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The Intensity of Zodiacal Light

Allan F. Beck

BECK — THE INTENSITY OF ZODIACAL LIGHT

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By

Allan F. Beck

A Thesis

In partial fulfillment of the

Requirements for the Degree of

Master of Science in Physics

The University of New Mexico

1951

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[illegible]

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This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

E F Castetter
DEAN

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Thesis committee

Victor H. Regener
CHAIRMAN

Roy Thomas

John G. Breiland

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INTRODUCTION

Light of the Night Sky

The brightness of the light of the night sky has been a subject of systematic study for only the past fifty years. We all know that darkness is not complete even well after sunset and in the absence of moonlight. An opaque object placed between the observer and the sky remains visible by contrast, and one sees much more by light of the night sky than one can see in a darkened room.

The first and simplest explanation of this light of the night sky was proposed by Newcomb in 1901. He suggested that the light was entirely due to starlight--both from those stars which are distinctly visible and those which escape all modes of observation. But it has since been computed that the total light from all the stars including scattered starlight in the universe accounts for only about 30 per cent of the total brightness of the light of the night sky. Therefore, we must conclude that portions of the sky which are devoid of stars are contributing the major portion of the illumination observed on a moonless night. Table I, from Mitra,[1] lists the components of the light of the night sky and gives the percentages that each make up of the total. The study of the intensities measured in the region

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1 S. K. Mitra, The Upper Atmosphere (Calcutta, India: The Royal Asiatic Society of Bengal, 1948) p. 454.

CHAPTER I

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1 S. K. Mitra, *The Upper Atmosphere* (Calcutta, India: The Royal Asiatic Society of Bengal, 1948) p. 454.

of the zodiacal light, the second most important contributor to this light of the night sky after starlight has been subtracted, is the purpose of this paper.

TABLE I

COMPONENTS OF THE LIGHT OF THE NIGHT SKY

SOURCE	PERCENTAGE
Starlight, direct and scattered	30
Zodiacal light	15
Galactic light	5
Luminescence of night sky (Perm. Aurora)	40
Scattered light from the last three	10

Description of Zodiacal Light.

The zodiacal light is the faint glow of light that can be seen extending up to about 60 degrees above the horizon in the west after the disappearance of twilight, and in the east for several hours preceding the appearance of dawn. This phenomenon appears most visibly in the middle and lower latitudes, and is best seen when the ecliptic is most nearly perpendicular to the horizon.

The glow is seen as a pyramid of light whose base is approximately centered on the ecliptic and whose vertex deviates slightly from the ecliptic, being shifted toward the north in northern latitudes. The intensity of the cone of light is comparable to that of the milky way, being brighter near the center of the base and growing fainter out and up from the center of the base. This glow can be seen on the western horizon for as long as six hours after sunset,

with the pyramid of light sinking with the sun. Similarly it can be discerned in the eastern horizon as early as six hours preceding the sunrise, and the pyramid rises up with the sun until its base spreads out into the dawn. In very clear weather and in lower latitudes, the vertex of the pyramid can be seen to extend through the zenith and the eastern and western zodiacal lights merge, forming the zodiacal band stretching across the whole sky. At a point 180 degrees from the sun there is a spreading out of this band into a faint glow brighter than the adjoining portion, and this glow is called the gegenschein or counter glow. This glow is visible only when the anthelion falls in a dark region of the sky. It is believed by some authors that the zodiacal light stretches over the entire sky with its brightest portion lying along the ecliptic or zodiacal band.

Intensity of Zodiacal Light

The intensity of the zodiacal light pyramid reportedly varies considerably from night to night and also from hour to hour in a particular night. The glow is very weak several hours before the dawn, if one is observing the morning zodiacal light, and then as the pyramid rises up as the sun's depression angle decreases the intensity increases. The intensity also has its seasonal variations as the brightness of the zodiacal light is greatest when the ecliptic at the time of observation is most nearly perpendicular to the horizon. This makes fall and winter the best time to read morning

zodiacal light. Quantitative measurements[2] made in Texas by Elvey and Roach show maximum intensities for evening zodiacal light in April and May.

It is also believed by some investigators that there are large variations in zodiacal light coincident with magnetic storms,[3] and that the rapid variations in zodiacal light are coincident with solar outbursts associated with bright eruptions on the surface of the sun.[4]

Statement of the Problem

One of the important characteristics of the zodiacal light is its reported irregular fluctuations in intensity. Measurements of the fluctuations in relation to magnetic storms and sunspot activity are desirable. Measurements of the magnitude and direction of seasonal variations in zodiacal light would also be valuable in determining its origin and position.

The device described in this thesis is designed to measure and record these variations in intensity. Along with measurements of the zodiacal light star intensities must be measured for different elevations so that an extinction curve can be determined for the atmosphere. The data can then be corrected for the atmospheric extinction and also for background light due to atmospheric luminescence.

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2 C. T. Elvey and F. E. Roach, Astrophysical Journal, 85, 213 (1937).

3 E. O. Hulburt, Physical Review, 35, 1098 (1930).

4 Ibid., 34, 344 (1929).

CHAPTER II

DESCRIPTION AND CHARACTERISTICS OF APPARATUS

General

The experimental equipment consisted of a sixty inch parabolic mirror with a photomultiplier tube set at its focus. The signal from the photo-tube was amplified and fed into a discriminator circuit which gave a potential output varying in finite steps. This step-output was connected to the control grid of an oscilloscope tube, varying the intensity of the spot in finite steps. The spot was driven across the face of the tube in synchronization with the azimuth control of the mirror. The vertical deflection of the spot was controlled by the elevation control of the mirror. The spot on the oscilloscope screen was photographed, giving a record of a complete sweep of the sky on one negative. The complete sweep of the sky took eight minutes.

The Mirror and Mounting

The reflector, with its control apparatus and carriage, was a war surplus item manufactured by General Electric for the Armed Forces during World War II for use as a sixty inch searchlight. The arc assembly was removed and a 5819 photo-multiplier tube was mounted on the arc support. The searchlight carriage wheels were removed and the carriage was mounted by its rear hubs to a heavy U-frame which in turn was bolted to a level cement slab set solidly in the ground. This fixed end was oriented north, and slots were provided

in the U-frame so that it could be swung several degrees east and west for zeroing in. The other end of the carriage, on the south, was jacked up and bolted solidly in place with the carriage making an angle of 55° 20' with the horizontal. This supplied an equatorial mounting for the mirror, as the axis of the searchlight now pointed toward the celestial pole. This mount was adjustable with one inch bolts allowing for raising or lowering the elevated end. The mounting was checked by reading several sets of stars for hour angle and declination and making the necessary corrections until a star could be located directly by setting hour angle and declination. Rails were built alongside the searchlight on either side and a prefabricated building was mounted on these rails so that it could be moved over the equipment for protection when not in use. When in operation the building was moved to the north where it gave no interference with the readings. The photograph in Figure 1 shows the reflector on its equatorial mounting.

The motors to drive the searchlight housing in azimuth (now hour angle) and elevation (now declination) were retained as were the selsyn synchrogenerators to control the power for the motors. The selsyns were hooked through a switch to two different sets of control selsyns which were mounted in the control panel (see Figure 2) located in the observatory. One set of these control selsyns was driven automatically[5] and the other set was manually controlled for locating

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5 James D. Lindsay, "Determination of the Shape and Position of the Zodiacal Light by Use of an Automatic Recording Method," (unpublished Master's thesis, The University of New Mexico, Albuquerque, New Mexico, 1951).

