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STUDIES OF THE DISTURBED UPPER ATMOSPHERE UTILIZING ROCKETBORNE--ETC(U)
OCT 77 K D BAKER, L C HOWLETT, D J BAKER F19628-74-C-0130
UNCLASSIFIED AFGL-TR-77-0223 NL

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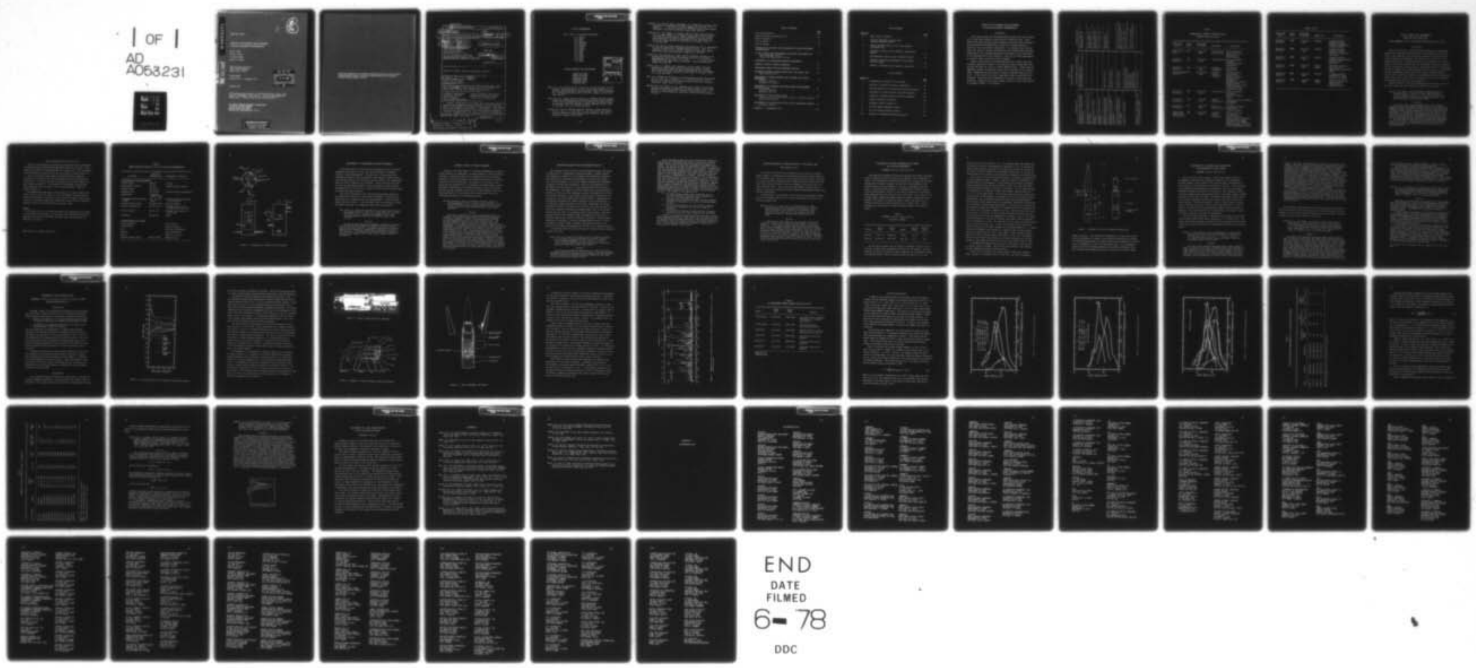

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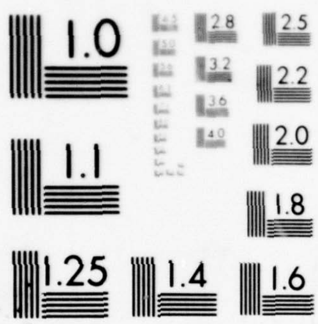

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STUDIES OF THE DISTURBED UPPER ATMOSPHERE UTILIZING ROCKETBORNE INSTRUMENTATION

Kay D. Baker

Doran J. Baker

L. Carl Howlett

Larry L. Jensen

Space Science Laboratory
Utah State University
Logan, Utah 84322

FINAL REPORT

1 March 1974 - 1 November 1977

October 1977

This research was sponsored by the Defense Nuclear Agency under Subtask L25AAXHX604, Work Unit 01, entitled "Development of Energy Input - Energy Output Multi Rocket Payloads."

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UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
18 AFGL-TR-77-0223

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
6 Studies of the Disturbed Upper Atmosphere Utilizing Rocketborne Instrumentation

5. TYPE OF REPORT & PERIOD COVERED
[redacted] - Final rept.
1 Mar 74 - 1 Nov 77

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 [redacted] Baker, [redacted] Howlett, [redacted] Baker, [redacted] Jensen
L. Carl
Larry L.

8. CONTRACT OR GRANT NUMBER(s)
15 F19628-74-C-0130

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Space Science Laboratory
Utah State University
Logan, Utah 84322

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
CDNA 15AD

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Geophysics Laboratory
Hanscom AFB, Massachusetts 01731
Contract Monitor: Thomas D. Conley/OPR

12. REPORT DATE
11 Oct[redacted]77

13. NUMBER OF PAGES
68 12 46p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
16 CDNA, L25AAXH
17 15, X604

18. SUPPLEMENTARY NOTES
This research was sponsored by the Defense Nuclear Agency under Subtask L25AAXHX604, Work Unit 01, entitled "Development of Energy Input - Energy Output Multi Rocket Payloads."

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Ionospheric Measurements
Rocketborne Payloads
Infrared Airglow
Atomic Oxygen Measurements
In-situ Ionospheric Measurements
Measurement of Electric Fields
In-situ Auroral Measurements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Between 1 March 1974 and 31 August 1977, Utah State University developed and used fourteen rocket payloads to investigate ionospheric parameters and new techniques of measurement. Additionally, theoretical studies were undertaken in the laboratory to assist in interpretation of measurements. This report details experiments conducted, instrumentation, and results of these efforts.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

407 724

This report contains summaries, with reference to techical reports, describing development and use of

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LIST OF CONTRIBUTORS

Kay D. Baker -- Principal Investigator

G.D. Allred
D.J. Baker
D.A. Burt
D.G. Frodsham
W.F. Grieder
L.C. Howlett
R.J. Huppi
L.L. Jensen
J.C. Kemp
P.C. Neal
E.F. Pound
A.J. Steed
G.A. Ware
C.L. Wyatt

RELATED CONTRACTS AND PUBLICATIONS

F19628-73-C-0048
F19628-72-C-0255
F19628-70-C-0302
F19628-69-C-0007
F19628-67-C-0275
AF19(628)-4995

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Wheeler, N.B., A.T. Stair, Jr., G. Frodsham, and D.J. Baker, Rocket-borne spectral measurement of atmospheric infrared emission during a quiet condition in the auroral zone, *AFGL-TR-76-0252, HAES Rept. No. 32*, 102 pp., Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts, Oct 1976.

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Introduction

This report details work performed between 1 March 1974 and 31 August 1977 by Utah State University under Contract F19628-74-C-0130. These efforts have been directed toward studying the disturbed upper atmosphere using rocketborne instrumentation to measure the energy deposition, electrons, ions, and chemical composition. In conducting these studies, effort was devoted to design and fabrication of sounding rocket payloads, development of new, improved measurement techniques, and the utilization of the techniques and rocket payloads to carry out the field measurements for auroral, polar, and other research programs.

Many of the research areas performed under this contract have been previously reported in detail in six scientific report issued under this contract and hence will only be briefly summarized here. Those areas not completely covered by scientific reports will be detailed in this report. Table 1 summarizes the major areas of research completed under this contract. In the sections to follow, these major areas of research will be discussed. Since the research programs are centered around rocket measurements, a summary of the rocket flights carried out under this contract is included in Table 2 for reference.

TABLE 1

MAJOR AREAS OF RESEARCH

Research Area	Rocket Flights or Other Programs	Reports, Papers
Measurements of Auroral E-fields and Energy Input Associated with an Auroral Arc	Paiute-Tomahawk 10.312-3 Honest John-Nike-Javelin IC 511.21-1A	USU Sci. Report No. 2 HAES Report No. 11
Development of Rocketborne Electron Spectrometer		USU Sci. Report No. 1 HAES Report No. 8
Geometric Aspects of Rocket Photometry		USU Sci. Report No. 3 HAES Report No. 41
Rocketborne Faraday Rotation Experiment		USU Sci. Report No. 4
Background Shortwave Infrared Radiation in the Auroral Zone	Nike-Javelin NJ-74-1	AFGL-TR-76-0252 HAES Report No. 32
Development of Gerdien Condenser and RF Probes for D-region Measurements	Astrobee D 30.413-1 Astrobee D IC 503.22-1	
Development of Resonance Lamp Probe System for Measurement of Atomic Oxygen	Astrobee D 30.413-4 Astrobee D 30.413-5	1976 Spring AGU; SA-71, SA-72 EOS 57, 4; p. 301 (abstract) USU Sci. Report No. 5
Measurement of OH Airglow	Astrobee D IC 503.14-3 Nike-Javelin IC 506.14-2 Astrobee D 311-5 Astrobee D 311-7 Astrobee D 311-8 Astrobee D 30.205-7	1976 Fall AGU; SA-21 EOS 57, 12; p. 967 (abstract) 1977 Spring AGU; SA-96 EOS 58, 6; p. 460 (abstract)
Development of Small Rocket Payload for VLF Propagation Studies	Astrobee D 30.413-2	

TABLE 2

CHRONOLOGICAL SUMMARY OF ROCKET FLIGHTS

CONTRACT F19628-74-C-0130

Rocket Type and No.	Launch Site*	Launch Date & Time(GMT)	Experiment	Instruments
Nike-Javelin NJ74-1	PFA	11 Apr 1974 0800	Auroral Short Wave Infrared	CVF Spectrometer, IR Horizon Sensor, Magnetometer, Recovery beacon
Astrobee D A30.413-1	PFA	11 Apr 1974 2338	Ions/Electrons	Gerdien Condenser, Z-θ Probe, IR Horizon Sensor, Magnetometer
Astrobee D A30.413-2	PFA	12 Apr 1974 2325	D-region Propagation	VLF Receiver Magnetometer
Paiute-Tomahawk A10.312-3	PFA	18 Apr 1974 0840	E-field & Auroral Parameters	E-field, Electron Spectrometer, Particle Counter, Langmuir Probe Photometer, Electrostatic Analyzer, Hyperbolic RPA, Plasma Frequency Probe, IR Horizon Sensor, Magnetometer, Gyro
Astrobee D IC 503.22-1	PFA	26 Feb 1975 2250	Ions/Electrons	Gerdien Condenser, Z-θ Probe, IR Horizon Sensor, Magnet
Astrobee D IC 503.14-3	PFA	1 Mar 1975 0100	Hydroxyl (baffle test)	2-channel Baffled Radiometer, Magnetometer, Sun Sensor
Astrobee D IC 506.14-2	PFA	1 Mar 1975 0739	Hydroxyl (quiet night)	2-channel Radiometer Magnetometer, IR Horizon Sensor
Honest-John Nike-Javelin IC 511.21-1A	PFA	11 Mar 1975 0633	E-field & Auroral Parameters	E-field, Electron Spectrometer, Particle Counter, Langmuir Probe, Photometer, Electrostatic Analyzer, Hyperbolic RPA, Plasma Frequency Probe, IR Horizon Sensor, Magnetometer, Gyro

TABLE 2 (cont.)

