5-23-1949

A New Method of Measuring the Intensity of the Zodiacal Light

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A NEW METHOD OF MEASURING THE INTENSITY OF THE ZODIACAL LIGHT

A Thesis

Presented to

The Faculty of the Graduate School

University of New Mexico

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Physics

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by

Raymond Grenchik

May 1949

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

Dean A. Schooler

DEAN

May 23 - 1946

DATE

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CHAPTER I

DESCRIPTION AND CHARACTERISTICS OF ZODIACAL LIGHT

Description

On clear moonless evenings, just after the disappearance of twilight, there appears above the western horizon a pyramid of faint, whitish light. The line of maximum light intensity lies in or near the plane of the ecliptic, hence the name zodiacal light. The base of the pyramid is about 40° wide and its height about 60° measured along the ecliptic. Stretching across the sky from the apex is the narrow zodiacal band of about 5° to 10° in width. At a point of 180° from the sun the band widens into a knot of luminosity whose boundaries are not too well defined. This last phenomenon is called the gegenschein, or counterglow. Measurements at Montpellier, France[1] show that the intensity of the zodiacal light is about 2.4 times that of the night sky luminescence near the region of the pole star. An identical phenomenon occurs before the morning twilight hours on the eastern horizon.

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1 Dufay, J., Reunions de l'Institut d'Optique (Paris) Communic, June 13, p. 6 (1933).

Annual Variation of the Intensity of the Zodiacal Light

The following description of the changes of zodiacal light in the course of a year in moderately high northern latitudes is taken from Schmid[2] who has made a careful study of the phenomenon:

> The west zodiacal light begins to appear by the end of September and in November fully develops the character of zodiacal light. The cone of light rises out of the southwest horizon as the ecliptic rises, and it reaches the highest point in the month of January. It then sinks gradually and is lost in the summer night glow in the month of May. The sky is free from zodiacal light in the month of June. By the end of July we see the first appearance of morning zodiacal light shortly after midnight. At the beginning the cone of light is strongly inclined to the horizon like the ecliptic. With the approach of autumn the inclination gradually changes and in the month of November the cone of light becomes almost vertical. It then begins to incline more and more towards the south with increasing inclination of the ecliptic and disappears in the southeastern sky towards the middle of March.

Quantitative measurements by Elvey and Roach[3] made in Texas with a photoelectric recording photometer, depict the seasonal variations of the evening and morning zodiacal light. Their measurements show that, for the evening zodiacal light, the maximum intensity occurs in April and May, while the minimum occurs in January and February. The reverse

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2 Schmid, F., Das Zodiacallicht, Vol. 2, Probleme der Kosmischen Physik.

3 Elvey, C. T. and Roach, F. E., Astrophys Journal 85, 213 (1937).

is the case for the morning zodiacal light.

The intensity varies considerably from night to night, and also from hour to hour in a particular night. At times the light may be almost extinct.

Spectrum of Zodiacal Light

The spectrum of the zodiacal light is closely similar to that of sunlight. Absorption lines of the solar spectrum have been identified in the zodiacal spectrum. Recent observations[4] show that the spectrum also contains the usual night sky lines and bands, namely, the auroral green line (λ5577 due to atomic oxygen) and the N_2 bands. It should be remembered, however, that on any spectrum of the zodiacal light, the spectrum of the night sky must also be superposed. Even after making allowance for this there is strong evidence of the zodiacal matter itself emitting the lines and the bands of the night sky.

Polarization of the Zodiacal Light

Dufay[5] has made a comparative study of the polarization of light from regions of the sky in the zodiacal cone and from regions outside it. His results show that fifteen per-cent of

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4 Ramanathan, K. R., Nature, 129, 280 (1932).

5 Dufay, J., Jour de Phys, Ser. 6, 10, 219 (1929)

the zodiacal light is polarized, while two to four per-cent of the light of the night sky is polarized. The planes of polarization of both are found to pass constantly through the sun.

Parallax

Attempts to measure the distance to the zodiacal light by means of parallax have been unsuccessful. The light is too diffuse for parallax measurements. The reported absence of parallax may be only apparent, being masked by other effects.

Nightly Motion

During the winter solstice the zodiacal pyramid lies considerably off the ecliptic just after the twilight hours. As the observer moves toward the ecliptic during the evening's observation the pyramid tends to move toward the ecliptic until it coincides about midnight. The pyramid moves in the opposite sense for the morning zodiacal light.

Extinction

In the northern latitudes the observer sees the zodiacal pyramid inclined toward the south. The light from the far southern half of the pyramid must traverse a greater amount of atmosphere. Hence, the southern half of the light, being closer to the horizon, seems dimmer and gives the impression that the

light axis of the pyramid is shifted to the north.

Extinction and nightly motion have opposite effects on the zodiacal light. The nightly motion is best observable during the solstices.

CHAPTER II

THEORIES OF ZODIACAL LIGHT

The two theories that have been presented for the zodiacal light show that it is due to light scattered (and perhaps emitted) from an extensive lenticular cloud of particles lying in the plane of the ecliptic. The basic difference of the two theories is the position of the center of this cloud. One, the planetary theory, places the sun at the center of this cloud. The other, the atmospheric theory, places the earth at the center of the cloud.

Planetary Dust Theory

The planetary dust cloud may have its origin from the big splash when the planets were formed. The particles are much larger than molecules. Otherwise, they would soon be dispersed by solar radiation pressure. They also must have planetary motion around the sun to overcome gravitational attraction from that body.

Another more definite explanation for the planetary dust cloud has been advanced by Fessenkoff[6] as follows: the

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6 Fessenkoff, V. G., Astronomical Journal, Soviet Union, Vol. 20, Part II, 1942.

dust particles are produced by collision of sporadic meteors with asteroids. In support of his theory, Fessenkoff cites a parallel phenomenon, namely, the formation of thick clouds of dust on the surfaces of the moon and of mercury, and probably of all members of the solar system without atmosphere. Since the combined surface of all the asteroids is large, the amount of dust particles produced is large. Since the masses of the asteroids are small compared to that of the heavenly bodies, the asteroids cannot retain the dust cloud by gravitational forces. The particles are drawn into the solar system from different directions, and with different velocities, and form an oblate spheroid with the sun at the center. The spheroid is surrounded by a thick ring of dust in the asteroid zone. This spheroid, according to Fessenkoff, gives rise to the zodiacal light, and the ring of dust surrounding it is the zodiacal band along the ecliptic.

An explanation of the gegenschein is given by the application of a particular solution of the three body problem in celestial mechanics to the case of the earth, the sun, and the dust particle. The problem is presented by Moulton.[7] It can be shown that on the side of the earth opposite the sun, and on

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7 Moulton, F. R., An Introduction to Celestial Mechanics, (Second Revised Edition, 1935). Macmillan Company, New York, p. 305.

the line joining the two, there is a point of equilibrium around which a particle, assumed to be of infinitesimal mass, will move in a closed elliptical path if it entered with an appropriate initial velocity. Since the dust particle is not of infinitesimal mass it will move in a nearly closed orbit and remain in the region for a considerable time. Because the planetary dust theory proposes a very large number of dust particles, it is possible that some will pass near the point of equilibrium with the proper velocity. These particles would execute one or more orbits around the point before continuing their orbit around the sun. A concentration of particles would result at that point, and the light scattered from that region would be slightly more intense than from the surrounding region where the concentration of particles is lower.

To explain the intensity of the zodiacal light, the particles need not be numerous. The observed intensity can be accounted for if the particles are one millimeter in diameter, with a reflecting power of .073, and the average distance between particles is five miles.

Polarization is a characteristic of Rayleigh scattering by particles of molecular dimensions. One could not expect light to become polarized by being scattered from

particles of one mm. diameter. However, light reflected from minerals, such as granite, is partially polarized. One may assume that the zodiacal particles are made of such minerals.

Atmospheric Theory

The atmospheric theory leaves unexplained the origin of the cloud that surrounds the earth. The particles comprising the cloud may be dust particles smaller than the ones assumed in the planetary theory or air molecules. The extension of the cloud is uncertain, but it must be considerably beyond the distance at which the centrifugal force equals the gravitational attraction. The cloud lens participates in the motion of the earth around the sun but its plane always remains in the plane of the ecliptic.

Hulburt's Spray Region

Hulburt[8] assumes that the so-called "fringe" or "spray" region of the outer atmosphere, where the gas kinetic laws break down at very low pressures, is the scattering cloud of the zodiacal light. Some of the high flying molecules in the spray region are ionized, and those at levels beyond 30,000 km. will, under the combined solar radiation pressure and the earth's magnetic and gravitational fields, form a sort of oblong ring around the earth. On the daylight side of the

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8 Hulburt, E. O., Terrestial Magnetism and Electricity, Vol. VIII of series "Physics of the Earth", McGraw-Hill, p. 567. (1939).

earth the ring lies roughly in the plane of the equator, and on the night side it is warped off the equational plane, approximately in the plane of the ecliptic, and is stretched out into a long oval by light pressure. The ions in the ring are assumed to absorb the extreme ultraviolet light of the solar radiation and re-emit, as visible light, a portion of the absorbed energy. This, according to Hulburt, is the zodiacal light.

Vegard's Terrestial Corona

Another version of the formation of the atmospheric lens is given by Vegard. According to Vegard,[9] the terrestial atmosphere is topped by a corona, particularly on the daylight side.

The atoms and molecules of the topmost layers of the atmosphere are assumed to be ionized by the extreme ultraviolet solar radiation, and electrons of considerable energy are released. The ejected electrons are more free to move in an upward direction where they suffer less collisions. They produce an electric field between themselves and the positive ions left behind. The electric field not only prevents the photoelectrons from escaping from the terrestial atmosphere, but also drives upward to some extent the positive-ions. This region, crowning the highest layers of the

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9 Vegard, L., Erg. der Exakt Naturwiss, 17, 229 (1938).

atmosphere, is called the Vegard terrestial "corona". Due to the action of the terrestial magnetic field the corona, consisting of charged particles, bulges out near the equator and assumes a lenticular shape. The axis of the lens coincides with the magnetic equator, and the main extension of the bulge is on the daylight side. This bulge, illuminated by the solar rays, appears as the zodiacal light on the earth. Since the extension of the bulge is towards the sun, the zodiacal pyramid appears to be in the plane of the ecliptic.

The gegenschein, according to the atmospheric theory is due to a portion of the lens receiving scattered light from both the morning and evening zodiacal cones. Hence, the gegenschein will always appear in the region of the sky opposite the sun.

Polarization

The particles of the cloud are assumed small enough to produce Rayleigh scattering, and hence, polarization. However, the intensity of the scattered light in Rayleigh scattering should vary inversely as the fourth power of the wave length. No such distribution of intensity has been observed in the zodiacal spectrum. However, the zodiacal light contains a large percentage of unpolarized light the origin of which may not be due to scattering. This unpolar-

ized component may mask the inverse fourth-power distribution.

Irregular Variation of Intensity

One of the important characteristics of the zodiacal light is its reported irregular fluctuations of intensity[10] mentioned in the previous chapter. These fluctuations are allegedly of the order of hundreds of per-cent within a period of minutes. Neither theory explains satisfactorily this characteristic. This cannot be explained entirely by scattered sunlight because no strong fluctuations of the solar constant have been observed. Some of the variations may be caused by a fluorescent part of the zodiacal light as a result of solar outbursts of ultraviolet radiation, which are known to occur during magnetic storms. Part of the irregular variations of intensity may, perhaps, be due to variations in the humidity of the upper regions of the atmosphere. That such variations may cause change of visibility is evidenced by the color, size, and general appearance of lunar and planetary corona and visibility and length of meteor trails.

The measurement of these irregular fluctuations is one of the purposes of the self-recording instrument in this paper.

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10 Hulburt, E. O., Phys. Rev. 35, 1098 (1930).

CHAPTER III

DESCRIPTION AND CHARACTERISTICS OF APPARATUS

The equipment consists essentially of a 931A photo-multiplier tube set in the focus of a sixty inch parabolic reflector. The output of the 931A is amplified by a one-stage D. C. amplifier whose output is connected across the deflecting plates of an oscilloscope. The trace is photographed on continuously moving 16 mm. film.

Reflector

The reflector revolves at some fixed elevation once every twenty-five seconds, and during that interval about three inches of film are exposed.

The reflector, with its carriage and control apparatus, is a war surplus item manufactured by General Electric for the army as a sixty inch searchlight. A 931A tube socket replaces the arc assembly at the focus of the mirror. The frame on which the tube is mounted can be moved a short distance along the principal axis of the mirror to adjust for proper focusing.

Plate No. One shows the reflector mounted inside its carriage. The trailer was used to haul it to its present

Searchlight
Plate 1

location. The reflector, with its carriage, is removed from the trailer and mounted semi-permanently for observation.