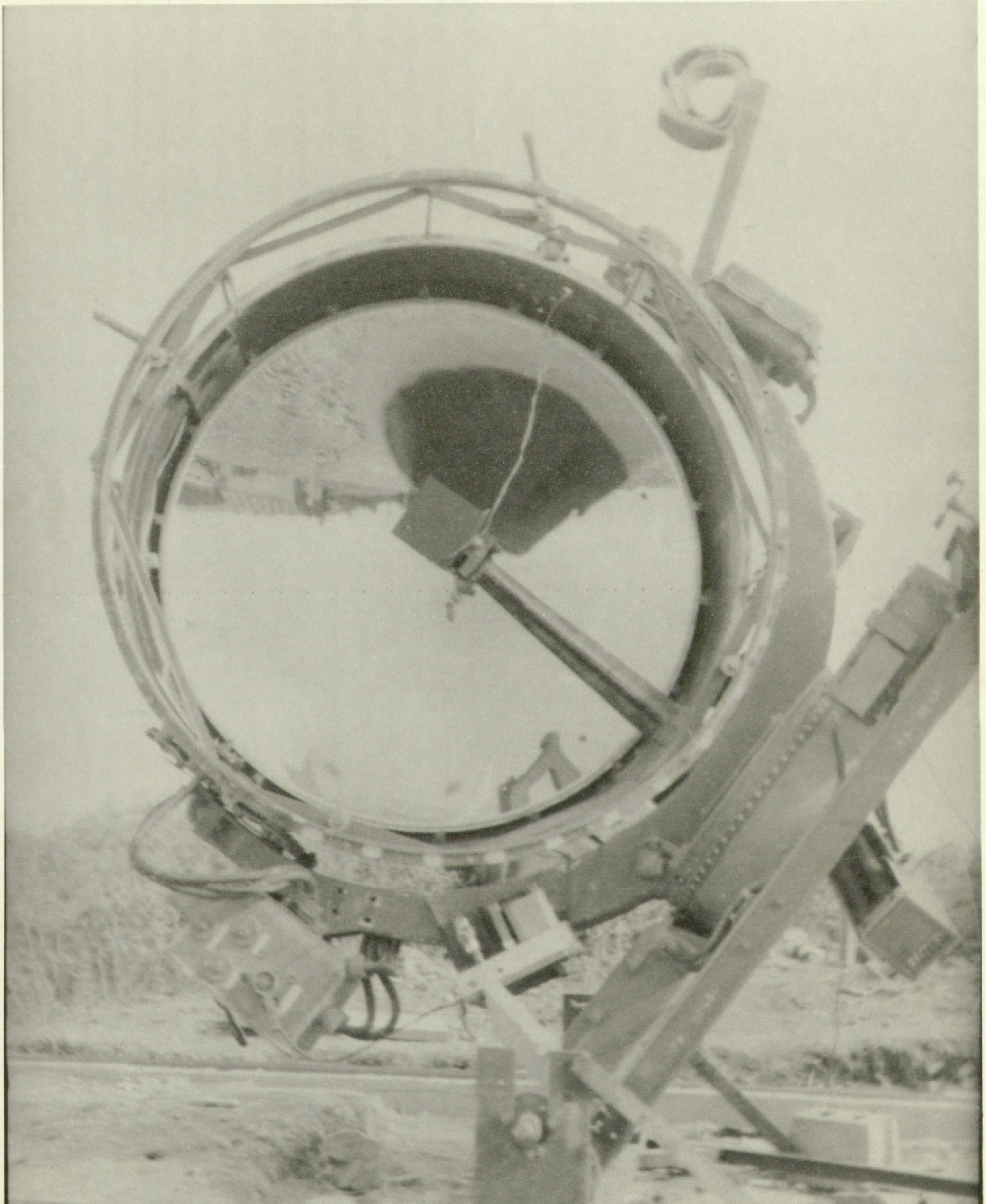

FIGURE 1

REFLECTOR IN EQUATORIAL MOUNTING POSITION

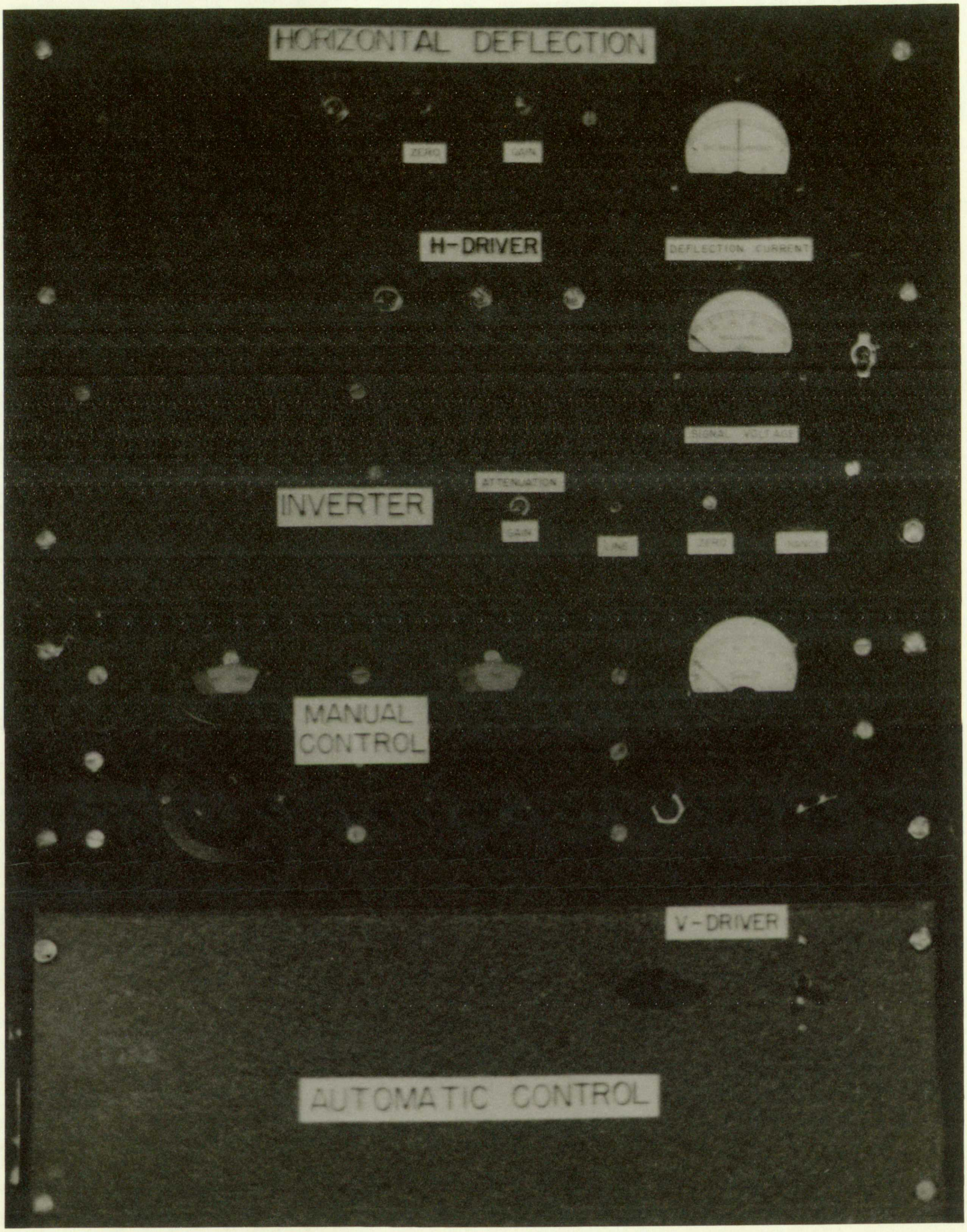

FIGURE 2

CONTROL PANEL NO. 1

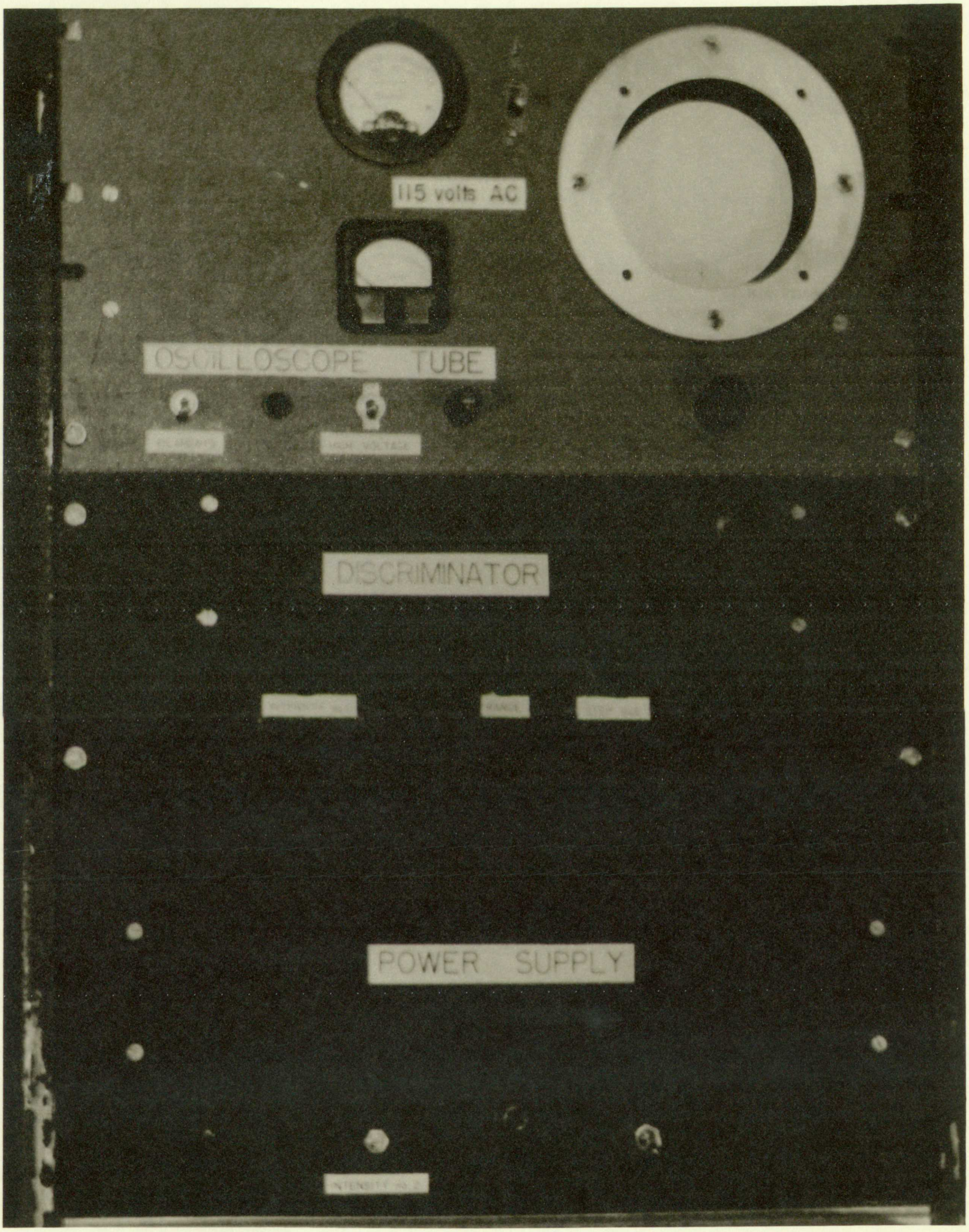

FIGURE 3

CONTROL PANEL NO. 2

particular stars for extinction and background readings.

Block Diagram

A block diagram showing the whole circuit of the experimental equipment is shown in Figure 4. The photomultiplier tube with its power supply and the amplifier with its power supply are both mounted on the searchlight unit. The power for these units and all other units in the circuit except the D. C. voltages was supplied by a 7.5 KW 115 volt AC gasoline driven generator. The reflector unit required 80 volts D. C. which was supplied by seven 12 volt storage batteries. The batteries were trickle-charged by an 80 volt D. C. motor which was driven by a pulley drive as a generator. These storage batteries also supplied the voltages needed on the automatic control units.[6]

The Photomultiplier Tube

The photomultiplier tube type 5819 contained ten stages with 90 volts per dynode. The response curve of the tube, shown in Figure 13, lies entirely in the visual range. The tube socket and chassis were mounted so that they could be adjusted in all directions for proper focusing of the light on the cathode. The face of the cathode was provided with adjustable apertures so that the amount of light falling on the surface of the cathode could be regulated to get the output of the tube in the proper range. These aperture changes were made in finite steps and a record kept of the tube aperture for each

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6 Ibid.

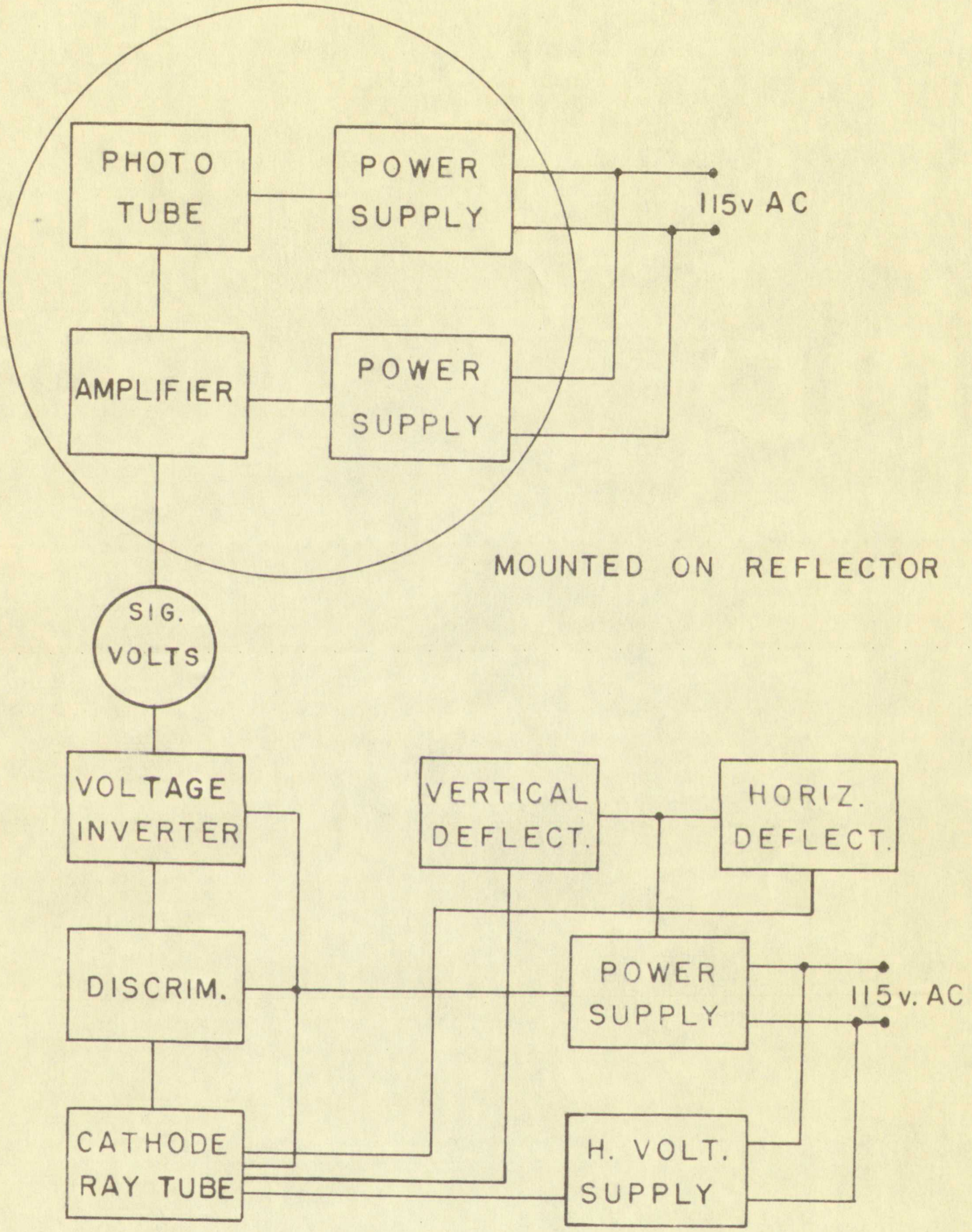

FIGURE 4

BLOCK DIAGRAM

reading. A magnetic shielding was placed over the tube in its mount as the photo tube is sensitive to the earth's magnetic field. Figure 5 gives the wiring circuit for the photomultiplier tube and Figure 6 gives the circuit of the power supply for the photo-tube. Figure 7 gives the orientation of the photo-tube with respect to the mirror of the searchlight.

The ten stages of the photomultiplier tube were each provided with ninety volts accelerating potential with a total potential between cathode and anode of about 900 volts D. C. The current caused by the background with an aperture of .346 cm diameter in front of the tube at these potentials was 0.2 microamps, and the zodiacal light current was in the range of 0.3 to 0.5 microamps. This plate current developed a potential across a 0.5 megohm resistor mounted in the phototube power supply, and the voltage across this output resistor was fed into the amplifier and then to the observatory. All leads from the photo-tube to the power supply and to the amplifier were shielded, as were the leads from the searchlight unit to the observatory.

Signal Voltmeter

It was pointed out under the discussion on the photo-tube that the output of the photo-tube went to the amplifier which was also mounted on the searchlight. From the amplifier the signal went through an underground lead cable to the observatory where the signal operated a voltmeter and a voltage inverter. The voltmeter was calibrated to read ten volts full scale, which was the linear range

