to be justified, but in the recent work of Beut (see section 2-5-5) such a view is given theoretical support. Elvey (16) reduced the visual observations made by observers during the early 1930's to a uniform intensity scale. He corrected for scattered light, for extinction of the region of observation, and for extinction of the observed region. These comparison regions were especially selected portions of the sky. He found a sharp yearly maximum for the evening and evening ecliptical light, the intensity variations being about one. The evening maximum occurs in approximately the same maximum in October.

Hoffmeister (17) has recently presented arguments on the basis of long personal experience and published data which purport to explain some of the discordances of visual observations as "Psycho-Physiological" effects rather than true variations of the fainter portions of the zodiacal light and gegenschein. He claims that this is in part due to the fact that the rod apparatus of the eye is not identical in every observer and, in addition, changes with time. He also suggests common spring avitaminosis as a cause of annual fluctuations of the visibility of faint details rather than any real effect. He concludes, however, that only strong observational bias can explain many of the glaring contradictions.

4. VISUAL POLARIZATION MEASUREMENTS. Dufay (18,19), using a visual polarimeter, made polarization measurements of the night sky light and of the zodiacal light in the region extending from an elongation of 30 to 90°. Both measurements showed a small maximum at about 60° elongation with a slow decrease toward smaller elongations and a more rapid decrease toward larger elongation. The maximum polarization of the zodiacal light amounted to about 15%, while only 2 to 4% of the night sky light was polarized. The plane of polarization (magnetic vector) was found to pass through the sun. These results led to the conclusion that the zodiacal light is the only polarized component of the night sky radiation, and that the zodiacal light is present over the entire sky. This conclusion implies that the present

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polarization attributed to the zodiacal light is too small because of the dilution caused by other night sky radiation. Later investigators who have corrected for the non-polarized background component obtain values of 20 to 30% polarization.

B. PHOTOELECTRIC STUDIES. The introduction of photoelectric scanning devices marked a great stride forward in obtaining accurate unbiased data on the intensity and shape of the zodiacal light. Of course, although these data are strictly objective there can be instrumental calibration errors, and there is the ever present problem of properly accounting for the composite background light source. Consequently, even today, there exists a variation over a range of two to one in the intensity values reported by different investigators.

1. THE WORK OF ELVEY AND ROACH. The night sky investigation by Elvey and Roach (20) from 1934 to 1936 at Mount Locke, Texas was a comprehensive photometric study of the entire sky. Sweeps with a recording photometer were made at five elevations and took about one hour. The light receiver was a potassium photocell and accepted light from a nine square degree area of the sky. The current produced by the photocell was amplified, fed into a galvanometer, and then recorded on a strip chart as a function of azimuth. Readings of bright stars were taken to calibrate the instruments in terms of absolute intensities, and to determine the nightly extinction coefficient. Observations were attempted each lunation.

polarization attributed to the molecular axis as well as to the
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values reported by different investigators.

1. THE WORK OF HILLY AND HARRIS. The investigation

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Texas was a comprehensive photometric study of the
Sweeps with a recording photometer were made at five microns
and took about one hour. The light meter was a photometer
cell and accepted light from a small aperture area of one sq.
The current produced by the photocell was amplified and read on
galvanometer, and then recorded on a strip of film as a function of
wavelength. Readings of bright stars were also taken and
instruments in terms of absolute intensities, and calibration
highly extinction coefficient. The results are summarized in
table.

The total brightness obtained was considered as the sum of all contributing sources i.e., direct star light, airglow, zodiacal light, diffuse galactic light, scattered star light, and scattered light due to the sum of all the other sources. In order to reduce the number of unknown components in this sum, data from other studies were used. The mean star counts tabulated by Bottlinger (21) were employed to correct for the direct starlight contribution at all galactic latitudes, but these corrections could be considered exact only at latitudes greater than 30° . The known total number of stars used in conjunction with the atmospheric scattering function determined by C. G. Abbott (22) permitted correction for the scattered light due to stars. This correction rested upon the assumption that the stars were uniformly distributed over the celestial sphere.

For further separation and determination of the unknowns, selected areas of the sky with accurate star counts were observed at many zenith distances. The intensity was plotted as a function of zenith distance so that observed intensity could be interpolated for any zenith distance. The data were then reduced to a single region of the sky by determining graphically the variation due to zodiacal light and galactic light along almucantars. For high galactic latitudes the galactic light was set equal to zero and all of the variation attributed to zodiacal light. Thus, using many regions in high galactic latitude, the following unknowns could be determined by a least squares solution: the zodiacal light, the

[illegible]

airglow intensity, the airglow height, and the total scattered light not due to stars.

Rather than attempt a least squares solution for all four unknowns, the height of the airglow layer was determined by successive approximations. This was accomplished by assuming a height for the emitting layer and using van Rhijn's law (23) for the variation of airglow intensity with zenith distance, then performing the least squares solution for the three remaining unknowns and taking as the true height of the emitting layer that value which gave the smallest residuals for all of the components. Further, having obtained values for airglow and scattered light at high galactic latitudes which could then be assumed true for any azimuth, data from other regions of the sky were corrected. Then by determining the zodiacal light behaviour on either side of the milky way, at latitudes larger than 30° , the zodiacal light isophotes were extrapolated smoothly across the milky way. The excess light in the low galactic region was attributed to the galactic radiation. In this way the three radiations were separated satisfactorily.

The reduction method employed here is quite elegant despite the fact that it necessarily uses tabulated values of questionable accuracy. It is of interest to note that the height determined for the airglow emitting layer is significantly lower than the present day value of 100km. The values of 50 to 65km, when used in van Rhijn's law, lead to an overcorrection for airglow at large zenith distances.

airglow intensity, the airglow height, and the airglow intensity
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unknown, the height of the airglow layer was determined
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height for the emitting layer and then calculating the
the variation of airglow intensity with distance from the
performing the least squares solution for the best fit
unknown and taking as the true height of the emitting layer
value which gave the smallest residuals for all the observations.
Further, having obtained values for the height of the emitting layer
at high galactic latitudes where the airglow intensity is low
any estimate, data from other regions of the sky were used
Then by determining the residual intensity of the airglow
of the Milky way, at latitudes where the airglow intensity is high
light isophotes were extrapolated across the sky to the Milky way.
The excess light in the low galactic latitude region was attributed to the
galactic radiation. In this way the airglow intensity was
separated satisfactorily.
The reduction method employed here is quite different
despite the fact that it necessarily involves the use of
questionable accuracy. It is of interest to note that the height
determined for the airglow emitting layer is in excellent agreement
than the present day value of 100 km. The value of 100 km
when used in van Rijn's law, leads to the same result for air-
glow at large zenith distances.

The analytic solution proved very tedious and later routine reductions consisted of grouping all light sources which could be considered constant in one coordinate, such as elevation angle, galactic latitude, or ecliptic latitude. A graphical method was then used to correct for the "background" of a particular source.

The findings of this investigation indicate that the air-glow increases toward the north, with a maximum nearly in the direction of the north magnetic pole. An isophote map of the excess "galactic" light which originates from the scattering of star light by the interstellar medium and from emission by gaseous nebulae is presented. This light is concentrated near the galactic plane, and at the galactic equator amounts to about 100 tenth-magnitude stars per square degree. The zodiacal light is presented on four maps of the entire sky, which were constructed by averaging the intensity values obtained for six nights. Upon examination of the maps a seasonal variation is evident. The evening light has a maximum in April-May and a minimum in November-December. The morning light behaves in the opposite manner. These seasonal variations should be compared with the Japanese visual results in section B-1, namely a maximum in January for the evening light, and a maximum for the morning light in October. All of the maps show a consistent northerly displacement of the light axis for the brighter regions, while the gegenschein is always centered on the ecliptic and slightly to the west of the antisolar point. The seasonal variation is interpreted

The analysis of the spectra of the stars in the
reductions consisted of measuring all lines which could be
considered constant in one position, and an exception made
galactic latitude, or elliptical latitude. A graphical method was
then used to correct for the "distortion" of the spectrum.
The findings of this work indicate that the stars
show increases toward the left, with little or no change in the
direction of the north magnetic pole. A negative one of the
excess "galactic" light which is observed in the spectrum of
star light by the interstellar medium and from which the observed
nebulae is produced. This light is produced in the galactic
plane, and at the galactic equator amounts to about 100 units.
magnitude stars per square degree. The nebular light is not
scattered on four rays of the same size, which are concentrated by
averaging the intensity values over the four quadrants. The
examination of the rays a seasonal variation is evident. The
evening light has a maximum in April-May and a minimum in
November-December. The morning light shows the opposite
manner. These seasonal variations are in accordance with the
Japanese visual results in which a maximum is reached in
January for the evening light, and a maximum for the morning
light in October. All of the rays show a seasonal variation
displacement of the light axis for the winter region, while the
Gegenstein is always centered on the equator and slightly to the
west of the anticlockwise point. The seasonal variation is indicated

as due to a swarm of meteors which come to conjunction with the sun in the winter months.

In connection with the previous investigation, Elvey and Rudnick (24) determined the color index of the zodiacal light and found it to be that of a type G-1 star, i.e., about equal to that of the sun. They conclude that there is no Rayleigh scattering component in the zodiacal light nor is there a component due to very small dust particles.

2. THE WORK OF HURUHATA. During the period from 1945 to 1949, Huruhata (25) in Japan observed the intensity variation along the ecliptic using two types of photocells with maximum sensitivities at 7200 and 4500A. His results show rapid short-period intensity variations as well as a long period variation of about seven to one. He claims to correlate these variations with the Taurid meteor swarm associated with Encke's comet, and further asserts that he can explain all of the zodiacal illumination out to 60° elongation by this source alone. He determined atmospheric extinction by observing known stars at various elevation angles. The method of obtaining the background correction is not divulged.

These results are of an unusual character. The correlation with Encke's comet, which passed perihelion slightly before the maximum intensity was observed, seems quite good, but it should be borne in mind that the Taurid meteors are a minor shower, having the second lowest hourly rate (6/hr.) of the

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In connection with the previous investigation, it was
Radnik (24) determined the color index of the radiation from the
found it to be that of a type L-1 star, i.e., about equal to that
of the sun. They conclude that there is no radiation from the
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the faint meteor swarm associated with the comet, and further
asserts that he can explain all of the radiated radiation and
to 60° elongated by this source. He determined that the
spheric extinction by observing from above at various elevations
angles. The method of obtaining the radiation extinction in the
divided.

These results are of an unusual character. The variation
tion with Burke's comet, which passed perihelion slightly before
the maximum intensity was observed, seems quite good, but it
should be borne in mind that the faint meteor swarm is a
showing, having the second lowest activity rate (26) of the

twelve principal showers listed by Allen (26). Thus it appears that except for the advantageous position of this shower's orbit with respect to the ecliptic there is little to qualify it as a good source of zodiacal light. Surely, if one wishes to call upon meteors for reflecting particles the Perseids should not be overlooked, even though the inclination of their orbit is 68° . Their hourly rate is 50, and the shower duration is 21 days compared to 30 for the Taurids.

Another point to consider in this connection is the maximum solar activity which occurred at about the same time as the maximum zodiacal light. It is well known that the airglow varies through wider limits at the time of maximum solar activity. If these airglow variations were not properly accounted for, some of the reported variation in zodiacal illumination could be due to improper background correction. Also the possibility that the zodiacal light varies with solar activity should not be overlooked.

3. THE WORK OF BEHR, STEDENTOPF AND ELSASSER. A new approach to the study of the zodiacal light phenomenon was introduced by Behr and Siedentopf (6) when, during February and March of 1952, they simultaneously recorded the light intensity and its polarization in two colors. The observations were made from the Jungfraujoeh in the Swiss Alps, at an elevation of 3526 meters.

The photometer employed in this investigation had a 60 mm diameter f-5 objective lens carried on an alt-azimuth mounting. Light from a 2.6 square degree area of the sky passed through a

twelve principal showers listed by Allen (1931). This is apparent that except for the advantageous position of the showers and with respect to the eclipse there is little to be gained as a good source of nodal light. Surely, it is better to have upon nodal light reflecting particles the showers should be overlooked, even though the inclination of the nodal light. Their hourly rate is 50, and the shower duration is 21 days compared to 30 for the Taurids.

Another point to consider in this connection is the maximum solar activity which occurred at about the same time as the maximum nodal light. It is well known that the activity varies through wider limits at the time of maximum solar activity. If these airglow variations were not properly accounted for, some of the reported variation in nodal light would be due to improper background correction. Also the possibility that the nodal light varies with solar activity should be overlooked.

3. THE WORK OF BEHR, STEDERBERG, AND HARRISON. A new approach to the study of the nodal light phenomenon was introduced by Behr and Stederberg (1952) when, during February and March of 1952, they simultaneously recorded the light intensity and the polarization in two colors. The observations were made from Jungfraujoch in the Swiss Alps, at an elevation of 3550 meters. The photometer employed in this investigation had a 10 cm diameter f-5 objective lens exposed on an aluminum housing. Light from a 2.5 square degree area of the sky passed through

rotating polaroid and a stationary color filter, and then into a 1P21 photomultiplier tube. The transmission characteristics of the blue and green color filters used, combined with the spectral response of the 1P21, gave effective wavelengths of 4440 and 5420 Å, respectively.

The rotating polaroid and the partially polarized light source produced a photocurrent composed of a direct and an alternating component, the d.c. being proportional to the unpolarized light and the a.c. proportional to the polarized light. These components were separated by resistance-capacitance filters and then fed into a d.c. amplifier and a narrow-band a.c. amplifier. The resulting currents drove recording galvanometers.

Sweeps were made with the photometer at an elevation of 20° above the horizon covering some 120° in azimuth from northwest to southwest. A sweep took about five minutes, and the color filter was changed after each sweep. The recordings continued until the diurnal motion of the earth brought the brightest portion of the zodiacal light through the region of observation. Recordings of the gegenschein were made as well as star calibration readings. A continuous check on the sensitivity of the photometer was obtained by recording the intensity of a radioactive scintillator light source.

The recordings were analyzed at every sixth degree of azimuth. The a.c. readings were found to have a very high but rather constant noise component of unexplained origin (other

rotating polaroid and a stationary color filter, a 1000 Å
1P21 photomultiplier tube. The photomultiplier tube was
the blue and green color filter used, which was the source
response of the 1P21, gave a positive response at 440 Å and
450 Å, respectively.

The rotating polaroid and the stationary color filter
source produced a photomultiplier response at a distance of 10
alternating component, the a.c. signal was proportional to the
polarized light and the a.c. proportional to the unpolarized light.
These components were separated by means of a polarizing filter
and then fed into a d.c. amplifier and a narrow-band 1.0 Mc. amplifier.
The resulting currents drove recording galvanometers.

Measurements were made with the photomultiplier at a distance of
20° above the horizon covering an angle of 15° in azimuth. The
west to southwest. A sweep coil about five inches long and the color
filter was changed after each sweep. The photomultiplier was
until the diurnal motion of the earth brought the maximum
of the solar light through the region of observation. The
of the Gegenstein were used as well as the color filter.
A continuous check on the sensitivity of the photomultiplier was obtained
by recording the intensity of a radioactive source.

Source.
The recordings were analyzed at every 10 minutes during the
solar day. The a.c. readings were found to have a very high
rather constant noise component of the order of 10%.

investigators using rotating polaroids have also noted this phenomenon). Hence these readings were first corrected for extraneous noise by the following process.

The polarization of the night sky, far from the zodiacal band is about 1%. The investigators assumed that this value of polarization was reached at the southern-most azimuth of observation and could be safely set equal to zero at that point because it is small compared to the percentage polarization of the zodiacal light itself, which is greater than 10%. Then the a.c. component appearing at this southern-most azimuth could all be attributed to noise and subtracted away from the a.c. reading at any other azimuth, leaving only the a.c. due to polarized light. This assumption no doubt introduced a systematic error in the zero point of their polarization measurements.

After the noise problem had been dealt with no other correction except an atmospheric extinction correction was needed for the polarization measurements. However, stars brighter than the eighth magnitude appeared as pips upon the d.c. recordings. These irregularities were removed by drawing a smooth curve through the d.c. trace. All data were then corrected for extinction using the work of Bemporad (27). No correction for a possible dust extinction component was applied.

The results could then be expressed in terms of absolute intensities as a sum of zodiacal light, airglow, scattered light, and star background. The airglow and scattered light were assumed

investigators using various polarizing filters have also noted this phenomenon. These cases involve various types of scattering phenomena, noise by the following means.

The polarization of the light is, in the case of the band is about 1%. The investigation was made at the same time of polarization was measured at the same time. The results of the action and could be safely assumed to be the same. It is small compared to the measured polarization of the scattered light itself, which is about 10%. The component appearing at this angle is not due to the scattered light but is attributed to noise and scattered light. The results of the investigation, leaving only the d.c. and the a.c. components. This assumption is based on the fact that the polarization of the scattered light is not the same as the polarization of the incident light.

After the noise correction had been made with the use of the correction except an atmospheric extinction correction was needed for the polarization measurements. However, the results of the the light intensity appeared as a function of the angle. These irregularities were removed by using a smoothing curve. The d.c. trace. All data were then corrected for atmospheric extinction. The work of Bumpard (27) is the correction for atmospheric extinction component was applied.

The results could then be obtained in terms of absolute intensities as a sum of scattered light, which is scattered light and star background. The star background is the same as the

independent of azimuth. The total intensity at the southernmost azimuth was subtracted from all other readings. The resulting value was then corrected for the difference in star background between the southernmost point and any other data point using composite charts constructed by Roach (5). The zodiacal light was assumed to have reached a small and nearly constant value at the southernmost azimuth. It was further assumed for the green recordings that small unknown value of zodiacal light, which had been removed in the subtraction of the total intensity, could be taken from the results of Elvey and Roach (20) and restored to the final data. For the blue recordings the corresponding constant value of the zodiacal light was left unspecified.

The final results are presented, in part, as four isophote maps of the zodiacal light. Two are total intensity maps for the blue and green spectral regions, and two are polarized intensity maps for the same colors. The total intensity maps show the light to lie close to the ecliptic, but with the intensity decreasing more slowly to the north than to the south. There is some evidence of irregularities caused by improper background corrections.

The maps for the polarized component are of an entirely different character. The light is much less concentrated toward the ecliptic, and the isophotes are less pointed. There is no evidence of the asymmetry shown by the total light maps. The percentage polarization along the ecliptic shows a steady decrease with elongation. At 35° its value is 23.4% and at 90° it has

independent of azimuth. The local minimum at the equator
azimuth was subtracted from the local maximum. The resulting
value was then corrected for the difference in latitude
between the southernmost point and the other points.
Composite charts constructed by using (1) and (2) and
was assumed to have reached a value of unity and nearly constant value at
the southernmost point. It was assumed that the value of unity was reached for
recordings that small without value of unity being reached, which had
been removed in the subtraction of the local maximum, could be
taken from the results of (1) and (2) and returned to the
final data. For the data recorded, a correction was made
value of the nodal line was also made.
The final results are presented in Fig. 1, as two separate
maps of the nodal line. The two maps are shown for the
blue and green spectra, red and blue, and two maps for the
maps for the same colors. The local minimum was also shown
to be close to the equator, and with the same character.
more slowly to the north than to the south. There is some evidence
of irregularities caused by magnetic anomalies.
The maps for the polarized component are also shown in
different character. The maps show that the local minimum is
the equator, and the responses are less polarized. There is no
evidence of the asymmetry shown by the local minimum. The
percentage polarization along the equator is about 10% at the
with elongation. At 30° the value is 25.5 and at 60° it is

decreased to 10.9%.

In addition a comparison of zodiacal light along the ecliptic is given for these results and for those of Hoffmeister (11) and Elvey and Roach (20). The new results lie considerably lower than the earlier values at elongations of less than 50° , but agree well for the range of 50 to 90° . At an elongation of 35° , 855 stars per square degree are obtained as compared to the 1200 obtained by Elvey and Roach.

A composite chart of the gegenschein is given. It shows the intensity to be about 30 stars per square degree more than the light bridge. It is centered about two degrees to the west and north of the antisolar point.

The authors, assuming the entire polarized component of the zodiacal light arises from scattering by free electrons, derive electron densities from the data. The integral expressing the intensity of the polarized component due to Thomson scattering is solved by a graphical-numerical method. When the integral is written in terms of the line of sight elongation from the sun, only three variables are left in the integrand. These variables are the electron density which is a function of solar distance, the sun to scattering volume element distance in au, (astronomical unit) and the differential length of the scattering volume element.

For numerical evaluation the integral is approximated by a sum of the contributions along the line of sight. The polarized intensity is then equal to a constant multiplying the sum of the

decreased to 10.9%.

In addition a comparison of calculated and observed

eclipse is given for these results and for those on July 1957.

(11) and Elvey and Hoach (1957). The new results are consistent

lower than the earlier values at distances of less than 10°.

but agree well for the range of 10 to 30°. At an altitude of

35°, 855 stars per square degree are obtained as compared to 1000

1500 obtained by Elvey and Hoach.

A composite map of the sky is given in Fig. 1. It shows

the intensity to be about 50 stars per square degree at the

light bridge. It is noted that the intensity is lower at the

north of the antipodal point.

The authors, as well as a table of calculated and observed

the nodal light bridge from scattering of light electrons.

derivative electron densities from the data. The results are shown

the intensity of the light bridge is shown in Fig. 2. The

is solved by a graphical method. The results are shown in

written in terms of the time of light travel from the

only three variables are left in the equation. These variables

are the electron density which is a function of time, distance,

the sun to scattering volume element distance in cm , scattering

angle) and the differential length of the scattering volume element.

For numerical evaluation the method is represented by a

sum of the contributions along the line of sight. The calculated

intensity is then equal to a constant multiplying the sum of the

electron density as a function of solar distance and a constant coefficient, involving distances, which is a function of both solar distance and elongation. The constant coefficients are determined graphically.

A graph of circular line segments centered at the sun and spaced 0.1 au apart cover the region of observation from 33.4 to 90° elongation. Lines of sight from the earth are drawn in tangent to consecutive circular zones. Ten lines of sight cover the region of observation. The coefficient for the electron density at a given point can be obtained directly from the graph as the length of the line of sight segment between the two circular zones containing the point in question, multiplied by the fourth power of the sun-volume element distance in au.

The simultaneous solution of the ten linear equations, one for each line of sight on the graph, determines the electron density as a function of solar distance. The electron density function indicates about 1000 electrons/cc at 0.6 au, 600/cc at 1 au, then a rapid drop to 120/cc at 1.3 au.

With the electron density function determined, they calculated the total light due to electron scattering as a function of the elongation. Then, subtracting the electron contribution from the total observed intensity, they were able to calculate the dust density as a function of solar distance. By considering the particles to be much larger than the wavelength of visible light, and by the integration over a wide range of

of visible light, and by the integral and over a wide range of
considering the particles to be much larger than the wavelength
calculate the dust density as a function of altitude.
tribution from the total observed absorption, each with its own
function of the elongation. Then, subtracting the elongation con-
calculated the total light due to elongation scattering as a
With the electron density function determined, 1967

scattering angle, they assumed the scattering function independent of wavelength. Calculations of the density were then performed using selected values for the dust particle radius and for the constant scattering function. This procedure is necessary because the two parameters, particle radius and scattering function, cannot be separated with photometric data alone. The space density of particles turns out to be essentially constant with a small decrease for distances less than 0.6 au. Taking the specific gravity of the particles as 3, and the radius as 0.001 cm the space density of dust at the earth's orbit is 10^{-21} gm/cc. This amounts to very nearly one dust particle per cubic kilometer.

The gegenschein, following Moulton (28), was assumed to originate from sunlight reflected from a cloud of particles near the libration point of the earth-sun system. The cloud is located at 0.01 au, and a dust density about 20 times greater than that in the surrounding space is found. No polarization data were obtained for this region and hence no electron densities were found for the gegenschein.

Elsasser (29), using the observational data of Behr and Siedentopf, calculated the space density distribution of the cloud responsible for the zodiacal light. He assumed the entire polarized component arose from electron scattering. A distribution of dust particles, with radii lying between 2 and 2000 microns was assumed to produce the ^{0.4}polarized component. The number of particles with radii larger than 2 microns was assumed to be distributed as

scattering angle, they assumed the scattering function
of wavelength. Calculations of the scattering function
using selected values for the dust particle radius and the
scattering function. This function is generally
the two parameters, particle radius and scattering function,
be separated with photometric data alone. The
particles turn out to be essentially constant with a small change
for distances less than 0.5 au. The scattering function is
particles as λ^{-3} , and the radius as 0.001 or 0.002 au.
dust at the earth's orbit is 10^{-21} g/cm³. This
nearly one dust particle per cubic kilometer.
The gegenschein, following Mielke (1955) was assumed to
originate from sunlight reflected from a cloud of particles near
the libration point of the earth-moon system. The cloud is
at 0.01 au, and a dust density about 10^{-21} g/cm³ is
the surrounding space is found. The calculated gegenschein
for this region and hence no electron beam was found for
gegenschein.
Elstner (1955), using the gegenschein data of Mielke and
Studenoff, calculated the space density of particles of the cloud
responsible for the gegenschein light. He assumed the dust
had component arose from electron scattering. A distribution of
dust particles, with radii lying between 2 and 2000 m μ was
assumed to produce the polarized component. The number of particles
with radii larger than 2 m μ was assumed to be proportional to

$(a/a_0)^{-3.5}$, where a_0 is 2 microns. The exponent, 3.5, corresponds closely to the frequency distribution for meteor radii. The constant scattering function was that of a totally reflecting sphere.

The integral expressing the intensity of the polarized and non-polarized components was evaluated by a graphical-numerical method similar to that used by Behr and Siedentopf.

The surfaces of constant electron density were determined as ellipsoids of revolution with axis in the ratio 3.4 to 1. They are centered at the sun with their long axes lying in the ecliptic plane. The dust was found to lie in layers parallel to the ecliptic plane. The dust density distribution perpendicular to the ecliptic, was approximated well by a Gaussian curve. No significant change from the electron or dust densities obtained by Behr and Siedentopf was found.

4. THE WORK OF ROACH, PETTIT, TANDBERG-HANSEN, AND DAVIS. In 1953, Roach et al. (5), examined the zodiacal light which had been recorded during five nights by the airglow station at Cactus Peak, California. At this station in the Mojave Desert, the entire night sky was surveyed every 32 minutes by a four channel recording photometer. Each survey consisted of eight sweeps from horizon to horizon, through the zenith, at 22.5° intervals of azimuth. Records of the red and green oxygen lines and the sodium D-lines were obtained as well as a control region at 5300A. Each spectral interval was isolated by an interference

$(\lambda/\lambda_0)^{-2.5}$, where λ_0 is the wavelength. The constant scattering function was used for the calculation of the constant scattering function. The constant scattering function was used for the calculation of the constant scattering function.

The integral expressing the intensity of the scattered light as a function of the scattering angle was evaluated by a numerical method similar to that used by other workers. The surfaces of constant intensity were determined as ellipsoids of revolution, with axes in the ratio 3.4 to 1. The ellipsoids are centered at the sun with the long axis lying in the scattering plane. The dust was found to lie in a plane parallel to the scattering plane. The dust density distribution perpendicular to the scattering plane was approximated well by a Gaussian curve. The ellipsoid was approximated well by a Gaussian curve. The ellipsoid was approximated well by a Gaussian curve. The ellipsoid was approximated well by a Gaussian curve. The ellipsoid was approximated well by a Gaussian curve.

by Behr and Stedentrop was found.

4. THE WORK OF ROSS, WHITE, LATHROP, HARRIS, AND DAVIS. In 1953, Ross et al. (1953) examined the spectrum of light which had been recorded during the night of the total eclipse at Cactus Peak, California. At this station the sky was clear and the entire night sky was surveyed with 35 minutes of a low channel recording photometer. Each sweep consisted of eight sweeps from horizon to horizon, through the zenith, at 2.5° intervals of azimuth. Records of the red and green light and the sodium D-lines were obtained as well as a control spectrum. Each spectral interval was labeled by its wavelength.

filter. The photometer accepted light from a 19.6 square degree area of the sky. During the evening and morning hours the zodiacal light was recorded as well as the airglow.

In this study the authors proposed to examine the relationship between the F-corona of the sun and the zodiacal light, and also the reported (30) enhancement of the airglow lines in the zodiacal light spectrum.

The light of the solar corona has two main components known as the K and F coronas. The K-corona arises from sunlight scattered by free electrons surrounding the sun. This component of coronal intensity is characterized by a very rapid decrease with distance from the sun. The intensity drops by a factor of 10^6 at 10 solar radii. The spectrum of the K-corona is continuous with no apparent absorption lines, indicating a very high temperature for the electron gas. The F-corona exhibits a slow decrease in intensity with solar distance, amounting to a factor of 1000 at 10 solar radii. Sharp Balmer absorption lines are present in this radiation. Grotrian (31), in 1934 suggested that the F-corona might arise from sunlight reflected by dust particles in the sun's direction, but not necessarily near the sun in space. This view was adopted by Allen (32) and van de Hulst (33) in theoretical studies. Both of these investigations gave strong support to the dust origin of the F-corona, see section F. Van de Hulst noticed also that the F-corona intensity and that of the zodiacal light, when plotted on a log-log scale versus solar distance could be

filter. The phenomenon occurred at 11:15 a.m. and lasted for
area of the sky. During the evening and morning hours the

radiation light was recorded as well as the temperature.

In this case the radiation was recorded as occurring in the

ship between the 1- and 2- sections of the sky and a radiation light, and

also the reported (3/3) radiation at the 1- section of the

radiation light spectrum.

The light of the solar corona has been recorded

known as the E and F coronae. The coronae are known as the

scattered by free electrons situated in the sky. This coronae

of coronal intensity is characterized by a very high intensity

with distance from the sun. The intensity is high at a distance of

10° at 10 solar radii. The spectrum of the coronae is continuous

with no apparent absorption lines. Radiation is very high at

core for the entire sky. The radiation is very high at

in intensity with distance from the sun. The intensity is high at

10 solar radii. The radiation is very high at

radiation. The radiation is very high at

might arise from a high radiation of the coronae in the sky

direction, but not necessarily from the sun in general. This

was adopted by the (3/3) and the 1- section of the

radiation. Both of these coronae are the same in general

dust origin of the 1- section, but section 2. The radiation is

also that the 1- section is very high at the 1- section of the

when plotted on a log-log scale, versus solar distance.

joined by a straight line of slope -2.4. Both Grotrian (31) and Baumbach (34) had found an exponent of -2.5 for the variations of log-intensity of the F-corona with respect to log-distance from the sun.

The study of Roach et al. restricts itself to the intensity variation of the zodiacal light along the ecliptic. The method of correction for extinction and scattered light is not mentioned. A new intensity unit, H , defined as 10^{-15} times the intensity at the center of the sun's disk is used. The intensities expressed in this unit, are plotted as functions of azimuth. Three assumptions are then used to establish the true zero level of the zodiacal light: 1) it is assumed that the lowest reading on an azimuth plot corresponds to zero zodiacal light, 2) the results of Elvey and Roach (20) are assumed to set the true zero value, and 3) an empirical correction to be described later, is applied to the data of Elvey and Roach.

In using assumption 2 the highest and lowest intensity readings were corrected for the contribution due to direct star light. This was accomplished by use of a map giving values of integrated star light over the entire sky. The map was based on the data of van Rhijn (35). Next, the amount of zodiacal light at the minimum point was obtained from composite charts of the zodiacal light over the entire sky, using the results of Elvey and Roach.

Having completed these two corrections the zodiacal light

joined by a straight line of slope -2.41. The
Barnbach (20) and found an intercept of -2.5 for
log-intensity of the 7-6000 Å line. The intercept
the sun.

The study of Jones et al. (1961) shows a
variation of the ionospheric height with solar activity. The height of
correction for extinction and absorption is 1.5 in the ionosphere.
new intensity unit, I , defined as 10^{-15} times the ionospheric
center of the sun's disk is used. The ionospheric expression
this unit, are plotted as a function of activity. These curves
are then used to establish the true and level of the ionospheric
light: (1) it is assumed that the lowest reading on the
plot corresponds to zero ionospheric light; (2) the reading of five
and Rosen (20) are assumed to be the true zero value; and (3) the
empirical correction to be described later, is applied to the data
of Eivey and Rosen.

