PSU-IRL-SCI-446

Classification Numbers 1.5.1, 3.2.2

THE PENNSYLVANIA STATE UNIVERSITY

IONOSPHERIC RESEARCH

Scientific Report 446

POSITIVE ION DENSITIES AND MOBILITIES IN THE UPPER STRATOSPHERE AND MESOSPHERE

by

Steve Leiden

July 13, 1976

The research leading to this report was supported by the National Aeronautics and Space Administration under Grant No. NSG-6004.

IONOSPHERE RESEARCH LABORATORY

University Park, Pennsylvania

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 446	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) Positive Ion Densities and Mobilities in the Upper Stratosphere and Mesosphere		5. TYPE OF REPORT & PERIOD COVERED Scientific Report
		6. PERFORMING ORG. REPORT NUMBER PSU-IRL-SCI-446
7. AUTHOR(*s*) Steve Leiden		8. CONTRACT OR GRANT NUMBER(*s*) NSG-6004
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Ionosphere Research Laboratory 318 Electrical Engineering East Building University Park, Pennsylvania 16802		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE July, 1976
		13. NUMBER OF PAGES 54
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) Grants Officer National Aeronautics and Space Administration Wallops Flight Center Wallops Island, Virginia 23337		15. SECURITY CLASS. (*of this report*) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

None

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Rocket-Satellite Techniques and Measurements
D-Region

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A brief sketch of the theory concerning the use of the Gerdien condenser as a mobility spectrometer is presented. Data reduction of three parachute borne Gerdien condenser probes is given, as well as that of one blunt conductivity probe. Comparisons of concentrations calculated by two different methods indicate consistency of results. Mobility profiles demonstrating remarkable fine structure are discussed in detail. Finally, theoretical implications of the results on ionospheric structure, including possible night-day differences and latitudinal variations, are considered.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

PSU-IRL-SCI-446
Classification Numbers 1.5.1, 3.2.2

Scientific Report 446

Positive Ion Densities and Mobilities in the Upper Stratosphere and Mesosphere

by

Steve Leiden

July 13, 1976

The research leading to this report was supported by the National Aeronautics and Space Administration under Grant No. NSG-6004.

Submitted by: L. C. Hale

L. C. Hale, Professor
Electrical Engineering

Approved by: J. S. Nisbet (LCH)

J. S. Nisbet, Director
Ionosphere Research Laboratory

Ionosphere Research Laboratory

The Pennsylvania State University

University Park, Pennsylvania 16802

ACKNOWLEDGEMENTS

The author wishes to thank his advisor, Dr. Leslie C. Hale for the guidance and patience which was so often needed. Dr. Charles Croskey provided inestimable knowledge and time in assisting with the compilation of this work. Numerable discussions with Drs. John J. Olivero and Lynn A. Carpenter as well as many other members of The Ionosphere Research Laboratory were beneficial in completing this thesis.

The research leading to this report was supported by the National Aeronautics and Space Administration Grant No. NSG-6004.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

ABSTRACT

A brief sketch of the theory concerning the use of the Gerdien condenser as a mobility spectrometer is presented. Data reduction of three parachute borne Gerdien condenser probes is given, as well as that of one blunt conductivity probe. Comparisons of concentrations calculated by two different methods indicate consistency of results. Mobility profiles demonstrating remarkable fine structure are discussed in detail. Finally, theoretical implications of the results on ionospheric structure, including possible night-day differences and latitudinal variations, are considered.

CHAPTER I

INTRODUCTION

1.1 Introduction

A basic understanding of the stratosphere and mesosphere, the lower part of what is becoming to be known as the middle atmosphere, must include a knowledge of the structure of the ionized portion of the medium. A number of unresolved questions pertaining to this region of the atmosphere have led to the investigation of the D-region with Gerdien condenser rocket probes. These particular probes were chosen because of their unique ability to differentiate between ions of different mobilities. The atmospheric parameters yielded by the data are the mobility, K, the conductivity, σ, and the concentration, N. This report contains the analysis of three flights of these instruments, as well as one flight of the blunt probe. Two of the Gerdien probes and the blunt probe were launched during the "Aladdin" Project of June 1974 at Wallop's Island, Virginia. The other Gerdien probe was fired during the "Antarqui" program in Peru in May 1975.

A brief history of related research and a statement of the problem complete the introduction. Chapter 2 presents a sketch of the theory involved, as well as comments comparing the two types of probes. Chapter 3 contains the data analysis. Results deduced from the data and comments concerning possible time and latitudinal variations in the D-region are included in Chapter 3. Finally, a conclusion summarizes the report and presents suggestions for future research.

1.2 History of Related Research

The use of the Gerdien condenser as a tool to investigate the characteristics of charged particles in the atmosphere has spanned the last three quarters of a century. H. Gerdien (1905) originated the application of concentric cylinder geometry to atmospheric investigation at ground level. Israel and Schulz (1933) experimented with the Gerdien condenser as a mobility spectrometer. At sea level, they were able to differentiate between four ion species.

As time increased so did the altitude at which the experiments occurred. In 1958 Sagalyn reported of the use of the probe aboard an aircraft. However, the data probably contains many uncertainties due to various complications (e.g. air flow around the plane or noise from the aircraft.) The condenser was then flown on the nosetips of several sounding rockets by investigators Bourdeau, Whipple, and Clark (1959). Their results are probably contaminated; however, due to the effect of supersonic flight. More recently, the probe has been installed on platforms for balloon ascent (Paltridge, 1965). Unless extreme care is taken, in every phase of the operation, the data can easily be contaminated. This contamination has been mainly due to water vapor degassing. Another major problem is that balloons do not get high enough for investigation of altitudes higher than about

50 km.

An aforementioned rocket experiment encountered difficulties due to supersonic speed. The present investigation employs parachute borne subsonic Gerdien condensers. Pedersen (1964) used a similar system; however, his data was affected by the wake of the detached nosecone. Rose and Widdle (1972) flew a twin system of probes. Two similar geometries were flown. One of these geometries contained a flowmeter to monitor the air stream velocity during the flight, and the other was the probe itself. Their resulting profiles show two groups of ions in the altitude range 72 to 58 km. No data was received in the altitudes 58 to 52 km, and one ion family was seen below 52 km.

A profile as deduced from a Gerdien flight at White Sands Missile Range in 1974 is given by Farrokh (1975). It gives two ion families from 65 to 47 km. The lighter of the two groups was approximately twice as mobile as the heavier group. Below 47 km, a continuous smear of mobilities with the range limits being a continuation of the two families higher up was found. The Gerdien flown in this instance was a rather crude instrument, using a logarithmic current detector and also was not very aerodynamically clean. A more recent flight having a cleaner design and also including an ionization source, (i.e. a flashing UV lamp) has been reported on by Croskey (1976). The data from Croskey's Alaskan flight shows very complex structure. Through a careful comparison of concentrations and mobilities, individual families were identified. The more consistent families were: a low mobility group in the range 72 to 50 km, another low mobility group between 45 and 30 km, a group of median mobility from 58 to 42 km, and two high mobility ion groups from 72 to 52 and 43 to 36 km respectively. There were assorted high and medium mobility ions throughout the middle atmosphere, mainly concentrated in the 50 to 30 km altitude region. It has been observed that as instrument resolution improved, the results show a multitude of ions existing in the middle atmosphere, a fact supported by the results of this study.

1.3 A Statement of the Problem

There are many driving factors behind middle atmospheric investigation. This region includes the upper stratosphere and mesosphere. To fully understand stratospheric-mesospheric coupling, the nature of this region must be thoroughly explored. This region is also important in the propagation of radio waves. The atmosphere in this region is relatively lightly ionized but this ionization is of importance in the absorption of radio waves, and may be important in chemical processes relating to minor constituents such as ozone and to coupling between various levels of the atmosphere.

The mobilities measured by the Gerdien rocket probes can provide better values for ionization parameters than simpler instruments. Photochemical reaction rates can then be estimated from the mobility and concentration.

These reactions are the main products which result from the driving forces in the ionosphere. One of the electromagnetic energy sources is solar Lyman α (1216 Å), which ionizes nitric oxide (NO) (Nicolet and Aiken, 1960), and does so down to approximately 63.5 km (Hale, 1974). From 63.5 km and down (and throughout the D-region at night) cosmic ray ionization of all atmospheric constituents is dominant. These energy sources generate the ionization on a typically quiet or undisturbed day. During solar flares or other disturbances enhanced X-ray flux becomes significant, and ionization due to particle influx becomes important at higher latitudes.

Gerdien flights for this report were flown in Peru and Virginia. These flights, in conjunction with an Alaskan flight analyzed by Croskey (1976), suggests latitudinal variations in the structure of the D-region. From these flights latitudinal and photochemical aspects contributing to the formulation of the D-region can be investigated. The Wallop's Island, Virginia flights launched both during the day and night provide data from which time variations can be deduced. Once diurnal, latitudinal, and photochemical factors have been determined, a more complete picture of middle atmosphere ionization can be drawn.

CHAPTER II

PROBE THEORY

2.1 Ion Collection

Both the blunt probe and the Gerdien condenser probe employ the same basic mechanism of ion collection. An electric field is generated electronically, and the ions are accelerated by this field toward a collecting electrode. The following is a brief sketch of the theory involved, using this method of ion collection.

Previous to entering a state of saturation, normal ion collection is described by the equation:

$$J = N e U + K N e \nabla V - e D N \qquad (2.1)$$

where J is the current density; N is the ion number density; e is the electronic charge; U is the convection velocity; K is the mobility of the ion; V is the probe potential, and D is the coefficient of diffusion of the respective ion (Conley, 1974).

The first term on the right hand side of the equation is the component to the current due to convection. The second term represents the effect of conduction, and the third is the contribution due to diffusion. Under the assumption that the air flow is parallel to the axis of the detector, the convective term can be eliminated and equation (2.1) takes the form:

$$J = K N e \nabla V - e D N \qquad (2.2)$$

Assuming that the characteristic lengths of the gradients of V and N in (2.2) are the same, the term due to diffusion can be neglected. This is shown by applying Einstein's relation:

$$D/K = k\,T/e \tag{2.3}$$

where e, D, and K are as before; k is Boltzmann's constant, and T the absolute temperature.

$$J = K\,N\,e\,V\,\nabla V/V - e\,D\,N\;\;N/N$$

Let the characteristic length of the gradients of V and N be L

$$J = K\,N\,e\,L\,(V - K/K) \tag{2.4}$$

Substituting (2.3) into (2.4) yields:

$$J = K\,N\,e\,L\,(V - kT/e) \tag{2.5}$$

In the ionosphere $kT/e \leq 0.03V$, therefore, for probe potentials much greater than this (usually V varies from approximately -5.5V to 3.8V), the diffusive term is negligible compared to conduction. Finally, equation (2.1) becomes:

$$J = K\,N\,e\,\nabla V \tag{2.6}$$

Equation (2.6) has been shown to be applicable to the types of probes used in this investigation (Hoult, 1965 and Sonin, 1967). It represents a one ion species collection mechanism, and can be readily extended to a multicomponent case:

$$J = e \nabla V \sum_i K_i N_i \tag{2.7}$$

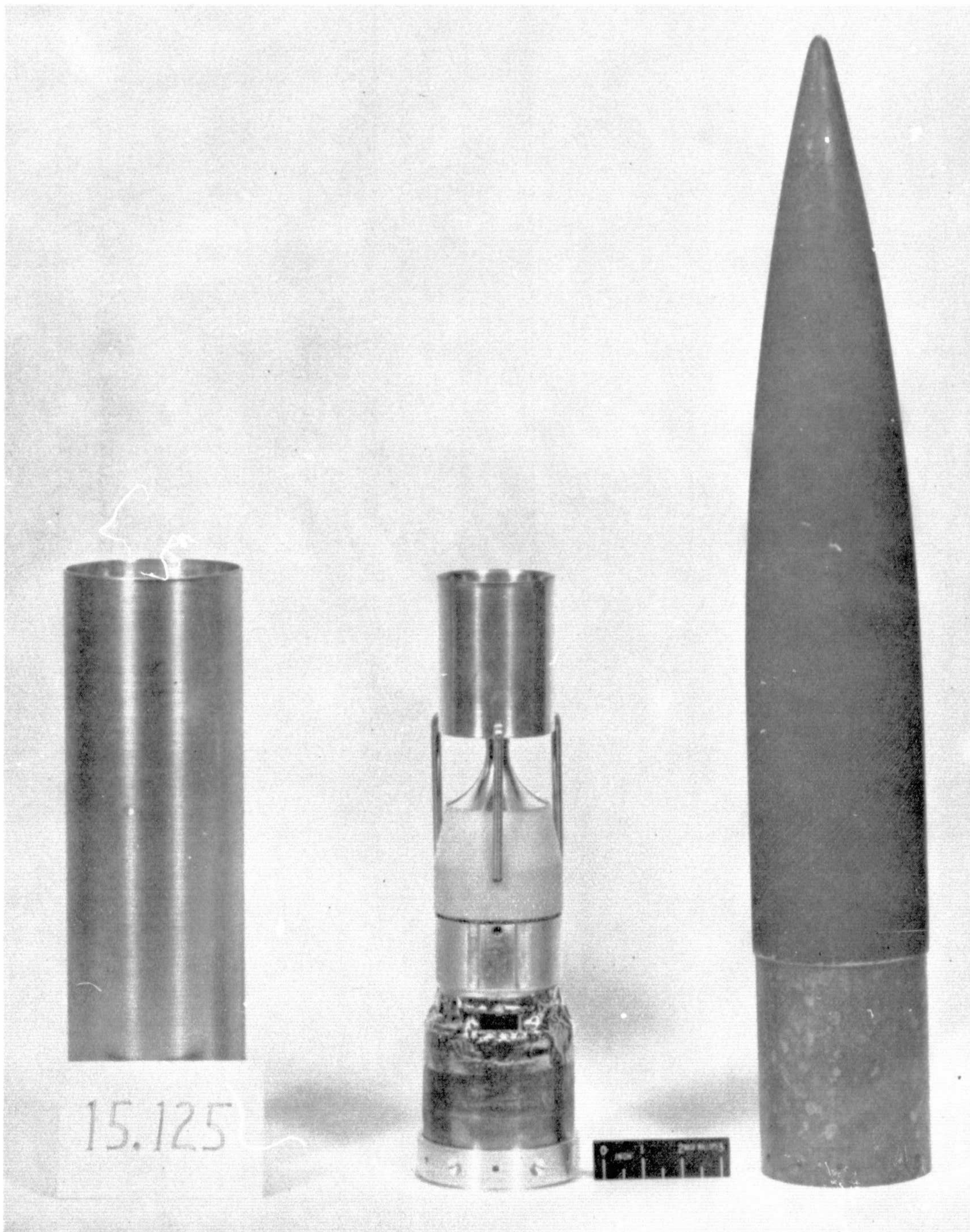
where the subscript i denotes the mobility and the concentration of the ith species.

2.2 The Gerdien Condenser Subsonic Probe

A picture of the completed instrument is shown in Figure 1. This version of the Gerdien condenser was flown twice in Virginia at Wallop's Island and once in Peru. The probe basically consists of two parts, an aspirated condenser and the supporting electronics.

