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ROCKET AND LABORATORY STUDIES IN AERONOMY AND ASTROPHYSICS

NASA Grant NAG5-619

Status Report for the Period

March 1, 1986-August 31, 1986

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I. INTRODUCTION

This report covers the period from March 1, 1986 to August 31, 1986 and includes the work performed in response to a proposal entitled "A SPARTAN Payload for Spatially Resolved Spectroscopy of Extended Faint Sources in the EUV". During the present reporting period, one rocket was launched, the reflight of our payload to observe Halley's comet, on March 13, 1986 (21.095 UG). Most of our effort during this period was concentrated on detailed mechanical and electronic design of a SPARTAN payload (SP-211 UG) and on the reduction and analysis of the data from the two Halley rocket flights and from the UVX experiment which flew on STS-61C in January 1986.

II. ROCKET EXPERIMENTS

The Faint Object Telescope payload was launched successfully on both February 26, 1986 (21.093 UG) and March 13, 1986 (21.095 UG) to observe comet Halley in the far ultraviolet. The latter launch was scheduled after the postponement of the Astro-1 Shuttle mission, and occurred ~ 13 hours before the European Giotto encounter mission with the comet. It was accomplished by refurbishing the payload at White Sands Missile Range after recovery of 21.093 UG on February 26. Both launches provided excellent long-slit spectra of comet Halley and an initial report of the results has been accepted for publication in Nature. A copy of this report is attached as Appendix A. It clearly illustrates the advantage obtained by correlating the in situ Giotto results with remote ultraviolet observations made from the sounding rocket experiments and with observations made by the International Ultraviolet Explorer satellite observatory. This work was carried out by Dr. Woods, Dr. Feldman, Mr. Dymond and Mr. Sahnow.

As a result of the excellent performance of the imaging spectrograph in the FOT, we intend to refly the payload, which was again recovered in excellent condition, to repeat the unsuccessful June 1985 observation of the Io torus, probably in the autumn of 1987. In addition, we will use the reflight of the FOT as a flight-test the intensified array detector (see Section IV below) currently being developed for our SPARTAN payload. Although the two-dimensional Ranicon detector used on the Halley flights performed well the intensified array detector has several advantages in resolution, stability and dynamic range over the Ranicon and a flight version is expected to be available early next year. The modifications required to adapt the present payload to this detector are minor and do not affect any of the electrical or mechanical interfaces.

III. SPACE SHUTTLE EXPERIMENTS

The UVX ultraviolet background experiment was flown on the GAS bridge on the Space Shuttle Columbia on mission STS 61-C launched on January 13, 1986. This payload, consisting of three Get-Away-Special cannisters, included separate instruments from Johns Hopkins University and the University of California, Berkeley together with a Goddard Avionics Package containing the flight batteries and tape recorder. The primary objective of the experiment was the spectroscopy of various sources of cosmic ultraviolet background radiation and to this end nine targets, in different regions of the sky, were observed. A total of 4.6 hours of data was obtained. A secondary objective was to search for the possible presence of an ultraviolet spacecraft glow and to assess its possible impact on space astronomy missions such as Space Telescope and Astro. A preliminary reduction of the later has been completed by Dr. Tennyson, and no evidence of an ultraviolet "Shuttle glow" signature

was found in any of the observed targets. A report of these results, presented at the recent COSPAR meeting, is attached as Appendix B. Work is now beginning on the reduction of the data to physical fluxes and the investigation of systematic contributions to the background such as airglow, zodiacal light and stellar radiation. The UVX work was performed by Dr. Tennyson, Dr. Feldman, Dr. Henry and Mr. Murthy.

Following the two recent rocket launches and the UVX flight, all within the first ten weeks of 1986, the development of our SPARTAN payload (SP-211 UG) has become the major activity of this program. Thermal and mechanical analyses were performed on the payload with the detailed outline drawings completed by Research Support Instruments, Inc. in June 1986. The thermal analysis, done by Dr. Woods and Mr. Spigler with TRASYS and SINDA programs at JHU, shows that the payload is thermally stable with an expected average temperature of about 15 °C during a typical mission. The final documentation and data files of a 42-node and 9-node thermal model will be ready for GSFC thermal engineers before the design review meeting to be held in December 1986. The preliminary stress analysis, done by Mega Engineering, showed only one mechanical problem with the current design; the spectrometer mounting plate is not stiff enough. This problem is expected to be solved, along with the completed stress analysis, before the design review meeting. Some of the invar material for the payload has already been purchased in the anticipation of construction of the instruments after the design review meeting.