Rocket Type and No.	Launch Site*	Launch Date & Time(GMT)	Experiment	Instruments
Astrobee D A30.311-8	WSMR	2 Dec 1975 1250	Hydroxyl	2-channel Baffled Radiometer, Range Receiver, Magnetometer, IR Horizon Sensor
Astrobee D A30.311-5	WSMR	2 Dec 1975 1350	Hydroxyl	2-channel Baffled Radiometer, Range Receiver, Magnetometer, Sun Sensor
Astrobee D A30.311-7	WSMR	2 Dec 1975 1600	Hydroxyl	2-channel Baffled Radiometer, Magnetometer, Range Receiver, Sun Sensor
Astrobee D A30.413-5	WSMR	3 Dec 1975 0035	Atomic Oxygen	Resonance Scattering Lamp & Detector, Magnetometer, IR Horizon Sensor
Astrobee D A30.205-7	WSMR	3 Dec 1975 0059	Hydroxyl	2-channel Baffled Magnetometer, Range Receiver, Sun Sensor
Astrobee D A30.413-4	WSMR	3 Dec 1975 0200	Atomic Oxygen	Resonance Scattering Lamp & Detector, Magnetometer, IR Horizon Sensor

E-FIELD, ENERGY INPUT MEASUREMENTS
ASSOCIATED WITH AURORAL ARC

PAIUTE-TOMAHAWK 10.312-3 AND HONEST-JOHN NIKE-JAVELIN 511.21-1A

Introduction

During the duration of Contract F19628-74-C-0130, two rocketborne payloads have been developed and used for the investigation of electric fields, light emissions, spectral energy distribution of particles and electron density and temperature associated with an auroral arc. The program provided for a recoverable payload to be utilized in the initial flight; this recovered payload was then refurbished (with minor modifications), recalibrated, and used again in the second portion of the program. The initial flight used a Paiute-Tomahawk (10.312-3) vehicle configuration and was accomplished from the Poker Flat, Alaska, Research Range on 18 April 1974; the second flight of the payload was aboard an Honest-John Nike-Javelin (IC 511.21-1A) vehicle configuration and was also launched from the Poker Flat facility on 11 March 1975.

Complete details of the Paiute Tomahawk 10.312-3 payload as used in its first flight have been thoroughly reported as noted below.

Howlett, L.C. and R.J. Bell, Rocketborne instrumentation for the measurement of electric fields - Paiute Tomahawk 10.312-3, *USU Sci. Rept. No. 2, AFCRL-TR-75-0023*, 91 pp., Contract F19628-74-C-0130, Space Science Laboratory, Utah State University, Logan, Utah, Jan 1975.

Abstract

On 18 April 1974, Paiute-Tomahawk 10.312-3 was launched from Poker Flat Research Range, Alaska, as part of the ICECAP 74B COMMOCAP Program. Included in the payload were eight instruments to measure various auroral parameters. Of prime interest was the measurement of the magnitude and direction of the electric field in and over an auroral arc. Measurements were also made of the spectral energy distribution of primary and secondary particles, auroral light emission, and electron flux density and temperature.

Good data were received from seven of the eight experiments flown on PT 10.312-3. Following data acquisition the recovery system was activated and the payload was recovered intact the following morning.

Honest-John-Nike-Javelin IC 511.21-1A

The above investigations continued with the launch of the refurbished/recalibrated payload aboard Honest-John-Nike-Javelin IC 511.21-1A. This vehicle was launched at 0633:09.04(GMT) on 11 March 1975. The instrumented package achieved an apogee of 183.2 km and overflew a stable auroral arc.

With the exceptions noted below the payload has been completely described by *Howlett and Bell*, [1975] (above) and will not be described further here. A complete listing of instruments is included however, for easy reference (Table 3). The placement of instruments and associated look angles were also the same as for the earlier flight. These are shown in Figure 1.

Two modifications were made to the payload for its second application. First, the gyro notch was located at 7°12' (clockwise, looking from the front*) on the payload. Secondly, a small sensor was added to the payload in order to determine whether this instrument could be used for obtaining payload attitude if the payload did not include a gyro.

Results

The flight of IC 511.21-1A was successful and provided data to fulfill the objectives of the mission. Of the eight major instruments aboard the paylaod, seven (all but the plasma frequency probe) provided good data throughout the flight.

*With respect to vehicle launch lug.

TABLE 3

HONEST-JOHN NIKE-JAVELIN IC 511.21-1A PAYLOAD INSTRUMENTATION

Instrument	Model/SN (Manufacturer)	Measurement or Function
Instrumentation for Measurements		
E-field probe	NASA #6	E-field
Electrostatic analyzer	ESA 202	Primary electron spectra
Horizon sensor	USU IR-75-1	
Langmuir probe	USU LP72-4A	Electron density, temperature
Magnetometer	Schonstedt RAM-5C #7080	
Retarding potential analyzer (HARP)	Univ. of Mich. Mod 2	Secondary electrons between 1 ev and 500 ev
Plasma frequency probe	USU PFP 73A-1A	Electron density
Electron spectrometer	USU ES 73A-1A	Secondary electron flux between 100 ev and 3 kev
Particle counter	USU PC 74-1	Electron flux between 4.5 and 90 kev
Photometer	USU PM2-16	3914 A
Instrumentation for Support		
S-band telemetry		Data recovery
S-band beacon		Payload tracking
Gyro		Attitude determination
Recovery		Soft land payload
Despin		Despin to 1.5 rps
Magnetic aspect sensor	RAM 5C #7080	Magnetic angle

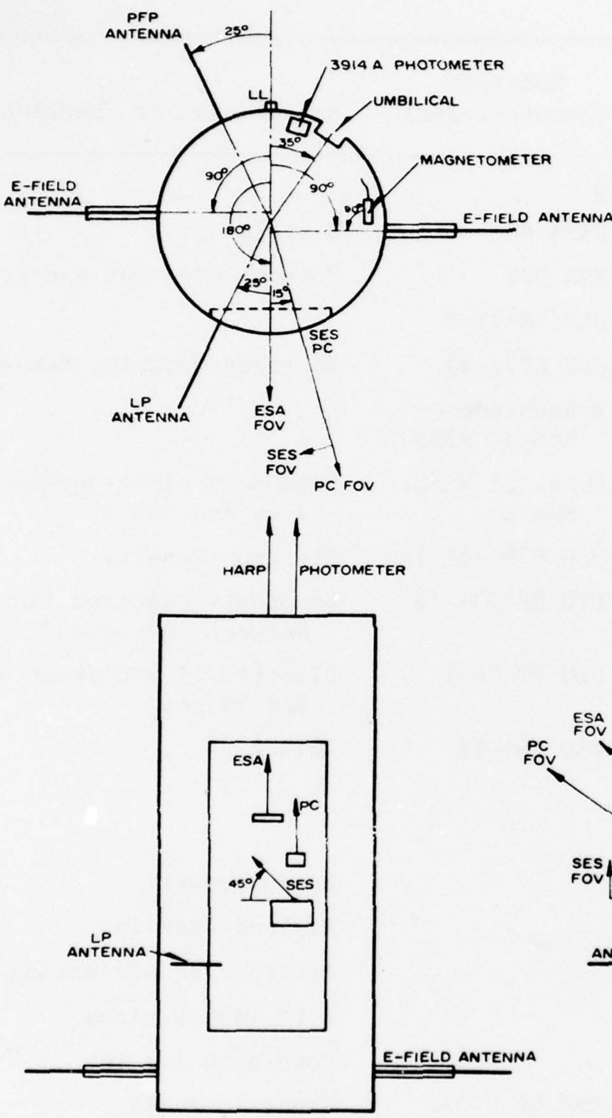

Figure 1. Configuration of HJNJ 511.21-1A payload.

DEVELOPMENT OF A ROCKETBORNE ELECTRON SPECTROMETER

The energy spectra of electrons which precipitate into the earth's atmosphere and result in aurora, has been the subject of extensive research and many measurements. Energies above ∿1500 ev have been repeatedly measured by such instruments as the familiar spherical plate electrostatic analyzer and retarding potential analyzer, but measurements below the 1500 ev range are not plentiful. These low energy electrons (<2 kev) contain enough energy for several ionizations, which require approximately 35 ev per ion pair created. They also contain enough energy for photon emitting excitation.

The need for additional, high resolution measurements within the low energy range resulted in the design, development, calibration and application of a rocketborne electron spectrometer to cover the energy range from 100 to 1500 ev. This instrument and its development has been thoroughly described in a scientific report under this contract.

Neal, Parris C., Design and calibration of a rocket-borne electron spectrometer, *USU Sci. Rept. No. 1, HAES Rept. No. 8, AFCRL-TR-74-0629*, 78 pp., Contract No. F19628-74-C-0130, Space Science Laboratory, Utah State University, Logan, Utah, Dec 1974.

Abstract

An electron spectrometer was designed, calibrated and applied in an auroral research program to measure the electron energy spectra from 100 to 1500 ev. The approach included the practical application of theoretical mathematics to design and calibrate the instrument. Such design and calibration using a digital computer for fast analysis can be used in the creation of similar instruments.

