AD-A129 274 THE EXCEDE SPECTRAL ARTIFICIAL AURORAL EXPERIMENT: AN OVERVIEW(U) AIR FORCE GEOPHYSICS LAB HANSCOM AFB MA R R O'NEIL ET AL. 01 DEC 82 AFGL-TR-82-0365 1/1

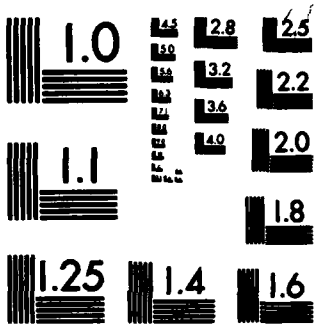
UNCLASSIFIED F/G 4/1 NL

END

DATE FILMED

7 83

DTIC



[redacted] Public Affairs Office (PA)
[redacted] National Technical Information Service (NTIS).

[redacted]

[redacted]

[redacted]

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-82-0365	2. GOVT ACCESSION NO. AD-A125	3. RECIPIENT'S CATALOG NUMBER 274
4. TITLE (and Subtitle) THE EXCEDE SPECTRAL ARTIFICIAL AURORAL EXPERIMENT: AN OVERVIEW		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim. 6. PERFORMING ORG. REPORT NUMBER ERP No. 809
7. AUTHOR(s) R. R. O'Neil D. A. Burt* E. T. P. Lee A. T. Stair, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (OPR-1) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 76701010
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (OPR-1) Hanscom AFB Massachusetts 01731		12. REPORT DATE 1 December 1982 13. NUMBER OF PAGES 13
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)

18. SUPPLEMENTARY NOTES

*Utah State University, Space Measurement Laboratory, Logan, Utah 84322

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

Rocketborne	Lyman-Birge-Hopfield	CO_2 4.3 μ
Infrared	Herman-Kaplan system	NO 5.4 μ
Spectral	N_2 first and second positive systems	
Wu Benesch	N_2^+ first negative	
Meinel systems		

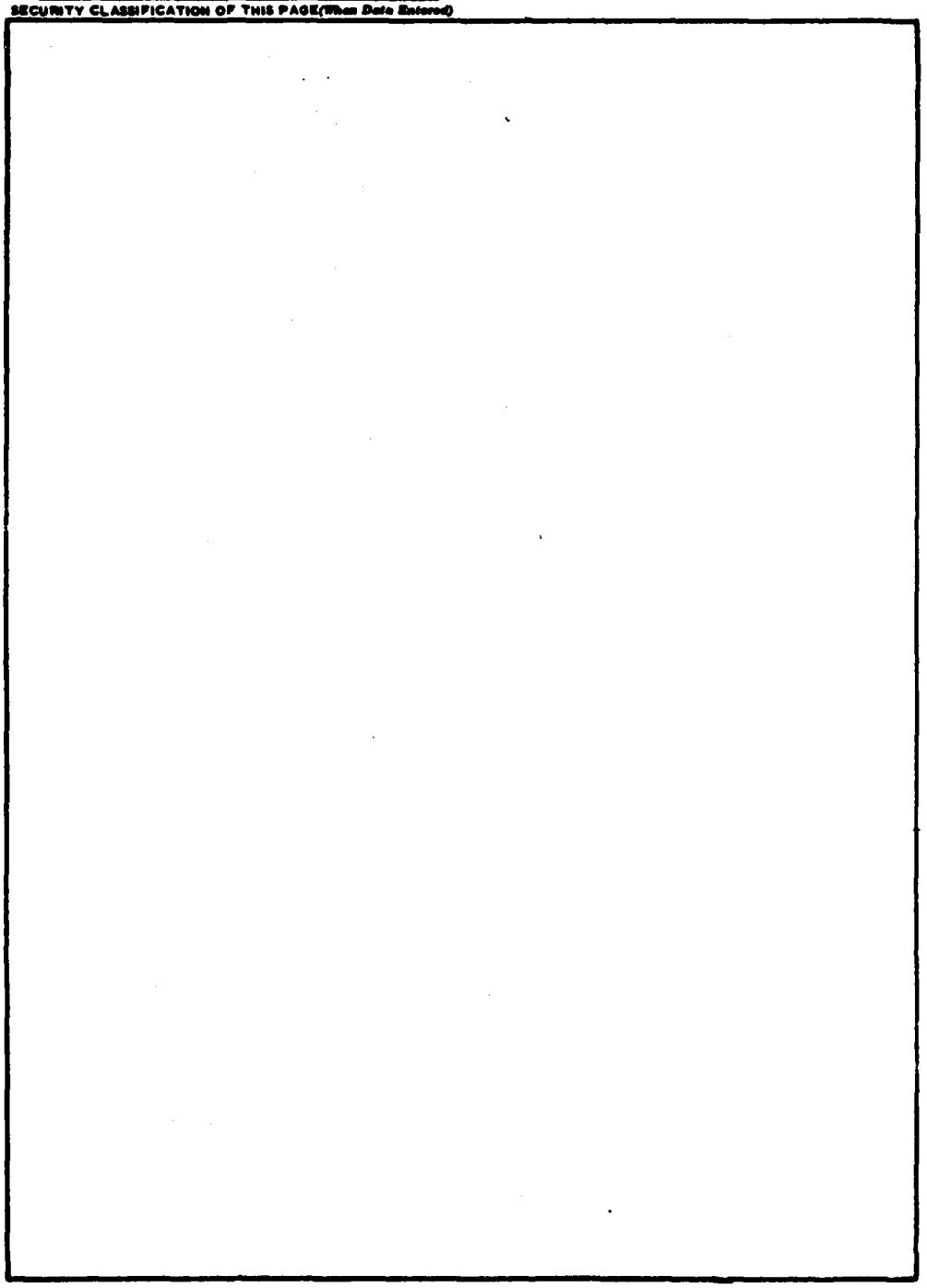
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

