Spring 5-8-1951

Determination of the Shape and Position of the Zodiacal Light by Use of an Automatic Recording Method

James D.G. Lindsay

LINDSAY — POSITION OF THE ZODIACAL LIGHT

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DETERMINATION OF THE SHAPE AND POSITION
OF THE ZODIACAL LIGHT
BY USE OF AN AUTOMATIC RECORDING METHOD

By

James D. G. Lindsay

A Thesis

In partial fulfillment of the

Requirements for the Degree of

Master of Science in Physics

The University of New Mexico
1951

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

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DEAN

February 8, 1951

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Thesis committee

Victor H. Regener

CHAIRMAN

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

CHAPTER I

THE PROBLEM

Introduction. "There can be little doubt that the zodiacal light is due to light received from an extensive cloud of material particles of some sort, illuminated by solar rays."[1] There are two main theories as to the position of this cloud of particles. In the planetary theory, the cloud is supposed to have the sun as its center; whereas in the atmospheric theory, the cloud has the earth as its center. In both theories, however, the cloud is lenticular in shape.[2]

Previous work. A good description of the zodiacal light is given by Russell, Dugan, and Stewart[3] and will not be given here. According to S. K. Mitra[4] the axis of the zodiacal light pyramid or cone does not lie exactly along the ecliptic, but is tilted away from the ecliptic in such a direction as to make the cone more nearly perpendicular to the horizon. The degree of tilt of the light axis

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1 S. K. Mitra, The Upper Atmosphere (The Royal Asiatic Society of Bengal, Monograph Series, Vol. V. Calcutta, India: The Royal Asiatic Society of Bengal, 1948) p. 459.

2 Loc. cit.

3 Henry Norris Russel, Raymond Smith Dugan, and John Quincy Stewart, The Solar System (vol. I, Astronomy, 2 vols.; Revised edition; New York: Ginn and Company, 1945) pp. 358-60.

4 Mitra, op. cit., p. 456.

is said by Mitra[5] to vary even during one night as the diurnal motion of the earth carries the observer away from or toward the plane of the ecliptic. It was, therefore, desired to see if these changes could be detected.

The problem. The problem was to determine the shape of the zodiacal light pyramid and also its position relative to the ecliptic using an automatic recording system. The main requirement was to be simplicity in the interpretation of data.

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5 Ger. Beitr. z. Geophys., Vol. 45, p. 5, cited by S. K. Mitra, op. cit., pp. 456-57.

CHAPTER II

DESCRIPTION OF EQUIPMENT

Telescope. The telescope used consisted of an army searchlight with a five foot diameter parabolic mirror. The glass face and the carbon arc were removed and a 5819 RCA photomultiplier tube was placed at the focus. The searchlight was then balanced and placed on an equatorial mounting, so that it was free to rotate continuously in hour angle. The declination could also be changed from 20 degrees S. to 90 degrees N. Positioning of the searchlight was accomplished by servo-systems which could be controlled either manually or automatically from inside the observatory building of the physics department on south Capillo Peak, New Mexico, at an elevation of 9,200 feet. The telescope is shown on Figure 1.

Electronic Equipment. The electronic equipment was designed so that the spot on an oscilloscope tube moved horizontally across the tube face from right to left as the telescope rotated in hour angle. At the completion of 360 degrees rotation in hour angle, the telescope was automatically raised 3 degrees in declination, and the trace on the oscilloscope tube was raised vertically by a corresponding amount. The intensity of the trace on the tube face was a measure of the intensity of the light incident upon the telescope. However, the intensity of the trace did not vary continuously, but was made to change by finite steps in order to simplify data interpretation.

FIGURE 1

TELESCOPE

The diagram in Figure 2 shows the components of the equipment in relation to one another. Light incident upon the parabolic mirror of the telescope is focused on to the phototube with a resultant increase in the anode current. The anode current flows through a resistor and the potential difference across this resistor is fed to the phototube amplifier. The output from the phototube amplifier is fed to the inverter which has a voltmeter across its input terminals. The voltmeter is used to monitor the signal voltage. The inverter changes the negative potential from the photo tube amplifier to a positive potential. This positive potential is fed to the discriminator where it is converted into voltage steps. The voltage steps are then applied to the control grid of the cathode ray tube and thus control the spot intensity.

The automatic positioning controls are used for positioning the telescope and the cathode ray tube spot simultaneously. Output potentials from horizontal and vertical voltage dividers of the automatic control units are fed to the corresponding deflection units of the oscilloscope. These deflection units, called drivers, on Figure 2, change the voltage variations to current variations which are fed to the deflection coils of the cathode ray tube. The automatic control unit also drives the control transmitters of the servo system which positions the telescope.

Photomultiplier amplifier. This amplifier, shown in Figure 3, was designed to have a gain of 20, 40, or 80 depending upon the

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FIGURE 2

BLOCK DIAGRAM OF EQUIPMENT

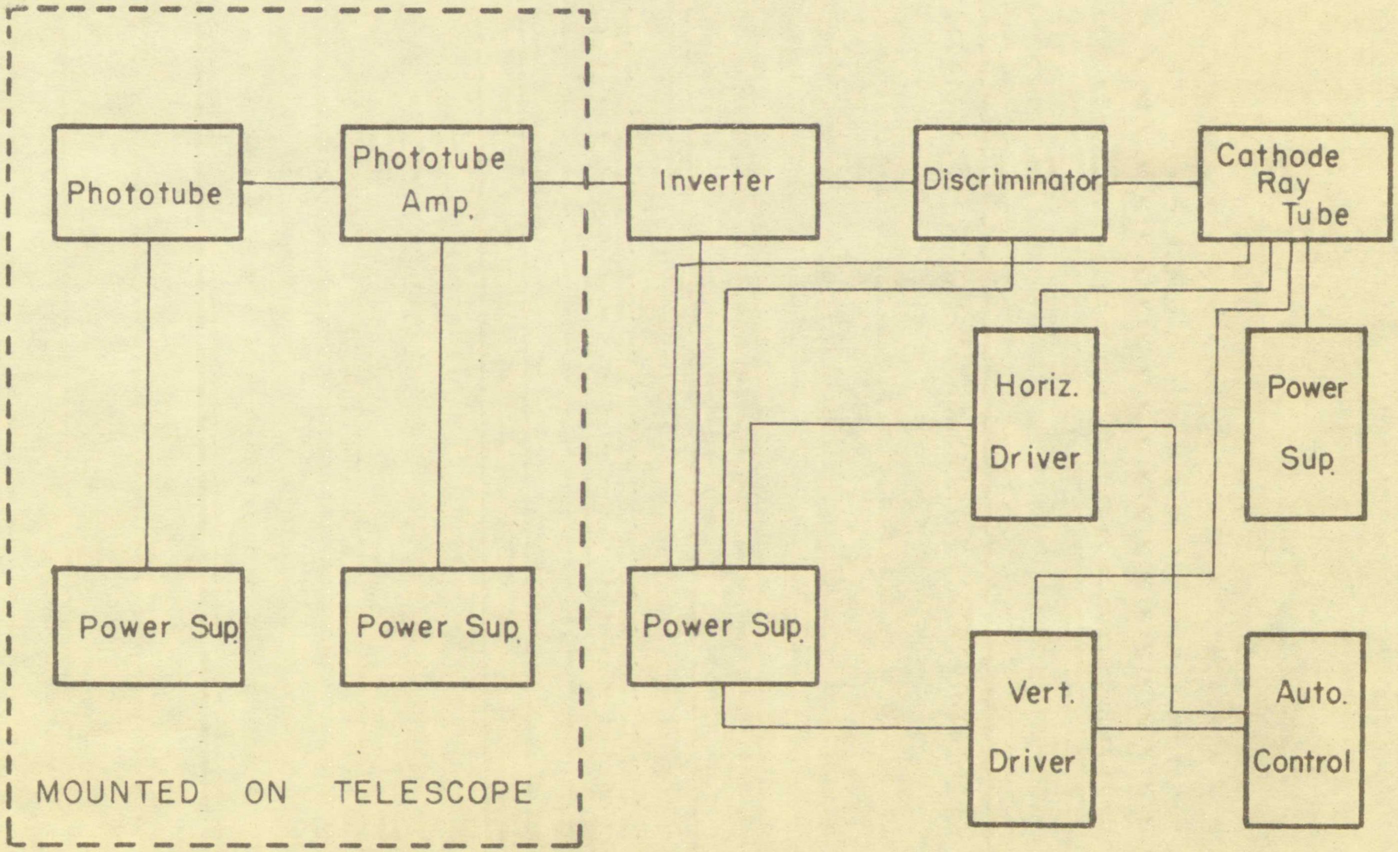
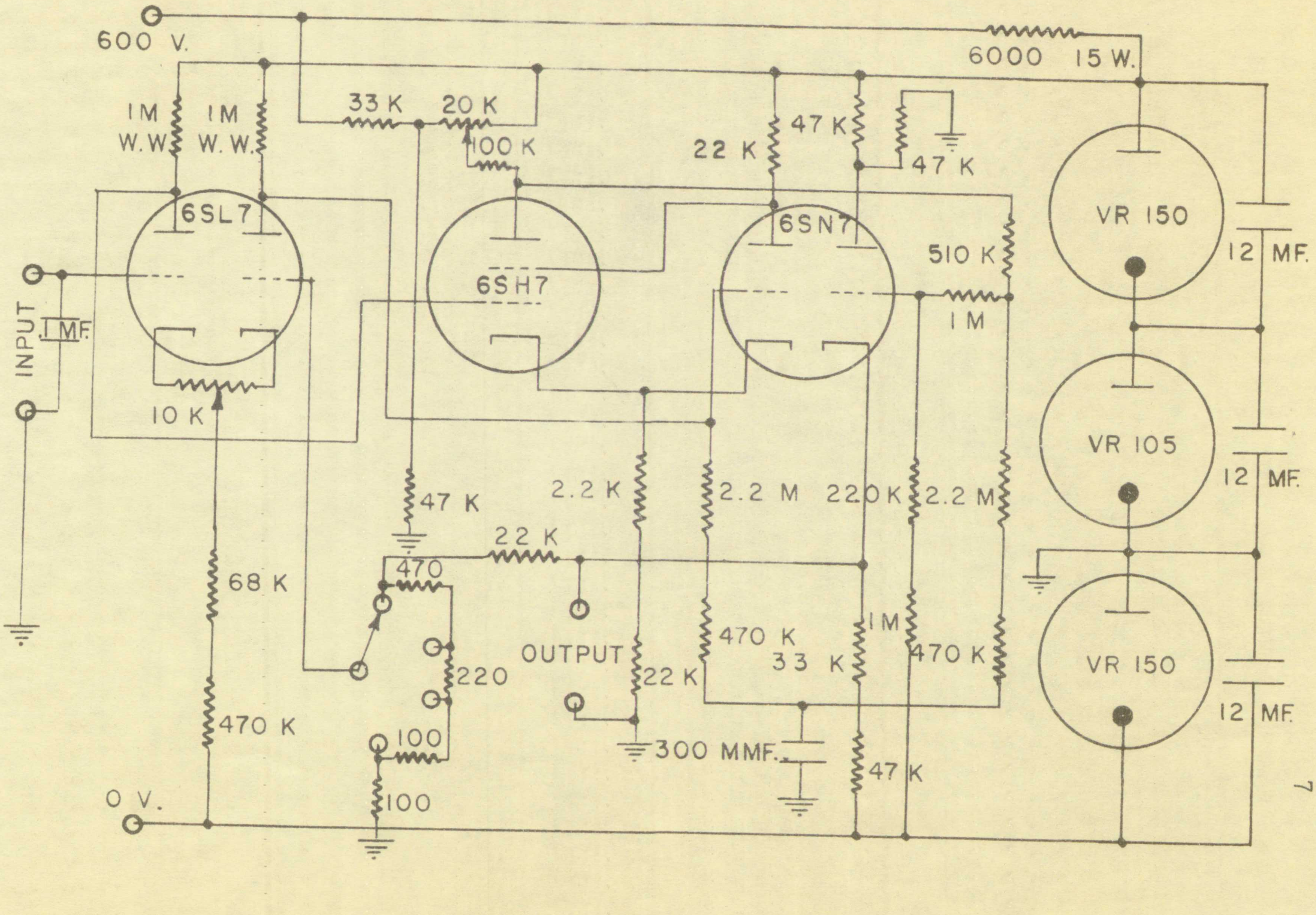