IV. DEVELOPMENT OF INTENSIFIED ARRAY DETECTORS

The solid state array fiber-optically coupled to a microchannel plate intensifier is the basic detector for the Spartan 211 spectrometer and slit-jaw camera. During the previous reporting period, laboratory electronics were received and tested with an 100 x 100 diode array. With the satisfactory operation of the centroiding electronics, the flight printed circuit boards are currently being designed with fabrication to begin soon. A prototype detector with 40 mm diameter microchannel plates, built by Galileo Electro-Optics Corp., has been tested and is currently being modified in the laboratory to achieve better pulse height resolution necessary for photon counting. This prototype detector, along with the flight centroiding electronics, is also being developed also for the sounding rocket experiment to be flown in the fall of 1987 to observe Io and its plasma torus about Jupiter.

This work is being performed by Mr. Sahnow, Mr. Budzien, Dr. Woods, Dr. Moos and Mr. Mackey of Spacom Electronics.

V. DATA ANALYSIS

As noted above, reduction and analysis of the data from both the UVX experiment and the two comet Halley rocket flights was a major activity during this period. Work is continuing in both of these areas. In particular, Dr. Woods and Mr. Dymond are developing detailed models of the cometary coma, including in them new information available from the spacecraft encounter experiments, for the interpretation of the spatial profiles of the ultraviolet emissions of Halley. One area of interest is the effect of energetic electrons in producing excitation, dissociation and ionization in the inner coma. The presence of these electrons was determined by the <u>in situ</u> plasma

instruments, and the rocket spectra clearly show several ultraviolet signatures from this electron population. Thus, in the future, remote ultraviolet observations of comets (with sufficient sensitivity and resolution) can provide a means of deducing the plasma environment in the inner coma.

VI. PERSONNEL NOTES

Dr. M. Daniel Morrison joined the SPARTAN team in July 1986. Dr. Morrison received his Ph.D. from the University of Texas, Dallas, in 1983 and was a member of the Spacelab 2 SUSIM team at the Naval Research Laboratory. His background is in EUV spectroscopy.

PAPERS PUBLISHED

P. D. Tennyson, P. D. Feldman, G. F. Hartig, and R. C. Henry, "Near-Midnight Observations of Nitric Oxide δ- and γ-Band Chemiluminescence", JGR 91, 10,141 (1986).

PAPERS SUBMITTED

C. W. Bowers, P. D. Feldman, P. D. Tennyson, and M. A. Kane, "Observations of the OI Ultraviolet Intercombination Emission in the Terrestrial Dayglow", accepted for publication in JGR, August 1986.

T. N. Woods, P. D. Feldman, K. Dymond, and D. J. Sahnow, "Rocket Ultraviolet Spectroscopy of Comet Halley: Abundance of Carbon Monoxide and Carbon", accepted for publication in Nature, June 1986.

P. D. Tennyson, P. D. Feldman, and R. C. Henry, "Search for Ultraviolet Shuttle Glow", submitted to Adv. Space Res., July 1986.

T. N. Woods, P. D. Feldman, K. Dymond, and D. Sahnow, "Rocket Observations of the Ultraviolet Spectrum of Comet Halley", submitted to Adv. Space Res., July 1986.

E. P. Gentieu, R. W. Eastes, P. D. Feldman, and A. B. Christensen, "The Ultraviolet Spectrum of Midday Cleft: 530-1400 Å", submitted to Canadian J. Phys., September 1986.

PAPERS PRESENTED

P. D. Feldman, "Observations of Halley's Comet from Earth Orbit", paper presented at the Joint Meeting of the American Philosophical Society and the Royal Society of London, Philadelphia, PA, April 26, 1986.

P. D. Feldman, "Ultraviolet Spectroscopy of Comet Halley", invited paper presented at the Am. Geophysical Union Meeting, Baltimore, May 19-22, 1986. EOS. Trans. Amer. Geophys. Union 67, 1986, p. 300.