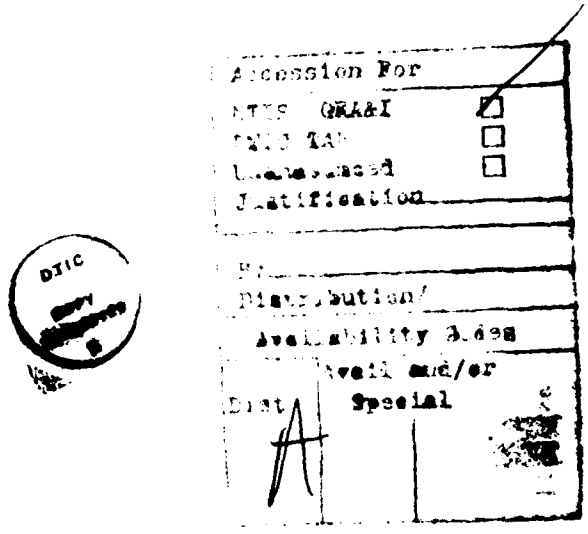
Atomic and molecular emissions from 1600 Å to 2800 Å and from 1.5 to 22 μ were measured by on-board instruments at altitude range 70 to 128 km. The observed dominant emissions are N_2 Wu-Bensch, CO_2 at 4.3 μ and NO at 5.4 μ.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)





Contents

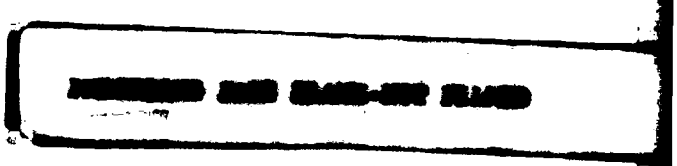
Illustrations

The EXCEDE SPECTRAL Artificial Auroral Experiment: An Overview

1. INTRODUCTION

EXCEDE is a Defense Nuclear Agency and Air Force Geophysics Laboratory program designed to study atmospheric radiative processes resulting from the controlled deposition of energetic electrons from rocketborne electron accelerators. On 19 October 1979, the 2600-kg EXCEDE SPECTRAL payload was successfully launched from Poker Flat, Alaska, into a dark, clear, and aurorally inactive night atmosphere. The stabilized payload contained: a 60-kW (3-kV) electron accelerator, an array of ultraviolet, visible, and cryogenic infrared spectrometers, photometers, and both photographic film and video cameras. Atomic and molecular emissions induced in the atmosphere by the pulsed rocketborne electron accelerator and radiating in the 0.15 to 22 μ wavelength range were recorded at altitudes from 70 to 128 km. Observed emissions included: the N_2 Lyman Birge Hopfield system, the N_2 Herman Kaplan system, the N_2 first and second positive systems, the N_2 Wu Benesch infrared system and the N_2^+ first negative and Meinel systems. In addition, the beam induced emissions recorded by the cryogenic infrared instrumentation, included CO_2 at 4.3 μ, NO at 5.4 μ and a feature at 4.7 μ as yet unidentified. The comprehensive set of spectral measurements are volume emission rates and will be analyzed in terms of production and loss mechanisms.