FIGURE 3

PHOTOMULTIPLIER AMPLIFIER CIRCUIT



position of the four-position switch shown in Figure 3. The amplifier is linear for all ranges up to 10 volts output. The output voltage can be read directly on the signal voltage meter mounted on the left-hand rack shown in Figure 4. The condenser across the input terminals is used to eliminate any alternating current due to stray fields around the amplifier and connecting cables. The amplifier is also equipped with a zero adjustment (the 10 K potentiometer shown in Figure 3) and a line voltage stabilization adjustment (the 20 K potentiometer shown in Figure 3). The amplifier is mounted on the telescope. Its output is taken from slip rings on the telescope and fed through shielded cable to the recording equipment in the observatory.

Amplifier power supply. This power supply is also mounted on the telescope adjacent to the phototube amplifier. The power supply delivers 600 volts at 50 milliamperes. A diagram of this power supply is shown in Figure 5.

Discriminator. The discriminator is shown in Figure 6, and is mounted in the right-hand rack shown in Figure 4. Its purpose is to convert a continuously varying voltage into one in which the changes are finite steps.

The 6SL7 twin triode shown at the bottom of Figure 6 is connected so that each section acts as a constant current source. The left-hand section supplies a constant current of approximately one milliampere to the resistors in the left-hand grid circuits of

FIGURE 4

ELECTRONIC EQUIPMENT

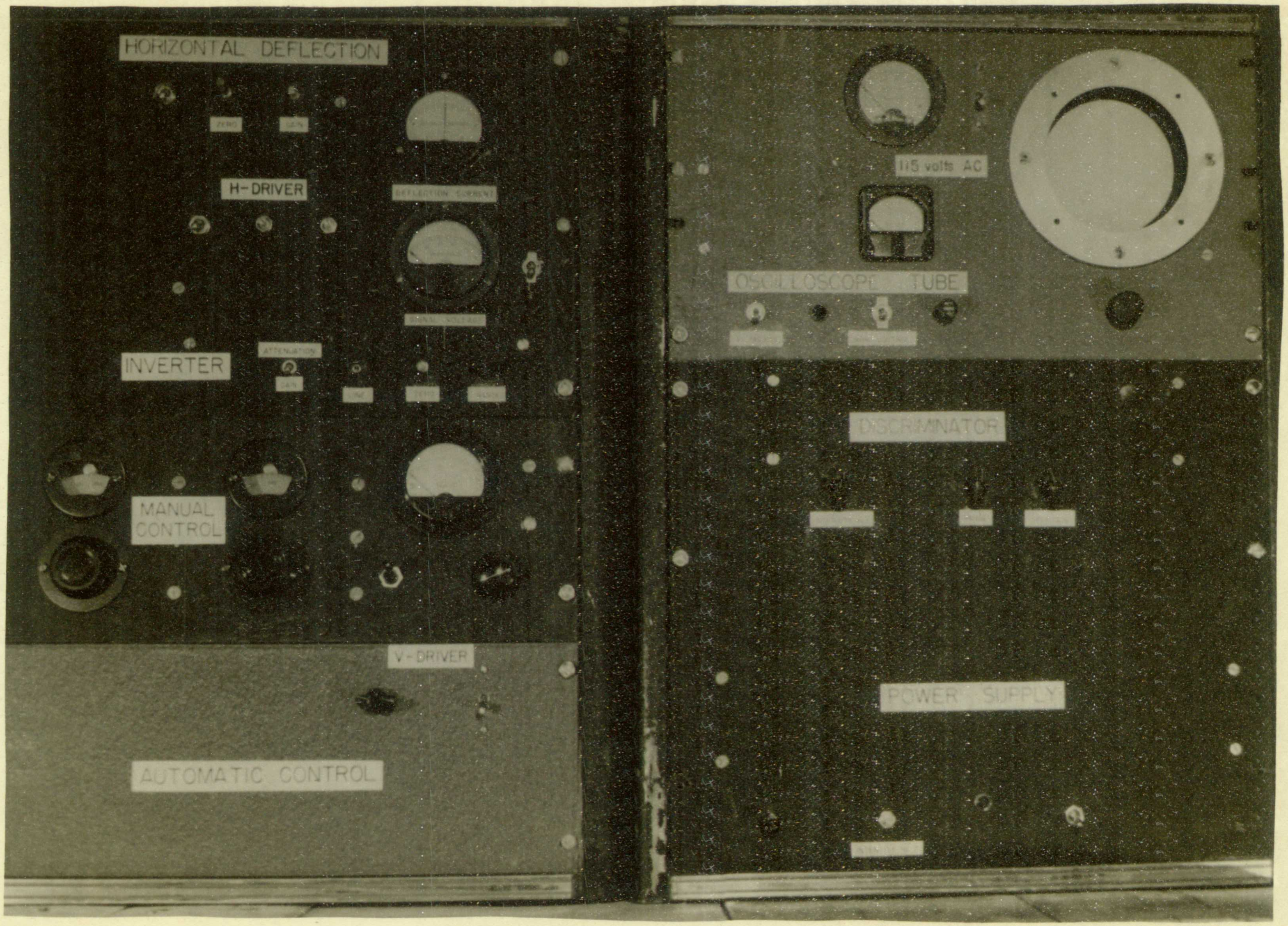
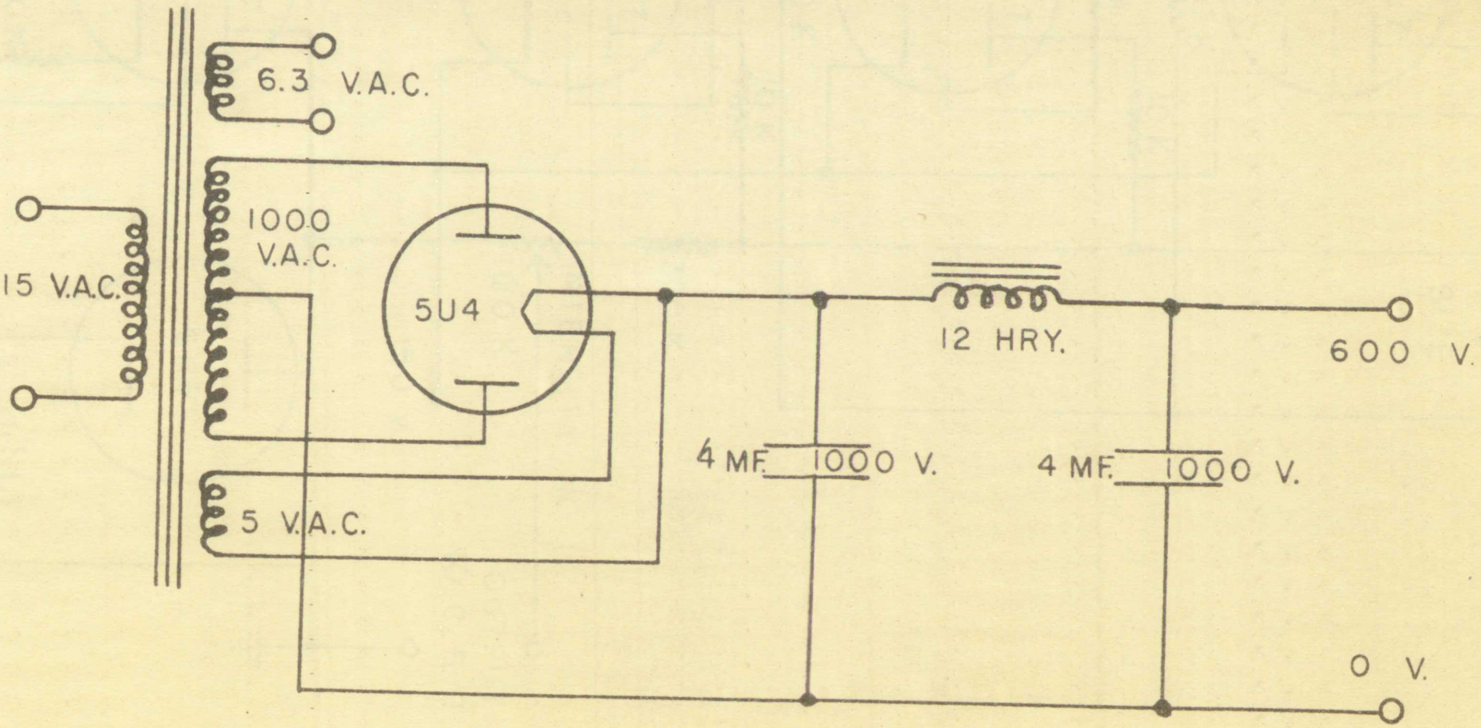