P. D. Tennyson, P. D. Feldman, R. C. Henry, and J. N. Murthy, "Search for Ultraviolet Shuttle Glow on STS-61C", paper presented at the Am. Geophysical Union Meeting, Baltimore, May 19-22, 1986. EOS. Trans. Amer. Geophys. Union 67, 1986, p. 322.

P. D. Feldman, P. D. Tennyson, R. C. Henry, and J. N. Murthy, "Search for Ultraviolet Shuttle Glow", paper presented at the XXVI COSPAR Meeting, Toulouse, 30 June-12 July, 1986.

P. D. Tennyson, P. D. Feldman, R. C. Henry, and J. N. Murthy, "Ultraviolet Emission Lines from the Galactic Halo", paper presented at the XXVI COSPAR Meeting, Toulouse, 30 June-12 July, 1986.

T. N. Woods, P. D. Feldman, K. Dymond, and D. Sahnow, "Rocket Observations of the Ultraviolet Spectrum of Comet Halley", paper presented at the XXVI COSPAR Meeting, Toulouse, 30 June-12 July 1986.

APPENDIX A

Rocket Ultraviolet Spectroscopy of Comet Halley: Abundance of Carbon Monoxide and Carbon

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10 September 1986

The ultraviolet (UV) spectrum of a comet's coma is dominated by emissions from the dissociation products of water, OH, H, and O, and from secondary species: C, C^+, CO, CO^+, CO_2^+, S, and CS[1]. We report here two far ultraviolet observations of comet Halley made on 26 February 1986 and 13 March 1986 with a sounding rocket experiment. This is the first time that long-slit spectroscopy, a standard technique for the study of extended objects such as comets and nebulae, has been applied to the far ultraviolet study of a comet. The observed CO spatial profiles can be modelled by a radial outflow model[2] for a parent molecule and suggest that the CO is produced directly from the nucleus of the comet. Using the observed OI emission profile to deduce the H_2O production rate, the abundance of CO relative to H_2O is found to be 20% ± 5% for the first flight and 17% ± 4% for the second flight, making CO the second most abundant parent molecule in the coma. The derived production rate of atomic carbon is consistent with that expected from the photodissociation of carbon monoxide.

Atomic carbon is a common feature in the UV spectrum of many comets, yet its origin remains unclear. In comet West (1976 VI), the observed CI emission was consistent with a model of carbon as a daughter of CO which is vaporized from the nucleus as a parent molecule[3]. However, for comet Bradfield (1979 X) the CI brightness and spatial distribution were not consistent with models of carbon either as the daughter of the observed CO or as the granddaughter of CO_2[4]. The differences may reflect intrinsic compositional differences between comets or deficiencies in the models used to interpret the observations. Festou[5] has discussed this "carbon puzzle" in the context of similiar results on other comets observed by the International Ultraviolet Explorer (IUE) satellite.

Instrumentation and Flight. The spectral range for the sounding rocket observations, 1200 to 1750 Å at 12.5 Å resolution, is well suited for studying the carbon chemistry of the coma as it includes CI λ1657, CI λ1561, CII λ1335, and the CO fourth positive system whose strongest bands are at 1478 and 1510 Å. While these observations augment the many UV observations of comet Halley made with IUE[6], the sounding rocket payload is especially designed for the study of the emission profiles in the coma since the spectrograph provides 10 arc-second spatial resolution along the 7.7 arc-minute slit. In addition, a higher sensitivity, needed because of the short observing time (~ 300 seconds) available with a sounding rocket experiment, is achieved with the use of a photon-counting detector.

The Faint Object Telescope (FOT) payload flown previously[7] was modified for long-slit spectroscopy of extended emission objects. The basic structure of the FOT is a Dall-Kirkham telescope, a Rowland circle spectrograph, and a slit-jaw camera. The spectrograph modifications included the use of an ellipsoidal grating to reduce astigmatism at the focal plane and a two-dimensional resistive anode detector. The first launch of the experiment, NASA 21.093UG, was on 26 February 1986 at 12:02 UT, 17 days after perihelion, when the heliocentric distance, r, was 0.70 AU and the geocentric distance, Δ, was 1.32 AU. The payload was recovered, refurbished, and flown again on 13 March 1986 at 11:20 UT when r was 0.90 AU and Δ was 0.98 AU. This flight, NASA 21.095UG, preceded the Giotto encounter by ~ 13 hours. Both launches were from the White Sands Missile Range, New Mexico (106.3° W, 32.4° N).