A schematic diagram of the condenser is presented in Figure 2. Two concentric cylinders of radii .7 cm and 3.7 cm were used as the electrodes in the aspiration portion of the probe. The outer cylinder is used as a driver in accelerating the charged particle toward the inner detector. A potential sweep between the electrodes is generated by the electronics housed behind the condenser. A block diagram of this section would include a sweep voltage generator, an electrometer, a power supply, a voltage-controlled oscillator, and a 1680 Megahertz transmitter with an associated antenna. A complete discussion of these can be found in Farrokh (1975). The only difference between the two instruments is that the output of the electrometer in this case was linear; whereas, the other electrometer pro-

FIGURE 1. Picture of Gerdien Condenser Payload



ORIGINAL PAGE IS
OF POOR QUALITY

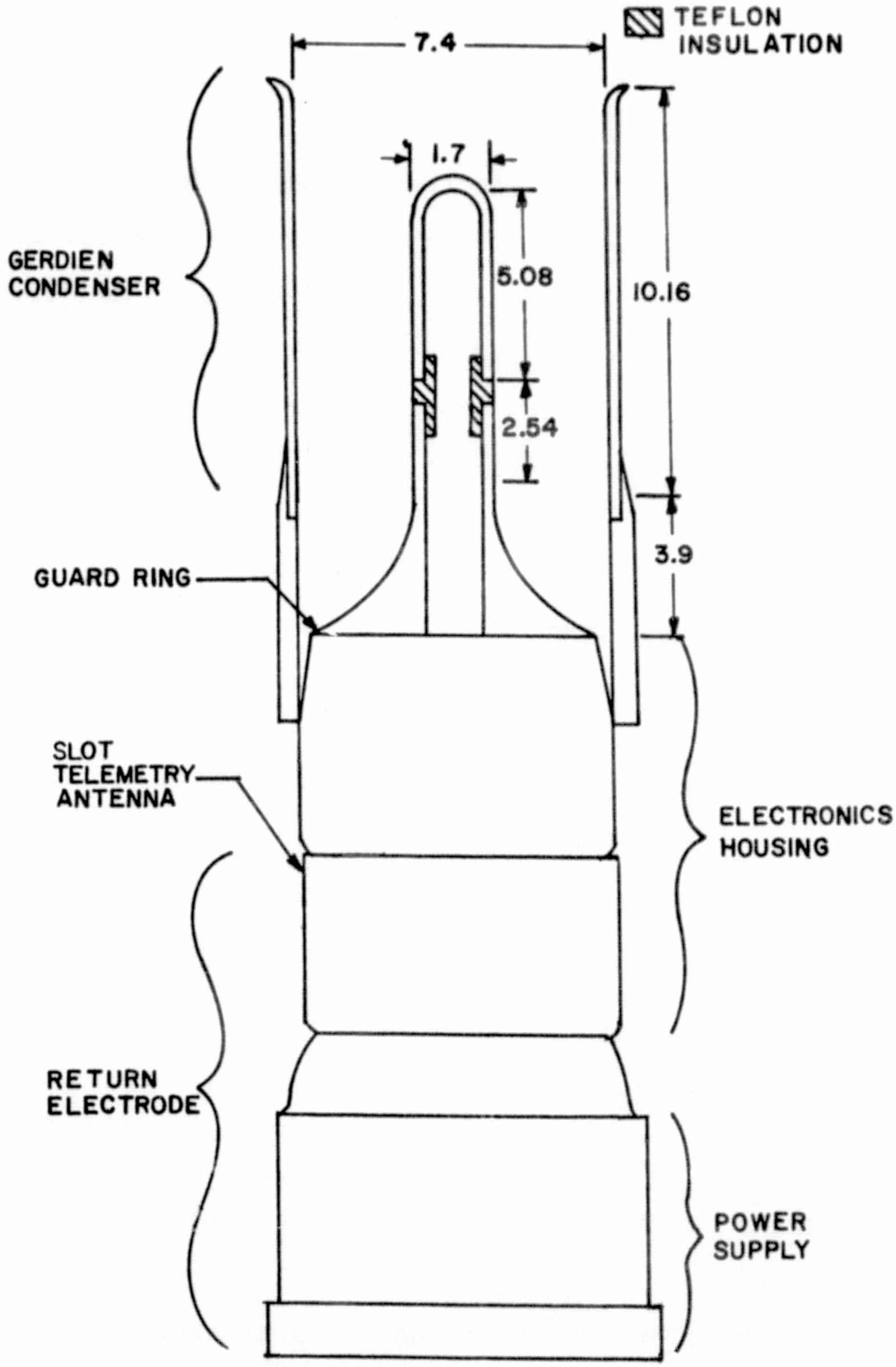


FIGURE 2. Schematic Diagram of Gerdien Condenser Probe

duced a logarithmic output. This greatly facilitated data reduction, although the dynamic range of the measurement was somewhat restricted.

A concentric cylinder geometry was used for the aspiration condenser. The electric field in this configuration can be derived using Laplace's equation in cylindrical coordinates and solved for the appropriate boundary conditions. Laplace's equation can be used here for the assumption of a neutral net space charge has been shown to be valid for the altitude range of this experiment. Its solution for this case is as follows:

$$E(r) = \frac{-V}{r \ln \frac{R_o}{R_i}} \tag{2.8}$$

where E(r) is the radial electric field; V is the potential, R_o and R_i the radii of the outer and inner cylinders respectively. For this system angular as well as z axis symmetry are assumed. The capacitance of the system is:

$$C = \frac{2\pi\varepsilon L}{\ln \frac{R_o}{R_i}} \tag{2.9}$$

where L is the length of the detector and ε the permittivity of the medium.

Using flow considerations as presented by Farrokh (1975), it is shown that the ions collected by the detector results in a current given by:

$$I = N\, e\, K\, V\, C/\varepsilon \qquad (2.10)$$

This equation describes the current-voltage characteristic of the Gerdien condenser (see Figure 3). Equation (2.10) can be extended to a multicomponent plasma:

$$I = e\, V\, C/\varepsilon\; N_i\, K_i \qquad (2.11)$$

where the index i denotes the mobility and density of the ith component (see Figure 4). By definition, σ (the conductivity) $= N\, e\, K$, thus equation (2.10) can be rewritten:

$$I = \sigma\, V\, C/\varepsilon$$

or upon solving for σ:

$$\sigma = I\, \varepsilon/(V\, C) \qquad (2.12)$$

The conductivity can be calculated by (2.12). In actual data reduction, the slope of the current-voltage characteristic rather than the ratio I/V is used. Substituting equation (2.9) into (2.12) and using the slope of the I-V curve yields:

$$\sigma = \frac{\ln \frac{R_o}{R_i}}{2\, \pi\, L}\; dI/dV \qquad (2.13)$$

The tape recorded data is transferred to a strip chart recording. In this transferral, the current becomes a function of time. Upon differentiation Ohm's Law becomes:

$$dV = R\, dI \qquad (2.14)$$

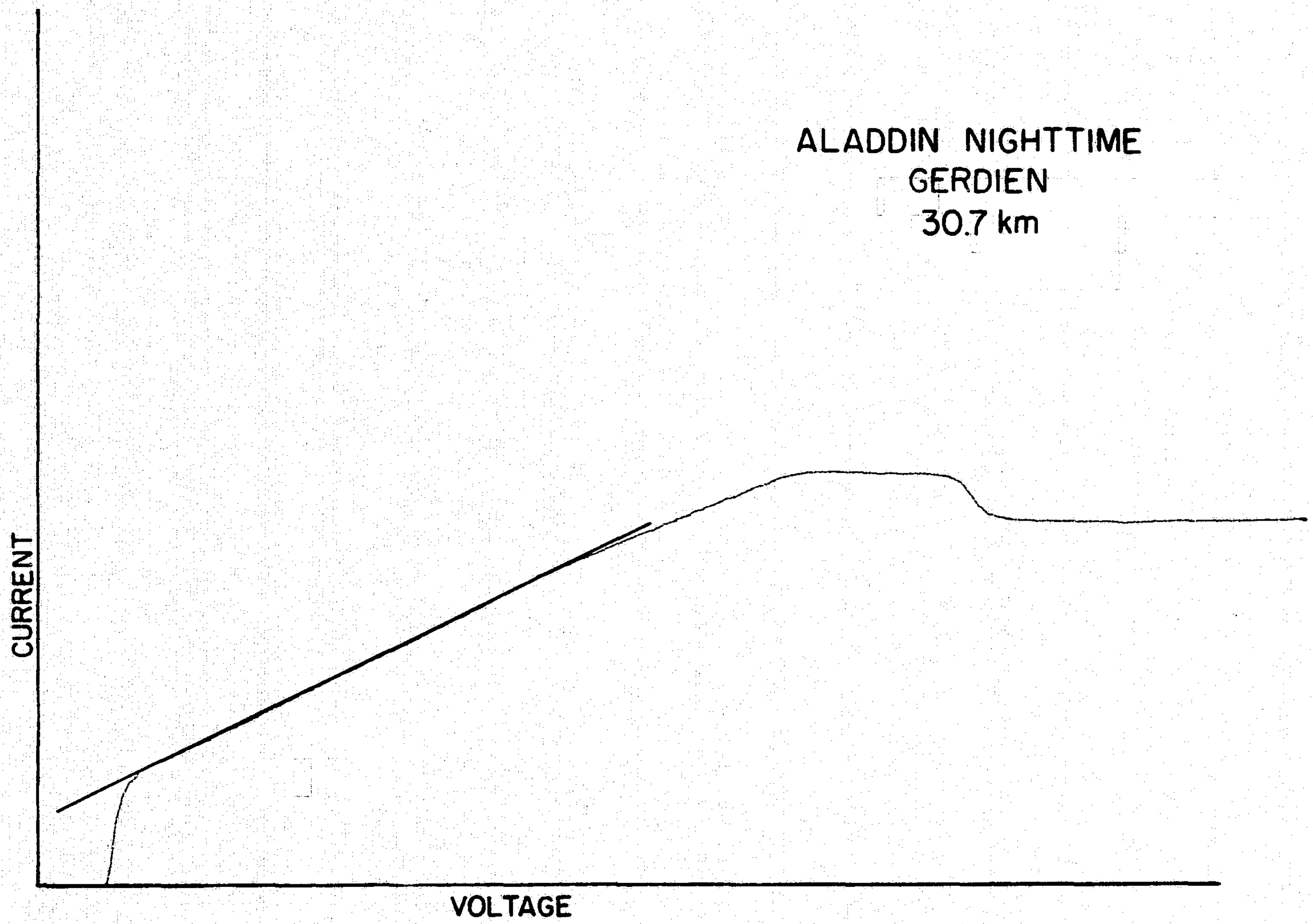


FIGURE 3. Current-Voltage Characteristic Typical of One Component Plasma

After applying the chain rule of differentiation (2.13) and (2.14) become:

$$\sigma = \frac{\ln \frac{R_o}{R_i}}{2 \pi L} \quad \frac{\frac{dI}{dt}}{\frac{dV}{dt}} \tag{2.15}$$

and

$$\frac{dV}{dt} = R \frac{dI}{dt} \tag{2.16}$$

By performing preflite calibrations on the instrument using a known resistance R_{cal}, equation (2.16) can be substituted into (2.15):

$$\sigma = \frac{\ln \frac{R_o}{R_i}}{2 \pi L} \quad \frac{dI/dt\ (data)}{dI/dt\ (cal)} \tag{2.17}$$

where dI/dt (data) and dI/dt (cal) are the slopes of the current-voltage characteristics of the data and the calibration sweeps respectively.

When all the ions of one polarity entering the condenser are deflected to the detector the instrument is said to be in saturation. This can occur before the potential reaches a maximum. Assuming an average air stream velocity $\overline{U}$, using equation (2.10), and the same volume flow considerations as used previously (Farrokh, 1975), the voltage at saturation is given by:

$$V_s = \frac{\ln \frac{R_o}{R_i}}{2 \pi L} \quad (R_o^{\,2} - R_i^{\,2}) \quad \frac{\overline{U}}{K} \tag{2.18}$$

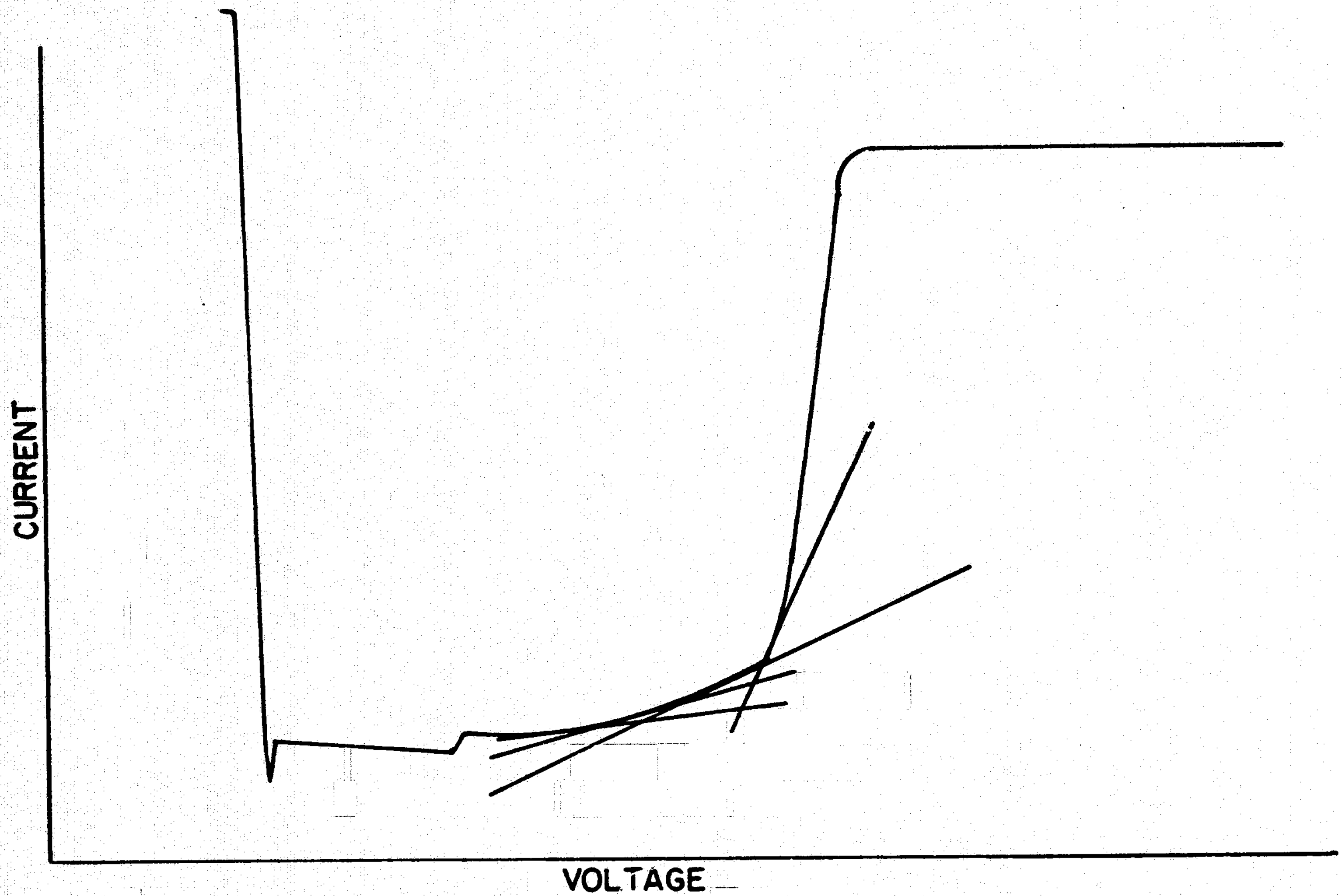


FIGURE 4. Current-Voltage Characteristic Typical of a Multicomponent Plasma

where L is the length of the detector. This equation can easily be solved for the mobility K. The respective radii, R_o and R_i and the length, L of the detector can be measured. The mean air speed is taken as the vertical descent velocity measured by radar during the flight (Croskey, 1976). The voltage at saturation can be calculated from the data. From the above variables and equation (2.18), the mobility can be calculated. Note that V_s is inherent to a particular ion species and not a composite of many. Had these calculations been performed via the saturation current method (equation (2.11) with I_s and V_s replacing I and V respectively), the resulting saturation current is a superposition of each individual current. This does not lend well to calculating either the concentration or the mobility.