GEOMETRIC ASPECTS OF ROCKET PHOTOMETRY

Because of the large number of rocketborne photometers and radiometers employed for measurement of light emissions in current research programs, a theoretical study of the geometric factors influencing rocketborne optical measurements was undertaken to assist in the interpretation of the data obtained. The subject of the study was the derivation and application of a technique to transform oblique rocket photometric measurements of emission phenomena to vertical altitude profiles and the subsequent derivation of volume emission rates from these measurements. The technique and its application have been thoroughly described in the following document.

Grieder, William F. and Leo A. Whelan, Geometric apsects of rocket photometry, *USU Sci. Rept. No. 3, HAES Rept. No. 41, AFGL-TR-76-0046*, 107 pp., Contract F19628-74-C-0130, Space Science Laboratory, Utah State University, Logan, Utah, Feb 1976.

Abstract

This report describes the derivation and application of a technique to transform oblique rocket photometric measurements of emission phenomena to vertical altitude (zenith) profiles and the subsequent derivation of volume emission rates. The van Rhijn method of aspect correction is analyzed including limitations of the method when applied to D and E region emission measurements. A theoretical study is presented in which the general rocketborne photometer geometry is solved for a set of practical volume emission rate cases. The study definitizes the effects of finite fields of view, system directional responsivity and extinction on interpretation of measured emission data and derived volume emission rates. The results of the theoretical study are applied to an actual photometric measurement accomplished on rocket A17.110-3 flown from Poker Flat Rocket Range in Alaska on 16 March 1972. Zenith profiles are derived from oblique hydroxyl emission measurements in the band 1.67 to 1.90 μm, made at 60°, 70°, and 80° zenith angle as the rocket ascended. Volume emission rates deduced from these zenith profiles are consistant with results reported in the literature.

ROCKETBORNE FARADAY ROTATION EXPERIMENT ANALYSIS

The presence of free electrons in the ionosphere cause a VHF signal to divide into two independently propagating modes. Faraday rotation (the difference in phase of the two modes) and differential absorption (the difference in amplitude) are dependent on the electron density and collision frequency to differing degrees throughout the ionosphere. A computer code has been developed to calculate the propagation of a VHF signal from the ground to a rocket moving through the D-region of the ionosphere. For ranges of electron density and collision frequency profiles, criteria have been developed to select frequencies that yield the maximum variations in the Faraday rotation and/or differential absorption for the given density and collision profiles. Measurements of differential absorption are limited primarily by the determination of the amplitude (signal strength) of each mode. Measurement of Faraday rotation is limited by the above factor as well as by the ability of an electronics system to differentiate between phase nulls of the Faraday rotation and the nulls of a spinning-coning rocket antenna. Different frequencies have their maximum change in absorption and rotation at different density and collision conditions; therefore, a multifrequency experiment is desirable to cover the maximum height interval. Errors introduced by rocket coning, telemetry, and signal-to-noise levels have been investigated and implemented into the code to improve accuracy.

A scientific report detailing this project in depth has been submitted to AFGL as follows:

McCue, R.A., R.D. Harris, K.D. Baker, and C.D. Westlund, Analysis of the Faraday rotation-differential absorption technique for D-region measurements, *USU Sci. Rept. No. 4, AFGL-* 97 pp., Contract F19628-74-C-0130, Space Science Laboratory, Utah State University, Logan, Utah, Aug 1977.

Abstract

This report describes the optimization of a radio propagation experiment suitable for studies of the ionospheric D-region utilizing relatively low power, portable ground-based transmitters and simple receivers aboard small sounding rockets.

A wave propagation model has been developed that numerically calculates the radio signal that would be received by a dipole antenna aboard a rocket traveling up through the ionospheric D-region. The Faraday rotation and differential absorption experienced by the wave can be used to deduce both electron concentrations and electron-neutral collision rates in the D-region. Faraday rotation and differential absorption were numerically calculated for a number of radio frequencies for three types of extreme conditions such as occur at high magnetic latitudes. Altitude profiles of these quantities provide to base a selection of 2 or 3 frequencies that will yield maximum information on electron density and collision rate, based on the expected ionospheric conditions. The propagation experiment proposed employs multiple frequencies together with low power transmitters, and inexpensive, movable antennas. Signal limitations such as atmospheric noise, telemetry error and transmission power were also used to interpret the Faraday rotation and differential absorption curves in order to achieve maximum accuracy. The results of this analysis are:

1.) For high electron density (PCA conditions) and low collision frequency conditions, wave frequencies of 3.25, 10, and 19 MHz should be used.
2.) For high electron density and high collision frequency conditions, frequencies of 3.25, 14, and 25 MHz should be used.
3.) For low electron density and low collision frequency conditions, frequencies of 3.25 and 4.25 MHz are sufficient.
4.) For low electron density and high collision frequency conditions, 3.25 and 6 MHz frequencies are sufficient.

A method of estimating transmission power and rocket receiver range requirements (based on noise levels) were developed, as well as equations by which coning modulation of the received signal can be separated from actual Faraday rotation and differential absorption. A data reduction scheme was developed to remove errors associated with motions of the rocket.

BACKGROUND SHORTWAVE INFRARED RADIATION IN THE AURORAL ZONE

NIKE-JAVELIN NJ-74-1

On 11 April 1974 NJ-74-1 was launched from the Poker Flat Research Range, Alaska, to investigate the background shortwave infrared radiation in the auroral zone. The vehicle was launched into quiet night conditions (no aurora) and was instrumented with a SWIR spectrometer which scans the short wave infrared portion of the electromagnetic spectrum using a circular variable filter. This non-auroral measurement provided control data for previously acquired short wave infrared measurements during strong auroral disturbances.

A description of this payload, rocket flight and measurements results have been thoroughly reported in the following document and will not be further discussed here.

Wheeler, N.B., A.T. Stair, Jr., G. Frodsham, and D.J. Baker, Rocket-borne spectral measurement of atmospheric infrared emission during a quiet condition in the auroral zone, *AFGL-TR-76-0252, HAES Rept. No. 32*, 102 pp., Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts, Oct 1976.

Abstract

A Nike-Javelin rocket (NJ-74-1) was launched at Poker Flat, Alaska, on 11 April 1974 at 0801 hours UT during a non-auroral condition. A near-zenith spectral radiance profile was obtained from 54 km to an apogee of 118 km down to about 85.6 km on descent, using a circular variable filter spectrometer. About 464 spectral scans were obtained during flight, covering the range from 1.7 to 5.4 μm at a resolution of about 4 percent. The dominant emission feature was at 4.3 μm, which is attributed to the $CO_2 \nu_3$ fundamental. The upward viewed spectral radiance of 3 MR/μm at 118 km. In this report are given the first quiet condition (no aurora) rocket data in the auroral zone.

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DEVELOPMENT OF GERDIEN CONDENSER AND RF PROBES
FOR D-REGION MEASUREMENTS

ASTROBEE D 30.413-1 AND IC 503.22-1

Two similarly instrumented Astrobee D payloads were used as described below to monitor electron and positive ion density in the ionospheric D region. The payloads were launched from Poker Flat, Alaska, and each was equipped with a Gerdien condenser and Zθ probe for measurement of the desired electron and ion parameters, and with a magnetometer and sun sensor to describe vehicle aspect. The payloads were developed sequentially, with Astrobee D 30.413-1 as the initial endeavor and IC 503.22-1 being developed after the flight of the first rocket. As a result of the initial flight, significant modifications of physical design were incorporated in IC 503.22-1 to make the payload lighter and shorter in an attempt to extend the altitude capability to a higher level. Table 4 describes the two vehicles in terms of length, weight, and resulting apogee.

TABLE 4
ASTROBEE D 30.413-1 AND IC 503.22-1
PAYLOADS & APOGEES

Vehicle	Launch Date	Launch Time	Apogee	Payload Weight	Payload Length
30.413-1	11 Apr 74	2338 (UT)	83 km	33 lb	72"
503.22-1	26 Feb 75	2250 (UT)	103.5 km	25 lb	52¼"

No data were received from the flight of Astrobee D 30.413-1 due to peculiar circumstances accompanying the launch of the vehicle. The payload was launched into stable D-region conditions (no disturbance) during the afternoon hours. When the ignition pulse was sent at T = 0, the vehicle motor did not function. At T + 14 seconds, power was removed from the payload electronics and immediately thereafter, at T + 16 seconds the vehicle motor ignited, resulting in a flight with no power to the payload. The vehicle was skin tracked by the NASA MPS-19 radar for 114 seconds (to approximately 79 km) and the peak altitude was calculated to be about 83 km.

As a result of the first flight Astrobee D, IC 503.22-1 was developed to attain greater altitude. Figure 2 shows the overall configuration of this payload and its dimensions. The payload of this vehicle contained a Gerdien condenser (AFGL and Tri-Con) [*Burt*, 1967], and a Z-θ probe [*Burt*, 1972] developed and built by Utah State University. The Z-θ probe operated at frequencies of 3.0 MHz and 7.2 MHz, and provided outputs relative to Z x 1, Z x 10 and phase angle. The Z-θ probe used all of the payload from the TM section forward against the Astrobee D motor as the dipole antenna. Additionally, this instrument provided electron density measurements at high altitudes (near apogee) where the atmospheric density was insufficient for the Gerdien condenser mode measurements. As can be seen from Figure 2, the Gerdien condenser was mounted on the forward portion of the payload and was covered by an ejectable clamshell nose tip. The bottom portion of the nose tip had a ring which fit into a groove provided structural integrity to the nose tip until the cone segments were released. The two cone halves were held together at the base by aircraft cable which could be tightened from the outside by a screw. The cable was cut by a timer controlled guillotine to release the nose cone. A brass screw (midway up the nose cone) which also held the two halves together was also simultaneously cut. Vehicle attitude and dynamics were measured by a magnetic aspect sensor mounted across the vehicle spin axis and a solar aspect sensor (Bayshore Systems Model SS-11) which provided aspect with respect to the sun. The magnetometer and solar sensor were oriented in the same direction with the magnetometer leads going the opposite direction to the sensor field of view.

A 430 MHz AACOM ranging receiver was also included in this payload to provide vehicle tracking. This receiver was located in the telemetry section (immediately behind the main payload).