During both flights a central exposure was taken with the entrance slit (16 arc-sec wide by 7.7 arc-min long) of the spectrograph centered on the

brightest part of the coma and with the long axis of the slit oriented along the sun-comet line. The first flight also included a tail exposure that was obtained with the slit centered 8 arc-minutes away from the comet in the anti-sunward direction, again with the slit along the sun-comet line.

Spectra and Brightness. A spectrogram of the central exposure taken during the first flight is represented as a two dimensional photographic image in Figure 1. The vertical axis depicts the spatial distribution of the emissions from the coma. The extended and brighter features in the spectrogram are HI λ1216, OI λ1304, CI λ1561, and CI λ1657, which have been observed in almost all comets studied in the far ultraviolet region[1]. The spectra of the central coma ($16'' \times 72''$ centered on the nucleus) are shown in Figure 2 for both flights. Other features identified in the spectra include the emissions from CII λ1335 and the CO fourth positive system. At least eleven bands of CO are clearly identified by comparison with a synthetic spectrum based on CO fluorescence of UV solar radiation[8]. While a few of these bands are seen in the IUE spectra of comet Halley[6], the poor signal-to-noise ratio in the IUE spectra makes it difficult to extract reliable band intensity ratios from those data.

A tentative identification of OI λ1356 at a level of 60 R in the 26 February spectrum is made. This intercombination line is not excited by solar fluorescence as the other emissions are, and suggests the presence of a region of electron excitation within the inner coma. Other indications for a collisional destruction mechanism within ~ 10^4 km of the nucleus besides solar photodissociation and photoionization are given by the IUE observations of CO_2^+ during an outburst[9] and by the unexpectedly high C^+

abundance measured by Giotto[10]. An enhanced flux of keV electrons at 15,000 km measured by Vega 1 and Vega 2[11] and a maximum in the total ion current at 12,000 km as measured by Giotto[12] indicate that it is plausible that a region in the inner coma exists where collisional excitation or destruction mechanisms are significant. Additional modelling is needed to verify this identification of OI λ1356.

The brightnesses of the strongest emission features for both flights are listed in Table 1, and are given for an area of 10" by 16" centered on the nucleus of comet Halley. Table 1 also gives the derived column densities and the fluorescence efficiencies used to derive them. The IUE data in Table 1, given for comparison with NASA 21.095UG, are the average of observations made on 12 and 13 March 1986 at 22 UT on each day. The IUE data are reduced to an effective aperture of 10" by 15". These brightnesses are consistent within the uncertainty in the two measurements, which results from a combination of calibration errors and the different spatial resolution and tracking stability of the two instruments. Although the visual brightness of the comet varied by a factor of two over a period of a day during many of the IUE observations[6], the OI and CI emissions should not vary as rapidly since their parents' lifetimes are longer than a day. Since the visual brightness was reasonably constant from 12 to 13 March, only a small effect due to the intrinsic variability is expected in comparing the two data sets.

Production Rates. Since the composition of the comet's nucleus cannot be directly inferred from the given brightnesses, modelling of the coma to fit the observed radial distributions of the emissions is performed to determine

the production rates of the molecular species. A radial outflow model of CO with a production rate of 2.4×10^{29} s^{-1} for the first flight and 1.0×10^{29} s^{-1} for the second flight yields a good fit to the observed CO distributions as shown in Figure 3a. This strongly suggests that the CO is vaporized directly from the nucleus, but cannot exclude the possibility of a parent species which has a lifetime shorter than 1000 seconds. A possible parent for CO is H_2CO, but it is improbable since a radial outflow model of H_2CO that reproduced the observed CO profile would require a production rate larger than the water production rate and would produce a detectable level of H_2 fluorescence in our spectral range. By fitting an outflow model with H_2O and CO parents to the observed oxygen distributions in Figure 3b, a production rate for water of 1.2×10^{30} s^{-1} is derived for the first flight and 6×10^{29} s^{-1} for the second flight. The average water production rate derived from the OH (0,0) band brightness measured by IUE, using a vectorial model[2], is 5×10^{29} s^{-1} for comet Halley on 12 and 13 March 1986. The water production rate derived from the Giotto neutral mass spectrometer data[12] is 5.5×10^{29} s^{-1} with an estimated 50% uncertainty. Because of the uncertainties in the parameters (lifetime and velocity of each species) used in the model, the H_2O production rates derived from a coma model have at least a 30% uncertainty. Therefore, these water production rates are consistent within the uncertainties in the models, instrumental calibrations, and the solar fluxes used in deriving the fluorescence efficiency for OI λ1304[13]. Note that since CO appears to be a parent molecule and is modelled with fewer parameters, the uncertainty in the derived CO production rate is less than the uncertainty in the H_2O production rate.