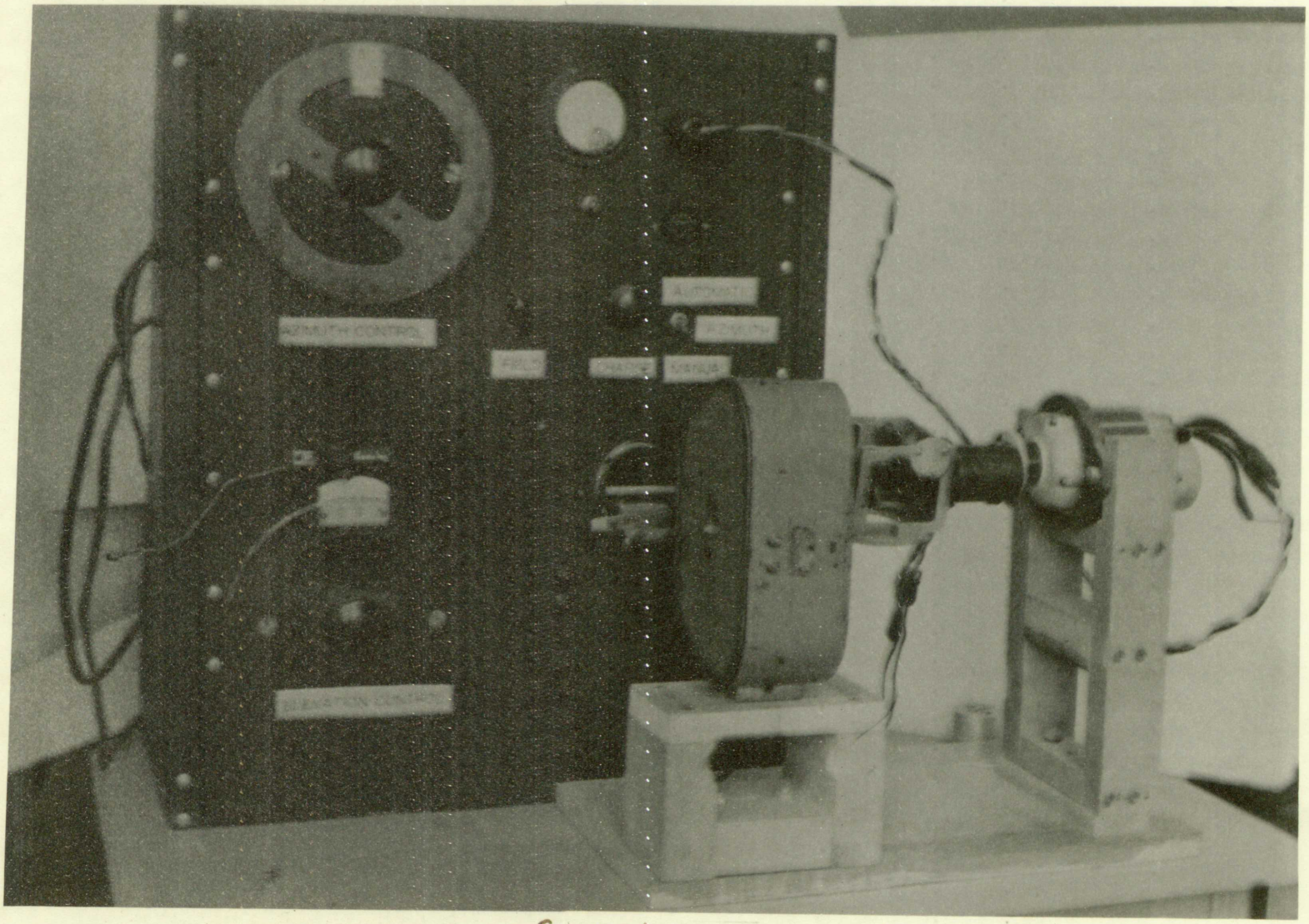
The motors to drive the reflector housing in azimuth and elevation are retained and, also, the Selsyn synchro-generators which control the power for the motors.

In Plate No. One the tube socket mount is visible and also the elevation control box which contains the elevation drive motor. Obscured by the trailer side is the azimuth control box with its drive motor and syncho-generator unit. This box is mounted below the reflector carriage.

Not shown in Plate No. One is the one-stage D. C. amplifier unit which amplifies the photoelectric signal. It is normally mounted against the elevation control box.

Power Generator

A 3KW 110 volt D. C. gasoline driven motor generator provides enough power to operate all the instruments necessary for observation. The governor of the gasoline driven motor is adjusted so that the output potential is only eighty volts, for which the searchlight is designed. The generator proves substantially stable at the slower speed. The output can be adjusted at the central control unit by



Control
Plate 2

varying the field current of the generator (Plate No. Two).

Central Control Unit

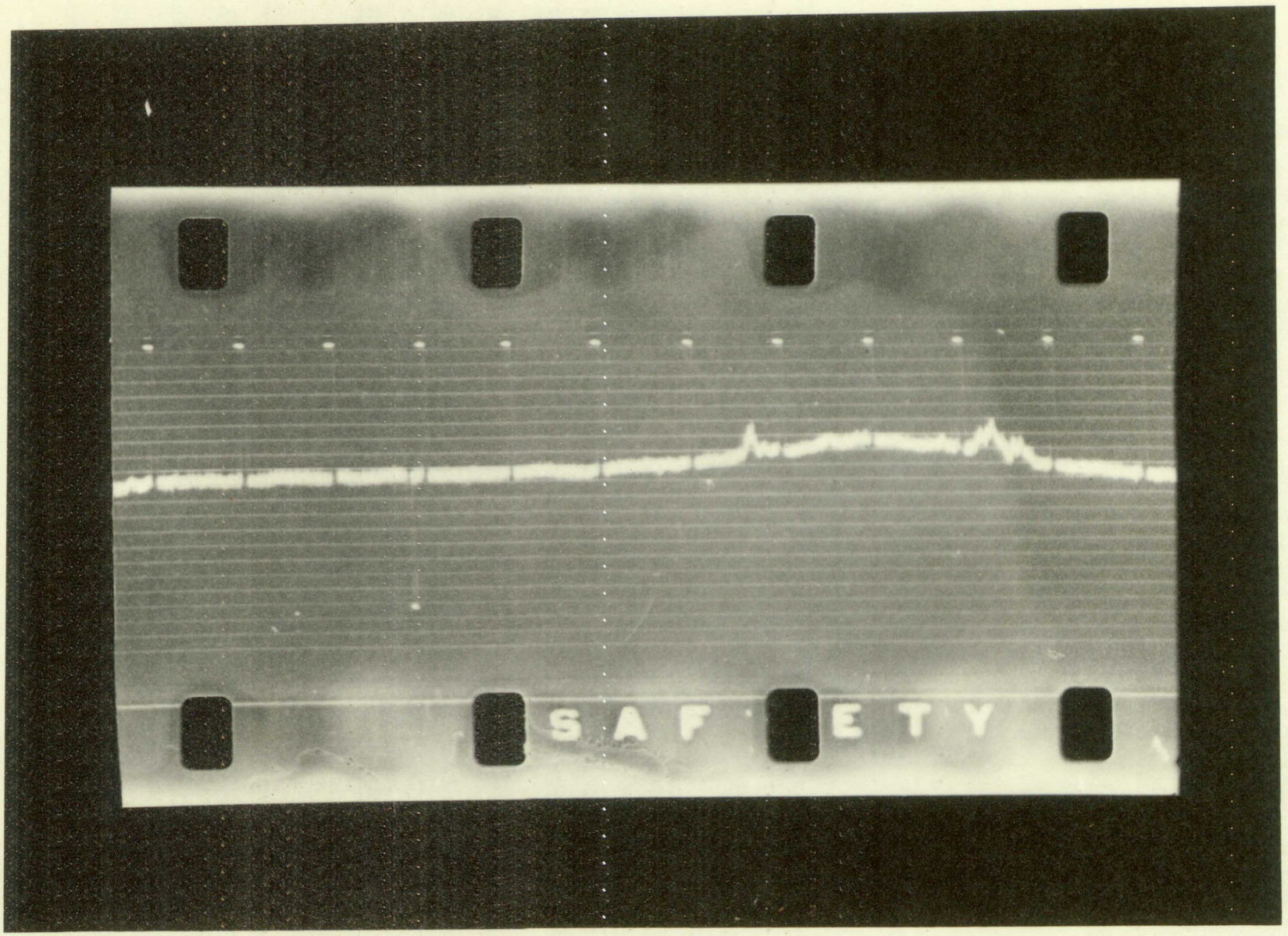
Besides the automatic azimuth sweep of twenty-five seconds, the central control unit also provides means to set the elevation and azimuth at any desirable setting. During operations only the manual elevation control is used. For a complete sweep of the sky the elevation is changed in five degree steps from 0° to 50°, and in ten degree steps from 50° to 80°.

To synchronize the film with the rotation of the mirror both the camera drive and the Selsyn type synchro-generator for the automatic azimuth control are mounted on the same shaft of a fiftieth horsepower twenty-four volt D. C. motor. (Plate No. Two). During operations the batteries are trickle charged by the eighty volt generator. By a switching arrangement the meter on the control panel, which reads the output voltage of the generator, can be made to read the charging current for the batteries. This current is about 0.6 ampere.

The generator also provides power to a dynamotor, which produces 115 volts A.C. for the oscilloscope.

Explanation of Film Record

Each complete revolution of the mirror in azimuth throws



Film Strip
Plate 3

a microswitch so that the input of the amplifier is shorted momentarily. This appears on the scope screen as a negative pulse (Plate No. Three). The reflector carriage is set up so that this pulse occurs at 0° (north). On one of the gears of the azimuth motor drive, whose ratio is eighteen to one, there is mounted another microswitch, which is tripped for each revolution of that gear. The switch shorts out, for an instant, the plate resistor of the D. C. amplifier. This appears on the scope screen as a positive pulse. These pulses occur at twenty degree intervals on the film strip.

A transparent plastic plate with vertical scratches, equally spaced, is fitted in front of the scope screen. (Plate No. Two). The scratches are illuminated indirectly by a twenty-four volt panel light so that a scale is superimposed on the scope trace (Plate No. Three). The panel light obtains its power from the storage batteries.

Semi-Permanent Installation

The equipment is set up on South Capillo Peak, New Mexico, (elevation approximately 9,000 feet) located at 34° 42' N and 106°24' W. The high elevation avoids the hazy atmosphere that clouds the lower elevations. Locating the apparatus at South Capillo also places Albuquerque north northwest where the disturbing influence of its lights is

far out of the region of the sky to be studied. The city of Belen is directly west, but, because of the high elevation of Capillo, the lights appear below the horizon. On the eastern horizon not too much extraneous illumination is encountered. The lights that do appear are below the horizon.

The reflector carriage is mounted on a point of the hill where the least horizon interference is encountered from nearby trees. The carriage is leveled with the jacks attached to the chassis of the searchlight. A Polaris sight, using the photomultiplier tube in the focus of the mirror, is used to align the microswitch that gives the 0^{o} marker on the film. Placing a screen just above the tube socket and moving the socket frame in and out enables one to locate the photomultiplier at the exact focus of the mirror.

The generator is set up to the north and a little below the mirror so that the sparks from the exhaust do not interfere with measurements of the desired regions of the sky. The control station is also set up to the north where its horizontal obstruction is of no consequence.

Two heavy power leads connect the reflector to the generator. Ten leads connect the reflector to the control station. These are as follows: three each for the stators of the azimuth and elevation synchro-generator, respectively; two leads for the

synchronizing A. C. current to the rotors of the synchro-generators at the control station; and two (shielded) for the amplified output signal to the deflecting plates of the scope.

Beside the power leads to the reflector, the generator has power lines to the dynamotor which provides the 115 volts A. C. for the scope. Two power lines also connect to the control unit for charging purposes. One other lead carries the field current to the control station so that the output potential of the generator can be adjusted at that point.

Characteristics of Measuring Apparatus

For stability and ease of operation dry cells are used for the photomultiplier and the amplifier. The batteries for each unit are placed as near as possible to that piece of equipment to which they provide power. The battery container for the photomultiplier is secured to the bottom of the reflector carriage, just about two feet below the tube socket. The amplifier and its batteries are contained in one box, attached to the elevation control box of the searchlight.

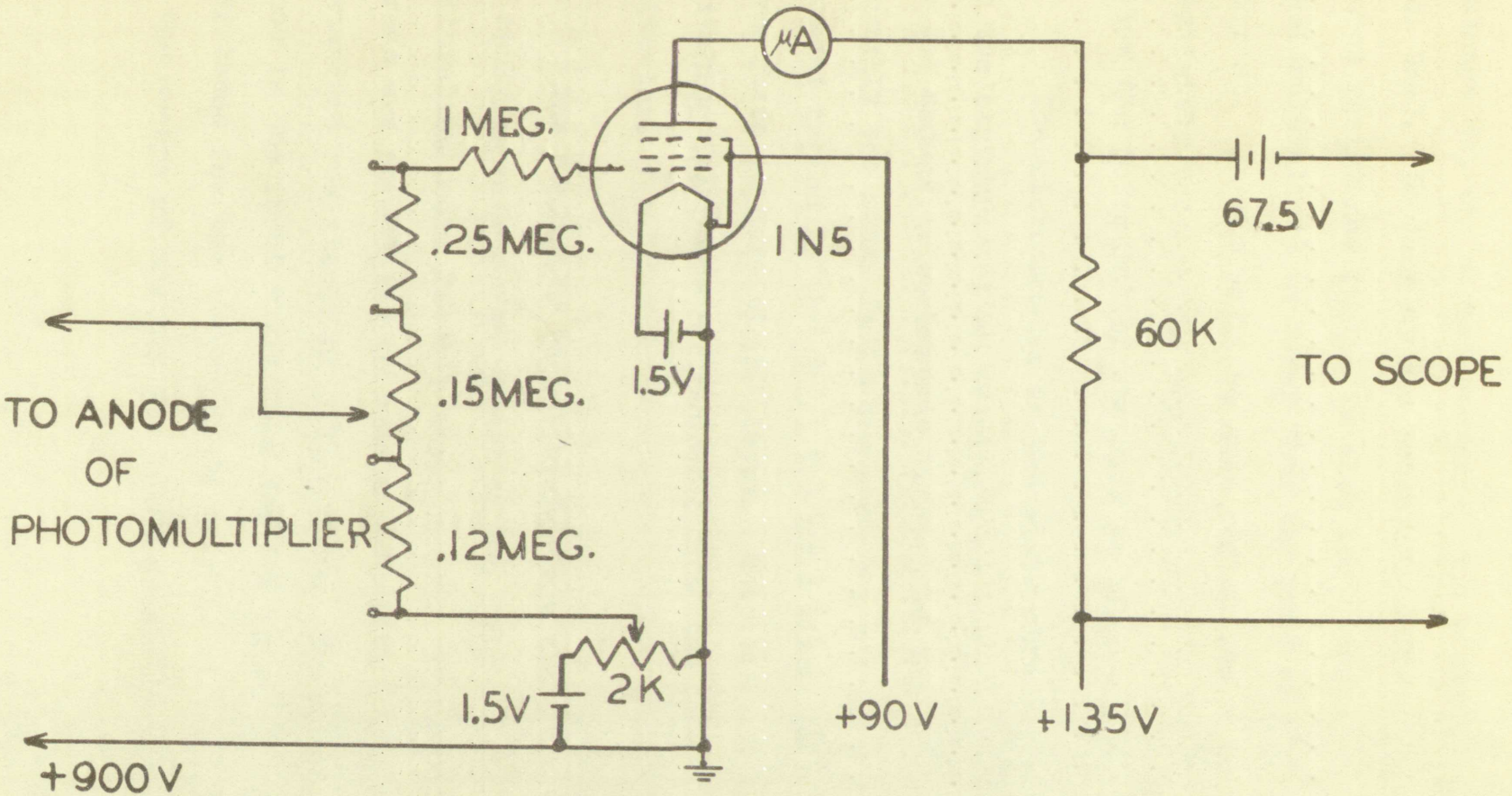
The ten stages of the photomultiplier are each provided with ninety volts accelerating potential with a total potential between cathode and anode of 900 volts D. C. With such working potentials the current caused by the background light is about five microamperes in the anode circuit of

the phtomultiplier. The zodiacal light causes a current of about 10-15 microamperes. At such a low current drain the hearing aid batteries used could be expected to last almost as long as their shelf-life.