(Received for publication 29 November 1982)



The EXCEDE SPECTRAL experiment also used remote measurement platforms in an attempt to measure visible and infrared time dependent pulse shapes and to record the spatial extent of the 3-kV electron beam with imaging systems. The AFGL KC-135 aircraft was instrumented with a 2.7-μ radiometer, a 3914 Å photometer and a low-light-level television system. The Hilltop Optics Site at Poker Flat was instrumented with an array of film and video cameras and a dual channel telephotometer monitoring optical emissions at 3914 and 5577 Å.

The primary scientific interest of this experiment is investigation of the detailed production and loss processes of various excited electronic and vibrational states that result in optical and infrared emission as energetic primary electrons and their secondaries and all subsequent generation electrons that are stopped in the atmosphere. In this artificial auroral experiment, the dosing conditions of electron energy and power, deposition volume, deposition altitude, and dosing duration are parameters that may be controlled and monitored. In natural aurora, these excitation conditions must be inferred and the observed atmospheric emissions typically are effects integrated over a range of conditions (electron energy, electron-flux density, altitude, and dosing time). Observations of these integral effects complicate the interpretation of auroral optical/infrared emissions in terms of basic production and loss processes.

Results from a number of previous launches in the EXCEDE series of artificial aurora experiments have been reported.[1,2,3] The major innovations in the EXCEDE SPECTRAL experiment were a significant increase in the size and number of payload instruments, in the power of the rocketborne electron accelerator, and the addition of optical- and infrared-spectral instruments to record detailed band profiles rather than photometric and radiometric instruments that isolate specific wavelength intervals as used in the earlier launches. The experimental approach is described by O'Neil et al.[4]

The dose level realized in the EXCEDE SPECTRAL experiment was on the order of 10^{13} ion pairs cm^{-3} sec^{-1} at 75 km on rocket descent. The high dose level

---

1. O'Neil, R. R., Bien, F., Burt, D., Sandock, J. A., and Stair, Jr., A. T. (1978) Summarized results of the artificial auroral experiment, PRECEDE, J. Geophys. Res. 83(No. A7):3273.
2. O'Neil, R. R., Shepherd, O., Reidy, W. P., Carpenter, J. W., Davis, T. N. Newell, D., Ulwick, J. C., and Stair, Jr., A. T. (1978) EXCEDE II Test An artificial auroral experiment: Ground based optical measurements J. Geophys. Res. 83(No. A7):3281.
3. O'Neil, R. R., Lee, E. T. P., and Huppi, E. R. (1979) Auroral O(^{1}S) production and loss processes: Ground based measurements of the artificial auroral experiment PRECEDE, J. Geophys. Res. 84(No. A3):823.
4. O'Neil, R. R., Lee, E. T. P., Stair, A. T., Jr., and Ulwick, J. C. (1976) EXCEDE II, AFGL-TR-76-0308, AD A042491.

significantly enhanced the concentration of species (metastable atoms and molecules, nitric oxide, various positive ions and electrons) that are important to the production and loss processes of the excited states resulting in optical and infrared emission. The beam induced concentration of electrons at low altitudes was sufficient to make collisional deactivation of $N(^2D)$ by electrons and dissociative recombination of vibrationally excited NO^+ competitive with other loss mechanisms for these species.

2. EXPERIMENTAL APPROACH

The EXCEDE SPECTRAL flight profile is presented in Figure 1. As indicated, the payload was despun and oriented such that the long dimension was elevated at an angle of approximately 43 degrees after nosecone and door ejection and payload separation. The proposed nominal electron-accelerator power was 100 kW (3 kV, 32A) using four electron-gun modules each providing an 8-A beam. The electron accelerators initiated a pulse sequence at approximately 120 km on payload ascent which continued through apogee, 128 km, and continued to approximately 70 km on payload descent providing a total experiment duration of 180 sec.