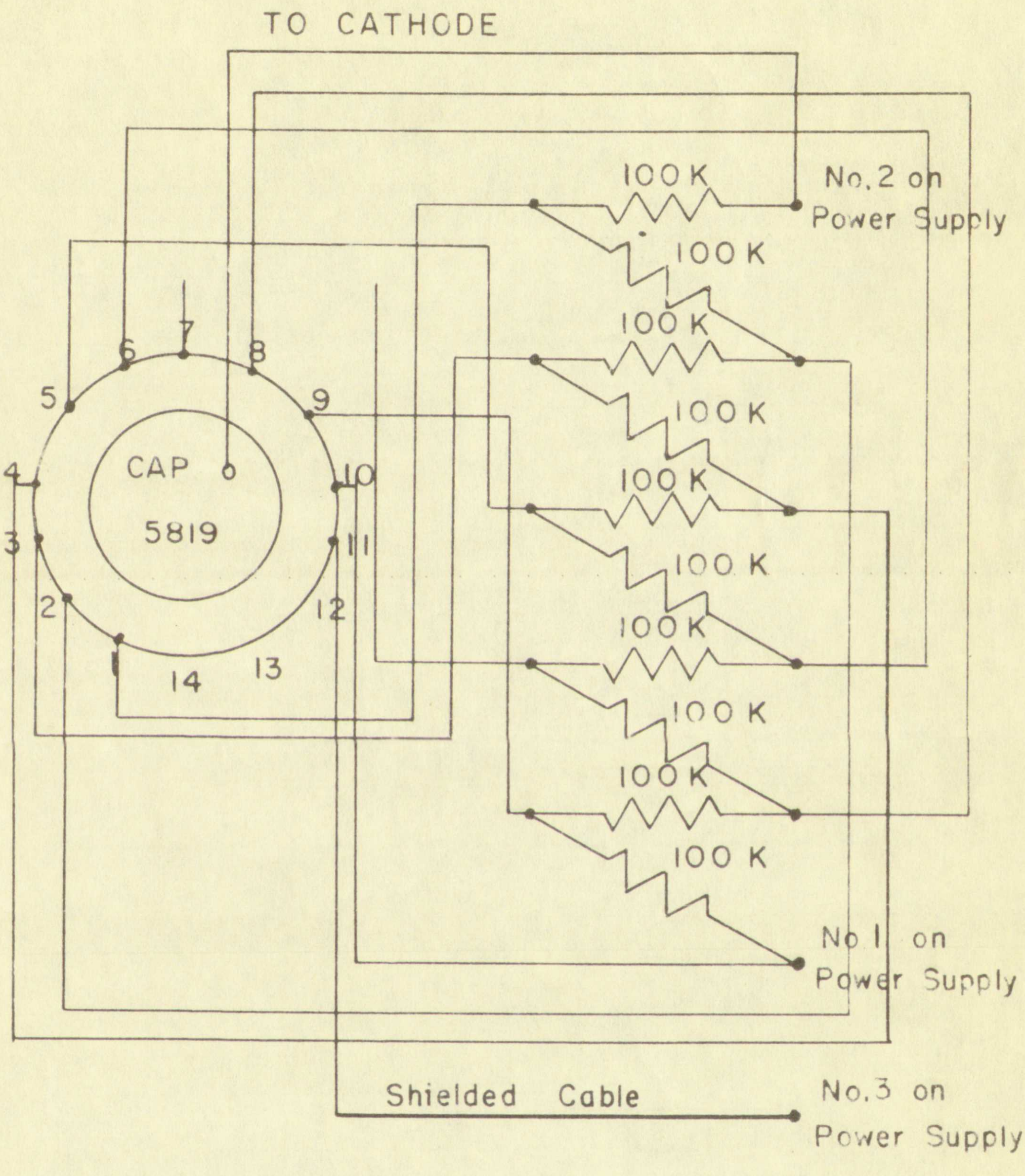

FIGURE 5

PHOTOMULTIPLIER CIRCUIT DIAGRAM

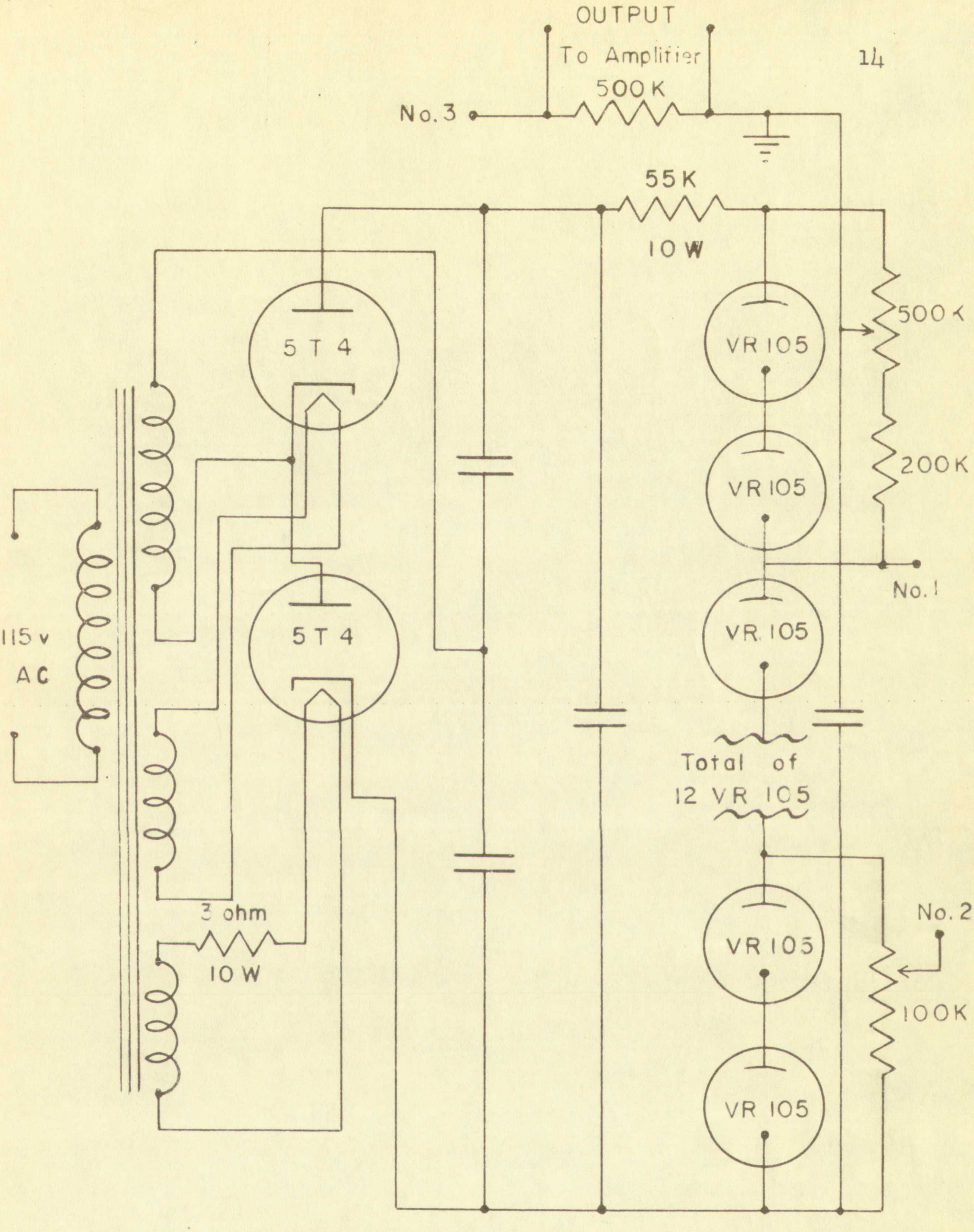

FIGURE 6

POWER SUPPLY FOR PHOTOMULTIPLIER

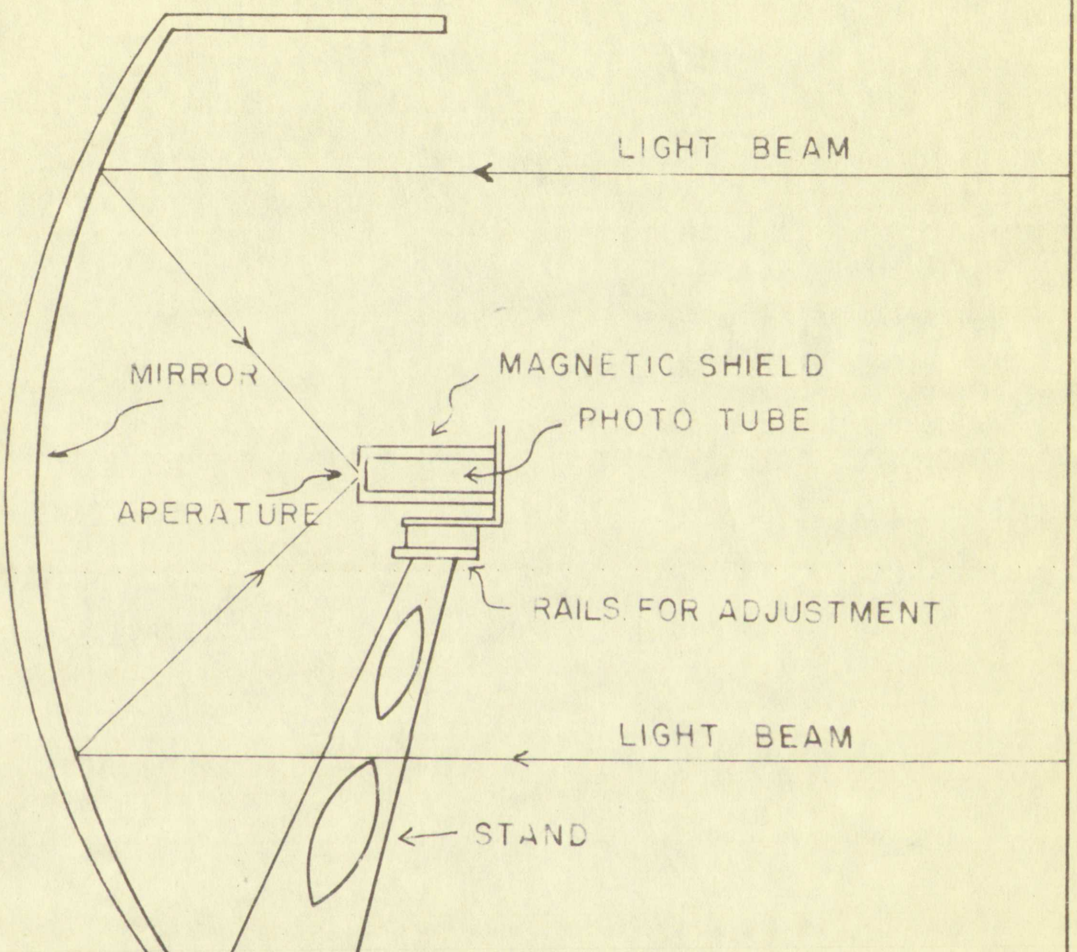

FIGURE 7

TUBE MOUNT ASSEMBLY IN REFLECTOR

of the amplifier. The signal on this voltmeter was what was read for star intensities in determining extinction data and background data. This was the indication, also, of the voltages at which each of the intensity steps occurred on the oscilloscope tube for the automatic recording device.[7] Polarization readings were also made on this signal voltmeter.[8] The position of this signal voltmeter with respect to the general circuit can be seen in Figure 4.

Oscilloscope Tube

The photo-tube signal was fed from the voltage inverter[9] to the discriminator.[10] The output of the discriminator was put onto the control grid of the oscilloscope tube. This output varied in finite steps and therefore the potential on the control grid of the oscilloscope tube varied in steps. This caused the intensity of the spot on the screen to vary similarly. The potential at which each of these steps occurred was recorded for each sweep of the sky and the position of these steps was varied to give an opportunity for drawing differently spaced isophotes on the negative. In this manner it was possible to spread or crowd the isophotes as desired,

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7 Ibid.

8 Maynard Cowan, "The Polarization of Zodiacal Light," (unpublished Master's thesis, The University of New Mexico, Albuquerque, New Mexico, 1951).

9 Cowan, op. cit.

10 Lindsay, op. cit.

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9 Cowan, op. cit.

10 Lindsey, op. cit.

depending upon the intensity of the zodiacal light. Figure 8 gives the circuit diagram for the oscilloscope tube and its power supply. The tube used was a 5FP7-A oscillograph tube. It has magnetic focusing and magnetic deflection with a long persistent screen. The useful diameter of the face of the tube was 4.25 inches. The anode operating voltage was 7000 volts with a variable potential of plus 200-300 volts on grid No. 2. This power supply obtained its power through an electronic voltage regulator as the output of the gasoline-driven generator was not sufficiently constant. The control grid potential varied from minus 20 to minus 30 volts. The focusing coil current was supplied by the power supply unit described by Cowan.[11]

Deflection Unit

The oscilloscope used was described above as having magnetic deflection. The deflection current was supplied by a magnetic oscillograph driver[12] whose circuit diagram is shown in Figure 9. Vertical and horizontal deflection each had its own unit, but both were identical. For the continuous horizontal deflection the signal going to grid C_2 was taken off a continuously rotating potentiometer that was driven by the D. C. motor driving the selsyn control. One end of this pot was connected to plus $1\frac{1}{2}$ volts and the other end was connected to minus $1\frac{1}{2}$ volts. Thus, the grid C_2 was driven successively plus and minus with respect to grid C_1. This gave current flowing

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11 Cowan, op. cit.

12 G. E. Valley, Jr., and H. Wallman, editors, Vacuum Tube Amplifiers, MIT Radiation Laboratory Series, vol. 18, (New York: McGraw-Hill Book Co., Inc. 1948), p. 481.

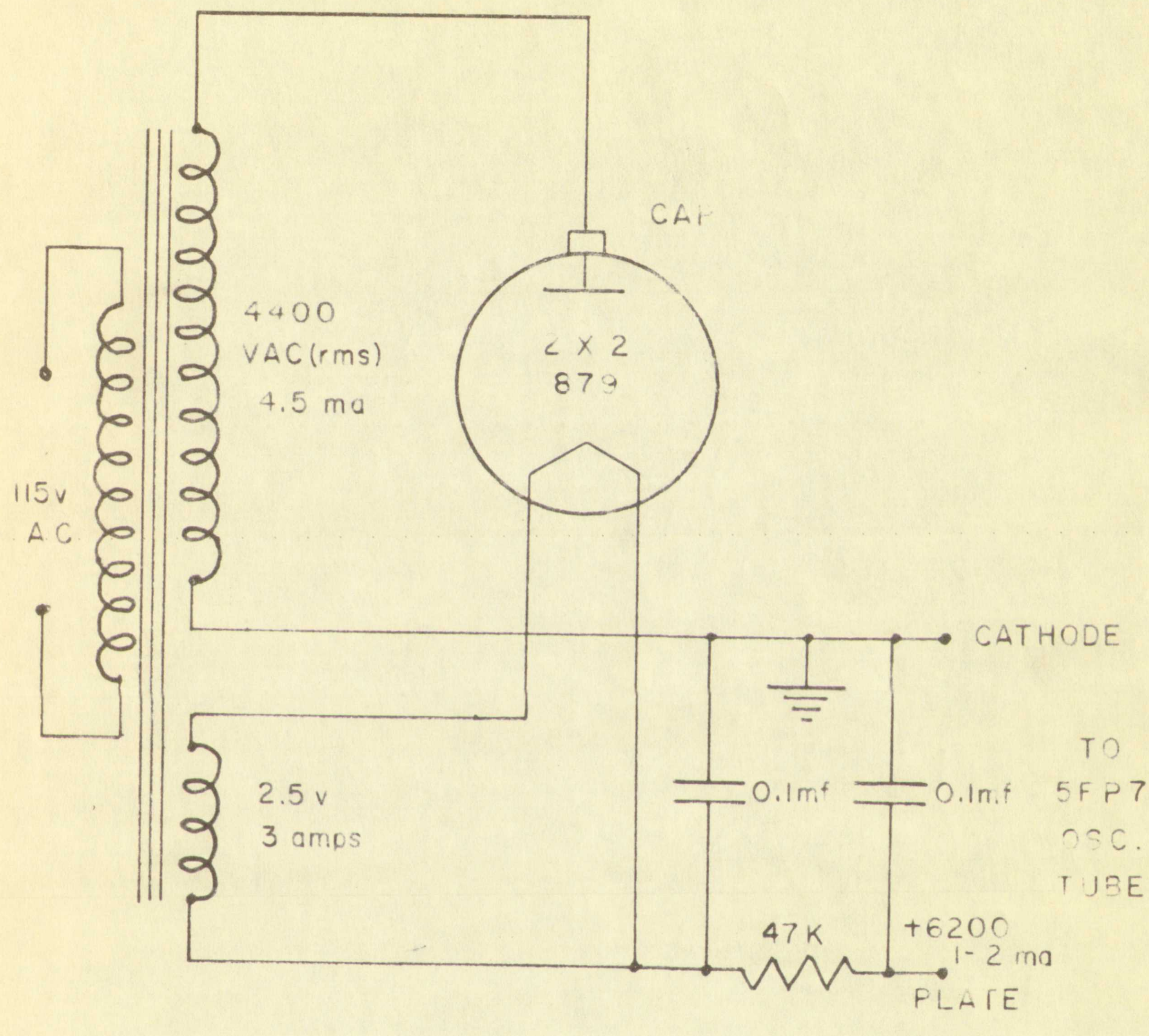

FIGURE 8

HIGH VOLTAGE POWER SUPPLY FOR 5FP7

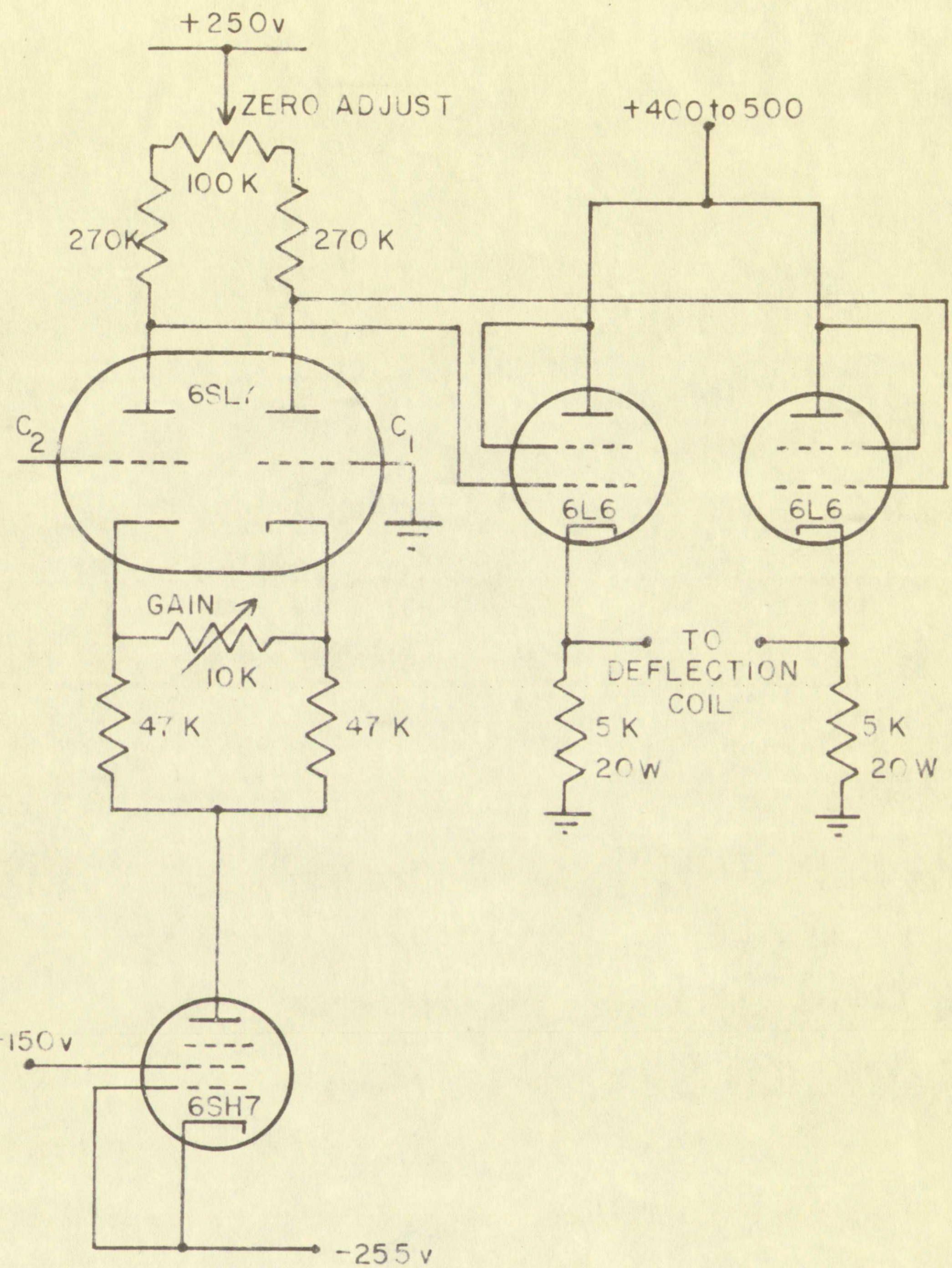

FIGURE 9

MAGNETIC OSCILLOGRAPH DRIVER

FIGURE 10

CAMERA MOUNT ON OSCILLOSCOPE TUBE

in one direction through the deflection coil when the grid C_2 was positive with respect to C_1 and the magnitude of the current was linear with respect to the potential difference between the two grids. Then when the two grids C_1 and C_2 were at the same potential no current flowed through the deflection coil. As grid C_2 went negative the current through the deflection coil reversed direction and deflected the spot in the opposite direction. The vertical deflection circuit was identical except that the voltage on C_2 was controlled in steps with respect to C_1 by the stepping relay[13] used to control the vertical selsyn control. These deflection units were found to be strictly linear as there is no grid current flowing at negative grid potentials with respect to the cathodes.