At the light intensities involved the photomultiplier behaves as a constant current source. The current in the anode circuit depends only on the light intensity and not on the resistance in the anode circuit.

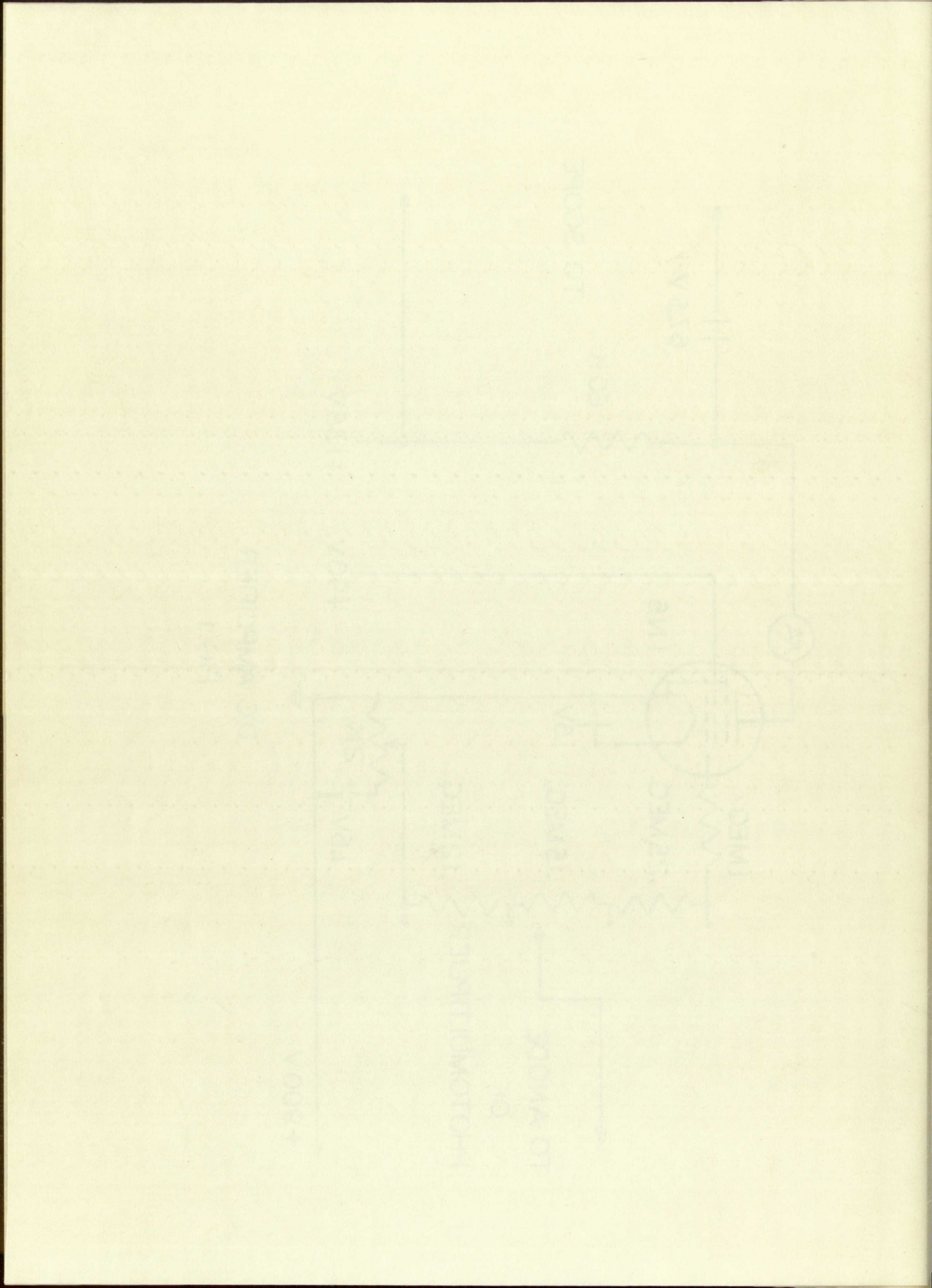
Figure No. One represents the circuit diagram for the one-stage amplifier with the connections to the photo-multiplier and to the recording device. The amplification is reasonably linear up to a signal input of one volt. With a signal input greater than one volt the tube begins to cut off and the amplification drops off about logarithmically. At about four volts input the tube cuts off completely. So the considerable light intensity from a star will only cause the tube to cut off. Even under those conditions the scope spot remains on scale.

The current which flows because of the background light develops a potential across 0.27 megohm of about one volt. The signal from the zodiacal light then causes the tube to operate in the non-linear region. To eliminate this disad-vantage a positive grid bias is used in the input stage to



D.C. AMPLIFIER

FIG. 1



balance out the signal caused by the background light (Fig. No. One). As long as the potential difference across the input resistance (which is also the output resistance of the photomultiplier) is lower than the grid bias, there is grid current. In the positive grid region the amplification is negligible because the one megohm grid resistor does not allow the potential of the grid to rise with the input signal.

The microammeter in the plate circuit serves as a guide at the beginning of an evening's or morning's operations as to the amount of background light. As the carriage is rotated manually the meter indicates when the mirror is directed at the darkest region in the sky. The grid bias is then adjusted so that there is zero signal input. This bias is measured by switching the plate microammeter into the grid circuit as a voltmeter.

The amplifier is calibrated for the three gain steps by applying a measured signal input. Figure 1A shows the calibration curve for all three gains. The full and low gain curves are normalized to read a potential difference across a standard resistance of 0.27 megohm. This standard resistance is the input resistance for the intermediate gain. The resistance for the intermediate gain is chosen because most of the sweeps of the sky are taken at that setting.

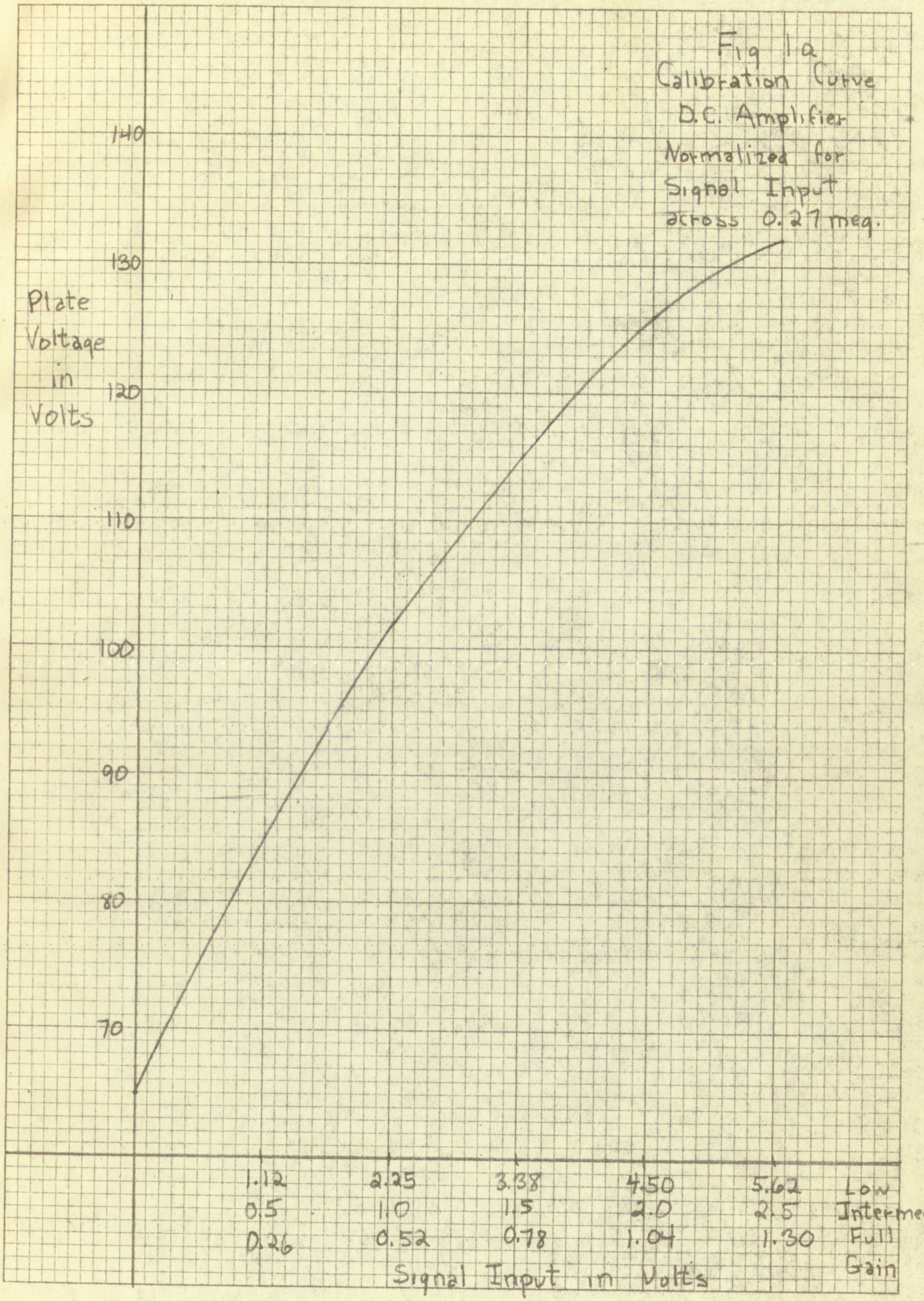


Fig 1a
Calibration Curve
D.C. Amplifier
Normalized for
Signal Input
across 0.27 meg.
140
130
120
110
100
90
80
70
Plate
Voltage
in
Volts
1.12
0.5
0.26
2.25
1.0
0.52
3.38
1.5
0.78
4.50
2.0
1.04
5.62
2.5
1.30
Low
Intermed.
Full
Gain
Signal Input in Volts

So that the full scope screen could be utilized, a fixed potential (67.5 volt battery) is used in the output to deflect the electron beam. With zero signal the scope spot appears on one side of the screen. As the signal increases the spot moves across the screen and remains more nearly in the field of the camera. With an input signal that cuts off the amplifier a motion of something less than two inches on the three inch screen is encountered. This corresponds to a signal of about seventy volts on the deflecting plates of the scope.

To obtain this sensitivity a 3AP1 cathode ray tube is operated with as low an accelerating potential as possible without sacrificing spot definition. An accelerating potential of about 600 volts proves satisfactory. Working at low potentials also made the construction of a regulated power supply simple.

Because the eighty volt D. C. motor generator is not sufficiently stable, the power supply for the scope has to be input regulated. No trouble is to be expected at the output because the scope tube can be depended upon to act as a constant load. Figure No. Two shows the circuit diagram of the power supply.[11] A portion of the unregulated input