The IC 503.22-1 payload was launched from the Poker Flat Research Range, Alaska, on 26 February 1975 at 2250 (UT), into quiet ionosphere,

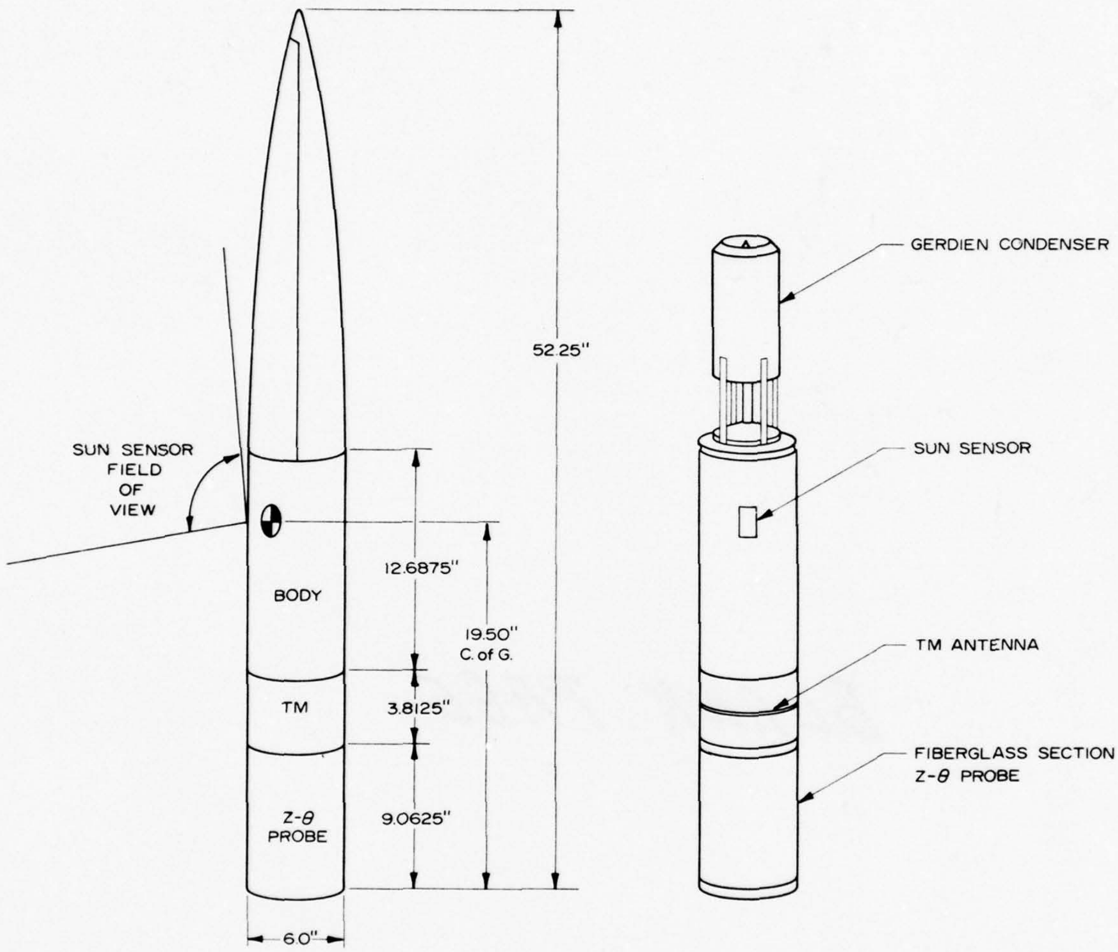


Figure 2. Astrobee D IC 503.22-1 payload configuration

midday conditions. This flight was developmental in nature and was primarily accomplished as a means of evaluating the experimental technique for obtaining measurements of D-region conductivity preparatory to further future investigation of polar cap absorption events. All instruments aboard the payload functioned properly and provided ionospheric data. Good telemetry and ranging signals were received for the entire flight.

DEVELOPMENT OF A RESONANCE LAMP PROBE SYSTEM
FOR MEASUREMENT OF ATOMIC OXYGEN
ASTROBEE D 30.413-4 AND 30.413-5

Due to its very reactive nature, atomic oxygen number density is of significant importance in atmospheric chemistry from stratospheric altitudes upward. Also because of its reactive nature, measurements of atomic oxygen at such altitudes are difficult to achieve. A new technique to accomplish such measurements was investigated with the experimental payloads of Astrobee D's 30.413-4 and 30.413-5. This technique utilized the large resonance scattering cross-section of the atomic oxygen resonance triplett at 1304, 1306, and 1308A. The ambient atmospheric atomic oxygen was excited by emissions from an atomic oxygen lamp, housed within the rocket payload. The lamp developed to produce a high intensity emission from an optically thin source was RF excited and modulated at a low frequency to provide a means of discriminating against natural background emission. The light was formed into a beam which was viewed by a vacuum ultraviolet detector to provide the measurements.

The two payloads developed to implement this technique were launched from the White Sands Missile Range, New Mexico, on 2 December 1975. The theory behind this technique, development of the payloads and their application and results have already been thoroughly described in the following report.

Howlett, L. Carl and Kay D. Baker, Development of a rocket-borne resonance lamp system for the measurement of atomic oxygen, *USU Sci. Rept. No. 5, AFGL-TR-*   , 81 pp., Contract No. F19628-74-C-0130, Space Science Laboratory, Utah State University, Logan, Utah, Aug 1977.

Abstract

Two small rocket payloads containing atomic oxygen resonance lamps and detectors were flown from White Sands during twilight and night conditions on 2 December 1975 to measure atomic oxygen profiles from 70 to 130 km. The payloads each consisted of a closed, flowing rf excited, modulated, oxygen resonance lamp producing on the order of 10^{13} photons/sec sr of 130.2, 130.4, 130.6 nm oxygen

triplett radiation. The emissions were generated with minimal self reversal. The lamp output was baffled into a beam 38° wide normal to the payload axis. A segment of this beam was viewed by a photon counting detector designed for good sensitivity at 130 nm while rejecting Lyman-α and wavelengths beyond 130 nm. The system absolute calibration was achieved by two totally independent techniques. The first technique required a knowledge of all physical parameters associated with the system; i.e., lamp intensity, directivity, spectrum, atomic oxygen scattering cross section, temperatures, overall instrument geometry, and detector quantum efficiency. The second technique utilized the measurement of zenith 5577 nm intensity at the time of launch and an atmospheric model to place the absolute scale on the measured relative O profile. Preliminary calculations of absolute numbers from the two techniques are in good agreement.

The night instrument provided the capability for measurement of densities form $\sim 1 \times 10^{8}$ to 5×10^{12} atoms/cm^{3} and the day instrument was approximately an order of magnitude less sensitive. The night payload in particular provided a well-defined atomic oxygen profile showing significant upper D-region structure. Two peaks occurring at approximately 91 and 98 km were apparent in both up and down leg data from this flight.

Two scientific papers dealing with the instrumentation of Astrobee D 30.413-4 and 30.413-5 and with analysis of the results obtained from the flights of these vehicles have been presented to the scientific community during the period of this contract, as follows:

Howlett, L.C., K.D. Baker, J.C. Ulwick, and R.A. Young, In-situ measurement of atomic oxygen by the resonant scattering of 130.4 nm radiation from an on-board source, Paper presented at the 1976 Spring Annual Meeting of the American Geophysical Union, Washington, D.C., 12-15 April 1976. Abstract in *EOS, Trans. Am. Geophys. Union, 57*, 4, 301, Apr 1976.

Abstract

Two small rocket payloads containing atomic oxygen resonance lamps and detectors were flown from White Sands during twilight and night conditions on 2 December 1975 to measure atomic oxygen profiles from 70 to 130 km. The payloads each consisted of a closed, flowing, rf excited, modulated, oxygen resonance lamp producing on the order of 10^{13} photons/sec sr of oxygen triplet (130 nm) radiation. The lamp output was baffled into a beam 38° wide, normal to the payload axis. A segment of this beam was viewed by a photon counting detector designed for good sensitivity at 130 nm while rejecting Lyman-α and wavelengths beyond 130 nm. Preliminary system calibration for converting the measured photon intensity to atomic oxygen density was derived by a calculation involving optical geometry, scattering cross

cross sections and other system parameters. This was checked for consistency with the measured airglow emissions.

The instrument as flown at night provided the capability for measurement of densities from about 10^8 to 10^{13} atoms/cm^3 and the day instrument was approximately an order of magnitude less sensitive. Both payloads made successful measurements, but the night payload in particular provided a well-defined atomic oxygen profile with a layer with a general maximum at about 95 km, although significant structure were obvious in the profile. In particular, a double peak was observed at altitudes of about 91 and 98 km.

Megill, L.R., L.C. Howlett, W.R. Pendleton, and K.D. Baker, Structure observed in atomic oxygen profiles, Paper presented at the 1976 Spring Annual Meeting of the American Geophysical Union, Washington, D.C., 12-15 April 1976, Abstract in *EOS, Trans. Am. Geophys. Union, 57*, 4, 301, April 1976.

Abstract

Nighttime and twilight O(^{3}P) concentrations in the mesosphere and lower thermosphere (75-127 km) were investigated above White Sands Missile Range, New Mexico, on 2 December 1975 by means of Astrobee-D rockets instrumented with an [OI] λ1304-A *resonant*-scattering system. The details of the system are reported in a companion paper.

A direct absolute calibration of a resonant-scattering system of the design used in the present experiment poses a formidable experimental problem and was not attempted in this developmental effort. Groundbased measurements of the [OI] λ5577-A nightglow intensity are compared with predictive intensity models for the λ5577-A emission to test the reliability of the indirect calibration of the experimental system.

Fine structure in the inferred variation by [O] with altitude was detected near 91 and 98 km on both 70-leg and down-leg. The structure in the vicinity of 94 km consists of a local minimum similar to that reported by *Bolden et al.* [1974] in an earlier, similar experiment. In view of the similarity of these independent spatially and temporally separated results, it is speculated that this local minimum in the [O] height profile may be a semipermanent feature. Acceptance of this feature would require a revision of current atmospheric [O] models. Possible consequences of this [O] fine structure will be discussed.

R.C. Bolden, P.H.G. Dickenson, and R.A. Young, *Nature, 252*, 289, 1974.

MEASUREMENT OF THE OH AIRGLOW LAYER

ASTROBEE D's 503.14-3, 30.311-5, 30.311-7, 30.311-8, 30.205-7 AND NIKE-JAVELIN 506.14-2

Introduction

Although a number of ground-based techniques have been attempted over the years, at present there are only two satisfactory methods of ascertaining the distribution of OH airglow emissions with altitude:

1. Measure the dependence of the zenith radiance with altitude by flying a rocket with an onboard sensor through the layer.