Camera Assembly

The face of the oscilloscope tube was continuously photographed during a sweep of the sky. As the searchlight rotated the spot on the oscilloscope tube moved horizontally across the screen. The spot was centered horizontally on the screen when the searchlight reflector had an hour angle of zero degrees. As the reflector went up three degrees declination after every complete revolution, the spot jumped up and made another horizontal track across the screen. As the signal from the discriminator changed, the spot intensity varied. This intensity variation, as previously mentioned, was in finite steps. Figure 10 shows the camera mount on the face of the

13 Lindsay, *op. cit.*

in one direction through the [illegible]

positive with respect to G_2 [illegible] of the current [illegible]

linear with respect to [illegible] between the two [illegible]

Then when the two grids G_1 and G_2 were at the same potential no cur-

rent flowed through the [illegible]. [illegible] grid G_2 [illegible]

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the spot in the opposite [illegible] deflection circuit

was identical except that [illegible] controlled [illegible]

with respect to G_1 by the [illegible] to control the verti-

cal selsyn control. These [illegible] found to be [illegible]

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tials with respect to the [illegible]

Camera Assembly

The face of the [illegible] photo-

graphed during a sweep [illegible] the

spot on the oscilloscope [illegible] the screen

The spot was centered [illegible] the screen [illegible]

reflector had an hour [illegible] the reflector [illegible]

up three degrees [illegible] revolution, [illegible]

jumped up and made another [illegible]

the signal from the discriminator [illegible]

This intensity variation, [illegible]

steps. Figure 10 shows [illegible] the face of the [illegible]

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13 Lindsey, op. cit.

oscilloscope tube. Figures 2 and 3 show the assembled control panels containing deflection units, power supply, oscilloscope tube, discriminator, voltage inverter, signal voltmeter, and manual and automatic selsyn controls.

CHAPTER III

EXPERIMENTAL RESULTS

Presentation of Data.

The observations were all made at South Capillo Peak in the Manzano mountains of New Mexico at an elevation of 9200 feet, and a location of 34° 42' N and 106° 24' W. The observation point was very ideal for measurements of zodiacal light or light of the night sky. The atmosphere was almost entirely free from dust and the nights were as haze free and cloud free as can be found anywhere. Being at such a high elevation also assured that none of the surrounding lights would lie close to the horizon and, therefore, interfere with the observations. The field of view was unobstructed in all directions.

As the searchlight made one complete sweep of the sky the camera, as discussed in the previous chapter, made a photograph of the spot on the oscilloscope screen. The photograph shown in Figure 11 is an example of this record. The horizontal lines on this photograph each represent a 360° sweep at a constant declination angle. The bottom line is at a minus 18° declination, and each successive line represents a rise of three degrees in declination. The seventh line up from the bottom is zero declination, or the celestial equator. The left edge of the celestial equator line is the west point of the projection and the right edge of the line is the east point of the projection. The length of the celestial equator represents an angular

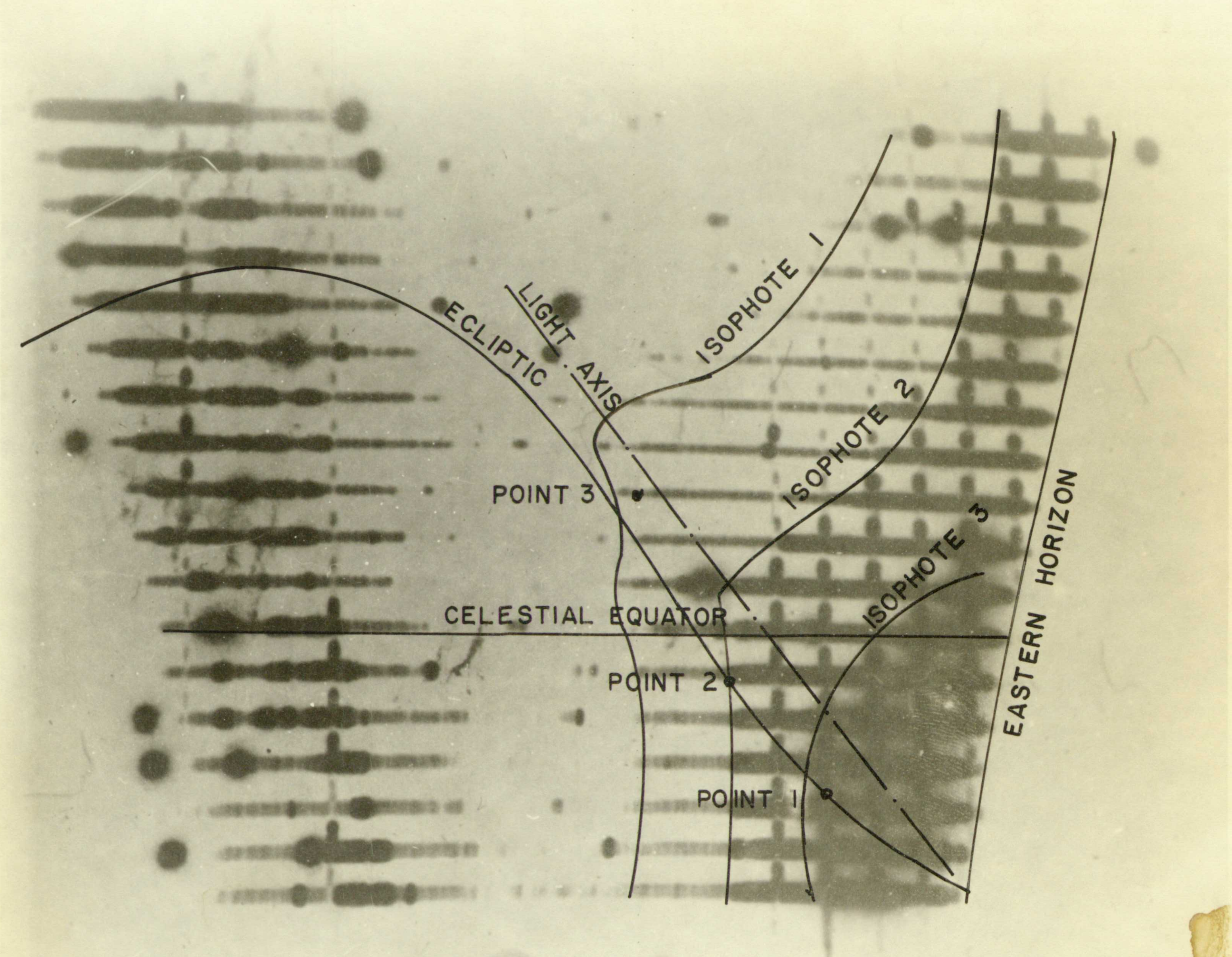

FIGURE 11

PHOTO TAKEN ON 9 DECEMBER 1950 AT 10^h 24^m LST

distance in hour angle of 180°. The vertical marks are hour angle marker pips with those on the right being ten degrees apart. The line drawn on the right edge of the picture represents the eastern horizon, and the left outline the western horizon. The isophotes are drawn in and it can be seen how the light axis lies to the north of the ecliptic.

The total angular distance in declination represented in the picture is 51°. The stepping arrangement which regulated the vertical deflection on the oscilloscope was so adjusted to give this stretching-out of the vertical projection against the horizontal projection. This stretching of the vertical scale is responsible for the great inclination of the ecliptic to the horizon. Figure 12 shows how the ecliptic actually is inclined to the horizon when the vertical scale is reduced to the same as the horizontal scale. The angle of inclination on the corrected scale measures 66°, whereas it measures 120° on the oscilloscope screen.

Determination of Extinction

The loss in intensity that a light ray experiences in passing through the atmosphere is termed the extinction. The extinction curve was obtained by measuring the intensities of certain stars, selected for their color index and range of intensities.[14] The stars used for this measurement were also selected to present the greatest variation in elevation angle for morning readings. These stars are listed in Table II.

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14 O. J. Eggen, Astrophysical Journal, 112, 145 (July, 1950).

distance in hour angle of 100°. The vertical marks are hour angle marker pips with those in the middle being ten degrees apart. The line drawn on the right edge of the picture represents the eastern horizon, and the left outline the western horizon. The isophotes are drawn in and it can be seen how the light axis lies to the north of the ecliptic.

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14 O. J. Eggen. Astrophysical Journal, 112, 145 (July, 1950)

EXPLANATION OF STRETCHING OF VERTICAL COORDINATE ON PHOTOGRAPH

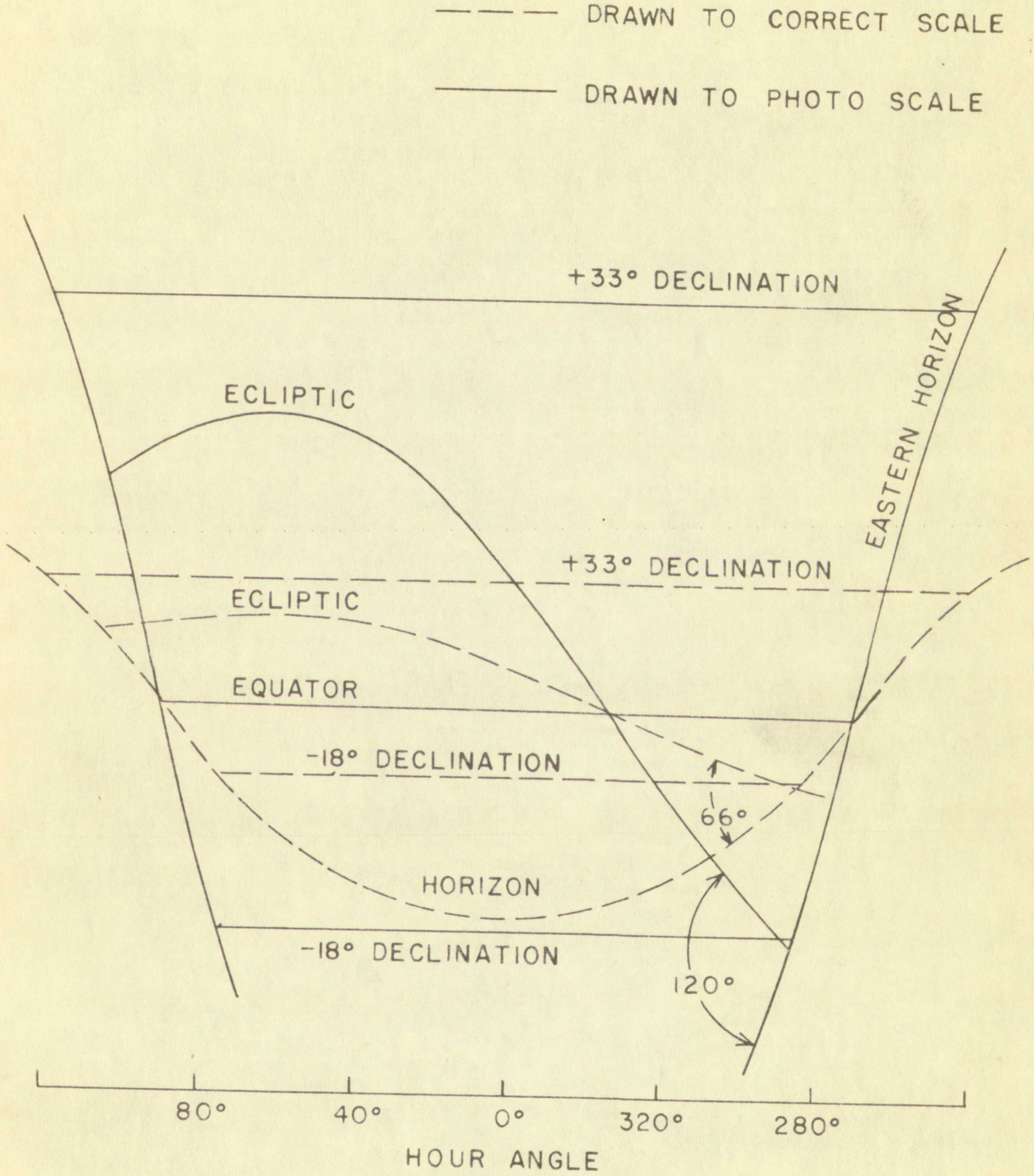

FIGURE 12

TABLE II

STARS USED FOR EXTINCTION READINGS

No.	Name	Right Ascension		Declination		Pg_p	Color Index
40	β Vir	11 hr	45 min	2°	20'	4.00 m	0.49 m
42	βC Vn	12	29	41	54	4.72	0.48
44	β Com	13	07	28	23	4.63	0.47
45	61 Vir	13	13	-17	45	5.21	0.60
47	η Boo	13	50	18	54	3.22	0.52
48	λ Ser	15	42	7	40	4.87	0.52
49	γ Ser	15	52	15	59	4.26	0.405
51	ζ Her	16	38	31	47	3.31	0.53

The reason that stars in the intensity range of 3.0 to 5.0 magnitude were chosen was so that readings could be made of the output of the photomultiplier amplifier without changing the gain of the amplifier.

Since the photo-tube also received light from a region of the sky around each star, it was necessary to make measurements of the sky background around each star. These background observations also gave data for studying the variation in the light of the night sky with elevation.

The color index was chosen to be in that range which is most nearly the range of the sun. The color temperatures[15] for stars having different color indices is given in Table III. Figure 13 gives the graphs of the normalized intensities for black body radiation at the color temperatures of the stars chosen for the extinction readings.

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15 H. N. Russell, R. S. Dugan, J. Q. Stewart, Astronomy II (Boston: Ginn and Company, 1938), p. 734.