In using assumption 2 the highest and lowest ionospheric
readings were corrected for the contribution due to direct
light. This was accomplished by use of a ray-tracing
integrated over light over the entire sky. The data was based on
the data of van Rijn (20). Here, the amount of ionospheric light
at the minimum point was obtained from comparison of the
ionospheric light with the entire sky, using the method of Eivey and
Rosen.

Having completed these corrections the ionospheric light
was plotted as a function of activity.

at specific points was plotted as a function of elongation. The intensity was then interpolated every 5° of elongation. When these values were plotted against the corresponding intensity found previously by Elvey and Roach, a considerable discrepancy existed at high intensities. Approximation 3 then assumes that the present and previous intensity values can be reconciled by using 0.70 times the value of Elvey and Roach's intensity for the true zero correction. The log-intensities obtained using approximation 3 were subsequently plotted against log-elongation. A straight line relation was obtained with a slope of -2.22 in the range of elongation from 30° to 60° . Beyond 60° elongation there is a slight curvature toward smaller slope.

A comparison of the slopes for the region of the F-corona, the zodiacal light, and the interpolation region between 1.5 and 30° gives values of -2.5, -2.22, and -2.3, respectively. Of course the three regions join smoothly. A plot of the results is shown in Figure 1. It is concluded that such close agreement could not be the result of chance, especially when there are theoretical grounds for such behavior. The F-corona and the zodiacal light are thus shown to be different manifestations of the same entity, namely a dust cloud in interplanetary space.

The second phenomenon which was examined was the enhancement of the principal airglow lines in the zodiacal light. Karimov (30), on the basis of spectrographic results, noted marked enhancements of the airglow lines. This result, if substantiated,

at specific points was plotted as a function of elongation. The intensity was then interpolated every 2° of elongation. When these values were plotted against the corresponding intensity found previously by Elvey and Bosch, a considerable discrepancy existed at high intensities. Approximation 3 then assumes that the present and previous intensity values can be reconciled by using 0.70 times the value of Elvey and Bosch's intensity for the zero correction. The log-intensities obtained using approximation 3 were subsequently plotted against log-elongation. A straight line relation was obtained with a slope of -1.22 in the range of elongation from 30 to 80°. Beyond 80° elongation there is a slight curvature toward smaller slopes.

A comparison of the slopes for the region of the 1-cotons, the nodal light, and the interpolation region between 1.5 and 30° gives values of -2.5, -2.22, and -2.3, respectively. Of course the three regions join smoothly. A plot of the results is shown in Figure 1. It is concluded that such close agreement could not be the result of chance, especially when there are theoretical grounds for such behavior. The 1-cotons and the nodal light are thus shown to be different manifestations of the same entity, namely a first order interference space.

The second phenomenon which was examined was the enhancement of the principal diffraction lines in the nodal light. Karimov (30), on the basis of spectrographic results, noted marked enhancements of the diffraction lines. This result, if substantiated,

Fig. 1 Log H versus Log e for the Corona and the Zodiacal Light

would give strong support to a proposal by Fesenkov (36) that a major portion of the zodiacal light originates from a gaseous tail of the earth composed of escaping atmospheric gases.

Since the zodiacal light intensities were expressed in terms of the sun's central intensity, the readings for the four spectral regions could be directly compared to see if there were any enhancement of the zodiacal light in a spectral region containing a bright airglow emission line as compared to a region which had no significant emission. The ratios $H(\text{emission})/H(5300)$ were calculated for the zodiacal light, recorded in the three emission regions, and the results averaged. The average enhancement for all the lines combined turned out to be zero. Few individual points showed more than a 20% scatter. These results are to be compared to the 50 to 100% enhancement obtained by Karimov in his spectrophotometric analysis.

An additional method of ascertaining an enhancement is used which is essentially the same as that used in the routine analysis of airglow data. The procedure is merely to subtract the intensity of the 5300A control region from the intensity obtained in a region containing an emission line. Ten maps of the 5577A oxygen line emission were given. The characteristic cloud-like pattern is present but there is no concentration of the emission near the ecliptic at smaller elongations as would be expected if the airglow were enhanced there. The net result of these two types of analysis was to indicate that neither the zodiacal light is enhanced in the

spectral region containing airglow emission nor is the airglow emission enhanced in the region of the sky containing bright zodiacal light. A precise explanation of how the erroneous results of Karimov were obtained will be given in the review of the work of Divari and Asaad in a later section.

5. THE WORK OF REGENER. From March, 1953 until May 1954 Regener (37) obtained observations of the zodiacal light from Capillo Peak, New Mexico at an elevation of 9200 feet. The purpose of the investigation was to obtain a long series of recordings, almost 200, of the brightest portion of the zodiacal light band in order to validate and record any time variations of its intensity or shape. Only recordings of the total light intensity were made.

The light collector was 60" search light mirror of 26" focal length. The entire searchlight was equatorially mounted and its motion was controlled remotely from inside an observatory building some distance away. A band 48° wide was scanned from horizon to horizon in 2° steps of declination during a period of about 20 minutes. Star readings were taken for calibration purposes.

Light collected from an area of 0.3 square degree entered a type 5819 photomultiplier tube of S-9 response. The resulting photocurrent was amplified and fed into the observatory where a step-amplifier changed the current variations into 18 preselected voltage steps. These voltage steps changed the width and position of the trace on a cathode ray tube and this information was

spectral region containing the emission lines of the hydrogen
emission expanded in the region of the hydrogen lines
sodium light. A series of measurements were made with the
results of Karmov were obtained with the hydrogen lines
the work of Divert and Karmov was later repeated.

2. THE WORK OF RAGNER. (1954)

1954 Ragner (27) obtained observations of the hydrogen lines
from Capilla Peak, New Mexico at an elevation of 2300 feet. The
purpose of the investigation was to obtain a more accurate
recordings, almost 200, of the hydrogen lines in the spectral
light band in order to obtain a more accurate record of the
its intensity or shape. Only recordings of the spectral lines
intensity were made.

The light collector was 50" central light meter of 20" focal
length. The entire assembly was supported on a wooden frame and the
motion was controlled remotely from inside an observation building
some distance away. A band 10" wide was centered on the spectral
horizon in 2° steps of declination during a period of about 20
minutes. Star readings were taken for 10 minutes at each step.
Light collected from an area of 0.5 square degrees was measured
type 2819 photomultiplier tube of 8-9 response. The resulting
photocurrent was amplified and fed into the oscilloscope where a
step-amplifier changed the current variations into 10 potential
voltage steps. These voltage steps were fed into a recorder
of the trace on a cathode ray tube and the information was

recorded photographically as an image of varying position and width by a traveling-lens camera. The camera's lens moved in front of the photographic film in synchronism with the reflector's motion across the sky and therefore resulted in a map of the sky being plotted in terms of position and intensity.

Data points for analysis were taken wherever the recording trace changed its character. This allowed uncorrected isophotes to be plotted directly on a reproduction of the original recording. Because of the large number of data points per recording (200 to 300), a rapid method of coordinate transformation was used. Transparent grids of the horizon and ecliptic coordinate systems were optically projected upon the recordings and the coordinates of the data points were read off directly.

During routine analysis of 47 maps a preliminary background correction, the output reading along a line of constant azimuth, was taken from the region of the sky opposite the zodiacal light. This reading was subtracted from all data points with corresponding elevations. Such a correction removed all airglow and scattered light which was independent of azimuth, and also some direct star light and zodiacal light which were present in the background region.

A theoretical average extinction correction was used because the star readings taken did not allow an accurate determination of the nightly atmospheric extinction coefficient. Using the known spectral response of the photomultiplier tube (38), air masses

recorded photographically as an image of varying intensity and
width by a travelling-jaw camera. The camera's lens was
front of the photographic film in synchronism with the
motion across the sky and therefore resulted in a series of
being plotted in terms of position and intensity.
Data points for analysis were taken whenever the
trace changed its character. This allowed the points to
to be plotted directly on a reproduction of the original
because of the large number of data points per hour (1500 at
300), a rapid method of coordinate transformation was used. It was
parent grids of the horizon and elliptical coordinate systems were
optically projected upon the recordings and the coordinates on
the data points were read off directly.
During routine analysis of 47 days a velocity distribution
correction, the output reading along a line of constant
was taken from the region of the sky opposite the horizon line.
This reading was subtracted from all data points with correspond-
ing elevations. Such a correction removed all light from
scattered light which was independent of altitude and also
direct star light and nebular light which were present in the
background region.
A theoretical average extinction correction was used because
the star readings taken did not allow an accurate determination of
the highly atmospheric extinction coefficient. During the
spectral response of the photomultiplier tube (3500 Å) and

for different elevation angles tabulated by Link (39), Rayleigh extinction coefficients tabulated by Wempe (40), and ozone absorption coefficients tabulated by Paetzold (41) the theoretical response of the photomultiplier was calculated for several elevation angles. The ratio of the zenithal response to that at any elevation angle was regarded as the extinction correction which corrected the readings to that value which would have been obtained for zenithal incidence. A further dust correction was theoretically established but was used only in a small number of cases.

After the preliminary background and extinction corrections had been made, isophote maps in terms of zenithal readings were plotted. The majority of the maps were left in this incomplete form because an error in calibration did not allow the readings to be converted to absolute intensities. The calibration error most probably arose from the use of a photomultiplier mask which was too small to accept the entire cone of light from the calibration stars. This defect was corrected and the last 14 maps analyzed were converted to absolute intensities.

All of the maps indicate the same high degree of symmetry with respect to the ecliptic. Two methods of searching for assymetries were used, the first was to bisect all isophotes in each five degree interval of elongation. The second was to compare the total intensity coming from the north half of the light cone to that coming from the south half.

for different elevation angles calculated by (3.1) and (3.2) and the extinction coefficients calculated by (3.3) and (3.4) and the absorption coefficients calculated by (3.5) and (3.6) and the total response of the photomultiplier was calculated for each elevation angle. The ratio of the measured response to that of any elevation angle was regarded as the extinction coefficient which corrected the readings to that value which would have been obtained for normal incidence. A further check of the correction was experimentally established but was not used in this paper.

cases.

After the preliminary background had been subtracted, the data had been made, the maps in terms of intensity were plotted. The majority of the maps were left in this uncorrected form because an error in calibration did not affect the results to be converted to absolute intensities. The calibration error probably arose from the use of a photomultiplier which was not small to accept the entire cone of light from the source. This defect was corrected and the last 14 maps were converted to absolute intensities.

All of the maps indicate the same high degree of symmetry with respect to the ecliptic. Two methods of averaging the asymmetries were used, the first was to take the average of each five degree interval of elongation. The second was to compare the total intensity coming from the north with the total coming from the south half.

For all 47 maps no significant time variations were found for a particular point of the ecliptic at 60° elongation. The fluctuations of 10 to 15% that are present were attributed to variations in star background and to the lack of complete correction.

The three maps which were expressed in absolute intensities were corrected by a method similar to that employed by Roach et al. The background milky way and zodiacal light intensities were from the charts in this publication. At an elongation of 60° an average value of 326 tenth-photographic magnitude stars per square degree resulted. This is to be compared to 295 obtained by Roach et al., 425 by Elvey and Roach, and 235 by Behr and Siedentopf. The intensity decrease along the ecliptic is found to obey a power law similar to that found by Roach et al. The exponent determined was -2.02 for the present investigation as compared to -2.22 for Roach et al.

An empirical formula for the intensity distribution of the zodiacal light is given which indicates an intensity of 1000 photographic stars at an elongation of 35° as compared to 945 for Roach et al. and 1200 for the mean values of Elvey and Roach.

This work is characterized by the large number of recordings which were obtained and by the high angular resolution exhibited in the records. The misbehaviour of the corrected isophotes which were attributed to anomalies in atmospheric extinction could also be explained by considering the finite response time of the

For all 47 maps no significant differences were found
for a particular point of the earth's surface. The
distinctions of 10 to 15% that are observed were
variations in star background and to the point of
correction.

The three maps which were obtained in the
were corrected by a method similar to that used by
The background Milky Way and nebulae light were
the effect in this position. The correction of 50% at
average value of 326 tenth-magnitude stars per square
degree resulted. This is to be compared to 25% obtained by
et al., 42% by Hiley and Hatch, and 55% by Hiley and Hatch.
The intensity decreases along the axis as found in other
law similar to that found by Hiley et al. The intensity
was -2.02 for the present investigation as compared to -2.52 for
Hatch et al.

An empirical formula for the intensity distribution of the
nebulae light is given which indicates an intensity of 1000
at an elongation of 90° as compared to 245 for
Hatch et al. and 1200 for the mean value of Hiley and Hatch.
This work is characterized by the large number of
which were obtained and by the high angular resolution obtained in
the records. The misbehavior of the corrected records which was
attributed to anomalies in the background and to the
explained by considering the linear background as a

equipment and the tracking error in the camera-lens servo system, both of which had the effect of displacing consecutive traces two or more degrees in right ascension with respect to each other.

6. THE WORK OF ELSASSER AND SIEDENTOPF. In the fall of 1956, Elsasser and Siedentopf (42) observed the zodiacal light and gegenschein from the Boyden Station near Bloemfontein, South Africa. They used a revised version of the photometer constructed by Behr and Siedentopf (6). The same 60mm f-5 objective was used. The spectral sensitivity of the blue and green filters, combined with the response of the 931A photomultiplier tube and Abbott's energy distribution for the sun, gave effective wavelengths of 4500 and 5420Å respectively. Light coming from a 0.28 square-degree area of the sky was measured. Recordings covering 200° in azimuth were made in 2.5° steps between 25° and 60° elevation. A recording of this area was obtained in 30 minutes. Star readings were taken for calibration purposes while a separate photometer, with the same type of filters, was used to determine the nightly zenithal extinction.

Only the results for the gegenschein have been published but preliminary results for the zodiacal light are available.

The data are first corrected for extinction and scattered light. The observed intensity, as a function of zenith distance, is set equal to the scattered light plus the product of the extinction factor and the sum of zodiacal light, star background,

and airglow. This step assumes that the same atmospheric scattering function applies to the airglow emission at a finite height as applies to the truly extraterrestrial light. The observed intensity can then be set equal to the extraterrestrial intensity multiplied by the sum of the atmospheric extinction factor and the value of the scattering function. A simple division subsequently allows the extraterrestrial intensity of the combined sources to be determined from the observed intensity.

The scattering function for a pure Rayleigh atmosphere has been calculated by Ashburn (43) using Chandrasekhar's theory of radiative transfer (44). The nightly zenithal extinction observed by Elsasser and Siedentopf indicated an appreciably greater value than was to be expected from Rayleigh extinction and ozone absorption alone. This additional extinction is attributed to dust. Its value as a scattering coefficient is calculated and added to the Rayleigh scattering coefficient. Values of this combined extinction and scattering function are tabulated. Comparison values of the Rayleigh extinction factor alone are also entered. These values indicate that for zenith distances less than 45° , scattering compensates for atmospheric extinction by almost 50%. For example at a zenith distance of 35° , the combined scattering and extinction correction is 1.068 while the pure extinction correction is 1.132.

Having obtained the extraterrestrial intensity of the combined zodiacal light, star light, and airglow; Elsasser and

and airglow. This step assumes that the air is dry.

scattering function applies to the airglow emission at a 2 km

height as applies to the truly exponential light. The

observed intensity can then be set equal to the airglow emission

intensity multiplied by the factor f and the observed intensity

factor and the value of the scattering function f is

division subsequently allows the exponential emission to be

combined sources to be determined from the observed intensity.

The scattering function for a pure airglow emission

has been calculated by Ashbury (1953) using the following

of radiative transfer (4). The highly scattered light

observed by Eliazar and Friedberg (1954) is approximately

greater value than was to be expected from a pure airglow

emission alone. This additional emission is assumed to

be due to its value as a scattering coefficient in addition to

added to the Rayleigh scattering coefficient. Values of this

combined extinction and scattering function are calculated in

Figure 1. The Rayleigh extinction factor is also shown

in Figure 1. These values indicate that the airglow emission

is less than 45% scattering component for a pure airglow

almost 50%. For example at a height of 2 km, the combined

scattering and extinction coefficient is 1.05 which is

extinction correction is 1.13.

Having obtained the exponential emission factor f and

combined radiative light, the airglow emission and

Siedentopf then separate the components. The airglow intensity is assumed to follow van Rhijn's law. For three azimuths far from the ecliptic it is assumed that the zodiacal light and star light are independent of zenith distance in the range 30 to 65° . This area was located between -30 and -55° ecliptic latitude and 45 to 60° galactic latitude. For each night of observation the extra-terrestrial intensities of these three azimuths were averaged for zenith distance intervals of 5° . The difference in intensity for each interval, with respect to the intensity at the 30° zenith distance, was attributed to the variation of airglow with respect to the 30° point. The airglow was then assumed independent of azimuth which allowed all data to be corrected for the variation in airglow.

The intensity for any region of observation is now the sum of zodiacal light star background, and airglow intensity at a zenith distance of 30° . These values were then averaged over the eight nights of observation. This procedure smoothed out the irregularities caused by the cloud-like structure of the airglow and the star background fluctuations.

The airglow contribution at the zenith distance of 30° was determined from the average over all observations of the extra-terrestrial intensities, as a function of zenith distance, at the azimuths where the zodiacal light and star background were assumed constant. Assuming van Rhijn's law, with an emission height of 100 km, represents the airglow intensity variation with zenith

distance, ratios of the extraterrestrial intensities minus a constant are taken for each 5° in zenith distance. The average value of this constant which gives intensity ratios most closely approximated by the corresponding ratios of van Rhijn's law is the sum of zodiacal light plus star background light.

Expressing the intensities in units of tenth-magnitude stars per square degree allowed the star background to be removed. For the green recordings the star background data was taken from the chart of Roach et al. The data of Bottlinger were used to correct the blue recordings.

The gegenschein is presented on two very detailed isophote maps of the antisolar region. It is centered at -1.5° ecliptic latitude and is thus near the invariable plane of the solar system. The green intensity at the antisolar point is 207 tenth-magnitude stars per square degree. The blue intensity is 117 tenth-magnitude stars per square degree. The color index is calculated as $+0.62 \pm 0.18$ or that of a dG-5 star, however, the sun's color index of $+0.49$ lies well within the error limit. In all, four complete isophotes are shown to encircle the antisolar point for the blue map and three for the green map. Previous investigations have done well to obtain one or two closed isophotes.

Elsasser (45) discusses preliminary results for the entire zodiacal light cone. The intensity was found to decrease from 1180 tenth-visual magnitude stars per square degree at an elongation of 30° to 105 at an elongation of 90° . New polarization

measurements indicate much larger values than found by Behr and Siedentopf. The polarization was found to increase uniformly from 22% at 30° elongation to 36% at 90° elongation. These large polarizations are a factor of two to three higher than any previously reported values. As in earlier reports the plane of polarization was found to pass through the sun. New electron densities were calculated which reflect the higher polarizations. At the earth's orbit, the new electron density is 750/cc compared to 600/cc found previously. At 1.2 au, the number was increased from 200 to 520/cc. The dust densities took a corresponding drop from 2.0 to 1.2 in arbitrary units, at the earth's orbit and from 2.0 to 0.8 at 1.2 au.

The results reported here exhibit an extreme character when compared to other observations. The intensities lie consistently lower than those reported by other investigators while the polarizations are consistently higher. See Figure 2 for a comparison of these and other polarization measurements and Figure 3 for a comparison of electron densities.

7. SOVIET ZODIACAL LIGHT STUDIES. Soviet astronomers, because of their northerly location, must necessarily observe the zodiacal light strongly inclined to the horizon. This situation enhances any deleterious atmospheric effects. Of the scanty information available for the period previous to 1958, the following results are worthy of note.

1. Observations of the morning zodiacal light, in

measurements indicate that the rate of polymerization is proportional to the concentration of the monomer.

The polymerization was carried out at 30°C. The results are given in Table I. The polymerization is a first-order reaction with respect to the monomer.

Previously reported values for the rate of polymerization of styrene at 30°C. are 0.001 to 0.002 per cent per hour.

The polymerization was carried out in a sealed tube. The results are given in Table I. The polymerization is a first-order reaction with respect to the monomer.

At the same time, the rate of polymerization is proportional to the concentration of the monomer.

The rate of polymerization is proportional to the concentration of the monomer. The results are given in Table I.

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Fig. 2 Measured Polarization of the Zodiacal Light

atmospheric transmission and sky polarization were made while at night zodiacal light intensity, color, and polarization measurements were made by visual, photographic, and photoelectric techniques. The majority of the observational results have not yet been published.

Divari and Asaad (50) used the photometer, during the expedition, to check on the zodiacal light enhancement of the oxygen green line. A vertical, stationary telescope was fitted with two totally reflecting prisms in an alt-azimuth mounting. The prisms were directed manually by one observer at the celestial point of interest. Light from a 19.8 square degree area of the sky was incident upon a photomultiplier tube, the photocurrent was amplified and drove a galvanometer. Readings of the galvanometer were taken visually by a second observer. In this study two interference filters were used with maximum transmissions at 5570 and 5220Å. Observations were taken at 10° intervals for 100° of azimuth at zenith distances between 30° and 70° . A set of ten readings took about four minutes.

Star readings were taken for calibration purposes and a constant-luminosity scintillator was used for a sensitivity standard. Intensities were expressed in terms of the number of 5th magnitude G-2 stars per square degree.

The absolute intensity of the green line was taken as the difference in absolute intensities of the two spectral regions. Many plots of the green line intensity versus azimuth are given

atmospheric conditions and the...
night submersible light...
made were made by...
techniques. The majority of the...
yet best preserved.

Divers and... (3) used the...
expedition, to track on the...
oxygen given...
with two...
The prime...
point of...
sky was...
was amplified and...
meter were...
two...
5570 and 5520...
of...
readings...
5570...
constant...
standard...
5570...
The...
difference...
Many plots of...

for the zodiacal light region and none show any significant increase near the ecliptic.

A graph is presented showing the green line and the control intensity as a function of time for a zenith distance of 70° and on the ecliptic. For the three-hour period from 2 A.M. to 5 A.M. local time the green line intensity decreases irregularly but steadily by a factor of two while the control intensity increases almost exponentially by a factor of 2.5 as the zodiacal light rises.

The assumption that the continuous night-sky spectrum is the same at 5220 as at 5570A was investigated. This is the assumption which allows the subtraction of the absolute intensities of the two regions. The lack of enhancement is confirmed even if the spectral energy distributions differ appreciably.

The previously measured enhancement of the green line in the zodiacal light by spectrographic methods (30) is thus again refuted. The enhancements which were measured spectrographically are attributed to a north-south intensity gradient frequently exhibited by the green line emission. If the airglow increases toward the north and the spectroscopist uses a control region to the south of the ecliptic then he will quite naturally find the airglow more intense at the ecliptic. Such an occurrence does not, however, mean the airglow is enhanced by or in the zodiacal light itself.

In addition to their study of the green line enhancement,

for the sodalite light region and the same is observed
crease near the eclipse.

A graph is presented showing the variation of the
control intensity as a function of time for the light
70° and on the eclipse. For the same light intensity
5 A.M. local time the green line (sodalite) intensity
has increased by a factor of two while the control line
increases almost exponentially by a factor of 2.5. The
light rises.

The assumption that the control line is
the same at 5250 as at 5250 is unreasonable. The
assumption which allows the separation of the two
lines of the two regions. The line of control is
even if the spectral energy distribution is not

The previously mentioned assumption of the
the sodalite light by spectral analysis (30) is
related. The enhancement which is observed is
are attributed to a north-south direction. The
exhibited by the green line. The light is
toward the north and the spectral analysis shows a
the north of the eclipse. The light is
show more intense at the eclipse. The light is
however, when the light is observed by the
itself.

In addition to their effect on the light

Divari and Asaad (51) report other findings for the zodiacal light. Only results can be quoted as this paper has not yet appeared in translation. The intensity along the ecliptic was tabulated for three wavelengths namely 4140, 5220, and 5410A. At 60° elongation, the corresponding intensities are 300, 250, and 280 tenth-magnitude stars per square degree. The polarization increases from 15% at 30° elongation to 22% at 60° , then decreases to 16% at 85° . The mean color index determinations have indicated a color bluer than the sun.

C. PHOTOGRAPHIC STUDIES.

1. THE WORK OF SANDIG. Sandig photographed the zodiacal light pyramid, the zodiacal band, and the gegenschein from Windhuk, South Africa. The original work (52) is unavailable, but a later theoretical discussion of the results (53) covers the main points of the study. This theoretical discussion was published in 1939. After considering the general status of the zodiacal light problem, with particular emphasis on the findings of Hoffmeister, Sandig examined several aspects more specifically. One of these was the possibility that some lingering traces of twilight are superimposed upon the zodiacal light after the cessation of astronomical twilight. This possibility was mentioned in a zodiacal light theory by W. Brunner and son (54). They consider the zodiacal light to be a band of uniform intensity and they assume that the triangular shape and the intensity increase toward the sun are due to traces of twilight illuminating the highest

layers of the atmosphere.

In order to evaluate any effect of twilight, after the end, or before the beginning of astronomical twilight, Sandig assumed the extraterrestrial zodiacal light intensity at a given elongation is constant. Comparing intensities at the point $e = 40^\circ$, for different depressions of the sun, he concluded that the first, or last, twilight effects are for a solar depression of 33.4° rather than 18° . He subsequently evaluated the twilight effect and corrected his data for the resulting twilight contribution.

Sanding also presents a calculation for the differential height of a lunar atmospheric tide at an altitude of 1000 km. A value of 1 km. is obtained and ionospheric height measurements are quoted which indicate a similar tide for the ionosphere. This result, in effect, refutes Schmid's postulated lunar tides, which are supposed to deform the upper atmospheric layers to such an extent that they would be pulled out of the earth's shadow and therefore contribute to the zodiacal light.

A suggested test of Hoffmeister's two-ring hypothesis consists of examining the intensity distribution of the zodiacal light off the ecliptic at an elongation of 75° to 90° . If Hoffmeister's theory is correct, there should be a break or wave in the curve representing the zodiacal light intensity as a function of ecliptic latitude. No such break or wave was found, and it was therefore concluded that no outer ring of zodiacal

light material exists. A further test to determine whether or not the material within the earth's orbit has a ring shaped distribution proved negative.

The possibility that the asteroids provide a major part of the zodiacal illumination was examined. If such a contribution were established, it would lend support to Hoffmeister's two ring hypothesis. The empirical distribution of asteroid masses was determined and then extrapolated to such values that smaller masses would be swept out of the solar system by radiation pressure. It was found that only by assuming the frequency function of the masses to be independent of the mass could the observed intensities and the zodiacal band be explained. Since the observed mass frequency depends upon the asteroid mass, even after correction for observational selection, it was concluded that this contradiction indicates that the asteroids do not add significantly to the zodiacal illumination.

Sandig investigated the fact that visual observers invariably see the zodiacal light cone narrower and more pointed than the cone defined by photometric results. He found that the eye, instead of determining true lines of constant intensity (isophotes), actually traces out lines of constant contrast. When lines of constant contrast were entered on a map of zodiacal light isophotes, they indeed proved to be very narrow compared to the isophotes. A table of normalized intensities measured by photoelectric, photographic, and visual observations,

as a function of ecliptic latitude at $e = 60^\circ$ is provided. The values agree only between $\pm 2^\circ$, then the visual estimates diverge and at 10° ecliptic latitude the values run 0.79, 0.74, and 0.53 respectively.

The study also includes a calculation of the intensity distribution of the zodiacal light along the ecliptic, assuming Lambert's phase law holds for the scattering particles. Five different particle density distributions were used with space variations of r^{-1} , r^{-2} , $1 - ar$, $1 - ar^2$, and $1 - ar^3$, where r is the distance from the sun to the scattering element. The density function which most closely approximated the observed intensity distribution was the linear relation, $1 - ar$.

Using the observed intensity distribution perpendicular to the ecliptic, Sandig calculated the space distribution of the material responsible for the zodiacal light. He concluded that the observations indicate that the particle distribution is best represented by ellipsoids of revolution with axes in the ratio of 1 : 3.5. Sandig's gegenschein observations indicate that the gegenschein arises from light reflected by a particle cloud near the earth-sun libration point rather than from an increased reflectivity of the particles with near normal illumination.

2. THE ZODIACAL LIGHT ECLIPSE PROJECT OF THE UNIVERSITY OF COLORADO. Members of the University of Colorado Physics Department (55) photographed the total solar eclipse of

1952 February 25 from a B-29 at an altitude of 32,000 feet over Saudi Arabia with the primary objective of recording the zodiacal light in the range of elongation from 5 to 15° .

Despite a shutter failure, two successful photographs were obtained with an f-0.9 Schmidt camera covering a 40° field of view. Sixteen polaroid wedges of 22.5° angle were placed in front of the circular film and successive wedges transmitted radially and tangentially polarized light. The plates were calibrated with a standard lamp and a step wedge. Corrections were applied for scattered light arising from instrumental and atmospheric scattering.

The resulting plates could only be measured in the range of elongation from 5.5° to 13° . The average polarization for the two plates was 10.5% at 5.5° and increased smoothly to 14.9% at 13° . (Figure 2). These measurements appear to be systematically high and will not join smoothly with other experimental or theoretical results for larger or smaller elongations. The absolute intensity of the zodiacal light was 71.8B at 5.5° and decreased to 17.8B at 13° elongation. The intensity unit B is 10^{-13} times the average brightness of the sun. The isophotes were nearly circular even at the greatest elongation measured.

3. THE WORK OF BLACKWELL. Blackwell (56) examined the zodiacal light problem so as to achieve a better understanding of the outer solar corona. His particular interest was to separate the K and the F-coronas and to obtain the

1952 February 23 from 10-15 at an altitude of 32,000 ft. over

Saudi Arabia with the primary objective of finding the

light in the range of 1000-1500 Å.

Because of the small size of the instrument, the

were obtained with a 100-Å slit and a 100-Å slit.

Field of view, 100-Å slit, 100-Å slit, 100-Å slit.

placed in the center of the instrument. The instrument was

transmitted radiation and the instrument was used.

plates were obtained with a 100-Å slit and a 100-Å slit.

Concentrations were varied for a series of plates.

Strontium and a mixture of strontium.

The results of the experiment are shown in the

of elongated form (Fig. 1). The results of the

two plates are shown in Fig. 2 and Fig. 3.

13. (Fig. 3). The results of the experiment

high field with the 100-Å slit and the 100-Å slit.

Theoretical results for the 100-Å slit and the 100-Å slit.

absolute intensity of the 100-Å slit and the 100-Å slit.

decrease in intensity of the 100-Å slit and the 100-Å slit.

10-13 times the average intensity of the 100-Å slit and the 100-Å slit.

were nearly identical with the 100-Å slit and the 100-Å slit.

3. The results of the experiment.

the x-rayed film was used as a detector.

standing of the x-rayed film was used as a detector.

was to separate the 100-Å slit and the 100-Å slit.

electron density as a function of distance from the sun. High altitude photographs from an aircraft of the 1954 June 30 eclipse allowed the coronal brightness to be measured out to 13.5° elongation but the polarization could be measured only to 5° elongation because of its rapid decrease in magnitude with angular distance from the sun.

In attempting to calculate electron densities from the polarization data at 5° elongation, where the observers line of sight passes within 20 solar radii of the sun, Blackwell notes that about 25% of the light comes from points at a distance of more than 40 solar radii. Thus arose the need for polarization measurements at larger elongations. By assuming Behr and Sidentopf's value of electron density at 0.6 au., he was able to extrapolate the electron densities to 1 au. The electron density function shows a rather sharp break at 25 solar radii.

With these data a complete separation of the corona components is carried out. The calculations for the K corona, using the theory of van de Hulst (57), are then extended into the zodiacal light region. These calculations are based upon the assumptions that the dust polarization is zero at an elongation of 35° , that the electron density gradient is constant for the region outside 123 solar radii, and that the observed quantities are accurately known.

The brightness of the outer K corona is calculated, first assuming the electron density gradient is constant between 123

electron density as a function of distance from the sun. The
ultraviolet photographs from an altitude of 100 miles
eclipse allowed the coronal brightness to be measured out to
13.5° elongation and the polarization could be measured only to
5° elongation because of the very low brightness of the corona
against distance from the sun.