The payload orientation during the experiment positioned the electron accelerator and instruments so that: (1) the electron-beam injection angle was canted 30 degrees from the normal to the payload; (2) the fields-of-view of the optical sensors were normal to the payload, intersected the magnetic field (and the electron-beam axis) at 30 degrees, a few meters from the accelerator port, and were aligned with the plane of the vehicle trajectory to observe both the prompt emissions in the primary electron deposition region and slower emissions in the electron-beam afterglow.

In the EXCEDE SPECTRAL experiment, the accelerator was activated for approximately 4 sec in which the spectral instruments completed one or more wavelength scans. After accelerator turn-on, the radiance of each emitting species, as observed by the payload based sensors, was determined in part by: the characteristic production and/or emission time constant of a given excited state, payload velocity, and the instrumentation viewing aspect relative to the payload velocity. Since the horizontal component of payload velocity was on the order of 200 m/sec, production and/or emission processes having characteristic times on the order of 0.001 sec or longer were anticipated to show an afterglow emission displacement that is significant in terms of the primary electron deposition volume near the payload. Preflight estimates of N_2^+ first negative 3914 Å band radiance indicated a single electron accelerator module would produce approximately 100 mega-rayleighs at lower altitudes. The time dependent emission profiles to be observed by the

remote sensors, aircraft and ground based, were intended to record the total volume of the electron excited atmosphere and to monitor the rise and decay of the emission signature of a complete 4-sec accelerator pulse at selected wavelengths. The remote sensors supplement and assist the analysis and interpretation of the rocketborne measurements

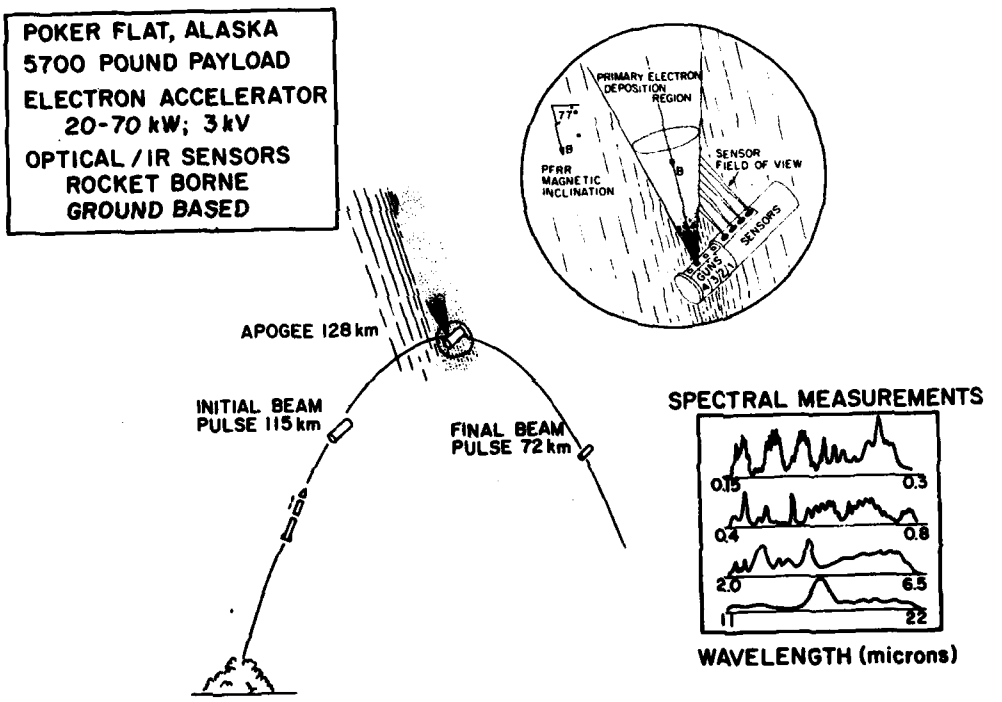


Figure 1. EXCEDE SPECTRAL Flight Profile

3. INSTRUMENTATION AND FLIGHT RESULTS

Figure 2 is a photograph of the optical and infrared instrumentation in the payload sensor module. Payload instruments, in addition to the electron accelerator, included ultraviolet and visible grating spectrometers, liquid nitrogen and liquid helium cooled circular variable filter (CVF) spectrometers and a newly developed liquid nitrogen cooled Michelson interferometer. Electron induced atomic and molecular emissions in the wavelength range from 0.15 to 22 μ were monitored by the rocketborne spectrometers. Selected measurements will be presented in this

review of the EXCEDE SPECTRAL experiment. Data from the rocketborne film cameras has been reported by Kofsky et al.[5]