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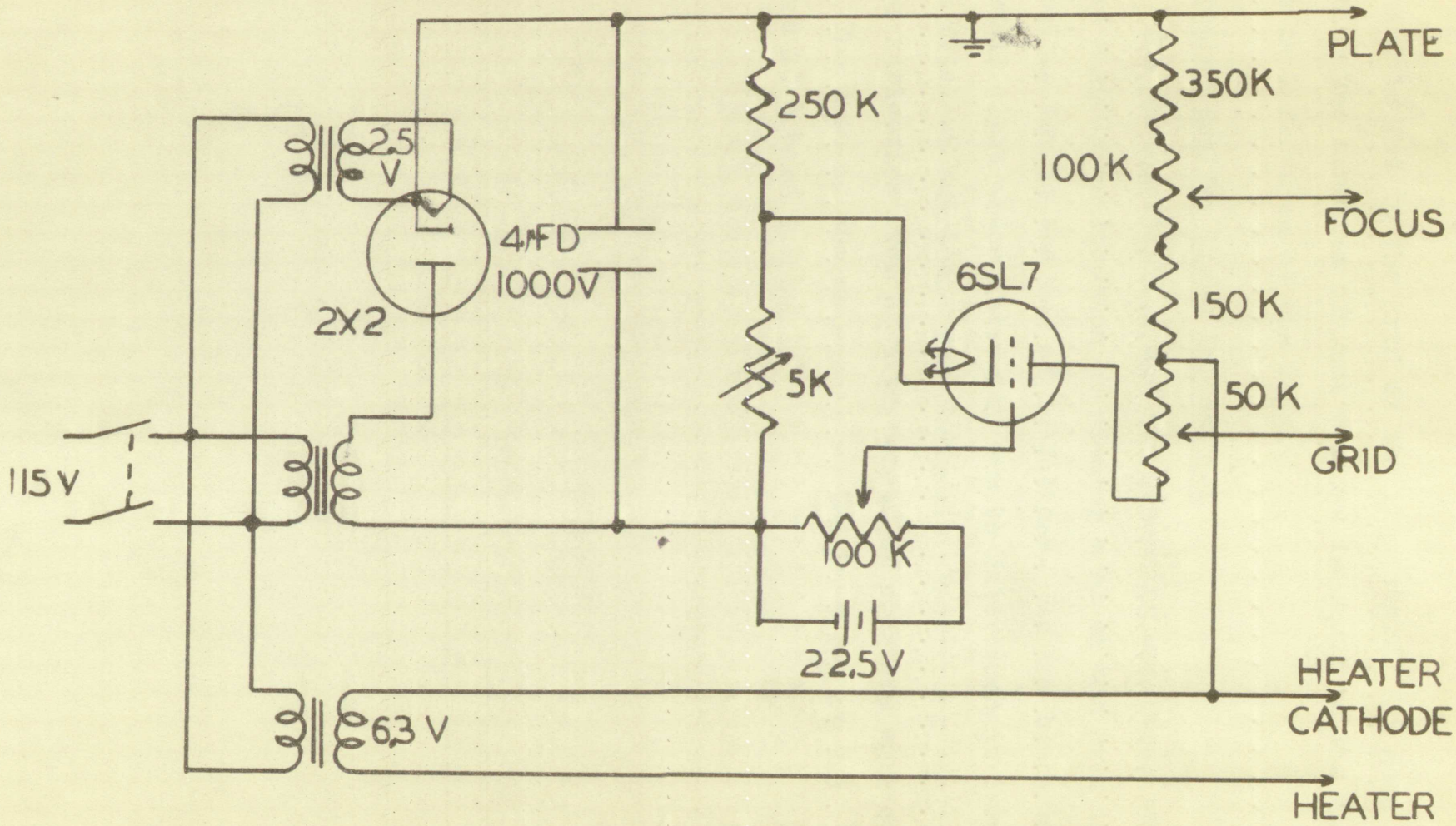
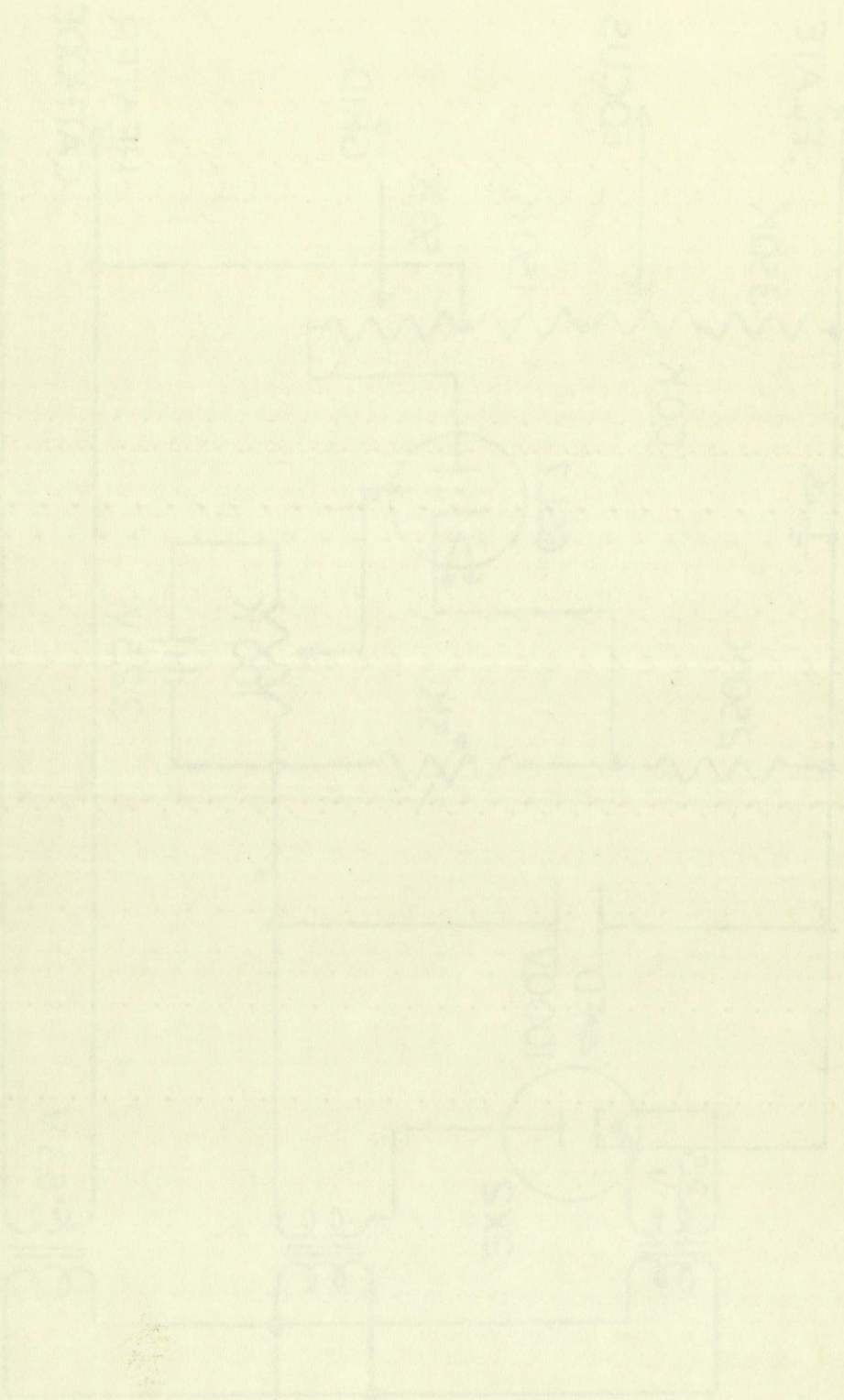
11 Brainerd, Ultra High Frequency Techniques, Van Nostrand Company Inc. p. 73.



REGULATED SCOPE POWER SUPPY

FIG. 2



potential is fed to the grid of the regulator. For good compensation the fraction of that voltage is equal to the inverse of the amplification of the regulator.

Calibration Box for Light Intensities

The photomultiplier and its measuring apparatus can be checked nightly on location by placing a black box over the photomultiplier at the end of operations. In the black box is a small light whose intensity can be determined in terms of its filament current. The photomultiplier receives light only by reflection from a white screen of measured surface area. The area of the screen is varied in steps of 2.5, 5, 7,5, and 10 square inches.

CHAPTER IV

EXPLANATION OF GRAPHS

Polar Graphs

The thirteen polar graphs included in this paper are those of the morning of September 13, 1948 from 3:03 A.M. to 4:34 A. M. The late summer period of observation was ideal for observing morning zodiacal light because at that time the ecliptic was tending toward perpendicularity with respect to the horizon.

Data were also obtained on the mornings of the 11th of July, 9th and 12th of August, and 3rd, 8th, 10th, and 11th of September. Mornings for observation are chosen, weather permitting, when the moon is below the horizon.

A complete sweep of the sky lasted slightly less than six minutes. Azimuthal runs were obtained for elevations of 0^{o} to 50^{o} in five degree steps and thence by ten degree steps to 80^{o} degrees. In all, fourteen azimuthal revolutions constituted a full sweep.

All plots are normalized to read input signal in volts across a .27 megohm resistor. The input includes the background signal, as if the total signal of the bias had not been applied.

The ecliptic and the equator are drawn into each of the plots. The position of the ecliptic changes for the fixed observer while the position of the equator remains constant.

The first two runs were taken with the amplifier at full gain, i. e. the input resistance is 0.52 megohm. However, the signal and the bias are normalized to read potential across 0.27 megohm which is the input resistance for the intermediate gain. At full gain the background signal corresponded to 0.73 volt across 0.27 megohm. Isophotes (lines of equal light intensity) are plotted for total signal input of 0.75 volt to 1.20 volts in 0.05 volt steps. The gegenschein came through very well on both graphs. One might notice that the isophote of the gegenschein corresponds to an input signal of 0.80 volt, just a few hundredths of a volt more than background.

The Milky Way appears at an azimuth of 305°. Its brightest isophote corresponds to a total signal of 0.90 volt in Run One and 0.95 volt on Run Two.

Runs Three to Eight, inclusive, were carried out at intermediate gain with a grid bias of 1.0 volt. Unfortunately, it was poor choice of bias, because, while it cancelled the effect of background light, it also did the same to a great

part of the Milky Way and to all of the gegenschein. These six graphs are plotted with isophotes spaced at 0.05 volt.

Runs Nine through Thirteen are also at intermediate gain with a grid bias of 1.0 volt. These are plotted with isophotes spaced at 0.25 volt. The original spacing of 0.05 volt would cause the isophotes to crowd together. In these last runs the zodiacal light attains its maximum brightness. Run Thirteen may have a little of the dawn interfering. The Milky Way just begins to be visible on the last two runs.

All of the plots show that the zodiacal light pyramids are shifted to the north. This can be explained as due to extinction. The nightly motion during September is negligible.

Graph of Intensity vs. Time

Figure Three is a plot of the total signal input to the amplifier in volts vs. the time in minutes from 3:07 A.M. to 4:31 A.M. The time in each instance is taken for the middle of the run and the signal input is normalized as previously mentioned. The intensity is plotted for a point on the ecliptic,a fixed angular distance from its intersection with the horizon. It corresponded to a point very nearly due east and about thirty degrees in elevation above the horizon.

Figure Four shows on semi-logarithmic paper total input minus background (one volt) vs. time in minutes. The line is fairly straight for most of the runs except for the last two which were taken not long before dawn.

On the particular morning of September 13, 1948 the zodiacal light behaved normally. There were no strong fluctuations of intensity.

CHAPTER V

CONCLUSIONS

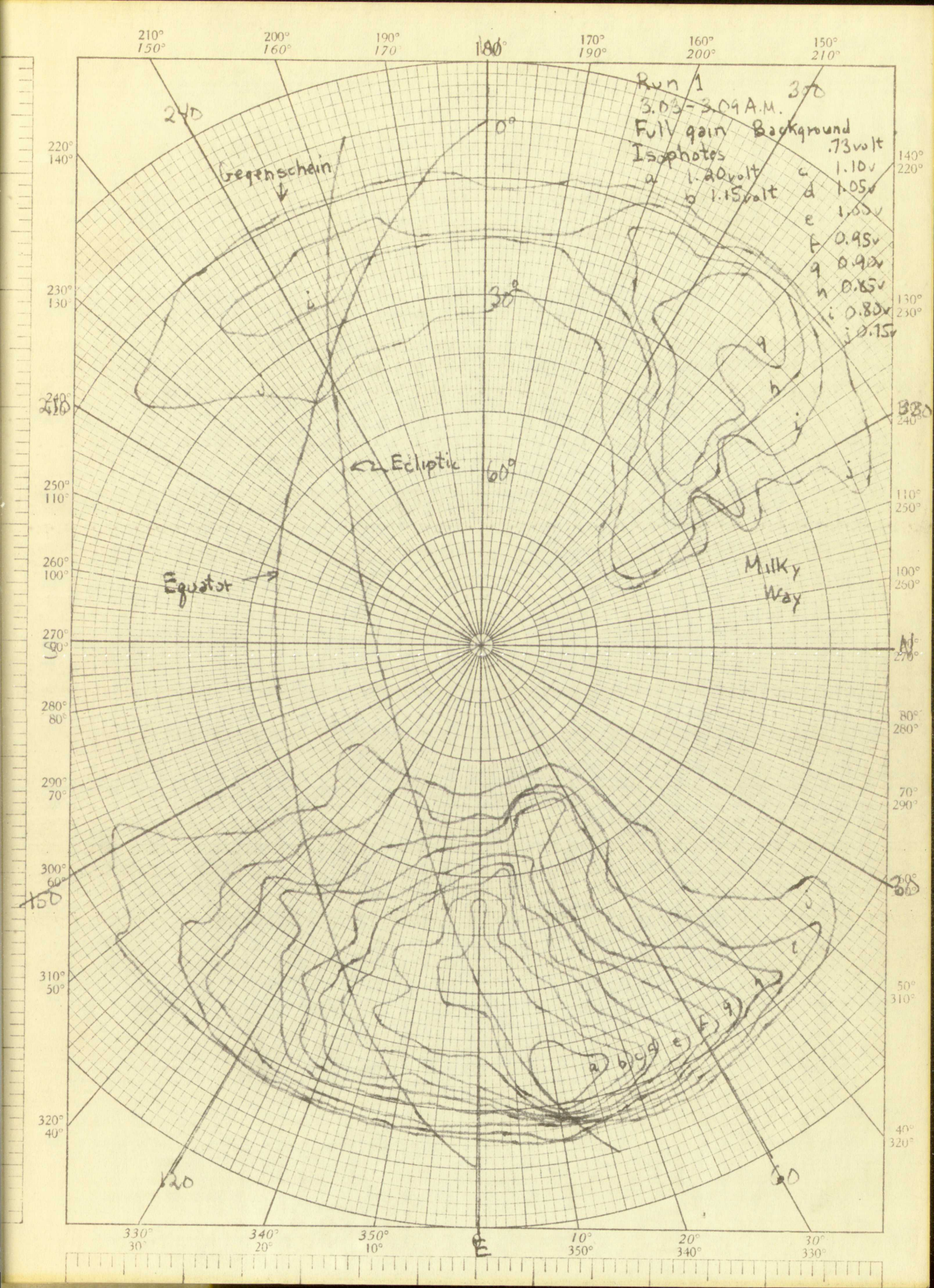
The ease of operation of this recording photoelectric photometer makes it a desirable instrument for the study of the strong fluctuations of intensity and nightly motion reported in the literature. In a matter of two hours an observer can obtain twenty complete sweeps of the sky.