In attempting to calculate electron density from the
polarization data at 5° elongation, where the polarization is
right passes within 20 solar radii of the sun, it was found
that about 25% of the light comes from the sun and that the
more than 40 solar radii. This shows the need for polarization
measurements at larger elongations. In general, the data at 5°
gives a value of electron density of 10^{11} per c.c. at 10 solar
radii. The electron density at 10 solar radii is
usually, however, shows a rather sharp drop at 10 solar radii.
When these data are compared with the data of Robinson and
Parker, the latter are carried out. The electron density at 10 solar
radii, the theory of van de Hulst (1951) and other authors and
the theoretical light region. These calculations are based upon
the assumption that the dust polarization is due to the
action of 35°, that the electron density is constant at
the region outside 10 solar radii, and that the electron
quantities are exactly known.

The brightness of the sun is known to be 10^{26} ergs/cm²/sec.
Assuming the electron density at 10 solar radii is 10^{11}

and 500 solar radii. The K corona polarization is determined to be 56% at 35° elongation whereas the observed zodiacal light polarization is 23%, thus electron scattering constitutes 41% of the observed brightness at this elongation. The corresponding electron density at 123 solar radii is 1080/c.c. and in agreement with that obtained by Behr and Siedentopf.

Assuming further that the dust component has zero polarization for all angles of observation, the total brightness and percent polarization are then calculated for elongations from 5 to 90° . The calculated polarization is too high when compared with the results of Behr and Siedentopf. In order to make the calculations fit the observed data two assumptions are made i.e., there exists negative polarization of a variable amount for the dust component and there exists a sharp cut off in the electron density at some variable distance from the sun. These two parameters are then varied to obtain a closer fit of the observations.

However, no choice of these parameters produces a theoretical curve which even approximates the shape of the polarization curve observed by Behr and Siedentopf and the predicted values agree only at the 35° elongation point, then diverge toward larger elongations with the theoretical curves higher.

It should be pointed out that these attempts to force the theoretical results to agree with the observations can now only be regarded as exercises since Elsasser and Siedentopf have subsequently revised their polarization measurements upward by a

and 500 solar radii. The K corona polarization is determined to be 50% at 35° elongation whereas the observed horizontal light polarization is 25%, thus electron scattering contributes 4% of the observed brightness at this elongation. The corresponding electron density at 15 solar radii is 10^{10} c.c. and is in agreement with that obtained by Beer and Stedden. Assuming further that the dust component has zero polarization for all angles of observation, the total brightness and percent polarization are then calculated for elongations from 5 to 90° . The calculated polarization is too high when compared with the results of Beer and Stedden. In order to make the calculations fit the observed data two assumptions are made, i.e., there exists negative polarization of a variable amount for the dust component and there exists a sharp cut off in the electron density at some variable distance from the sun. These two parameters are then varied to obtain a closer fit of the observations. However, no choice of these parameters produces a theoretical curve which even approximates the shape of the polarization curve observed by Beer and Stedden and the predicted values agree only at the 35° elongation point, then diverge toward larger elongations with the theoretical curves higher. It should be pointed out that these attempts to force the theoretical results to agree with the observations can now only be regarded as exercises since Misses and Stedden have subsequently revised their polarization measurements upward by a

factor of 1.2 to 3 in the range of elongation from 50° to 90° . These later polarization values agree better with this theory but still diverge at large elongations although this time in the opposite direction. Most important, serious doubt has been cast upon the validity of all of the polarization measurements of Behr, Elsasser and Siedentopf by later work. The polarization measurements of these investigators fail to show a characteristic maximum at about 60° elongation as was found by Divari and Assad (see Figure 2) and even by Dufay who did not correct for background. This maximum at about 60° elongation is also obtained by all the theoretical investigations. A maximum at about 50° has been observed for diffuse reflection from roughened meteorite surfaces by Kloverstrom and Rense (58).

Since Blackwell was unable to extend his corona polarization measurements beyond 5° elongation, he examined the possibility of closing the gap between the zodiacal light and the corona by measuring zodiacal light polarization closer to the sun than the usual 35° . He concluded that observations from an aircraft over the open sea would allow polarization measurements to be extended inward to about 22° elongation provided the sky were sufficiently clear and dust-free to permit observations at an elevation of 4° above the horizon.

In conjunction with an eclipse expedition to the south Pacific. Blackwell (59), made several direct photographs of the morning zodiacal light and the first appearance of the twilight

factor of 1.2 to 3 in the case of the ...

These latter polarizations ...

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band from the open hatch of an aircraft at an altitude of 9000 feet over the sea. The multi-lens camera used three simple lenses of 7.1 cm diameter with a relative aperture of $f-1.8$. A red filter was used with each lens and, in addition, two lenses were provided with suitably oriented polaroid filters. Each lens exposed a separate area of the same photographic plate; the field of view was 60° and the effective wavelength was $6300\text{\AA}$. The camera was not guided during the exposures. Relying upon the stability of the aircraft's motion resulted in a smearing of the star images into about 1° diameter circles which still gave sufficient positional accuracy. A standard lamp was used to impress an absolute calibration scale upon a piece of film from the same batch as that from which the zodiacal light plates were taken, and they were developed together.

Atmospheric transmission at the 9000 foot level was determined from calibrated aerial photographs of the rising moon. The resulting absorption coefficient showed practically no dust component. The probable error in determining the absorption coefficient was about 10% and this error was passed on to the measured brightnesses of the zodiacal light as a 10% error also.

The position of the light axis was determined from two photographs taken when the ecliptic was vertical to within 0.3° . The deviation was 0.17° and agrees well with the results of Regener who finds no significant deviation from the ecliptic.

band from the spot, it is evident that the distance of 1000
feet over the sea. The distance between the spot and the
lenses of 7.1 and 8.1 was 1000 feet. The distance between the
A red filter was used in the spot. The distance between the
lenses were provided, 1000 feet. The distance between the
Each lens exposed a separate spot. The distance between the
plate, the film of view was 1000 feet. The distance between the
was 1000A. The camera was not further from the spot.
Relying upon the stability of the instrument, the distance
a scattering of the spot, the distance between the spot and the
which still gave satisfactory results. The distance between the
lamp was used to produce an artificial light. The distance between the
piece of film for the spot was 1000 feet. The distance between the
radical light plates were used, and only one was available
together.

Atmospheric conditions were not too good. The distance between the
examined from the spot, it is evident that the distance of 1000
The resulting spot, it is evident that the distance of 1000
component. The distance between the spot and the lens was 1000
coefficient was not too good. The distance between the spot and the
measured brightness of the spot was 1000 feet. The distance between the
The position of the spot was not too good. The distance between the
photographs as well as the distance between the spot and the lens
0.3°. The distance between the spot and the lens was 1000 feet. The distance between the
of Heger, who found the distance between the spot and the lens was 1000 feet.

Absolute intensities were determined in the range of elongation 28° to 50° . The method of background correction is similar to that of Roach et al. The intensities are expressed in units of 10^{-13} times the brightness of the average solar disk at 6300A, and will be designated by B. At $e = 35^{\circ}$, Blackwell finds 3.89 B while Roach et al. report 5.15 B, also for 6300A. Behr and Siedentopf at 5400A report 3.46 B, and Regener obtains, for about 5000A, a value of 7.29 B.

Commenting upon these discrepancies, Blackwell makes the following statements, 1) it is very undesirable to use star intensity measurements for absolute intensity calibrations because the effect of atmospheric extinction enters twice and reduces the accuracy, 2) the reported variations cannot all be ascribed to errors in determination of the background because on his plates the total background plus the zodiacal light does not equal the zodiacal light brightness obtained by Roach et al., and Regener's value is 30% higher still. He concludes, in spite of Regener's results and comments to the contrary, that it is difficult to believe that the observed intensity variations are other than real.

Two photographs taken for solar depression angles of 19.7° and 18.1° permit the determination of the brightness and polarization of the low elevation scattered light due to the approaching dawn. The dawn polarization was found to be very nearly that predicted by Rayleigh scattering. The night sky polarization,

Associate Professor of Physics, University of California, Berkeley, California 94720. The results of the measurements are similar to that of Heisenberg et al. (1955) and are in units of 10^{-10} times the value of the constant k at 3000 Å, and will be compared with the value of 3.69 obtained by Heisenberg et al. (1955) for about 5000 Å, a value of 7.29. The following statement (1) is the most satisfactory for the density measurements for the purpose of the present study. The effect of atmospheric absorption on the results of the measurements (2) the reported values are all corrected to errors in determination of the wavelength and are given in terms of the total wavelength. The total wavelength is equal to the total wavelength of the light plus the wavelength of the light and Regener's value is 308 Å higher than the value of Regener's results and is in good agreement with the value of 308 Å. It is difficult to see how the value of 308 Å can be obtained from the data. Two photographs taken at angles of 18.1° and 18.1° give the same value of the wavelength and the action of the low frequency scattered light on the system is the same. The data for the action of the low frequency scattered light on the system are given in the table. The results are that predicted by the high frequency. The high frequency is the same as the low frequency.

according to van de Hulst (81), is about 6% near the horizon and 1% at 10° elevation. With the above values, Blackwell corrects the observed polarization and thus determines the zodiacal light polarization.

The values run from 12% at 20° elongation to 20.5% at 35° , and apparently join smoothly with the values of Behr and Siedentopf for 35° elongation. The later results of Elsasser and Siedentopf also join smoothly but continue the upward trend until 100° elongation. Divari and Asaad's results will not join Blackwell's values at all well, see Figure 2.

Electron densities were calculated using these new intensity and polarization measurements, and their extrapolations into the coronal region. At a distance of 0.6 au from the sun 700 electrons/cc are found while at 1 au the density has dropped to about 440/cc (Figure 3).

During the IGY Blackwell and M. F. Ingham made an extended series of direct photographs and spectrograms of the zodiacal light at Chacaltaya, Bolivia at an altitude of over 17,000 feet. Preliminary results from the partially analyzed data were discussed by Redman (4). They indicate an intensity increase, by a factor of 2, was observed during the magnetic storm which followed the large solar flare of 1958 July 7. At this time the light axis was observed to be displaced to the north of the ecliptic. A color anomaly was also noted but the type or magnitude was not mentioned.

Fig. 3 Calculated Electron Densities

The high resolution spectra indicate no appreciable broadening of the absorption lines as would be expected if there were a free electron component of the size required to explain the observed polarization. Preliminary conclusions indicate an upper limit to the free electron density at 1 au should now be set at about 150/cc.

D. SPECTROGRAPHIC STUDIES

1. INTRODUCTION. The continuous spectrum of the zodiacal light is a very difficult subject for spectrographic investigation. The extremely low surface brightness necessitates the use of fast cameras, wide slits, and low dispersion which in turn destroys all but the coarsest details. If a detailed spectrum is desired, an exposure of many nights is required and consequently few such attempts have been made. On the other hand, the night sky luminosity which is so feeble as to almost elude naked-eye detection, can have its major emission lines recorded in exposures of a few minutes and therefore has received much attention from spectroscopists.

2. THE WORK OF FATH. One of the first successful attempts to record the zodiacal light spectrum was that of E. A. Fath (60) in 1909. He used a 30° angle prism of refractive index 1.61 and a 50 mm diameter f-5 camera lens to record a spectrum 2.2 mm long of the region from 3900 to 5000A. From an exposure of six hours and using a slit width of 0.4 mm Fath was led to suspect the presence of the K and H lines at 3950A

The high resolution spectra indicate that the

broadening of the absorption lines is not expected to

there were a free of other components of the spectrum

explain the observed features. The intensity of the

indicates an upper limit to the intensity of the

should now be set at about 1000.

D. SPECTROGRAPHIC STUDIES

1. INTRODUCTION

Spectral light is a very important subject for spectroscopic

investigation. The intensity, line width, and position

states the use of fast cameras, wide slits, and low dispersion

which in turn decreases all the absorption lines. It is

detailed spectrum is desired, in order to obtain a

reduced and consequently low resolution spectrum.

On the other hand, the light spectrum which is an

as to almost all the features, and it has been

emission lines recorded in a few minutes.

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2. THE WORK OF KIRBY

attempts to record the spectra of the spectrum of the

Kirby (60) in 1905. He used a 50 mm diameter lens

index 1.61 and a 50 mm diameter lens to record

spectrum 2.2 m. long. The resolution of the

an exposure of 1/100 sec. with a slit width of 0.1 mm.

was led to a spectrum of the spectrum of the

and the G band at 4300A. A later exposure of 12.5 hours allowed positive identification of the blended H and K lines and the G band. It was concluded that the spectrum was definitely of the solar type and no doubt due to reflected sunlight.

3. THE WORK OF RAMANATHAN. In 1932 Ramanathan (6) photographed the green airglow line from Poona, India with an f-1.5 spectrograph and a 0.7 mm slit in one to two hours. Photographs of the zodiacal light region showed the airglow line strongly enhanced with the continuous spectrum not recorded. The variation of the green line was the same as the diurnal variation of the zodiacal light. He concluded that there was neutral oxygen at great heights above the earth which contributed to the zodiacal light. This series of observations began a rather long standing controversy over whether or not other green line was actually enhanced in the zodiacal light.

4. THE WORK OF SLIPHER. In 1932 Slipher (62) obtained zodiacal light spectra which showed a solar type continuous spectrum with the airglow emission lines superimposed upon it. No enhancement was reported.

5. THE WORK OF CABANNES AND DUFAY. In 1935 Cabannes and Dufay (63) investigated the enhancement question with observations from the Alps while Eropkin and Kozirev made simultaneous, cooperative observations from central Asia. Cabannes and Dufay used an f-0.7 spectrograph camera and an exposure of 5 hours for the zodiacal light. A comparison

spectrum from the night sky was obtained in 7.5 hours. Microphotometer tracings showed the emission lines in both spectra to be of equal intensity and hence they concluded there was no enhancement in the zodiacal light. The findings of Kozirev and Erokin were the same.

6. THE WORK OF HOFFMEISTER. Hoffmeister (64), in 1939, photographed the zodiacal light and gegenschein from Windhuk, South Africa. Microphotometer tracings indicate a solar type spectrum with superimposed airglow lines. The H and K lines of ionized calcium are blended. The gegenschein spectrum appears identical to that of the zodiacal light and not similar to the airglow spectrum as Fesenkov (47) has reported.

7. THE WORK OF KARIMOV. In 1950 Karimov (30) measured the airglow enhancements in the zodiacal light with respect to the intensity obtained 20° to either side of the ecliptic and on the same almucantar. After correction for the continuous background, he obtained enhancements of 1.40 and 1.53 for the red and green oxygen lines. He also determined the zodiacal light color index as + 0.53 or that of a class G star. This is a color very similar to that of the sun.

With the appearance of the negative photoelectric results obtained by Roach et al. (see section B-4), Karimov (65) and independently Karyagina (66) again obtained spectrographic results which confirmed the previously reported enhancements.

Presumably, the enhancement question is now settled by

spectrum from the ... was ...
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the analysis of Divari and Asaad (see section B-7) who attribute the spectrographic enhancements to airglow intensity gradients across the zodiacal light region.

8. SPECTROGRAPHIC INVESTIGATION OF THE INTERPLANETARY MEDIUM. As well as determining the color of the zodiacal light and airglow enhancements in it, spectrographic analysis offers a very powerful, but very difficult method, of learning more about the physical nature of the interplanetary medium. An appreciable molecular component of the interplanetary gas can be dismissed on purely photometric grounds because of the color-independent nature of the scattering, but the possible existence of an electron component escapes proof by this method. Opik (67) suggests that high resolution spectrograms of the intense H and K absorption lines should indicate the presence of an electron gas by having broadened wings due to electron scattering superimposed upon sharp cores due to dust scattering. His calculations of the interplanetary electron gas temperature indicated values in the thousands of degrees which would provide electrons with ample kinetic energy for Doppler broadening.

The same test, suggested by Johnson (68), was to decide between a stationary interplanetary gas and one which is continuously supplied by corpuscular radiation from the sun. Corpuscular radiation, similar to that which initiates terrestrial magnetic storms, is known to travel at 500 to 2000 km/sec. If these streams are of sufficient density to contribute to the

the analysis of Givert and Assar (see footnote 1) and the spectrographic examination to a few degrees of freedom across the visible light region.

2. EXPERIMENTAL INVESTIGATION OF THE PHENOMENON

METHOD. As well as determining the color of the medium and air flow phenomena in it, the present investigation is a very powerful, but very difficult method of determining about the physical nature of the phenomenon. An appreciable molecular component of the medium can be dismissed as purely phenomenological. The color-independent nature of the scattering, and the existence of an electron component, suggest that the existence of an electron component is not a possibility. Optic (67) suggests that high scattering is a function of intense H and K absorption lines which are observed as an electron gas by having observed light and scattering superimposed upon an electron gas. His calculations of the interplanetary scattering indicated values in the thousands of degrees which would indicate electrons with kinetic energy of 100 eV or more. The same result, suggested by Givert (68), was obtained between a stationary interplanetary gas and an electron component supplied by corpuscular radiation from the sun. Corpuscular radiation, similar to that which is observed in a magnetic storm, is known to travel at 500 to 2500 km/sec. If these streams are of sufficient density to be observed in the

zodiacal light then their line of sight velocity component would be enough to produce a broadened absorption line.

The possibility of observing solar corpuscular streams offers two very interesting lines of investigation. First it may be possible to observe the Doppler wings of absorption lines in the zodiacal light spectrum. Second, Schlovskii (69) in discussing charge transfer processes between a proton stream and the neutral hydrogen atoms which may exist in interplanetary space with a density of about $0.5/\text{cc}$, contends that if there are about 400 protons/cc in the stream, enough excited hydrogen atoms will be produced to emit an observable H-alpha line. The presence of neutral hydrogen atoms in interplanetary space rests upon the interpretation of rocket observations which show diffuse Lyman-alpha radiation is present over the night hemisphere. If this radiation arises from the scattering of solar Lyman-alpha radiation, then the above density of neutral hydrogen atoms is required.

Blackwell is the first investigator to devise a spectrograph of sufficient speed and resolution to obtain spectra of a quality that will permit definitive statements to be made on the line width problem. This spectrograph and a high quality night-sky spectrum are described by Blackwell et al. (70). Dispersions of $78 \text{ \AA/mm}$ are obtained in the first-order red, and $39 \text{ \AA/mm}$ in the second order violet. The grating has a $150 \times 203 \text{ mm}$ ruled area with 600 lines/mm. An $f=0.87$ Schmidt camera of 17.7 focal length

radical light than their line of sight
would be enough to produce a substantial
The possibility of secondary emission
offers two very interesting lines of investigation.
may be possible to observe the
lines in the radical light spectrum.
in discharging charge transfer processes
and the neutral hydrogen atoms which
space with a density of about 0.5×10^{18} atoms/cm³
about 400 protons/cm³ in the stream, enough to
atoms will be produced to emit an observable
The presence of neutral hydrogen atoms in the
rests upon the interpretation of the
diffuse Lyman-alpha radiation is present over the
hemisphere. If this radiation arises from the
solar Lyman-alpha radiation, then the
hydrogen atoms is required.
Blackwell is the first investigator to
graph of sufficient speed and resolution to
quality that will permit definitive
line width problem. This spectrograph and a
any spectrum are described by Blackwell et al.
of 78 Å are obtained in the first-order
the second order violet. The first-order
with 600 lines/mm at 2-0.87 Å resolution

is used and suitable zodiacal light spectrograms were obtained with exposures over seven nights.

Only the preliminary statements of Redman (4) to the effect that no broadening was observed in spectra taken from the Bolivian Andes have been published.

E. SUMMARY AND CONCLUSIONS. Naked eye observations cannot be regarded as accurate enough or objective enough to contribute much useful information to the zodiacal light problem. The use of a visual photometer, such as in Hoffmesiter's work (Section A-3), increases the accuracy of measurement but there remain systematic calibration errors which are difficult to cope with. Visual photometers are particularly difficult to calibrate in terms of star intensities.

The use of photoelectric scanning devices enables large areas of the sky to be accurately and rapidly surveyed. The night-sky survey of Elvey and Roach (Section B-1) determined not only the absolute zodiacal light distribution over the entire sky but also the distribution of the galactic light. The absolute intensities obtained in this survey now appear to be too high by about 30%. This was discovered by Roach et al. (Section B-4) who used successive approximations to establish the true zero level of the zodiacal light. The work of Roach et al. also establishes an observational connection between the zodiacal light and the solar F-corona.

Huruhata's work (Section B-2) indicates large time

is used and suitable nodal light spectrograms were obtained with exposures over seven minutes.

Only the preliminary statements of fact (4) to the effect that no broadening was observed in spectra taken from the Bolivian Andes have been published.

E. SHAPIRO AND W. K. WILSON. Nodal light observations

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The use of photoelectric measuring devices enables large

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night-sky survey of Elvey and Rosen (Section 2-1) determined

not only the absolute nodal light distribution over the

entire sky but also the distribution of the galactic light.

The absolute intensities obtained in this survey now appear to

be too high by about 30%. This was discovered by Rosen et al.

(Section 2-4) who used sensitive photometers to establish

the true zero level of the nodal light. The work of Rosen

et al. also establishes an observational connection between

the nodal light and the solar γ -ray.

Hartman's work (Section 2-2) indicates large time

variations of the zodiacal light intensity, and presents the interesting possibility of a meteor cloud contribution to the zodiacal light. However, other investigations concerned with possible time variations of the zodiacal light intensity, such as Regener (Section B-5), have found no detectable effect.

The photoelectric color index of the zodiacal light has been determined by several investigators and found to be nearly equal to that of the sun, or slightly redder. The sole exception occurs in the work of Divari and Asaad (Section B-7) where the color index determined is slightly bluer than that of the sun. Spectroscopic results yield a color index similar to the sun.

Early polarization measurements of the zodiacal light showed a maximum percentage polarization of about 15%, but these results were not corrected for dilution by airglow. Later results indicate a maximum polarization of approximately 22 to 25% which occurs at about 60° elongation. However, Elsasser and Siedentopf (Section B-6) find a maximum polarization of 36% at 90° elongation. Most polarization maxima measured fall within the range of 22 to 25% but all measurements agree within a factor of 1.5 to 3 for any elongation.

The theory of free electrons in interplanetary space seemed quite well founded a few years ago, but free electrons now seem to be superfluous as a source of zodiacal light. If all of the observed polarization is attributed to scattering by free

variations of the sodium light, and the
interesting possibility of a weakly
sodium light. However, other
possible time variations of the sodium light
as Regener (Section B-5), have been
The photoelectric effect of the sodium light
been determined by several investigators and found to be
equal to that of the sun, or slightly less. It is
this occurs in the case of several other (Section B-7) and
the color index determined as slightly different from that
sun. Spectroscopic results also show a slight shift to the
sun.
Early polarization measurements of the sodium light
showed a maximum percentage polarization of about 15% at
results were not corrected for the effect of scattering. These
results indicate a maximum polarization of approximately 25% at
25° which occurs at about 60° elevation. However, Regener
and Stedentrop (Section B-5) found a maximum polarization of 35%
at 90° elongation. Most observations have been made at
in the range of 25 to 35° and the maximum polarization found
a factor of 1.5 to 2 for any elongation.
The theory of the effect of the sodium light on the
seemed quite well founded. A few years ago, the theory
now seem to be superfluous as a quantum mechanical treatment
of the observed polarization is sufficient to explain the results.

electrons one can calculate electron densities of about 1000/cc inside the earth's orbit. Other effects which should arise as the result of such an electron density have not been observed.

Measurements, from many sources, show that dust can produce partially polarized light upon reflection. This mechanism is entirely adequate to explain the observed polarized component of the zodiacal light.

Conclusions made from spectroscopic observations which indicated enhancements of the bright airglow lines in the zodiacal light region have now been effectively refuted by the results of photoelectric observations. The enhancements which were detected spectrographically have been shown to be the result of horizontal variations in airglow intensity across the zodiacal light region and as such are not at all connected with the zodiacal light.

The use of high-flying aircraft has enabled Blackwell (Section C-3) to close the gap in observation both outward from the sun during a solar eclipse and inward toward the sun before dawn. The long-standing unobserved range of elongation from 2 to 30° has been reduced to a range extending from 13.5 to 22° by the measurements.

Several things come to mind upon contemplation of the experimental results which have been reviewed. It appears that each investigator can obtain fairly reliable and consistent results using his equipment and his method of analysis. The

fact that each investigator uses a different method of analysis based upon different assumptions and different values for the pertinent corrections appears to be the major cause for the discordant intensity values.

There is apparently no adequate explanation of how or why some investigators detect time variations in the zodiacal light intensity. Blackwell's observation (Section C-3) of an intensity increase during the magnetic storm which followed an intense solar flare cannot be called upon to explain the large variations observed by Elvey and Roach or Huruata. Small, rapid variations as listed by Roach et al. can, however, be attributed to changes in atmospheric transparency.

The widely used assumption that the airglow intensity is independent of azimuth is certainly not true. The cloud-like airglow irregularities are still present in the zodiacal light when the above assumption is used. Only average values of zodiacal light intensity over many nights remove such irregularities, but such time averages also obliterate any possible true time variation of the zodiacal light.

The correction for background star light is usually based upon the work of van Rhijn or Bottlinger. Van Rhijn's work has been shown by Hoffmeister (11) to suffer from a systematic zero point error in the intensity scale. Bottlinger's photographic star counts give only a mean variation of star density with galactic latitude, and hence any variations from the mean appear

fact that each... based upon different... pertinent corrections... discordant... there is... some investigators... intensity... increase during the... solar flare cannot be... errors observed by... variations as... no changes in... The widely used... independent of... single irregularities... when the above... medical light... lies, but such... the variation of... The correction... upon the work of... been shown by... point error in the... star counts give only a... galactic latitude, and hence...

in the zodiacal light intensity.

The work of Elsasser and Siedentopf (Section B-6) shows that atmospheric extinction and light scattered by the atmosphere are intimately connected and partially counteract each other. The opposing effect of scattered light and extinction has led some observers to use an extinction coefficient of one-half the true value. The usual assumption that atmospheric scattered light is independent of azimuth is probably only a very rough approximation. Certainly with a light source of small angular dimensions, such as the zodiacal light, the atmospheric hemisphere on the same side as the light source would contain more scattered light than the opposite hemisphere.

F. THEORETICAL STUDIES

1. INTRODUCTION. Theoretical studies of the zodiacal light, to be discussed in this section, can be broadly classified as calculations of the total zodiacal light intensity, and calculations of the polarized intensity. Theories dealing with the more general properties of the interplanetary medium, except as they pertain to possible sources of the zodiacal dust, will not be discussed.

The three basic parameters which enter into every intensity calculation are, 1) the radius distribution, 2) the space distribution, and 3) the scattering function of the particles constituting the zodiacal cloud, i.e., the differential intensity distribution as a function of scattering angle. In

in the modern light.

The work of the present is a continuation of the work of the past.

There are many things which are not yet known, and which are not yet understood.

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THE FUTURE OF THE PAST

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be discussed.

The future of the past is a subject which is not yet understood.

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There are many things which are not yet known, and which are not yet understood.

practice, a variety of choices are made for these parameters; some are based on observational evidence, while other choices appear quite arbitrary. The nature of the problem is such that a broad range of scattering angles and distances enter into the brightness calculation at each point on the sky, thus some simple analytical form is generally chosen to describe the behavior of these parameters.

The solution of the integral expressing the brightness of the zodiacal light as a function of elongation have come mainly from astrophysicists who merely extended their calculations for model solar coronas outward to encompass the zodiacal region.

2. CALCULATIONS OF THE TOTAL INTENSITY.* The brightness integral for the zodiacal light, following van de Hulst (33) and Beard (71), can be set up quite generally as follows. The sun is assumed to be a point light source with an intensity J , ergs per square centimeter per second, at a distance D equal to 1 au. The flux of solar radiation intercepted by a particle of radius a , at a distance r from the sun is, in ergs per second,

$$J \frac{D^2}{r^2} (\pi a^2) \quad .$$

If the particles are distributed in space such that $n(a,r) da dV$ is the number of particles with radii between a and $(a+da)$, in

* The notation used in this section should be considered standard and will be used without redefinition in later sections.

practice, a variety of one case and the other.

some are based on observational evidence, while others are

appear quite arbitrary. The nature of the problem is such that

a broad range of scattering angles and a wide range of

brightness variations at each angle, and a wide range of

analytical form in general, must be considered in the analysis of

these parameters.

The selection of the form of the function is

the selection of the form of the function is

from astrophysical and other evidence that the form of the

model point sources is not known and is not known.

2. CALCULATIONS OF THE FORM OF THE FUNCTION

has been used for the selection of the form of the function (1)

and has been used for the selection of the form of the function.

and is assumed to be a point source with a radius of

size per square centimeter per second, and a radius of

1 cm. The form of the function is assumed to be

radius a , at a distance r from the center of the source.

$$\frac{1}{r} \left(\frac{r}{a} \right)^2$$

If the particles are distributed in space as a point source

is the number of particles with radii between a and $a + da$.

* The notation used in this section should be understood

standard and will be used without further explanation.

the volume element dV at a distance r from the sun and if they reflect or diffract light of relative intensity $I(\theta) dW$, then the intensity of sunlight dF , scattered into dW by particles of radius a to $(a+da)$ in a volume element dV will be

$$dF = J \frac{D^2}{r^2} (\pi a^2) n(a,r) da I(\theta) dW dV$$

The scattering volume element, $dV = l^2 \Delta w dl$, of length dl and located at a distance l from the earth, subtends a solid angle Δw at the earth, (Figure 4). The flux dj in ergs, received per square centimeter and second at the earth due to scattering of sunlight in this volume element is the ratio of the light scattered to the area, at the earth, of dW . Thus $dj = dF/l^2 dW$ or

$$dj = J D^2 \pi a^2 n(a,r) da \frac{I(\theta)}{r^2} dl \Delta w \quad \text{ergs per}$$

square centimeter per second. For convenience in calculation, Δw is taken as the solid angle of a given area on the sky, usually one square degree, and will thus be set equal to unity in the ensuing discussion.

The total flux of scattered light, as seen at the earth, due to a column of all particles along the line of sight is

$$j = J D^2 \int_0^\infty \int_{a_1}^{a_2} \pi a^2 n(a,r) \frac{I(\theta)}{r^2} da dl \quad . \quad 1)$$

It is customary to write the particle density in the form

$$n(a,r) = N a^{-p} (D/r)^{-q} \quad 2)$$

which separates the size distribution of the particles from their

the volume element dV at a distance r from the origin O , the
 reflex of diffuse light of relative intensity $I(r)$ from
 the intensity of sunlight I_0 , scattered from a volume element
 radius a to $(a+da)$ in a volume element dV will be

$$dI = I_0 \frac{dV}{S} (\pi a^2) \sin^2 \theta \quad (1)$$

The scattering volume element, $dV = 4\pi a^2 da$, of length da is
 located at a distance r from the earth, subtending a solid angle
 Ω at the earth, (Figure 1). The light of this, received
 per square centimeter and second at the earth can be scattering
 of sunlight in this volume element as one of the light
 scattered to the area, at the earth, of area dA . Thus $dI = dA \Omega$ or

$$dI = I_0 \frac{dV}{S} (\pi a^2) \sin^2 \theta \quad (2)$$

square centimeter per second. For convenience in calculation,
 Ω is taken as the solid angle of a given area of one dA , usually
 one square degree, and will thus be set equal to $\frac{1}{3600}$ in the
 ensuing discussion.

The total flux of scattered light, as seen at the earth,
 due to a column of all scattering objects along the line of sight is

$$I = I_0 \int_0^\infty \frac{dV}{S} (\pi a^2) \sin^2 \theta \quad (3)$$

It is customary to write the intensity of light as a function of distance
 $I(r) = I_0 e^{-\tau(r)}$ (4)
 which separates the area element dA from the volume element dV

Fig.4 Scattering Geometry

space distribution. In this expression Na^{-p} is the number of particles per cc with radii a to $(a+da)$ at the earth's distance d from the sun.