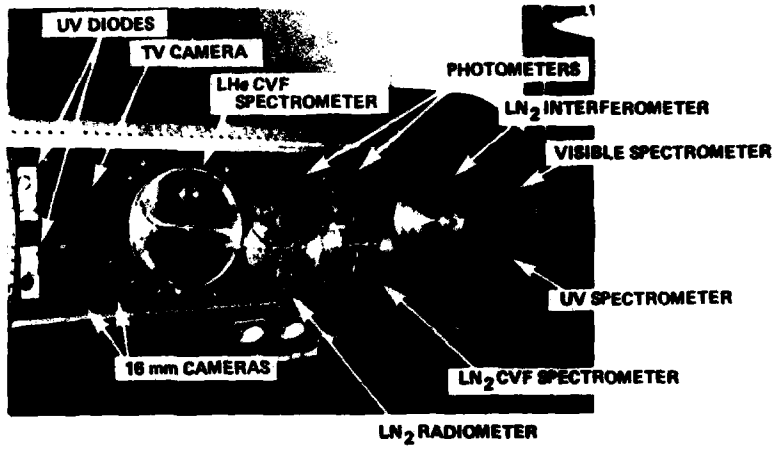


Figure 2. The EXCEDE SPECTRAL Sensor Module Showing the Location of the Optical Instruments. The payload diameter was 0.8 m and the sensor module was 1.8 m. The accelerator was of comparable size and attached near the ultraviolet and visible spectrometers

The electron accelerator modules were intended to be synchronously pulsed for a period of 4 sec followed by a 2 sec off period and every third pulse was to be the master gun module (the unit closest to the sensor module) operating alone. The operation of either one or four accelerator modules provided a measure of atmospheric emission as a function of dose magnitude. The electron accelerator experienced periods of high voltage breakdown, different in time and duration for each module, which reduced the accelerator duty cycle and beam power from the design levels. Single modules operated at power levels of 15 to 30 kW during the experiment with the smaller values occurring during the final period of the experiment. A maximum accelerator power level of approximately 60 kW was achieved at times when three of the four modules contributed to a stable beam pulse.

5. Kofsky, I.L., Sluder, R.B., and Villanucci, D.P. (1981) On-board radiometric photography of EXCEDE SPECTRAL's ejected-electron beam, Artificial Particle Beams in Space Plasma Studies, Edited by Bjørn Grandal, p. 217, Plenum Press, 1981.

Figure 3 presents the ultraviolet emissions recorded by the grating spectrometer during a 2.8-sec period when the payload was at an altitude of approximately 125 km on ascent and the accelerator operated at 20 kW. The spectrometer was a 1/4 meter Ebert-Fastie scanning instrument and utilized a photon counting detection system. The Lyman Birge Hopfield (LBH) system ($a^1\Pi_g \rightarrow X^1\Sigma_g^+$), Herman Kaplan (HK) system ($E^3\Sigma_g^+ \rightarrow A^3\Sigma_u^+$) and Vegard Kaplan (VK) systems ($A^3\Sigma_u^+ \rightarrow X^1\Sigma_g^+$) of N_2 are the dominant band systems recorded in this wavelength region. The data, recorded at high count rates, were measured with excellent precision and provide the initial definitive observation of the N_2 Herman Kaplan system in an electron excited atmosphere.