The desired results from Gerdien condenser data reduction are ion mobilities and densities. The mobilities can be obtained by methods found in the previous discussion. Recalling the definition of conductivity ($\sigma \equiv N e K$), and knowing the mobility, the density can be calculated. Ion density and mobility profiles can now be constructed, and analysis of the results begun.

2.3 The Blunt Probe

Another instrument used for ionospheric investigation is the blunt probe. This instrument was originally designed and constructed by Drs. Leslie C. Hale and D. P. Hoult, and a more complete discussion of it can be found in

Mitchell (1973). Its geometry consists of a disc detector centered on the face of the instrument. This is suspended downward, and faces into the direction of the fall. The detector is held at a potential equal to that of the circular guard ring, which surrounds the detector and makes up the rest of the front of the instrument. This potential is referenced to the return electrode situated at the base of the payload. The resulting electric field is described by the equation:

$$E = 2\ V/(\pi R)$$

where V is the potential of the disk, and R is the radius of the guard ring. The current collected by the detector is:

$$I = a^2\ J \qquad (2.20)$$

where J is the current density (see equation (2.6)), and a is the radius of the detector. Substituting (2.19) into (2.6) for ∇V and this into (2.20) yields:

$$I = \frac{2\ a^2}{R}\ K\ N\ e\ V \qquad (2.21)$$

A typical current-voltage characteristic is shown in Figure 5. Recalling the definition of conductivity, equation (2.21) can be rewritten:

$$I = \frac{2\ a^2}{R}\ \sigma\ V \qquad (2.22)$$

In a manner exactly paralleling the previous discussion of the Gerdien condenser, an equation for sigma in terms of the

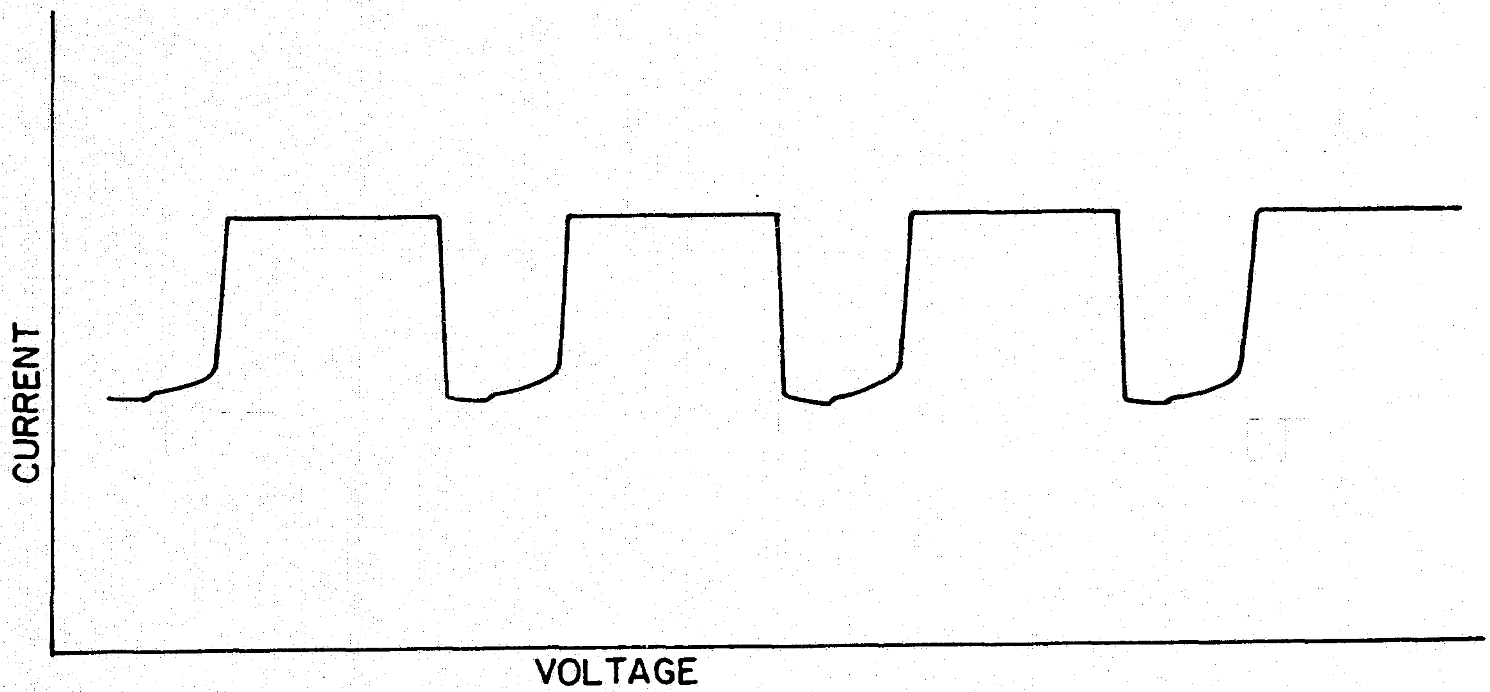


FIGURE 5. Current-Voltage Characteristics From The Blunt Probe

data slope can be deduced. This equation is:

$$\sigma = \frac{R}{2\ a^2\ R_{cal}} \quad \frac{dI/dt\ (data)}{dI/dt\ (cal)} \tag{2.23}$$

From the given constants and the measured slopes, the conductivity can be calculated. This is the only real result that can be obtained from the data. To obtain mobility or density profiles either one has to be assumed (taken from a reference atmosphere or some other source), and the other can be calculated. Usually one assumes the density profile and calculates the mobility profile. It is at this point that the analysis of the results begins.

2.4 Comments Concerning the Two Systems

During the 1974 Aladdin Project, conductivity measurements were taken by both instruments. Figures 6 and 7 show the conductivity profiles as calculated from the data for that day. These profiles present a comparison between the blunt probe's and Gerdien probe's derived conductivity profiles. The solid line represents the blunt probe data. This line corresponds well with the far right portion of the Gerdien data. Note that the Gerdien derived profile as presented, represents a composite conductivity, i.e., the right-most curve is the total conductivity. The result of the superposition of that due to each individual species. The proximity of the blunt probe data and that of the Gerdien demonstrates the consistency of the results. This fact is one of many which supports the reliability of the Gerdien

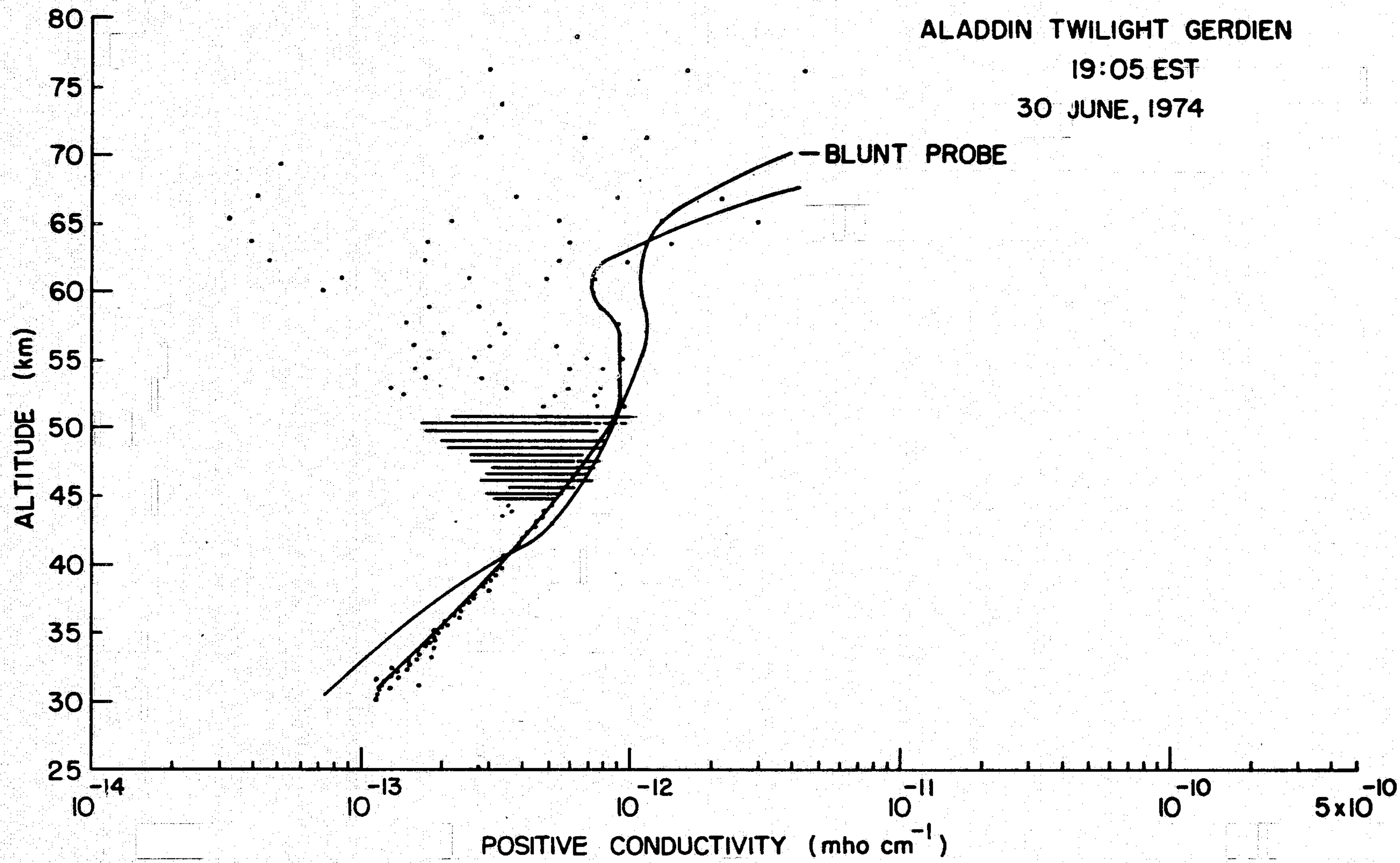


FIGURE 6. Conductivity Comparison Between the "Aladdin" Twilight Gerdien and Blunt Probes

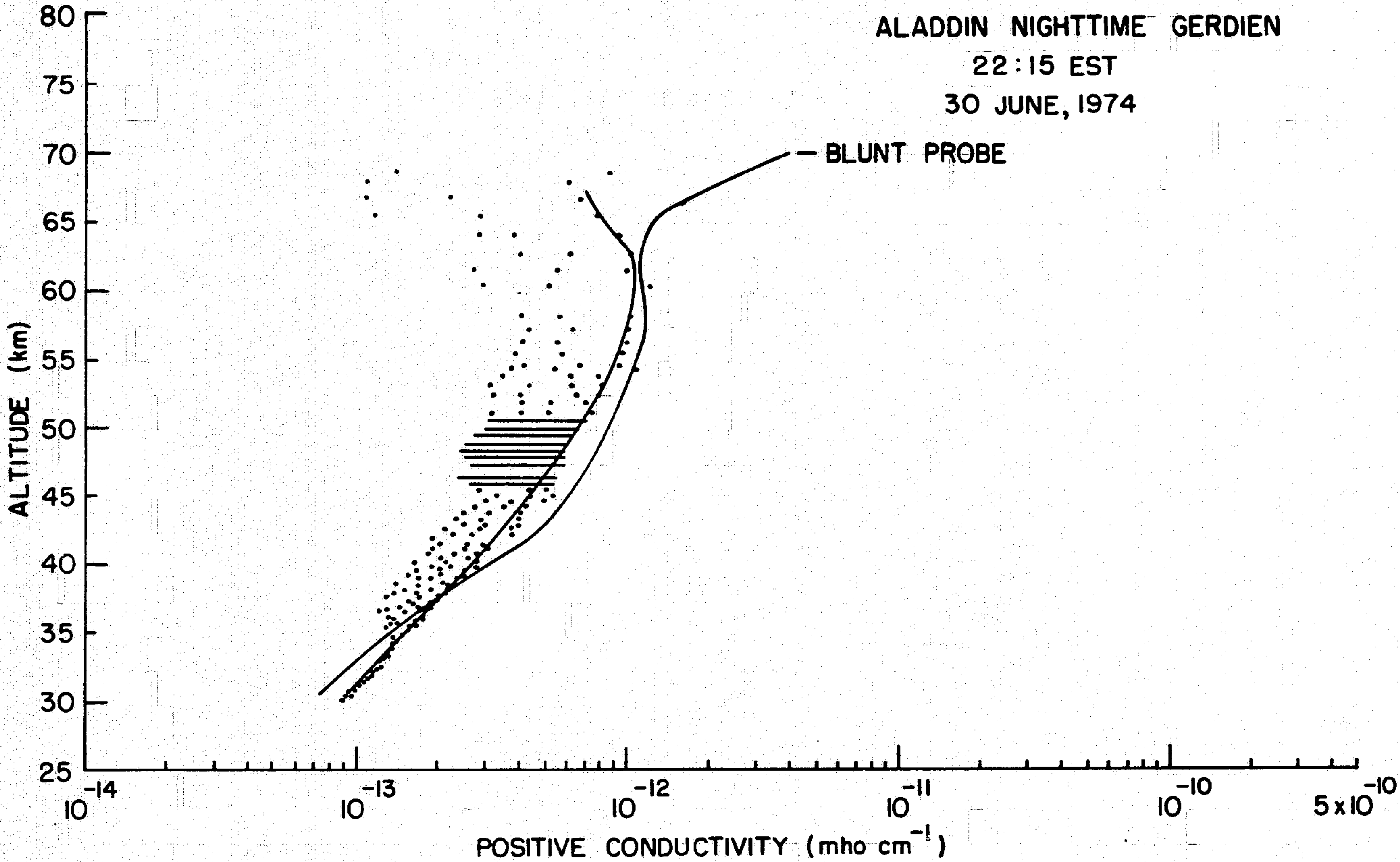


FIGURE 7. Conductivity Comparison Between the "Aladdin" Nighttime Gerdien and Blunt Probes

condenser probe when used as an ionospheric investigative instrument.