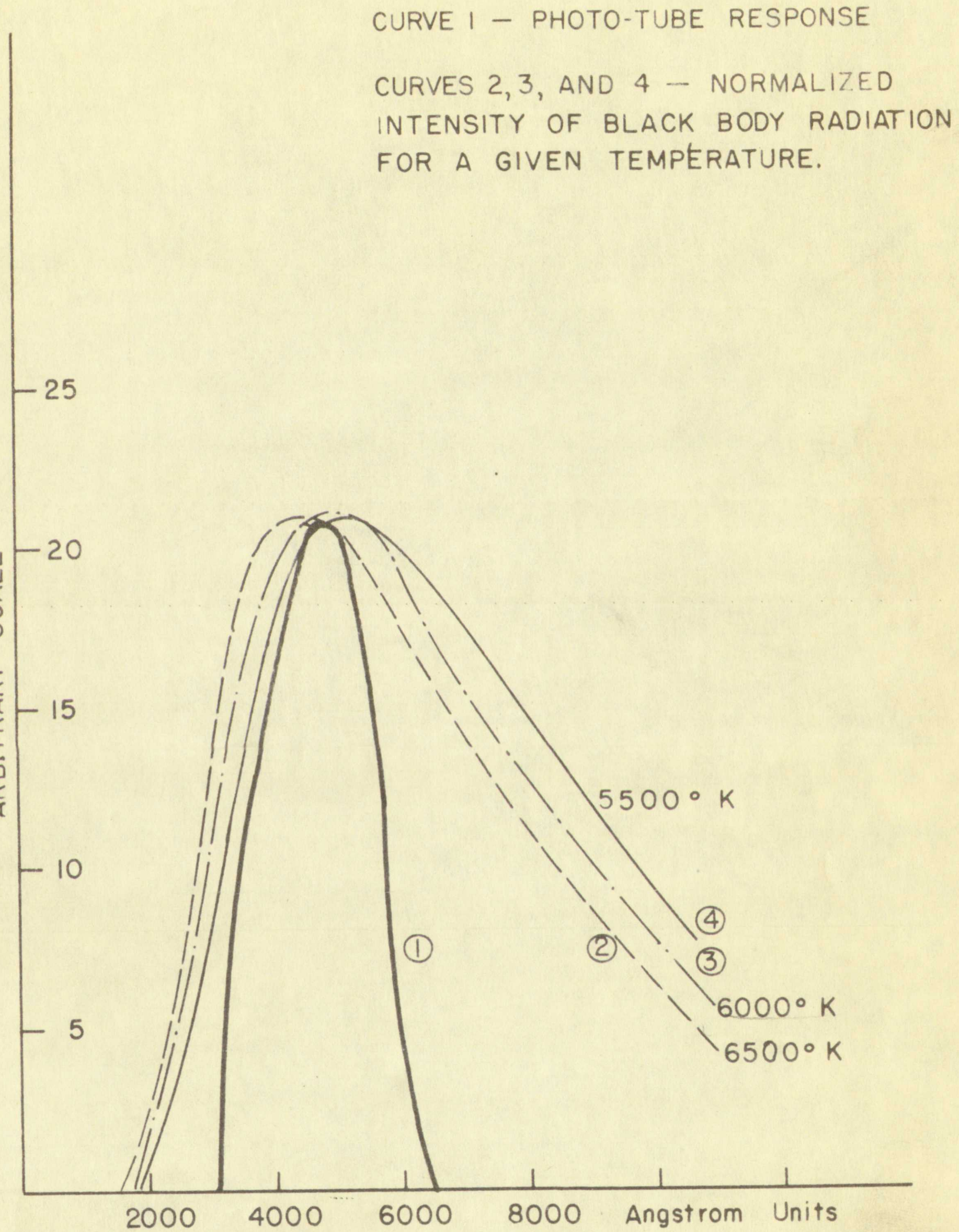

FIGURE 13

TUBE RESPONSE FOR A GIVEN WAVE LENGTH

The black body curves were normalized by multiplying by a suitable factor to give them all the same maximum reading on the ordinate. As the response of the photo-tube lay in the range of wave lengths for maximum energy radiation of the stars chosen and for the sun having an effective temperature of 6000° K, the photo-tube removed approximately the same percentage of radiation from each of the spectral energy distributions shown.

TABLE III

COLOR TEMPERATURES OF STARS

Spectrum	Color Index	Temp. °K
A0	0.00	11,200
A5	0.20	8,600
F0	0.33	7,400
F5	0.47	6,500
dG0	0.57	6,000
gG0	0.67	5,500
dG5	0.65	5,600
gG5	0.92	4,700

The intensity of a star, I_o, was determined by subtracting the background reading, I_b, from the meter reading of the star, I_s.

$$I_o = I_s - I_b$$

As these stars were of different magnitudes, it was necessary to correct their intensity readings to one magnitude in order to plot intensity against elevation angle. All intensity readings were, therefore, corrected to 4.00 mag. by means of the following relationship:

$$\frac{I_{4.00}}{I_n} = (2.512)^{(n - 4.00)}$$

where n is the magnitude of the star. Then, taking the logarithm, we get

$$\mathrm{Log}_{10} \frac{I_{4.00}}{I_n} = (n - 4.00)\ (0.4000)$$

These corrected intensities were then plotted against elevation, and the resulting curve represents the intensity of a star of 4.00 mag. at different elevations. The loss in intensity towards the horizon is due to extinction. Figure 14 shows a graph of the extinction curve for the morning of 18 December 1950 plotted together with an average extinction curve for visual light.[16] The average visual extinction is 0.23 mag. at 30° elevation; 0.45 mag. at 20°; 1.00 mag. at 10° and 1.70 mag. at 5°. As the response curve of the photo-tube lay right in the center of the visual wave length band, the average visual extinction curve should closely parallel the extinction curve of the photo-tube. Figure 14 shows that the two curves are very close together. Figure 15 gives the background intensity plotted as a function of elevation angle.

Correction to Data for Extinction

The photograph in Figure 11 gives the isophotes for $10^h\ 24^m$, Local Sidereal Time, 9 December 1950. The projection is in terms of hour angle and declination. In order to correct for extinction and background, both functions of elevation, it was found convenient to plot the isophotes on an elevation and azimuth graph. This graph is shown in Figure 16. The isophotes as taken from the photograph are the solid lines, and the dotted lines indicate the zodiacal light isophotes after correction for extinction and background. The ecliptic

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16 Ibid., p. 616.

where n is the magnitude of the star. Then, taking the logarithm, we get

$$\log_{10} \frac{I_{4.90}}{I_n} = (n - 4.90)(0.4000)$$

These corrected intensities were then plotted against elevation, and the resulting curve represents the intensity of a star of 4.90 mag. at different elevations. The loss in intensity towards the horizon is due to extinction. Figure 14 shows a graph of the extinction curve for the morning of 18 December 1950 plotted together with an average extinction curve for visual light.[16] The average visual extinction is 0.23 mag. at 70° elevation; 0.45 mag. at 20°; 1.00 mag. at 10° and 1.70 mag. at 5°. As the response curve of the photo-tube lay right in the center of the visual wave length band, the average visual extinction curve should closely parallel the extinction curve of the photo-tube. Figure 14 shows that the two curves are very close together. Figure 15 gives the background intensity plotted as a function of elevation angle.

Correction to Data for Extinction

The photograph in Figure 13 gives the isophotes for $10^4 S_{10}/°^2$, Local Sidereal Time, 9 December 1950. The projection is in terms of hour angle and declination. In order to correct for extinction and background, both functions of elevation, it was found convenient to plot the isophotes on an elevation and azimuth graph. This graph is shown in Figure 16. The isophotes as taken from the photograph are the solid lines, and the dotted lines indicate the zodiacal light isophotes after correction for extinction and background. The ecliptic