While data from the Giotto ion mass spectrometer gave an upper limit of 20% for the ratio of CO to H_2O abundance[10], and a rough estimate from the IUE observations in March for this ratio is 10-20%[6], the result from the rocket data give a relative abundance of CO to H_2O as 20% ± 5% for the first flight and 17% ± 4% for the second flight. The uncertainty in these ratios includes the errors from the absolute calibration of the instrument and the fit of the models to the observed radial profiles. Krankowsky et al consider CO_2, NH_3, and CH_4 to be the second most abundant molecules in the coma[12]; however, our results indicate that CO is the second most abundant parent molecule with a mixing ratio of about 18% relative to H_2O. For comparison, a 27% abundance of CO to H_2O was derived for Comet West[3], and 1% for Comet Bradfield[4].

While these data strongly suggest that the CO is vaporized directly from the nucleus, there remains an unresolved difference between the observed radial distribution of carbon shown in Figure 3c and the predictions of the CO outflow model. The data appear to require an additional source of carbon. However, the inclusion of a CO_2 source fails to provide the extra carbon, and since there is no pronounced tailward asymmetry in the observed carbon emissions, dissociative recombination of either CO^+ or CO_2^+ to produce atomic carbon[3] cannot be significant. An outflow model with a small additional source of carbon from the nucleus, at about 2% of the H_2O production rate, improves the fit to the observed carbon profile, but it is not adequate to firmly identify a direct source of carbon from the nucleus. An alternative evaluation of the atomic carbon production rate can be obtained if the total flux in a CI emission multiplet is known. Although the present experiment did not measure the total flux, a reliable

estimate can be obtained from the observed radial profiles since the measurements in the tailward exposure on the first flight extend to 7×10^5 km. Circular symmetry of the carbon emission, necessary for this derivation, is a safe assumption since the observed carbon emissions are symmetrical on the sunward and anti-sunward sides of the nucleus. The derived carbon production rate, Q_C, is 4.3×10^{28} s^{-1} for the first flight. Since the carbon scale length is ~ 2.5×10^6 km at 0.70 AU, this production rate is only a lower limit. Extrapolating the observed carbon radial distribution to 3×10^6 km yields $Q_C = 6.4 \times 10^{28}$ s^{-1}, while extrapolation to 1.5×10^7 km gives $Q_C = 6.6 \times 10^{28}$ s^{-1}. Thus, a reasonable estimate for the total carbon production rate for the first flight is 7×10^{28} s^{-1}, which gives a ratio of Q_{CO}/Q_C of 3.4 ± 1.2. Since our derived carbon production rate is a lower limit, we consider this ratio to be consistent with the expected ratio of 2.1, assuming that C is produced only through the photodissociation of CO[14].

The apparent contradiction between the need for an additional carbon source and the result that the Q_{CO}/Q_C ratio is consistent with photodissociation of CO may be resolved by the inclusion of an electron impact source in the models. Evidence for such a source, including the OI λ1356 emission seen in Figure 2, has already been cited above. If electron impact enhanced the dissociation of CO in the inner coma, without destroying a significant fraction of the total CO, then the radial distribution of C would exhibit a steeper slope in agreement with the observations, while the radial distribution of CO and the Q_{CO}/Q_C ratio would not be significantly altered. Quantitative modelling using the <u>in situ</u> plasma measurements[10,11] is needed to evaluate the possible importance of

this mechanism. In addition, improved coma models, such as the vectorial model[2], or models based on the in situ measured abundances of CO_2, CH_4, and other carbon-bearing molecules may also provide better agreement with the observed radial distributions of the carbon emissions.