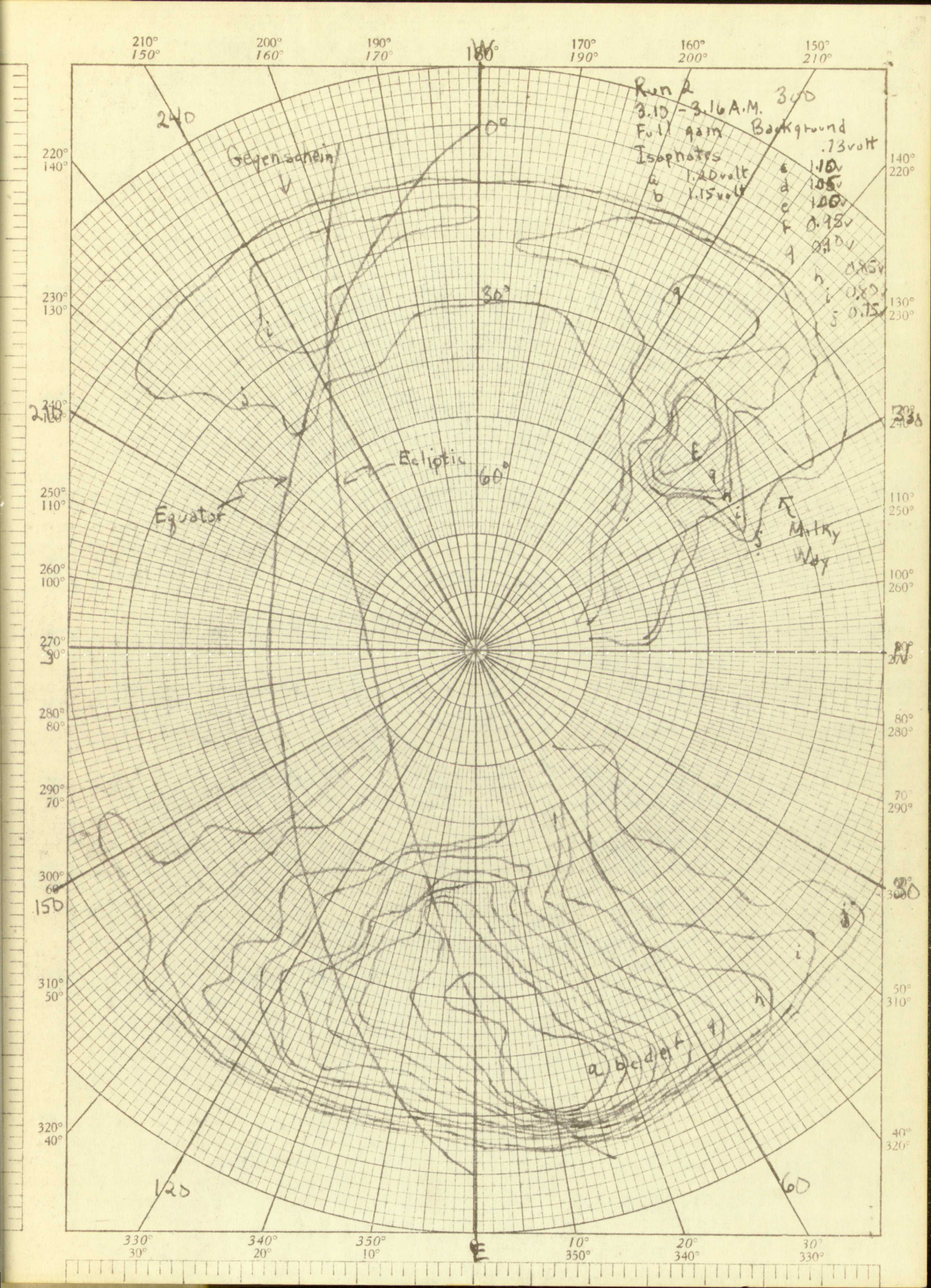
Acknowledgements

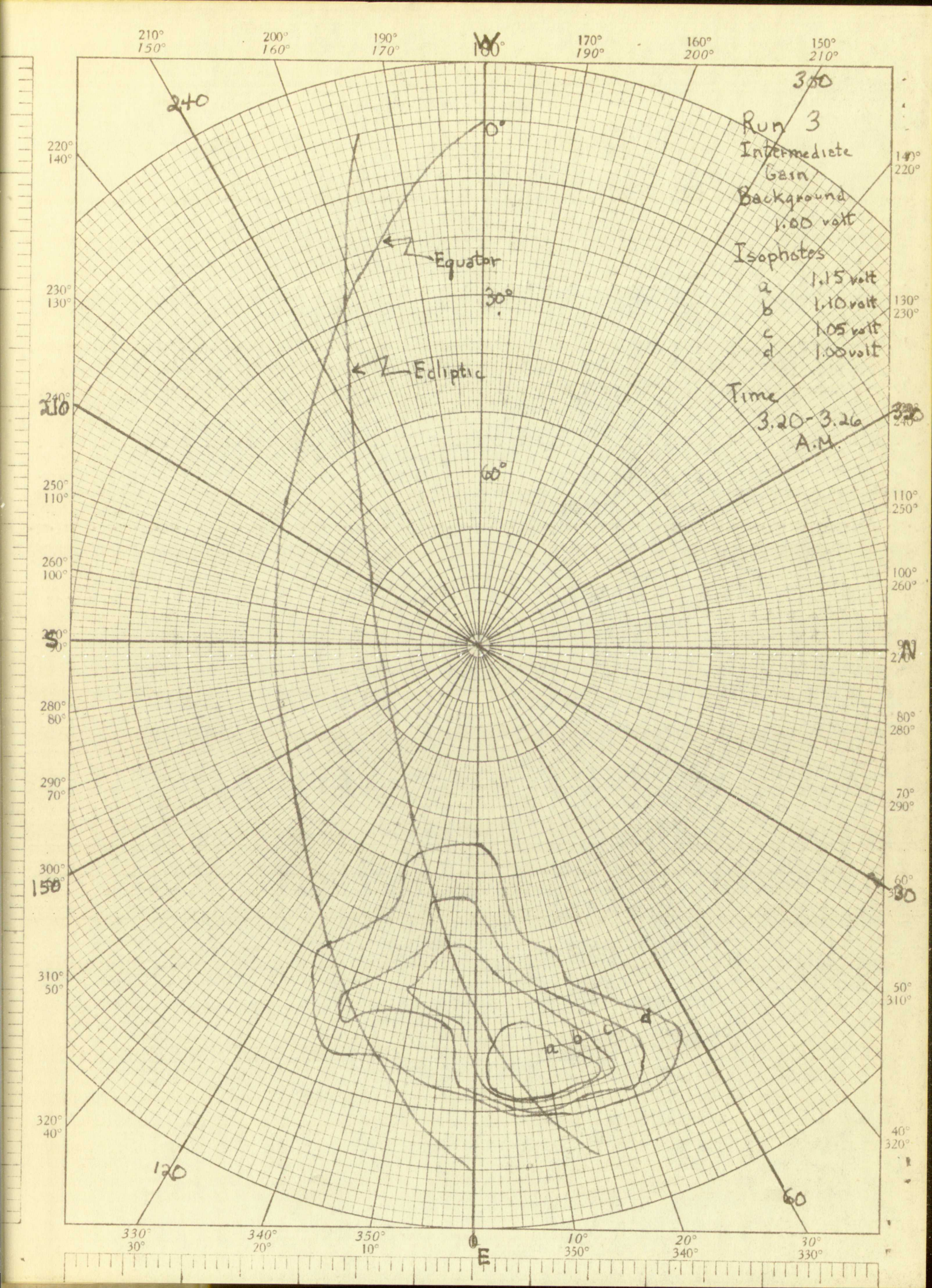
Thanks are due Professor V. H. Regener for his counsel and guidance throughout the entire project. Technical assistance, both mechanical and photographic were gratefully accepted from J. MacLean and R. Nobles.

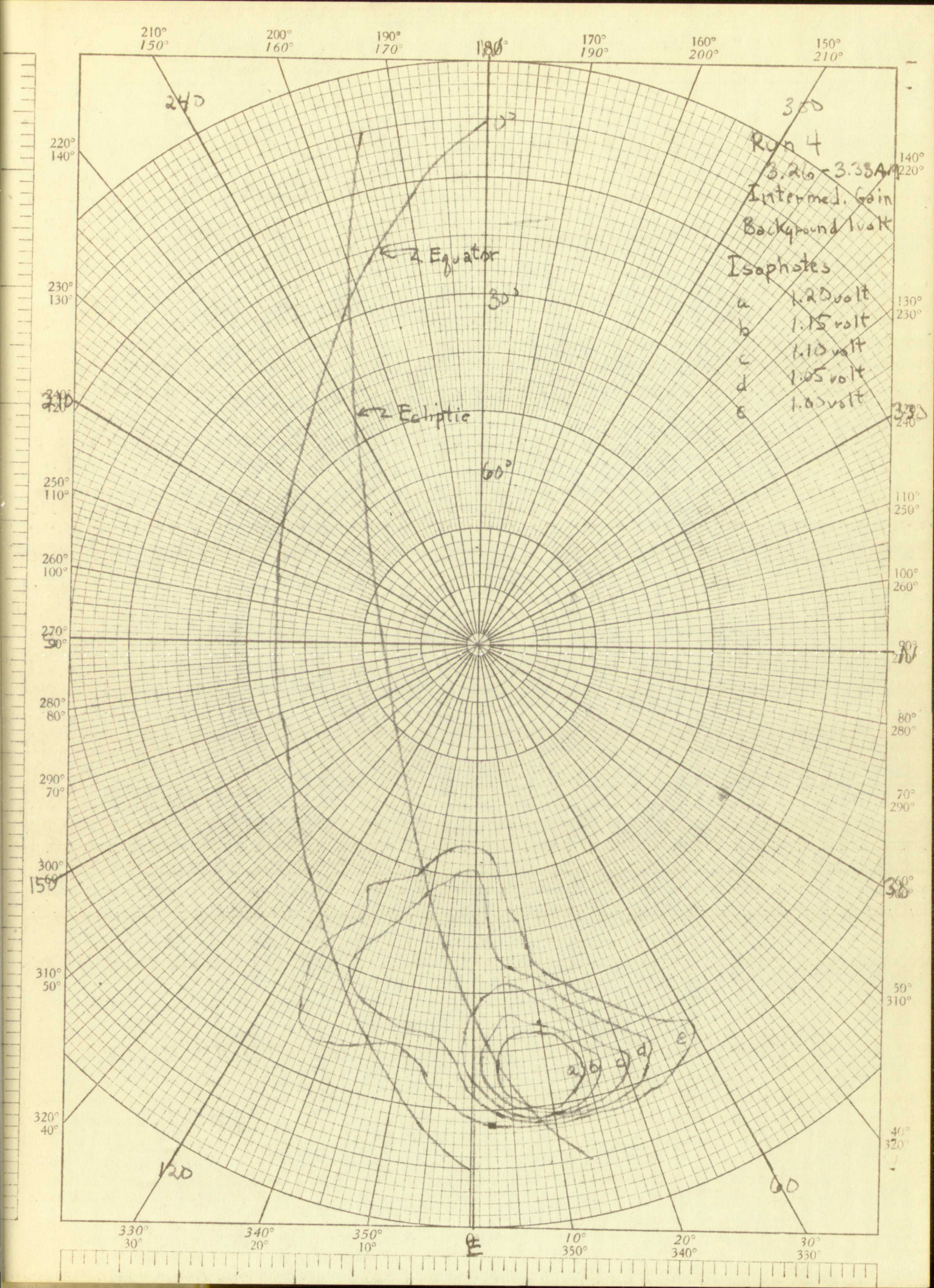
Thanks are also due G. Tenery, A. Beck, G. Zorn, and W. Nobles for assisting with the numerous tasks in assembling and setting up the apparatus.