16 Ibid., p. 676.

STAR INTENSITY vs ELEVATION ANGLE

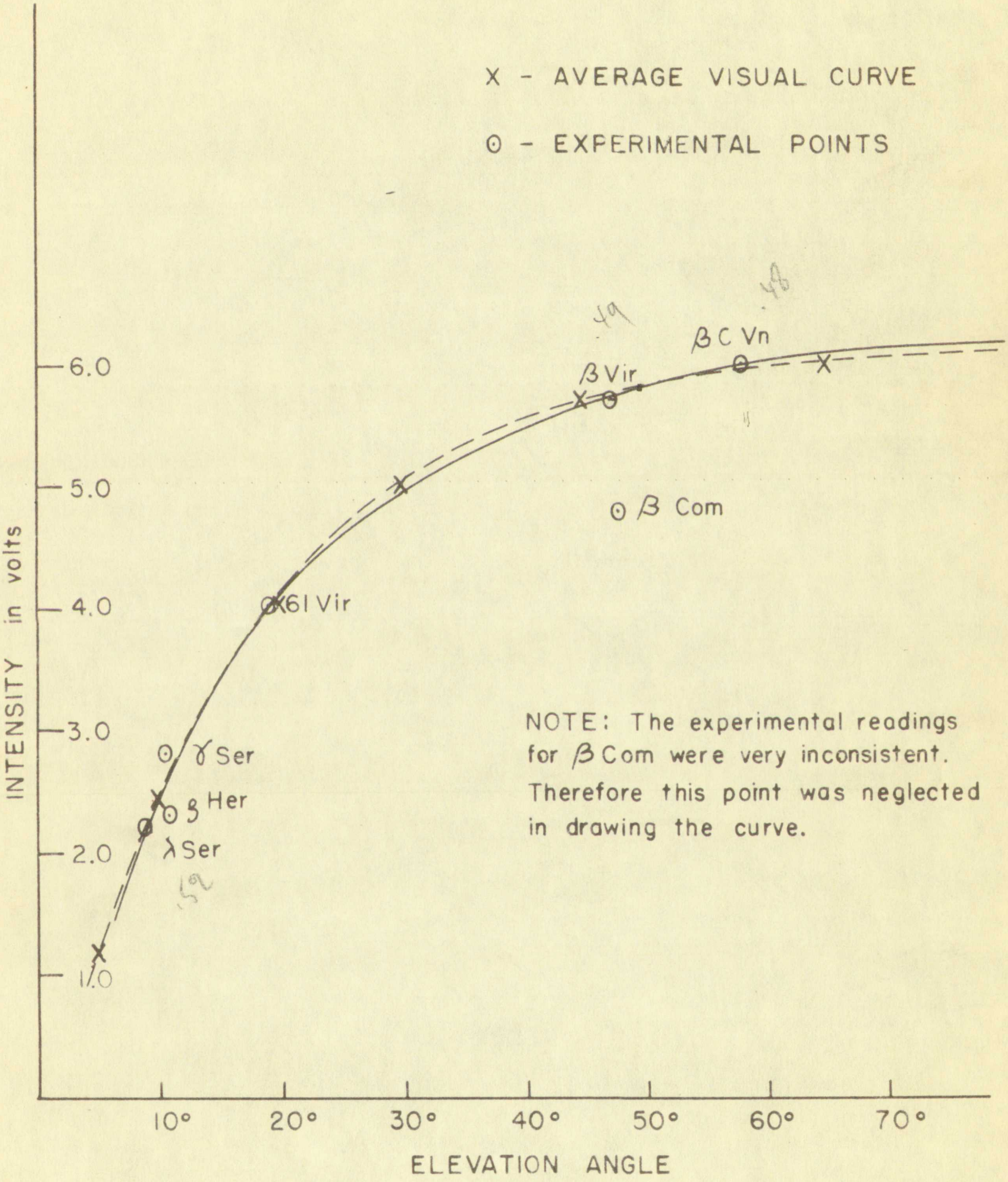

FIGURE 14

EXTINCTION CURVE FOR 18 DEC. 1950

BACKGROUND INTENSITY vs ELEVATION ANGLE

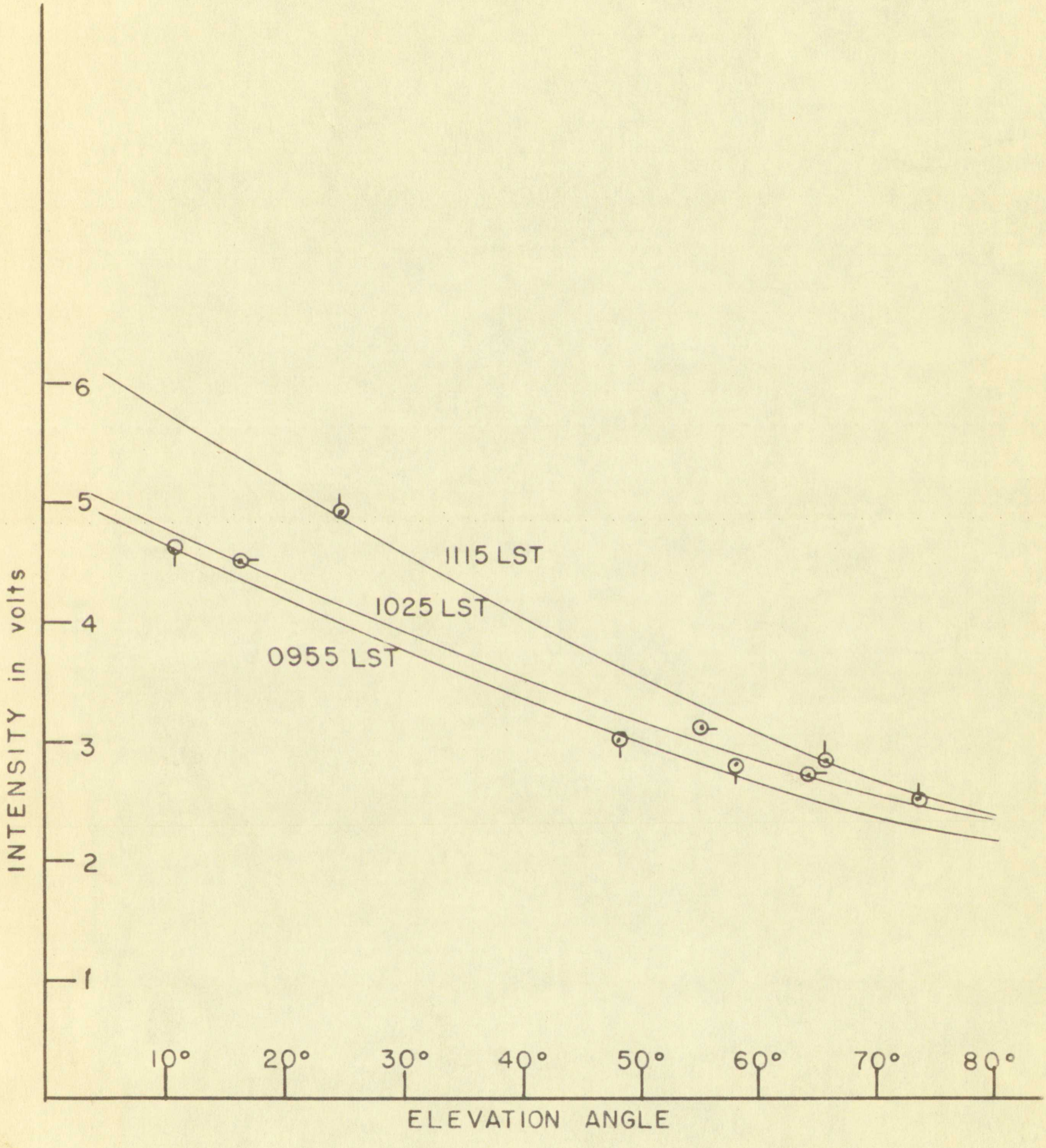

FIGURE 15

BACKGROUND CURVE FOR 18 DEC. 1950

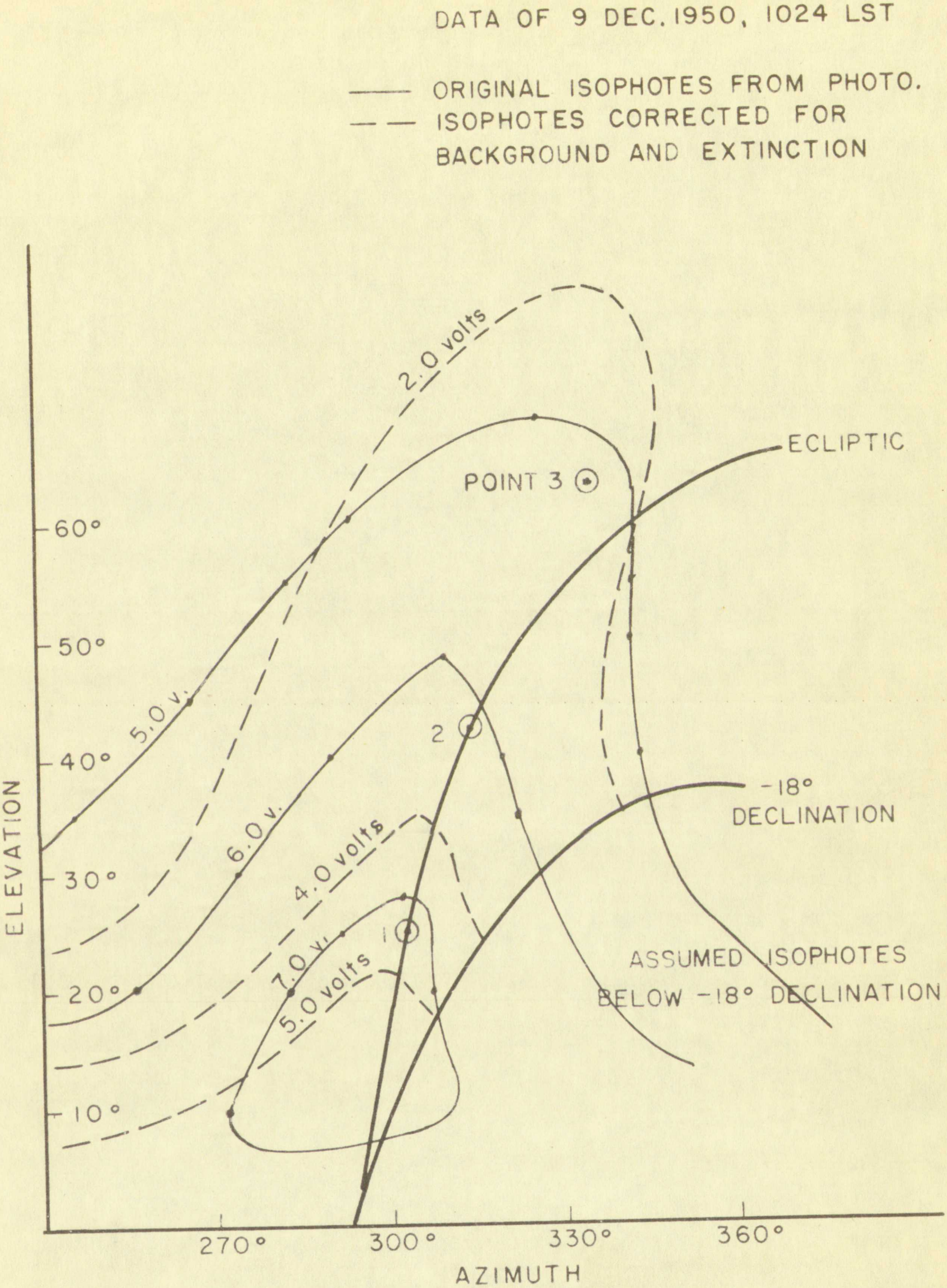

FIGURE 16

ISOPHOTES OF ZODIACAL LIGHT

is shown on the graph, as is the section of the sky that was not scanned because the mirror could not be depressed lower than minus 18° in declination.

The following procedure was used in making the corrections for extinction and background. The intensity of the background was subtracted from the voltage reading for each isophote for elevation angles in steps of five degrees. Then this resultant intensity was multiplied by a factor to correct for extinction. This gave an absolute intensity at each intersection of an isophote with every five degree elevation line, except that the background which was subtracted was assumed to contain no zodiacal light. Polarization readings of the light of the night sky indicate that zodiacal light extends over the whole sky,[17] and for greater accuracy in determining absolute intensities this fact should be corrected for also. Not having sufficient data to make this correction, the background readings used for Figure 16 are those as read on the meter. These absolute intensity values were then plotted on the graph and new isophotes drawn in by interpolating between the values on the graph. Table IV lists the data used in correcting the isophotes of Figure 11. The intensities were all given in terms of volts read on the signal voltmeter. The background and extinction data used in correcting the record of $10^h\ 24^m$, Local Sidereal Time, 9 December 1950, were obtained on 18 December 1950. However, as both nights were

17 Cowan, *op. cit.*

is shown on the graph, as it is that portion of the sky that was not scanned because the mirror could not be depressed lower than minus 15° in declination.

The following procedure was used in making the corrections for extinction and background. The intensity of the background was subtracted from the voltage readings for each isophote for elevation angles in steps of five degrees. Then this resultant intensity was multiplied by a factor to correct for extinction. This gave an absolute intensity at each intersection of an isophote with every five degree elevation line, except that the background which was subtracted was assumed to contain no zodiacal light. Polarization readings of the light of the night sky indicate that zodiacal light extends over the whole sky,[17] and for greater accuracy in determining absolute intensities this fact should be corrected for also. Not having sufficient data to make this correction, the background readings used for Figure 13 were those made on the meter. These absolute intensity values were then plotted on the graph and new isophotes drawn in by interpolating between the values on the graph. Table IV lists the data used in correcting the isophotes of Figure 13. The intensities were all given in terms of volts read on the signal voltmeter. The background and extinction data used in correcting the record of 19h 25m, Local Standard Time, 5 December 1950, were obtained on 18 December 1950, because, as both nights were

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17 Cowan, op. cit.

very clear and several of the same stars gave the same intensity readings, it was believed that the extinction data could be applied without loss of accuracy. Insufficient readings were taken on 9 December 1950 to draw an extinction curve for that date.

TABLE IV

DATA FOR CORRECTION OF ISOPHOTES
FOR PHOTO TAKEN AT 1024 LST ON 9 DECEMBER 1950

1	2	3			4	5		
ELEV.	BACK-GND.	ISOPHOTE CORRECTED FOR BACKGROUND			EXTINCTION FACTOR	ISOPHOTE CORRECTED FOR 2 AND 4		
A	I_b	$I_c = I_p - I_b$			f(A)	$I_a = I_c\,(f(A))$		
		I_p=7.7	=6.0	=5.0		I_p=7.7	=6.0	=5.0
5°	4.9v	2.8v	1.1v	0.1v	6.00	16.8v	6.6v	0.6v
10	4.7	3.0	1.3	0.3	2.40	7.2	3.1	0.7
15	4.6	3.1	1.4	0.4	1.76	5.5	2.5	0.7
20	4.4	3.3	1.6	0.6	1.46	5.0	2.4	0.9
25	4.2	3.5	1.8	0.8	1.33	4.7	2.4	1.0
30	4.0	3.7	2.0	1.0	1.23	4.6	2.5	1.2
35	3.8	3.9	2.2	1.2	1.15	4.5	2.5	1.4
40	3.6	4.1	2.4	1.4	1.11	4.5	2.7	1.5
45	3.5	4.2	2.5	1.5	1.07	4.5	2.7	1.6
50	3.3	4.4	2.7	1.7	1.03	4.5	2.8	1.8
55	3.1	4.6	2.9	1.9	1.00	4.6	2.9	1.9
60	2.9	4.8	3.1	2.1	1.00	4.8	3.1	2.1
65	2.7	5.0	3.3	2.3	1.00			2.3

Determination of Extinction Factor

With a clear sky, the decrease in intensity due to scattering is the major contribution to the extinction;[18] as the selective

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18 W. J. Humphreys, Physics of the Air (New York: McGraw Hill Book Company, 1940) p. 562.

absorption, diffraction, reflection, and refraction are secondary effects. A beam of light of intensity I will suffer a loss in intensity dI in penetrating a distance dx into a scattering medium. This is represented by the following formula:

$$dI = -k\,I\,dx$$

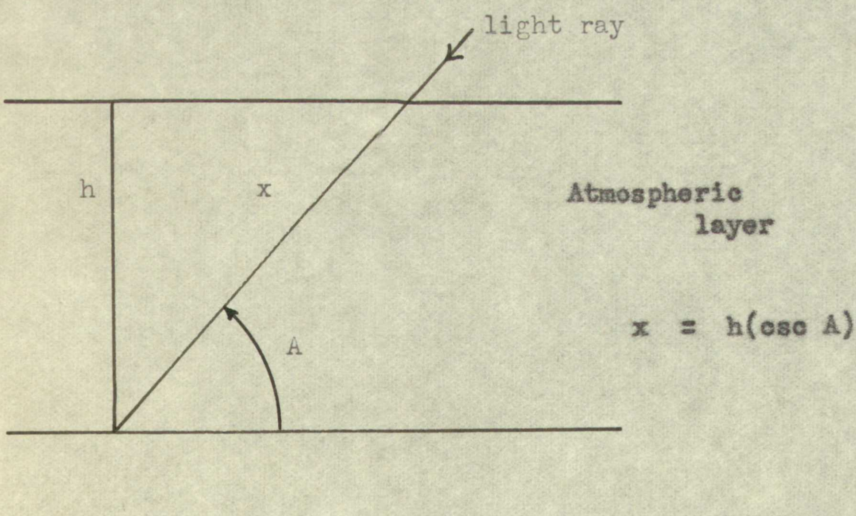
where k is the extinction coefficient. Integrating this expression over a distance x of scattering medium, gives:

$$\ln I - \ln I_o = -k\,x$$

$$I = I_o e^{-kx}$$

where I_o is the intensity of the light before entering the atmosphere.

Applying the data of the morning of 18 December 1950 to this equation and plotting ln I on the y- axis and csc A on the x-axis, we get the straight line graph as shown in Figure 17. The diagram below shows that the slope of the curve in Figure 17 represents the product of the extinction factor, k, and the thickness of the homogeneous atmosphere, h.



absorption, diffraction, reflection and refraction are secondary effects. A beam of light of intensity I will suffer a loss in intensity dI in penetrating a distance dx through a scattering medium. This is represented by the following formula:

$$dI = - k\, I\, dx$$

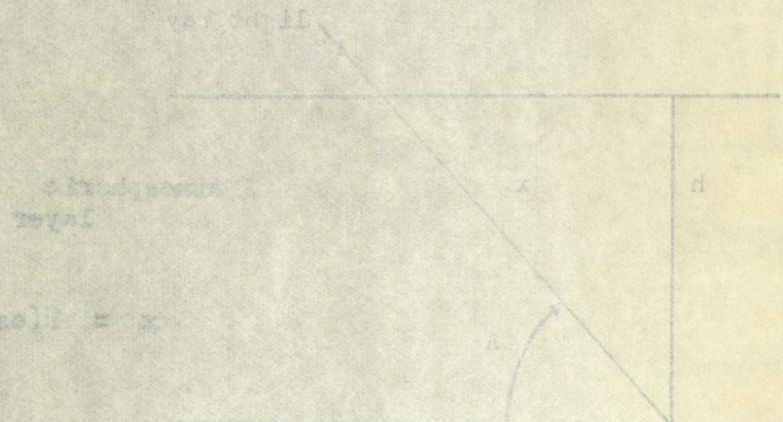
where k is the extinction coefficient. Integrating this expression over a distance x of scattering medium gives:

$$\ln I - \ln I_0 = - k x$$

$$I = I_0 e^{-kx}$$

where I_0 is the intensity of the light before entering the atmosphere.

Applying the data of the morning of 18 December 1950 to this equation and plotting ln I on the y-axis and sec A on the x-axis we get the straight line graph as shown in Figure 17. The diagram below shows that the slope of the curve in Figure 17 represents the product of the extinction factor, k, and the thickness of the homogeneous atmosphere, h.



STAR INTENSITIES FOR 18 DECEMBER 1950

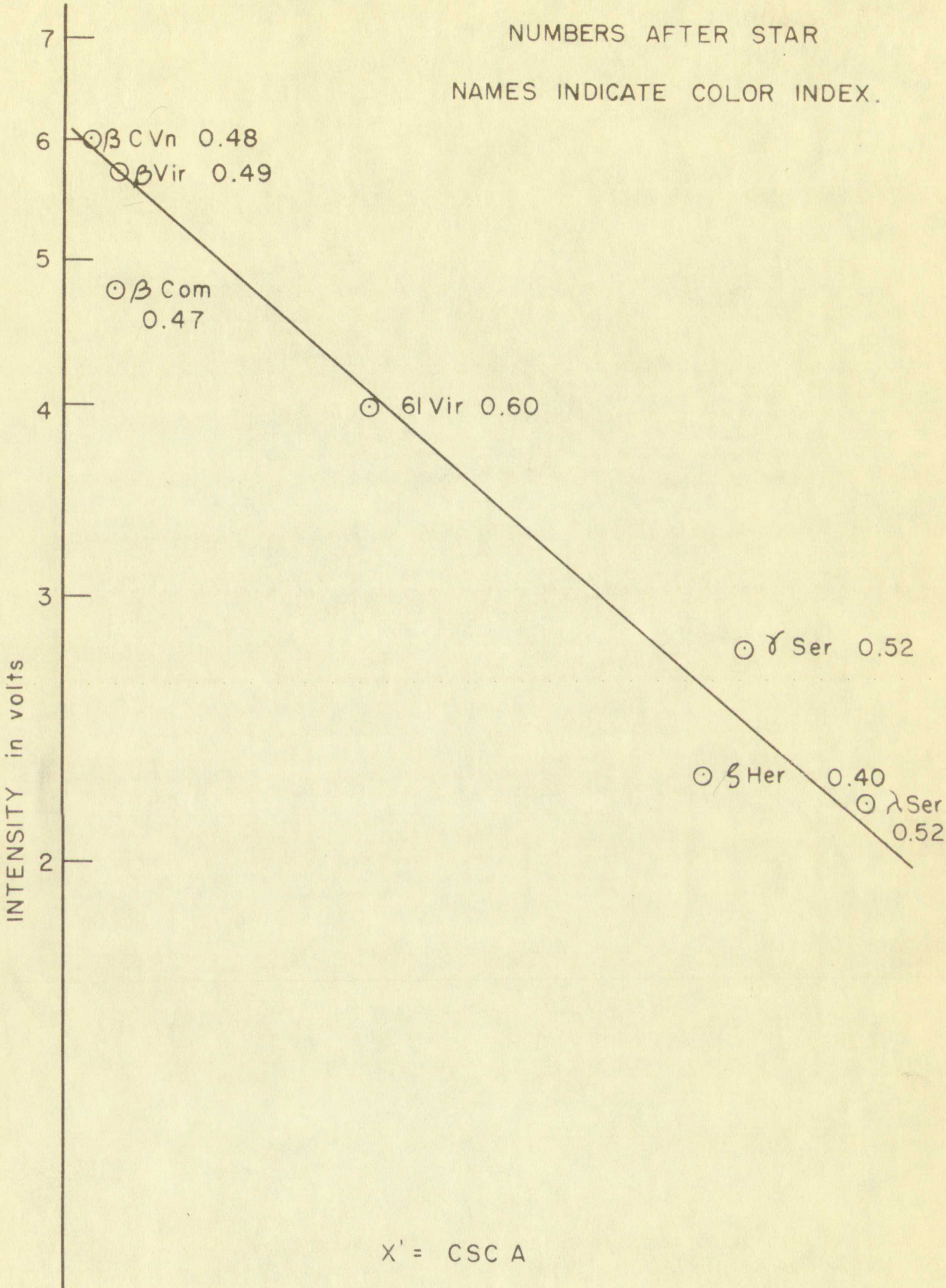


FIGURE 17

INTENSITY AGAINST COSECANT OF ELEVATION ANGLE

The equation for the intensity now becomes:

$$I = I_o e^{-kh\,(\csc A)}$$

And if we write this in form of the general equation, we get:

$$I = I_o\ e^{-mx'},$$

where the slope $m = kh$, and the new variable $x' = (\csc A)$. If we solve for k, by putting into the expression for m the value for h, the height of the homogeneous atmosphere,[19] corrected for the pressure at Capillo, we get a value for k, the extinction coefficient.

$$k = \frac{m}{h} = 1.5 \cdot 10^{-6}\ \text{cms}^{-1}$$

If we solve for the extinction coefficient from the formula for a scattering process[20] and using several different wave lengths, we get the following values for k.

$$k = \frac{32\pi^3(u - 1)^2}{n\,\lambda^4},$$

where u is the refractive index of air, and n is the number of molecules of air per cubic centimeter.

$$k_{(4000\,\text{Å})} = 4.3 \cdot 10^{-6}\ \text{cms}^{-1}$$

$$k_{(5000\,\text{Å})} = 1.8 \cdot 10^{-6}\ \text{cms}^{-1}$$

$$k_{(6000\,\text{Å})} = 0.8 \cdot 10^{-6}\ \text{cms}^{-1}$$

These figures show that the atmospheric absorption on Capillo Peak during the early morning of 18 December 1950 was almost entirely due to Rayleigh scattering only.