The main advantage of the condenser probe over the blunt probe is in the greater quantity of information provided. The only directly calculated variable available from the blunt probe is the conductivity of the atmosphere as a whole. However, this is only a part of the available data, charged particle number densities and mobilities can also be obtained with the Gerdien probe. With the blunt probe, an average mobility is sometimes assumed and the concentration then calculated. Thus, the Gerdien probe yields more realistic values for these important ionospheric parameters than does the blunt probe.

The major advantage of the blunt probe over the condenser probe is its shape. Due to the impact nature of the flight (the blunt face is perpendicular to the direction of the flow) the probe is able to sense a stagnation layer. Therefore, this instrument is highly insensitive to angle of attack, and is not affected significantly by phenomenon such as parachute swing. On the obverse, the Gerdien's flow-through type geometry makes it very sensitive to angle of attack. More stable parachutes of recent design have lessened the severity of the problem.

The chemical and flow complications which are a result of supersonic flight present many drawbacks to data reduction and analysis (Conley, 1974). It is for this reason that both the probe types developed at the Ionosphere Research

Laboratory, under the guidance of Dr. Hale, are parachute borne. In the initial stage of descent, the probe may approach supersonic speeds before the parachute encounters enough resistance from the atmosphere. Consequently, the high altitude data (approximately 70 to 80 km) may have slight errors, and less reliability is placed on it. It is also in these altitudes that mean free path considerations in the condenser theory become important (Farrokh, 1975).

Photoemission of electrons hinders as well as assists in the operation of the Gerdien condenser. In cases of high wind sheers or extreme parachute swing, the detector surface may become exposed to direct sunlight. In such cases, photoemission of electrons can cause a spurious current and can alter the data. This adds to the uncertainty of the results. However, radar tracking of meteorological sounding rockets, immediately previous to the launch of these probes, has usually shown a lack of such wind sheers, and parachute swing usually occurs early in the flight. Daytime electronic photoemission on the outer surface of the outer cylinder acts as a low impedance connection to the environment, and this effectively potential locks the probe during flight. This prevents zero shift in the data, which is important in the data reduction. During daytime flights, photoemission occurs consistently throughout the duration of the flight. Consequently, photoemission seems to play a more constructive role than a destructive one.

CHAPTER III

DATA ANALYSIS

3.1 Flight History

The Ionosphere Research Laboratory participated in both the "Aladdin" Project of 1974 and the "Antarqui" program of 1975. This investigation was headed by Dr. Leslie Hale. Its part in the "Aladdin" Project consisted of one blunt probe and two Gerdien condensers. These were launched on 29 June, 1974 at 16:12, 19:05, and 22:15 E.S.T. respectively. This took place at the NASA Wallop's Island, Virginia facility, which has a latitude and longitude of 37.8 degrees N and 75.5 degrees W respectively. All of the probes were launched by Super Arcas rockets, and achieved apogees of 91, 82, and 69 km respectively. Previous to firing, all payloads were activated and calibrated. Typical calibration current-voltage characteristics are shown in Figure 8.

During the "Antarqui" D-region study, three blunt probes and one Gerdien condenser were launched. Data from the three blunt probes has been reduced by Bassi (personal communication). The condenser payload was launched at the Chilca Rocket Range in Peru on 28 May, 1975 at 16:16 E.S.T. This rocket site is located at 12° 13' 15" S latitude and 76° 47' 20" W longitude. The system reached apogee at 91 km and proceeded with a subsonic descent.

Data is telemetered down during these rocket flights by using a 1.68 Gigahertz transmitter with a meteorological

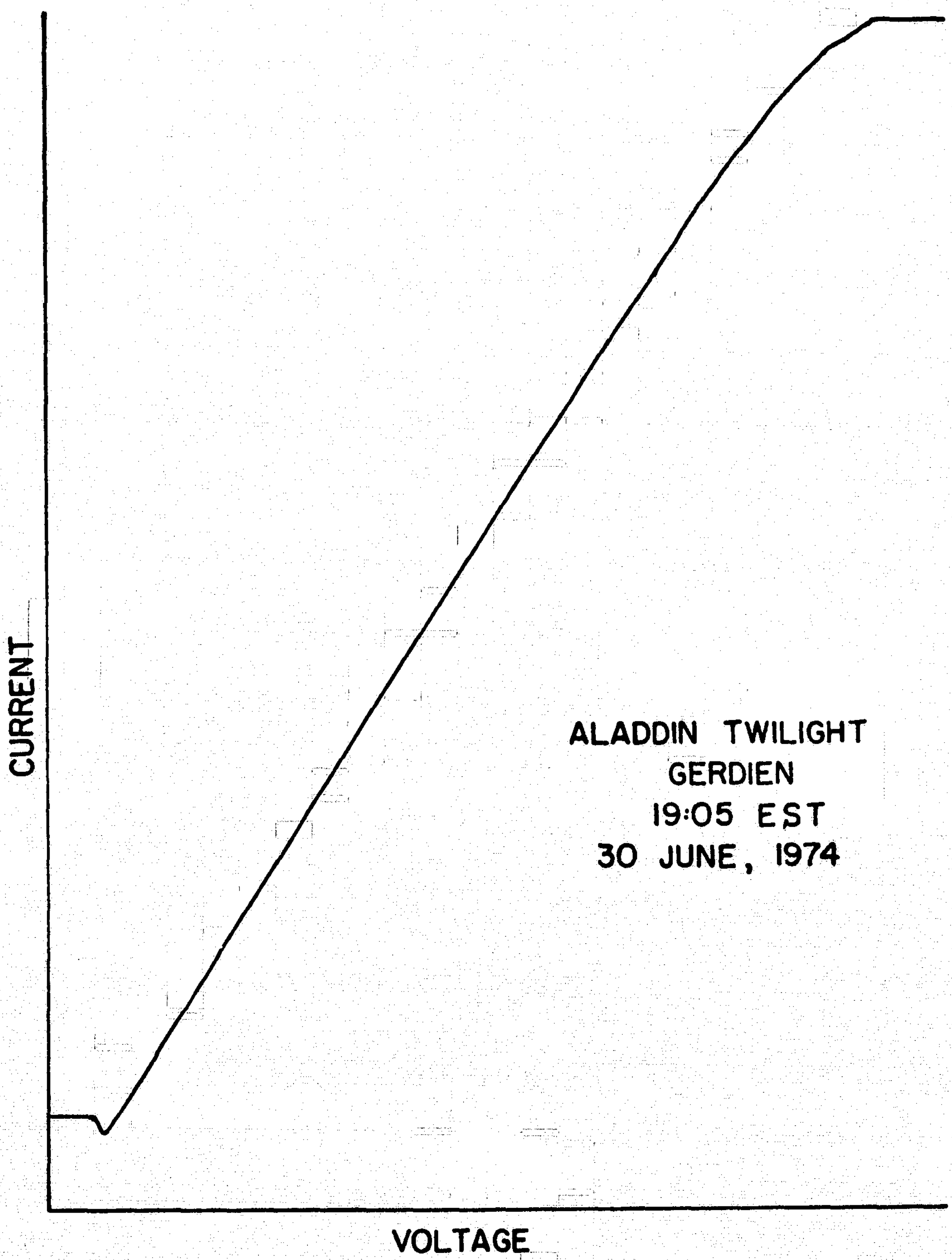


FIGURE 8. A Typical Calibration Current-Voltage Characteristic

"GMD" tracking system used for reception. During the flights of these Gerdiens, the conductivity of the surrounding medium is measured. The vertical descent velocity and the saturation voltage yields the mobilities of the constituents of the medium (see equation (2.18)). From the measured conductivity and the calculated mobility, the density of each individual ion and the ionosphere (unipolar) can be determined. The results of these flights is now presented and discussed.

3.2 Conductivity Profiles

Figures 9 through 12 are the conductivity profiles as constructed from the data. The procedure used is presented in the previous chapter. Figure 9 is the profile determined by the blunt probe. It is given here mainly for historical reasons, and does not contribute to the conclusions concerning the structure of the D-region. Note the conductivity minimum occurring at 63 km; this agrees well with the transition layer from Lyman α to galactic cosmic rays as aforementioned. Below 43 km it was no longer possible to differentiate between positive or negative ions, indicating that they have similar properties.

Figures 10 through 12 are the profiles measured by the Gerdien condenser probes. Note well that these represent composite conductivities and not profiles of each individual species. In these profiles, the rightmost curve (solid line etched in) represents the total conductivity of the positive ions. Both of the daytime total conductivities