2. Obtaining an exo-atmospheric limb scan of the layer from a sensor onboard a rocket or satellite.

The first method has the advantages of a simple aspect geometry, elimination of long path absorption or stimulated emission effects, and relief from the need for very narrow fields of view (at least in one dimension) with extremely good out-of-field rejection. The latter on the other hand, has the advantage of higher signal levels, more nearly simultaneous observation of the portions of the profile, observation of lateral spatial variations, and longer observing times of the layer.

A number of OH emission altitude profiles available to date have been obtained from vertically-viewing sensors flown aboard rockets. The technique has been well described by *Packer* [1961]. A composite of such measurements is given in Figure 3. These measurements, which were made in the visible region were complicated by a background continuum as well as the usual problem of unfolding the aspect geometry [*Grieder and Whelan*, 1976].

Measurements

In the AFGL/USU program of rocketborne measurements of OH altitude profiles, emphasis was placed on infrared rather than visible range observations. The primary reason was to alleviate the background continuum

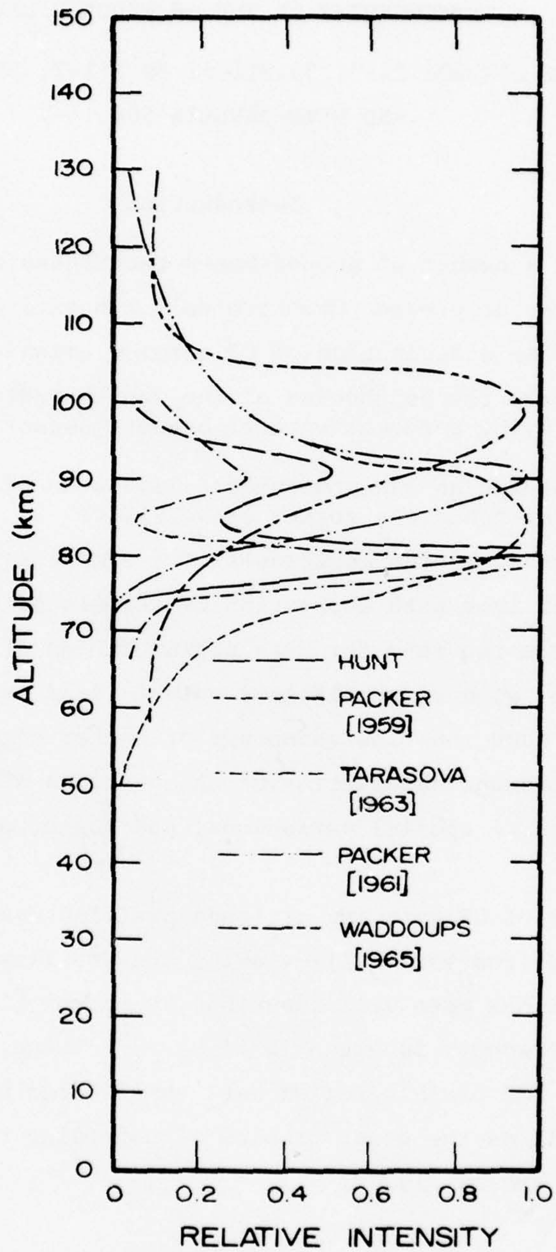


Figure 3. Altitude profiles of the night-sky airglow OH emission.

and auroral emission contamination problems. These interfering radiations, of course, have different altitude distributions than do the $OH^{\ddagger}$ emissions.

The infrared rotation-vibration bands observed were those of the $\Delta v=2$ sequence resulting from spontaneous radiative transitions within the ground electronic state $({}^2\Pi_i \rightarrow {}^2\Pi_i)$ of the neutral hydroxyl radical. These bands occur in the 1.5 to 2.2 μm range and most of the sequence can be seen from the ground through atmospheric transmittance windows. The photon radiance of this sequence is comparable with that of the fundamental ($\Delta v=1$) and is some four times greater [*Baker*, 1975] than that of the $\Delta v=3$ sequence which occurs in the visible. An additional advantage is that the entire first overtone band sequence can be observed simultaneously, with a minimum of band overlapping, using a single spectrometer.

The sensors used were developed in the USU Electro-Dynamics Laboratories [*Wyatt and Kemp*, 1973]. These instruments use a bandpass interference filter in front of an indium antimonide solid state infrared detector. The incoming radiation is chopped and the detector output is synchronously rectified in a phase-sensitive amplifier. The optical system and detector are cooled to liquid nitrogen temperature in a closed dewar which is opened after the rocket has ascended to an altitude such that window frosting or heating is not a problem. A complete technical description of the spectrometer version of the USU SWIR sensors is being published by *Wyatt and Frodsham* [1977].

A photograph of the radiometer is shown in Figure 4 and a schematic is shown in Figure 5. It consists of an optical subsection containing Indium Antimonide (InSb) detectors, collecting optics, and interference filters in a cryogenic dewar cooled to near liquid nitrogen temperature (77°K). The components provide two independent optical channels, which utilize a common optical chopper to modulate the incident radiation. The system has an ejectable cold cover to keep the optical system cold and yet protect it from frosting until a suitable altitude (approximately 50 km) where the cover is ejected along with the payload nose tip, thereby exposing the radiometers (see Figure 6).