Using this form of the density function, the brightness integral can be expressed in terms of angles. With the aid of Figure 4, and the sine law one obtains $r = D(\sin e / \sin \theta)$ where D is 1 au, e is the elongation from the sun and θ is the scattering angle. Then using this expression for r we have $l = D(\cos e - \sin e \cot \theta)$ and $dl = D(\sin e / \sin^2 \theta)$. Direct substitution of these expressions for r and dl give the brightness integral $j(e)$ for a column in the direction e .

$$j(e) = J \pi^2 S_N^2 \int_{a_1}^{a_2} a^2 a^{-p} da \int_e^{\pi} \frac{\sin^q \theta}{\sin^{1+q} \theta} I(\theta) d\theta \quad 3)$$

The scattering function $I(\theta)$ can be separated further in the form $I(\theta) = \gamma f(\theta)$, where γ is the albedo and $f(\theta)$ is the so-called phase function. By including the albedo, some idea of the surface character of the scattering particles is obtained.

a. THE WORK OF ALLEN. Allen (32) was the first investigator to suggest that diffraction produces the large increase in intensity responsible for the solar corona, rather than an increase in space density of the scattering particles near the sun. He approximated the Bessel function behavior of the Fraunhofer diffraction pattern by a circular aperture with the simpler function $1/(1+4m^2)$, where $m = \pi a \theta / \lambda$.

Here a is the particle radius, θ the scattering angle and the wavelength of light used. This approximate function represents an average smooth curve very similar in shape to the envelope of the diffraction pattern.

Corona models for several discrete radius values and density laws were calculated. Best results were obtained for a radius of 10^{-3} cm and with the density decreasing as $N(E)/r$, where $N(E)$ is the number/cc of particles at the earth's orbit. Predicted intensity values which closely approximated the observed values were obtained.

The successful corona calculations led to a trial calculation for the zodiacal light region. Here, however, Allen assumed a reflection type scattering function, namely the empirical function found by Hoffmeister (12). His evaluation of the brightness integral assumed particles of a single radius, and used Hoffmeister's empirical values for the integral of the space density law and phase function. The unknowns remaining to be evaluated occurred in an algebraic equation involving the particle radius, its albedo, and the space density of the particles at the earth's orbit as well as the absolute intensity of the scattered light.

Using the observed absolute zodiacal light intensity at an elongation of 40° , found by Elvey and Roach, and assuming an albedo of 0.14, Allen obtained the relationship $a^2 N(E) = 1.8 \times 10^{-21} \text{ cm}^{-1}$. This equation allowed $N(E)$ to be plotted as a

Here is the particle radius, R , and the wavelength of light, λ . The average smooth curve very closely follows the envelope of the diffraction pattern.

Corona models for several different particle sizes and density laws were calculated. These results were compared with radius of 10^{-5} cm and with the density distribution $\rho(r) = \rho_0 \exp(-r^2/R^2)$, where $N(E)$ is the number of particles at the energy E . Predicted intensity values were closely approximated by observed values were obtained.

The successful corona calculations led to a trial calculation for the solar light region. However, since we assumed a reflection type scattering function, namely the empirical function found by Hoffmeister (1953), the evaluation of the brightness integral assumes particles of a single radius. We used Hoffmeister's empirical values for the intensity of the scattered light and phase function. The unknown quantity to be evaluated occurred in an algebraic equation involving the radius, the albedo, and the space density of the particles at the earth's orbit as well as the absolute intensity of the scattered light.

Using the observed absolute radial light intensity at an elongation of 40° , found by Elvey and Ford, and assuming an albedo of 0.14, Allen obtained the relationship $N(E) = 1.8 \times 10^{-21} \text{ cm}^{-1}$. This equation allowed (1) to be plotted as

function of a . Similar curves for the corona region were plotted and thus, an indication of the true value of $N(E)$ and of a was obtained where the zodiacal light and corona curves intersected. Employing the best corona model, and assuming that the zodiacal light results could be in error by a factor of 2, the consequent values were $a = 10^{-3} \text{ cm}$ and $N(E) = 3 \times 10^{-15} \text{ cm}^{-3}$. Allen concludes that if the zodiacal light arises from particles of the size and density derived, then the observed solar F-corona would be reproduced by his theory.

The albedo for this model, while chosen arbitrarily, is approximately the average albedo of the asteroids but about twice that of the moon.

b. THE WORK OF VAN DE HULST. Van de Hulst (33), a year later, but independently of Allen, came to the conclusion that diffraction by interplanetary particles is the reason for the inconsistency between the observed corona intensities and the predicted particle densities near the sun. He examined the corona and the zodiacal light photometric data and noted that when both are plotted on a log-log scale of intensity versus distance, both can be joined across the unobserved region from 2 to 30° elongation by a straight line of slope -2.4 . Several explanations for the F-corona were examined and discarded as being inadequate. These included atmospheric and instrumental scattering, multiple atmospheric scattering, and diffraction around the edge of the moon.

function of α . Similar curves for the corona region were obtained
and thus, an indication of the true value of α and of β was
obtained where the solar wind speed and density were known.
Employing the basic corona model, and assuming that the solar
light results could be derived by a factor of 2, the calculated
values were $\alpha = 10^{-3}$ and $\beta = 3 \times 10^{-11}$. These values
include both the solar wind and the corona. The solar wind
size and density derived, that the solar wind is 7-10%
would be represented by this theory.

The albedo for this model, while being extremely low,
approximately the average albedo of the sun, and thus the
that of the moon.

b. THE WORK OF VAN DE HULST. Van de Hulst (1957), a year
later, but independently of Alton, came to the conclusion that
diffraction by interplanetary dust is the reason for the
inconsistency between the observed and calculated values of the
predicted particle densities near the sun. He showed that
corona and the solar wind light phenomena are not the same
when both are plotted on a log-log scale of wavelength versus
distance, both can be joined across a 100-fold distance from
2 to 30° elongation by a straight line of slope -2.5. Several
explanations for the P-corona were suggested and discussed as
being inadequate. These included dust, gas, and ionospheric
scattering, multiple atmospheric scattering, and diffraction
around the edge of the moon.

The brightness integral, in a form similar to Equation 3, is developed. On the basis of Mie's theory of scattering by a sphere, van de Hulst writes $I(\theta) = I_r(\theta) + I_d(\theta)$, where $I_r(\theta)$ is the combined scattering due to reflection and refraction and $I_d(\theta)$ is the scattering due to diffraction. This separation is valid only when x is much larger than unity. The value of x is $2\pi a/\lambda$, where a is the particle radius and λ the wavelength of light being scattered. The exact form of $I_d(\theta)$ is $J_1^2(x\theta)/\theta^2$ where $J_1(\theta)$ is a first order Bessel function.

The reflection part of $I(\theta)$ is taken as a classical reflection law. Calculations were made using both totally reflecting spheres and Lambert spheres. For these cases $I(\theta)$ is $1/4\pi$ and $\frac{2\gamma}{3\pi^2}(\sin \theta - \theta \cos \theta)$, respectively.

Calculations for the diffraction behavior were made for an assumed constant space density, i.e., $q=0$ in Equation 3. Particles characterized by parameters $x = 10, 100, \& 1000$ at a wavelength of 4400Å were used in the equation.

$$F(e) = \frac{e}{\sin e} \int_e^\pi 4\pi I(\theta) d\theta$$

It is to be noted that $F(e)$ is e times the surface brightness of the predicted zodiacal light.

When plotted on the usual log-log scale of intensity versus elongation, the curves show a region of constant value extending to greater angular distances for smaller particles, then an

The brightness distribution, as a function of angle θ ,

is developed. On the basis of this analysis, the following

sphere, van der Waals writes $I(\theta) = I_0(1 - \cos^2 \theta)$, where

$I_0(\theta)$ is the combined scattering and is proportional to $\sin^2 \theta$

and $I_0(\theta)$ is the scattering due to anisotropy. This equation

is valid only when λ is much larger than a , the radius of the

sphere, where λ is the wavelength of the incident light.

light being scattered. The intensity $I(\theta)$ is given by

where $J_1(x)$ is a first order Bessel function.

The reflection part of $I(\theta)$ is taken as a constant in

reflection law. Calculations were made for $\lambda/a = 1, 2, 3, 4, 5$

for spheres and for the sphere. The curves are shown in Fig. 1

and $I_0(\theta) = I_0(1 - \cos^2 \theta)$, respectively.

Calculations for the reflection part of $I(\theta)$ were made for

assumed constant sphere radius $a = 10^{-5}$ cm. The results are

characterized by parameters $k = 10, 100, 1000$ and are shown in

Fig. 2. The curves were used in the calculations.

$$I(\theta) = \frac{a^6}{4\pi} \int_0^\pi \frac{1}{r^2} \sin^2 \theta \, d\theta$$

It is to be noted that $I(\theta)$ is a function of the angle θ and

the predicted nodal light.

When plotted on the usual logarithmic scale, the curves

elongation, the curves show a region of constant intensity

to greater angular distances for smaller particles, that is

abrupt change to an e^{-2} dependence at increased elongations. $F(e)$ was also calculated for totally reflecting and Lambert spheres. Both of these curves show an almost constant value.

The predicted surface brightness, which is e^{-1} times the values just mentioned, thus has three distinct regions of differing angular dependence. The inner corona region varies as e^{-1} , then from roughly 0.5 to 10° the variation is e^{-3} , and then returns to an e^{-1} behaviour for large elongations.

It appears that the e^{-3} dependence, which approximately characterizes the zodiacal light behaviour in the region from 30 to 60° , could also be made to hold in this region by choosing smaller particles. Thus, the possibility of a test, to determine the most effective particle radius in the zodiacal region also presents itself. This point will be discussed further in Chapter 6 in Section B.

By assuming that the zodiacal light follows an intensity law of $e^{-2.4}$ along the ecliptic, and by using the integrated theoretical expression for the intensity along the ecliptic which varies as e^{p-5} , van de Hulst equates these angular dependences and obtains $p = +2.6$. This value of p , which determines the particle radius distribution of Equation 2, is considerably lower than would be expected from an extrapolation of telescopic meteor data to very small radii. The observed meteor distribution has $p = 5$, and later radar observations set p for very faint meteors at 4. These results would predict many

sharp change to an ω^{-1} dependence at a certain distance.
F(e) was also calculated and is shown in Figure 2.
Both of these curves show a minimum at $\omega = 1$.

The predicted values of ω for the minimum of F(e) are
values just mentioned, which are shown in Figure 2.
differing slightly depending on the value of ω .
as ω^{-1} , then from roughly 10^{-1} to 10^0 the value of ω is
then returns to an ω^{-1} dependence at large distances.

In agreement with the experimental results, the calculated
characteristics of the electron beam are shown in Figure 3.
to 60° , could also be used to find the value of ω for
smaller particles. The calculated values of ω for the
the most effective particles in the electron beam are
presented in Table 1. The values of ω are shown in Figure 4.

Chapter 5 in Section 1.
By assuming that the electron beam follows an
law of $\omega^{-2.4}$ along the distance, and by using the
theoretical expression for the electron beam, the
which varies as $\omega^{-2.4}$ was used to find the values of
pendences and obtained $\omega = 1.5$ for $\omega = 1$, which

determined the particle size distribution of the electron beam.
considerably lower than would be expected from the
of electron beam size is very small. The
meteor distribution is shown in Figure 5. The
p for very large meteoroids is shown in Figure 6.

more small dust particles than would the density law of van de Hulst.

In order to estimate the albedo of the particles, the reflection region of 60 to 90° elongation is considered. The integrated expression for the column brightness using Lamberts law is equated to an assumed approximate intensity variation of $1.0 \times 10^{-7} e^{-1}$ in this region. The upper limit of particle radius is taken as 0.035 cm. The resulting albedo is 0.005. This value appears quite low when compared to minerals or even to basalt rock with an albedo of 0.08.

A comparison of the theoretical dust density and the observed meteor particle density with similar radii, shows the dust is about 10,000 times more abundant. This discrepancy can only be explained by assuming the major portion of the dust particles revolve about the sun in direct orbits which do not allow meteor velocities to be attained when and if a dust particle collides with the earth's atmosphere.

c. THE WORK OF ELSASSER. Elsasser (72) developed a model Fraunhofer corona using a minimum of arbitrary assumptions. The great majority of his results apply only to the corona region and hence no detailed description of their derivation will be given; however, the inferred particle properties should apply to the zodiacal light region also.

A density law of the form of Equation 2, section E-2 is assumed, with a particle cut-off, due to vaporization, at

more small particles than the larger ones.
Hence.

In order to estimate the amount of particles
reflected from the surface of the planet, we
integrated expression for the number of particles
law is applied to an assumed spherical planet
 $1.0 \times 10^{-7} e^{-1}$ in this region. The value of the
radius is taken as 0.03. The value of the
This value appears since the number of particles
to particle rock with an amount of 0.03.

A comparison of the calculated and observed
observed meteor particle density with the
that is about 10,000 times more. This is
only be explained by assuming the major portion of the
particles revolve about the planet in orbits which
allow meteor velocities to be calculated from the
particle collisions with the earth's atmosphere.

c. THE WORK OF L. J. L. L. L.

model of the solar corona and the solar wind.
The great majority of his results apply to the solar region
and hence no detailed description of his work will be
given; however, the latest results are reported in a paper
to the National Academy of Sciences.

A density law of the form $\rho = \frac{1}{r^2}$ is
assumed, with a particle density of 10^8 per cm³ at

distances of less than 0.4 au. The exact Mie scattering functions are approximated in the corona region, and particle radii ranging between 3×10^{-4} and 3×10^{-2} cm are assumed. The brightness integral is evaluated for p values of 3.5, 3.0, 2.5, 2.2, 2.0, and 1.8. The best agreement is for a p of about 2.0.

The albedo of the dust particles was determined in the following manner. Since the particle space density was assumed constant, the number/cc of dust particles of minimum radius a_1 could be determined by equating the observed and calculated intensities for a given point in the corona. Behr and Siedentopf, assuming an albedo of unity, had calculated a minimum-particle density from their zodiacal light measurements. Thus γ could be calculated as the ratio of the corona particle density to the zodiacal light density. These calculations were made for several choices of minimum and maximum particle radius. Albedos of 0.002 to 0.02 were obtained. It was then concluded the particles were metallic, namely iron of specific gravity 7.5.

Again as in van de Hulst's case, very low albedos are determined theoretically. Since such values are rather implausible, both authors advance arguments which would justify higher albedos of about 0.1. The fact that the zodiacal light source is assumed to be sunlight scattered by dust, would also require albedos which at least approximate the terrestrial minerals and stones.

d. THE WORK OF BEARD. To derive all of the pertinent parameters, Beard (71) solved the brightness integral for the F-corona in a very general manner. He employed a minimum number of assumptions and approximations.

An argument based upon the Poynting-Robertson effect indicates that all particles of less than about 0.5 microns radius will be swept out of the solar system by radiation pressure, while larger particles will be slowed down and tend to spiral into the sun. According to Whipple (73) this latter effect produces a constant flux of particles impinging upon the sun. If the dust orbits were circular as is required by a prolonged action of the radiation deceleration, a dust density variation of r^{-1} would be indicated; if the orbits are highly elliptical, a dust density variation approaching r^{-2} would be expected. In view of these considerations it was concluded that the range of q is between 1 and 2, and most probably close to 1.5.

Beard expanded the brightness integral as a twelve-term power series. This twelve-term series was reduced to three valid terms by introducing the observed intensity versus elongation dependence. A further condition, set by the constant coefficient of the leading term of the series, requires that a_1 be greater than 0.1 micron; but if both the series expansion and the particle size requirements of the Poynting-Robertson effect are to be valid, a_1 should be larger than 1 micron. In addition an upper limit, set by the series representation of the observed

intensities requires that a_1 be less than 5 microns. Then with valid ranges of the parameters q and a_1 , p is required to be greater than 2.5. If p is about 2.5 then the dust albedos must be less than 0.01. The albedo can be validly raised by requiring a p value greater than the minimum of 2.5. Very low values of albedo have previously been determined by van de Hulst and Elsasser.

In the zodiacal light region, at an elongation of 90° , the theoretical and observed intensities are equated. Then assuming an albedo of 0.1 and an a_1 of a few microns, p again must be greater than 3, and preferably 3.5, if satisfactory theoretical results are to be obtained.

With parameter values of p about 3.5, q about 1.5, and a_1 about 2 microns, and with the observed and the theoretical intensities for a given point in the corona equated, particle densities of about $10^{-14}/\text{cc}$ are predicted. The predicted density is therefore from 2 to 10 times the densities obtained by Allen, van de Hulst and Elsasser.

Theoretical relative zodiacal light intensities were calculated for several phase functions, and for assumed q values of 1.0, 1.5, and 2.0. The intensity values obtained for a q of 1.5 produced the best accord with observations.

The following table lists the values for the various parameters as determined or assumed by Allen, van de Hulst, Elsasser and Beard. In the Table a dagger '†' indicates an assumed

intensities reported that a ...
valid ranges of the parameters ...
greater than 2.5. If it is ...
be less than 0.01. The ...
and a value greater than ...
of albedo are previously ...
Alas, ...
in the ...
the ...
assuming an albedo of 0.1 and ...
must be greater than 3, and ...
theoretical ...
with parameter values of ...
at about 2 microns, and with the ...
intensities for a given ...
densities of about 10^{-10} ...
density is therefore from 2 to 10 ...
by Allen, van der ...
theoretical relative ...
calculated for several ...
of 1.0, 1.5, and 2.0. The ...
1.5 produced the best ...
The following table ...
parameters as determined ...
Alas, and ...

rather than a calculated value.

TABLE I
PARAMETER VALUES

	p	q	a_1	albedo	N/cc at 1 au
Allen	0.1	1	10'	0.14'	3×10^{-15}
van de Hulst	2.5	0'	0'	0.005, 0.1'	5×10^{-15}
Elsasser	2.0	0'	2	0.01, 0.1'	$5-10 \times 10^{-14}$
Beard	3.5	1.5	2-3	0.1	10^{-15}

In unpublished work, Beard has shown that the interplanetary dust should move toward the ecliptic plane because of the combined gravitational attraction of all the inner planets. He predicts a dust velocity toward the ecliptic plane roughly proportional to the square root of the particle distance from the ecliptic plane. The Poynting-Robertson effect results in a decrease in the particles orbital eccentricity according to Wyatt and Whipple (74). The net result is to have dust moving in orbits closely approximating that of the planets, which in turn produces a particle flux toward each planet because of gravitational capture. An expression was developed for the particle density as a function of distance from the earth. This expression indicates that the dust density near the earth should be about 1000 times that of free space. This prediction agrees well with the micrometeorites measured by the Explorer 1 satellite.

Beard argues that each planet should be accompanied by a "dust blanket". Hoffmeister, who claims the zodiacal light axis is determined by the orbits of the nearer planets, is cited to support this view. Planetary dust blankets would indeed complicate the interpretation of zodiacal light results in as much as it would require the ability to distinguish between those effects produced by a terrestrially centered cloud and those produced by irregularly distributed interplanetary matter.

A terrestrial dust cloud would, however, aid in the interpretation of the gegenschein horizontal parallax of 3.5° which has been reported by Soviet workers. It would also present a more pleasing explanation of the so-called zodiacal light twilight, and the false zodiacal light which Fesenkov attributes to an atmospheric tail associated with the earth.

3. POLARIZATION STUDIES

a. THE WORK OF WHIPPLE AND GOSSNER. Whipple and Gossner (75) calculated an upper limit to the concentration of free electrons near the earth's orbit. Under the assumptions that the zodiacal light is scattered sunlight, that the polarized component arises solely from electron scattering, that the electron density decreases with solar distance, and that no other scattering processes add or detract from the electron polarization, Whipple and Gossner set up a brightness integral using the Thomson scattering function for free electrons. They assumed a space density law for the electrons similar to Equation

Heard argues that each planet should be accompanied by a "true planet". Hoffmann, who claims the solar system is determined by the orbits of the major planets, is also to support this view. Planetary mass planets would indeed support the interpretation of a solar light system as well as it would require the ability to distinguish between those effects produced by a substantially scattered cloud and those produced by irregularly distributed interplanetary matter. A terrestrial dust cloud would, however, aid in the interpretation of the geostrophic potential function at 3.5° which has been reported by several workers. It would also provide a more pleasing explanation of the so-called solar light light, and the solar radiation light which is associated with the solar atmosphere and associated with the earth.

3. POLARIZATION STUDIES

a. THE WORK OF WHIPPLE AND GOSSETT. Whipple and Gossett (1955) calculated an apparent limit of the concentration of free electrons near the earth's orbit. Under the assumption that the solar light is scattered sunlight, that the polarized component arises solely from electron scattering, that the electron density decreases with solar distance, and that no other scattering processes are or depend from the electron polarization, Whipple and Gossett set up a brightness integral equation. The Thomson scattering function for free electrons. They assumed a space density law for the electrons similar to equation

2 of section E-2-b. Their brightness integral has a particularly simple analytic form for relative intensities $i(e)$,

$$i(e) = \frac{1}{2 \sin^{p+1} e} \int_e^{\pi} (1 + \cos^2 \theta) \sin^p \theta \, d\theta$$

and since (polarized light) / (total light) is equal to $\sin^2 \theta / (1 + \cos^2 \theta)$ the integral for the relative polarized component $i_p(e)$,

$$i_p(e) = \frac{1}{2 \sin^{p+1} e} \int_e^{\pi} \sin^{p+2} \theta \, d\theta$$

The integrals were evaluated in the range of elongation from 5 to 180° for p values of 1, 2, and 3. Each case showed a polarization which slowly rose from 50 to 70% at 0° , up to a maximum of 60 to 75% at about 60° , and then dropped rapidly to zero at 180° . When plotted against elongation, the polarization for all three cases show a trend similar to the trend displayed by the early measurements of Dufay, although the polarization values are larger by a factor of 4 to 5. The maximum of polarization at 60° elongation is also exhibited by the recent work of Divari and Asaad but not by either the work of Behr and Siedentopf or that of Elsasser and Siedentopf.

From the known polarization measurements of Dufay, a ratio of the observed and calculated polarizations gives the fraction of the zodiacal light due to electron scattering. The relative polarized intensities $i_p(e)$ are related to the absolute intensities by a constant involving such factors as the brightness

2 of section 1-2-4. The following is a summary of the simple analysis for the relative polarization (19).

$$i(e) = \frac{1}{2 \sin^2 \theta} (1 - \cos^2 \theta)$$

and since (polarized light) is equal to $i(e)$ (1+cos²θ) the integral for the relative polarization is $i_p(e)$.

$$i_p(e) = \frac{1}{2 \sin^2 \theta} (1 - \cos^2 \theta)$$

The integrals were evaluated in the range of angles from 0° to 180° for p values of 1, 2, and 3. The case shown in Figure 1 which slowly rose from 50 to 70 at 0°, and then dropped rapidly to zero at 180°. When plotted against elevation, the polarization for all three cases show a trend similar to the trend observed in the early measurements of Data, although the polarization values are larger by a factor of 4 to 5. The variation of polarization at 0° and 180° is also explained by the reason work of Gershwin and Gershwin by either the work of Gershwin and Gershwin or that of Gershwin and Gershwin.

From the known polarization measurements of Data, a ratio of the observed and calculated polarizations giving the fraction of the scattered light due to electron scattering. The relative polarization $i_p(e)$ was related to the scattering intensities by a constant involving a factor of 1/2.

of the sun, the solid angle in which the brightnesses are to be expressed, the electron scattering cross-section, and the electron density. All factors save the electron density have known numerical values. Hence division of the scattered light due to electrons by the above mentioned constants allows the electron density to be determined. It is assumed the electron density determined for an elongation angle of 90° represents the value at the earth's orbit. For the p-values of 1, 2, 3, electron densities of 800, 900, and 1000/cc are obtained and are regarded as the maximum possible values at the earth's orbit.

The section of Whipple and Gossner's work dealing with polarization by small particles seems to have been generally overlooked by the workers in this field. The conclusion reached, that the majority of the zodiacal light polarization could be explained by reflection from solid particles, seems to have been ignored in favor of the simpler analytic possibilities rendered by electron scattering.

Polarization measurements, of various minerals and rocks with albedos around 0.1, given in Lyot's thesis were extensive enough to allow the brightness integral to be numerically evaluated for elongations of 90° and 60° . Lambert's phase law for diffuse reflection was assumed in the calculation. For distribution laws of $1/r$, $1/r^2$, and $1/r^3$, polarizations of around 8, 10, and 11% were found at an elongation of 90° . The calculated polarization at an elongation of 90° in all cases was

 

larger than Dufay's observed 2.5%. Later work has revised the observed polarization upward to between 15 and 35%.

At 60° elongation polarizations in the 9, 12, and 15% range were obtained and compared with Dufay's value of 15%. Latest measurements give 20 to 25%.

b. THE WORK OF RENSE. Rense (76) used experimentally determined reflection and polarization data from actual meteorite samples in a calculation of the expected polarization and intensity of the zodiacal light. The optical properties of the meteorites were taken from a study by Kloverstrom and Rense (58).

A dust density variation of $1/r$ and the phase function for a spherical planet, which closely approximates the average reflection properties to the meteorites, were assumed in the calculation. The phase function has the form $(1 + \cos 2\phi) / 2$, where ϕ is the angle of observation with respect to the sun's direction, i.e., the supplement of the scattering angle. A graphical integration of the brightness integral was performed for the range of elongations from 30° to 90° .

The total relative intensity variation was compared to the averaged zodiacal light measurements of Elvey and Roach. The agreement was quite good. Dufay's polarization measurements were corrected for night-sky dilution; the result at 60° elongation was 22% which is about the value of present measurements. The predicted polarization curve agrees very well with the form and

Reims (58).

magnitude of Dufay's corrected curve.

This study indicates that no free electron component in the interplanetary medium is required for an explanation of the large polarizations observed in the zodiacal light.

c. THE WORK OF FESENKOV. Fesenkov (77) under the assumption that an electron component is superfluous, argues that the entire polarized zodiacal light component is adequately explained if the scattering particles are identified with the dust particles in the earth's upper atmosphere.

He calculates expected polarizations for an electron cloud surrounding the sun using density laws with $q = 0, 1, \text{ and } 2$. His results are identical to those of Whipple and Gössner for the same calculations. Fesenkov further argues that if one accepts the predicted 60% polarization for the $1/r$ law, then electron scattering can at most contribute about 50% of the total observed zodiacal light. But he further asserts that if one accepts the present electron density value of 600/cc at the earth's orbit, the entire zodiacal light illumination is accounted for and no dust component at all is needed. This view is substantiated by a sample calculation of the total intensity of the zodiacal light as being due to electrons only. Leaving the electron density unspecified but evaluating the brightness integral at an elongation of 45° yields $j(45^\circ) = 1.7 \times 10^{-2} N$, where j is the brightness expressed in number of fifth magnitude stars/square degree, and N is the electron density in number/cc. The

magnitude of 3.4 at a distance of 100 km.

This study indicates that the seismicity is concentrated in the

the tectonically active region in the area of the earthquake.

Large earthquakes are observed in the central part of the

the area of the earthquake. The results of the study are

assumed that the seismicity is concentrated in the area of the

the seismicity is concentrated in the area of the earthquake.

explained in the section on the seismicity of the area.

that recorded in the area of the earthquake.

the earthquake is concentrated in the area of the earthquake.

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2. The results are consistent with the results of the earthquake.

for the same earthquake. The results of the earthquake are

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electron spectrum is concentrated in the area of the earthquake.

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ed for and no other observation is concentrated in the area of the earthquake.

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electron spectrum is concentrated in the area of the earthquake.

total at a distance of 100 km. The results of the earthquake are

It is the earthquake spectrum is concentrated in the area of the earthquake.

separate degree, and it is the earthquake spectrum is concentrated in the area of the earthquake.

total zodiacal light brightness at 45° elongation is about 7 of these units, and the resulting electron density turns out to be only 410/cc. Thus Fesenkov is able to explain the entire zodiacal light brightness with fewer electrons/cc than other investigators have derived from the polarized component only.

The fact that dust can polarize light by reflection is based upon several experimental results according to Fesenkov. He cites daytime atmospheric polarizations which are too high to be accounted for by Rayleigh scattering alone, and attributes the excess to dust aerosols. He also cites observations of the comet Arend-Roland which exhibited 10 to 20% polarizations for various portions of the comet.

The peculiar vertical distribution of atmospheric aerosols, a decreasing concentration with altitude, then a steady increase above 4 to 5 km, leads Fesenkov to identify them as cosmic dust being precipitated upon the earth from space.

The Soviet expedition to Egypt made extensive observations of the daytime sky polarization on the same almucantar as the sun. When the sun was near the horizon, between 10 and 20° elevation, the major portion of the sky illumination could be assumed to originate in the upper layers of the atmosphere. When the observed polarization, as a function of azimuth from the sun, was corrected for the polarization due to Rayleigh scattering, the remainder could be ascribed to dust polarization.

In this way the scattering function for the atmospheric aerosols was evaluated. Since the observations were made from a very arid desert, it was assumed that the aerosols were dry and not water coated as with condensation nuclei.

This aerosol scattering function was then identified with that of cosmic dust, and predicted zodiacal light polarizations were calculated assuming a $1/r$ dust density variation. Values of 25.8, 27.9, and 27.8% were obtained for elongations of 30, 60, and 90° respectively. It was concluded that if the dry aerosols are identified with cosmic dust, then the aerosol scattering function adequately predicts the zodiacal light polarization.

A concluding remark indicates that the observations were corrected for atmospheric extinction using Bouger's secant law, but that ozone absorption was neglected in determining the optical thickness of the earth's atmosphere. If account is taken of ozone absorption then the aerosol polarizations and consequently the predicted zodiacal light polarization will be smaller than stated.

The zodiacal light polarization curve predicted by this theory is characterized by a broad maximum with considerable polarization at all elongation angles. The shape of the curve is such that it would not join the theoretical polarization curves for the solar corona which have been extended out to the zodiacal light region, nor would it join Blackwell's small-

In this way the scattering function for the
suspension was evaluated. It was found that the
a very wide band, it was found that the
and not water, as was expected, on the basis of

This result shows that the scattering is due to
with that of osmium tetroxide, and the results
izations were calculated assuming a 10% concentration of
Values of 25.5, 27.5, and 29.5 were obtained for
of 30, 60, and 90 magnitudes. It was observed that the
dry aerosols are associated with water, and the
scattering function was calculated for the
polarization.

A conclusion from these results is that the
corrected for atmospheric extinction, the results are
but that some absorption was neglected. It is
optical thickness of the film is 0.1. It is
taken of osmium tetroxide film was 0.1. It is
consequently the calculated results are in good
agreement with the results.

The method of a film of osmium tetroxide
theory is characterized by a constant value of
polarization at all angles of incidence. The
is such that it would be expected that the
curves for the other cases would be similar to the
osmium tetroxide case.

elongation zodiacal light measurements (Figure 2).

The identification of upper atmospheric aerosols with cosmic dust appears quite well founded. Beard's theory indicated cosmic dust should move toward the earth and be captured by it. The capture process can occur either as a meteor disintegration or, for very small dust particles, a non-destructive braking can take place and leave the particle intact. Either process provides a steady flux of small particles which drift slowly through the earth's atmosphere.

4. SOURCES OF THE COSMIC DUST

a. INTRODUCTION. It is interesting to investigate the possible sources of the cosmic dust which gives rise to the zodiacal light. Since the Poynting-Robertson effect and radiation pressure require that the dust particles either spiral into the sun or leave the solar system, the proposed dust source must be one capable of a steady-state creation to off-set the continuous loss of material. Several possible sources of dust may be listed, 1) solar capture of interstellar particles, 2) condensation of interplanetary gases, 3) collisional fragmentation of asteroids, and 4) ejection and/or disintegration of cometary matter. Only the last two processes have been examined in detail, and these will now be discussed.

b. THE WORK OF WHIPPLE. Whipple (73) proposed to explain the constant flux of cosmic dust necessary to sustain the zodiacal cloud as matter ejected from comets. Using his

The ... of ...
cosmic dust ...
dissolved cosmic dust ...
captured by ...
meteor ...
non-destructive ...
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particles ...