FIGURE 5

AMPLIFIER POWER SUPPLY



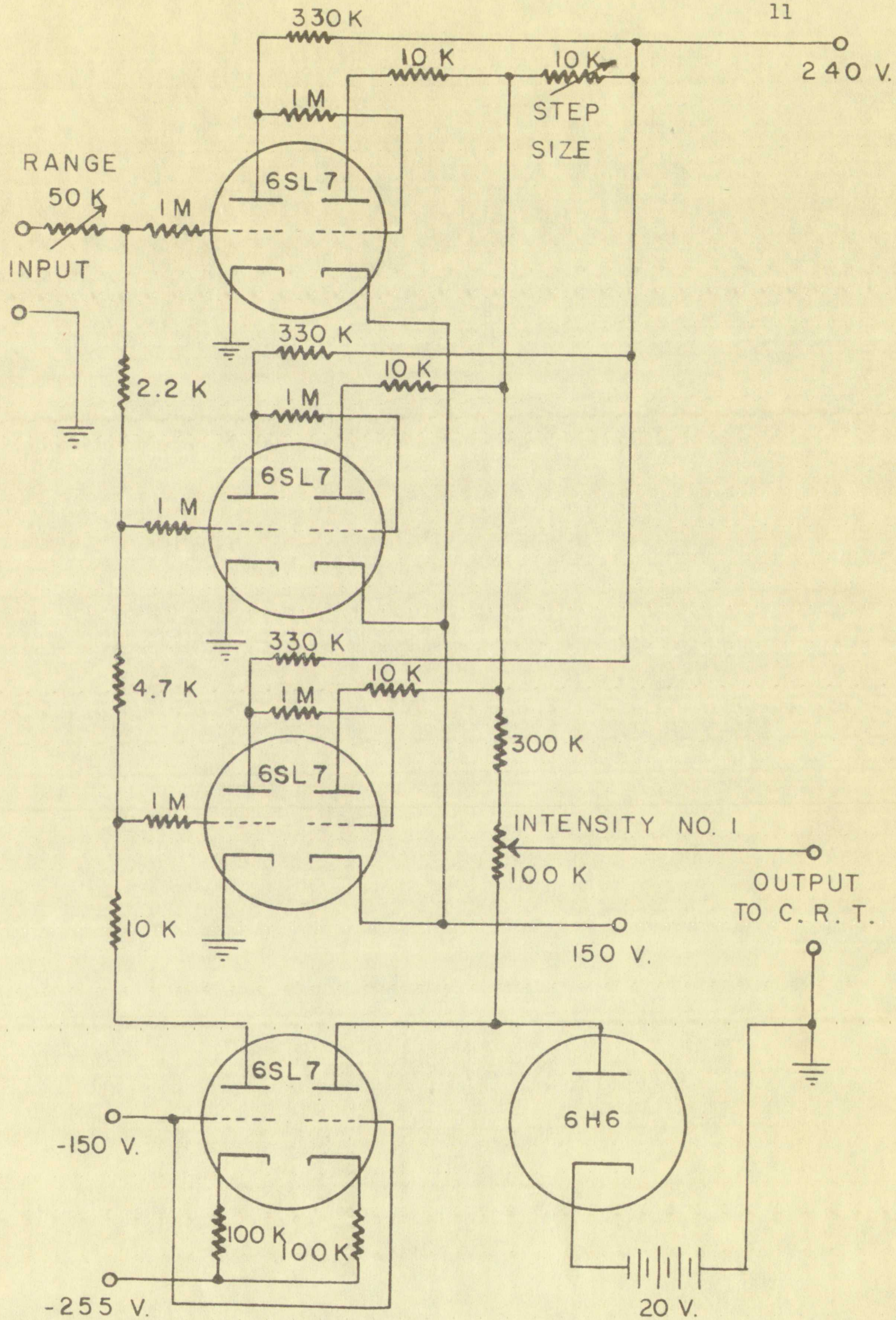


FIGURE 6

DISCRIMINATOR CIRCUIT

the other 6SL7's. This constant current creates a constant potential difference, between the grids of these tubes, which the input potential has to overcome in order to fire the tubes. That is, the input potential will have to increase approximately two volts in order to fire the second tube and about seven volts in order to fire the third tube. The other constant current source (the right-hand section of the 6SL7 at the bottom of Figure 6) is needed to change the positive output potential of the discriminator to a negative potential suitable for the control grid of the cathode ray tube.

The graph in Figure 7 shows the output voltage of the discriminator plotted against the input voltage of the discriminator. To control the trace intensity on the tube screen, the output voltage of the discriminator is fed directly to the control grid of the cathode ray tube. The 6H6 diode, shown in Figure 6, p. 11, limits the control grid voltage so that the trace on the tube screen will not become bright enough to burn the tube phosphor. The controls (right-hand rack, Figure 3, p. 7) are "step size," "intensity number 1," and "range". The "step size" control changes the potential difference between the voltage steps. To control the input potential necessary to trigger the first step, the "range" adjustment was incorporated. The purpose of the "intensity number 1" control is to set the control grid voltage of the cathode ray tube within its specified ratings.

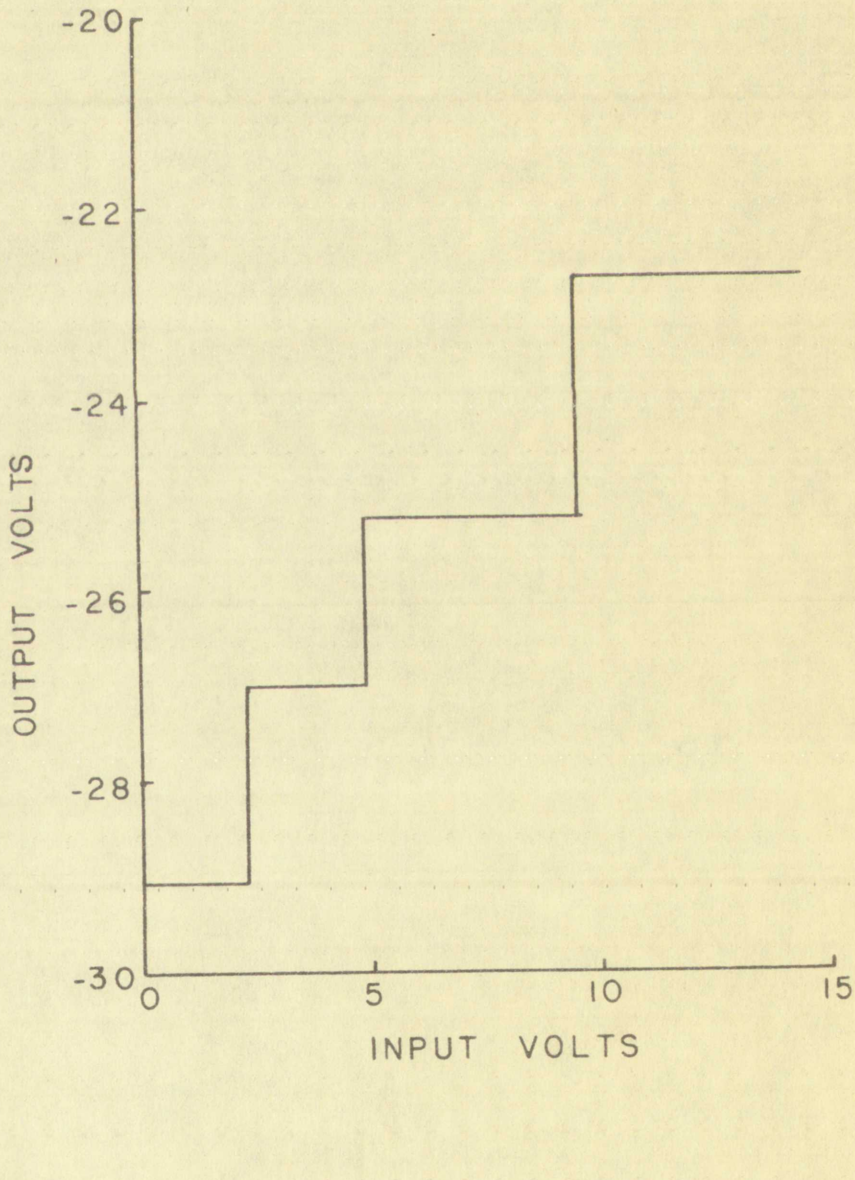


FIGURE 7

OUTPUT VOLTAGE OF DISCRIMINATOR

Automatic positioning controls for telescope. The automatic controls are shown in Figure 8 and Figure 9. The hour angle control (Figure 8) consists of a 24 volt direct current motor geared to the control selsyn and a continuous rotation potentiometer. The output voltage of the potentiometer is fed to the horizontal deflection unit. A cam on the selsyn shaft trips micro-switch S2 (Figure 9) at the completion of each revolution of the control selsyn.

Micro-switch S2 of Figure 9 energizes stepping relay R1 of Figure 9. The stepping relay is geared to the declination control selsyn through a 5 to 1 reduction gear. The contacts on the stepping relay are connected to a potential divider, and the output potential from this divider is fed to the vertical deflection unit. When the stepping relay has rotated through all 24 positions, that is, from point A to point B of Figure 9, a cam on the relay shaft trips micro-switch S3 which energizes the release relay R2. The release relay allows the stepping relay to be returned, under spring tension, to slightly past position A. A cam on the stepping relay shaft then engages micro-switch S1 which cuts off the release relay and energizes the stepping relay so that it is again set in position A.

Other equipment. Descriptions of the other equipment shown in the block diagram of Figure 2 are given by Allan Beck[6] and Maynard Cowan.[7]

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6 Allan F. Beck, "Intensity of Zodiacal Light," (unpublished Master's thesis, The University of New Mexico, Albuquerque, N.M. 1951).