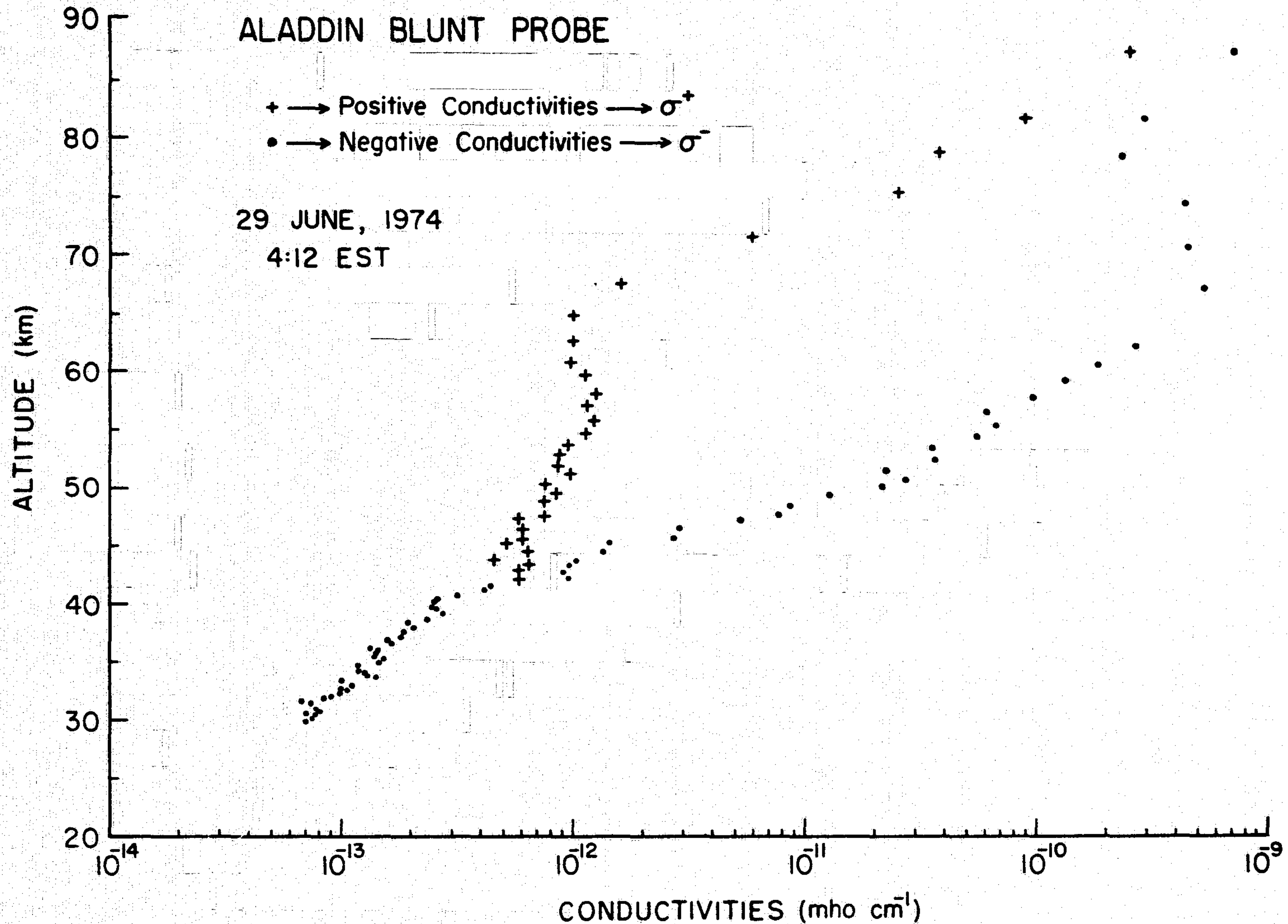


FIGURE 9. Positive Ion Conductivity Profile - Blunt Probe

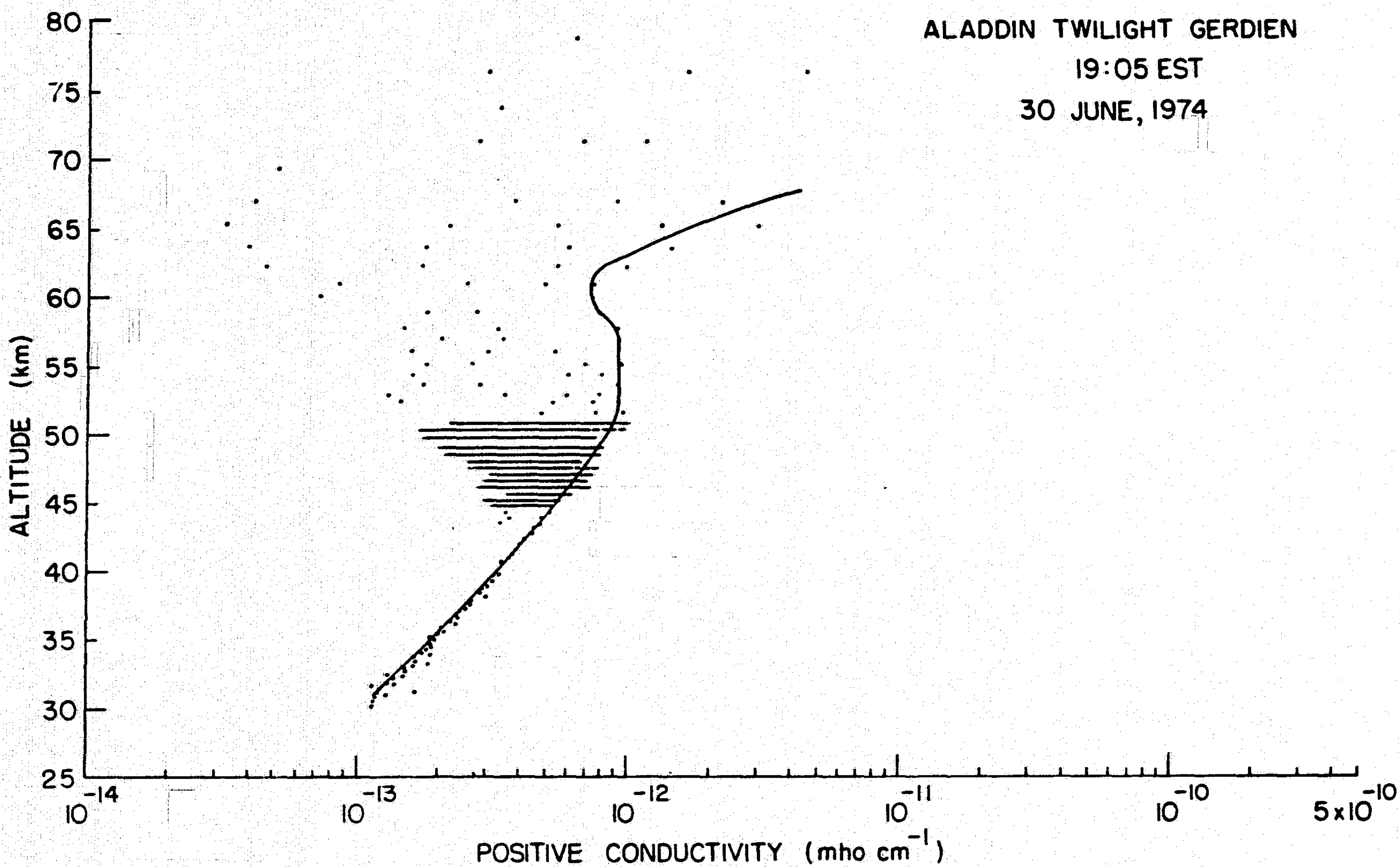


FIGURE 10. Positive Ion Conductivity Profile - Twilight Gerdien Probe

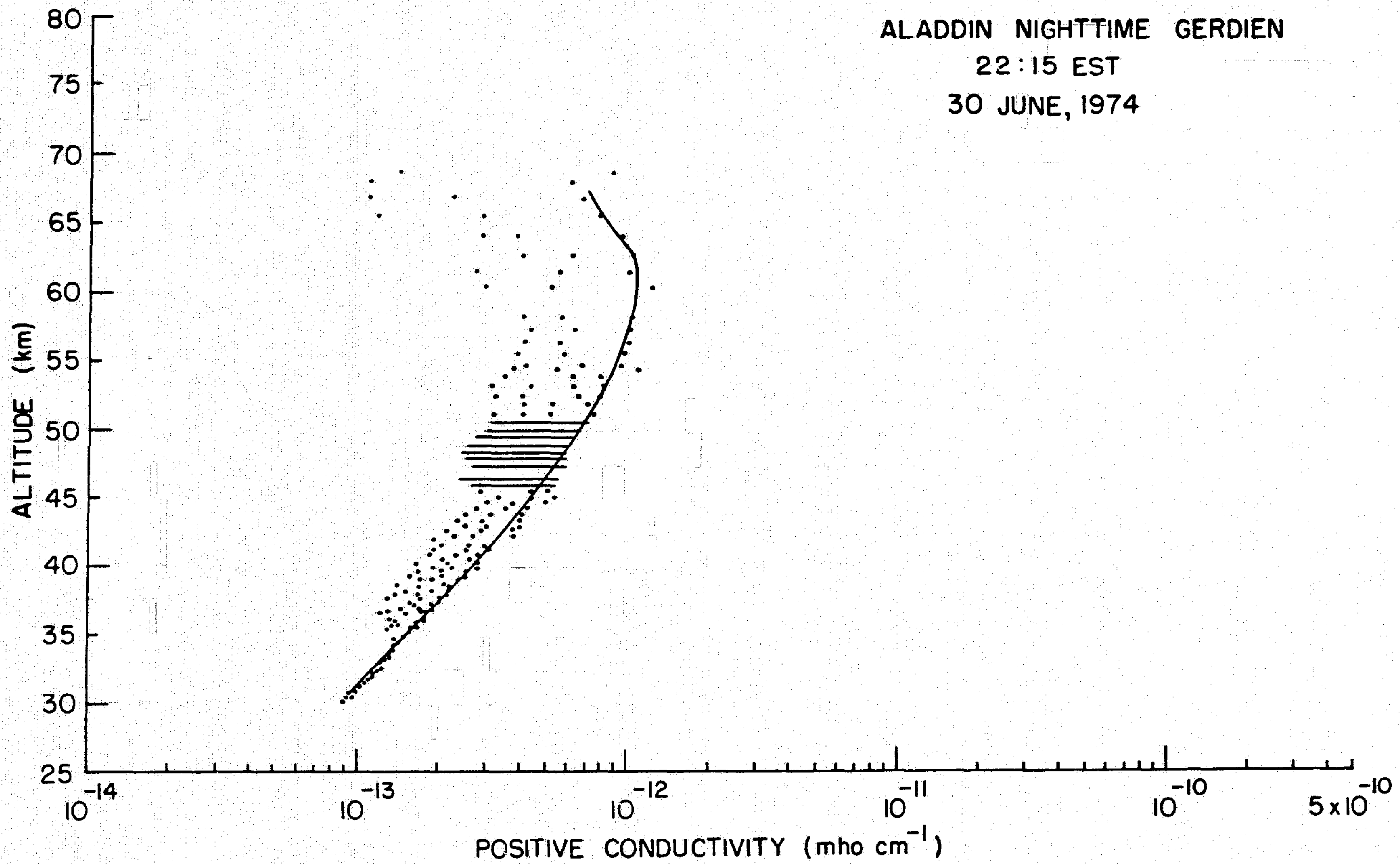


FIGURE 11. Positive Ion Conductivity Profile - Nighttime Gerdien Probe

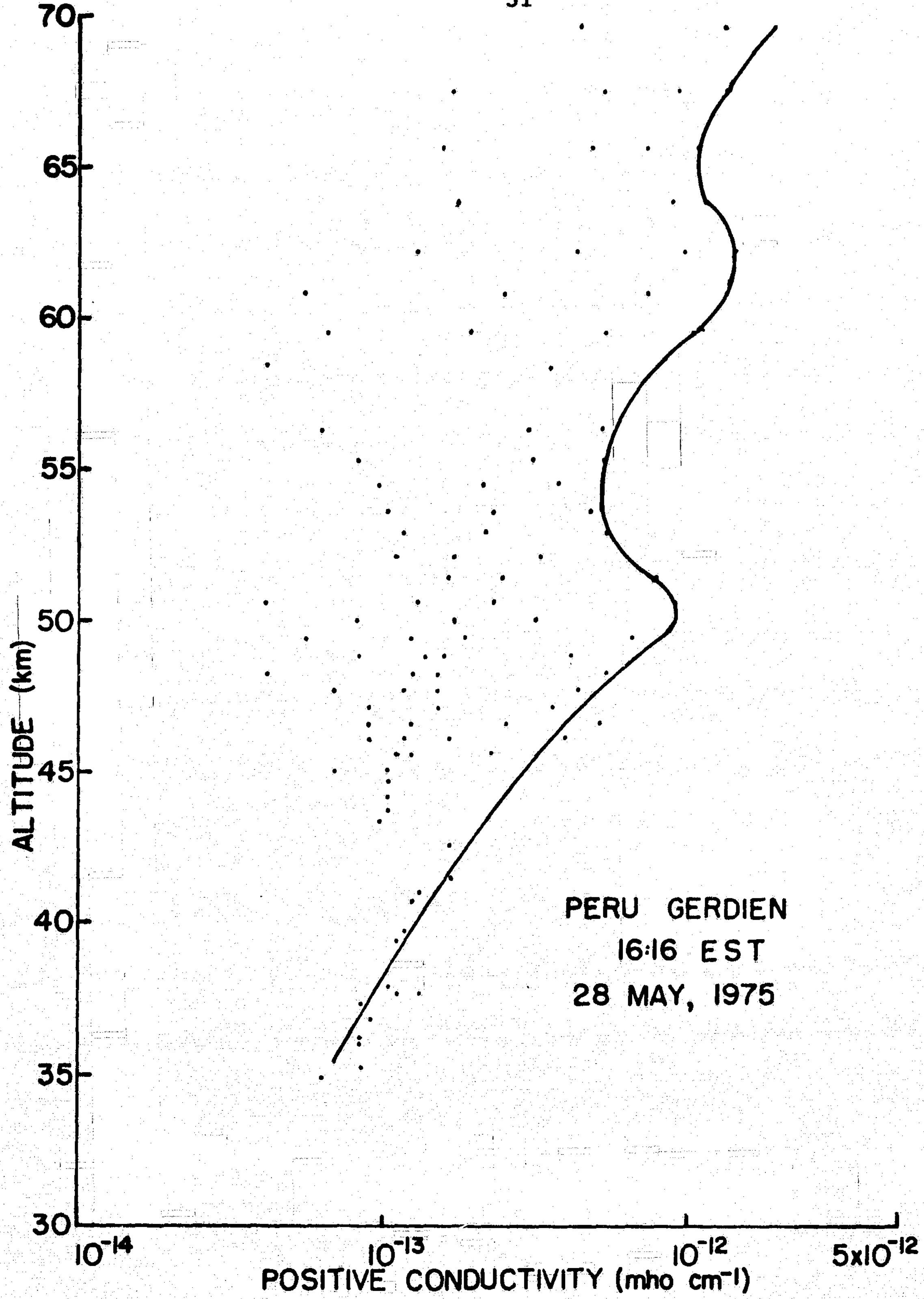


FIGURE 12. Positive Ion Conductivity Profile - Peru Gerdien Probe

show the "knee" at about 63 km. It is around 65 km for the Peru shot and 62 km for the "Aladdin" twilight shot. The "knee" is not present in the nighttime profile. In general, above 55 km all of the profiles show two or three distinct families. Between 55 and 50 km there is an increase in the number of constituents. For the two daytime rockets, this increase ends in a smear between about 50 and 45 km. They then converge to one family from 44 km down. Whereas, the nighttime continues as a multiple ion medium down to 35 km before merging into one. The Peru Gerdien total conductivity profile also demonstrates a wave nature. This suggests the presence of an equatorial gravity wave (Holton, 1975).

3.3 Observed Mobilities and Concentrations

Figures 13 to 15 are the mobility versus altitude plots as calculated from the data. In these graphs the line of connected L's represents the mobility limit of the instruments flown. Any ion of mobility to the left of the line was too small to be measured by the instrument. Figure 16 is the mobility profiles from two Gerdien flights at Poker Flat, Alaska as analyzed by Croskey (1976). A comparison of these with the results of Rose and Widdel (1972) is also on the plot. This plot has been included for later discussion. Having a voltage sweep period of only four seconds, as compared to nine seconds for the Gerdiens covered in this report, these Alaskan flights yielded at least twice as many data points as previously received. From such large sample Dr. Croskey was able to distinguish individual short