4. SOURCES OF THE COSMIC DUST

a. INTERSTELLAR

the possible sources of the cosmic dust ...
cosmic dust ...
radiation ...
spiral ...
dust sources ...
off-set ...
sources of dust ...
particles ...
at fragmentation ...
formation of secondary ...
been examined ...

b. THE SUN AND SOLAR WIND

explain the ...
the ...

icy-conglomerate comet model which had previously been shown capable of ejecting matter, he estimated that all comets should contribute about 30 tons/second of meteoritic material, and approximately 100 tons/second of gases, to the interplanetary medium.

The Poynting-Robertson effect was shown to reduce the dust orbit eccentricities, and in time, to force the particles into nearly circular spiral orbits which eventually lead to their vaporization near the sun. On this basis a dust density variation of $1/r$ near the sun is predicted. At moderate distances it is assumed a $1/r^2$ variation will set in to prevent an excessive dust mass in the solar system.

The total brightness of the F-corona and the zodiacal light is estimated. As a result of the Poynting-Robertson effect and the known amount of sunlight scattered, the mass of dust spiraling into the sun per unit time can be estimated. A value of one ton/second is found. It is concluded that comet dust ejection is adequate to supply the steady-state mass flux required to maintain the zodiacal light and F-corona.

Since most periodic comets move in low inclination (median 15°), direct orbits, the particles ejected will be placed in suitable orbits for the formation of a dust cloud which should approximate the zodiacal cloud quite closely.

The remainder of this extensive study examines the dynamical aspects of the dust particles motion in interplanetary

icy-conglomerate comet model which had previously been
capable of ejecting matter, he estimated that all of the
contribute about 30 tons/second of meteoritic material, and
approximately 100 tons/second of gases, to the interplanetary
medium.

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dust orbit eccentricities, and in time, to force the particles
into nearly circular spiral orbits which eventually lead to
their vaporization near the sun. On this basis a dust density
variation of $1/r$ near the sun is predicted. As eccentricities dis-
cussed it is assumed a $1/r^2$ variation will set in to prevent an
excessive dust mass in the solar system.

The total brightness of the Z-dust and Z-comet

light is estimated. As a result of the Poynting-Robertson
effect and the known amount of sunlight scattered, the mass of
dust spiraling into the sun per unit time can be estimated.
Value of one ton/second is found. It is concluded that
dust ejection is adequate to supply the steady-state mass
required to maintain the zodiacal light and Z-comet.

Since most periodic comets move in low inclination
(median 15°), direct orbits, the particles ejected will be
placed in suitable orbits for the formation of a dust cloud
which should approximate the zodiacal cloud plane which
The remainder of this extensive study examines the
dynamical aspects of the dust particles within the interplanetary

space. No attempt was made to calculate theoretical isophotes for the zodiacal light.

c. THE WORK OF FESENKOV: Fesenkov has closely examined the possibility that asteroid collisions and the consequent fragmentation would contribute an adequate supply of dust to explain the zodiacal light. An early paper on this subject (78) in 1943 established only that the dust density should vary as $1/r$ from the sun with a ring of dust in the asteroid belt. The dust cloud was assumed to explain the main zodiacal light pyramid while the asteroid belt dust ring explained the light bridge.

Fesenkov's later paper (79) advances arguments in support of the asteroid-dust hypothesis. The age of meteorites, determined by their Helium-3 content, has indicated in all cases an age much less than that of the solar system. On the basis of this fact, it is argued that such meteorites were until recently part of a much larger body, and were not subject to irradiation by cosmic rays which produce the Helium-3. Arguments against an electron component, similar to those used in his work reviewed in section E-3-c, are advanced.

Theoretical isophotes for the zodiacal light are calculated using an empirically determined frequency function for the asteroid orbital inclinations with respect to the ecliptic. Two scattering functions for the dust were assumed i.e., totally reflecting spheres and the atmospheric aerosol function which

was determined experimentally. A $1/r$ dust density law was used.

The resulting theoretical isophotes appear considerably narrower than those observed. The isophotes calculated using the atmospheric aerosol scattering function are wider than those for the totally reflecting spheres and consequently resemble the true zodiacal light isophotes more closely.

These calculations are based upon the implicit assumption that the dust produced by the asteroid collisions retains the same distribution of orbital inclinations as the asteroids. If one accepts the calculations of Beard which predict the dust will gravitate toward coincidence with the ecliptic plane, then the steady-state situation would appear to require a smaller range of orbital inclinations for the dust than for the parent asteroids. If the stated situation prevailed, then either the theoretical isophotes should be still narrower or some other dust producing mechanism should be called upon to produce dust in high inclination orbits.

Whipple's paper states Piotrowski (80) has examined the asteroid dust problem and has concluded that it is adequate to supply the quantity of dust for the steady-state zodiacal cloud.

5. SUMMARY. The theoretical works which explain the zodiacal light intensity all center upon the evaluation of a single integral expressing the surface brightness of the zodiacal light as a function of angular distance from the sun

was determined experimentally. A 100-gram sample of the material was heated in a vacuum oven at 100°C for 24 hours.

The resulting material was then heated in a vacuum oven at 100°C for 24 hours. The material was then heated in a vacuum oven at 100°C for 24 hours. The material was then heated in a vacuum oven at 100°C for 24 hours.

These calculations are based on the assumption that the first product of the reaction is a solid. The same distribution of crystal sizes is assumed for the reaction. One accepts the assumption of a solid which is a solid. Will crystals form in a vacuum oven at 100°C? The steady-state situation would be a solid. The range of crystal sizes is assumed to be the same. Asteroids. If the solid is a solid, then the range of crystal sizes is assumed to be the same. Theoretical isotherms are assumed to be the same. Dust producing reactions would be the same. In high insulation of the.

Whipple's paper states that the material is a solid. The asteroid is a solid and the material is a solid. To supply the quantity of dust for the reaction.

cloud.
5. SUMMARY. The phenomenon of dust production by the asteroid is a solid. The phenomenon of dust production by the asteroid is a solid. The phenomenon of dust production by the asteroid is a solid.

along the ecliptic. The parameters in the "brightness" integral are usually based, at least in part, upon intensity measurements of the solar corona rather than upon the zodiacal light alone.

In the zodiacal light region the parameters are best expressed by ranges in value because of the experimental uncertainties. Thus the dust density (Equation 2) may be taken to vary with solar distance as $1/r$ to $1/r^2$, i.e., a q value of between 1 and 2 with a value of 1.5 quite probable. The exponent p in Equation 2, which sets the relative number of particles of a given radius, has been given values from 0 to 3.5 with the latter value more closely resembling experimental results obtained from meteor observations. The minimum particle radius for any semi-permanent member of the solar system is in the 1 to 5 micron range and probably about 2 microns. Most calculated particle albedos are very low, 1% or less. Beard overcame this difficulty by taking p larger and obtains an albedo of about 10%. The number of particles/cc is most probably within one decade of $10^{-15}/\text{cc}$.

Calculations expressing the polarized component as due exclusively to scattering of sunlight by free electrons give very large polarization values. At most, less than half of the observed zodiacal light intensity can be ascribed to electron scattering, even assuming no polarization arises from the dust component. A large mass of data from comets, meteorites, and upper atmospheric dust indicates solid particles can and do

reflect enough partially polarized light to adequately explain the polarized component of the zodiacal light.

Sources that may replenish the continuous depletion of the zodiacal dust have been examined. Collisional fragmentation of asteroids and ejection of dust from comets have both been found to be adequate dust sources. Theoretical isophotes based upon asteroid dust have been calculated and do reproduce the general shape of the zodiacal light pyramid.

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CHAPTER III

THE ZODIACAL LIGHT RECORDER AT CAPILLO PEAK

A. DESCRIPTION OF THE RECORDER. A block diagram of the recorder is presented in Figure 4. An equatorially mounted Schmidt telescope, with a photomultiplier tube located at its focus, automatically performs a predetermined number of sweeps completely across the sky along equally spaced parallels of declination. A photocurrent, corresponding to the sky brightness in the photomultiplier's field of view, is amplified and metered by the dc amplifier. The background suppressor permits the zeroing of the oscilloscope spot at a known signal voltage corresponding to that obtained from the faintest part of the sky which is surveyed. The deflection amplifier causes the signal, from the minimum value to the maximum value in the survey region, to deflect the trace completely across the oscilloscope screen. The position of the trace with respect to a set of illuminated fiducial markers is continuously photographed on a rotating drum by the recording camera. The axis of rotation of the drum coincides with the polar axis of the telescope, and the drum participates in the sweeping motion of the telescope. After each scan across the sky the camera lens is shifted axially by a constant amount. Thus each survey of the sky results in a map of the sky being plotted in terms of intensity versus position.

THE CONTACTAL LIGHT RECORDER AND CAMERA

A. DESCRIPTION OF THE RECORDER

The recorder is presented in Figure 1. It consists of a Schmidt telescope, with a photographic camera attached to the eyepiece, automatically providing a photographic record of the sky completely across the sky along any great circle of declination. A photoconductor, corresponding to the sky brightness in the photomultiplier's field of view, is utilized and metered by the dc amplifier. The amplifier's output permits the setting of the oscilloscope at a known signal voltage corresponding to that obtained from the instrument prior to the sky which is surveyed. The relationship between the signal, from the amplifier, and the oscilloscope is the survey region, to define the lines of declination across the oscilloscope screen. The position of the lines is always a set of illuminated lines, the position of which is photographed on a rotating drum by the camera. The axis of rotation of the drum coincides with the polar axis of the telescope, and the drum is equipped with a recording medium of the telescope. After each hour's observation, the drum is shifted axially by a constant amount, so that the sky results in a map of the sky in terms of intensity versus position.

Fig. 4 Block Diagram of the Recorder

B. THE LIGHT COLLECTOR. Sky light to be measured is collected with a 16-inch f-0.75 Schmidt camera. The wide field characteristics of this type of camera are not used in the present application. A photomultiplier mask restricts the field of view to about 1° in diameter. Only the central 16-inches of the 24-inch primary mirror are utilized for this reason. Photographic star images in the center of the field of this camera have a diameter of about $1/32$ inch which is much smaller than the $7/32$ inch diameter photomultiplier mask used; therefore, no calibration error can arise by not having all of the light from a calibration star enter the photomultiplier mask.

C. THE EQUATORIAL MOUNTING. A double yoke mounting was chosen to facilitate carrying the heavy (650 pounds) Schmidt camera. Four-inch aluminum channel irons were used for most of the construction. The south-polar axis, bearings, driving gears, and housing were taken as a unit from a dismantled 60-inch searchlight. The south pier of the mounting is incorporated in the north wall foundation of a 6 by 8-foot observing shed. The shed encloses the right ascension drive gears and the recording camera. A slow-motion right ascension hand wheel and the film drum are easily accesible. A 187.5 RPM, $1/70$ horsepower motor with suitable gear reduction drives the telescope in right ascension. A sweep completely across the sky takes about one minute.

A sidereal rate drive was constructed so that direct photographs could be taken. Its synchronous motor is driven at the true sidereal rate by a frequency standard with a 60.164 cycle per second output. The output shaft of the sidereal motor is connected to the scanning motor shaft through an adjustable, cork-lined friction clutch. The scanning motor remains attached to the gear train at all times whereas the sidereal motor was engaged only for direct photography. A hand-wheel was also attached to the gear train which allowed the telescope to be moved manually by small amounts. This permitted stars to be located and followed easily when star intensity readings were taken.

The telescope is driven in declination by a 187.5 RPM motor through a gear train which ends as a 60-tooth worm wheel on the declination axis. Since one revolution of the worm gear provides 6° motion in declination, a two notch cam attached to the worm shaft for actuating a micro-switch makes 3° steps possible. Declinations are relayed to the observer inside the shed by two synchro transmitters. Declination settings could be read to about 0.1° . The drive in declination was relatively slow, taking about one minute for 36° rotation.

D. THE PHOTOMULTIPLIER. The light sensing element is an RCA 5819 photomultiplier tube with type S-4 response (38). The photomultiplier is carried in an aluminum housing which replaces the focusing adjustment and plate holder of the Schmidt camera.

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photographs could be taken. The ...
at the time sideral rate of ...
cycle per second ...
motor as connected to the ...
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The telescope as ...
motor through a gear ...
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slow, taking about one ...

B. THE PHOTOGRAPHIC ...
KOA 519 photographic ...
photometer. It is ...
the focusing adjustment and ...

The entire tube envelope is tightly wrapped with four layers of mu-metal. A jumper from the cathode places this magnetic shielding at a high negative potential and thus provides electrostatic shielding. A further magnetic shield, also four layers of mu-metal, is placed around the inside of the photomultiplier housing. Tests indicated no noticeable effect due to motion or orientation of the photomultiplier in the earth's magnetic field.

A copied version of a John Fluke model 404-m stabilized high-voltage power supply provided power for the photomultiplier. Dynode potentials were taken from a bleeder using 100K, 1%, precision wire-wound resistors. The photomultiplier was normally operated at 1000 volts.

The photomultiplier proved to have an abnormally low dark-current. After an hour warm-up it was about 2×10^{-10} amp and, after several hours use, values as low as 0.8×10^{-10} amp were noted. With such low dark-current it was entirely feasible to use a 10-megohm load resistor.

The response time of the photometer could be varied over a wide range by switching different capacitors across the photomultiplier load resistor. Eleven different capacitors were used but most recordings were made with a response time of 0.05 second.

The cone of acceptance of the photomultiplier is set by a circular mask in the focal plane of the telescope. All of the analyzed recordings were made with a mask aperture of 0.219 inch,

The entire same envelope, a slightly smaller 1.5 inch by 1.5 inch
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ing at a 1.5 inch by 1.5 inch, placed over the envelope
envelope, a 1.5 inch by 1.5 inch, placed over the envelope
metal, is placed around the envelope, a 1.5 inch by 1.5 inch,
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A 1.5 inch by 1.5 inch, placed over the envelope
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Dyode rectifier, a 1.5 inch by 1.5 inch,
protection, a 1.5 inch by 1.5 inch,
ally operated at 1000 volts.
The protection, a 1.5 inch by 1.5 inch,
data-curve, a 1.5 inch by 1.5 inch,
and, a 1.5 inch by 1.5 inch,
were noted, a 1.5 inch by 1.5 inch,
to use a 1.5-inch lead resistor.
The response time of the envelope, a 1.5 inch by 1.5 inch,
a wide range of switching, a 1.5 inch by 1.5 inch,
multiplication, a 1.5 inch by 1.5 inch,
but most responses were with a 1.5 inch by 1.5 inch,
second.
The control, a 1.5 inch by 1.5 inch,
differential, a 1.5 inch by 1.5 inch,
analyzed recordings with a 1.5 inch by 1.5 inch.

resulting in a field of view of 1.04 degree in diameter. Two mounted color filters could be slid back and forth in front of the photomultiplier mask by a motor driven lead screw. A second interchangeable filter mount provided two additional filters. The motion of the filter mount was controlled by two micro-switches on the filter changer. They stopped the motor and reversed the leads after each operation. Thus filters could be changed from inside the observing shed by means of a switch.

E. THE SIGNAL AMPLIFIER. The signal voltage at the photomultiplier load resistor ranged from about 0.030 to 0.500 volts depending upon the color filter and the area of observation. Amplification of this signal to the level needed for deflection of the oscilloscope trace was accomplished in two steps.

A General Radio model 1230-A dc amplifier and electrometer was used to amplify and monitor the signal. This unit is essentially a very stable, very sensitive, vacuum-tube millivoltmeter. The scales of 30, 100, 300, and 1000 millivolts were frequently used. The manufacturer claims the meter readings are accurate to 2% of full scale on all but the 30 mv scale where it is 4% of full scale. Variable input impedances from 10^4 to 10^{14} ohms are available. The zero drift is extremely small, and of the order of 1 mv per hour. The meter movement requires 5 ma for full scale deflection with provision for an additional

Fig. 5 Background Suppressor and Deflection Amplifier

series load of 1500 ohms. A 1000 ohm series resistor provides a 5 volt signal for driving the deflection amplifier.

F. THE BACKGROUND SUPPRESSOR AND THE DEFLECTION AMPLIFIER. The circuit diagram in Figure 5 shows the background suppressor and the deflection amplifier. The output of the General Radio amplifier is connected to the grid of the first 12AX7 triode. The circuit is a cathode follower with a variable cathode resistor. A constant cathode current source is supplied by the second section of the 12AX7. The 11-pole switch and the 10K potentiometer allow a wide, continuous range of input potentials, to be set at the zero deflection position on the oscilloscope screen. The 11-position deflection gain control allows a wide selection of potential changes to cause full-screen deflection of the oscilloscope trace. The deflection amplifier is taken, with modifications, from Volume 18 of the MIT Radiation Laboratory Series (82).

G. THE OSCILLOSCOPE. The oscilloscope consists of a 5AMP11 blue phosphor cathode ray tube operated by a stabilized R-F high-voltage power supply. A saw-tooth voltage generated by a type 974 thyratron tube continuously deflects the spot in the vertical direction. This merely prevents burning the screen phosphor should the spot stand still for any length of time. The signal voltage deflects the spot in the horizontal direction.

The entire cathode ray tube face is covered except for a 1/8 inch wide horizontal slit across the screen diameter.

series load of 100 ohms. The output is taken across
a 5 volt signal for driving the amplifier.

1. THE SIGNAL SOURCE AND THE AMPLIFIER

AMPLIFIER. The signal source is a 5 volt signal
ground reference and the output is taken across
the General Radio amplifier as a 5 volt signal. The
first 12AV triode. The output is a 5 volt signal
variable cathode resistor. A 500 ohm resistor
is supplied by the 5 volt source of the 12AV triode
switch and the 100 ohm resistor. The output is
of input potentials. As we see the 500 ohm resistor
on the oscilloscope screen. The input is 5 volts
control allows a wide range of potential changes to occur
full-screen deflection of the oscilloscope. The output
from amplifier is taken, with a 500 ohm resistor, the output is
the MIT Radio Lab. Report No. 100 (1947).

2. THE OSCILLOSCOPE

SAMPLE plus phosphor cathode ray tube. The output is a 5 volt signal
R-F high-voltage power supply. A 500 ohm resistor is connected
by a type 5A cathode ray tube. The output is 5 volts and is
the vertical direction. The output is 5 volts and is
phosphor coated and the spot size is 1/8 inch in diameter.
The signal voltage deflection is 5 volts. The output is 5 volts
The output is 5 volts and is 1/8 inch in diameter.
1/8 inch wide horizontal deflection is 5 volts.

Nineteen vertical, polished drill-rod segments are glued on the front side of the slit. The rod segments are convex cylindrical mirrors designed to reflect a narrow but bright image of two dial lamps. A second wider slit prevents the recording camera from seeing anything but the oscilloscope trace and the brightly illuminated cylindrical mirrors. When photographed upon the moving film of the recording camera, the mirror images appear as 19 equally spaced fiducial marks.

One advantage of this method of recording is that when the oscilloscope trace moves behind one of the fiducial markers it is temporarily occulted. This interrupted trace allows a very accurate determination of where the trace attains a given signal voltage. A photographic reduction of Recording #54 is shown in Figure 6. The original recording size is 11x14 inches. Uncorrected isophotes have been drawn in as well as the meridian, the horizons, and two lines of constant right ascension.

H. THE RECORDING CAMERA. The purpose of the recording camera is to plot a large-scale map of the sky in terms of intensity and position. Since the telescope scans in right ascension and declination it was desired to have right ascension and declination plotted as a rectangular coordinate system. The method of generating the map consists of attaching a film drum to the telescope mounting polar axis, projecting an image of the oscilloscope face on a small area of the film, and letting the scanning motion in right ascension produce a strip image of the

Fig. 6 Recording No. 54 with Raw Isophotes

fiducial markers and oscilloscope trace. After each sweep across the sky, the camera lens is moved a distance equal to the width of the trace and the return sweep is recorded.

The camera is shown schematically in Figure 7. The lens motor turns a lead screw which moves the lens carriage in milled rails a prescribed distance between scans. Two micro-switches on the lens carriage slow and stop the lens motor. The slowing is accomplished by shunting the lens motor armature with a resistor of low value. The stopping micro-switch is actuated when its roller lever falls into carefully milled slots which are so spaced as to eliminate any parallax displacement of the image.

Because of the earth's motion during each 18-minute recording a further motion must be imparted to the film drum in order to obtain truly orthogonal map coordinates in the equatorial system. The required motion consists of rotating the film drum, to the west, at the same angular speed as the earth rotates to the east. The drum motor (Figure 7) is so geared that the film drum rotates on the polar axis once per sidereal day. A further advantage of the rotating film drum is that an hour scale from 0 to 24 could be added. This provides a sidereal clock. If this scale is set to the local sidereal time while the telescope points toward the meridian, then for any other orientation of the telescope the right ascension for the hour circle at that orientation can be read from the scale.

Fig.7 The Recording Camera

Stars can therefore be easily located without calculating the hour angle with respect to the meridian.

The maps are recorded on 11x14 inch, type A-1 Kodabromide enlarging paper. Only one processing is necessary to produce a positive image map. The map size and surface texture is quite adequate for analysis without further enlargement or processing.

I. THE SEQUENCE TIMER. At the end of each sweep across the sky the telescope must be depressed 3° in declination, the right ascension motor must be reversed, and the recording camera lens must be shifted. It is the purpose of the sequence timer (Figure 8) to perform these operations automatically. Further provisions are made to direct the telescope at individual stars, and to return the camera lens and the telescope to their starting positions.

Two switches, the α -micro and the α -reverse switch, are mounted on the stationary housing of the polar axis driving gears. Two paddles which are spaced about 210° apart on the periphery of the rotating housing actuate the switches at the end of each sweep when the telescope is pointing below the horizon. When the α -micro switch is closed relay 1 closes. Relay 1 is held down by one set of contacts which parallel the α -micro switch. The other set of contacts close the series combination of relays 2, 3, and 4. The parallel contacts of relay 2 remove the power from the α -motor and apply it to the δ -motor. Inertia carries the telescope mounting far enough

Stars can characterize in easily located positions. The stars are observed with respect to the horizon.

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1. First observation. The stars are observed in the same way as in the case of the stars. The stars are observed in the same way as in the case of the stars. The stars are observed in the same way as in the case of the stars.

Two switches, the X-switch and the Y-switch, are mounted on the same assembly. The X-switch is mounted on the same assembly. The X-switch is mounted on the same assembly. The X-switch is mounted on the same assembly.

Fig. 8 The Sequence Timer

Handwritten text, possibly a signature or a date, located in the center of the page. The text is very faint and difficult to read.

to throw the α -reverse switch on the telescope mounting. Relay 3 discharges capacitor C2 through the coil of the stepping relay 5 and advances it one notch. Relay 4 applies power to the lens-motor. Relay 1 is so timed that it opens before the δ -micro switch opens, and thus the δ -motor continues to rotate until it is stopped by the 3° cam-operated δ -micro switch. The lens motor also operates until stopped by its slow and stop micro switches rather than by relay 4.

J. THE RECORDING PROCEDURE. The equipment is warmed up at least one hour before any measurements are taken. For zodiacal light recordings the telescope is directed to the area where the zodiacal light is brightest and the signal voltage read. The telescope is then directed to the darkest area of the sky within the desired survey region. A dc calibration signal is then applied to the input of the signal amplifier and its value set to the minimum sky reading. The background suppressor and oscilloscope are set so that this minimum signal places the oscilloscope trace under the first fiducial marker. By proper adjustment of the deflection gain the maximum signal can be made to deflect the trace across the entire oscilloscope screen. An estimate of the expected increase of zodiacal light intensity is made in the case of morning observations and this value is set for the #19 isophote. After these adjustments the signal voltage for the #1 and #19 isophotes is recorded.

The telescope is then directed below the horizon on the

northernmost declination to be surveyed. The film drum must then be centered accurately so that the entire sky area surveyed is recorded on the map. The α -motor is started by rotating the stepping relay to the #1 position and the entire recording proceeds automatically. The local sidereal time is recorded at the beginning and at the end of the recording, as well as the range in declination, the color filter used, and the #1 and #19 isophote potentials.

K. STAR INTENSITY READINGS. In this study stars of known magnitude and color were used as standards of intensity for calibration purposes. Stars in the range of magnitude from 3.5 to 5 and in spectral classes from A0 to K were used. No star was used for calibration which had neighboring stars brighter than 8th-magnitude in the area equal to the telescope's field of view centered on the star. A background area as near to the star as possible, also containing no stars brighter than 8th-magnitude, was also selected with the aid of star maps. The telescope is directed at the star and at the background area. Signal voltages from both areas are recorded along with the local sidereal time for the observation.

L. POLARIZATION MEASUREMENTS. The polarization of the zodiacal light can be measured by manually rotating a polaroid screen in front of the telescope and measuring the maximum and minimum signal, this method is time consuming and requires two observers. A more refined method consists of mounting the

polaroid so that it can be rotated rapidly at a known angular speed by a motor. The maximum and minimum signals then appear as an ac component riding upon a dc voltage. The ac component can be separately amplified and recorded. Thus the need for a second number to be recorded as well as the need for an additional observer is eliminated.

In the present investigation the polaroid is rotated at one RPS, thus, a two cycle per second ac signal is obtained. The combined signal is amplified and a narrow band two-cycle filter separates the ac signal from the dc. The two-cycle band-pass filter was especially designed and constructed by V. H. Regener (an earlier version of this unit is described in the Master's thesis of R. A. Nobles, University of New Mexico, Physics Department, 1950) for similar polarization measurements in previous work. There are 24 R-C elements (2-megohm, 0.005-mfd.) in a transmission line configuration. Two vacuum tubes, one at the center and one at the end of the line, provide regenerative feedback for the two-cycle signal and degenerative feedback for all other frequencies. The voltage band width of the filter is about 1.5-cycles with the high-frequency transmission dropping to 10% at 5-cycles and the low-frequency transmission dropping to 10% at about 0.2-cycle (extrapolated). Using a sensitive ac millivoltmeter to read the magnitude of the signal, polarization data were recorded manually for a number of points lying along the ecliptic.

M. AUXILIARY EQUIPMENT. Two pieces of auxiliary equipment were constructed for specialized observations.

A fast f-1 camera was constructed to replace the regular camera of the Physics Department's Hilger spectrograph. The camera lens had an equivalent focal length of 1.25 inches and the visible region of the spectrum occupied about 4 mm on the plate. Ansco Super Hypan film with a daylight exposure index of 500 was used. The red and green oxygen lines could be recorded in a 15 minute exposure with a slit width of 0.4 mm. The continuous spectrum of the zodiacal light took two or more hours exposure before darkening the film to a detectable degree. The optical quality of the Kellner eyepiece, which was used for the camera lens, was so poor that slit widths narrower than about 0.2 mm did not add to the spectral resolution.

A transistorized 27-kilocycle atmospheric noise receiver (83) was constructed for the purpose of monitoring solar activity, particularly the occurrence of solar flares. Most relatively intense solar flares can be detected indirectly by a sudden increase of atmospherics (SEA) on the very low radio frequencies. The 27-kilocycle frequency is used because there is little man-made interference on this frequency. The atmospheric noise is rectified and integrated by a long time constant circuit and recorded on a strip chart. Figure 9 shows a sample of the trace recorded during the daytime on November 30, 1959. The SEA was due to a solar flare of magnitude 3 as reported by The High Altitude Observatory, Boulder, Colorado.

Fig. 9. The SEA of November 30, 1959

CHAPTER IV

ATMOSPHERIC AND INSTRUMENTAL CORRECTIONS

A. ATMOSPHERIC EXTINCTION: A beam of light traveling through the earth's atmosphere suffers a loss of intensity because of several effects. Light is scattered from the beam by air molecules in a manner predictable by Rayleigh's law. Rayleigh scattering weakens the shorter wavelengths more strongly than long ones according to the familiar $1/\lambda^4$ dependence. The ozone molecules absorb strongly in the ultraviolet and also have a broad absorption region in the visible spectrum with a maximum in the orange. Atmospheric refraction, at very small elevation angles, has the effect of spreading a beam of light in the meridional plane. The effect is quite small, about 2% at 5° elevation. More variable effects are due to atmospheric dust, haze, and even clouds, but these can be minimized by careful selection of observing nights.

B. INSTRUMENTAL SPECTRAL SELECTIVITY: The spectral selectivity of the photometer is governed mainly by the color filter transmission. The limits of spectral sensitivity are set by photomultiplier response. Further modification of the spectral response is afforded by the transmission of the corrector plate and the reflectivity of the aluminized mirror. Transmissibility data (84) for ordinary crown glass indicate that the corrector plate transmission is approximately constant in the spectral regions where measurements were made. The aluminum reflectivity is also approximately

constant. Figure 10 shows the relative spectral response for the photomultiplier tube, and the transmission characteristics of the filter combinations employed.

C. THE INTEGRATED PHOTOMETER RESPONSE. The method of correcting for atmospheric extinction consists of computing a theoretical response $S(\theta)$ for the photometer at various elevation angles, including the zenith. The ratio of the zenithal response to that at any other elevation angle is the "constant correction" $C(\theta)$ i.e., $C(\theta) = S(90^\circ)/S(\theta)$. When the observed voltage readings are multiplied by the appropriate $C(\theta)$ they become zenithal voltages which still differ by a constant amount from truly extra-atmospheric voltages. The zenithal voltages are converted to absolute intensities by taking the ratio of the zenithal voltage observed to the zenithal voltage which would be obtained from a single tenth-magnitude star per square degree.

The response of the photometer, following Regener (85), can be expressed as a sum over all contributing wavelengths of the product of all factors which condition the response. A factor τ_λ which takes into account the color filter transmission has been included in Regener's expression for $S(\theta)$ which now has the form

$$S(\theta) = R \sum_{\lambda} \left[I_{\lambda} \alpha_{\lambda} \frac{1}{\beta_{\theta}} \tau_{\lambda} 10^{-0.4 (M_{\theta}^{\text{air}} k_{R,\lambda} + M_{\theta}^0 k_{O_3,\lambda})} \right] \Delta \lambda$$

constant. Figure 10 shows a typical example of the
photomultiplier tube, and the constant value of the
the filter combination was used.

5. THE INTERPOLATED PHOTOGRAPHIC METHOD

correcting for atmospheric extinction and for the
theoretical response $S(\theta)$ for the instrument at various angles
angles, including the zenith. The value of $S(\theta)$ is
so that at any other elevation $S(\theta)$ is
 $S(\theta) = S(90^\circ) \cos^2(\theta - 90^\circ)$. The observed values
are multiplied by the appropriate $S(\theta)$ and
values which still differ by a constant amount from
atmospheric voltages. The zenith voltages are
interpolated by taking the ratio of the zenith voltage
observed to the zenith voltage which would be observed from a
single zenith-angle curve for each of two.

The response of the photometer, $S(\theta)$, can be expressed as a sum over all contributing angles θ
the product of all factors which contribute to the response.
factor λ which takes into account the color filter and

relation has been included in the response $S(\theta)$ and
now has the form

$$S(\theta) = R \sum_{\lambda} I_{\lambda} \alpha_{\lambda} \frac{1}{\lambda^2} \cos^2(\theta - 90^\circ)$$

Fig. 10 The Relative Response of the Photomultiplier and the Color Filter Transmissions

where the symbols have the following meanings,

- $S(\theta)$ is the response of the photometer, summed over all contributing wavelength intervals. This quantity is proportional to the current output of the photomultiplier.
- R is a constant of proportionality.
- I_{λ} is proportional to the average extra-atmospheric intensity in the interval $\Delta\lambda$ centered at the wavelength λ .
- α_{λ} is proportional to the average response of the photomultiplier in the interval $\Delta\lambda$ centered at the wavelength λ .
- $1/\beta_{\theta}$ is a factor which accounts for the reduction in light intensity due to widening of the beam by refraction. It is a function of the elevation angle θ .
- γ_{λ} is the average transmission of the color filter in the interval $\Delta\lambda$ centered at λ .
- M_{θ}^{air} is the effective "air mass" at Capillo as a function of the elevation angle θ . This is a pure number which is proportional to the mass of the air column which is traversed by the light beam and which is normalized to unity for the total air mass vertically above sea level.
- $k_{R,\lambda}$ is the average Rayleigh extinction coefficient for scattering of light by air molecules in the interval $\Delta\lambda$ centered at the wavelength λ . This coefficient is given in stellar magnitudes per "air mass".
- $M_{\theta}^{\text{O}_3}$ is the effective "ozone mass" as a function of elevation angle θ normalized to unity at ninety degrees. This is again a pure number which is proportional to the mass of ozone in the air column which is traversed by the light beam.
- $k_{\text{O}_3,\lambda}$ is the average extinction coefficient for ozone in the interval $\Delta\lambda$ centered at the wavelength λ . This coefficient is given in stellar magnitudes per "ozone mass".
- $\Delta\lambda$ is the interval of wavelength small enough to permit the use of average values, over this interval, of those parameters which depend on the wavelength λ . A value of 100 Angstroms was used in the calculations.

where the asymptotic behavior is given by

(2.6)

is a consequence of the asymptotic behavior of the function $f(x)$ as $x \rightarrow \infty$. The function $f(x)$ is defined by

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is a consequence of the asymptotic behavior of the function $f(x)$ as $x \rightarrow \infty$. The function $f(x)$ is defined by

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The factor 0.4 in the exponent removes the 2.5 multiplier contained in the Rayleigh and ozone extinction coefficients because they are expressed in stellar magnitudes per air mass or per ozone mass.