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

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FIGURE 8

HOUR ANGLE CONTROL SYSTEM

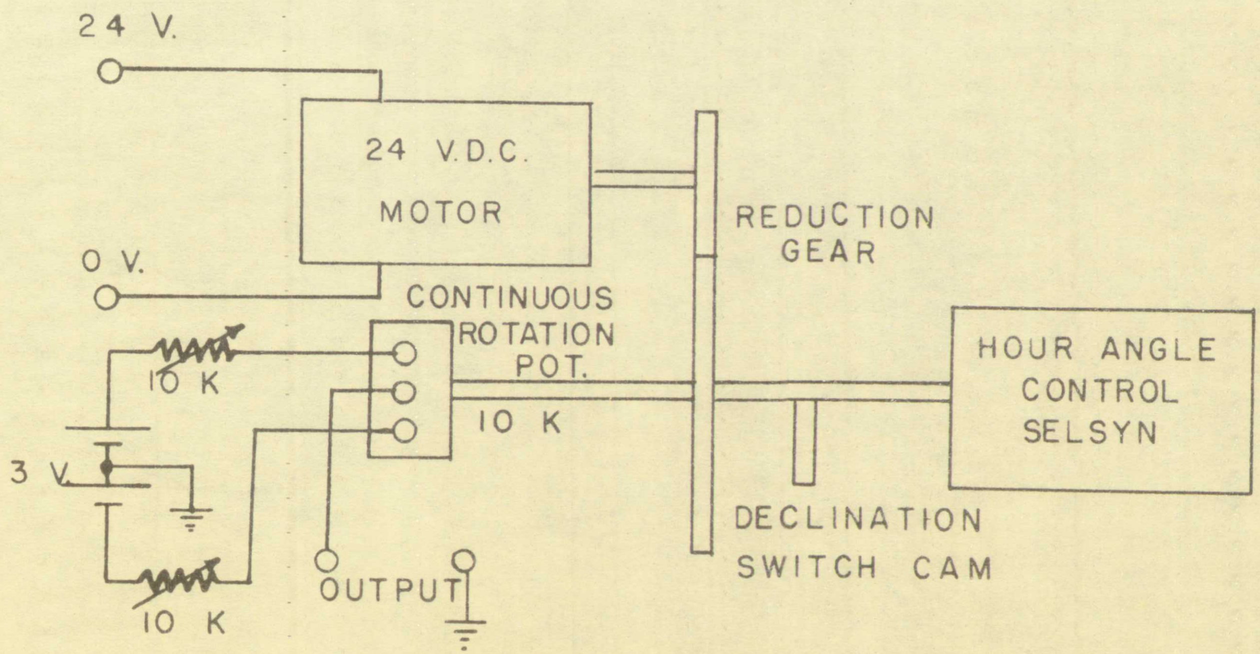
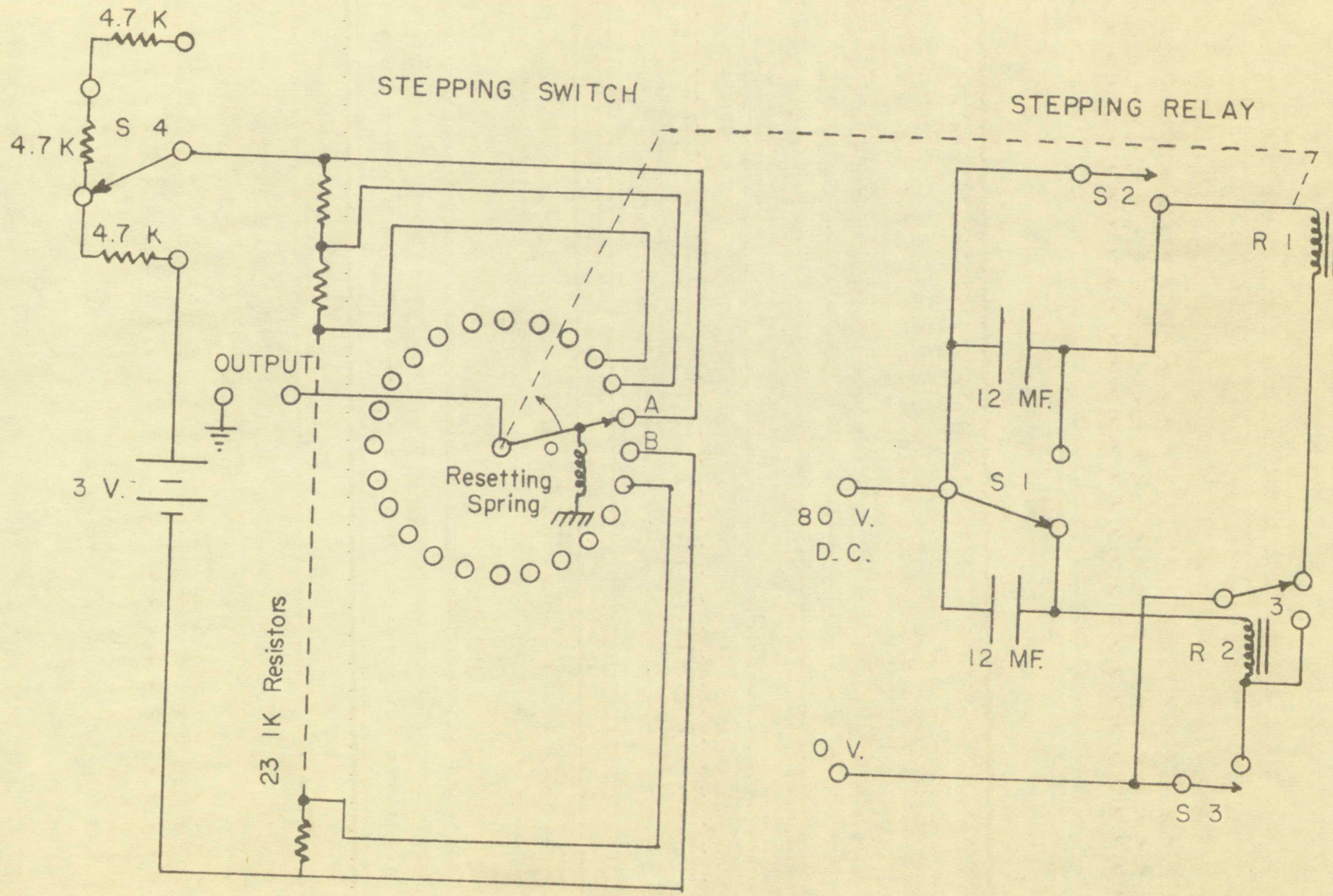


FIGURE 9

DECLINATION CONTROL SYSTEM



CHAPTER III

MEASUREMENTS AND METHODS OF RECORDING DATA

Recording data. The method used to record data had to be one capable of continuous recording. It was, therefore, decided to photograph the trace on the cathode ray tube. The camera was left open for one complete scanning of the sky. The shutter was then closed and a new frame inserted for the next scanning. Positive transparencies were made from the negatives and the final prints, Photographs 1 through 8, were made from the positive transparencies.

Measurements. Since the position of the ecliptic had to be known in order to determine the position of the zodiacal light, it was decided to make a template of the ecliptic and to use this template to draw in the ecliptic on the photographs. The trace on the photographs was linear and contained hour angle marker pips at 10 degree intervals in the east and 30 degree intervals in the west which could be measured to determine the scale. The hour angle at which the ecliptic crossed each of the three degree declination traces was calculated using the following formula:

$$(1) \quad \sin b = \tan a \cot \alpha$$

Arc b is the desired arc of hour angle; arc a is the declination; and the angle α is the angle the ecliptic makes with the celestial equator. The hour angle was taken to be 0 degrees when arc a was

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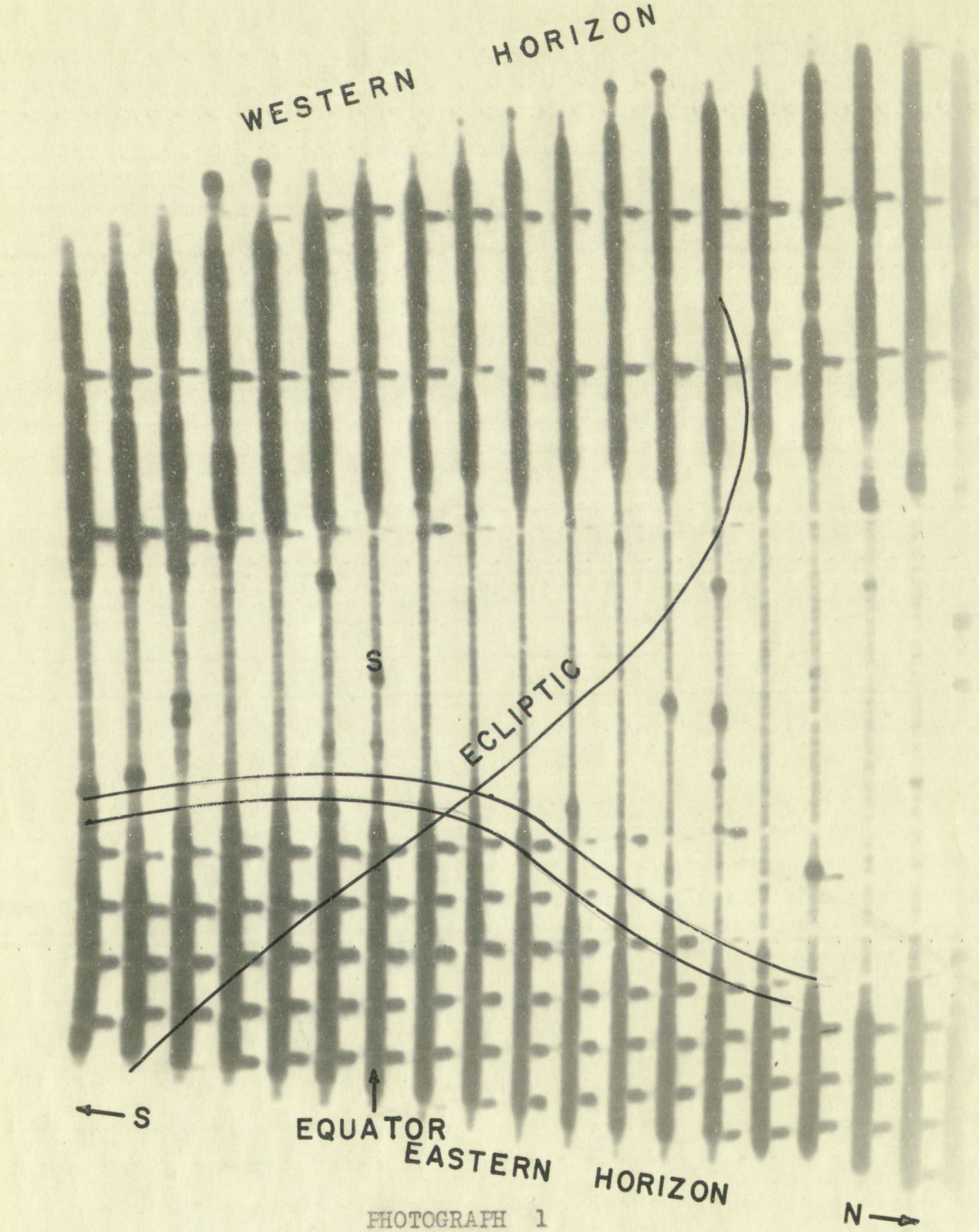
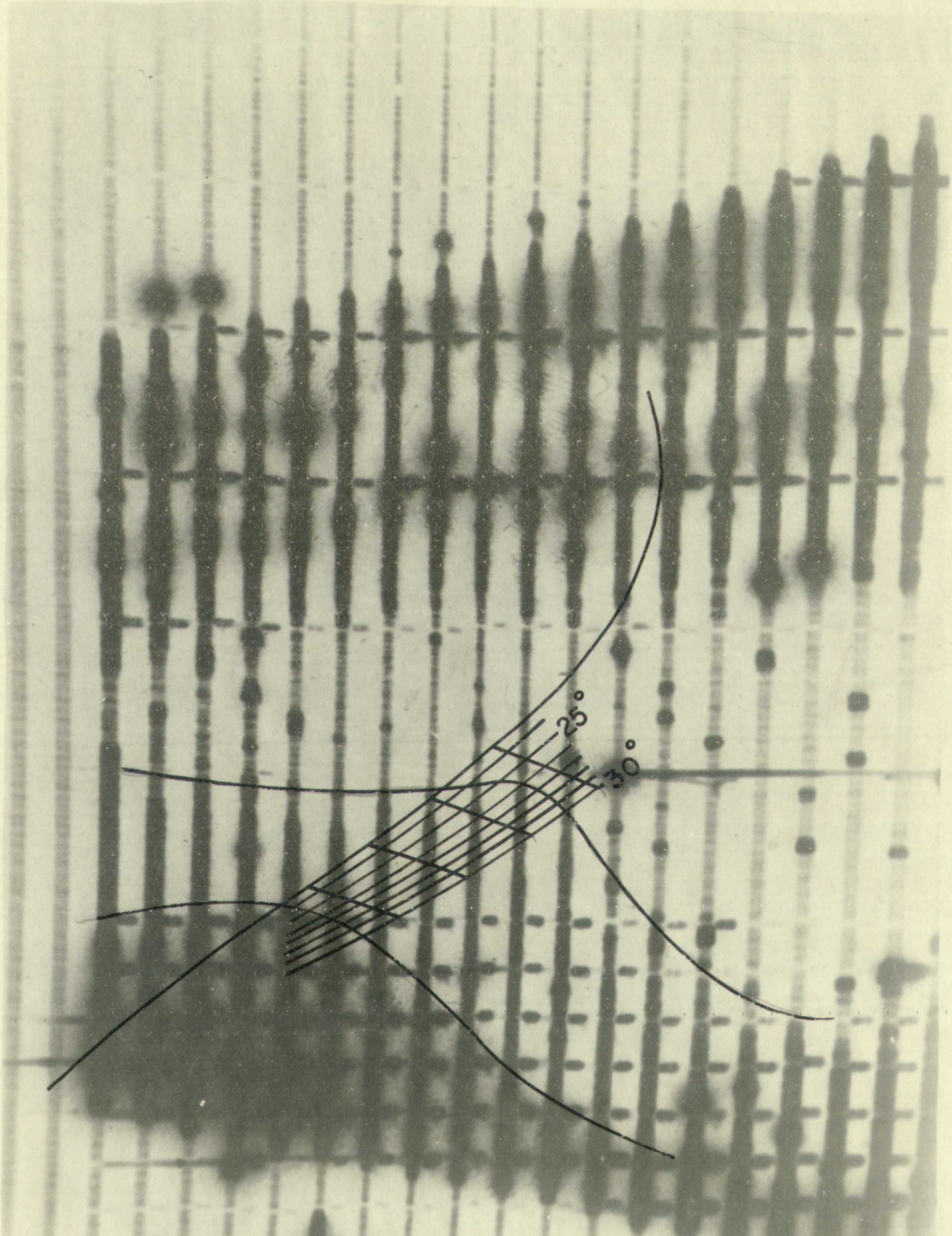