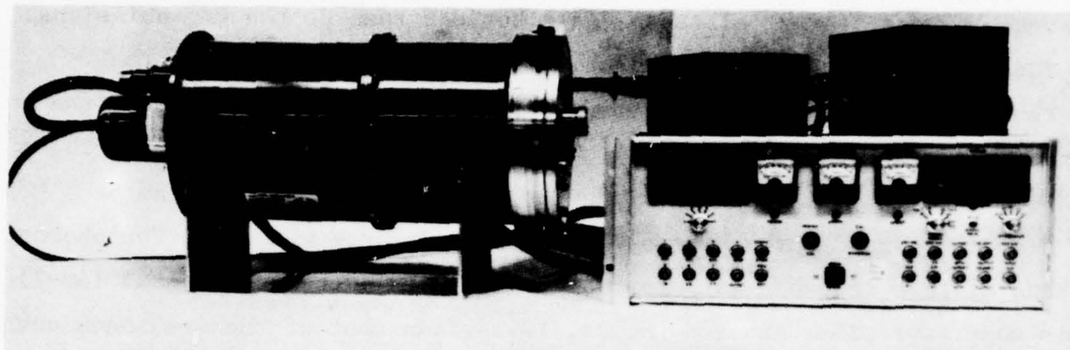


Figure 4. Liquid nitrogen cooled OH radiometer

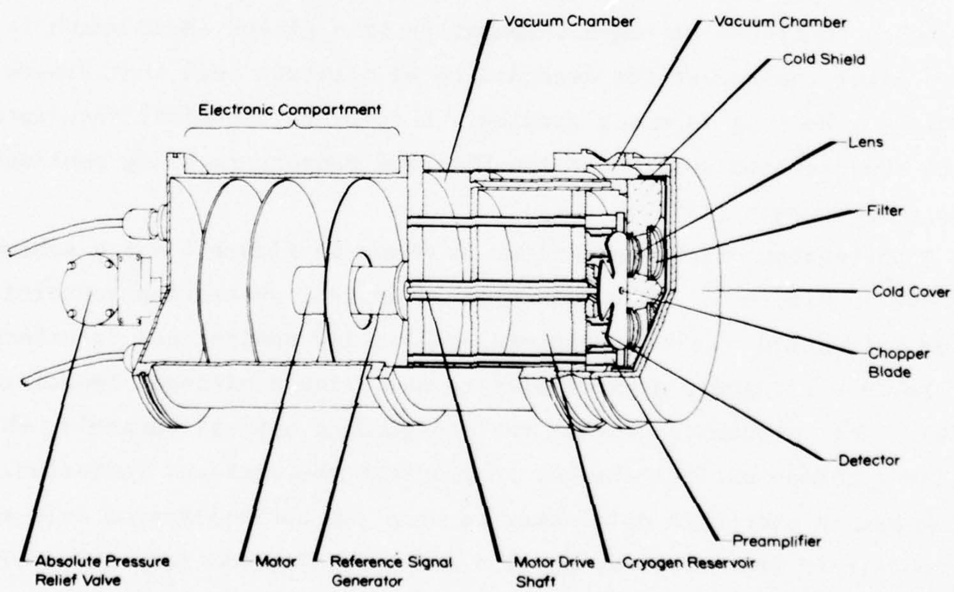


Figure 5. Schematic of liquid nitrogen cooled OH radiometer

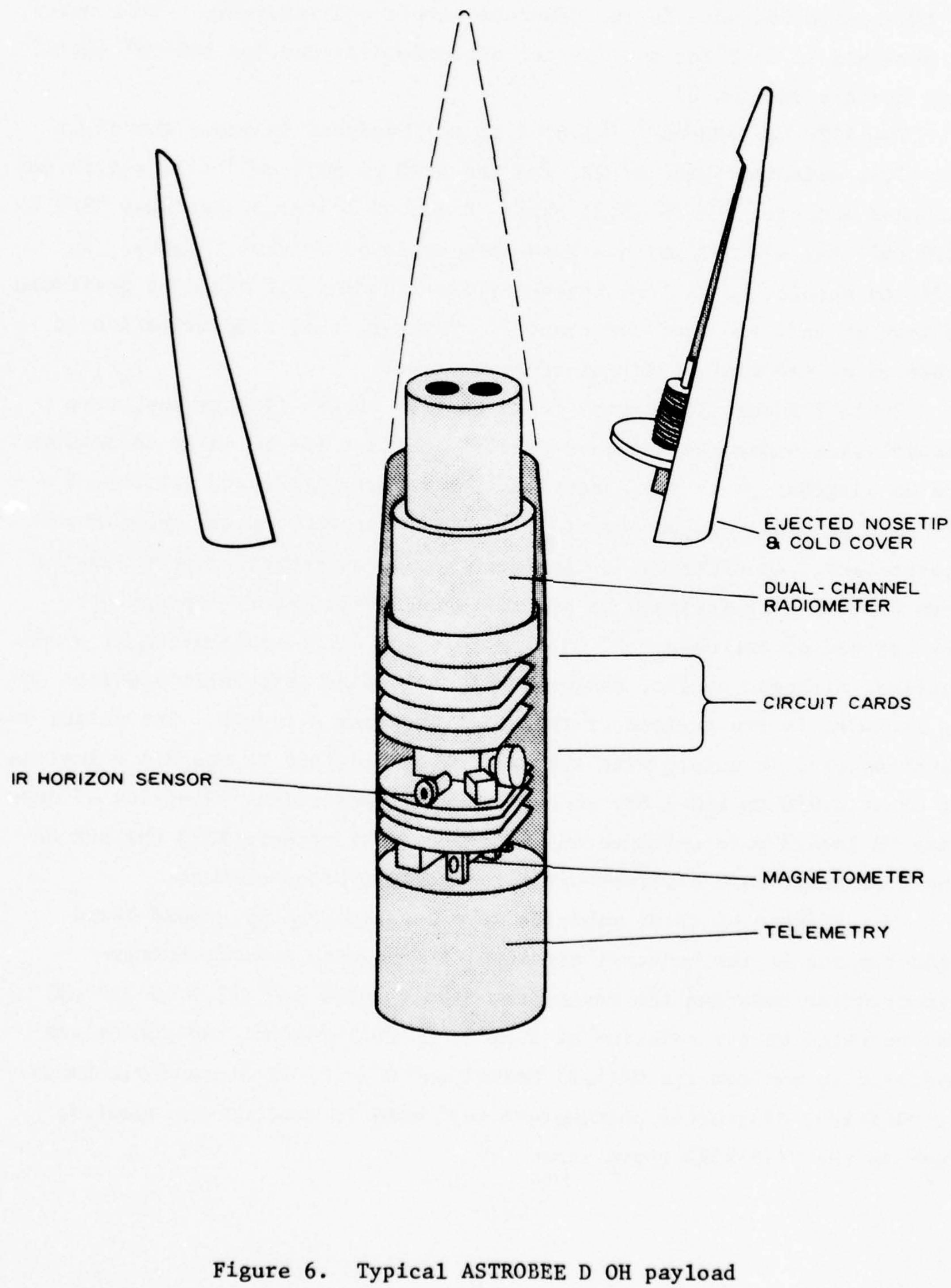


Figure 6. Typical ASTROBEE D OH payload

Filters were selected (Figure 7) to obtain simultaneous measurements of the zenith radiance in two separate wavelength intervals. This makes it possible to look for a different altitude distribution for $OH^{\ddagger}$ ($\Delta v<6$) than for the $OH^{\ddagger}$ ($\Delta v>6$).

The 4720 to 5400-cm^{-1} (λ1.85-2.12 μm) bandpass includes the (8,6) and (7,5) emission bands of OH, and the 5820 to 6075-cm^{-1} (λ1.64-1.72 μm) bandpass includes the OH (5,3) band. A second filter of bandpass 5960 to 6820 cm^{-1} (λ1.47-1.68 μm) has also been employed on some flights. In order to obtain the OH band intensity distribution, it would be desirable to look at only one band per channel. However, this simplification is achieved at the cost of signal-to-noise ratio.

Table 5 shows, in summary form, the six rocket flights that were accomplished under the suspices of this contract specifically to measure the OH airglow. With one exception, the rockets used were Astrobee D's and each payload carried one of the liquid nitrogen cooled, two-channel radiometers. In addition, a magnetometer and an optical aspect sensor (sun sensor) were included as part of each payload where appropriate. The payload of Astrobee D IC 503.14-3 was the first application of a new, baffled, nitrogen cooled, dual-channel radiometer especially designed to be included in the payload of the small Astrobee D rocket. The flight was developmental in nature with the radiometer designed to measure emissions of OH at 1.978 μm and 1.684 μm under sunlit conditions. Profiles of daytime OH levels were obtained and no deletorious effects from the sun on the instrument were observed until rocket tipover on descent.

The flights of these vehicles were supplemented by ground-based measurements of the hydroxyl airglow. A cryogenic interferometer-spectrometer covering the range from 3500 to 6000 cm^{-1}(λ1.5 to 2.7 μm) was operated at a resolution of 3 cm^{-1}. A dual-channel radiometer was operated to monitor the OH(5,3) Meinel and O (0,0) IR atmospheric bands. In addition, diagnostic photometers were used to monitor key species, such as the O(λ5577A) green line.

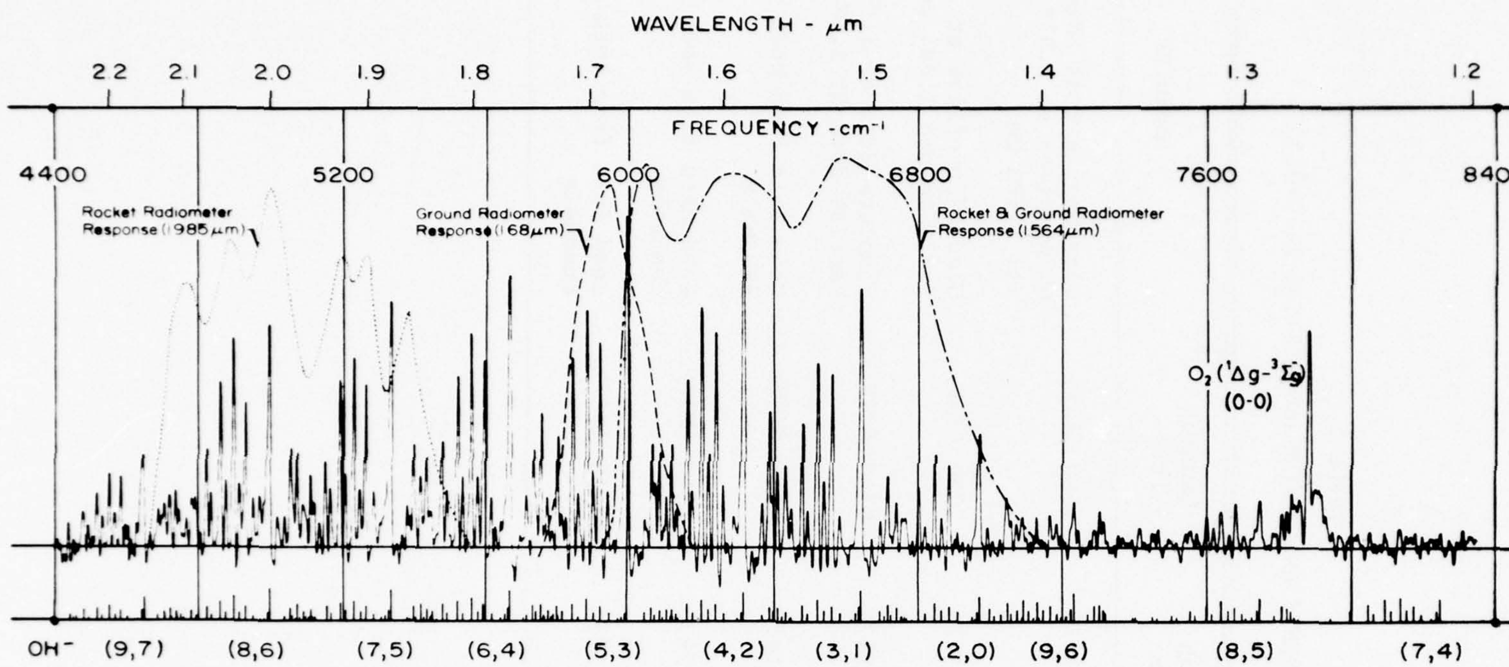


Figure 7. Radiometer filter coverage of OH ($\Delta v=2$) sequence superimposed on *Gush et al.* balloon-borne spectrum.

TABLE 5

OH MEASUREMENTS UNDER CONTRACT F19628-74-C-0130

Rocket	Launch Date	Launch Time	Results
IC 503.14-3*	1 Mar 1975	1600 (AST)	Good baffle test (daylight) OH profiles at 1.978 μm and 1.683 μm
IC 506.14-2**	4 Mar 1975	2239 (AST)	Good OH profiles at 1.978 μm and 1.684 μm
A30.311-8*	2 Dec 1975	0550 (MST)	Complete data at 1.978 μm Partial data at 1.684 μm
A30.311-5*	2 Dec 1975	0650 (MST)	Good data from both OH channels
A30.311-7*	2 Dec 1975	0900 (MST)	Good data from both OH channels
A30.205-7*	2 Dec 1975	1759 (MST)	Good data from both OH channels

*Astrobee D's
**Nike-Javelin

Previous Measurements

In Figure 8 the volume emission rate profiles from four different flights from the AFGL/USU program are presented [reported by *Rogers et al.*, 1973; *Grieder et al.*, 1973; *Baker et al.*, 1973; *Grieder et al.*, 1976; *Ulwick and Grieder*, 1976; *Baker*, 1976; *Baker et al.*, 1977]. Two of the profiles were made under night conditions at the U.S. Army's White Sands Missile Range (WSMR) in New Mexico. The other two profiles were obtained at the University of Alaska's Poker Flat Research Range (PFRR) in Alaska. One was taken during the night and the other at evening twilight. In both latter cases, although the measurements were taken in the auroral zone, quiet conditions prevailed at the time. In Figure 9 the profiles of the $OH^{\ddagger}(v<6)$ band measurements of three of the flights are given, as indicated.

To facilitate the comparison, all six profiles are plotted on the same scale in Figure 10. The apparent emission layer centers and depths from each measurement are summarized in Table 6. From these data the layers appear as Chapman-like with a usual half-intensity depth of about 8 km. It would also appear that the centers (between half intensity points) lie between 84 and 89 km in altitude.

There is evidence that during evening twilight (χ = 80° in this case) that the layer is formed at a slightly lower altitude than is the case at nighttime (χ = 116°). However, the twilight signal-to-noise ratios of the measurement are much lower than during the daytime (Figure 8), and so at best the altitude resolution of the volume emission rate profile is several kilometers. The volume emission rate η is computed from the zenith radiance profile using [*Baker*, 1974]

$$\eta = 10 \frac{dR}{dh} \text{ (photons sec}^{-1} \text{ cm}^{-3}) \tag{1}$$

where R is in rayleighs [megaphotons $sec^{-1}(cm^{-2}$ column$)^{-1}$] and the altitude h is in km. The signal-to-noise ratio and therefore the altitude resolution of the slope dR/dh of the profile is much lower than that of the zenith radiance profile itself.