The response equation was evaluated at five specific elevation angles for which all of the parameters concerned were available in the literature. The elevation angles were 0.70, 1.96, 5.24, 11.28, and 90 degrees.

Separate correction factors were calculated for each color filter employed. In all cases the rather large range in θ from 11.28° to 90° is bridged with the approximate relation

$$c(\theta) \approx 10^{k(\operatorname{cosec} \theta - 1)}$$

where k is fitted at 11.28° so that the accurate and approximate functions join smoothly.

Various investigations (5,30,64) have shown that the zodiacal light color is nearly the same as that of the sun. Such results justify assuming the zodiacal light to have a spectral intensity distribution equal to that of a black body at a temperature of 6000°K . Since the correction factor is normalized at the zenith one is justified in using only relative ordinates of the Planckian curve. Values of the ordinates for a 6000°K black body were taken from the tables of Seares and Joyner (86). Relative ordinates were obtained by dividing all ordinates by the maximum value at $4810\text{\AA}$. These values were

The factor 0.4 in the exponent removes the 2.5 multiplier
 prior contained in the Rayleigh and ozone extinction coefficients
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Separate correction factors were calculated for each
 color filter employed. In all cases the latter large range in
 θ from 11.28° to 90° is bridged with the approximate relation

$$10^{k(\cos \theta - 1)} \approx \theta(9)$$

where k is fitted at 11.28° so that the accurate and approximate
 functions join smoothly.

Various investigations (2,30,34) have shown that the
 solar light color is nearly the same as that of the sun.
 Such results justify assuming the solar light to have a
 spectral intensity distribution equal to that of a black body
 at a temperature of 6000°K. Since the correction factor is
 normalized at the zenith one is justified in using only relative
 ordinates of the Planckian curve. Values of the ordinates for a
 6000°K black body were taken from the tables of Sears and
 Joyner (35). Relative ordinates were obtained by dividing all
 ordinates by the maximum value at 4810Å. These values were

plotted against wavelength, and average values over 100 Å strips were read from the graph. The logarithms of these values are given in Table II and plotted in Figure 11. The same type of averaging over 100 Å strips was used for all wavelength dependent data employed in the calculation of the constant correction $C(\theta)$.

The spectral response of the RCA 5819 photomultiplier tube with S-4 response was taken from curves published by RCA (38). Data for the color filters were obtained from the Eastman Reference Handbook (85) and from the Corning filter catalog. The transmission curves are shown in Figure 10 along with the response curve for the photomultiplier. Table II contains the same data in tabular form.

The Rayleigh extinction coefficients in stellar magnitude per air mass, as published by Wempe (40), are given in Table II and Figure 11. The ozone absorption coefficients in stellar magnitudes per ozone mass were obtained from Paetzold (41). The coefficients refer to a vertical thickness of 0.2 cm of ozone under standard conditions. Paetzold (41) also gives the ozone mass $M_{\odot}^{O_3}$ as a function of elevation angle.

Air masses $M_{\odot}^{\text{air}}$ obtained from tables by Link (39) and corrected for the altitude of Capillo were taken from Regener's work (85). The refraction factor $\beta_{\odot}$ was also obtained from Link's tables (39).

Figure 12 shows the constant correction for the blue,

plotted against wavelength, and average values were read from the graph. The logarithm of the values given in Table II and plotted in Figure 1. The values were averaged over 100 Å and the average values were plotted against wavelength. The values were corrected for the effect of the wavelength.

The optical response of the film was measured with a response which was taken from the optical response (38). Data for the optical response were obtained from the Reference Handbook (39) and from the optical response. The transmission curves are shown in Figure 1. The response curve for the photomultiplier is shown in Figure 1. The data are in tabular form.

The Rayleigh extinction coefficient is given in Table II and Figure 1. The optical response of the film was measured with a response which was taken from the optical response (38). Data for the optical response were obtained from the Reference Handbook (39) and from the optical response. The transmission curves are shown in Figure 1. The response curve for the photomultiplier is shown in Figure 1. The data are in tabular form.

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Figure 1 shows the optical response of the film. The data are in tabular form.

TABLE II

VALUES FOR CONSTANT CORRECTION PARAMETERS

λ	$\log I_\lambda$	$\log \alpha_\lambda$	$\log \gamma_\lambda$	$k_{R,\lambda}$	$k_{03,\lambda}$
4000	0.9618	0.9991	-0.3979	0.367	0.000
4100	0.9716	0.9965	0.6628	0.331	"
4200	0.9797	0.9912	1.0645	0.300	"
4300	0.9862	0.9827	1.1553	0.272	"
4400	0.9913	0.9713	0.8976	0.248	"
4500	0.9956	0.9600	0.8976	0.226	"
4600	0.9978	0.9425	0.4914	0.206	"
4700	0.9994	0.9269	-0.0458	0.188	"
4800	-	-	-	0.173	"
4900	-	-	-	0.159	"
5000	0.9985	0.8525	-0.3979	0.146	0.005
5100	0.9965	0.8195	0.3802	0.135	0.013
5200	0.9937	0.7782	0.7243	0.125	0.016
5300	0.9903	0.7259	1.1644	0.116	0.020
5400	0.9864	0.6665	1.1931	0.107	0.022
5500	0.9820	0.5798	1.1106	0.099	0.026
5600	0.9772	0.4843	0.9085	0.092	0.029
5700	0.9717	0.3424	0.5563	0.086	0.033
5800	0.9657	0.2672	0.1461	0.080	0.038
5900	0.9594	0.1461	-0.3010	0.075	0.040
6000	0.9521	0.0086	-----	0.070	0.057
6100	0.9448	-0.1420	0.000	0.065	0.054
6200	0.9380	-0.3019	0.656	0.061	0.046
6300	0.9308	-0.4428	0.854	0.057	0.040
6400	0.9231	-0.6019	0.918	0.054	0.034
6500	0.9144	-0.7442	0.938	0.051	0.028
6600	0.9062	-0.9210	0.946	0.048	0.024
6700	0.8974	-1.0960	0.951	0.045	0.020
6800	0.8885	-1.3980	0.954	0.042	0.016
6900	0.8805	-1.6982	0.956	0.040	0.013

TABLE 1. SUMMARY OF DATA FOR THE YEAR 1964					
Year	Month	Day	Time	Location	Value
1964	Jan	1	08:00	Station A	10.5
1964	Jan	1	09:00	Station A	11.2
1964	Jan	1	10:00	Station A	12.0
1964	Jan	1	11:00	Station A	12.8
1964	Jan	1	12:00	Station A	13.5
1964	Jan	1	13:00	Station A	14.2
1964	Jan	1	14:00	Station A	15.0
1964	Jan	1	15:00	Station A	15.8
1964	Jan	1	16:00	Station A	16.5
1964	Jan	1	17:00	Station A	17.2
1964	Jan	1	18:00	Station A	18.0
1964	Jan	1	19:00	Station A	18.8
1964	Jan	1	20:00	Station A	19.5
1964	Jan	1	21:00	Station A	20.2
1964	Jan	1	22:00	Station A	21.0
1964	Jan	1	23:00	Station A	21.8
1964	Jan	2	00:00	Station A	22.5
1964	Jan	2	01:00	Station A	23.2
1964	Jan	2	02:00	Station A	24.0
1964	Jan	2	03:00	Station A	24.8
1964	Jan	2	04:00	Station A	25.5
1964	Jan	2	05:00	Station A	26.2
1964	Jan	2	06:00	Station A	27.0
1964	Jan	2	07:00	Station A	27.8
1964	Jan	2	08:00	Station A	28.5
1964	Jan	2	09:00	Station A	29.2
1964	Jan	2	10:00	Station A	30.0
1964	Jan	2	11:00	Station A	30.8
1964	Jan	2	12:00	Station A	31.5
1964	Jan	2	13:00	Station A	32.2
1964	Jan	2	14:00	Station A	33.0
1964	Jan	2	15:00	Station A	33.8
1964	Jan	2	16:00	Station A	34.5
1964	Jan	2	17:00	Station A	35.2
1964	Jan	2	18:00	Station A	36.0
1964	Jan	2	19:00	Station A	36.8
1964	Jan	2	20:00	Station A	37.5
1964	Jan	2	21:00	Station A	38.2
1964	Jan	2	22:00	Station A	39.0
1964	Jan	2	23:00	Station A	39.8
1964	Jan	3	00:00	Station A	40.5
1964	Jan	3	01:00	Station A	41.2
1964	Jan	3	02:00	Station A	42.0
1964	Jan	3	03:00	Station A	42.8
1964	Jan	3	04:00	Station A	43.5
1964	Jan	3	05:00	Station A	44.2
1964	Jan	3	06:00	Station A	45.0
1964	Jan	3	07:00	Station A	45.8
1964	Jan	3	08:00	Station A	46.5
1964	Jan	3	09:00	Station A	47.2
1964	Jan	3	10:00	Station A	48.0
1964	Jan	3	11:00	Station A	48.8
1964	Jan	3	12:00	Station A	49.5
1964	Jan	3	13:00	Station A	50.2
1964	Jan	3	14:00	Station A	51.0
1964	Jan	3	15:00	Station A	51.8
1964	Jan	3	16:00	Station A	52.5
1964	Jan	3	17:00	Station A	53.2
1964	Jan	3	18:00	Station A	54.0
1964	Jan	3	19:00	Station A	54.8
1964	Jan	3	20:00	Station A	55.5
1964	Jan	3	21:00	Station A	56.2
1964	Jan	3	22:00	Station A	57.0
1964	Jan	3	23:00	Station A	57.8
1964	Jan	4	00:00	Station A	58.5
1964	Jan	4	01:00	Station A	59.2
1964	Jan	4	02:00	Station A	60.0
1964	Jan	4	03:00	Station A	60.8
1964	Jan	4	04:00	Station A	61.5
1964	Jan	4	05:00	Station A	62.2
1964	Jan	4	06:00	Station A	63.0
1964	Jan	4	07:00	Station A	63.8
1964	Jan	4	08:00	Station A	64.5
1964	Jan	4	09:00	Station A	65.2
1964	Jan	4	10:00	Station A	66.0
1964	Jan	4	11:00	Station A	66.8
1964	Jan	4	12:00	Station A	67.5
1964	Jan	4	13:00	Station A	68.2
1964	Jan	4	14:00	Station A	69.0
1964	Jan	4	15:00	Station A	69.8
1964	Jan	4	16:00	Station A	70.5
1964	Jan	4	17:00	Station A	71.2
1964	Jan	4	18:00	Station A	72.0
1964	Jan	4	19:00	Station A	72.8
1964	Jan	4	20:00	Station A	73.5
1964	Jan	4	21:00	Station A	74.2
1964	Jan	4	22:00	Station A	75.0
1964	Jan	4	23:00	Station A	75.8
1964	Jan	5	00:00	Station A	76.5
1964	Jan	5	01:00	Station A	77.2
1964	Jan	5	02:00	Station A	78.0
1964	Jan	5	03:00	Station A	78.8
1964	Jan	5	04:00	Station A	79.5
1964	Jan	5	05:00	Station A	80.2
1964	Jan	5	06:00	Station A	81.0
1964	Jan	5	07:00	Station A	81.8
1964	Jan	5	08:00	Station A	82.5
1964	Jan	5	09:00	Station A	83.2
1964	Jan	5	10:00	Station A	84.0
1964	Jan	5	11:00	Station A	84.8
1964	Jan	5	12:00	Station A	85.5
1964	Jan	5	13:00	Station A	86.2
1964	Jan	5	14:00	Station A	87.0
1964	Jan	5	15:00	Station A	87.8
1964	Jan	5	16:00	Station A	88.5
1964	Jan	5	17:00	Station A	89.2
1964	Jan	5	18:00	Station A	90.0
1964	Jan	5	19:00	Station A	90.8
1964	Jan	5	20:00	Station A	91.5
1964	Jan	5	21:00	Station A	92.2
1964	Jan	5	22:00	Station A	93.0
1964	Jan	5	23:00	Station A	93.8
1964	Jan	6	00:00	Station A	94.5
1964	Jan	6	01:00	Station A	95.2
1964	Jan	6	02:00	Station A	96.0
1964	Jan	6	03:00	Station A	96.8
1964	Jan	6	04:00	Station A	97.5
1964	Jan	6	05:00	Station A	98.2
1964	Jan	6	06:00	Station A	99.0
1964	Jan	6	07:00	Station A	99.8
1964	Jan	6	08:00	Station A	100.5
1964	Jan	6	09:00	Station A	101.2
1964	Jan	6	10:00	Station A	102.0
1964	Jan	6	11:00	Station A	102.8
1964	Jan	6	12:00	Station A	103.5
1964	Jan	6	13:00	Station A	104.2
1964	Jan	6	14:00	Station A	105.0
1964	Jan	6	15:00	Station A	105.8
1964	Jan	6	16:00	Station A	106.5
1964	Jan	6	17:00	Station A	107.2
1964	Jan	6	18:00	Station A	108.0
1964	Jan	6	19:00	Station A	108.8
1964	Jan	6	20:00	Station A	109.5
1964	Jan	6	21:00	Station A	110.2
1964	Jan	6	22:00	Station A	111.0
1964	Jan	6	23:00	Station A	111.8
1964	Jan	7	00:00	Station A	112.5
1964	Jan	7	01:00	Station A	113.2
1964	Jan	7	02:00	Station A	114.0
1964	Jan	7	03:00	Station A	114.8
1964	Jan	7	04:00	Station A	115.5
1964	Jan	7	05:00	Station A	116.2
1964	Jan	7	06:00	Station A	117.0
1964	Jan	7	07:00	Station A	117.8
1964	Jan	7	08:00	Station A	118.5
1964	Jan	7	09:00	Station A	119.2
1964	Jan	7	10:00	Station A	120.0
1964	Jan	7	11:00	Station A	120.8
1964	Jan	7	12:00	Station A	121.5
1964	Jan	7	13:00	Station A	122.2
1964	Jan	7	14:00	Station A	123.0
1964	Jan	7	15:00	Station A	123.8
1964	Jan	7	16:00	Station A	124.5
1964	Jan	7	17:00	Station A	125.2
1964	Jan	7	18:00	Station A	126.0
1964	Jan	7	19:00	Station A	126.8
1964	Jan	7	20:00	Station A	127.5
1964	Jan	7	21:00	Station A	128.2
1964	Jan	7	22:00	Station A	129.0
1964	Jan	7	23:00	Station A	129.8
1964	Jan	8	00:00	Station A	130.5
1964	Jan	8	01:00	Station A	131.2
1964	Jan	8	02:00	Station A	132.0
1964	Jan	8	03:00	Station A	132.8
1964	Jan	8	04:00	Station A	133.5
1964	Jan	8	05:00	Station A	134.2
1964	Jan	8	06:00	Station A	135.0
1964	Jan	8	07:00	Station A	135.8
1964	Jan	8	08:00	Station A	136.5
1964	Jan	8	09:00	Station A	137.2
1964	Jan	8	10:00	Station A	138.0
1964	Jan	8	11:00	Station A	138.8
1964	Jan	8	12:00	Station A	139.5
1964	Jan	8	13:00	Station A	140.2
1964	Jan	8	14:00	Station A	141.0
1964	Jan	8	15:00	Station A	141.8
1964	Jan	8	16:00	Station A	142.5
1964	Jan	8	17:00	Station A	143.2
1964	Jan	8	18:00	Station A	144.0
1964	Jan	8	19:00	Station A	144.8
1964	Jan	8	20:00	Station A	145.5
1964	Jan	8	21:00	Station A	146.2
1964	Jan	8	22:00	Station A	147.0
1964	Jan	8	23:00	Station A	147.8
1964	Jan	9	00:00	Station A	148.5
1964	Jan	9	01:00	Station A	149.2
1964	Jan	9	02:00	Station A	150.0
1964	Jan	9	03:00	Station A	150.8
1964	Jan	9	04:00	Station A	151.5
1964	Jan	9	05:00	Station A	152.2
1964	Jan	9	06:00	Station A	153.0
1964	Jan	9	07:00	Station A	153.8
1964	Jan	9	08:00	Station A	154.5
1964	Jan	9	09:00	Station A	155.2
1964	Jan	9	10:00	Station A	156.0
1964	Jan	9	11:00	Station A	156.8
1964	Jan	9	12:00	Station A	157.5
1964	Jan	9	13:00	Station A	158.2
1964	Jan	9	14:00	Station A	159.0
1964	Jan	9	15:00	Station A	159.8
1964	Jan	9	16:00	Station A	160.5
1964	Jan	9	17:00	Station A	161.2
1964	Jan	9	18:00	Station A	162.0
1964	Jan	9	19:00	Station A	162.8
1964	Jan	9	20:00	Station A	163.5
1964	Jan	9	21:00	Station A	164.2
1964	Jan	9	22:00	Station A	165.0
1964	Jan	9	23:00	Station A	165.8
1964	Jan	10	00:00	Station A	166.5
1964	Jan	10	01:00	Station A	167.2
1964	Jan	10	02:00	Station A	168.0
1964	Jan	10	03:00	Station A	168.8
1964	Jan	10	04:00	Station A	169.5
1964	Jan	10	05:00	Station A	170.2
1964	Jan	10	06:00	Station A	171.0
1964	Jan	10	07:00	Station A	171.8
1964	Jan	10	08:00	Station A	172.5
1964	Jan	10	09:00	Station A	173.2
1964	Jan	10	10:00	Station A	174.0
1964	Jan	10	11:00	Station A	174.8
1964	Jan	10	12:00	Station A	175.5
1964	Jan	10	13:00	Station A	176.2
1964	Jan	10	14:00	Station A	177.0
1964	Jan	10	15:00	Station A	177.8
1964	Jan	10	16:00	Station A	178.5
1964	Jan	10	17:00	Station A	179.2
1964	Jan	10	18:00	Station A	180.0
1964	Jan	10	19:00	Station A	180.8
1964	Jan	10	20:00	Station A	181.5
1964	Jan	10	21:00	Station A	182.2
1964	Jan	10	22:00	Station A	183.0
1964	Jan	10	23:00	Station A	183.8
1964	Jan	11	00:00

Fig. 11 Graph of the Constant Correction Parameters versus Wavelength

Fig. 12 The Constant Correction for the Blue, Green, and Red Filters

green, and red spectral regions. The greater extinction of the blue light with a mean wavelength of 4355A as compared to the green at 5425A, or red at 6380A is apparent.

In actual use the correction factor $C(\theta)$ was tabulated to two-decimal accuracy for every 0.1° from 4° elevation to around 20° elevation. Above 20° elevation the value of $C(\theta)$ did not change in the second decimal place for several tenths of a degree and thus a different table was constructed giving ranges of θ for a given value of $C(\theta)$. The tabular form of $C(\theta)$ resulted in a very rapid and accurate means of application of this correction by eliminating a separate interpolation of $C(\theta)$ for each data point.

D. THE EFFECTIVE SOLID ANGLE OF ACCEPTANCE OF THE PHOTOMETER. There are two reasons why the effective solid angle of acceptance of the photometer is smaller than one would expect from the diameter of the photomultiplier mask and the telescope focal length. First the circular aperture of the mask is seen as an ellipse when viewed from positions on the mirror surface removed from the optical axis. Light is incident upon the mask at angles of up to 40° with respect to the optical axis. Second, the extra-axial positions on the mirror surface are farther removed from the photomultiplier mask than the focal length of the mirror; thus, the solid angle subtended by the mask is diminished.

The procedure for calculating the effective solid angle

green, and red somewhat brownish. The
blue light with a mean wave length of 4350 Å. and a mean
green at 5450 Å. on red at 6300 Å. and 6500 Å.

In general, the color of the light is
to two spectral components, one at 4350 Å. and one at 6300 Å.
around 25% absorption. The light is of a blue-green color
did not show any absorption bands in the visible spectrum
of a degree and a half of absorption. The light is of a
range of 4350 Å. to 6300 Å. and is of a blue-green color
C(6) resulted in a very weak absorption band at 4350 Å.
of this component is at 4350 Å. and is of a blue-green color
C(6) for each day.

D. The light is of a blue-green color
PHOTOMETRY. There are two factors which are of importance
of a substance of a given color. The first is the
from the surface of the substance. The second is the
local light. The light is of a blue-green color
as an ellipse which shows how the light is of a blue-green color
removed from the surface. The light is of a blue-green color
at angles of 45° and 90°. The light is of a blue-green color
Second, the color of the light is of a blue-green color
further removed from the surface. The light is of a blue-green color
length of the surface. The light is of a blue-green color
mask is eliminated.

The light is of a blue-green color.

of acceptance for a paraboloidal mirror is given by Regener (85.) This procedure is adapted to the case of a spherical primary mirror which is used in the Schmidt camera: Figure 13 presents the geometry for the calculation. It is assumed that the light rays passing through the corrector lens are deviated through such small angles as to be still sensibly parallel. The solid angle Ω subtended by the mask aperture of Area A as seen from a point on the mirror surface is

$$\Omega = \frac{A}{r^2} \cos \phi$$

where r is the distance of the point from the mirror focus, and ϕ is the angle with respect to the optical axis joining the point in question and the focus. The primary mirror is a sphere and therefore the radius vector from C to ds is perpendicular to ds . As seen from F the normal area of the circular zone ds is

$$ds \cos \phi/2 = \frac{2 \pi r^2 \sin \phi d\phi}{\cos \phi/2}$$

Light entering the zone dS falls on the circular zone ds which is again inclined to the line of sight by $\phi/2$ thus

$$dS = ds \cos \phi/2 = 2 \pi r^2 \sin \phi d\phi$$

With this expression for dS the average solid angle of acceptance is given by

$$\bar{\Omega} = \frac{\int_{\phi_1}^{\phi_2} \frac{A}{r^2} \cos \phi \cdot 2 \pi r^2 \sin \phi d\phi}{\int_{\phi_1}^{\phi_2} 2 \pi r^2 \sin \phi d\phi} = \frac{\int_{\phi_1}^{\phi_2} A \sin \phi d(\sin \phi)}{\int_{\phi_1}^{\phi_2} r^2 \sin \phi d\phi}$$

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Fig. 13 THE REFLECTOR GEOMETRY

The integral in the numerator is elementary. The one in the denominator is evaluated by expressing the equation for a circle centered at $(-R/2, 0)$ in polar coordinates and solving for r in terms of R and ϕ .

The mask aperture normally used was 0.219 inch.

Geometrically the aperture subtends a solid angle 1.04° in diameter, or a field of view of 0.794 square degree. Neglecting the central obstruction caused by the phototube ($\phi_1 = 0$) yields $\bar{\Omega}$ as 0.705 square degree. If one evaluates the effective solid angle, taking into account the 5.375 inch central obstruction caused by the photomultiplier mounting, then one obtains $\bar{\Omega}$ as 0.694 square degree. This value of effective solid angle of acceptance was used for converting the observed voltage readings into absolute intensities. It is interesting to note that the geometric solid angle is reduced by the factor 0.808 for the f-0.75 Schmidt telescope whereas the reduction factor determined by Regener for an f-0.44 paraboloid is 0.553.

CHAPTER V

EVALUATION OF THE RECORDINGS

A. THE RAW ISOPHOTES. The evaluation of the recordings begins by entering, free hand, the "raw" isophotes. These isophotes are contours of constant intensity on the sky. All data points (intersections of the intensity trace and a fiducial line) are projected downward to the lowest fiducial line which defines an exact declination on the map. Usually the 5th, 10th, and 15th isophotes are drawn in first because they are easily located (their marker mirrors are wider than the rest), and they then serve as guides for the remaining isophotes.

Stars brighter than 6th -magnitude are usually resolved on the map and their "pips" are ignored when drawing isophotes. The planet Venus, which was near greatest western elongation during the observing period, caused a noticeable distortion of the isophotes for a radius of 2 to 6° depending on the amplifier setting and the color filter employed. Most of the distortion was removed by interpolation but, in one final map, an isophote meander can be traced directly to Venus.

The finite response time of the photometer, about 0.05 second, causes the traces of consecutive sweeps across the sky to be displaced in right ascension about 0.4° with respect to each other. Although this displacement is less than the width of the field of view of the photometer (about 1°), it was corrected for

THE HAW IROCHTES

A. THE HAW IROCHTES

begins by entering, from the "Haw" side, the

isophotes are contours of constant intensity, and

data points (intersections of the isophotes) are

lines) are projected downward to the base of the

defines an exact definition of the "Haw" side

10th, and 15th isophotes are shown in the base of the

easily located (their relative positions are

and they then serve as guides for the remaining isophotes.

Starts project from 10th - 15th isophotes and

the map and their "pipes" are shown with lines

The planet Venus, which was the first to be

during the observing period, and the position of

the isophotes for a range of 10 to 15 seconds

setting and the color film analyzed. Most of the

was removed by interpolation and the result was

meander can be traced directly to Venus.

The finite region of the "Haw" side

second, causes the lines of constant intensity

to be displaced to their original position

other. Although the displacement is small, it

field of view of the photograph is 10th to 15th

by "holding" the raw isophotes consistently toward one horizon. Thus a particular raw isophote will go through one data point and miss the next one by about 0.8 mm. Such a procedure produces much smoother results when data very near the horizon are corrected for atmospheric extinction.

The right ascension scale, in degrees/cm, of the maps is determined from the distance between images of known stars. The present recordings have right ascension scale value of 6.41° /cm, and a declination scale value of 1.94° /cm.

Two lines of constant right ascension are entered on all maps for orientation purposes. The 6 and 12^{h} (hour) lines were appropriate for these recordings. The star Mu-Orionis proved very useful in this connection because its right ascension is $5^{\text{h}} 59.4^{\text{m}}$ and thereby accurately defines one point on the 6^{h} line. With one known line of right ascension others are easily entered on the map.

The local sidereal time, at the instant the telescope crosses the meridian on the first and the last sweep of the survey, is determined. When these times are located on the map as right ascensions and joined by a straight line, the line defines the meridian for the entire recording.

The distance from the meridian to the horizon along a line of constant declination is obtained by dividing the hour angle of the horizon by the map scale. Downing (88) has calculated hour angles of the horizon for Capillo Peak Observatory using 2°

by "golding" the raw isophotes and then by
Thus a particular raw isophote will be
and with the next one by about 0.5 m. This is
dross much smoother results were obtained
corrected for atmospheric extinction.

The right ascension scale, as determined
determined from the distance between
The present recordings have right ascension scale of 0.1
/cm, and a declination scale value of 1.5 m.

Two lines of constant right ascension are shown on all
maps for orientation purposes. The scale is (1 m) lines were
appropriate for these recordings. The scale is 1.5 m
very useful in this connection because the scale is
5.5 m and thereby accurately defines the width of the
With one knows line of right ascension and the other
on the map.

The local sidereal time, as the scale of the sidereal
the meridian on the first and the last of the survey is
determined. When these lines are located on the map as right
ascensions and joined by a curve, the line between
meridian for the entire recording.

The distance from the meridian to the right ascension
of constant declination is obtained by dividing the
the horizon by the map scale. The scale is 1.5 m
angle of the horizon for each of the recordings.

intervals in declination. His values are used wherever possible, and other hour angles were calculated for the 3° declination intervals employed in this study. Both east and west horizons are entered on every map.

B. THE COORDINATE SYSTEMS. Four celestial coordinate systems are used in the recording and the analysis of zodiacal light data. The maps are plotted in terms of right ascension and declination (α, δ). This coordinate system enables one to easily account for the time needed to record an intensity map because only one coordinate is a time variable. Ecliptic longitude and latitude (λ, β) characterize the solar system, and the zodiacal light is highly symmetric with respect to the equator of these coordinates. The horizon coordinates of azimuth and altitude (A, θ) allow atmospheric corrections to be handled most easily. Galactic coordinates (L, B) are needed in the determination of the star background correction.

The method of transforming the data point coordinates between the first three coordinate systems is that devised by Regener (85). Transparent grids of (λ, β) plotted on (α, δ), and (A, θ) plotted on (α, δ) are optically projected upon a tracing of the map. A positive and negative cylinder lens between the projection lens and the transparency permit the projected grids to be "stretched" in one direction for the purpose of accurately fitting the coordinate grid to the map. The distortion of the horizon system caused by the passage of time is

intervals in declination. The lines are drawn at intervals of 10 minutes and other lines are drawn at intervals of 10 minutes. The lines are drawn at intervals of 10 minutes and other lines are drawn at intervals of 10 minutes.

THE COORDINATE SYSTEM

systems are used in the present work. The first is the geocentric system and the second is the heliocentric system. The geocentric system is the one in which the Earth is at the center and the heliocentric system is the one in which the Sun is at the center. The geocentric system is the one in which the Earth is at the center and the heliocentric system is the one in which the Sun is at the center. The geocentric system is the one in which the Earth is at the center and the heliocentric system is the one in which the Sun is at the center.

The method of least squares is used to determine the best fit between the observed and calculated values. The method of least squares is used to determine the best fit between the observed and calculated values. The method of least squares is used to determine the best fit between the observed and calculated values. The method of least squares is used to determine the best fit between the observed and calculated values.

accounted for by rotating the horizon grid with respect to the parallel axes of the cylinder lenses. The "skew" which is introduced by this procedure can be adjusted to coincide with the value introduced by the motion of the sky during the recording. Further details concerning this method, and reproductions of the coordinate grids are given in Regener's work cited above.

The analysis routine for all maps comprises recording on a separate work sheet for each isophote, the following coordinates of each data point; the declination δ , the ecliptic latitude β , the ecliptic longitude λ , the longitude from the sun i.e., $\lambda_0 - \lambda$, and the elevation angle θ . The elevation angle θ is read first and all data points below 4° elevation are excluded. The remaining data points are then plotted in terms of ecliptic longitude from the sun, and ecliptic latitude. The raw isophotes are connected with straight line segments merely for identification of the points. Ecliptic coordinates, for points on the eastern horizon, are plotted and the horizon drawn in. The orientation and behavior of the final isophotes with respect to the horizon give a valuable check on the accuracy of the analysis and on the existence of any low-elevation atmospheric effects such as distant cirrus clouds.

When the tracing of the map is viewed with the ecliptic coordinate grid projected upon it, a bewildering maze of detail is seen. Even though every 5^{th} degree line of ecliptic latitude and every 10^{th} degree line of ecliptic longitude is drawn in heavy on

accounted for by the fact that the clouds are
parallel lines of the same length. The clouds are
directed by this process and are arranged in
value introduced by the fact that the clouds are
Further details concerning the clouds are given
coordinate grid is given in the following table.
The analysis of the clouds is given in the following
separate work sheet and is given in the following
of each area point and is given in the following
the elliptic longitude λ , the latitude ϕ , and the
and the elevation angle θ . The clouds are arranged
and all data points are given in the following
ing data points are given in the following
from the sun, and are arranged in the following
connected with the clouds and are arranged in the following
of the points. Elliptic longitude, latitude, and elevation
horizontal, are plotted and are arranged in the following
and behavior of the clouds are given in the following
give a valuable clue to the nature of the clouds and
existence of any low-level clouds. The clouds are
cirrus clouds.