PHOTOGRAPH 1

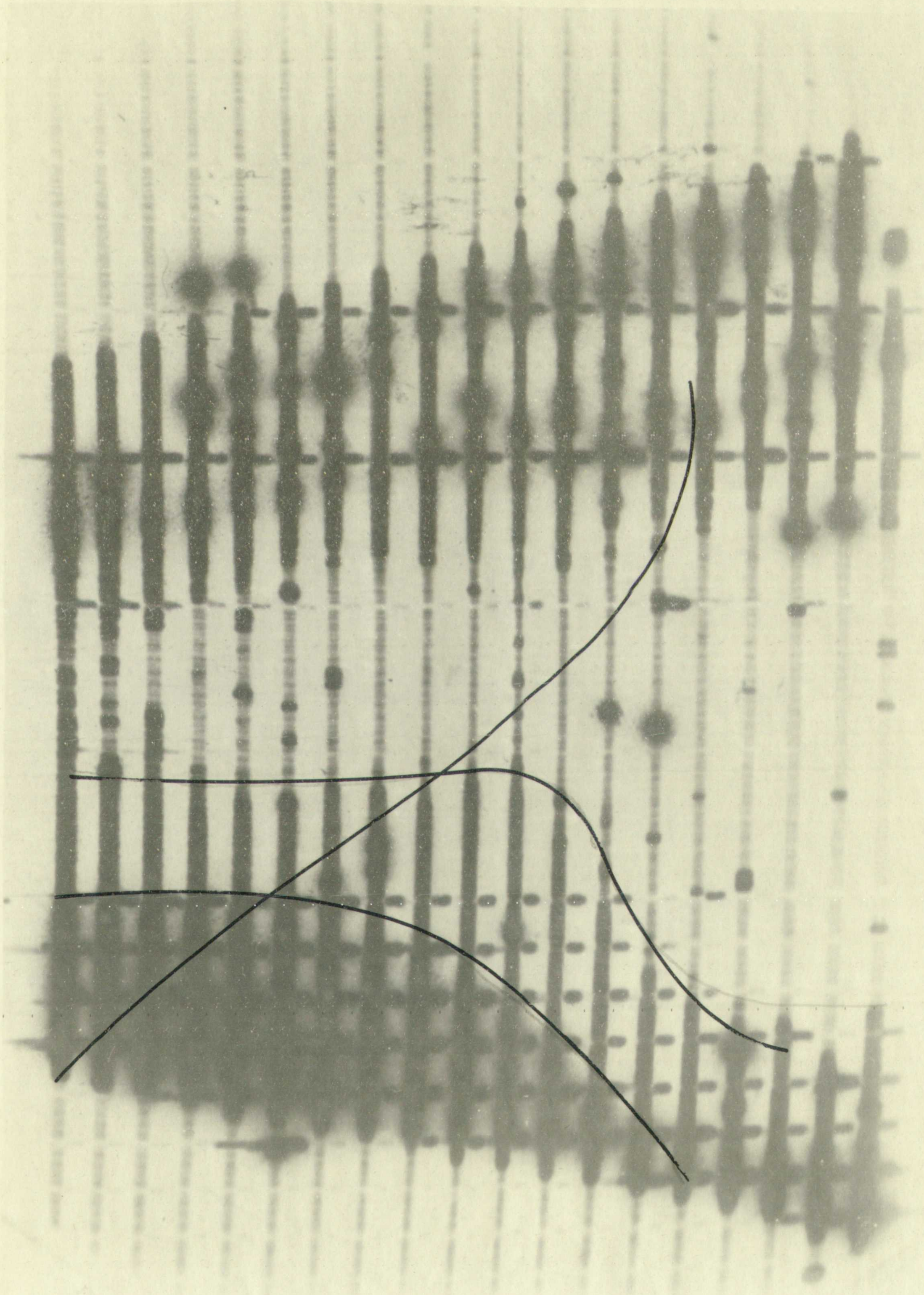
ZODIACAL LIGHT INTENSITY
12/9/50 0905 LST