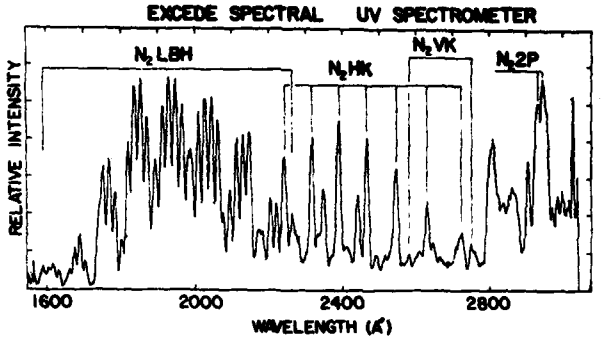


Figure 3. Beam Induced Ultraviolet Emissions at 125 km on Rocket Ascent

Data comparable to Figure 3 were recorded by a grating spectrometer scanning from 3500 to 8000 Å. The principle emissions are the first negative system ($B^2\Sigma_u^+ \rightarrow X^2\Sigma_g^+$) of N_2, the first positive system $B^3\Pi_g \rightarrow A^3\Sigma_u^+$) of N_2, the second positive system ($C^3\Pi_u \rightarrow B^3\Pi_g$) of N_2, the first negative system ($b^4\Sigma_g^- \rightarrow a^4\Pi_u$) of O_2^+ and several atomic transitions. These features are anticipated to serve as monitors of parameters essential to understanding and interpreting the infrared measurements. The emissions provide a measure of the relative abundance of N_2 and O_2 and possibly O in the electron excited atmosphere as well as a measure of the electron energy deposited in the field of view of the rocketborne sensors. The $O(^1S)$ emission at 5577 Å was not readily observed by the rocketborne visible spectrometer even at higher altitudes where collisional deactivation by ambient atmospheric species (O and O_2) is negligible. The suppression of this feature is due in part to collisional deactivation of $O(^1S)$ by H_2O which is outgassing from the

vehicle and contaminating the volume near the payload. The rate coefficient for the collisional quenching of $O(^1S)$ by H_2O is 6×10^{-10} cm^3 s^{-1}.[6] This interpretation is qualitatively consistent with the infrared sensors that observed H_2O emission at 2.7 and 6.3 μ. The ground based dual channel telephotometer observed the $O(^1S)$ 5577 Å emission with photon emission rates similar to the N_2^+ in 3914 Å band. This photometer observes the total volume excited by the electron beam and the small fraction of this volume near the payload contaminated by water vapor does not significantly effect the total $O(^1S)$ 5577 Å photon yield.

Figure 4 presents the spectra recorded by the low resolution circular filter spectrometer at 74 km on payload descent when the accelerator emitted 15 kW. The beam induced spectra were enhanced by several orders of magnitude over the ambient night atmosphere measurement (beam off) which detected only the 4.3 μ CO_2 emission. The dominant features are the Wu Benesch ($W^3\Delta_u \rightarrow B^3\Pi_g$) system of N_2, CO_2 emission at 4.3 μ, and NO at 5.3 μ. The spectral range of this cryogenic system operating at 77°K was 2.0 to 5.4 μ. The intense emission at 2.7 μ is H_2O which is attributed to outgassing from the payload and subsequent excitation by the pulsed electron accelerator. The CO_2 emission at 4.3 μ and NO at 5.3 μ saturate the data channel presented in Figure 4. The spectrum is also available for analysis on a lower gain amplifier.

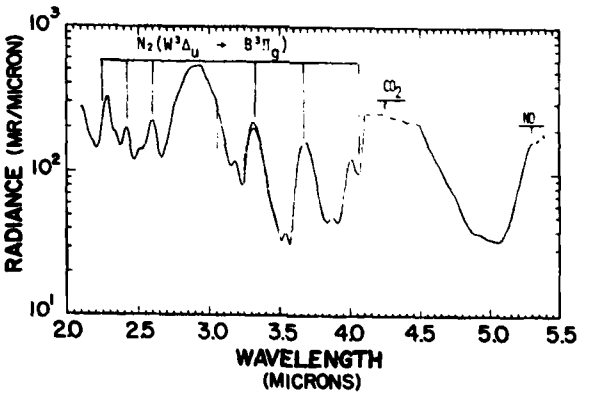


Figure 4. Liquid Nitrogen CVF Spectrometer Measurement of Beam Induced Emission at 74 km

6. Slanger, T.G., and Black, G. (1978) $O(^1S)$ Interactions—The product channels, J. Chem. Phys. 68(No. 3):989.

A 3.6- to 6.8-μ spectrum recorded by the liquid helium cooled CVF spectrometer, also at 74 km on descent, is presented in Figure 5. The CO_2 (001-000) transition at 4.3 μ and the NO fundamental emission, the dominant radiators, were recorded with high signal-to-noise ratios. These emissions were measured by the liquid nitrogen cooled spectrometer and interferometer as well as this instrument. However, the liquid helium CVF spectrometer is unique in that the responsivity at longer wavelengths fully defines the NO fundamental emission band profile. A preliminary analysis indicates that direct excitation of ambient CO_2 is the dominant source of 4.3 μ radiation observed in this experiment and the NO emission is formed by the chemiluminescent reaction of electron induced $N(^2D)$ and O_2.