When the clouds are arranged in the following
coordinate grid projected on a horizontal plane, the
seen. Even though every cloud is arranged in the
every 10° degree line of longitude and latitude.

the transparency, several errors in reading the projected coordinates occur regularly. These are misreading the ecliptic latitude by 1° , reading $5-\beta$ for β when the isophote crosses the ecliptic, and misreading the ecliptic longitude by 2° . All of these errors can be checked and located merely by sighting along the contours of equal declination when the data points are plotted in ecliptic coordinates. The ecliptic coordinates of any data point which deviate by more than about 0.3° from the apparent declination line usually have a correctable reading error.

C. THE COLOR INDICES. The color index of a star is defined as the difference of intensity, in stellar magnitudes, for two regions of the spectrum. When the two spectral regions are in the blue and green with "effective" wavelengths* of about 4300A and 5400A, the color index is said to be on the international scale and is denoted as C. The zero point of the international scale is for stars of spectral class A4, and all later stars have positive indices.

For a light measuring device with an effective wavelength departing slightly from those stated above, a linear transformation will usually permit the "natural" colors to be expressed on the international scale.

* Effective wavelength is the mean wavelength weighted by the spectral sensitivity of the light receiver.

the phenomenon, several errors in the measurements of the ordinates occur regularly. These are due to the fact that the ordinates are measured by 1°, reading 5-6 for 1 and 2, and 3-4 for 2 and 3, and misreading the multiple ordinates of 2 and 3. All these errors can be checked and fixed by plotting along the contours of equal ordinates. The ordinates are plotted in elliptic coordinates. The ordinates are plotted any data point which deviates from the mean value of the apparent deflection line usually have a systematic error.

error.

C. THE COLOR INDICES.

as the difference of intensities of the two colors, for two regions of the spectrum. When the two colors are red and blue and green with "reflective" wave-lengths of about 6500 Å and 5000 Å, the color index is said to be of the "reflective" type and is denoted as C. The zero point of the international scale is for stars of spectral class A, and all other stars have positive indices.

For a light measuring device with an absolute response, departing slightly from these stated values, a slight correction will usually permit the "natural" color to be expressed on the international scale.

* Reflective wave-lengths are the mean wave-lengths of the spectral sensitivity of the human eye.

The present use of the color index is twofold. First, since star brightnesses are catalogued in terms of visual magnitudes, addition of the star's color index to the visual magnitude gives the blue, or photographic, magnitude. A red color index C_r is developed for determining the "red" magnitude of the calibration stars from their known visual magnitudes. Second, when the color index of the zodiacal light is measured, it can be directly compared with the sun's color index.

The color indices listed in the Henry Draper Catalog (89), from which the standard stars are taken, are on the international scale. These colors were determined, long ago, from low dispersion spectra and consequently there are numerous errors among the stated colors and the spectral classifications. This fact, and the erratic behaviour of the natural color indices which were calculated, led to a search for more accurate color information, which is fortunately available in the work of Johnson (90), and Morgan, Harris, and Johnson (91).

The color system defined by Johnson is denoted as the (B-V) system, where B and V are the "blue", or photographic, and the "visual", or green, magnitudes. The effective wavelengths for this system are the same as for the international system. The B magnitude has the added restriction that no wavelength below 3800Å is to be passed by the blue filter. The zero point of the (B-V) system is defined by non-space reddened class A0 stars.

In the present work eight stars with (B-V) colors selected

The present use of the color index as a measure of stellar brightness is based on the fact that the color of a star is a function of its temperature. The color index is defined as the difference in magnitude between two colors, usually the blue and the red. The color index is a measure of the star's temperature, and it is used to determine the star's spectral type. The color index is also used to determine the star's distance. The color index is a function of the star's temperature, and it is used to determine the star's spectral type. The color index is also used to determine the star's distance. The color index is a function of the star's temperature, and it is used to determine the star's spectral type. The color index is also used to determine the star's distance.

from among the standards were regularly observed; it is upon the observations of these stars that the (B-V) color calibration rests. All standard stars with spectra in the range F0 to K0 are used for the intensity calibration.

The following transformation equation was obtained by a least squares solution, for the purpose of converting the natural color indices C_0 to (B-V) color indices.

$$(B - V) = 0.985 C_0 - 0.01$$

Inspection of the constants reveals that the natural colors are indeed very close to the (B-V) colors. The (B-V) colors can be expressed on the international color scale C using Johnson's transformation

$$C = 1.10 (B-V) - 0.18$$

Because there were no stars with known red magnitudes available for calibration purposes, the following procedure was used. A natural red color index was defined as

$$C_r = m_b - m_r = 2.5 \log (I_r/I_b)$$

where I_r and I_b are the corrected red and blue intensities. All stars which were observed in red and blue light were used to evaluate C_r for the various spectral classes. A linear transformation expressing C in terms of C_r was calculated yielding

$$C = 0.60 C_r.$$

from among the standards were regularly observed; it is upon the observations of these stars (B-V) color calibration tests. All standard stars with spectral type range 10 to K0 are used for the intensity calibration.

The following transformation equation was obtained by a least squares solution, for the purpose of converting the natural color indices I_n to (B-V) color indices.

$$(B-V) = 0.985 I_n - 0.01$$

Inspection of the characters reveals that the natural colors are indeed very close to the (B-V) colors. The (B-V) colors can be expressed in the linear form color index I_n using Johnson's

transformation

$$I_n = 1.10 (B-V) - 0.15$$

Because there were no stars with known red magnitudes available for calibration purposes, the following procedure was used. A natural red color index was defined as

$$I_r = I_n - m_r = 2.5 \log (I_n / I_r)$$

where I_r and I_n are the corrected red and blue intensities. All stars which were observed in red and blue light were used to evaluate I_r for the various spectral classes. A linear transformation expressing I_r in terms of I_n was obtained yielding

$$I_r = 0.10 I_n$$

This formula permits comparison of the red indices with the colors of a standard system. The inverse of this transformation

$$C_r = 1.67 C$$

enables red color indices to be calculated from the international colors, and allows "red" magnitudes to be obtained from "blue" magnitudes by the addition of C_r .

D. REDUCTION OF THE STAR READINGS. The star readings consist of a meter deflection for a field centered on the star, and a deflections for a neighboring background field. The difference in these deflections, S volts, is proportional to the true star intensity. The elevation angle of the star is calculated using the time of observation, and the star deflection is multiplied by the constant correction value, described in Chapter 4, yielding a zenithal star intensity. Although the constant correction is strictly valid only for stars of class G i.e., a surface temperature of 6000°K , no erratic behaviour of the intensities for class A stars at various elevation angles was noted. The validity of the constant correction is strengthened by the narrow spectral range passed by each color filter; within this range only changes in the slope of the Planckian curves with temperature would affect the constant correction.

Natural color indices for the color-calibration stars are calculated using

$$C_o = 2.5 \log (I_g/I_b)$$

where I_g and I_b are the corrected zenithal star intensities for the blue and green filters. A similar formula is used for the red color indices.

Star readings which are used for intensity calibration are further multiplied by a factor μ which converts the blue, green, or red deflection to the value which would be obtained if the star's magnitude were 5.0 in the corresponding spectral interval. The factor μ is obtained from $\log \mu = 2 - 0.4m$ where m is the star's apparent magnitude in the spectral interval. This procedure, and a simple transformation, permits the final intensities of the zodiacal light to be expressed in number of stars of magnitude 10.0 per square degree.

E. REDUCTION TO ABSOLUTE INTENSITIES. The constant correction converts an observed zodiacal light intensity value to one which would be observed for zenithal incidence. The light loss due to zenithal extinction is eliminated by comparing the zenithal zodiacal light intensity with that due to a star of known magnitude and spectral class. The final step of converting the zenithal voltages into number of stars per square degree is embodied in one conversion factor $K(*)$, whose value is

$$K(*) = 100/(\mu \bar{\Omega} C(\theta) S)$$

where μ is the factor which reduces S , the star voltage reading, to that of a 5th magnitude star. $C(\theta)$ corrects for extinction, and $\bar{\Omega}$ is the effective solid angle of acceptance of the

where $\bar{u}$ and $\bar{v}$ are the first and second moments of the blue and green distributions. A similar analysis is carried out for the red color channels.

Four regions with one, two, three, and four colors are further analyzed by a statistical analysis. The results are then compared to the results of the statistical analysis of the color channels. The factor of interest is the ratio of the first and second moments of the color channels. The results are then compared to the results of the statistical analysis of the color channels. The factor of interest is the ratio of the first and second moments of the color channels. The results are then compared to the results of the statistical analysis of the color channels.

The results of the statistical analysis of the color channels are compared to the results of the statistical analysis of the color channels. The factor of interest is the ratio of the first and second moments of the color channels. The results are then compared to the results of the statistical analysis of the color channels. The factor of interest is the ratio of the first and second moments of the color channels. The results are then compared to the results of the statistical analysis of the color channels.

$$f(x) = 100 / (x^2 + 1)$$

where $\bar{u}$ is the first moment of the color channels. The results are then compared to the results of the statistical analysis of the color channels. The factor of interest is the ratio of the first and second moments of the color channels. The results are then compared to the results of the statistical analysis of the color channels.

photometer in square degrees. The factor 100 is the equivalent number of 10^{th} -magnitude stars per 5^{th} -magnitude star.

The average value of the conversion factor $K(*)$ is calculated using all stars with the same spectral class. The values of $K(*)$ are plotted against spectral class and a regression line drawn in. The final value of $K(*)$ is read from the regression line at spectral class G0. $K(*)$ has units of number of 10^{th} -magnitude stars per square degree per volt of signal. Multiplication by the zenithal zodiacal light voltage yields the extra-atmospheric zodiacal light intensity in number of 10^{th} magnitude G0 stars per square degree. This unit will henceforth be referred to as stars per square degree or simply "stars", but it should be understood in all cases that the 10^{th} -magnitude refers to either the blue, green, or red magnitude depending upon the color filter employed for the recording.

F. THE BACKGROUND CORRECTION.

1. SOURCES OF EXTRANEEOUS ILLUMINATION. The sky intensity recorded by the photometer is due to several sources in addition to the zodiacal light. The brightness of the other sources must be evaluated as exactly as possible and their contributions removed if the true zodiacal light intensity is to be determined.

Both the green and the red filter combinations are quite transparent to the strong green and red airglow emission lines.

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The continuous spectrum of the airglow is recorded by all filter combinations. Further sources of background light are the milky way and the scattered light from all of the sources including the zodiacal light itself.

2. METHOD FOR BACKGROUND CORRECTION. The background correction in the present study was devised to be as simple as possible and yet provide adequate correction for all of the extraneous light. The "raw" background voltages are taken, as a function of elevation. Along two lines of constant azimuth and averaged. The azimuths are usually 270° and 280° , and are measured from south through east. Figure 14 shows the raw background from recording No. 54.

The voltages $V(\theta)$ are corrected for extinction and expressed in stars per square degree by multiplication with the factor $K(*)C(\theta)$, a step which assumes the airglow is extra-atmospheric so far as extinction is concerned. The background milky way and zodiacal light contributions can be subtracted away leaving only the combined airglow and scattered light.

The ecliptic coordinates are read for every 10° of elevation on each constant azimuth line. These coordinates are used to read the intensity of the zodiacal light in the background region from the composite chart given by Roach et al.(5). The values are averaged, multiplied by 0.75 which shifts the zero point of the intensity scale as was done by Roach et al., and if necessary the values are converted to green or red intensities

The continuous spectrum of the light is filtered by the
collimator. The light is then focused by the lens
on the slit and the scattered light is collected by the
detector. The light is then focused by the lens on the
slit and the scattered light is collected by the detector.

3. RESULTS AND DISCUSSION
The results of the experiment are shown in the figure
and are compared with the theoretical curve. The
theoretical curve is shown in the figure and is
calculated from the equation $I = I_0 \exp(-\alpha r)$.
The values of α and r are given in the table.

The values of α and r are given in the table
and are compared with the theoretical curve. The
theoretical curve is shown in the figure and is
calculated from the equation $I = I_0 \exp(-\alpha r)$.
The values of α and r are given in the table.
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The values of α and r are given in the table.
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and are compared with the theoretical curve. The
theoretical curve is shown in the figure and is
calculated from the equation $I = I_0 \exp(-\alpha r)$.
The values of α and r are given in the table.

Fig. 14 The Raw Background for Recording No. 54

assuming the zodiacal light has the same color index as the sun. The values are plotted, connected with a smooth free-hand curve, and the background intensity is corrected for the zodiacal light contribution.

The galactic coordinates are calculated for three or four points on each azimuth line. The value of milky way intensity is read from the chart of Roach et al. Again the values are multiplied by 0.75 because all stars brighter than 6th-magnitude are resolved on the recordings and ignored when drawing in raw isophotes. The milky way chart of Roach et al. is expressed in terms of visual (green) magnitudes, thus a color index for the milky way must be assumed if its intensity is to be expressed in blue or red stars. A milky way color index of $C=+0.75$ is assumed as was done by Behr and Siedentopf (6) and for the same reason, namely, lack of more precise information.

The intensities for the milky way are averaged, plotted, and joined by a smooth free-hand curve. The milky way contribution is then subtracted from the background values. Figure 15 shows the zodiacal light and milky way values for the background of recording No. 54.

The resulting background $B(\theta)$ now consists of only air-glow and scattered light. Any irregularities are removed by drawing in a smooth curve to represent the points. Both the air-glow and scattered light are assumed independent of azimuth and thus $B(\theta)$ can be subtracted from the total intensity at any

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Fig. 15 The Zodiacal Light and the Milky Way Contributions
in the Background Region of Recording No. 54

azimuth. The resultant background correction $B(\theta)$ for recording No. 54 is shown in Figure 16.

G. THE MILKY WAY CORRECTION. The milky way contribution in the zodiacal light region is removed by a procedure similar to that used in the background region. The milky way isophotes are replotted from the chart of Roach et al. onto a rectangular grid, in terms of $\alpha + \delta$, using the same scale as the maps. Three separate tracing paper grids were made with the milky way intensities for the three colors, using 0.75 of the stated values. The milky way grid is then laid over the tracing of the original map and the milky way intensities MW , are read for each data point.

H. CALCULATION OF THE FINAL INTENSITY. The extra-atmospheric zodiacal light intensity ZL , can now be calculated using

$$ZL = K(*)C(\theta)V(\theta) - B(\theta) - MW$$

where $K(*)$ is the factor which converts the zenithal voltages $C(\theta)V(\theta)$ of the data points into stars per square degree. $B(\theta)$ is the azimuth-independent background intensity and MW is the milky way intensity at the data point.

The final zodiacal light values are entered next to their corresponding points on the ecliptic coordinate plot of the raw isophotes. The extra-terrestrial isophotes for specific intensity values are then interpolated and drawn in free hand.

Thirteen absolute intensity maps of the zodiacal light in

Fig. 16 The Background Correction for
Recording No. 54

three colors are presented in Figures 17 through 23. The final zodiacal light values were followed as closely as possible in constructing the final isophotes with no attempt at "smoothing" the final data.

1. EVALUATION OF THE POLARIZATION DATA. The percentage polarization of a light source can be determined from the maximum (Max) and minimum (Min) intensities transmitted by a polaroid screen (92) using

$$\%P = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min}} \times 100$$

where Max-Min is proportional to the polarized light and Max+Min is proportional to the total light. If the polarized source contains an unpolarized background b, then this background must be removed from the total intensity by subtraction before the true polarization can be determined. Both quantities in the denominator of the expression for %P contain b, thus the correct expression is now

$$\%P = \frac{\text{Max} - \text{Min}}{\text{Max} + \text{Min} - 2b} \times 100$$

The zodiacal light polarization was measured on only one night for points on the ecliptic spaced approximately 4° apart. The points were selected with the aid of a star map so as to exclude all stars brighter than 8th-magnitude in the field of view. The data was recorded as an RMS ac millivolt signal

three points are shown in the figure. The points are labeled 1, 2, and 3. The points are located at the corners of a triangle. The points are labeled 1, 2, and 3. The points are located at the corners of a triangle.

The points are labeled 1, 2, and 3. The points are located at the corners of a triangle. The points are labeled 1, 2, and 3. The points are located at the corners of a triangle.

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Fig. 17

Fig. 18

Fig. 19

Fig. 20

Fig. 21

Fig. 22

Fig. 23

appearing at the output of the two-cycle filter. The signal must be converted to the actual peak to peak ac voltage at the photomultiplier load resistor. This is accomplished with the following factors $2(1.414)$ (1.09) $(1/G)$ where $2(1.414)$ expresses the RMS ac as a peak to peak value, the 1.09 corrects for attenuation by the two-cycle filter, $1/G$ is the reciprocal of the voltage gain of the General Radio Amplifier. This value is further multiplied by the reciprocal transmittance of the polaroid screen. The polaroid transmittance was determined from star observations with and without the screen in place. The resultant voltage is corrected for extinction and expressed in stars per square degree.

The denominator in $\%P$, $(\text{Max} + \text{Min} - 2b)$, is just twice the extra-terrestrial zodiacal light intensity. The value of this quantity is read from the fully corrected maps taken on the same evening. A graph of $\%P$ versus elongation for two colors, blue and green, is given in Figure 24.

appearing as the output of the low-pass filter.

must be converted to the normal form as follows:

photomultiplier load was 500 Ω . The input impedance of the

following factors 2(1.414) (1.414) (1.414) (1.414) (1.414)

the RMS across a load to the value of 1.414.

assumption by the low-pass filter, the input impedance of

the voltage gain of the low-pass filter is 1.414.

further multiplied by the factor 1.414.

polarized source. The polarized voltage is 1.414.

from star connections and the value is 1.414.

The resultant voltage is 1.414.

in stars per phase voltage.

The denominator is 1.414 (1.414 - 1.414 - 1.414).

the extra-terrestrial radiation is 1.414.

this quantity is found from the daily extra-terrestrial

same evening. A graph of the variation of the color

blue and green is given in Figure 1.

Fig. 24 Measured Polarization versus Elongation

CHAPTER VI

DISCUSSION OF RESULTS

A. THE ABSOLUTE INTENSITIES IN THREE COLORS. The final isophote maps are presented in Figures 17 through 23. Varying portions of the southern edge of the light pyramid were not recorded on the maps because the telescope could not be depressed below -18° declination without hitting the north wall of the observing shed.

In Table III the intensities found in this work are compared with those found in several recent investigations. The effective wavelength λ_{eff} represents the color in which the observations were made, but all values have been converted into 10^{th} -magnitude (visual) GO stars per square degree to facilitate intercomparison. The agreement between the intensities measured in three colors is quite good, particularly when one considers the three distinct airglow phenomena which occur in the color intervals.

The blue spectral region (4000 to 5000A) contains no strong emission lines. Thus the background correction is small, an average of 200 stars at 30° elevation.

The green region (5000 to 6000A) contains the intense oxygen green line close to the effective wavelength of the filter. The background removed for this region averages 350 stars at 30° elevation and it varies erratically.

DISCUSSION

A. THE ATMOSPHERIC ELECTRIC FIELD

Isophase maps are presented in figures 1 and 2. Portions of the contour map on the left are restricted on the right because the values are too small to be plotted. The values are plotted on the right of the map.

In Table III are listed the values of the field at the points where the field is zero. The values are listed in order of increasing magnitude. The values are listed in order of increasing magnitude. The values are listed in order of increasing magnitude.

The time spectral ratio (1000 to 10000) is shown in figure 3. The time spectral ratio (1000 to 10000) is shown in figure 3. The time spectral ratio (1000 to 10000) is shown in figure 3.

TABLE III

ZODIACAL LIGHT INTENSITIES

Elongation	25°	30°	35°	40°	50°	60°	70°	80°	90°	100°
Obs. λ (eff)										
Author 4355	3150 1780	1660 940	1230 695	926 525	697 395	380	292	246	223	191
Author 5425	2570	1820	1150	875	558	392	398	254	232	211
Author 6380		2020	1290	1010	645	432	327	278	237	202
B&S 5430		855	725	515	395	325	255	200		
R et al 5450		2330	1600	1185	755	499	372	297	247	212
R 4500		2335	1690	1270	820	542				
E&S 5400		1190	800	630	420	285	190	130	100	
B 6300	2300	1575	1120	846	547					
D&A 4140			900	690	410	300	220	160	110	77
D&A 5410				740	450	280	180	120	74	65
D&A 5220				700	390	250	170	120	91	59

List of investigators.

B&S Behr and Siedentopf (6)
 R et al, Roach et al. (5)
 R, Regener (37)

E&S, Elsasser and Siedentopf (45)
 B, Blackwell (4)
 D&A Divari and Asaad (51)

The red region (6000 to 7000Å) contains the red oxygen lines at 6330Å and the background at 30° elevation is 400 stars. The red lines, although less intense than the green line, exhibit a twilight enhancement (3) of 10 to 50 times, which commences when the sun's rays strike the atmosphere below 1300 km. At least part of the anomalous behaviour of the red isophotes near the horizon (maps 49, 50, and 53) is believed due to this twilight enhancement which makes the red airglow near the eastern horizon brighter than near the western horizon. The background correction, which is obtained from the western part of the sky, is powerless to cope with such a phenomenon. It would appear desirable in future work to avoid these airglow lines by a proper choice of color filters.

The agreement between the present red values and those of Blackwell for the same spectral interval is to be noted. The present values are about 20% higher. The intensities of Behr and Siedentopf, Elasser and Siedentopf, and Divari and Asaad lie considerably below the present values, 20 to 40% at high intensities and a factor of two to three at the low intensities. On the other hand, the values of Roach et al. and Regener lie some 20% above the present values at small elongations, but the similar method of background correction causes closer agreement at large elongations.

The isophotes of all of the maps appear quite symmetric with respect to the ecliptic. Due to this fact no extensive

The red region (5000 to 7000 Å) contains the red oxygen lines at 6300 Å and the background at 30% wavelength at 400 Å. The red lines, although less intense than the green lines, exhibit a twilight enhancement (2) at 10 to 20 Å, which becomes more and more obvious as the wavelength decreases below 1300 Å. At least part of the anomalous behavior of the red lines near the horizon (near 400 Å, near 20 Å) is believed due to this twilight enhancement which makes the red lines near the eastern horizon brighter than near the western horizon. The background correction, which is obtained from the western part of the sky, is possible to use with such a phenomenon. It would appear desirable in future work to avoid these regions in favor of a proper choice of color filters.

The agreement between the present red values and those of Blackwell for the same spectral interval is to be noted. The present values are about 20% higher. The intensities of H α and H β are, of course, not comparable, and H α and H β are consistently below the present values, 20 to 40% at H α and 10 to 20% at H β . On the other hand, the values of H γ at 4101 Å and H δ at 4101 Å are some 20% above the present values at small elongations, but the similar method of background correction gives almost agreement at large elongations.

The intensities of all of the lines appear quite symmetric with respect to the equator. Due to this fact no extensive

search for asymmetries was made; however, the ecliptic latitude of the tip of each isophote was determined and an average value calculated. The average ecliptic latitude and its RMS deviation for all isophotes is $-0.18^{\circ} \pm 1.11^{\circ}$.

The isophotes of maps 47 and 48 appear slightly under-corrected. Part of the undercorrection results from an over-correction for background. The excessive background which was removed resulted from illumination of a haze layer over the Rio Grande valley by city lights. Application of a "dust" correction would make the isophotes appear better near the horizon, but would not replace the values for a number of data points which were lost because the background correction exceeded them in value.

The low-elevation intensities (less than 15°) seem to be somewhat high, and thus lightly overcorrected. A point at constant elongation from the sun usually decreases in intensity (up to 20%) if it is observed near the horizon and subsequently at a larger elevation. The effect could be attributed to the greater scattering of the light from Venus when it is at a low elevation. Future observations, when Venus is not in the survey region, would give more definite results.

A deformity of the final isophotes which occurs in the November maps at around 70 or 80° elongation and to the south of the ecliptic can be traced to a variation in the star background. The same deformation occurs with greater prominence in the

search for a... of the tip of each... calculated. The... for all... is...

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isophote map published by Regener (37). Trumpler (93) presents a map of the entire sky in terms of variations of star density from the mean. The section of this map which contains the region of zodiacal light observation, when plotted in terms of ecliptic coordinates, coincides closely with the peculiar behaviour of the zodiacal light isophotes.

The behaviour of the final isophotes at very small elongations (less than 30°) indicates a certain degree of flattening when compared to the isophotes at larger elongations. The flattening may be due to dawn interference or possibly the beginning of the change from elliptical isophotes, as observed at large elongations, to circular isophotes, as observed in the corona and out to 13° elongation by the University of Colorado eclipse expedition (55).

B. THE RELATIONSHIP OF THE ZODIACAL LIGHT TO THE F-CORONA.

The theoretical work of van de Hulst (33) and the observations of Roach et al. (5) established a conclusive link between the zodiacal light and the solar F-corona. It is desirable to examine the results of the present work with regard to this problem. Roach et al. express their intensities in terms of a unit H , which is 10^{-15} times the intensity of the center of the solar disk. They give two conversion formulae for expressing visual and photographic 10^{th} -magnitude GO stars per square degree in terms of H , they are

isophote map published by Regener (37). Transler (38) presents a map of the entire sky in terms of variations of star density from the mean. The section of this map which contains the region of nodal light observation, when plotted in terms of ecliptic coordinates, coincides closely with the peculiar behaviour of the nodal light isophotes.

The behaviour of the final isophotes are very small elongations (less than 30°) indicates a certain degree of flattening when compared to the isophotes at larger elongations. The flattening may be due to dawn interference or possibly the beginning of the change from elliptical isophotes, as observed at large elongations, to circular isophotes, as observed in the corona and out to 13° elongation by the University of Colorado eclipse expedition (35).

B. THE RELATIONSHIP OF THE NODAL LIGHT TO THE E-CORONA.

The theoretical work of van de Hulst (33) and the observations of Roach et al. (5) established a conclusive link between the nodal light and the solar E-corona. It is desirable to examine the results of the present work with regard to this problem. Roach et al. express their intensities in terms of a unit H , which is 10^{-15} times the intensity of the center of the solar disk. They give two conversion formulas for expressing visual and photographic 10^{th} -magnitudes to stars per square degree in terms of H , they are

$$\log H = \log S_v - 0.480$$

$$\log H = \log S_p - 0.252$$

where S_p and S_v are the photographic and visual intensities in stars per square degree. A further conversion formula

$$\log H = \log S_r - 0.630$$

was developed for the present work to express H in terms of the intensity in red stars per square degree.

The intensities along the ecliptic are read at five degree intervals of elongation for each map and averaged for all maps of the same color. Using the conversion formulae to determine $\log H$ permits one to construct graphs of $\log H$ versus $\log e$, where e is the elongation. Figure 25, 26, and 27 present the $\log H - \log e$ plots for each color. Between 25° and 60° elongation a straight line relationship is obtained with the following slopes; blue, -2.22 ; green, -2.19 ; and red, -2.19 . The values compare well with the value of -2.22 obtained by Roach et al. but differ from Regener's value of -2.02 .

A second region of constant slope appears on these graphs which extends beyond 70° elongation as far as 120 to 135° where the very low intensities precluded further measurements. The slopes in this region are: blue, -0.521 ; green, -0.879 ; and red, -1.161 . The average of the slopes is -0.85 .

It appears that this interesting intensity behaviour around 65° elongation could be made to yield some information upon the

$$\log H = \log 3 - 0.45$$

$$\log H = \log 3 - 0.52$$

where H_1 and H_2 are the horizontal and vertical intensities in stars per square degree. The horizontal intensity is written

$$\log H = \log 3 - 0.50$$

was developed for the purpose of expressing in terms of the intensity in two stars per square degree.

The intensities along the equator are found as five degree intervals of elongation from the pole and averaged for

all maps of the same color. Using the conversion formulas for determining $\log H$ permits one to determine the value of $\log H$ for

$\log e$, where e is the elongation. The values of $\log H$ for $e = 0^\circ, 15^\circ, 30^\circ, 45^\circ$ and 60°

are plotted in a straight line relationship as shown with the elongation a straight line relationship as shown with the

following elongations: $0^\circ, 15^\circ, 30^\circ, 45^\circ$ and 60° . The values compare well with the value of -8.88 found by

Nosch et al. for different regions of the sky. A second region of interest is shown in Figure 1, which

extends beyond 90° elongation as far as 135° where the very low intensities are observed. The slopes in this region are: $0^\circ, 15^\circ, 30^\circ, 45^\circ$ and

60° . The average of the slopes is -0.50 . It appears that this is a general feature of the

65° elongation could be used to give a rough indication of the

Fig. 25 Log H versus Log e for Blue Light

Fig. 26 Log H versus Log e for Green Light

Fig. 27 Log H versus Log e for Red Light

particle size in the zodiacal cloud. Recalling the work of van de Hulst (33) who splits the dust scattering function into diffraction and reflection parts and finds that their intensity behaviour with elongation varies as e^{-3} and e^{-1} , respectively. The e^{-3} behaviour is found to extend to larger elongations for smaller dust particles. Thus by choosing a radius for the particles van de Hulst's curves can be made to show a break at 60° elongation. These considerations seem to indicate that the most effective scattering particle size is a few microns, say between one and five. There are several objections to this view. First, the separation of diffraction and reflection contributions in the scattering function is not possible, according to van de Hulst, for x-values less than three to ten depending upon the nature of the particle. Second, van de Hulst assumed a constant particle space density when he calculated the curves mentioned. A future calculation using the complete Mie formulae and a more realistic particle space density might yield valuable information upon the effective particle size in the zodiacal cloud. Such a calculation need only cover the limited range of elongation from 50 to 80° .

C. THE ZODIACAL LIGHT COLOR INDEX. The color index of the zodiacal light was calculated every five degrees along the ecliptic using consecutive pairs of maps obtained during the same night. No systematic trend of color index with elongation is found in contrast to the results of Behr and Siedentopf (6).

The mean (B-V) color index obtained for all blue-green map pairs using 70 separate determinations is $+0.60 \pm 0.12$. This indicates a color slightly redder than the sun whose (B-V) color index is $+0.57$. The value converted to the international color index scale C is $+0.48 \pm 0.12$. This converted value is again slightly redder than the sun whose color index C is $+0.45$. The mean value of the red-blue color index when converted to the international scale is $+0.62 \pm 0.09$ as obtained from 25 determinations.

Elvey and Rudnick (24), long ago, found a color index similar to that of a class G1 star i.e., $C = +0.57$. Behr and Siedentopf find color indices C, between $+0.40$ and $+0.88$, the values increasing with increasing elongation. Divari and Asaad (51) find a mean color index of $+0.35$ which implies a zodiacal light color bluer than the sun. This is the smallest color index value to be published.

Fesenkov (94) proposes that a correction should be applied to the observed zodiacal light intensities to account for the variation in the amount of zodiacal light scattered by the troposphere as a function of azimuth from the ecliptic. His calculations show that for positions at 15° elevation above the horizon, with the ecliptic normal to the horizon, the following contributions due to scattered zodiacal light should be found: on the ecliptic, 5.9%; at 10° ecliptic latitude, 7.8%; at 20° ecliptic latitude, 11.6%. These values were based upon an

experimentally determined atmospheric scattering function for a wavelength of 5460A. If one assumes a pure Rayleigh atmosphere and calculates the expected contributions for 4350A using the factor $(5460/4350)^4$ as a multiplier for Fesenkov's values, the following contributions for the points listed above are obtained 14.5%, 19.2%, and 28.5%. Such large contributions of "zodiacal twilight" should manifest themselves as a decrease in zodiacal light color index with ecliptic latitude. Indeed, a sample calculation was performed assuming that the blue intensity obtained at 20° ecliptic latitude was increased 17% over the green intensity as predicted above. The normal color index was +0.55 for this point but it decreased to +0.38 when the increased blue value was used.

As a test for the existence of this or similar color effects the color index was calculated at the intersection of every five-degree line of ecliptic latitude and ecliptic longitude thus forming a grid of color index determinations over the entire zodiacal pyramid. These calculations were carried out for four maps, nos. 45 and 46, and 54 and 55 which were obtained immediately before the onset of twilight when the zodiacal light was brightest and most extensively recorded.