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19 *Ibid.*, p. 70.

20 *Ibid.*, p. 562.

The equation for the intensity now becomes

$$I = I_0 e^{-kH(\sec z)}$$

And if we write this in form of the general equation, we get

$$I = I_0 e^{-mx},$$

where the slope m = kH, and the new variable x = (sec z). If we solve for k, by putting into the expression for m the value for H, the height of the homogeneous atmosphere,[19] corrected for the pressure at Capillo, we get a value for k, the extinction coefficient:

$$k = \frac{m}{H} = [illegible] \cdot 10^{-6}\ cm^{-1}$$

If we solve for the extinction coefficient from the formula for a scattering process[20] and using several different wave lengths, we get the following values for k:

$$k = \frac{32\pi^3(\mu - 1)^2}{n\lambda^4}$$

where μ is the refractive index of air, and n is the number of molecules of air per cubic centimeter:

$$k_{(4000\ Å)} = [illegible] \cdot 10^{-6}\ cm^{-1}$$

$$k_{(5000\ Å)} = [illegible] \cdot 10^{-6}\ cm^{-1}$$

$$k_{(6000\ Å)} = [illegible] \cdot 10^{-6}\ cm^{-1}$$

These figures show that the atmospheric absorption at Capillo during the early morning of [illegible] was almost entirely due to Rayleigh scattering only.

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19 Ibid., p. [illegible].

20 Ibid., p. [illegible].

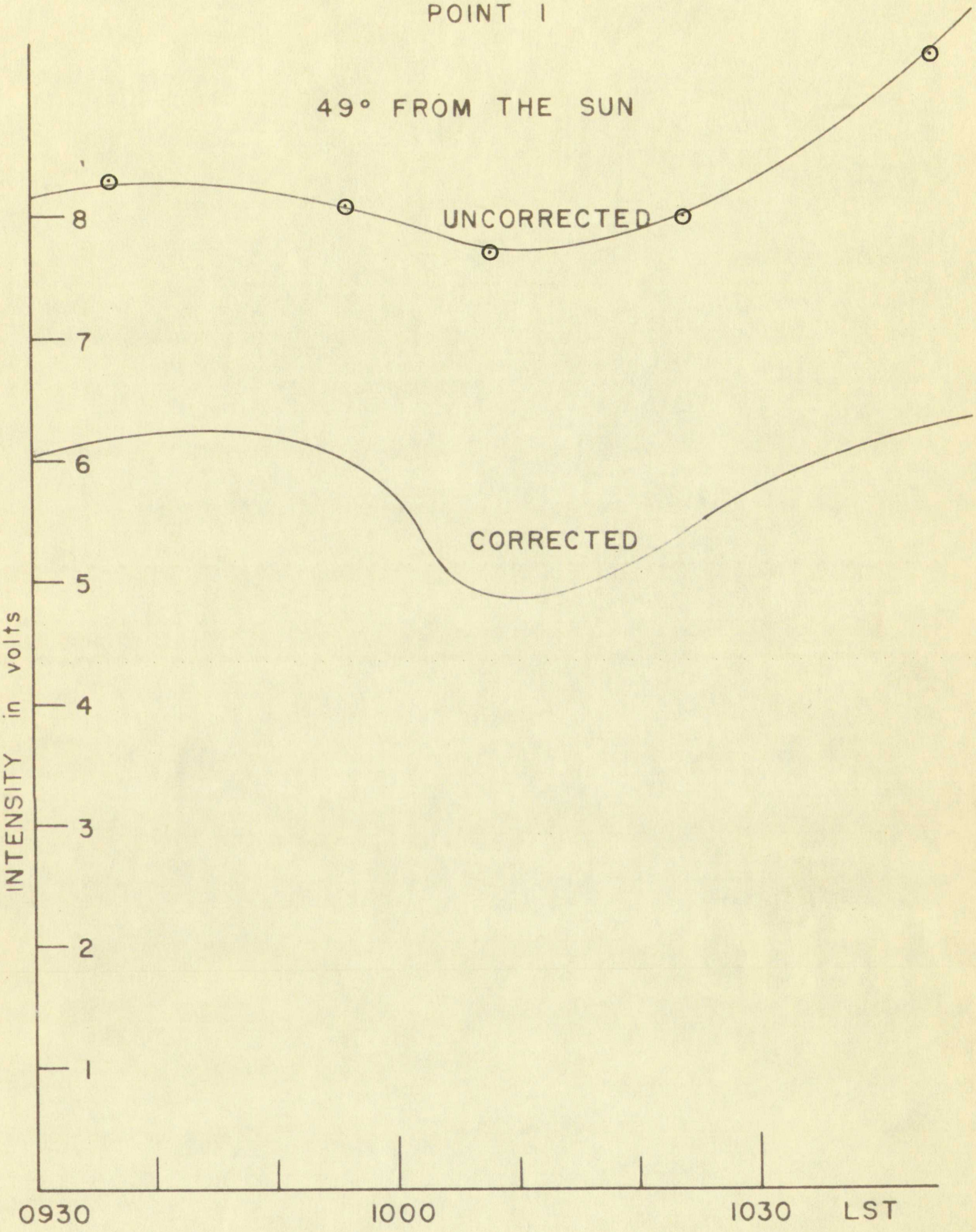

FIGURE 18

INTENSITY VARIATION WITH TIME

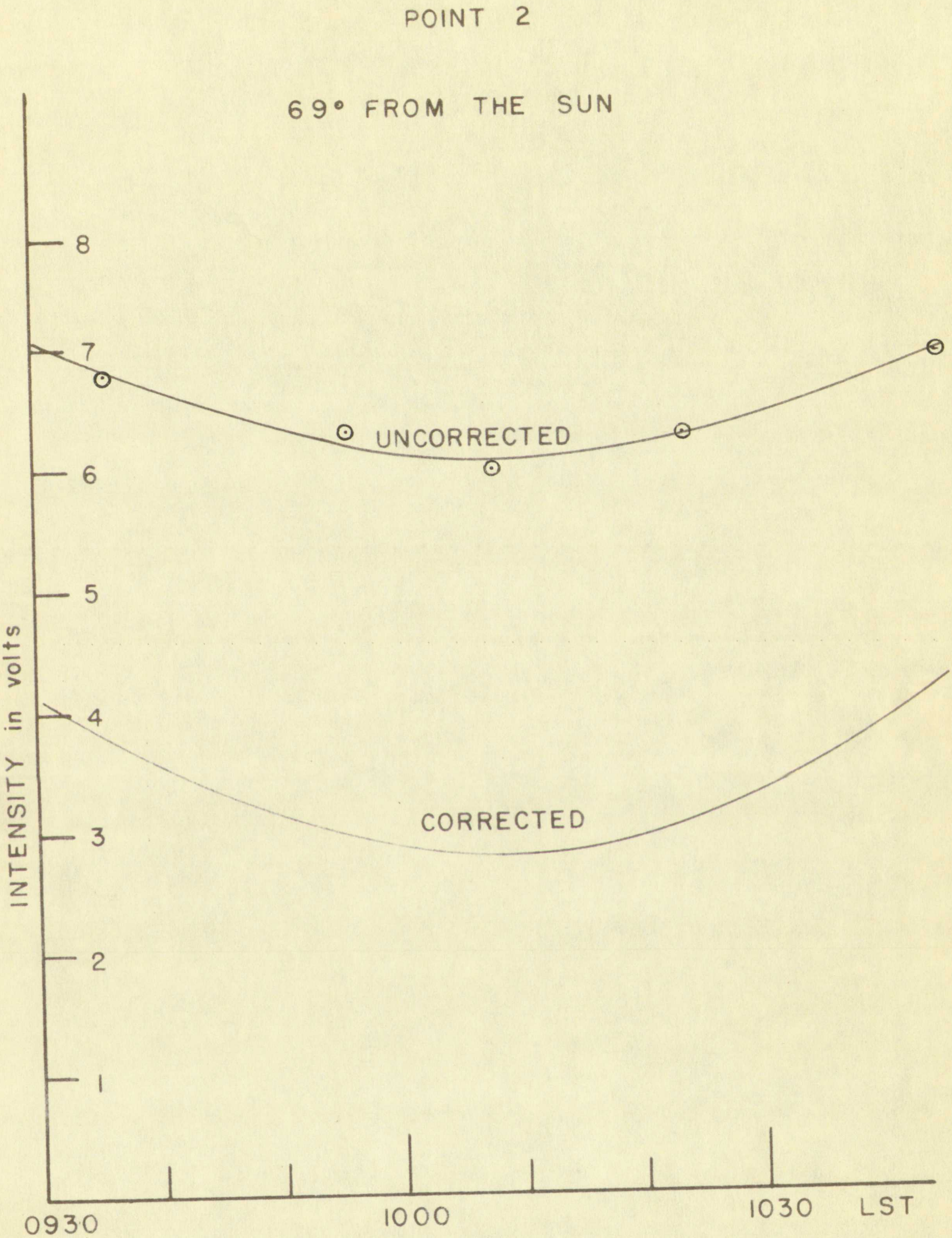

FIGURE 19

INTENSITY VARIATION WITH TIME

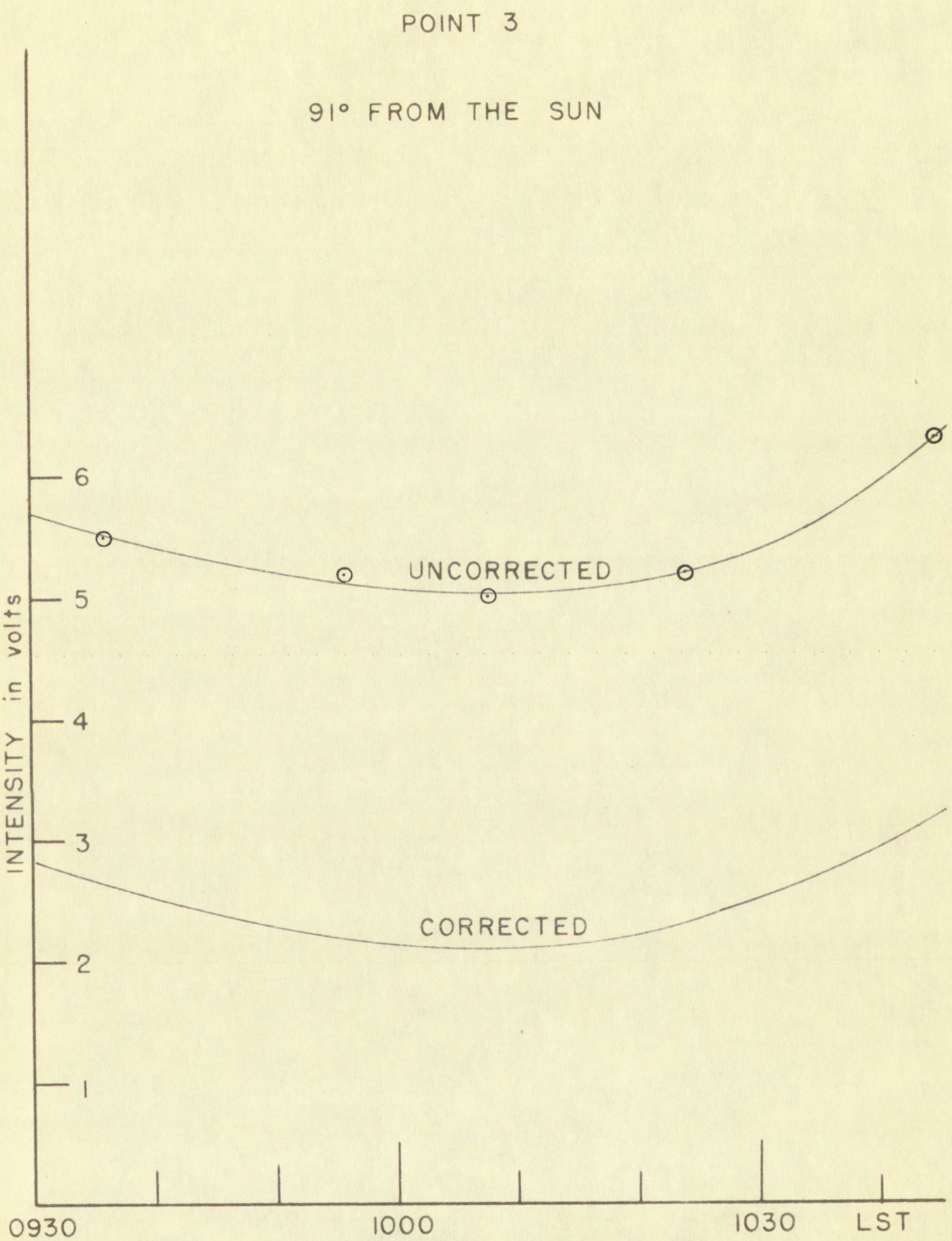

FIGURE 20

INTENSITY VARIATION WITH TIME

Intensity of Zodiacal Light

It was of interest to determine how the intensity of the zodiacal light varied with time during one night at a point in the sky having fixed right ascension and declination. Graphs in Figures 18, 19 and 20 represent intensity, in volts, plotted against local sidereal time for the readings taken on the morning of 9 December 1950. The graphs give both the uncorrected intensities read from the photographs and the intensities corrected for background and extinction for each of three points. The points 1, 2, and 3 chosen for these readings are shown plotted on the photograph in Figure 11, and also in the elevation and azimuth graph of Figure 16.