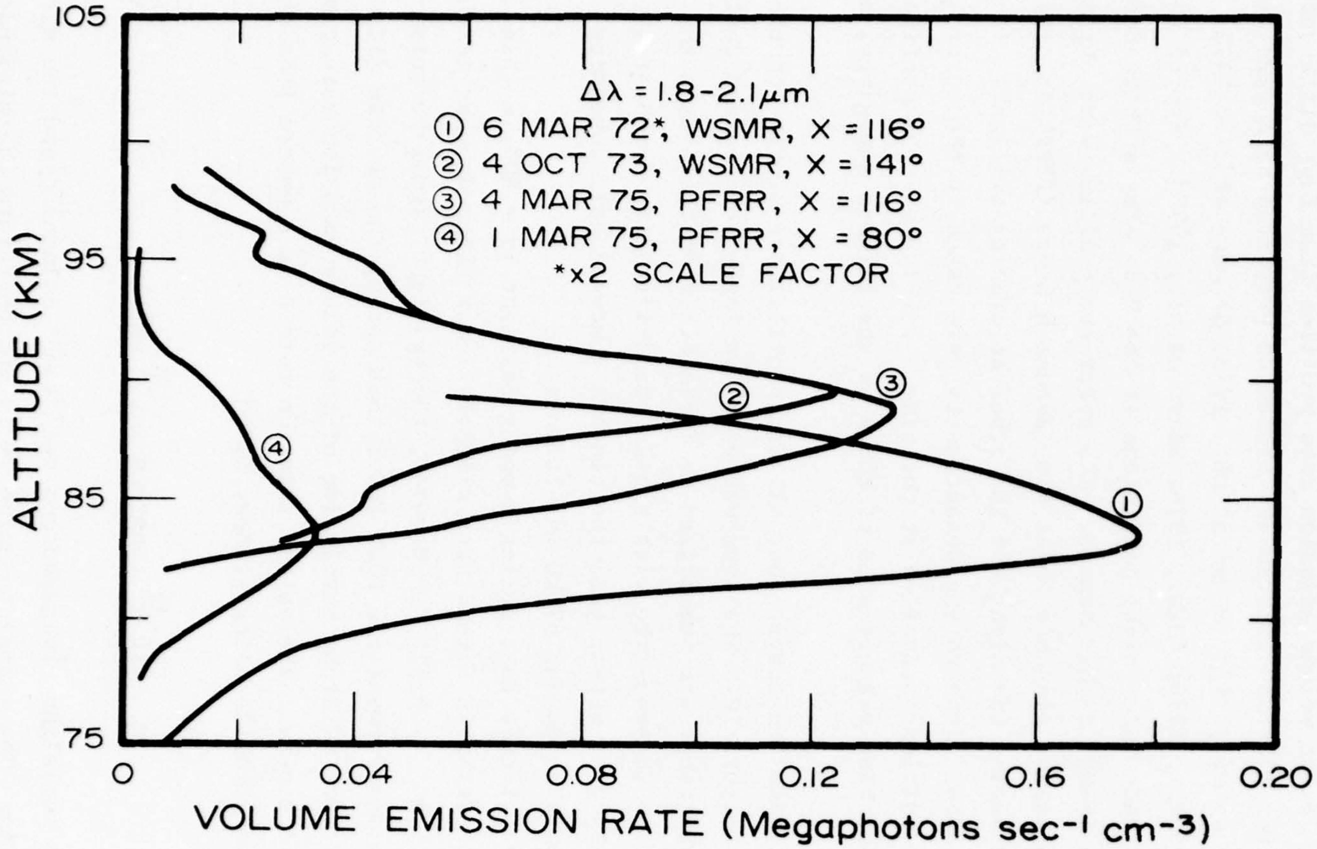


Figure 8. OH (v>6) airglow emission profiles.

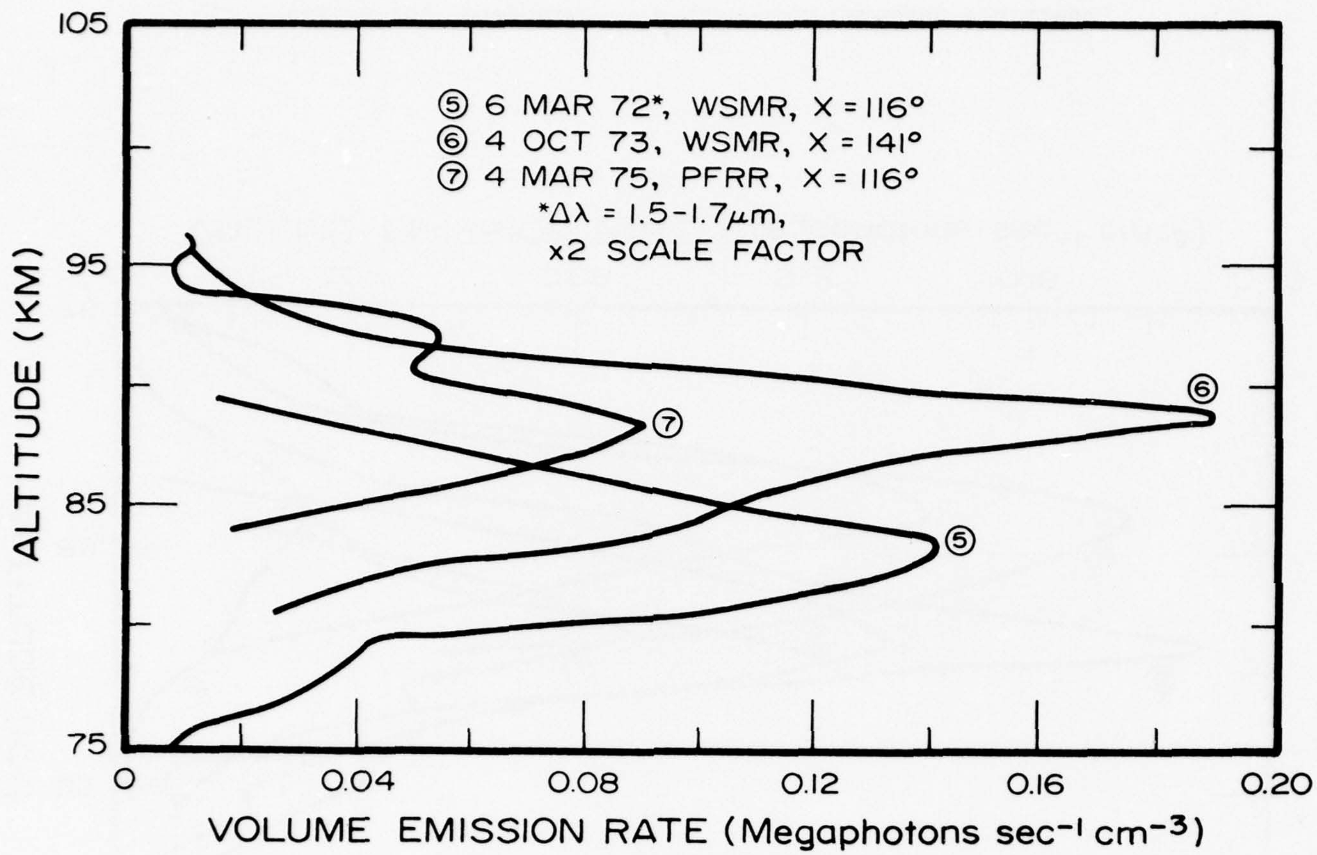


Figure 9. OH (v>6) airglow emission profiles.

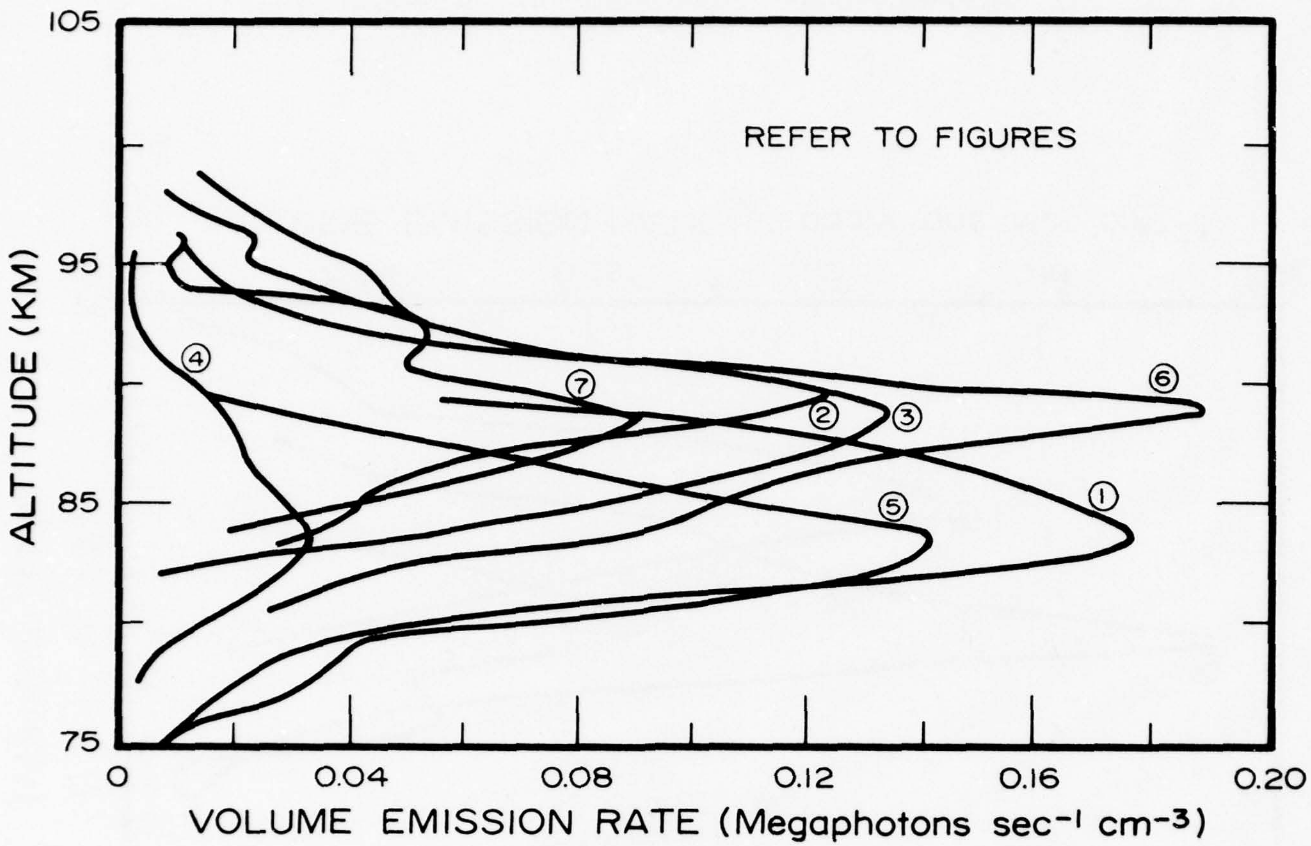


Figure 10. Composite of AFGL/USU OH emission profiles.