2-1



PHOTOGRAPH 2
ZODIACAL LIGHT INTENSITY
12/9/50 0932 LST

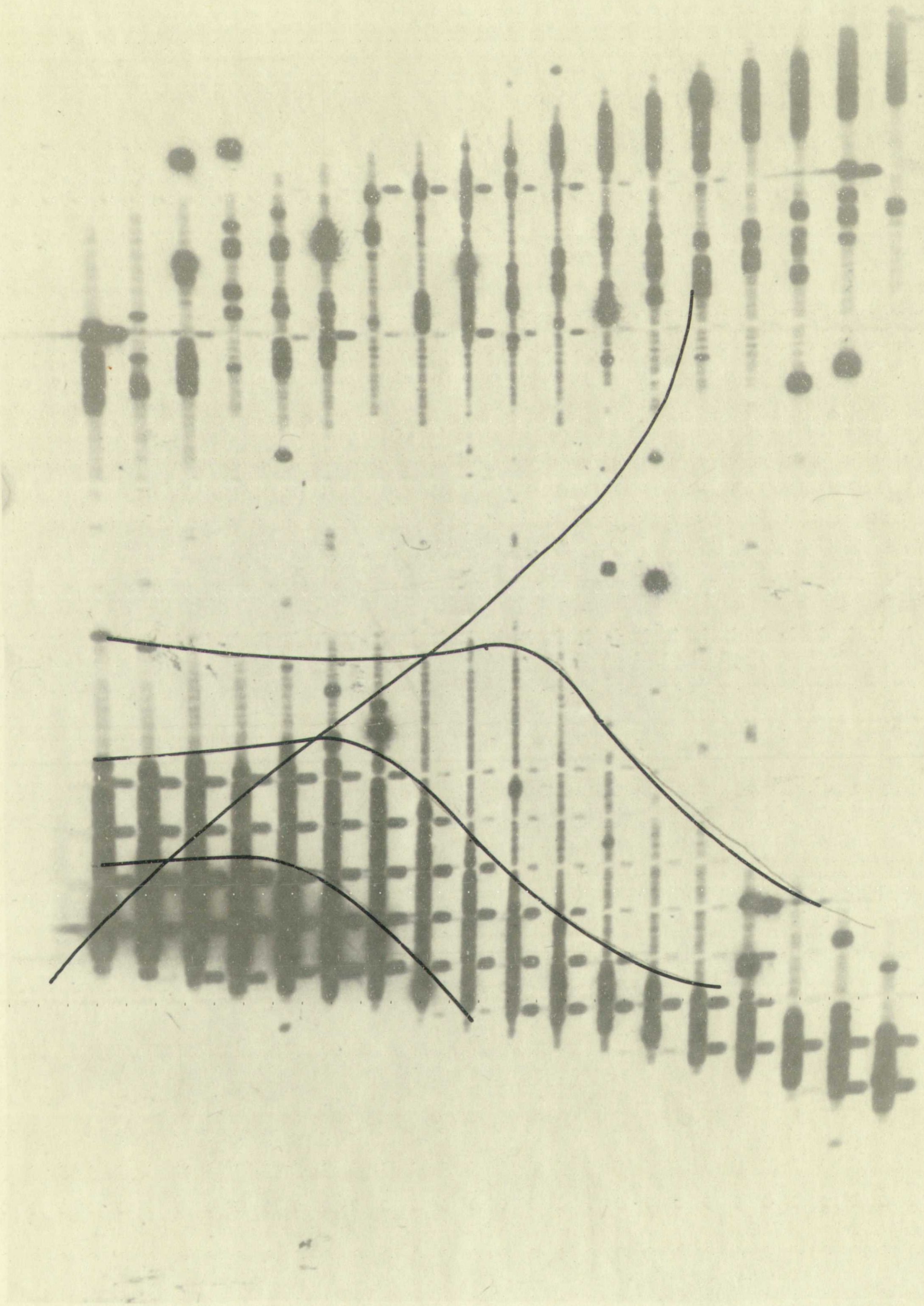
2-3



PHOTOGRAPH 3
ZODIACAL LIGHT INTENSITY
12/9/50 0952 LST

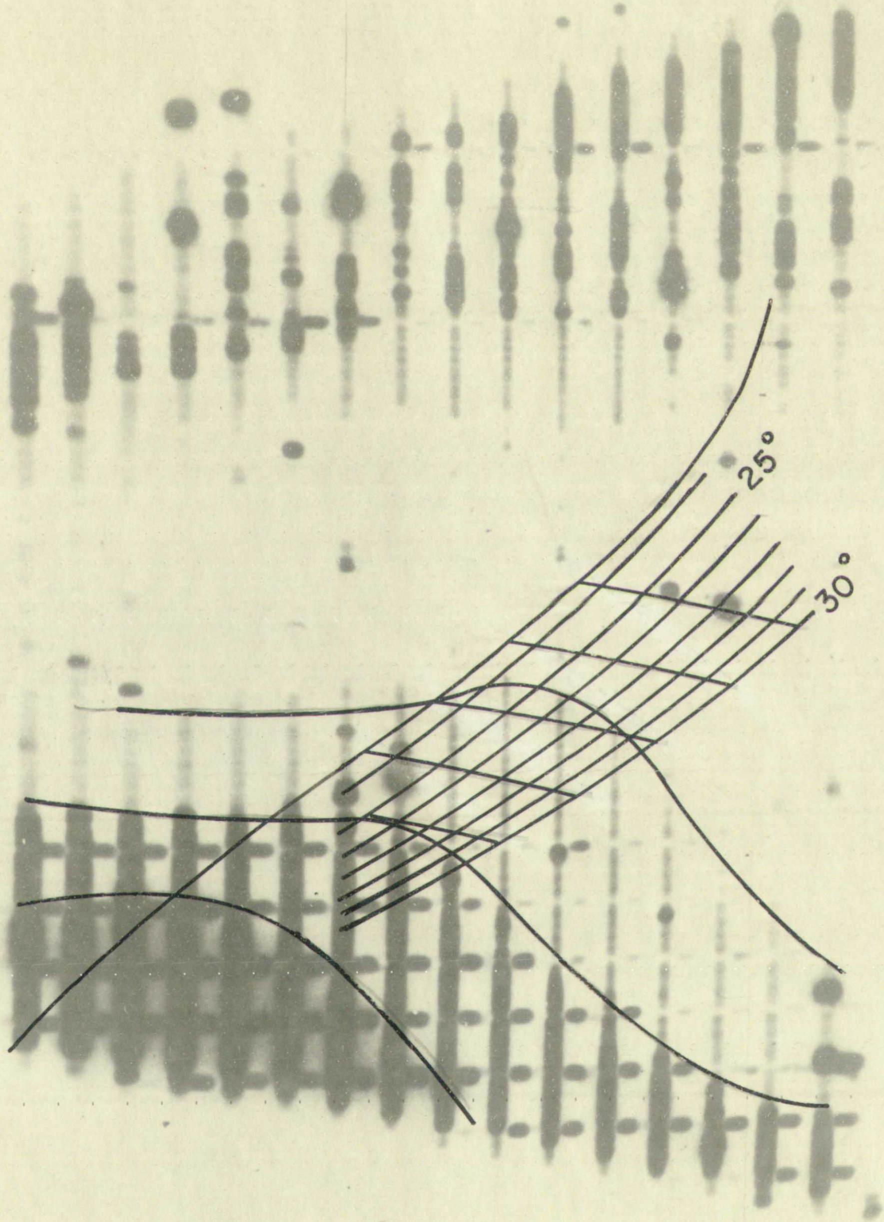
2-5

2 - 5



PHOTOGRAPH 4
ZODIACAL LIGHT INTENSITY
12/9/50 1005 LST

2-6



PHOTOGRAPH 5
ZODIACAL LIGHT INTENSITY
12/9/50 1014 LST

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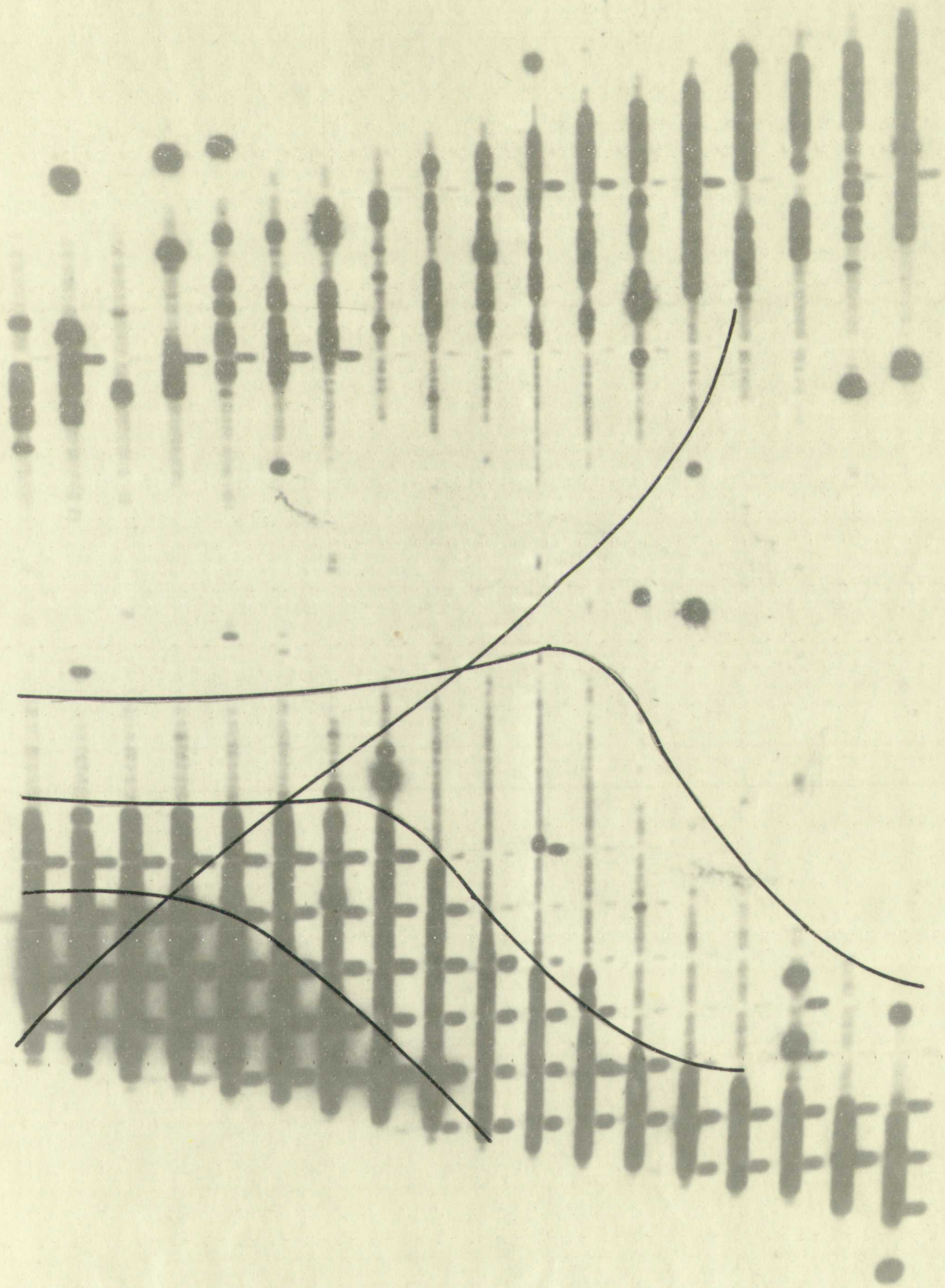