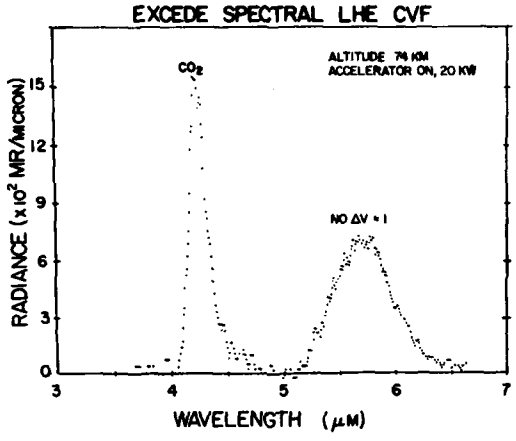


Figure 5. Liquid Helium Cooled CVF Spectrometer Measurement of Beam Induced Emission at 74 km

4. SUMMARY AND CONCLUSIONS

The comprehensive set of spectra measured in this experiment will be analyzed to determine production mechanisms for each excited state, to determine electron induced luminous efficiencies, and to determine collisional deactivation rate coefficients in the 72- to 128-km altitude range. The spectra also serve as a diagnostic measure of the electron energy distribution within the plasma produced by the electron beam based on known cross sections for the production of excited states as a function of electron energy.

The N_2 Wu Benesch system is the dominant electronic transition measured at infrared wavelengths greater than 2 μ. The electron induced luminous efficiencies for the N_2 Wu Benesch (2-0) and (3-1) transitions at 3.3 and 3.6 μ have been assigned a preliminary value in the range of 2-5 $\times$ 10^{-4}. The data indicate this band system is collisionally deactivated at lower descent altitudes (90 to 70 km).

Excited states with Einstein coefficients of 10^5 s^{-1} or less are vulnerable to collisional deactivation at the lower altitude range (70 to 80 km) of the EXCEDE SPECTRAL measurements. Electronic states susceptible to collisions at these altitudes prior to spontaneous relaxation to a lower state include the parent states of the Wu Benesch, the Herman Kaplan, the Lyman Birge Hopfield, the Vegard Kaplan, and the first positive systems of N_2 and the Meinel system of N_2^+. The electron induced luminous efficiencies for these and other band systems will be determined in the complete interpretation of the EXCEDE SPECTRAL data. In addition these systems will be analyzed to determine either a definitive value or upper bound for the collisional deactivation rate coefficient of an air-like gas mixture for each observed vibrational level.

References

1. O'Neil, R. R., Bien, F., Burt, D., Sandock, J. A., and Stair, Jr., A. T. (1978) Summarized results of the artificial auroral experiment, PRECEDE, J. Geophys. Res. 83(No. A7):3273.
2. O'Neil, R. R., Shepherd, O., Reidy, W. P., Carpenter, J. W., Davis, T. N. Newell, D., Ulwick, J. C., and Stair, Jr., A. T. (1978) EXCEDE II Test, An artificial auroral experiment: Ground based optical measurements, J. Geophys. Res. 83(No. A7):3281.
3. O'Neil, R. R., Lee, E. T. P., and Huppi, E. R. (1979) Auroral O(^{1}S) production and loss processes: Ground based measurements of the artificial auroral experiment PRECEDE, J. Geophys. Res. 84(No. A3):823.
4. O'Neil, R. R., Lee, E. T. P., Stair, A. T., Jr., and Ulwick, J. C. (1976) EXCEDE II, AFGL-TR-76-0308, AD A042491.
5. Kofsky, I. L., Sluder, R. B., and Villanucci, D. P. (1981) On-board radiometric photography of EXCEDE SPECTRAL's ejected-electron beam, Artificial Particle Beams in Space Plasma Studies, Edited by Bjørn Grandal, p. 217, Plenum Press, 1981.
6. Slanger, T. G., and Black, G. (1978 O(^{1}S) Interactions—The product channels, J. Chem. Phys. 68(No. 3):989.