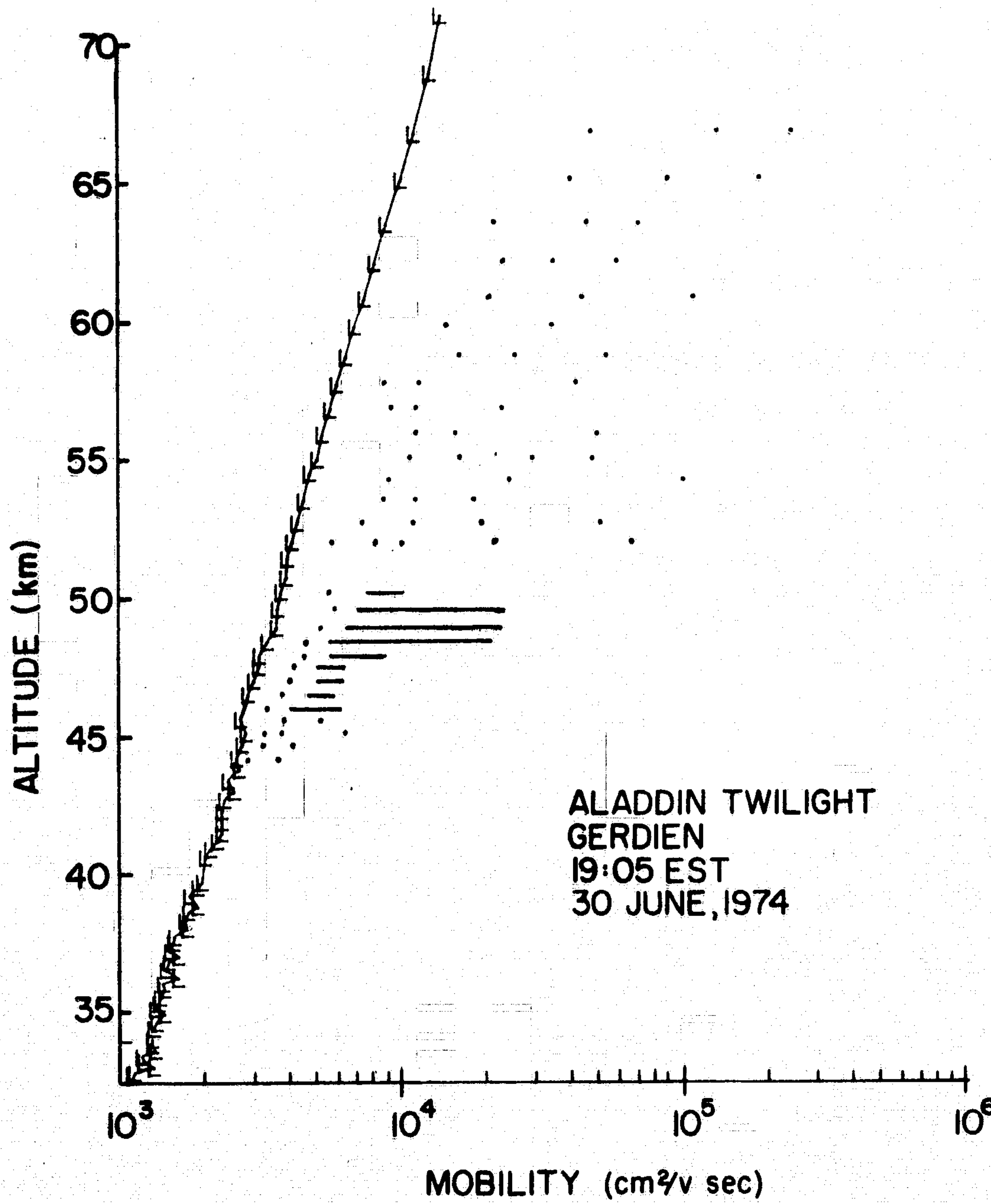


FIGURE 13. Positive Ion Mobility Profile - Twilight Gerdien Probe

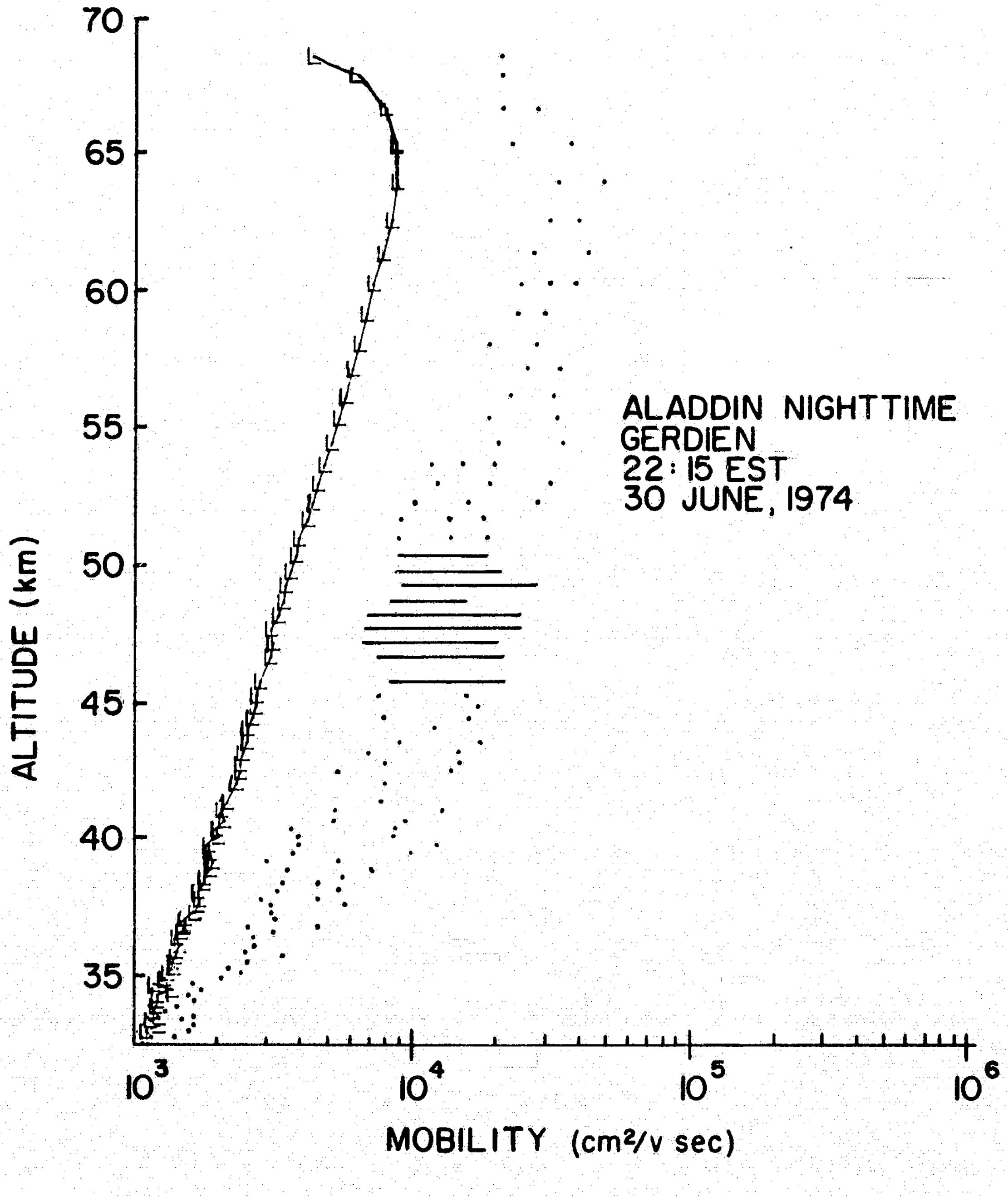


FIGURE 14. Positive Ion Mobility Profile - Nighttime Gerdien Probe

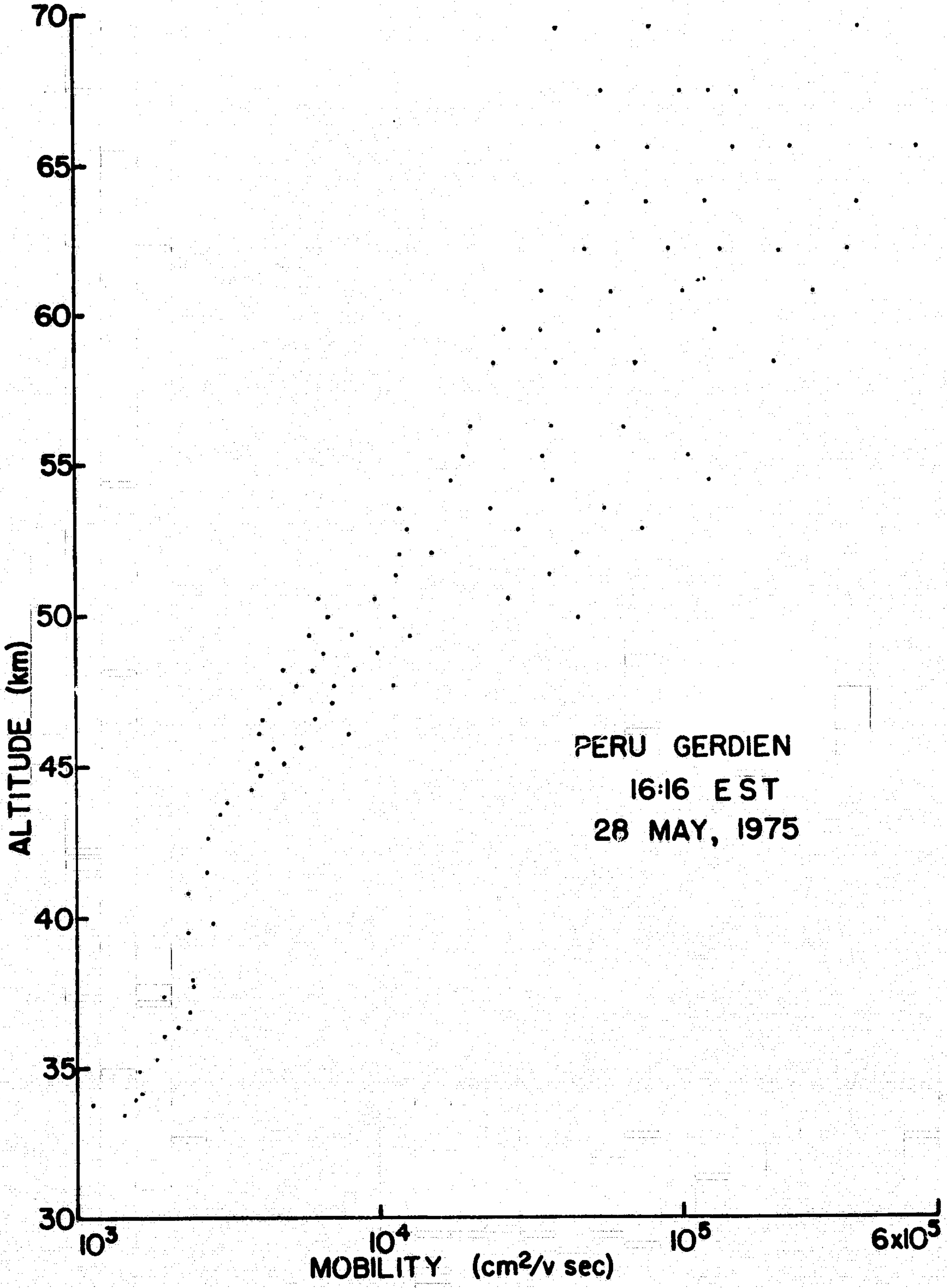
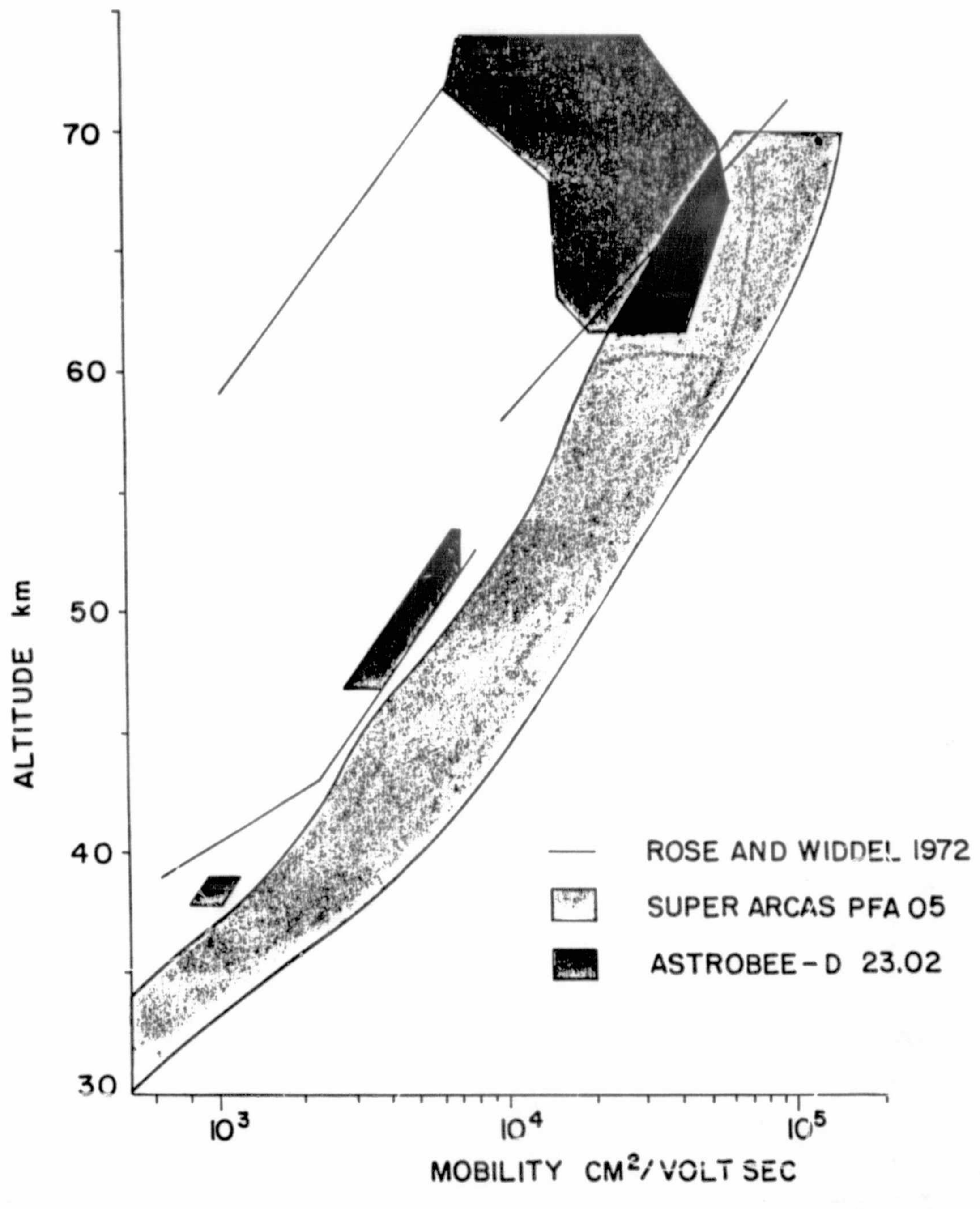


FIGURE 15. Positive Ion Mobility Profile - Peru Gerdien Probe



70
60
50
40
30
ALTITUDE km
10^3
10^4
10^5
MOBILITY CM^2/VOLT SEC
ROSE AND WIDDEL 1972
SUPER ARCAS PFA 05
ASTROBEE-D 23.02

range families. However, this could not be done for the profiles in this case due to the limited number of points.

Figure 13 is the profile resulting from the "Aladdin" twilight flight. From 70 to 50 km several (three or four) distinct groups exist. At 50 km a continuous smear of mobilities is present. Here the smear encompasses a smaller range of mobility than is obvious from the corresponding conductivity profile. Then at 44 km the one ion present (as is seen from Figure 10) has a mobility too small to be detected by the instrument.

Analysis of the data from the nighttime Gerdien flight resulted in Figure 14. As before, individual groups are easily distinguished. However, the instrument never completely saturated, which implies the existence of a very heavy ion of low mobility. Two families (and then three) exist from 70 to 50 km. The increase in mobility from 68 to 63 km is probably due to parachute swing. A wider smear of mobilities is present at night than at twilight from 50 to 45 km. As will be seen later, this is purely a time effect. During the night from 45 km down there is a conglomeration of several median mobile ions. This did not occur during the day, and will be discussed in detail later.

The Peru mobility profile (Figure 15) shows a higher number of constituents in the higher altitude range (50 to 70 km). From 45 km down, there is only one species as was seen in the twilight Gerdien of the "Aladdin" program. In comparing this profile with Figure 14, another important factor is seen in the 45 to 50 km range. The smear is not present, and individual species can be discerned. This fact will be employed later when considering possible latitudinal variations in the D-region.

Figures 17 through 19 are the resulting concentration versus altitude plots. These profiles are not yet fully understood, and only a few general comments are noteworthy. Figure 17 is from the "Aladdin" twilight rocket shot. Marked at about 65 km are two species which can be identified as having consistent mobilities and densities. These families both exhibit concentration minima around 62 km which is consistent with the same minimum on its conductivity profile. Also of interest is the density of the family approximately 44 km and down. This species is similar to the same family as seen from the Peru flight (see Figure 19). The similarity lies in the fact that there is only one family, and its density has jumped from the families above 45 km. This data suggests a change in ion identity during the day which occurs at 45 km. No data is shown for this or the next profile between 45 and 50 km. This results from the smear of conductivities which prevents the calculation of individual conductivities and consequently the densities.

A glance at the 63 km altitude area on Figure 18 seems to show no density minimum. This is expected since the profile represents the data from the Gerdien nighttime shot. The area under 45 km points out the existence of a multitude of ions at night. Figure 19 again demonstrates the Lyman α