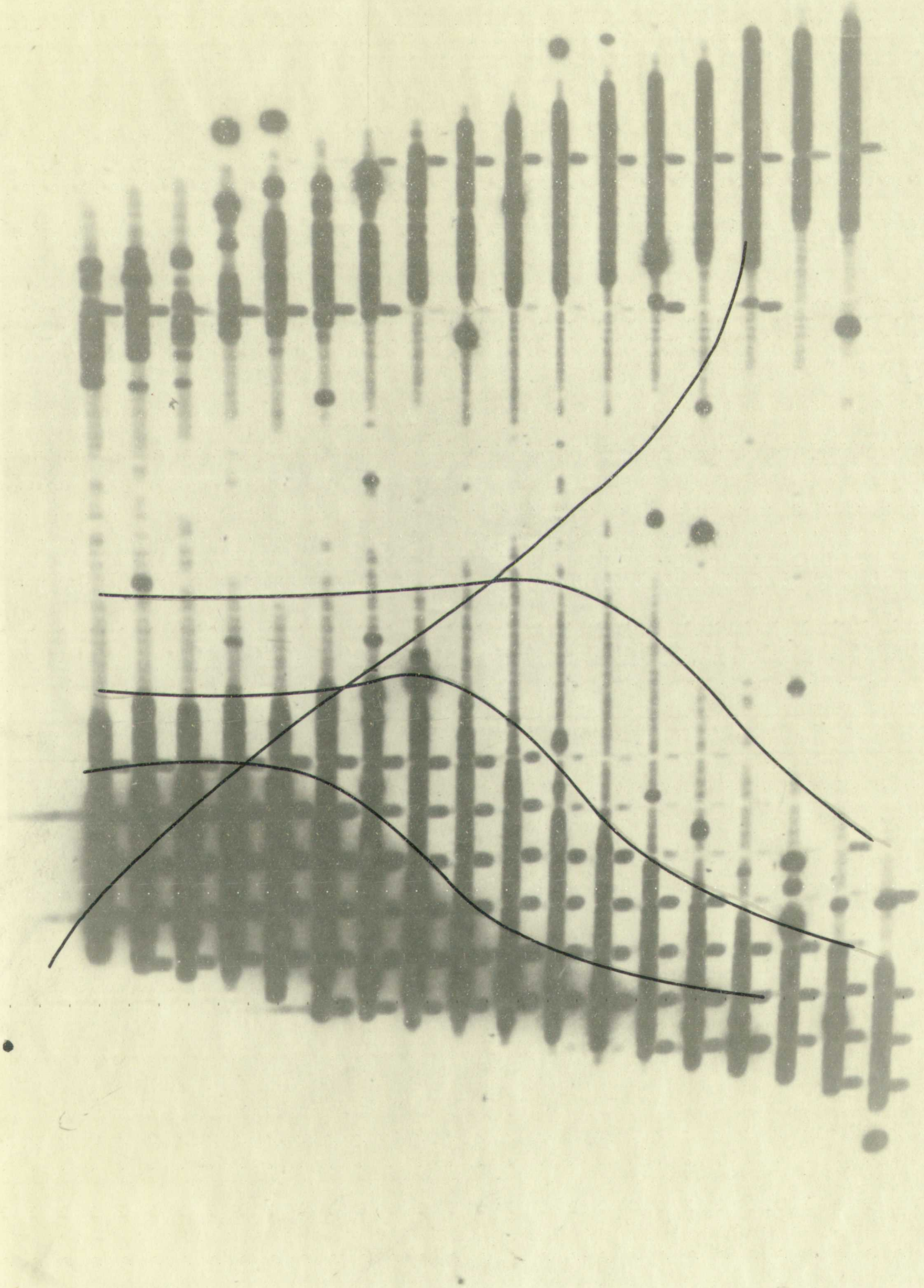
PHOTOGRAPH 6

ZODIACAL LIGHT INTENSITY

12/9/50 1022.5 LST

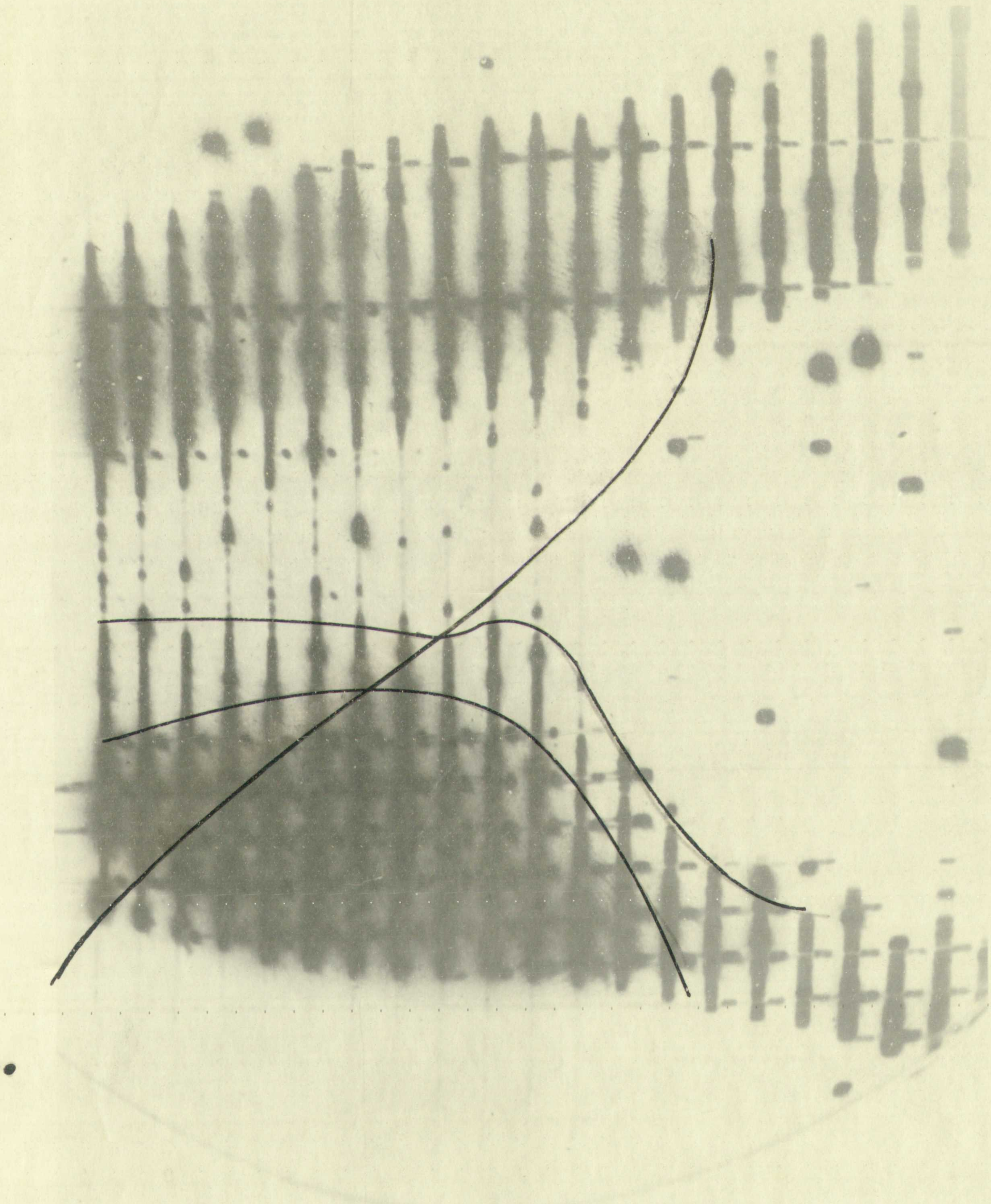
1.

2-8



PHOTOGRAPH 7
ZODIACAL LIGHT INTENSITY
12/9/50 1031.5 LST

2-9



PHOTOGRAPH 8

ZODIACAL LIGHT INTENSITY

12/11/50 0946 LST

3-3

0 degrees. Since angle α is constant and equals 23.5 degrees, table I contains only values of a and b. Using these values, a template of the ecliptic was constructed and used to draw in the ecliptic on the photographs. Since the local sidereal time is equal to the hour angle of the vernal equinox, the template had only to be shifted westard until the vernal equinox was west of the center of the photograph by an hour angle equal to the local sidereal time.

TABLE I

VALUES OF ARCS a AND b USED TO CONSTRUCT ECLIPTIC TEMPLATE

$\alpha = 23.5°$

a in degrees	b in degrees
3	6.9
6	14.0
9	21.4
12	29.2
15	38.0
18	48.3
21	62.0
23.5	90.0
21	118.0
18	131.7
15	142.0
12	150.8
9	158.6
6	166.0
3	173.1

CHAPTER IV

INTERPRETATIONS AND CONCLUSIONS

Interpretations. In order to determine the shape and position of the zodiacal light pyramid, the isophotes were drawn in on the photographs 1 through 8. From observations of the photographs it would appear that some of the isophotes are closed curves; however, from observed star intensities, Allan Beck[8] has shown that the extinction near the horizon is sufficient to cause this decrease of intensity.

To get the shape of the zodiacal light, the isophotes were transferred to polar coordinate paper. Then the background intensity, given by Allan Beck, was subtracted from each of the plotted points. The background was taken at a considerable distance from the bright part of the zodiacal light and, therefore, may be assumed to have very little zodiacal light included with it. To get the corrected isophotes, the extinction data taken by Allan Beck was applied in the following manner. The factor, by which the intensity at a given altitude had to be increased in order to give the true intensity, was calculated. Then each point was multiplied by its proper extinction factor and assigned its corrected intensity. The new isophote was then drawn through points having equal corrected intensities, interpolating where necessary. The corrected isophotes

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8 Beck, *op. cit.*

for photographs 2, 5, and 7 are shown in Figures 10, 11, and 12 respectively. Since the isophotes at each peak of the zodiacal light cones are nearly at a constant elevation, the corrected isophote curves coincide with the uncorrected curves at the peaks except for the difference in their assigned intensities as shown. That is, the background of each point in the peak is the same and the extinction factor is also the same for each point since the points are at the same elevation.

In order to determine the axis of the zodiacal light it was decided to make a graph of great circles inclined to the equator at intervals of one degree from an inclination of 24 degrees to 30 degrees. One set of these great circles shown on photograph 5 was constructed so that the circles intersected in the position of the sun. Another set shown on photograph 2 was constructed so that the circles intersected at the intersection of the ecliptic with the eastern horizon for photograph 2. Lines of equal distance from the sun were marked on the set of great circles on photograph 5. Lines of equal distance from the horizon were marked on the set of great circles on photograph 2. The great circle along which the peak of the zodiacal light was farthermost from the sun was chosen to be the axis of the zodiacal light. Since the lines of equal distance from the sun were almost parallel to the constant elevation circles, the uncorrected isophotes could be used instead of the corrected ones for determining the light axis. One of the lines of equal distance from the sun is shown in Figure 10.

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In order to determine the axis of the zodiacal light it was decided to make a graph of great circles inclined to the equator at intervals of one degree from an inclination of 28 degrees to 30 degrees. One set of these great circles shown on photograph 5 was constructed so that the circles intersected in the position of the sun. Another set shown on photograph 7 was constructed so that the circles intersected at the intersection of the ecliptic with the eastern horizon for photograph 2. Lines of equal distance from the sun were marked on the set of great circles on photograph 5. Lines of equal distance from the horizon were marked on the set of great circles on photograph 2. The great circle along which the peak of the zodiacal light was farthermost from the sun was chosen to be the axis of the zodiacal light. Since the lines of equal distance from the sun were almost parallel to the constant elevation circles, the uncorrected isophotes could be used instead of the corrected ones for determining the light axis. One of the lines of equal distance from the sun is shown in Figure 10.