TABLE 6

AFGL/USU ROCKETBORNE MEASUREMENTS OF OH AIRGLOW EMISSION LAYERS

Date	Location	Conditions*	Solar Zenith Angle ψ [deg]	Layer Center Altitude h_m [km]		Layer Depth Δh [km]	
				(5,3)	(8,6 & 7,5)	(5,3)	(8,6 & 7,5)
6 Mar 72	Midlatitude	Quiet Night 5, 1	116	84	85	7	8
4 Oct 73	Midlatitude	Quiet Night 6, 2	141	89	89	7	6
4 Mar 75	Auroral zone	Quiet Night 7, 3	116	89	88	8	8
1 Mar 75	Auroral zone	Quiet Twilight 4	80	-	85	-	9

*The circled numbers refer to the profiles of Figures 6-8.

Randall Murphy (AFGL) suggested that the OH volume emission rate profile, computer from the slope of the measured zenith radiance versus altitude curve, can in turn be used to calculate the altitude profile of atomic oxygen concentration. This technique was carried out by *Rogers et al.* [1973] and *Goode* [1976]. The formula, ignoring deactivation processes other than radiative relaxation, is

$$[O] = \frac{10\ dR/dh}{\varepsilon pk[O_2][M]}\ (cm^{-3}) \qquad (2)$$

where R is the zenith radiance in the radiometer filter bandpass, ε is the ratio of the radiance in the bandpass to the total radiance form $OH^{\ddagger}$ at all wavelengths, p = 3.9 is the production efficiency (number of photons emitted per OH molecule formed), $k = 1.1 \times 10^{-34} \exp(500/T)\ cm^{-6}sec^{-1}$ is the reaction rate for the formation of ozone by $O + O_2 + M \rightarrow O_3 + M$ and $[O_2]$, $[M]$ are the concentration of molecular oxygen and the total atmosphere (primarily N_2), respectively.

However, recent work [*Bruce et al.*, 1977; *Nagy et al.*, 1976; *Streit and Johnston*, 1976] has shown that selective quenching of OH by N_2 cannot be ignored. In order to model the situation a general cascading set of equations needs to be formulated and then solved. This involves production and destruction rates for each vibrational level of the hydroxyl radical. A set of first order coupled differential equations composes the cascade set; however, in the case of the quasi-steady state, the set reduces to a linear algebraic set of equations which can be solved in order to calculate volume emission rates for the airglow bands of interest.

This is currently being accomplished at USU using computer-aided matrix inversion methods. The time-dependent spectral and altitude distributions of the OH airglow predicted from this model is being compared with the measurements.

Table 7 summarizes the AFGL/USU rocket flights to date to measure OH.

TABLE 7

SUMMARY OF AFGL/USU ROCKET FLIGHTS TO MEASURE OH

Rocket Number	Rocket	Launch Date (UT)	Time (UT)	Launch Site	Solar Zenith Angle (χ°)	Apogee (km)
AD3.722	Aerobee	Sep 25, 1965	0300	WSMR	115.9	200
AD3.723	Aerobee	Apr 29, 1966	0249	WSMR	103.5	
A30.205-3	Astrobee D	Mar 6, 1972	1214	PFRR	116	90.5*
A30.205-5	Astrobee D	Mar 21, 1973	1011	PFRR	114.7	78
A30.205-6	Astrobee D	Apr 6, 1973	0845	PFRR	107.5	78
A030.311-1	Astrobee D	Oct 4, 1973	0040	WSMR	56	52
A030.311-2	Astrobee D	Oct 4, 1973	0127	WSMR	99	102
A030.311-3	Astrobee D	Oct 4, 1973	0500	WSMR	141	106
A30.311-8	Astrobee D	Dec 2, 1975	1256	WSMR	101.4	119
A30.311-5	Astrobee D	Dec 2, 1975	1350	WSMR	90.8	124
A30.311-7	Astrobee D	Dec 2, 1975	1559	WSMR	68.7	125
A30.205-7	Astrobee D	Dec 2, 1975	0059	WSMR	102.3	125
IC503.14-3	Astrobee D	Mar 1, 1975	0100	PFRR	79.8	111
IC506.14-2	Nike-Javelin	Mar 4, 1975	0739	PFRR	116	100

WSMR = White Sands Missile Range, New Mexico

PFRR = Poker Flat Research Range, Alaska

* Theoretical, track lost at $\sim T + 50$ sec.

Scientific papers dealing with the application and results of this portion of the F19628-74-C-0130 contract have been presented as noted below.

Bruce, M.H., D.J. Baker, and A.T. Stair, Jr., Hydroxyl infrared airglow, comparison of measurements with theoretical models, Paper presented at the 1976 Fall Annual Meeting of the American Geophysical Union, 6-10 December 1976, San Francisco, Calif., Abstract published in *EOS, Trans. Am. Geophys. Union, 57,* 12, 967, Dec 1976.

Abstract

The rotation-vibration bands of $OH(X^2\Pi)$ airglow are analyzed both from measurements and from models. Two different chemiluminescent reactions are considered for initial formation of vibrationally-excited OH. These are the hydration of ozone,

$$H + O_3 \rightarrow OH(v \leq 9) + O_2$$

and the reduction of perhydroxyl,

$$HO_2 + O \rightarrow OH(v \leq 6) + O_2$$

Loss mechanisms involving the thermally-averaged (rotational temperature) Einstein coefficients of Mies are used, along with the recently measured quenching coefficients for

$$N_2 + OH^{\ddagger} \rightarrow N_2^{\ddagger} + OH,$$

as well as the reaction

$$OH^{\ddagger} + O \rightarrow O_2 + OH \quad .$$

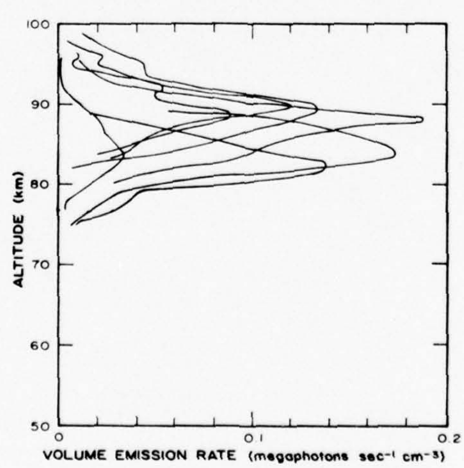
A general cascading problem emerges for calculating the vibrational population distributions. These distributions, in turn, are used to predict the emission as distributed spectrally, spatially, and temporally. Matrix methods are used in the solution and an error analysis is made for variances in the input data.

An atmospheric transmittance model is applied to spectral observations of the Δv=z band sequence taken from the ground. These data and also radiometric data taken from rockets as a function of altitude are compared with the theoretical predictions from a dynamic atmospheric photochemical reaction set model.

Baker, D.J., T.D. Conley, and A.T. Stair, Jr., On the altitude of the OH airglow, Paper presented at the 1977 Spring Annual Meeting of the American Geophysical Union, 30 May through 3 June, Washington, D.C., Abstract published in *EOS, Trans. Am. Geophys, Union, 58*, 6, 460, June 1977.

Abstract

Three methods have historically been used in the attempt to ascertain the distribution of OH airglow emissions with altitude, namely, (1) ground-based triangulation, (2) rocketborne *in-situ* sensors, and (3) exoatmospheric limb scans from satellites. Recent rocketborne measurements using sensitive, near-infrared sensors have greatly reduced the usual problems presented by backgrounds and the unfolding of the aspect geometry. Radiometric measurements have been made of the $\Delta\nu=2$ sequence with attention given to the vibration-rotation bands originating from high vibrational quantum levels ($\Delta > 6$). This made it possible to assess both the effects of reactions which might compete with the ozone hydration reaction, $H + O_3 \rightarrow OH^* + O_2$, and the effects of selective quenching. Measurements were obtained form rocket flights at both high latitude and at midlatitude. From these data profiles were calculated confirming that the OH airglow appears to originate from a Chapman-like layer. The typical half-intensity depth was found to be about 8 km and the center of the layer appears to range from about 84 to 89 km in altitude. A composite of the AFGL/USU measurements is shown below.



DEVELOPMENT OF A SMALL ROCKET PAYLOAD FOR VLF PROPAGATION STUDIES

ASTROBEE D 30.413-2

Astrobee D 30.413-2 was launched from Pad 5 of the Poker Flat Research Range, Alaska, at 2325 on 12 April 1974 (UT) into an afternoon, stable D-region condition. The purpose of the flight was to investigate VLF radio wave propagation through the ionospheric D region.

The primary payload instrument was a very low frequency (VLF) receiver tuned to receive a uniquely derived signal consisting of sequential pulses of approximately 28 KHz and 31 KHz. The transmitted signal originated at a Naval Electronics Laboratory (NELC) transmitter located approximately 20 miles to the west of the launch site.

The fiber glass nose section of the payload contained a 45-turn loop antenna and preamplifier. The signal output was applied to a filter section and then to the main amplifier. The Megatek Corporation model 5435 amplifier used for this application required +28 V at 28 ma and provided a maximum output level of >3 V peak to peak (into 3 K ohms). Three selectable gain settings were provided (94 db, 104 db and 114 db) and noise in a 6 KHz bandwidth was equivalent to a field strength of about 100 μv/meter when connected to the NELC loop. The outputs of the amplifier, a magnetometer and other payload monitors were then applied to telemetry.

The vehicle obtained an apogee of 129 Km with a total flight time of 350 seconds. Only slight coning action occurred until the vehicle turned over during the descent portion of the flight. Some signals were being received by the payload receiver during the entire flight, but a number of spurious noise bursts did occur. The spin rate and coning angle of the vehicle were determined from the magnetometer output. The payload did not have a recovery package and no attempt was made to retrieve the payload. Analysis of the results of this flight are being accomplished by NELC personnel.

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