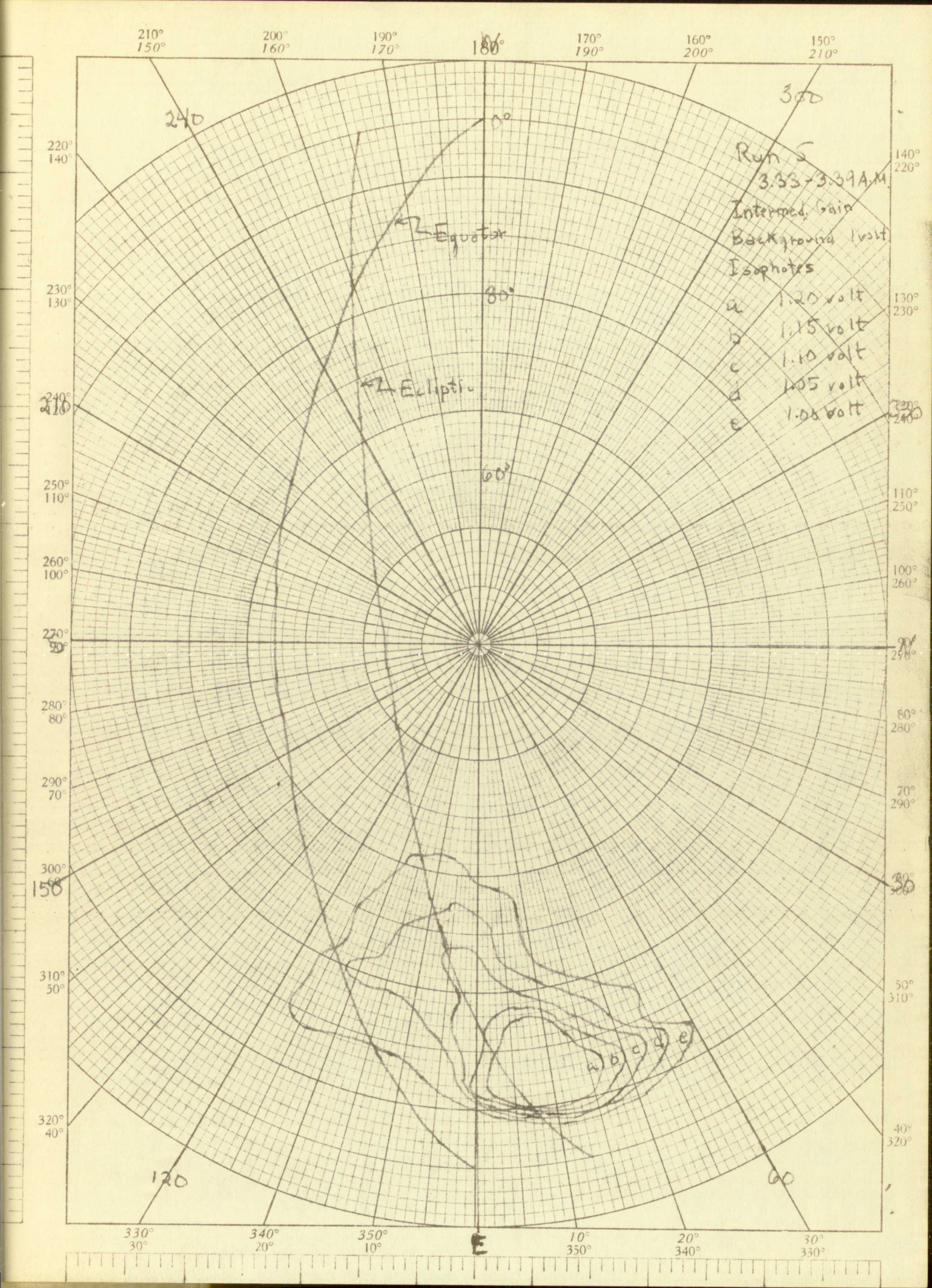
GRAPHS

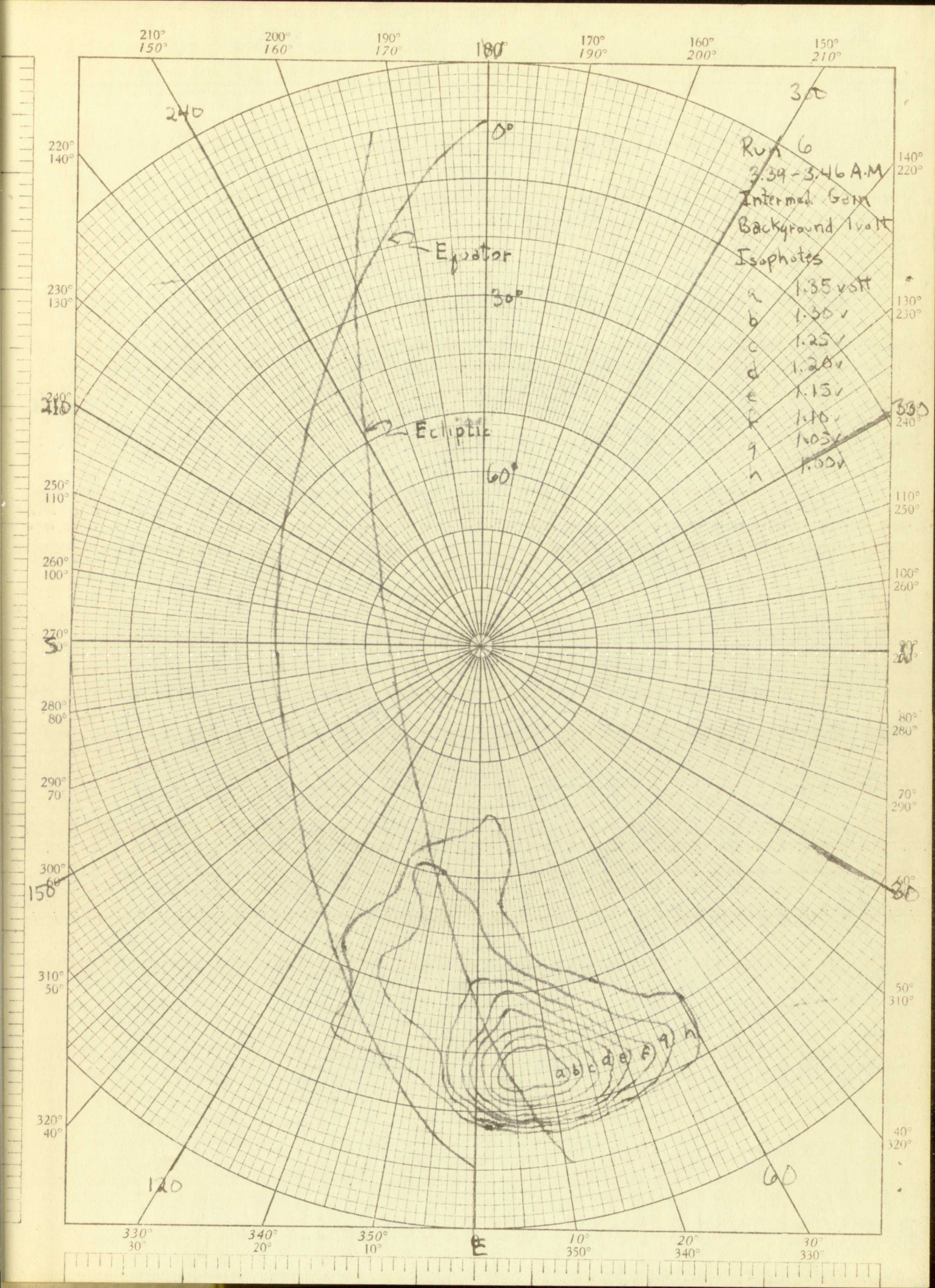

Run 1
3.03 - 3.09 A.M.
Full gain Background
Isophotes
a 1.20volt
b 1.15volt
c .73volt
d 1.10v
e 1.05v
f 1.00v
g 0.95v
h 0.90v
i 0.85v
j 0.80v
k 0.75v
Gegenschein
Ecliptic
Equator
Milky Way
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°

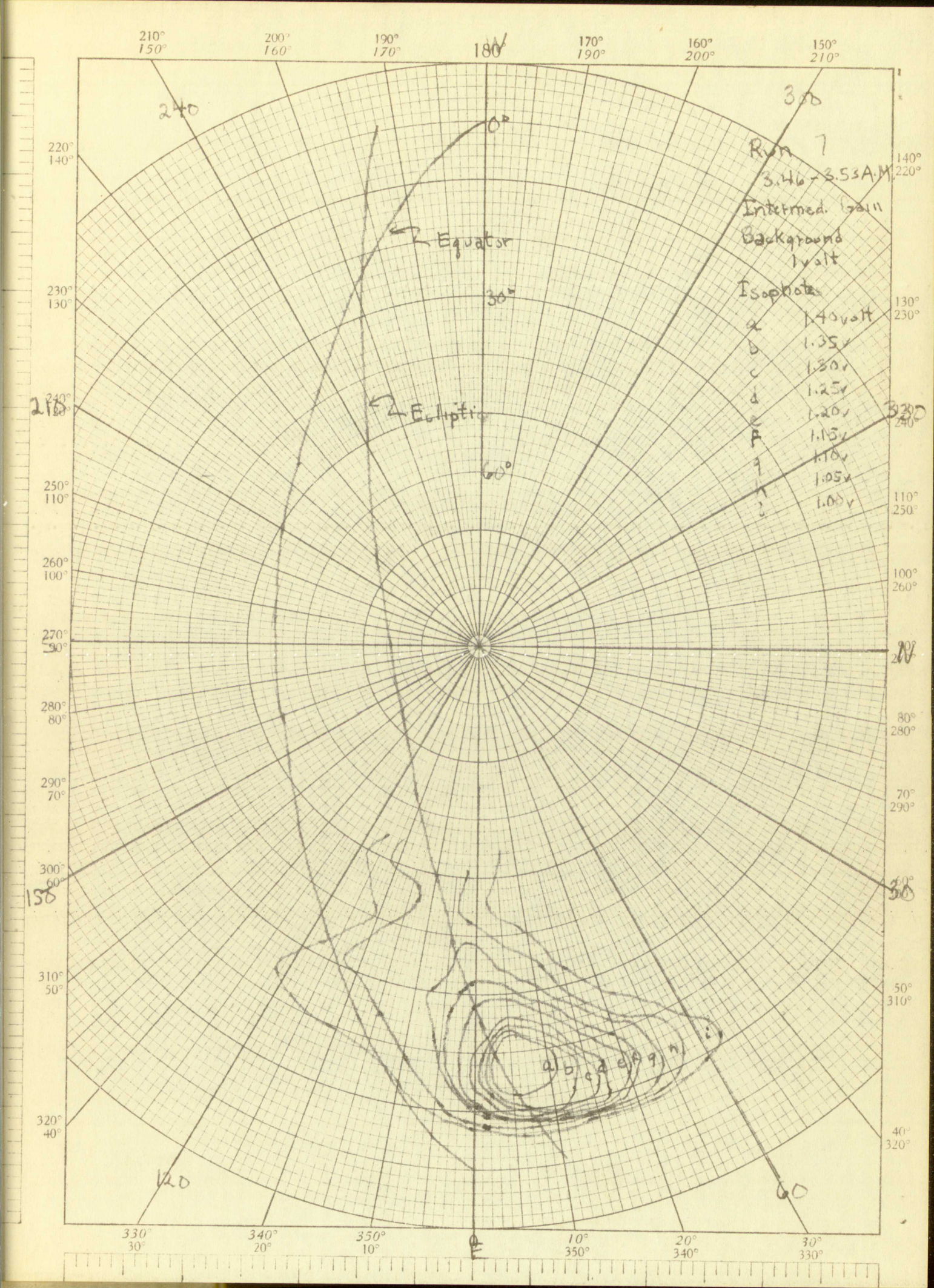

Run 2
3.10 - 3.16 A.M.
Full gain
Background
.73volt
Isophotes
a 1.20volt
b 1.15volt
c 1.10v
d 1.05v
e 1.00v
f 0.95v
g 0.90v
h 0.85v
i 0.80v
j 0.75v
Gegenschein
Ecliptic
Equator
Milky Way
0°
30°
60°
W
E
S
N
240
300
120
60
150
210°
200°
190°
180°
170°
160°
150°
30°
20°
10°
350°
340°
330°

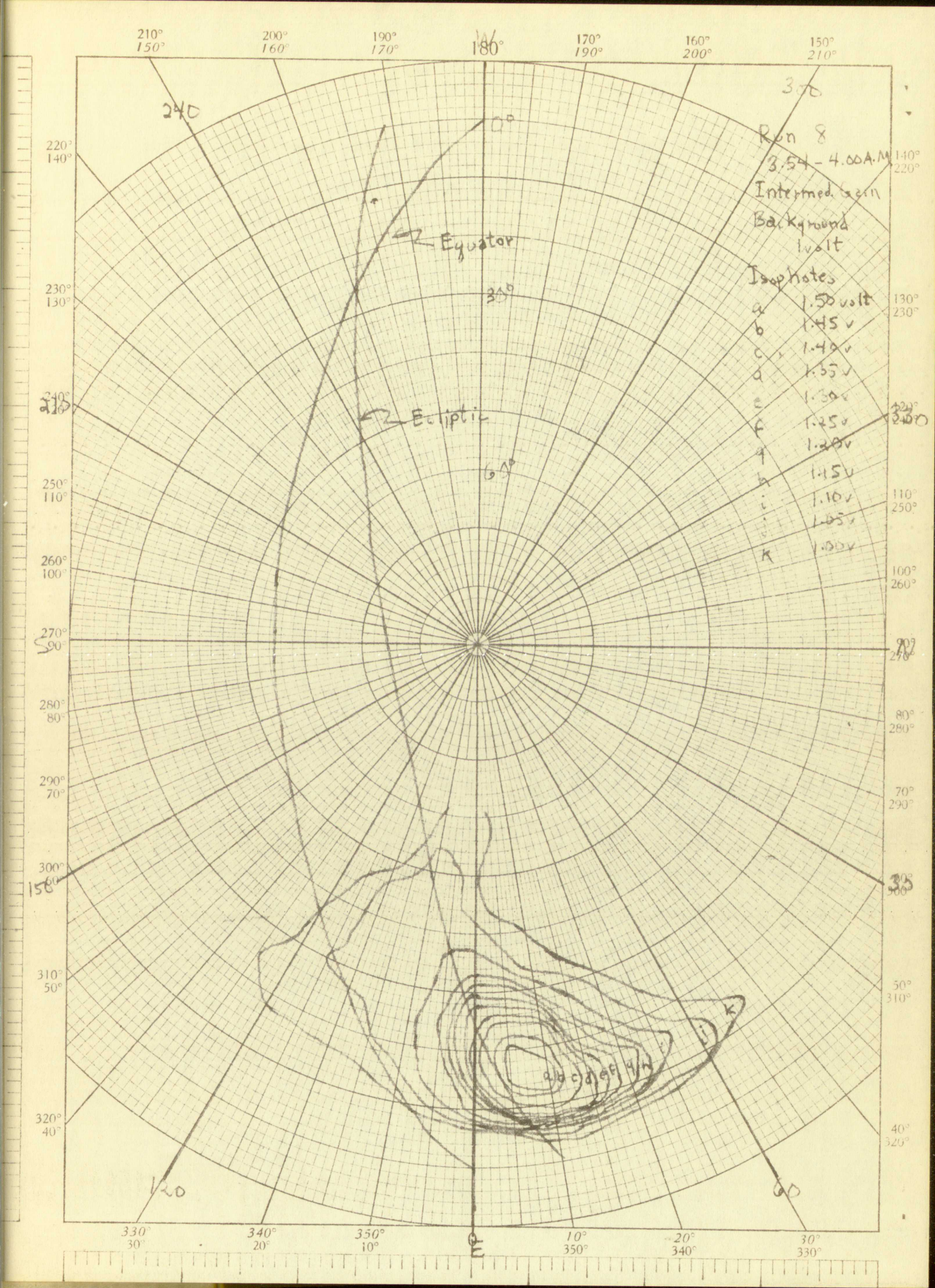

Run 3
Intermediate
Gain
Background
1.00 volt
Isophotes
a 1.15 volt
b 1.10 volt
c 1.05 volt
d 1.00 volt
Time
3.20-3.26
A.M.
Equator
Ecliptic
W
E
S
N
0°
30°
60°
a
b
c
d

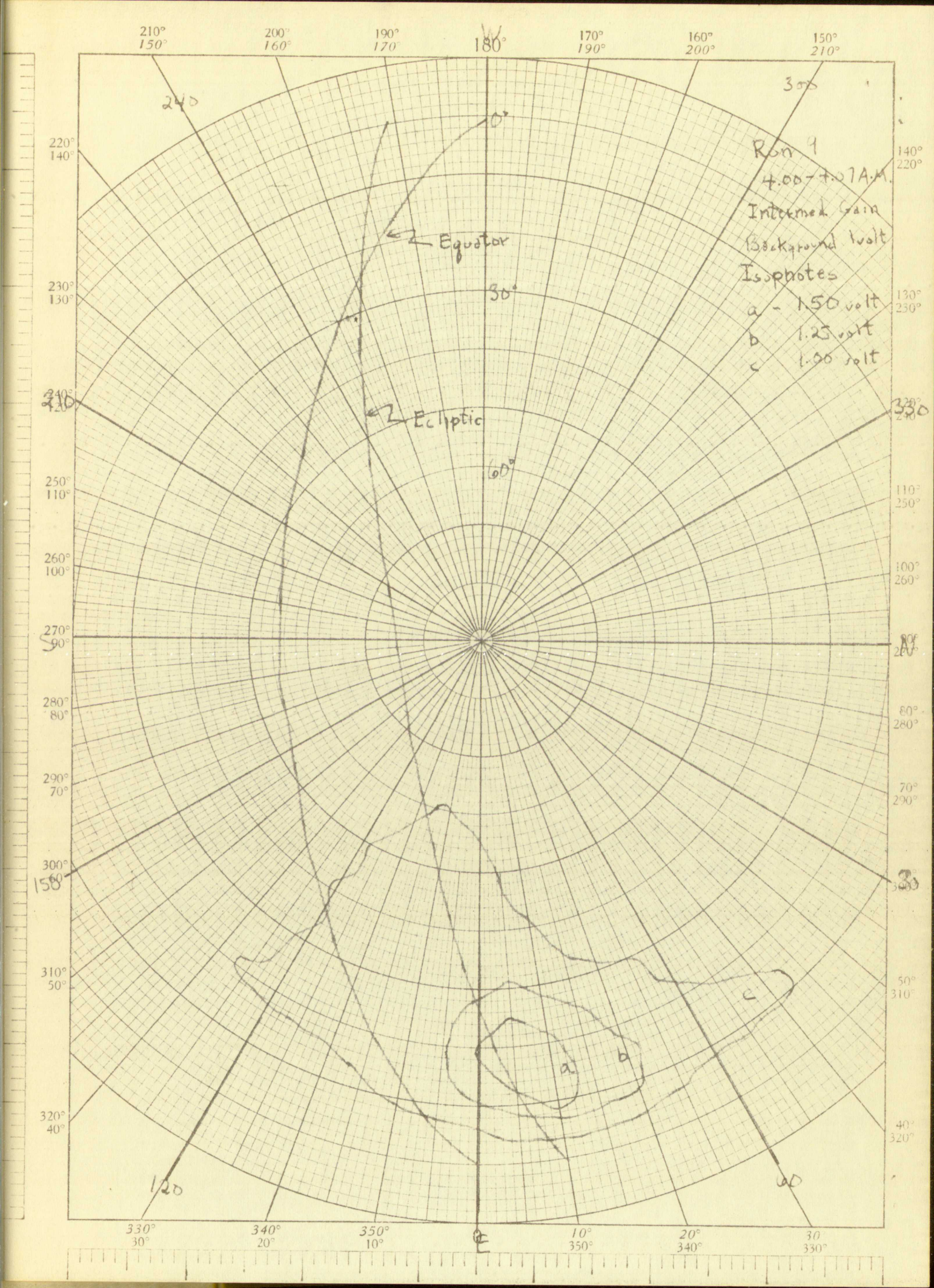

Run 4
3.26 - 3.38A
Intermed. Gain
Background 1 volt
Isophotes
a 1.20 volt
b 1.15 volt
c 1.10 volt
d 1.05 volt
e 1.00 volt
Equator
Ecliptic
30°
60°
E
240
300
120
60
159
58