The color indices show no ecliptic latitude or longitude dependence with all values quite close to a mean value. Maps 45 and 46 yield a mean color index for 125 determinations of $B-V = +0.57 \pm 0.05$ which converts to $C = +0.45 \pm 0.05$ or identical

to that of the sun. Maps 54 and 55 yield a mean color index for 126 determinations of $B-V = +0.67 \pm 0.06$ which converts to $C = +0.56 \pm 0.06$. The discrepancy between these two values will be discussed in the next section; however, at this point it can be concluded either that the zodiacal twilight mechanism postulated by Fesenkov does not follow Rayleigh scattering, or that if it does its magnitude has been overestimated.

A further point with regard to Fesenkov's theory is that he assumes the extra-atmospheric isophotes of the zodiacal light are narrower than normally observed, then calculates an effect which broadens them. The narrow isophotes are based, in part, upon his calculations of theoretical isophotes for the zodiacal light due to an asteroid-dust model. If the true extra-atmospheric isophotes are close to what one obtains after applying the usual corrections then the need for the postulated zodiacal twilight correction disappears.

D. THE OBSERVATIONS OF 11/30-12/1/59 and of 12/1-12/2/59.

The observations of 12/1 and 12/2/59 are of particular importance since they were made during a period of high solar and geomagnetic activity. These results can be compared with the 11/9-11/10/59 which were obtained during a "quiet" period.

Figure 28 graphically portrays the solar flares which occurred before, during, and after each observing period, as well as the resultant terrestrial effects due to this solar activity. The sudden enhancement of atmospherics (SEA), as recorded by

to that of the sun. Page 24 and 25 with a very small
for 125 determinations of $\delta = +0.7 \pm 0.05$ which is very close
 $\delta = +0.55 \pm 0.05$. The discrepancy between the two values will be
discussed in the next section. However, it is quite possible that
concluded either that the actual value is somewhat different from
by Pessenkov does not follow from the above. It is possible that
does its magnitude has been overestimated.

A further point with regard to Pessenkov's value is that
he assumes the extra-atmospheric spectrum of the solar light
are narrower than normally observed, which calls for an effect
which broadens them. The actual spectrum of the sun, in fact,
upon his calculations of cosmic-ray responses for the solar
light due to an asteroid-like object. If the extra-atmospheric
photic responses are close to what one obtains from a
the usual corrections than the need for the postulated additional
twilight corrected disappears.

6. THE OBSERVATIONS OF 11/9-11/10/59 AND 12/1-12/2/59

The observations of 12/1 and 12/2/59 are of particular importance
since they were made during a period of high solar activity
magnetic activity. These results can be compared with the
11/9-11/10/59 which were obtained during a "quiet" period.
Figure 28 graphically compares the two time series
occurred before, during, and after some magnetic activity, as well
as the resultant terrestrial effects and the solar activity.
The sudden enhancement of atmospheric ionization (A₁), as recorded

Fig.28 Solar and Geomagnetic Activity during the Observing Periods

the atmospheric receiver, due to the flare of importance 3 on 11/30/59 is given in Figure 9. The SEA's on 12/1 and 12/3 were also recorded. The magnetic A-index during the first four days of December was high. The sudden-commencement magnetic storm of 11/30 was due to the flare of importance 3 on 11/28. Apparently this magnetic storm was enhanced and lengthened by the flare of importance 3 on 11/30.

Fortunately, both spectrographic and photoelectric observations were secured during this period. A spectrogram (Figure 29) of the evening zodiacal light on 11/30 shows the blended red airglow lines strongly enhanced, and about four times more intense than the green line which appears with normal intensity. In the usual situation (11/29), before the magnetic storm onset, the green line appears about twice as intense as the red lines. Further inspection of this spectrogram, and comparison with one obtained under similar conditions on 11/29 indicates that the entire red end of the spectrum is more intense. This could possibly be due to the enhancement of unresolved molecular OH bands.

While obtaining recordings 50, 51, and 52 the entire sky was noted to have a strange pinkish cast and seemed quite bright. Some thin patches of cirrus (this was, in reality, a poor observing night) could be seen as dark stripes projected on a brighter sky background. Unfortunately, the recording drum was not properly centered when recording 51 was started

the atmospheric receiver, the line of the spectrum 3-5
11/30/39 is given in figure 9. The line of 11/30/39 was
also recorded. The magnetic field was 11/30/39
of December was high. The 11/30/39 was due to the
of 11/30 was due to the 11/30/39. The 11/30/39
this magnetic storm was observed and recorded on 11/30/39.
importance 3 on 11/30/39.
Fortunately, each spectrograph had a photoelectric
servations were secured during this time. The spectrograph
(Figure 29) of the evening of 11/30/39 shows the
blended red and green lines strongly, and also the blue
more intense than the green line which is more intense
tensity. In the case of 11/30/39, the red line is
storm onset, the green line becomes even more intense as
the red line. Further, the 11/30/39 is more intense
comparison with one obtained under similar conditions of 11/30/39
indicates that the entire red line of 11/30/39 is more
tense. This could possibly be due to the 11/30/39
unresolved molecular OH bands.
While obtaining records on 11/30/39, it was noted to have a strange pattern and some other
bright. Some thin patches of clouds (this was, in fact, a
poor observing night) could be seen as thin white patches
on a brighter sky background. The 11/30/39 was not properly
drum was not properly centered when recorded on 11/30/39.

Exposure	3 hours
Slit Width	0.4 mm
Direction	10° above SW horizon

Fig. 29 Zodiacal Light and Airglow Spectra

Exposure 3 min
Silt-Water 10 min
Direction 10° above S. horizon

and thus no information was obtained except the maximum and minimum sky brightnesses read prior to the recording. These values were normal.

The blue-light recording 52, obtained just before twilight appears normal. Its intensities agree well with previous blue intensities.

The red-light recording 50 appears abnormal even on the original map, where the raw zodiacal light isophotes are much less pointed along the ecliptic than usual and tend toward parallelism with the horizon. More isophotes than usual are apparently centered at the zenith and are approximately circular. The absolute zodiacal light intensities for this map are normal and compare well with the other two red recordings. The background correction, which contains the airglow contribution, is extremely high. At 60° elevation the background is 530 stars, and at 10° elevation it is 1800 stars. These values should be compared with the background values for recording 53, taken at the same time before dawn, of 340 and 1200 stars. For all elevation angles the background correction exceeds the most intense portions of the zodiacal light.

Redman (4) reports that Blackwell observed a large, twofold, increase in zodiacal light intensity during a magnetic storm which followed the large solar flare of 1958 July 7. During his photographic observations Blackwell used red,

and that no information was obtained from the subject and
minimum any other possible cause for the observed
values were normal.

The blue-light recording 25, dated 11/15/55, showed
light appears normal. The subject's eyes were closed
blue intensities.

The red-light recording 30 appears to be a normal
original map, where the raw red-light light responses are
less potent along the elliptic scan wall and tend toward
parallelism with the horizon. More responses were noted and
apparently centered at the wall and are approximately
circular. The response pattern is similar to the
map are normal and compare well with the other two red-
ings. The background correction, which contains the
correction, is extremely small. At 60° elevation the
ground is 230 stars, and at 10° elevation is 100 stars.
These values should be compared with the background values
recording 23, taken at the same time before and after
1200 stars. For all elevations angles and background correc-
tion exceeds the most intense portions of the subject's

Redman (4) reports that the wall observed during
twofold, increase in response is observed during the
nerve score which follows the procedure. The subject's
7. During the procedure the subject's eyes were closed.

yellow, and green color filters* thus it is entirely possible that the photographs taken with the red and yellow filters contained an abnormal red airglow contribution such as observed at Capillo on 12/1/59. If such a large increase in airglow was not properly accounted for, or entirely unnoticed, it could explain Blackwell's intensity increase. It is further stated that Blackwell finds an unexplained "color anomaly", no other details are given. If this color anomaly is a reddening it could be accounted for by the increased red airglow, particularly if the color index was determined from green-red intensities. A displacement of the light axis was also noted, and might be explained by the airglow structure.

The observations of 12/2 are also worthy of note not only because they were obtained during the magnetic storm, but also because recording 55 was begun 12 minutes before the occurrence of a solar flare of importance 2+, which lasted for about one hour; thus one third of this recording was obtained during the flare. No apparent intensity effect is noted for this recording; however, the mean of 126 color index determinations yields a slightly redder value (0.1 magnitude) than obtained for recordings 45 and 46. This effect might be due to the solar flare or magnetic storm, but is most probably due to the inherent

*A private communication to the author by J. F. Kenney.

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flare. No apparent intensity effect is noted for this record-
ing; however, the mean of 120 color index determinations yields
a slightly redder value (0.1 magnitude) than obtained for re-
cordings 45 and 46. This effect might be due to the solar flare
or magnetic storm, but is most probably due to the inherent

inaccuracies of the intensity measurements.

The results of the observations obtained both during a magnetic storm and during a solar flare indicate strongly that these phenomena have no detectable effect upon the zodiacal light intensity. Numerous accurate observations by a single observer might allow conclusions to be drawn about smaller intensity variations in the 20% range, but this is about the limit of accuracy of the present-day results. Table III illustrates the striking lack of agreement between the results of most observers.

E. POLARIZATION. The polarization of the zodiacal light was measured on only one occasion. The signals contained so much noise (from 20 to 50%) that they appeared valueless, but when analyzed the resulting polarizations were fairly consistent. Figure 24 gives the percentage polarization measured in the blue and green spectral regions on the morning of 11/8/50. The polarization values, denoted by $P(59)$, are also plotted in the earlier Figure 2 for comparison with the results of other investigators. The readings were taken prior to the morning series of recordings and therefore do not extend to elongations of less than 50° .

The fact that the blue measurements lie consistently below the green measurements may be due a change in the polaroid screen transparency with wavelength, although this was not indicated by star readings. The transparency in the green was determined

inaccuracies of the intensity measurements. The results of the observations obtained both during a magnetic storm and during a solar flare indicate strongly that these phenomena have no detectable effect upon the solar light intensity. Numerous accurate observations by a single observer might allow conclusions to be drawn about smaller intensity variations in the 20% range, but this is about the limit of accuracy of the present-day results. Table III

illustrates the striking lack of agreement between the results of most observers.

E. POLARIZATION. The polarization of the solar light

was measured on only one occasion. The signals contained so much noise (from 20 to 50%) that they appeared valueless, but when analyzed the resulting polarizations were fairly constant. Figure 26 gives the percentage polarization measured in the blue and green spectral regions on the morning of 11/2/50. The polarization values, denoted by $P(50\%)$, are also plotted in the earlier Figure 2 for comparison with the results of other investigators. The readings were taken prior to the morning series of recordings and therefore do not extend to elongations of less than 50° .

The fact that the blue measurements lie consistently below the green measurements may be due to a change in the polaroid screen transparency with wavelength, although this was not indicated by star readings. The transparency in the green was determined

from 15 star measurements obtained during preliminary observations in the spring of 1959, while the blue transparency was based upon only three star readings.

The maximum polarization value obtained was 25.2% for the blue measurements and 24.8% for the green measurements. The broad polarization maximum near 60° elongation agrees in shape with the polarization predicted by Fesenkov's dust-aerosol scattering function (77) but the relative polarization values lie about five percentage points lower. Preliminary measurements made on 3/1/59 confirm the broad maximum and extend the results inward to about 30° elongation; however, these values were deduced using incompletely corrected zodiacal light intensities and cannot be considered exact in magnitude.

The present measurements do not agree with the values obtained by Behr and Siedentopf (6) or Elsasser and Siedentopf (45) shown in Figure 2. The trend of polarization with elongation agrees with that found by Divari and Asaad (51) but the present values are slightly higher.

Beyond 90° elongation there are no published values for comparison, but the observation by Blackwell (4) showing that comet Arend-Roland exhibited about 20% polarization for a scattering angle of 118° indicates one should expect considerable polarization even at scattering angles above 100° . Cowan (92) measured polarization at one point with an elongation of

from its near momentary state of almost perfect equilibrium
various in the spring of 1932. While the first series of
was based upon only three near values.
The maximum polarization values obtained were 21.5% for the
blue measurements and 21.5% for the green measurements. The
broad polarization maximum near 10° elongation is
cause with the polarization predicted by Brewster's angle
normal scattering factor (7) for the incident polarization
values is about five percent above the values for the
measurements made on 3/1/32. The values for the
extend the results further to a 30° elongation. However,
these values were deduced using angles less than 30° and
light intensities and cannot be considered exact in this case.
The present measurements do not agree with the values
obtained by Bent and Shapovalov (4) or also by Bent and
(4) shows in Figure 5. The value of polarization at 30°
also agrees with that found by Bent and Shapovalov (4).
present values are slightly higher.
Beyond 30° elongation there are no reliable values for
comparison, but the observation of Shapovalov (4) showing
some broad-Roland extinction about 10° polarization for a
scattering angle of 110° indicates an angle of about 100°
and polarization even at scattering angles near 100°.
(92) measured polarization at one point with an elongation of

104° on the ecliptic and obtained 18%, a value which agrees very well with the present green measurements. Extrapolating the curve, which is roughly defined by the polarization values, to 0% indicates that this value of polarization will be reached at about 170° elongation.

104° on the ellipse and obtained 13.2 value with error
very well with the present green measurement.
the curve, which is roughly defined by the observation
values, to 0.5 indicates that this value of polarization will
be reached at about 170° elongation.

CHAPTER VII

SUMMARY

A. RESULTS. The extraterrestrial intensity of the zodiacal light is obtained in three colors in absolute units, from 13 fully corrected night-sky recordings. The intensity values lie close to the average of all published values. At an elongation of 35° from the sun, along the ecliptic, a value of 1150 stars per square degree is obtained. Other values vary between 1690 and 855 stars per square degree.

The relationship between the solar F-corona and the zodiacal light is confirmed for all colors by the intensity variation with elongation from the sun.

At an elongation of about 65° from the sun the change in slope of the intensity curve is interpreted, following theoretical results by van de Hulst, as the region where light scattered by reflection begins to predominate over light scattered by diffraction from the interplanetary particles. Using this interpretation one may obtain an estimate of the most effective scattering particle size. A particle radius of a few microns is indicated; however, a more exact theoretical development and further observations are necessary before conclusive results can be obtained.

A search for position-dependent color effects proved negative. A previous experimental result, by Behr and Siedentopf,

SUMMARY

A. RESULTS. The experimental results of the

scattered light is observed in white color in which the
from is fully scattered light-ray scattered. The scattered
values lie close to the average of all scattered values. At
elongation of 35° from the sun, along the ecliptic, a value of
1150 stars per square degree is obtained. Other values vary
between 1050 and 850 stars per square degree.

The relationship between the solar constant and the

scattered light is confirmed for all colors in the visible
variation with elongation from the sun.

As an elongation of about 35° from the sun the

slope of the intensity curve is interpreted, following a
ideal results of van der Waals, as the region where light is scattered
by reflection begins to predominate over light scattered by

diffraction from the interplanetary dust cloud. This
interpretation one may obtain an estimate of the total

scattering particle size. A particle radius of 1.5 microns is
indicated; however, a more exact character of the
further observations are necessary before definite results can
be obtained.

A search for position-dependent effects

negative. A previous experimental result, of which it is

showing a reddening of the zodiacal light with elongation from the sun is not confirmed. A theory by Fesenkov indicates that a large percentage of the high-ecliptic latitude zodiacal light is due to the scattering of zodiacal light in the earth's atmosphere. An observational test designed by the author fails to confirm Fesenkov's theory since no excess of blue light is detected at high ecliptic latitudes.

Observations in early December, 1959 were obtained during a magnetic storm and part of one recording was obtained during a solar flare of importance 2+. No detectable effect upon the zodiacal light intensity was noted during these events, although during one night a weak red aurora was in progress. At that time the red airglow lines were enhanced by a factor of about eight, as estimated from a low dispersion spectrogram, and the background correction (airglow and scattered light) for the red recording was increased by 50%. The lack of a detectable increase in zodiacal light intensity is in disagreement with Blackwell who observed a twofold increase in zodiacal light during a magnetic storm which followed a large solar flare. The possibility of an apparent intensity increase due to the enhancement of the red airglow is discussed.

The polarization of the zodiacal light at large elongations was measured upon one occasion. The maximum polarization occurs at about 60° and has a value of about 25%. A polarization of 12% was found at 137° elongation. These values lie near those

showing a reddening of the nodal light with elongation from the sun is not confirmed. A theory by Pessenkov indicates that a large percentage of the high-elliptic latitude nodal light is due to the scattering of nodal light in the earth's atmosphere.

An observational test designed by the author fails to confirm Pessenkov's theory since no excess of blue light is detected at high elliptic latitudes.

Observations in early December, 1959 were obtained during a magnetic storm and part of one recording was obtained during a solar flare of importance 2+. No detectable effect upon the nodal light intensity was noted during these events, although during one night a weak red aurora was in progress. At that time the red airglow lines were enhanced by a factor of about eight, as estimated from a low dispersion spectrogram, and the background correction (airglow and scattered light) for the red recording was increased by 50%. The lack of a detectable increase in nodal light intensity in its disagreement with Alcock's who observed a twofold increase in nodal light during a magnetic storm which followed a large solar flare. The possibility of an apparent intensity increase due to the enhancement of the red airglow is discussed.

The polarization of the nodal light at large elongations was measured upon one occasion. The minimum polarization occurs at about 60° and has a value of about 25%. A polarization of 13% was found at 137° elongation. These values lie near those

predicted by Fesenkov's theory which uses the atmospheric aerosol scattering function. The observed trend of polarization with elongation is similar to that found by Divari and Asaad, but the present values are slightly higher. There is little agreement, in value or trend, with the results of Behr and Siedentopf or with those of Elsasser and Siedentopf.

B. RECOMMENDATIONS. Perhaps the most serious shortcoming of the present work is the use of a theoretical extinction correction which is valid only for "average" conditions. On some occasions the atmospheric extinction deviates significantly from the average value. Any such variations appear as variations in the final intensity of the zodiacal light. This is particularly true when stars are used as intensity standards, as was done, since their intensity is also affected by extinction.

On a non-average night, say with more extinction than normal, the constant correction converts the observed star reading to a zenithal value which is lower than normal. Two things produce this result; first, the observed star reading is lower than normal and second, the added extinction, in excess of the average value, is not corrected for by the constant correction. Since the final zodiacal light intensities involve taking the ratio of the zenithal zodiacal light value to the zenithal star reading, and since both of the above deficiencies are present in the constant-corrected zodiacal light values, they can be assumed to cancel approximately. However, the cancellation will occur only

predicted by Resonance theory which is

normal scattering function. The observed

with elongation is similar to that of

the present values are slightly higher

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or with those of Hixson and others.

2. RECONSTRUCTION. Perhaps the most serious

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On a non-average night, any with

normal, the constant correction

to a central value which is lower

due this result; first, the observed

normal and second, the added extinction

value, is not corrected for by the

the final nodal light intensities

the central nodal light value to

and since both of the above

constant-corrected nodal light

cannot approximately. However, the

if the zodiacal light intensity and the star are observed at the same elevation angle, and if the zodiacal light and star have the same spectral energy distribution. This condition is rarely met in practice because most zodiacal light data points occur at small elevation angles while star readings, in the interest of obtaining accurate values, are taken at higher elevations. The net effect of using star calibrations obtained on poorer nights is to multiply the zodiacal light intensity by a factor e (the base of natural logarithms) raised to the power resulting from the product of the increase in extinction coefficient and the difference in air mass between the data point and the equivalent air mass determined by the average elevation of the calibration stars.

The great difficulty in determining experimentally an accurate value for the atmospheric extinction coefficient, especially when using star observations taken with a wide-field photometer, is well known. Hardie (95) indicates that the extinction coefficient can be determined rapidly and accurately only if one uses standard stars of accurately known magnitude and color. Future work should attempt a determination of the extinction coefficient each night and, if possible, several times per night so that corrections can be made for rapid variations in transparency. Stars for this purpose could be taken from the list of standard stars for the (B-V) color system.

The twilight enhancement of the red airglow lines makes

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If the redial light intensity and the star are observed at the same elevation angle, and if the redial light and star have the same spectral energy distribution. This condition is rarely met in practice because most redial light data points occur at small elevation angles while star readings, in the interest of obtaining accurate values, are taken at higher elevations. The net effect of using star calibrations obtained at poorer angles is to multiply the redial light intensity by a factor e (the base of natural logarithms) raised to the power resulting from the product of the increase in extinction coefficient and the difference in air mass between the data point and the equivalent air mass determined by the average elevation of the calibration

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The twilight enhancement of the red airglow lines makes

them a very undesirable background feature. In future work involving the red end of the spectrum the observer would do well to avoid these lines at 6330A. Spectrographic observations in conjunction with photoelectric recordings are valuable for keeping track of airglow variations.

The simultaneous observation of the zodiacal light in two or more colors is very desirable. In the present work, the color indices of the zodiacal light were calculated from intensities determined on successive recordings. Both the atmospheric transparency and instrumental calibrations can vary during the period of an hour needed to secure two recordings. As a result of the earth's rotation the present zodiacal light colors are always determined using intensities obtained at different elevation angles; thus, any inadequacy in the background or extinction correction occurs as an error in the final color index.

It would be desirable to make an accurate photometric study of the entire milky way in two colors in order to determine its brightness distribution more accurately and to determine its presently unknown and possibly position-dependent color index. Such a study would also provide data for a more accurate star background correction.

During periods of high solar activity it seems desirable to monitor the polarized component of the zodiacal light. Streams of solar particles might produce detectable fluctuations in the polarized component. A simple device such as a photomultiplier

them a very noticeable scattering of light was
involving the red end of the spectrum and the
to avoid these lines at 6300. The characteristic
contraction with phosphorescence was also
keeping track of slight variations.
The characteristic observation of the red end of the
two or more colors is very distinctive. In the
color indices of the red end light were obtained in the
sensitivities determined on successive photographs. The
photo transparency and instrumental calibration were very
the period of an hour needed to secure two photographs. The
results of the earth's rotation the present additional light
are always determined using a constant or fixed as
elevation angles; thus, any discrepancy in the
excitation contraction occurs as a result of the
It would be desirable to make an attempt to
study of the entire Milky Way. The color of the
its brightness distribution was carefully and
presently unknown and possibly positive-negative color
Such a study would also provide data for a more
background contraction.
During periods of high solar activity, it is
to monitor the polarized component of the red end of the
of solar particles might provide characteristic
polarized component. A simple device such as a

tube with a spinning polaroid filter aimed at a constant elevation above the horizon, and an ac amplifier with a strip-chart recorder would produce a continuous record of the polarization.

* * * * *

I wish to thank Professor V. H. Regener for making this project available to me and for assistance and council throughout its lifetime. Early phases of this project were supported by the Research Corporation while later support has been provided by the National Science Foundation.

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elevation above the horizon, and an amplifier with a scrip-
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BIBLIOGRAPHY

1. Schmid, F., Vol. II, Probleme der Kosmischen Physik, Henri Grand, Hamburg (1928)
2. Fesenkov, V. G., Soviet Astron. -AJ, 2, 276, (1958)
3. Mitra, S. K., The Upper Atmosphere, The Asiatic Society, (1952)
4. Redman, R. O., The Observatory, 72, No. 912, 172, (1959)
5. Roach, F. E., et al., Astrophys. J., 119, 253, (1954)
6. Behr, A., & Siedentopf, H. Z. Astrophys., 32, 19, (1953)
7. Roach, F. E., & Jamnick, P., Sky and Tel., 17, No. 4, 164, (1958)
8. Jones, J. G., "U.S. Japan Expedition", Vol. III, Washington, (1856)
9. Hulbert, E. O., Phys. Rev., 35, 1098, (1930)
10. Bayldon, F. J., Pub. Astron. Soc. Pac., 12, 13, (1900)
11. Hoffmeister, C., Veroff U. Sternw. Berlin-Babelsberg, 10, No. 2, (1930)
12. Hoffmeister, C., Veroff. U. Sternw. Berlin-Babelsberg, 12, No. I, (1932)
13. Hoffmeister, C., Popular Astronomy, 42, 426, (1934)
14. Hoffmeister, C., Astron. Nach., 271, 49, (1940)
15. Schoenberg, E., Astron. Nach., 272, 25, (1941)
16. Elvey, C. T., Astrophys. J., 86, 84, (1937)
17. Hoffmeister, C., Soviet Astron. - AJ., 2, 457, (1957)
18. Dufay, J., Journal de Phys., 10, 219, (1929)
19. Desjardin, G., Phys. Rev., 8, 1, (1936)
20. Elvey, C. T., & Roach, F. E., Astrophys. J., 85, 213, (1937)
21. Bottlinger, K. F., Z. Astrophys. 4, 370, (1932)
22. Abbott, C. G., Astron. J., 28, 129, (1914)

1. ...
2. ...
3. ...
4. ...
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8. ...
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11. ...
12. ...
13. ...
14. ...
15. ...
16. ...
17. ...
18. ...
19. ...
20. ...
21. ...
22. ...

23. van Rhijn, P. J., Pub. Astron. Lab. Groningen, No. 22,
(1909)
24. Elvey, C. T., & Rudnick, F., Astrophys. J., 86, 342,
(1937)
25. Huruata, M., Pub. Astron. Soc. Japan, 2, 156, (1951)
26. Allen, C. W., Astrophysical Quantities, Athlone Press
(1955)
27. Bemporad, A., Mitt. Heidelberg, No. 4, (1904)
28. Moulton, F. R., Intro. to. Celestial Mechs., 2nd edition,
Macmillen & Co., New York, (1935)
29. Elsasser, H., Z. Astrophys., 33, 274, (1954)
30. Karimov, M. G., Astron. J. U.S.S.R., 27, 97, (1950)
31. Grotrian, W., Z. Astrophys., 8, 124, (1934)
32. Allen, C. W., Monthly Notices R. A. S., 106, 137, (1946)
33. van de Hulst, H. C., Astrophys. J., 105, 471, (1947)
34. Baumbach, S., Astron. Nach., 263, 121, (1937)
35. van Rhijn, P. J., Pub. Astron. Lab. Groningen, No. 43,
(1929)
36. Fesenkov, V. G., Astron. J. U.S.S.R., 26, 344, (1949)
37. Regener, V. H., Astrophys. J., 122, 520, (1955)
38. Tube Handbook, (Harrison, N. J., Radio
Corp. of America)
39. Link, M. F., J. des Observateurs, 17, 41, (1934)
40. Wempe, J., Astron. Nach., 275, 1, (1944)
41. Paetzold, H. K., Astron. Nach., 281, 17, (1952)
42. Elsasser, H., & Siedentopf, H., Z. Astrophys., 43, 132,
(1957)
43. Ashburn, E. V., J. Atmospheric & Terrestrial Phys., 5,
83, (1954)

23. van der ... (1907)
24. ... (1907)
25. ... (1907)
26. ... (1907)
27. ... (1907)
28. ... (1907)
29. ... (1907)
30. ... (1907)
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34. ... (1907)
35. ... (1907)
36. ... (1907)
37. ... (1907)
38. ... (1907)
39. ... (1907)
40. ... (1907)
41. ... (1907)
42. ... (1907)
43. ... (1907)

44. Chandrasekhar, S., Radiative Transfer, Oxford, (1950)
45. Elsasser, H., Mitt. Astron. Instituts U. Tubingen, Nr. 35, (1958)
46. Divari, N. B., Astron. J. U.S.S.R., 29, 49, (1952)
47. Fesenkov, V. G., Astron. J. U.S.S.R., 27, 89, (1950)
48. Astapovitch, I. S., Memoirs of the Ashkhabad State Paedagog. Inst., 1-2, 46, (1945)
49. Rozhkhovski, D. A., Astron. J. U.S.S.R., 27, 34, (1950)
50. Divari, N. B., & Asaad, A. S., Soviet Astronomy - AJ., 3, 320 (1959)
51. Divari, N. B., & Asaad, A. S., Astron. J. U.S.S.R., 36, 856, (1959)
52. Sandig, H. U., Mitt. Univ.-Sternw. Breslau, 5, 23, (1939)
53. Sandig, H. U., Astron. Nach., 272, 7, (1941)
54. Brunner, W., Publ. Eidgenoss.-Sternw Zurich, 6, (1935)
55. Dept. of Physics, U. of Colorado,
Special Report No. 4., 2, Contract
No. W19-122ac-9 (October, 1952)
56. Blackwell, D. E., Monthly Notices R. A. S., 116, 56, (1956)
57. van de Hulst, H. C., Bull. Astron. Inst. Netherlands, 11, 135, (1950)
58. Kloverstrom, F. A., & Rense, W. A., Astrophys. J., 115, 495, (1952)
59. Blackwell, D. E., Monthly Notices R. A. S., 116, 365, (1956)
60. Fath, E. A., Bull. Liek Obs., 5, 141, (1909)
61. Ramanathan, K. R., Nature, 129, 280, (1932)
62. Slipher, V. M., J. R. A. S. Canada, 23, 365, (1933)
63. Cabannes, J., & Dufay, J., Comptes Rendus, 201, 696, (1935)

44. C. ...
45. ...
46. ...
47. ...
48. ...
49. ...
50. ...
51. ...
52. ...
53. ...
54. ...
55. ...
56. ...
57. ...
58. ...
59. ...
60. ...
61. ...
62. ...
63. ...

64. Hoffmeister, C., Z. Astrophys., 19, 116, (1939)
65. Karimov, M. G., Izv. Astrofiz. Inst. AN Kaz SSR, 5, 120, (1957)
66. Karyagina, Z. V., Izv. Astrofiz. Inst. AN Kaz SSR, 5, 110, (1957)
67. Opik, E. J., Z. Astrophys., 35, 43, (1954)
68. Johnson, H. M., The Observatory, 78, 904, (1958)
69. Shklovskii, I. S., Soviet Astron. - AJ., 2, 516, (1958)
70. Blackwell, D. E. et al., Astrophys. J., 131, 15, (1960)
71. Beard, D. B., Astrophys. J., 129, 496, (1959)
72. Elsasser, H., Z. Astrophys., 37, 114, (1955)
73. Whipple, F. L., Astrophys. J., 121, 750, (1955)
74. Wyatt, S. P., & Whipple, F. L., Astrophys. J., 111, 134, (1950)
75. Whipple, F. L., & Gossner, J. L., Astrophys. J., 109, 380, (1949)
76. Rense, W. A., Astrophys. J., 115, 501, (1952)
77. Fesenkov, V. G., Soviet Astron. - AJ., 2, 475, (1958)
78. Fesenkov, V. G., Astrophys. J., 98, 129, (1943)
79. Fesenkov, V. G. Soviet Astron. - AJ., 2, 303, (1958)
80. Piotrowski, S. L., Acta. astr., Ser. A., 5, 115, (1953)
81. Kuiper, G. P., The Atmosphere of the Earth and Planets, p. 89, U. of Chicago Press, (1952)
82. Valley, G. E. & Wallman, H., Vacuum Tube Amplifiers, P. 484, McGraw-Hill, (1948)
83. Del Vecchio, P. J., Sky and Tel., 18, N. 10, 546, (1959)
84. Hodgman, D. G., Handbook of Chemistry & Physics, P. 2495, Chemical Rubber Publishing Co., 33rd Edition, (1951)

85. Regener, V. H., Scientific Report No. 3, Contract No. AF 19 (604) - 181, Air Force Cambridge Research Center, June 16, 1959
86. Seares, F. W., & Joyner, M., *Astrophys. J.*, 98, 261, (1943)
87. Eastman Kodak Reference Handbook, Eastman Kodak Company, Rochester, N.Y.
88. Downing, M., unpublished M. S. thesis, Physics Department, University of New Mexico, (1954)
89. The Henry Draper Catalog, *Harvard Annals*, 91 to 99, Harvard Press, (1922)
90. Johnson, H. L., *Astrophys. J.*, 116, 272, (1952)
91. Morgan, W. W., Harris, D. L., and Johnson, H. L., *Astrophys. J.*, 118, 92, (1953)
92. Cowan, M., unpublished M. S. thesis, Physics Department, University of New Mexico, (1951)
93. Trumpler, R. J., and Weaver, H. F., Statistical Astronomy, P. 419, University of California Press, 1953
94. Fesenkov, V. G., *Soviet Astron. - AJ.*, 2, 299, (1958)
95. Hardie, R., *Astrophys. J.*, 130, 2, P. 663, (1959)

82. [Faint text]
83. [Faint text]
84. [Faint text]
85. [Faint text]
86. [Faint text]
87. [Faint text]
88. [Faint text]
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