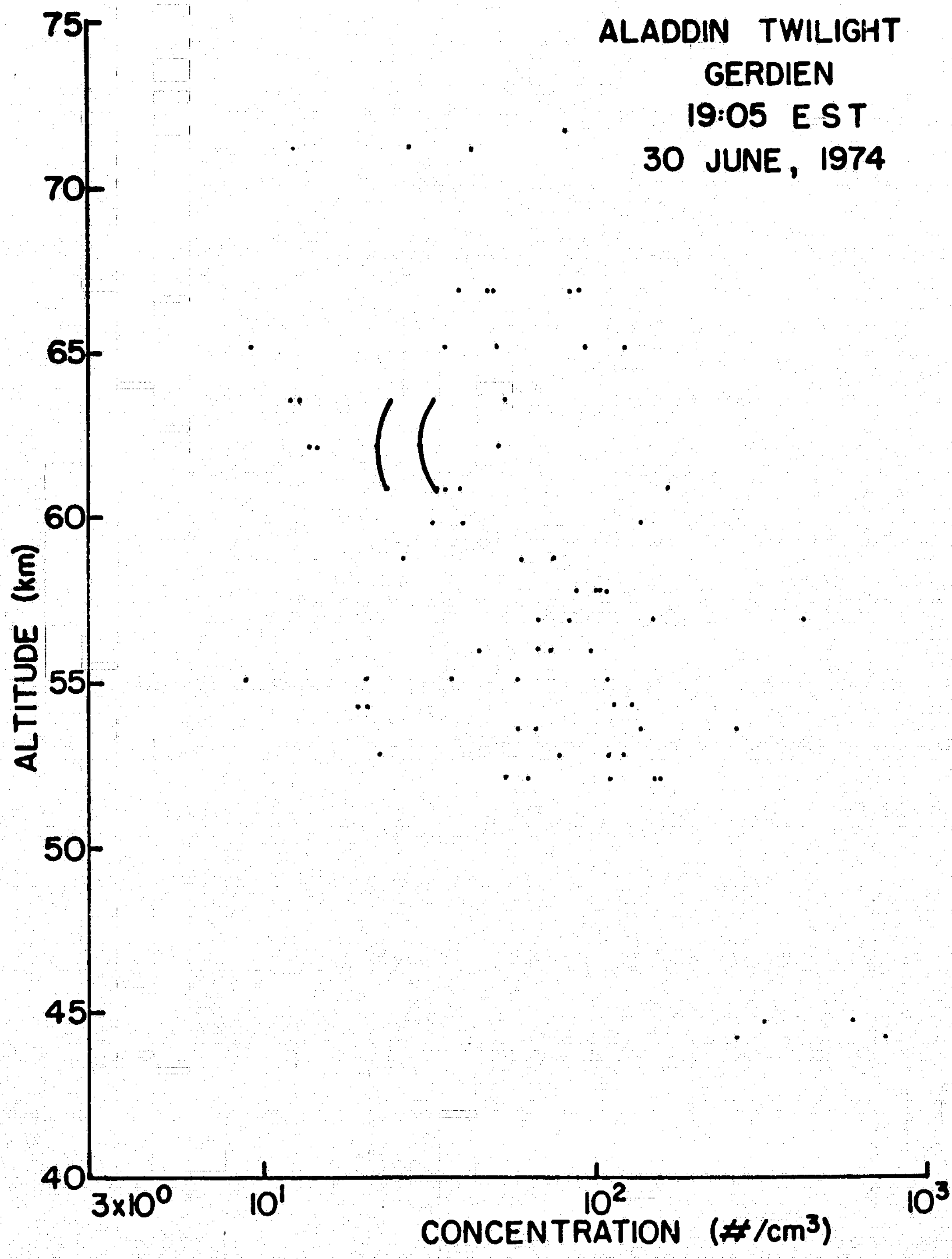


FIGURE 17. Positive Ion Density Data - Twilight Gerdien Probe

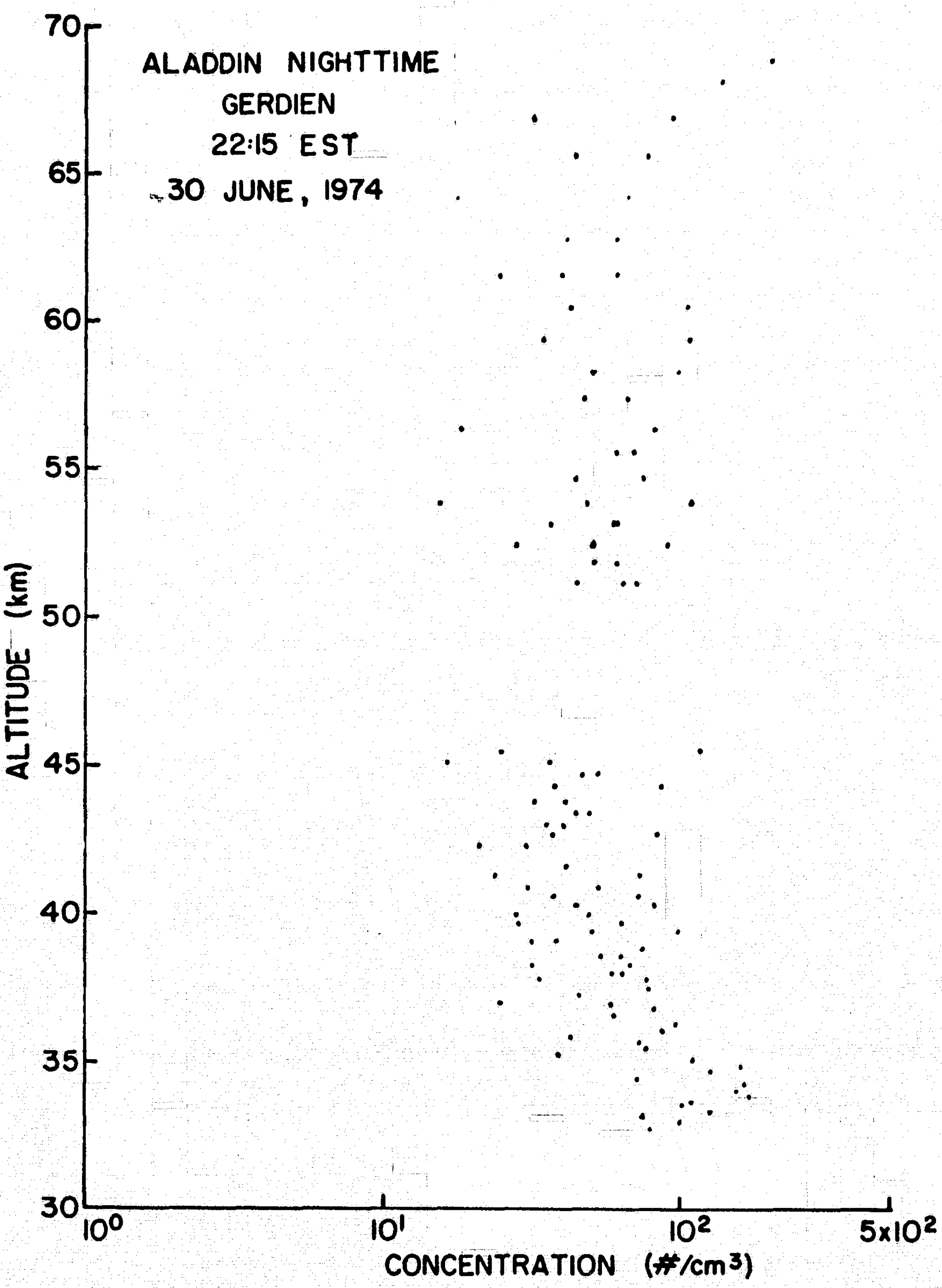


FIGURE 18. Positive Ion Density Data - Nighttime Gerdien Probe

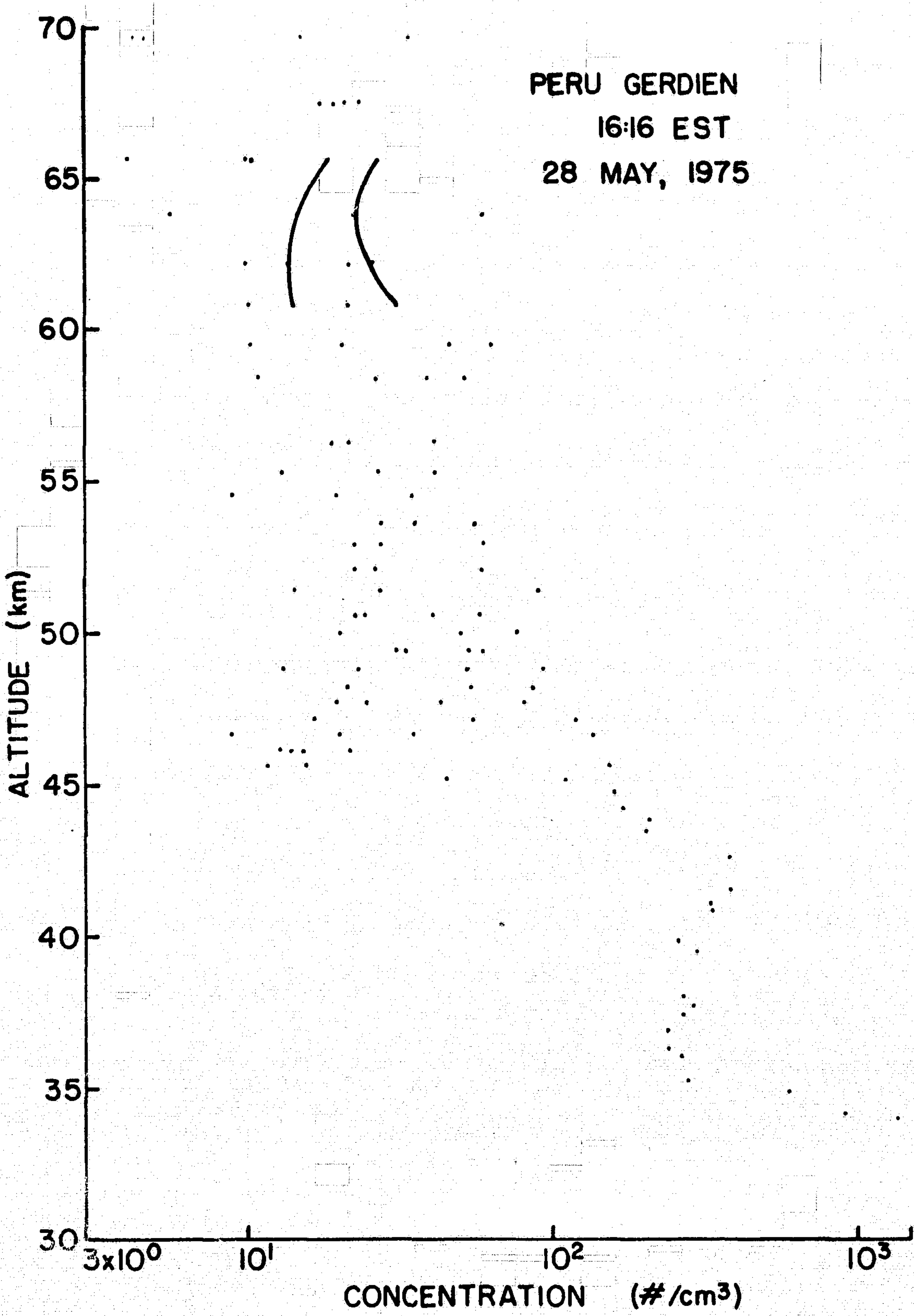


FIGURE 19. Positive Ion Density Data - Peru Gerdien Probe

transition layer around 63.5 km. As mentioned above, the density jump increase at 45 km suggests a transition from one ion chemistry regime to another. This profile also gives evidence of another transition at 35 km.

3.4 Instrument Verification

In section 2.4 a comparison of blunt probe's conductivities with the Gerdien's was offered as proof of the consistency in the results of the instrument. To further verify the use of the Gerdien condenser as a mobility spectrometer, total concentrations for the two daytime flights were calculated via two different methods. One method summed up the individual concentrations at each altitude level, as found through the saturation voltage method. This variable is indicated by a V on Figures 20 and 21. The other method utilized the saturation current in order to calculate the total density. This method takes equation (2.10) and substitutes (2.18) and (2.9) into it for the saturation voltage and the capacitance respectively. This value has been labelled I on Figures 20 and 21. Figure 20 contains both methods as used on the data from the twilight Gerdien. In general they are in agreement. However, in some cases, noise on the current-voltage characteristics hinders the proper calculation of these parameters.

Figure 21 represents the dual calculations as done on the Peru data. Here again the results agree quite well.