The intensity in volts being an arbitrary scale, it was decided that the intensity readings should be reduced to magnitude per square degree. The graph of Figure 14 gave the intensity reading in volts, corrected for background, for a star of 4.00 magnitude. The graphs in Figures 18, 19 and 20 gave the corrected intensities in volts for points 1, 2 and 3. These intensity readings represented the energy incident upon the photo-tube through a 0.346 cms. circular aperature. The solid angle subtended by this aperature was $2.33 \cdot 10^{-5}$ steradians or .0765 square degrees. Multiplying each intensity reading by the factor $\frac{1}{.0765}$ thus converted the intensity to what it would have been for a solid angle of one square degree. Then, using the relationship

$$\frac{I_n}{I_m} = (2.512)^{(m - n)},$$

Intensity of Zodiacal Light

It was of interest to determine how the intensity of the zodiacal light varied with [illegible] at a point in the sky having fixed right ascension and declination. Graphs in Figures 18, 19 and 20 represent intensity, in volts, plotted against local sidereal time for the readings taken on the morning of [illegible] December 1950. The graphs give both the uncorrected intensities read from the photographs and the intensities corrected for background and extinction for each of three points. The points 1, 2, and 3 chosen for these readings are shown plotted on the [illegible] in Figure 11, and also in the elevation and azimuth graph of Figure 16.

The intensity in volts being an arbitrary scale, it was decided that the intensity readings should be [illegible] per square degree. The graph of Figure [illegible] gave the intensity reading in volts, corrected for background, for a star of 1.00 magnitude. The graphs in Figures 18, 19 and 20 gave the corrected intensities in volts for points 1, 2 and 3. These intensity readings represented the energy incident upon the photo-tube through a [illegible] aperature. The solid angle subtended by this aperture was [illegible] 10^{-5} steradians or [illegible] square degrees. [illegible] reading by the factor $\frac{1}{[illegible]}$ thus converted the intensity [illegible] it would have been for a solid angle of one square degree. Then, using the relationship

$$\frac{I_b}{I_s} = ([illegible])([illegible])$$

DATA FOR 9 DECEMBER 1950

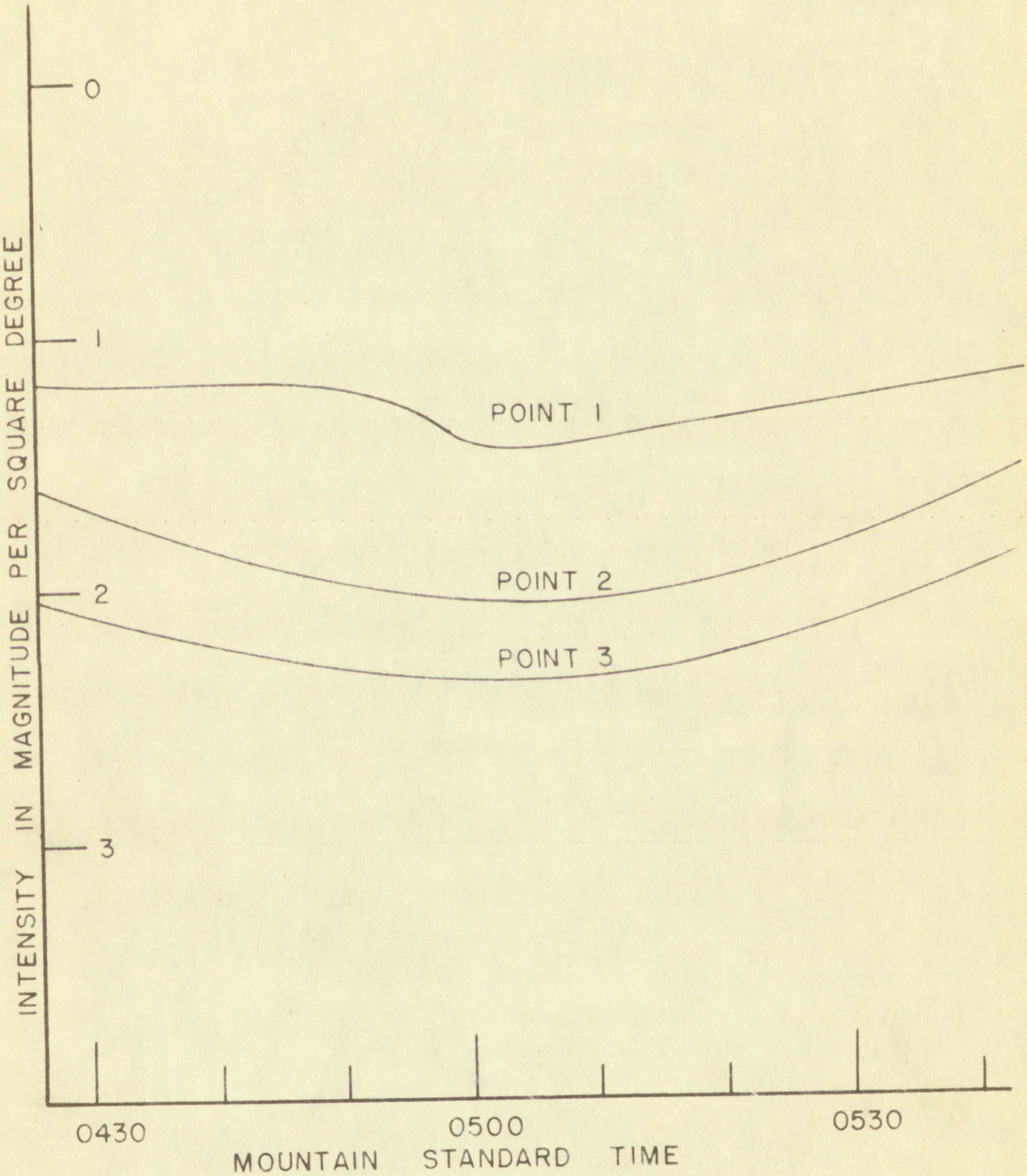

FIGURE 21

INTENSITY VARIATION WITH TIME

where I_n is the intensity in volts for a star of magnitude n, and I_m is an intensity in volts for a star of magnitude m; the magnitude could be determined of the star which would give the same intensity reading in volts as the reading from one square degree of the sky. Table V gives the magnitudes represented by different intensity readings of points 1, 2, and 3. Figure 21 shows the intensities of points 1, 2, and 3 plotted in terms of magnitude per square degree against mountain standard time. Sunrise on this date was at 0701 M.S.T.

TABLE V

MAGNITUDE PER SQUARE DEGREE FOR DIFFERENT INTENSITY READINGS

Intensity reading on voltmeter	Volts per square degree of sky	Magnitude of star giving same intensity
6.0 v	78.5 v	1.22 m
5.0	65.4	1.42
4.0	52.3	1.67
3.0	39.2	1.98
2.5	32.7	2.18
2.0	26.2	2.42

The variation in the intensity of the morning zodiacal light is very pronounced in the data of December 9, 1950. Figures 18, 19, 20, and 21 show that for each of the three points chosen, all lying on or near the ecliptic and in the cone of zodiacal light, there is a noticeable decrease in intensity for the first forty minutes during which measurements were taken. This decrease in intensity seems to indicate either that the zodiacal light weakened or that as the points

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Intensity reading on voltmeter	Volts per square degree of sky	Magnitude of star giving same intensity
6.0 v	78.5 v	1.22
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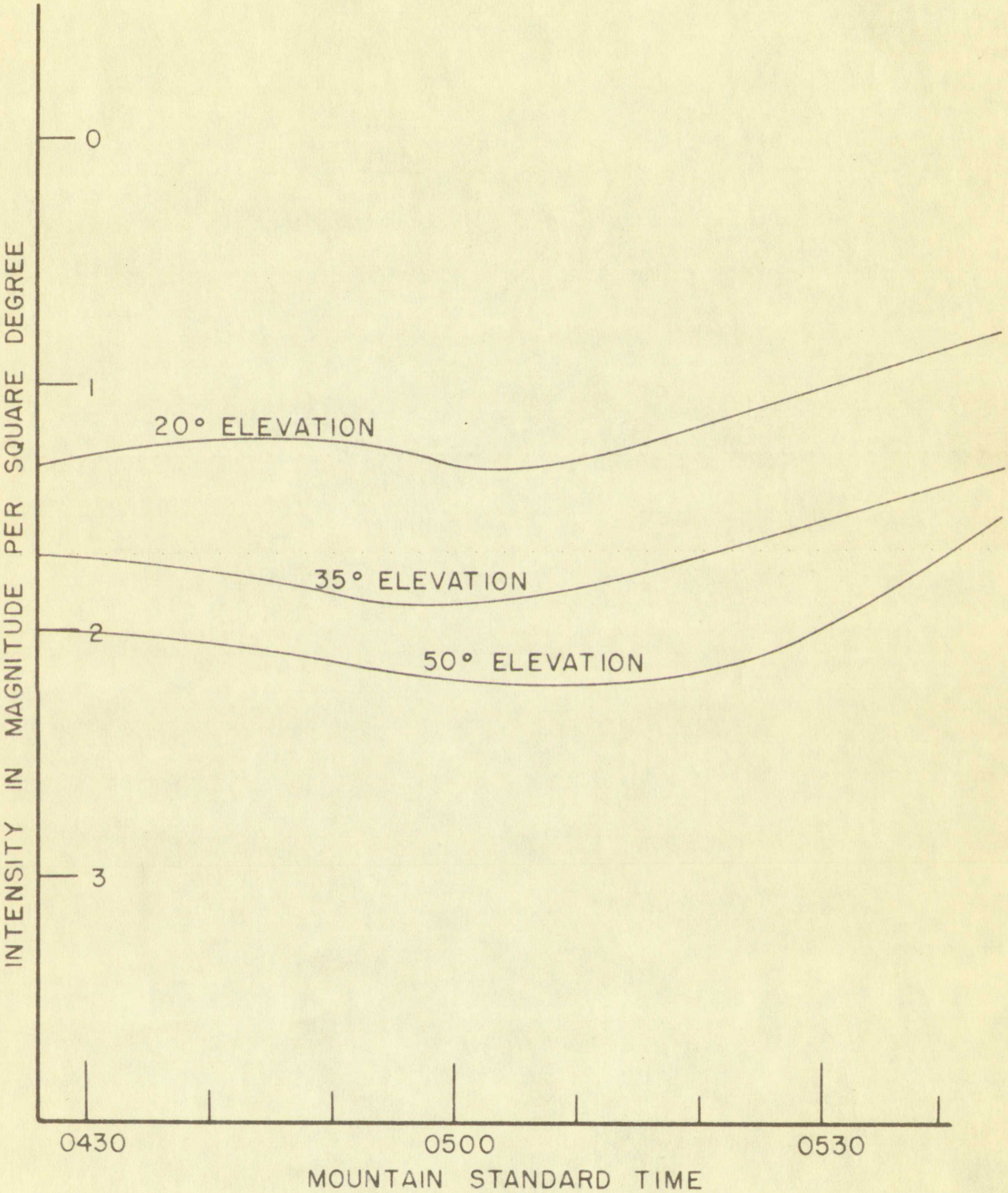

FIGURE 22

INTENSITY VARIATION FOR FIXED ELEVATIONS

selected moved upwards in the morning sky, they gradually moved out of the cone of zodiacal light. The increase which follows seems to be due to a general increase in the zodiacal light intensity preceding the dawn. The rather abrupt decrease shown for point 1 is possibly due to the difficulty experienced in drawing in the isophotes for the brightest portion of the zodiacal light on the on the photographs.

Figure 22 shows the star magnitude per square degree represented by points of constant elevation for the same set of readings as those plotted in Figures 18, 19, 20, amd 21. Three points are shown; of elevations of 20°, 35°, and 50°; all three of which lie on the ecliptic. Each of the elevations shows a slight decrease over the first forty minutes of measurements followed by an increase as dawn approaches.

Figure 21 shows that for point 1 in the zodiacal light cone, the absolute extraterrestrial intensity of the zodiacal light is approximately equal to one star of magnitude 1.25 per square degree of sky. This point was at an angular distance of 49° from the sun. At 0454 Mountain Standard Time this point had an intensity exactly equal to 1.25 mag. per square degree, and at this time the sun's depression angle was 24° below the horizon. Figure 22 shows that for elevations as high as 50° above the horizon the intensity of the zodiacal light is approximately equal to 2.00 mag. for each square degree of the sky.

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Figure 22 shows the star magnitude per square degree represented by points of constant elevation for the same set of readings as those plotted in Figures 18, 19, 20, and 21. Three points are shown; of elevations of 20°, 35°, and 50°, all three of which lie on the ecliptic. Each of the elevations shows a slight decrease over the first forty minutes of measurements followed by an increase as dawn approaches.

Figure 21 shows that for point 1 in the zodiacal light cone, the absolute extraterrestrial intensity of the zodiacal light is approximately equal to one star of magnitude 1.25 per square degree of sky. This point was at an angular distance of 15° from the sun. At 04h54 Mountain Standard Time this point had an intensity exactly equal to 1.25 mag. per square degree, and at this time the sun's depression angle was 21° below the horizon. Figure 22 shows that for elevations as high as 50° above the horizon the intensity of the zodiacal light is approximately equal to 7.00 mag. for each square degree of the sky.

CHAPTER IV

CONCLUSION

Summary of Thesis

The equipment described in this thesis has been used to measure the intensity of the morning zodiacal light. Intensities of known stars were measured along with the background intensity at different elevations. The graph of the absolute intensities of these known stars gave an extinction curve for the atmosphere lying above the point of observation. An extinction coefficient, k, was determined which agreed well with that computed from a consideration of Rayleigh scattering. From the extinction curve a factor was determined by which the isophotes of the photograph taken on 9 December 1950 were corrected for extinction after removing the background readings. Corrected isophotes with their intensities are shown. Intensities of zodiacal light were measured for three fixed points in the sky and graphs of intensity against time were made. The intensity readings in volts were converted to magnitude per square degree of sky. By this is meant the magnitude of a star which would give the same intensity reading as the light from a solid angle of one square degree of the sky.

Conclusion

The measurements made for this thesis show a definite variation in the intensity of zodiacal light for the morning of

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Conclusion

The measurements made for this thesis show a definite variation in the intensity of zodiacal light for the morning of

9 December 1950. The intensities of three fixed points in the sky showed a decrease and then an increase over a period of ninety minutes. The intensities at three fixed elevations above the horizon lying on the ecliptic showed a similar decrease followed by an increase over the same period.

The absolute extraterrestrial intensity of the zodiacal light cone on 18 December 1950 was one star of magnitude 1.25 for each square degree of sky at an angular distance of 49° from the sun when the sun is at an angle of depression of 24° below the horizon.

Further measurements of daily and seasonal variations in intensity of zodiacal light and also of variations in intensity in relation to magnetic storms and sunspot activity should prove of great interest. The equipment used and the method described in this thesis should be valuable in making further measurements of this type.

I wish to express my appreciation to Professor Victor H. Regener for the valuable help and guidance he provided throughout the work on this thesis. I also wish to thank Mr. Maynard Cowan and Mr. James D. Lindsay for their help in constructing and setting up the equipment and without whose aid this work could not have been completed.

9 December 1950. The intensities at selected points in the sky showed a decrease and then an increase over a period of ninety minutes. The intensities at Virgo [illegible] above the horizon lying on the ecliptic showed a similar decrease followed by an increase over the same period.

The absolute extraterrestrial intensity of the zodiacal light cone on 18 December 1950 was the order of magnitude [illegible] for each square degree of sky at an angular distance of [illegible] from the sun when the sun is at an angle of depression of [illegible] below the horizon.

Further measurements of daily and seasonal variations in intensity of zodiacal light and also of variations of intensity in relation to magnetic storms and sunspot activity should prove of great interest. The equipment used and the method described in this thesis should be valuable in making further measurements of this type.

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