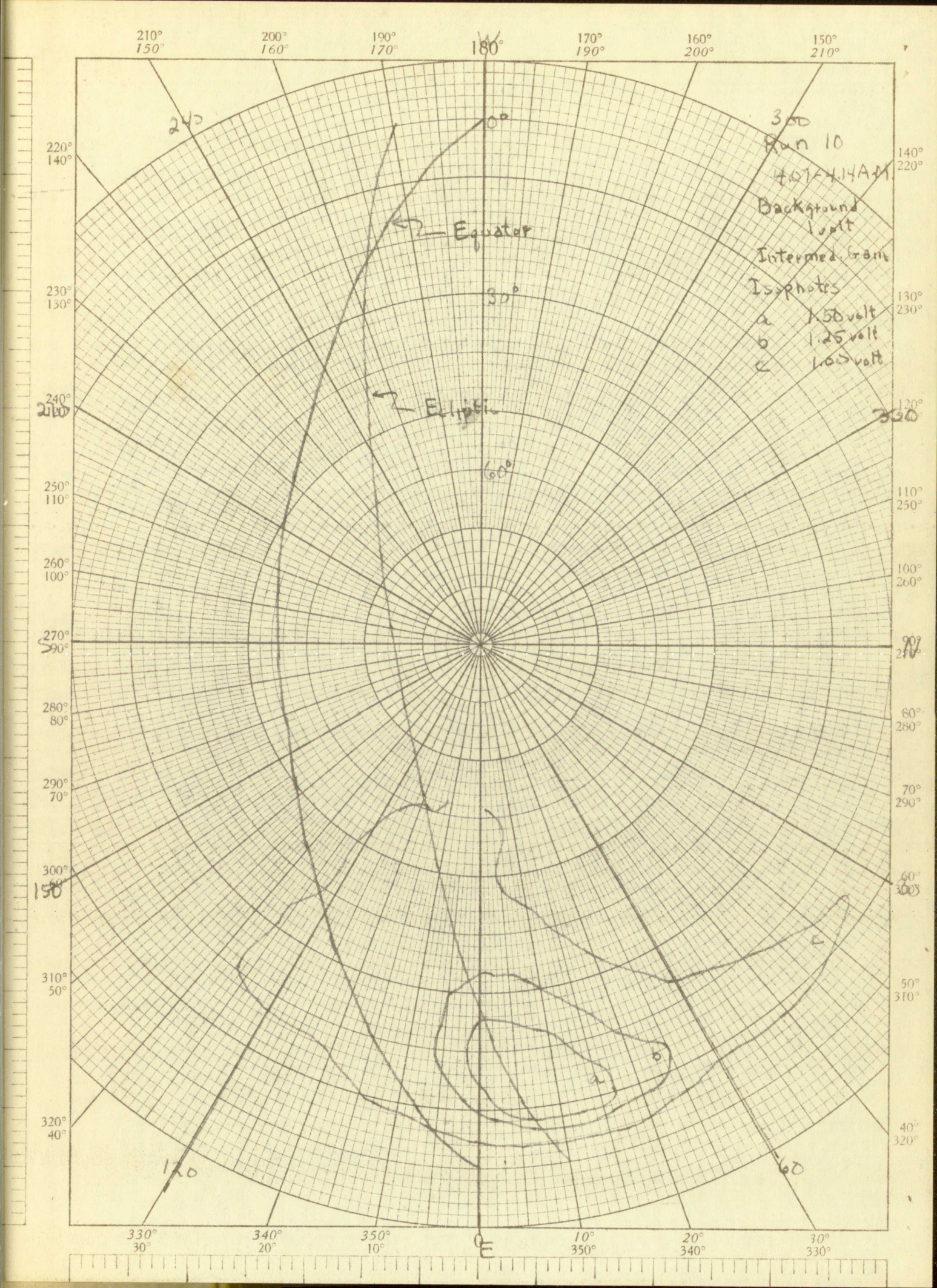

Run 5
3.33-3.39 A.M.
Intermed. Gain
Background 1 volt
Isophotes
a 1.20 volt
b 1.15 volt
c 1.10 volt
d 1.05 volt
e 1.00 volt
Equator
Ecliptic
E
W
a
b
c
d
e

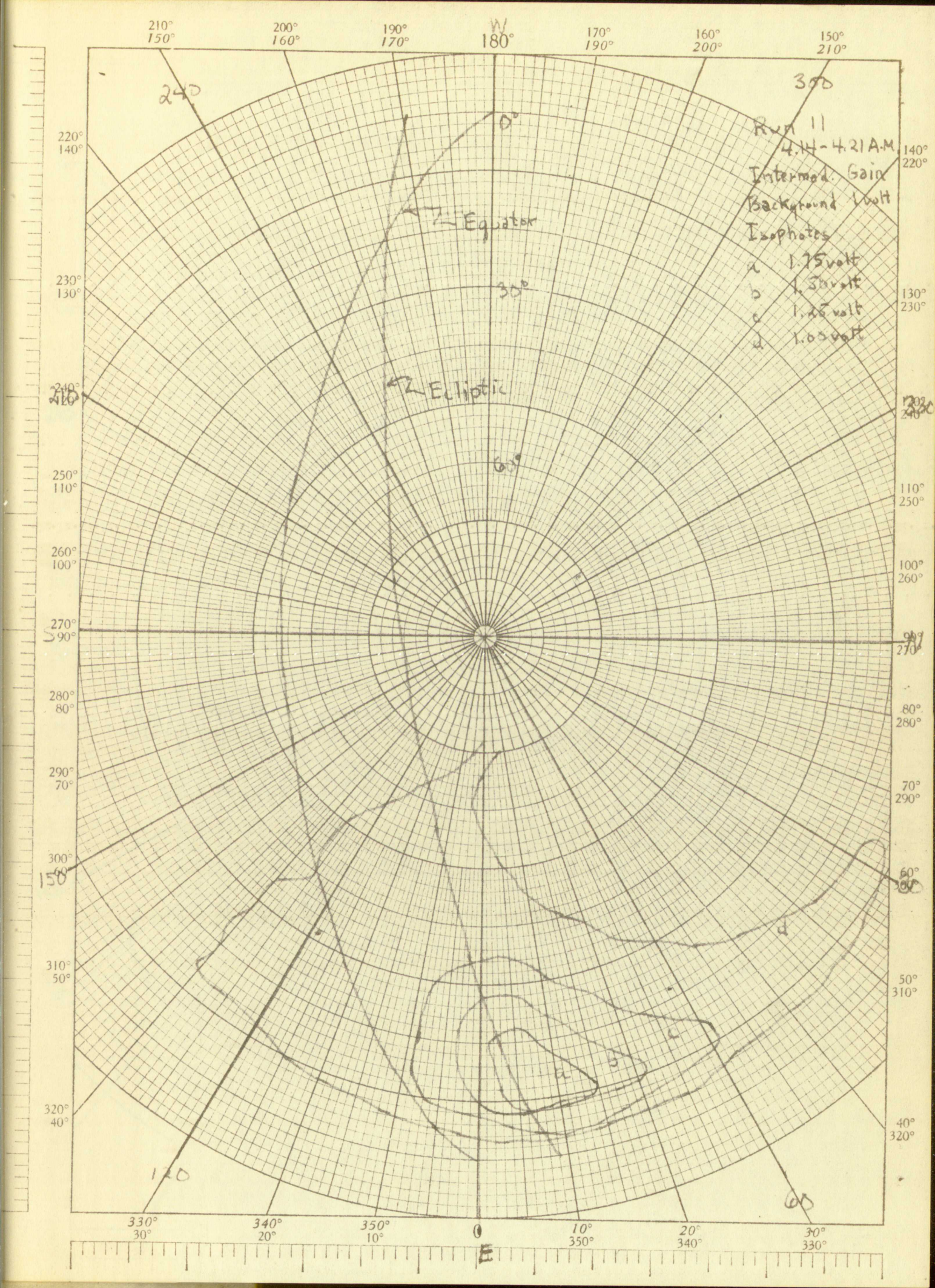

Run 6
3.39 - 3.46 A.M
Intermed. Gain
Background 1 volt
Isophotes
a 1.35 volt
b 1.30 v
c 1.25 v
d 1.20 v
e 1.15 v
f 1.10 v
g 1.05 v
h 1.00 v
Equator
Ecliptic
0°
30°
60°
E
a b c d e f g h

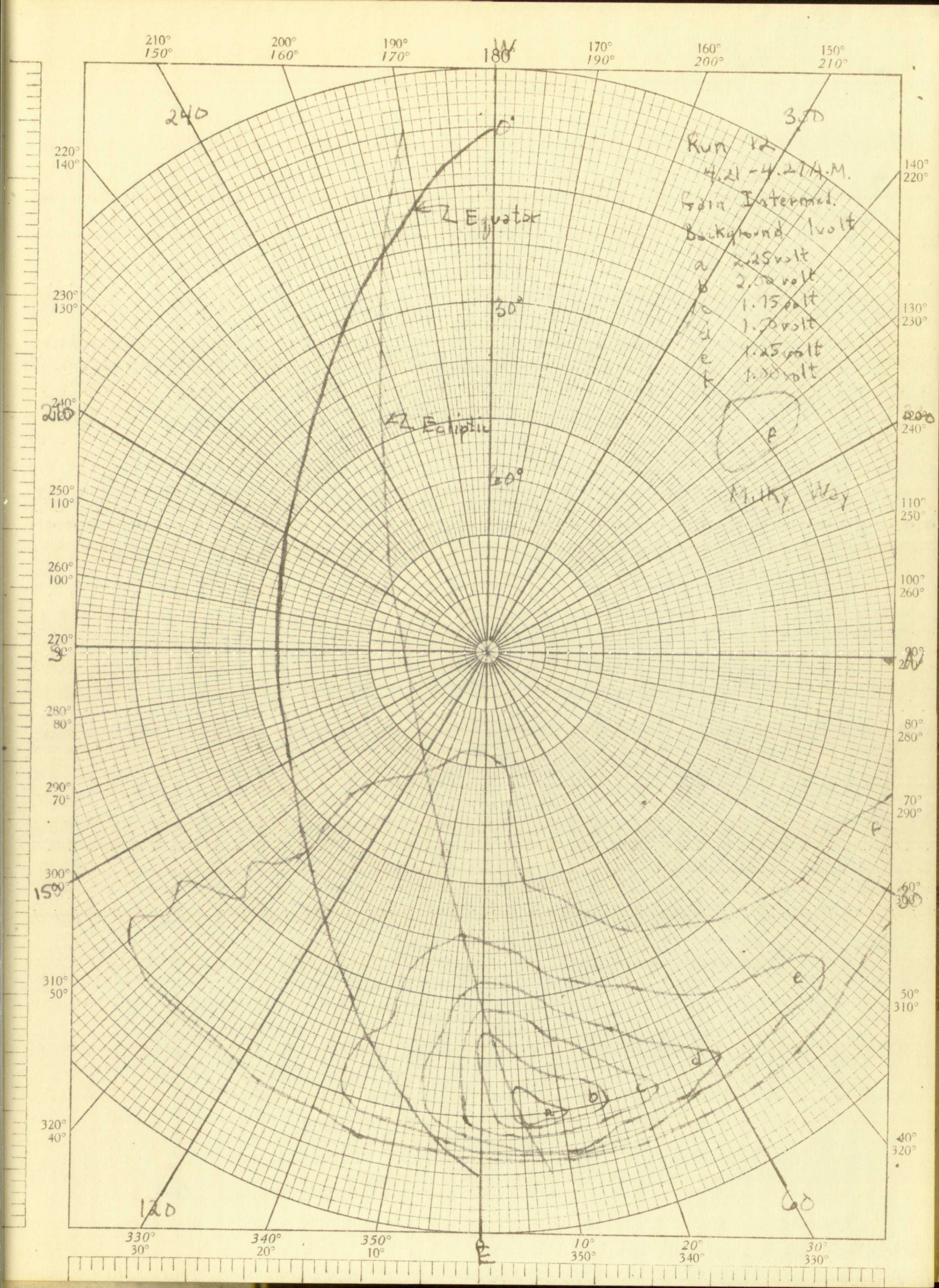

Run 7
3.46 - 3.55 A.M.
Intermed. Gain
Background
1 volt
Isophotes
a 1.40 volt
b 1.35 v
c 1.30 v
d 1.25 v
e 1.20 v
f 1.15 v
g 1.10 v
h 1.05 v
i 1.00 v
Equator
Ecliptic
0°
30°
60°
180°
210° 150°
200° 160°
190° 170°
170° 190°
160° 200°
150° 210°
220° 140°
230° 130°
240° 120°
250° 110°
260° 100°
270° 90°
280° 80°
290° 70°
300° 60°
310° 50°
320° 40°
330° 30°
340° 20°
350° 10°
10° 350°
20° 340°
30° 330°
140° 220°
130° 230°
120° 240°
110° 250°
100° 260°
90° 270°
80° 280°
70° 290°
60° 300°
50° 310°
40° 320°
240
300
210
330
150
30
120
60
E
N