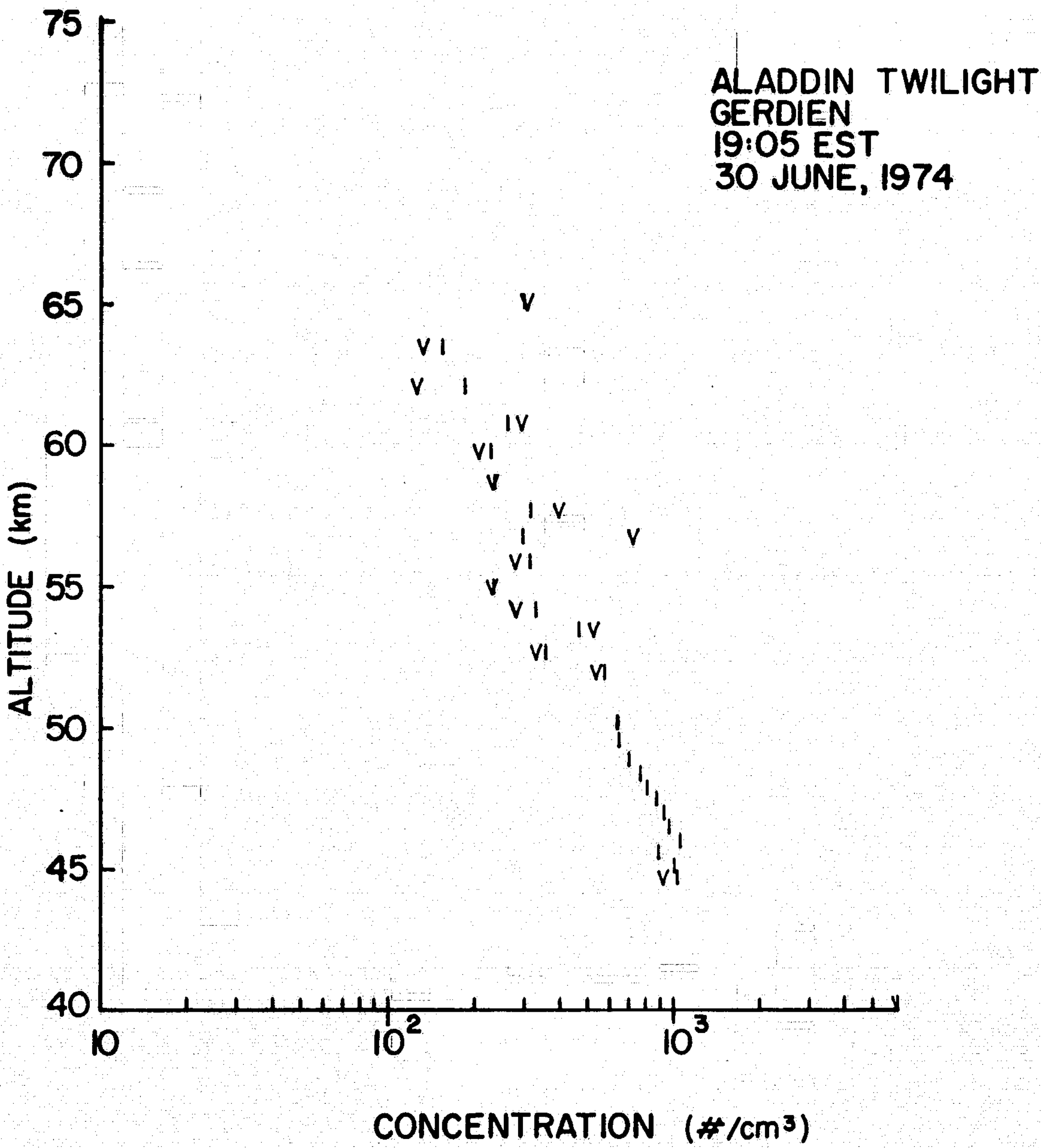


FIGURE 20. Total Density (Twilight Gerdien) Calculated Via Alternate Methods

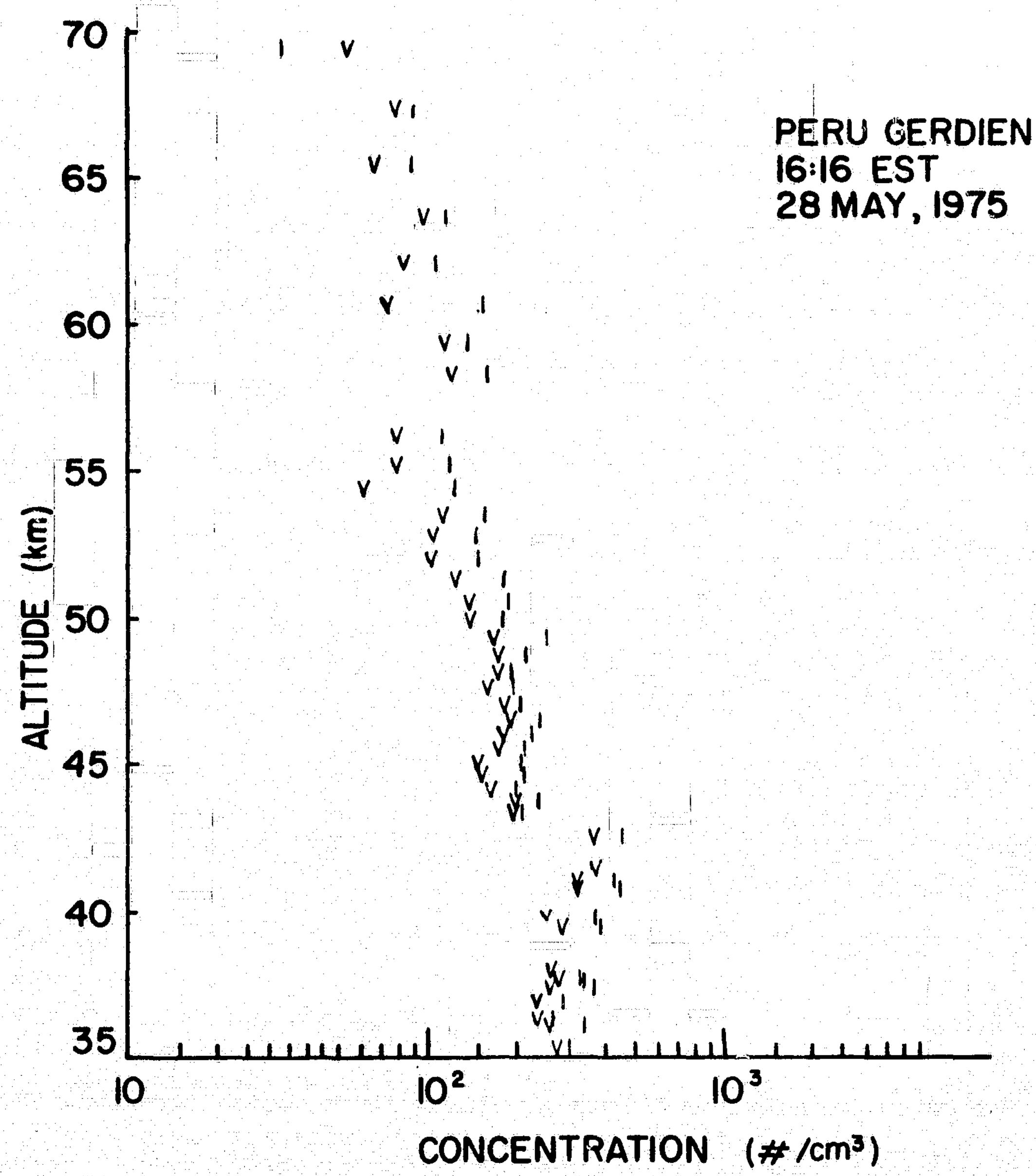


FIGURE 21. Total Density (Peru Gerdien) Calculated via Alternate Methods

It is interesting to note that trends are reflected in both methods. Also noteworthy is the total concentration in the smear region of the twilight Gerdien profile. Although individual concentrations could not be discerned by the saturation voltage method, the total density could be assessed via the saturation current method. Since both methods yielded similar results, it is assumed that the instrument can be used as a mobility spectrometer.

3.5 Interpretation of the Data

The nature of the data presented in this text enables one to deduce time and latitude variations of the ionosphere. Total density curves from all three Gerdien condenser rocket shots are presented in Figure 22. The letters represent the respective curves as indicated in the figure. For time variation, note the curves marked N and T. It is very significant that the N is much less than T. This indicates an order of magnitude drop in density during the night in the lower D-region. Earlier it was noted that there were many more light ions present at night than during the day in the upper stratosphere. This suggests that very large ions grow at night and become so immobile that the instrument could not saturate them. The fact that these grow out of the instrument's range at night throughout the D-region explains the absence of heavy ions in the nighttime profile. These large ions are present in the D-region when sunrise occurs. The daytime and nighttime presence of ions of median mobilities is easily attributed to the ionization

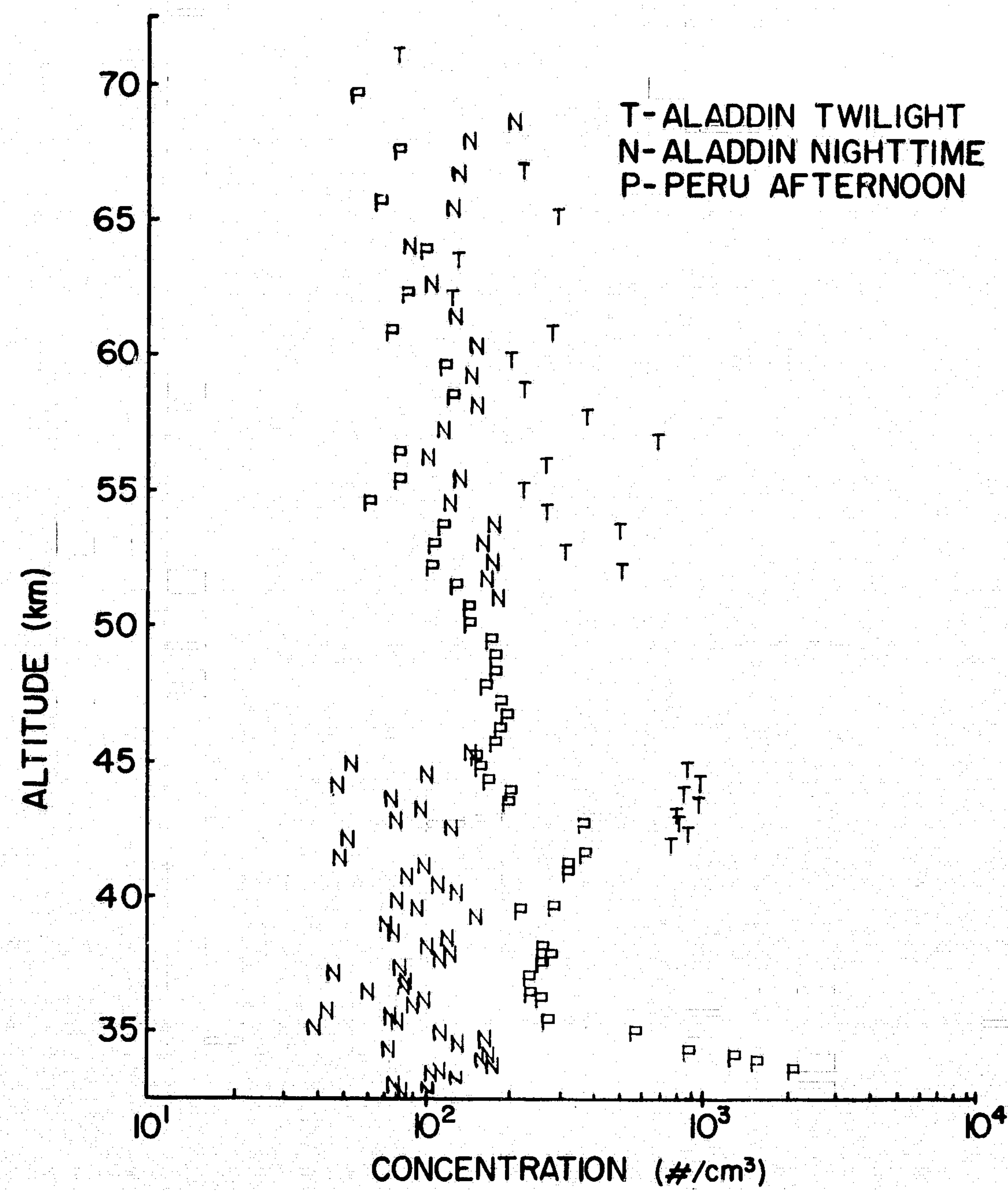


FIGURE 22. Total Density Vs. Altitude From the Gerdien Condenser Probes

of ubiquitous galactic cosmic rays. A more complete picture of this will be presented in the conclusion.

It is difficult to construct what could be an nth order curve from three data points. Such is the case when three rocket samplings at three different latitudes are used to construct variations of the D-region with latitude. The data available for this analysis is found in Figure 13 through Figure 16 and Figure 22. In the 50 to 45 km region a continuous smear of mobilities exists in the mid latitude as evidenced by the Virginia shots. Below 45 km only one family exists during the day as shown by Figures 13 and 15. Although Figure 16 does not show this (the rocket was launched during the day in Alaska), it is probably due to the perturbed conditions that existed in the D-region during the flight. The flight of Rose and Widdel (1972) also demonstrates that one family exists below 45 km. However, Rose and Widdel's profile has this one family extending up to 52 km with no smear present in the 45 to 50 km range. For the conclusions it will be assumed that the figures as presented in this thesis are correct. Throughout the latitudes there is one ion family in the middle stratosphere as is shown by the above.

The other variation seen between shots at different latitudes is that the ions are heavier at middle latitudes. This becomes obvious when comparing the curves marked P and T on Figure 22 and Figures 14 and 15. The latter figures demonstrate that the only difference in the mobility profiles is a group of heavy ions missing from Peru and included in Virginia. The existence of the smear is questionable in Farrokh's White Sands data, because of the resolution of the instrument. However, the smear is clearly present in the "Aladdin" shots. The most logical explanation for its presence over Virginia as opposed to Peru and Alaska (especially at the times of the launches) is the amount of water vapor over the respective areas. An increase in the water vapor might provide a greater opportunity for the growth of ions of different varieties.

CHAPTER IV

CONCLUSION

4.1 A Summary

The equations describing the use of a Gerdien condenser as a measuring device have been presented. Chapter II outlined the necessary theory, which demonstrated the use of the probe as a mobility spectrometer. This was further supported when the conductivity measurements of this instrument were compared to those measured by a blunt probe and were found to be in close agreement. It was reaffirmed by total concentration calculations done from the data by two different methods.

The actual values of the mobilities as calculated from the data are thought to represent reality. The highest values of the mobility are higher than might be expected, but this may be explained by a choked flow through the condenser. Nevertheless, the median mobilities and those of the nighttime flight all fall within the range of Croskey's Super Arcas flight (Figure 16).

The resulting conductivity profiles resemble those of past investigations. All of the daytime plots have the 63 km ($\pm$ 2 km) conductivity minimum which corresponds to the ionization transition layer. The Peru conductivity profile displays a wave nature which is believed to be present in the equatorial middle atmosphere.

The absence of high mobility ions during the daytime could indicate their conversion to larger ions of lower mobility by the action of sunlight, possibly ultraviolet in the 2000-3000 Å range. This would be consistent with the reappearance after sunset of higher mobility ions, presumably because they do not grow without sunlight. The numbers of these high mobility ions are small, however, indicating that the bulk of the low mobility ions seen in the daytime grow at night to sizes out of the mobility range of the Gerdien condenser. Some of these huge relatively immobile ions may fall slowly through the stratosphere. The majority of these ions will still be present at sunrise and may take part in the initial production of light ions of high mobility due to photodissociation. Some corroborative evidence has been presented by Mitchell (1976), who showed an order of magnitude increase in the average mobility of ions during the sunrise period.

The results also indicate some latitudinal variations. It seems safe to conclude that there are heavier ions with higher densities at higher latitudes. Another hypothesis suggested by the data is that there is a higher water vapor content present in the stratopause region over Virginia than there is over Peru and Alaska. Hopefully, the rocket reports contained in this paper have aided in the completion of the latitudinal picture of the D-region.

4.2 Possible Future Research

A higher degree of reliability may be attained from the Gerdien condenser once its aerodynamics are completely understood. This could be a major area for future research. A computer simulation of the probe system would yield invaluable knowledge. Wind tunnel and fluid flow experiments might also prove to be meaningful areas of future endeavor. Further flights of Gerdien condensers might include a sequence of Gerdiens flown at regular intervals during a single day. Also when a Gerdien is flown, meteorological sounding rockets could be fired to provide wind, temperature, and water vapor measurements. Finally, a standardization of analytical methods for data reduction brought about through a cooperative effort among investigators is strongly advised.

REFERENCES

Boudeau, R. E., E. C. Whipple, and J. F. Clark, Analytical and experimental electrical conductivity between the stratosphere and ionosphere, J. Geophys. Res., 64, 1363, 1959.

Chesworth, E. T., and L. C. Hale, Ice particulates in the mesosphere, Geophys. Res. Lett., 1, 347, 1974.

Conley, T. D., Mesospheric positive ion concentrations, mobilities, and loss rates obtained from rocket-borne Gerdien condenser measurements, Radio Sci., 9, 575, 1974.

Croskey, C. L., In situ measurements of the mesosphere and stratosphere, Scientific Report No. 442, Ionosphere Research Laboratory, The Pennsylvania State University, 1976.

Farrokh, H., Design of a simple Gerdien condenser for ionospheric D-region charged particle density and mobility measurements, Scientific Report No. 433, Ionosphere Research Laboratory, The Pennsylvania State University, 1975.

Gerdien, H., Demonstration eines apparates Zur absoluten messung der electreschen leitfahigut der luft, Terr. Magn. Atmos. Elec., 10, 65-79, 1905.

Hale, L. C., Positive ions in the mesosphere, COSPAR Symposium on Lower Ionosphere (proceedings), Akademie Verlag, Berlin, 219, 1974.

Holton, J. R., Dynamics of the stratosphere and mesosphere, Meteo Monographs, 15, 37, American Meteorological Society, Boston, 1975.

Hoult, D. P., D-region probe theory, J. Geophys. Res., 70, pp. 3183-3187, 1965.

Israel, H., and L. Schulz, The mobility-spectrum of atmospheric ions - Principles of measurements and results, Terr. Magn. Atmos. Elec., 38, 285-300, 1933.

Mitchell, J. D., An experimental investigation of mesospheric ionization, Scientific Report No. 416, Ionosphere Research Laboratory, The Pennsylvania State University, 1973.

Mitchell, J. D., Positive ions in the middle atmosphere during sunrise conditions, Paper presented at COSPAR Symposium, Philadelphia, 1976.

Nicolet, M., and A. C. Aiken, The formation of the D-region of the ionosphere, J. Geophys. Res., 65, 1469, 1960.

Paltridge, G. W., Experimental measurement of the small ion density and electrical conductivity of the stratosphere, J. Geophys. Res., 70, 2751, 1965.

Pedersen, A., Measurement of ion concentration in the D-region of the ionosphere with a Gerdien condenser rocket probe, FOA 3 Report A607, Research Institute of National Defense, Electronics Dept., Stockholm, 1963.

Rose, G., and H. V. Widdel, Results of concentration and mobility measurements for positively and negatively charged particles taken between 85 and 22 km in sounding rocket experiments, Radio Sci., 7, 81, 1972.

Sagalyn, R., The production and removal of small ions and charged nuclei over the Atlantic Ocean, in Recent Advances in Atmospheric Electricity, edited by L. G. Smith, Pergamon Press, London, 1958.

Sonin, A. A., Theory of ion collection by a supersonic atmospheric sounding rocket, J. Geophys. Res., 72, 4547-4557, 1967.