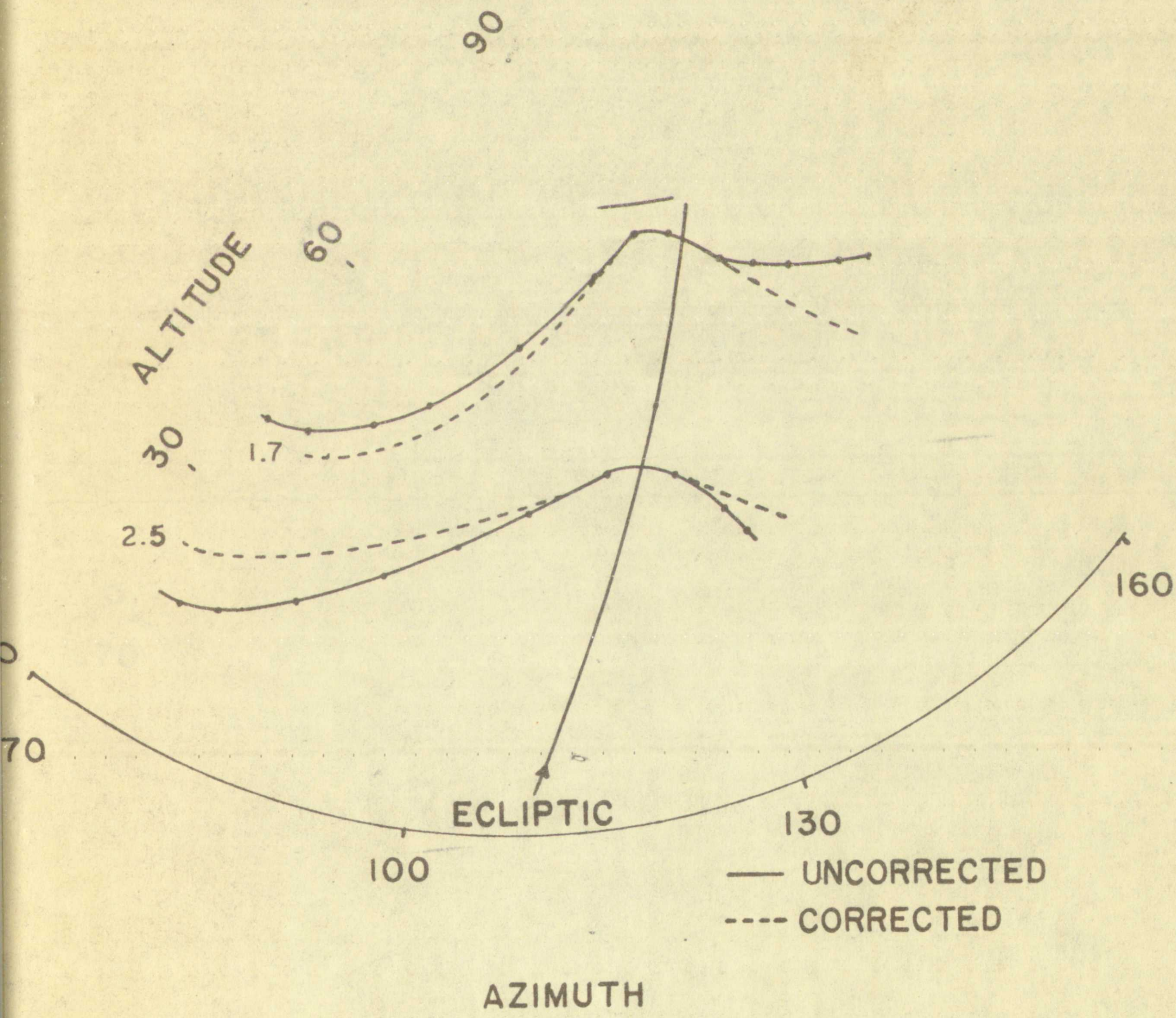

FIGURE 10

UNCORRECTED AND CORRECTED ISOPHOTES OF ZODIACAL LIGHT INTENSITY

USING ALTITUDE AND AZIMUTH FOR PHOTOGRAPH 2

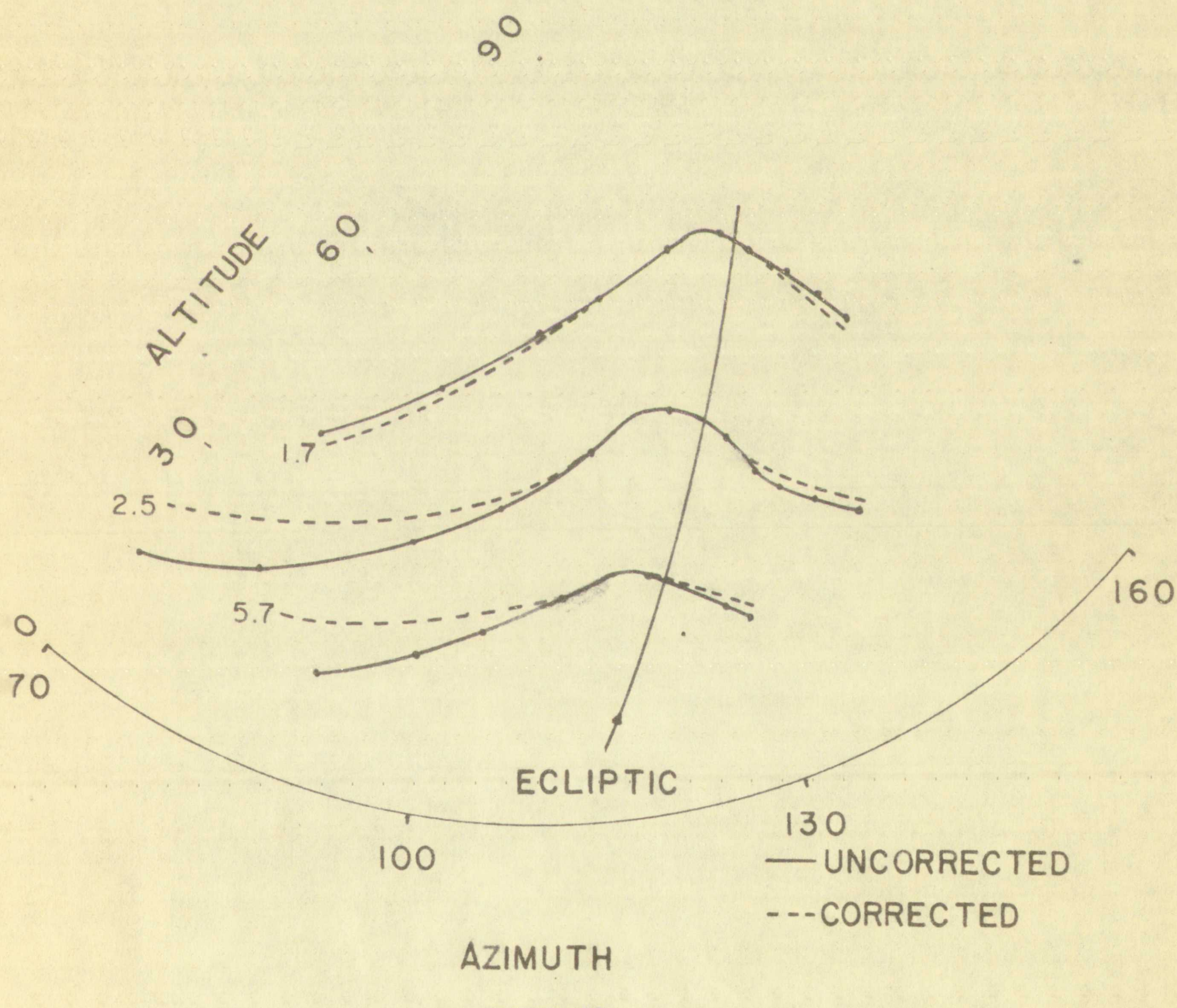

FIGURE 11

UNCORRECTED AND CORRECTED ISOPHOTES OF ZODIACAL LIGHT INTENSITY USING ALTITUDE AND AZIMUTH FOR PHOTOGRAPH 5

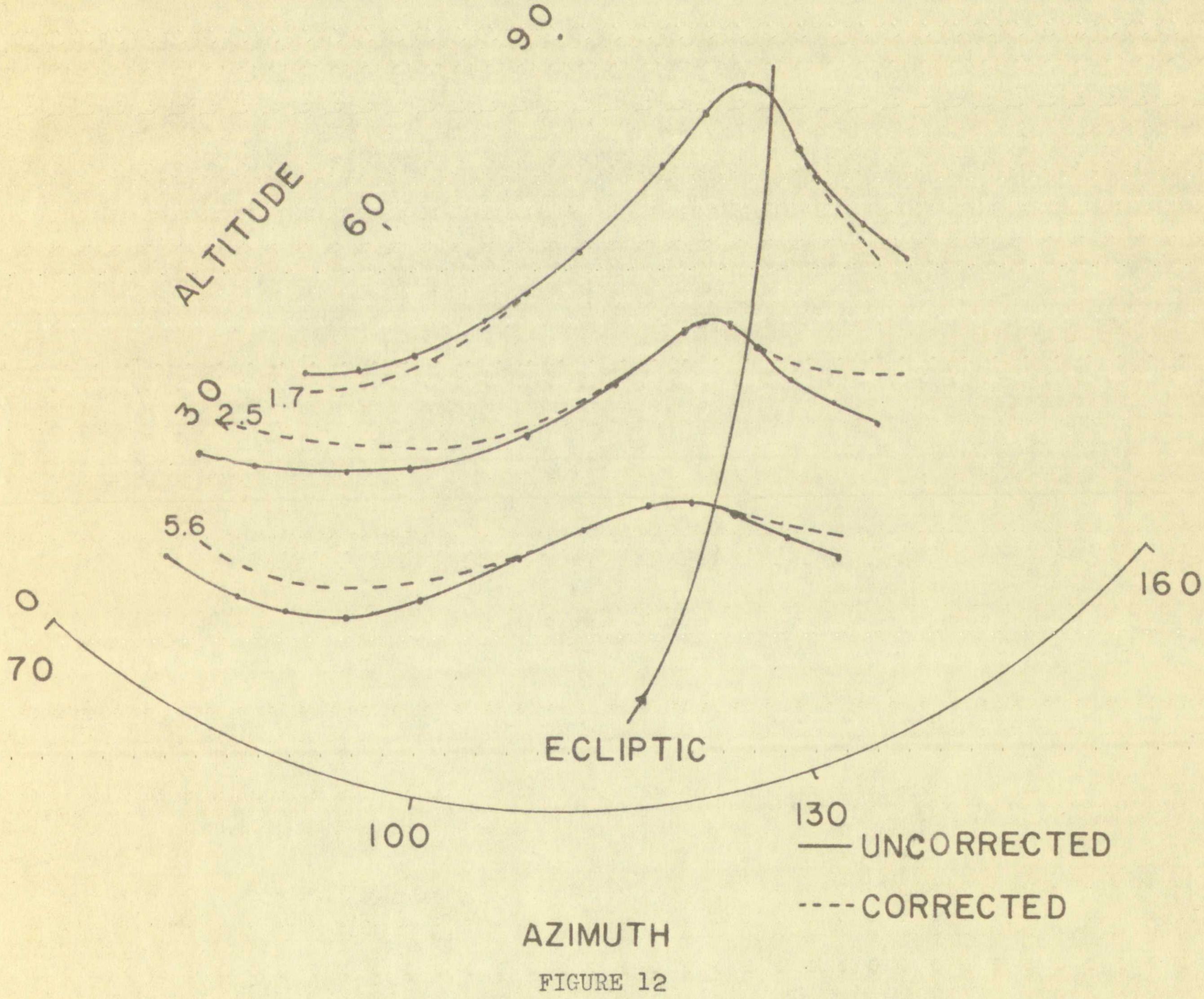

FIGURE 12

UNCORRECTED AND CORRECTED ISOPHOTES OF ZODIACAL LIGHT INTENSITY USING ALTITUDE AND AZIMUTH FOR PHOTOGRAPH 7

To get the angle between the zodiacal light axis and the ecliptic, the following formula was used:

$$\frac{\sin \alpha}{\sin a} = \frac{\sin \beta}{\sin b}$$

Arc a is the arc along the equator between the ecliptic and the zodiacal light axis; angle β is the angle the ecliptic makes with the equator ($23\frac{1}{2}°$); arc b is the arc along the zodiacal light axis from the sun to the equator; and the angle α is the desired angle between the ecliptic and the zodiacal light axis. The values obtained for angle α are listed in Table II for the set of great circles going through the sun and also for the set of great circles going through the horizon for photograph 2. Table II also gives the date and the local sidereal time for each of the photographs 1 through 8.

TABLE II

INCLINATION OF THE AXIS
OF THE ZODIACAL LIGHT AGAINST THE ECLIPTIC
FOR PHOTOGRAPHS 1 THROUGH 8

Photograph number	Date	Local Sidereal Time	Inclination of light axis against ecliptic for: Circles through sun	Circles through horizon
1	12/9/50	0905	close t o ecliptic	
2	12/9/50	0932	3.5° ± 1.5°	5.5° ± 1.5°
3	12/9/50	0952	4.5° ± 2.5°	
4	12/9/50	1005	3.5° ± 1.5°	
5	12/9/50	1014	3.5° ± 1.5°	
6	12/9/50	1022.5	4.5° ± 2.5°	
7	12/9/50	1031.5	3.5° ± 1.5°	
8	12/9/50	0946	3.5° ± 1.5°	

Conclusions. It can be seen from Table II that the light axis is tilted toward the north, which, from previous observations, was to be expected. However, the position of the light axis did not seem to vary to any considerable extent in the course of one night. Since there was only one night in which several consecutive observations could be made it was not possible to say that there is no nightly variation of the tilt of the axis. Also, the time interval over which the observations were made may not have been long enough to show any distinct variation of the tilt of the axis.

The shape of the zodiacal light approximates a pyramid when plotted without correction for extinction. If the extinction is taken into account, it can be seen from Figure 10 that the portion of the pyramid near the horizon is widened to a considerable extent. The upper portion of the pyramid (above 30°) remains practically the same shape.

It can be seen from Figures 10, 11, and 12 that the shape of the zodiacal light changes as the night progresses, becoming more pointed at the peak as dawn approaches. This would seem to indicate that the origin of the zodiacal light is terrestrial rather than planetary. Since the corrected isophotes are supposedly free of any atmospheric effects, it is not conceivable that the rotation of the earth would have any effect on the shape of the zodiacal light if its origin were planetary.

Suggested improvements in equipment. In order to make the

Conclusions. It can be seen from Table II that the light axis is tilted toward the north, which, from previous observations, was to be expected. However, the position of the light axis did not seem to vary to any considerable extent in the course of one night. Since there was only one night in which several consecutive observations could be made it was not possible to say that there is no nightly variation of the tilt of the axis. Also, the time interval over which the observations were made may not have been long enough to show any distinct variation of the tilt of the axis.

The shape of the zodiacal light approximates a pyramid when plotted without correction for extinction. If the extinction is taken into account, it can be seen from Figure 10 that the portion of the pyramid near the horizon is widened to a considerable extent. The upper portion of the pyramid (above 40°) remains practically the same shape.

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Suggested improvements in equipment. In order to make the

apparatus record continuously, a moving picture camera could be substituted for the camera used now. It could be made to change frames automatically after each complete scanning of the sky. For a more complete scanning of the sky, the declination steps could be reduced from 3° per step to 1° per step. Also, the number of intensity steps in the discriminator could be increased.

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