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REFERENCES

1. Feldman, P. D. Science 219, 347-354 (1983).
2. Festou, M. C. Astr. Astrophys. 95, 69-79; 96, 52-57 (1981).
3. Feldman, P. D. Astr. Astrophys. 70, 547-553 (1978); in Asteroids, Comets, Meteors II. (ed. Lagerkvist, C.-I. et al.), Reprocentralen HSC, Uppsala, 263-267 (1986).
4. Weaver, H. A. Ph.D. Dissertation, The Johns Hopkins University (1981).
5. Festou, M. C. Adv. Space Res. 4, 165-175 (1984).
6. Festou, M. C. et al. Nature 321, 361-363 (1986).
7. Hartig, G. F., Fastie, W. G. & Davidsen, A. F. Appl. Optics 19, 729-740 (1980).
8. Durrance, S. T. J. Geophys. Res. 86, 9115-9124 (1981).
9. Feldman, P. D. et al. submitted to Nature.
10. Balsiger, H. et al. Nature 321, 330-334 (1986).
11. Gringauz, K. I. et al. Nature 321, 282-285 (1986).
12. Krankowsky, D. et al. Nature 321, 326-329 (1986).
13. Rottman, G. Private communication of unpublished SME Solar Flux Data, University of Colorado (1986).
14. Huebner, W. F. & Carpenter, C. W. Solar Photo Rate Coefficients, Los Alamos Scientific Laboratory Report LA-8085-MS (1979).
15. Feldman, P. D., in Comets (ed. Wilkening, L. L.), Univ. of Arizona Press, Tucson, 461-479 (1983).

Table 1. The brightness B and the derived column density N of the species in the central coma (10" x 16") observed in both flights.

	NASA 21.093UG: 26 Feb. 1986, 12:07 UT			NASA 21.095UG: 13 MAR. 1986, 11:25 UT			IUE
SPECIES	B^a (R)	g^b (1 AU) (10^{-6} s^{-1})	N (10^{14} cm^{-2})	B^a (R)	g^b (1 AU) (10^{-6} s^{-1})	N (10^{14} cm^{-2})	B^c (R)
OI λ1304	1460 ± 320	3.7	1.9	280 ± 65	1.8	1.25	210 ± 40
CII λ1335	130 ± 30	50.	0.013	25 ± 15	37.	0.0054	-
CO λ1478	175 ± 50	0.24	3.5	65 ± 25	0.24	2.2	100 ± 60
CO λ1510	140 ± 40	0.18	3.8	60 ± 25	0.18	2.7	60 ± 40
CI λ1561	480 ± 110	6.0	0.39	150 ± 35	5.9	0.20	190 ± 50
CI λ1657	1600 ± 350	23.0	0.34	520 ± 115	22.	0.19	745 ± 110

a) The uncertainty is a combination of the 20% uncertainty in the absolute calibration of the instrument and the counting statistics.

b) The solar fluorescence efficiencies (or g-factors) are based on earilier values[15] which are adjusted for the heliocentric velocity of comet Halley and the solar flux[13] during the observation. The CO g-factors are from Durrance[8] scaled to 1 AU and corrected for the variation of the solar flux.

c) The average of IUE data from 12 and 13 March 1986; the CO brightness is from 13 March only.