Run 8
3.54 - 4.00 A.M.
Intermed. Gain
Background
1 volt
Isophotes
a 1.50 volt
b 1.45 v
c 1.40 v
d 1.35 v
e 1.30 v
f 1.25 v
g 1.20 v
h 1.15 v
i 1.10 v
j 1.05 v
k 1.00 v
Equator
Ecliptic
60°
30°
0°
E
W
240
300
120
60
210°
150°
200°
160°
190°
170°
180°
170°
190°
160°
200°
150°
210°
220°
140°
230°
130°
240°
120°
250°
110°
260°
100°
270°
90°
280°
80°
290°
70°
300°
60°
310°
50°
320°
40°
330°
30°
340°
20°
350°
10°
10°
350°
20°
340°
30°
330°


Run 1
4.00-4.07 A.M.
Intermed. Gain
Background Volt
Isophotes
a - 1.50 volt
b 1.25 volt
c 1.00 volt
Equator
Ecliptic
0°
30°
60°
a
b
c


Run 10
4:01 P.M.
Background
1 volt
Intermed. Iram
Isophotes
a 1.50 volt
b 1.25 volt
c 1.00 volt
Equator
Ecliptic
0°
30°
60°
180°
210°
200°
190°
170°
160°
150°
330°
340°
350°
10°
20°
30°


Run 11
4.1H - 4.21 A.M.
Intermod. Gain
Background 1 volt
Isophotes
a 1.75 volt
b 1.5 volt
c 1.25 volt
d 1.00 volt
Equator
Ecliptic
30°
60°
W
180°
E
0°
S
90°
N
270°
a
b
c
d


Run 12
4.21 - 4.21 A.M.
Gain Intermed.
Background 1 volt
a 2.25 volt
b 2.00 volt
c 1.75 volt
d 1.50 volt
e 1.25 volt
f 1.00 volt
Z Equator
Z Ecliptic
Milky Way
W
E
180°
30°
60°
90°

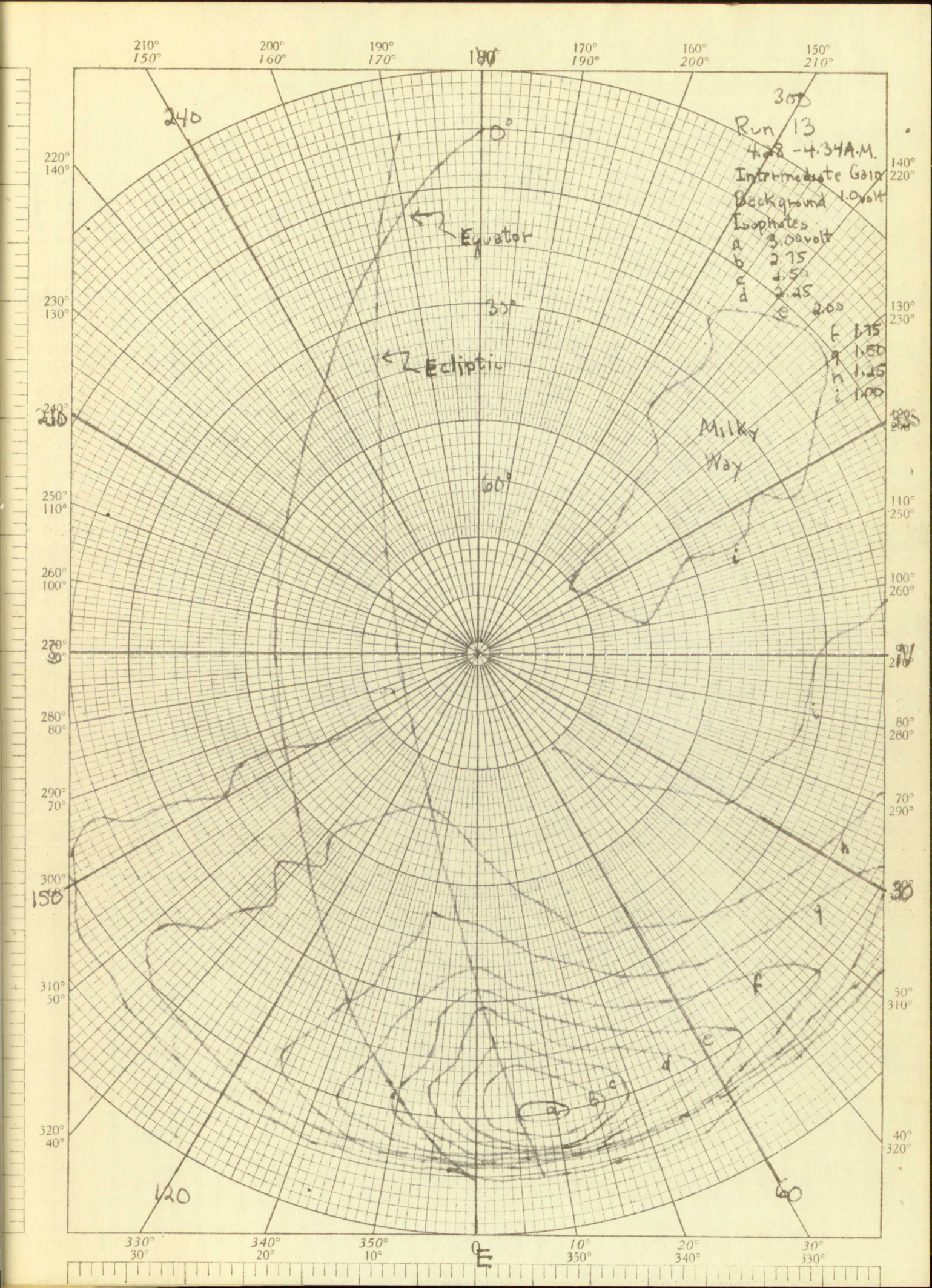
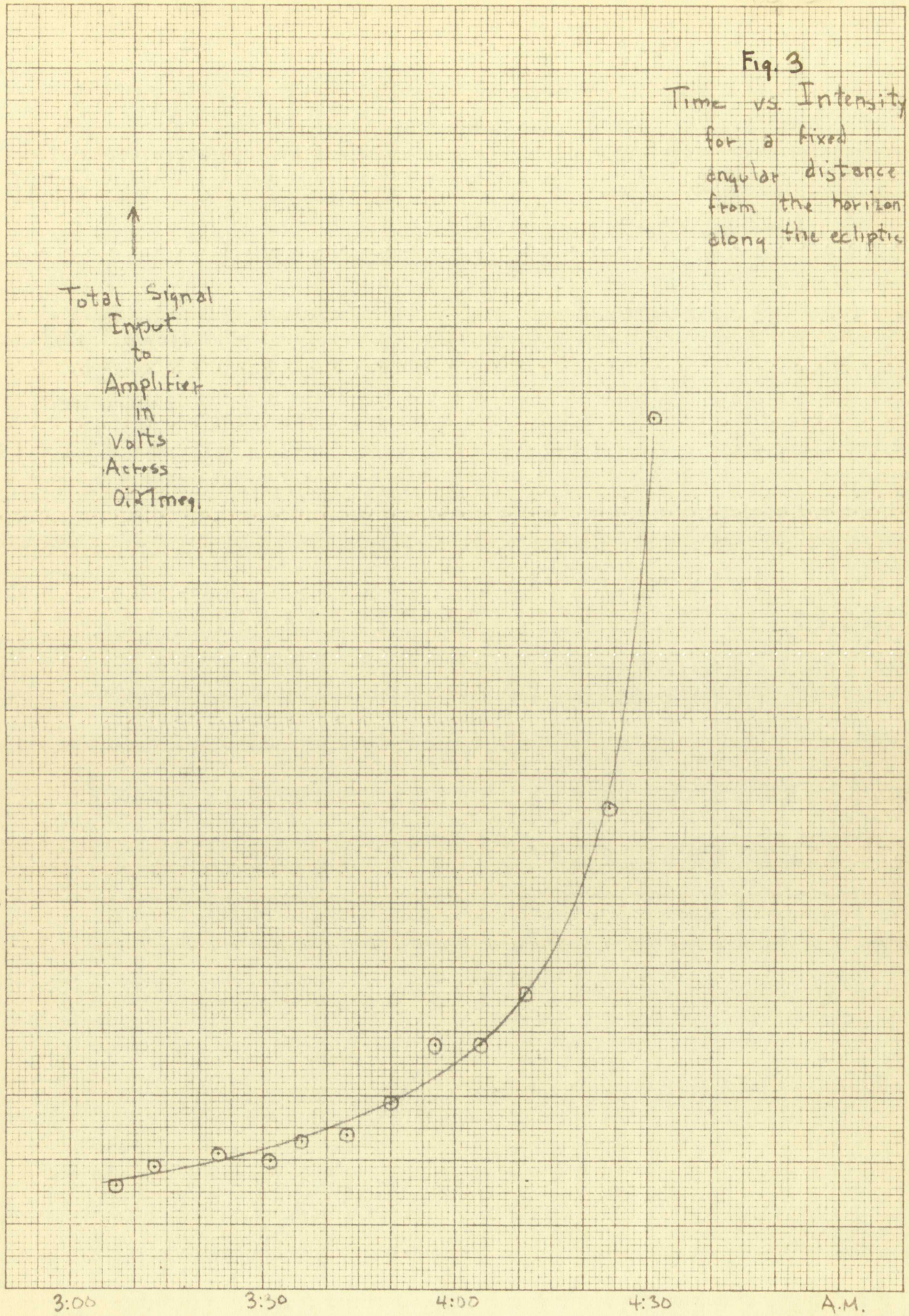

Run 13
4.28 - 4.34 A.M.
Intermediate Gain
Background 1.0 volt
Isophotes
a 3.00 volt
b 2.75
c 2.50
d 2.25
e 2.00
f 1.75
g 1.50
h 1.25
i 1.00
Equator
Ecliptic
Milky Way
0°
30°
60°
E
W
S
N

Fig. 3

Time vs. Intensity for a fixed angular distance from the horizon along the ecliptic



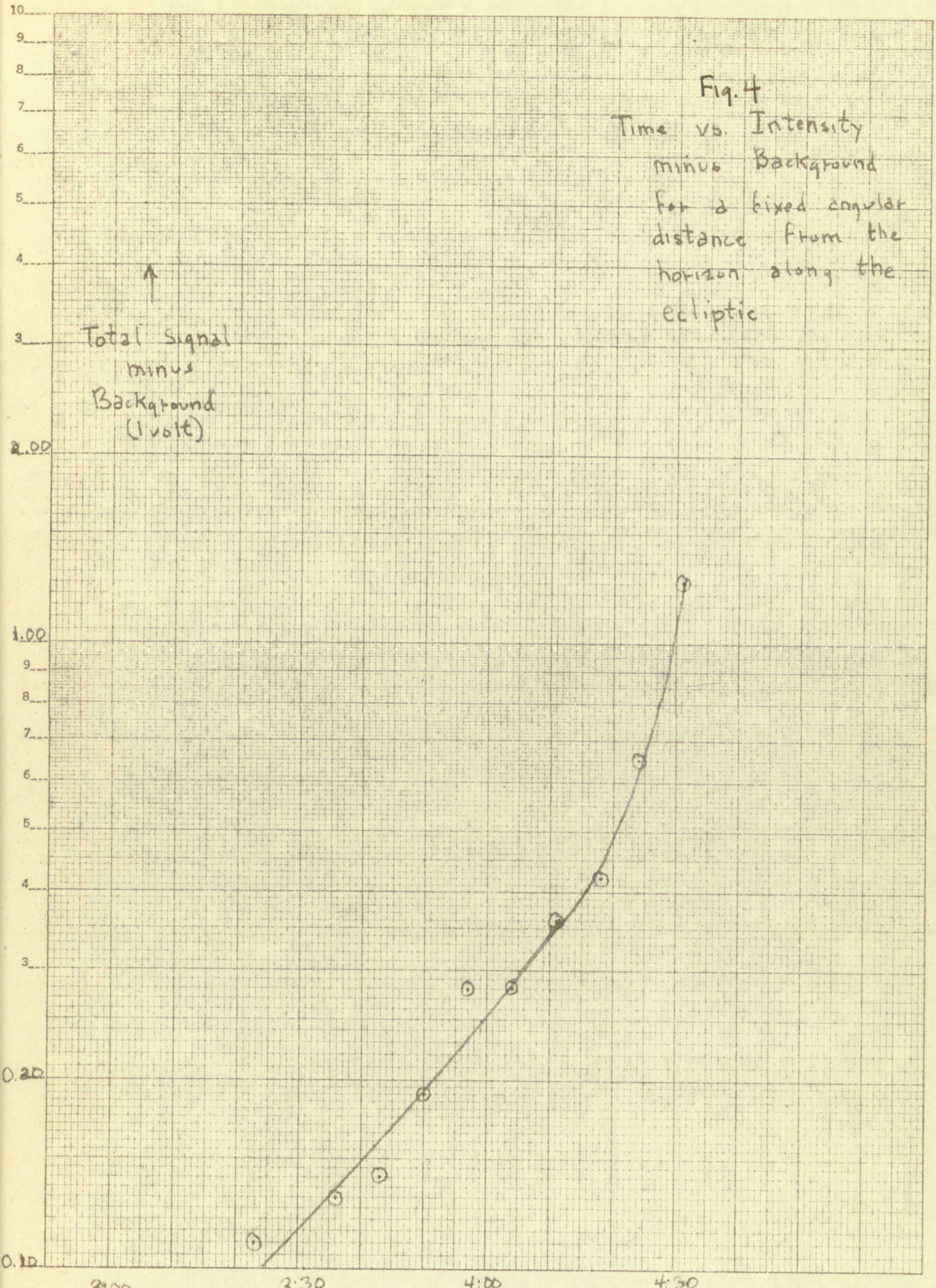


Fig. 4

Time vs. Intensity minus Background for a fixed angular distance from the horizon along the ecliptic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