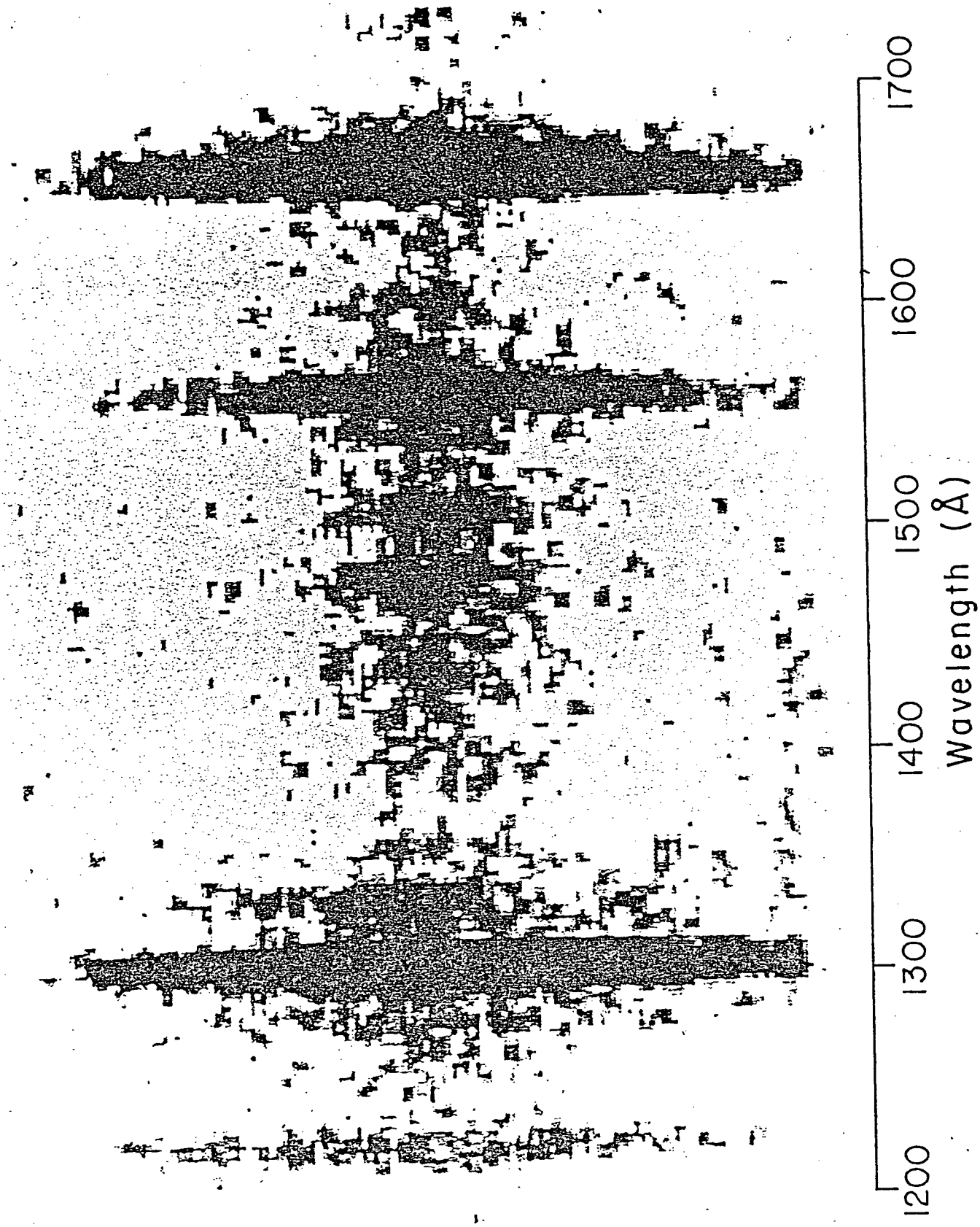
FIGURE CAPTIONS

Figure 1. A photographic representation of the raw counts from the spectrograph on NASA 21.093UG is shown for a 72.2 second exposure of comet Halley centered in the entrance slit of the spectrograph. The horizontal axis is the wavelength dispersion from about 1150 to 1800 Å, and the vertical axis is along the 7.7 arc-minute slit with the sunward direction pointing down. The three brightest lines are OI λ1304, CI λ1561, and CI λ1657. HI λ1216 appears as a weak feature due to the heavy attenuation below 1230 Å by a CaF_2 filter in front of the entrance slit.

Figure 2. The central coma spectrum from (a) the first flight on 26 February 1986 and (b) the second flight on 13 March 1986. The synthetic CO spectrum (diamonds), convolved to our instrument resolution, is based on the g-factors of CO fluorescence of UV solar radiation given by Durrance[8]. The feature at 1356 Å in (a) has been tentatively identified as OI λ1356 excited by electron collisions in the inner coma.

Figure 3. The observed radial distribution of (a) the 1478 Å CO band, (b) OI λ1304, and (c) CI λ1657 for both flights with the data from the first flight being the upper curve in each panel. The dashed lines, for comparison with the data from the first flight, are emission profiles, convolved to our instrument resolution, from a radial outflow model with the production rate of 2.4×10^{29} s^{-1} for CO and 1.2×10^{30} s^{-1} for H_2O. The

dot-dash lines, for comparison with the data from the second flight, are emission profiles from a model with the production rate of 1.0×10^{29} s^{-1} for CO and 6×10^{29} s^{-1} for H_2O.



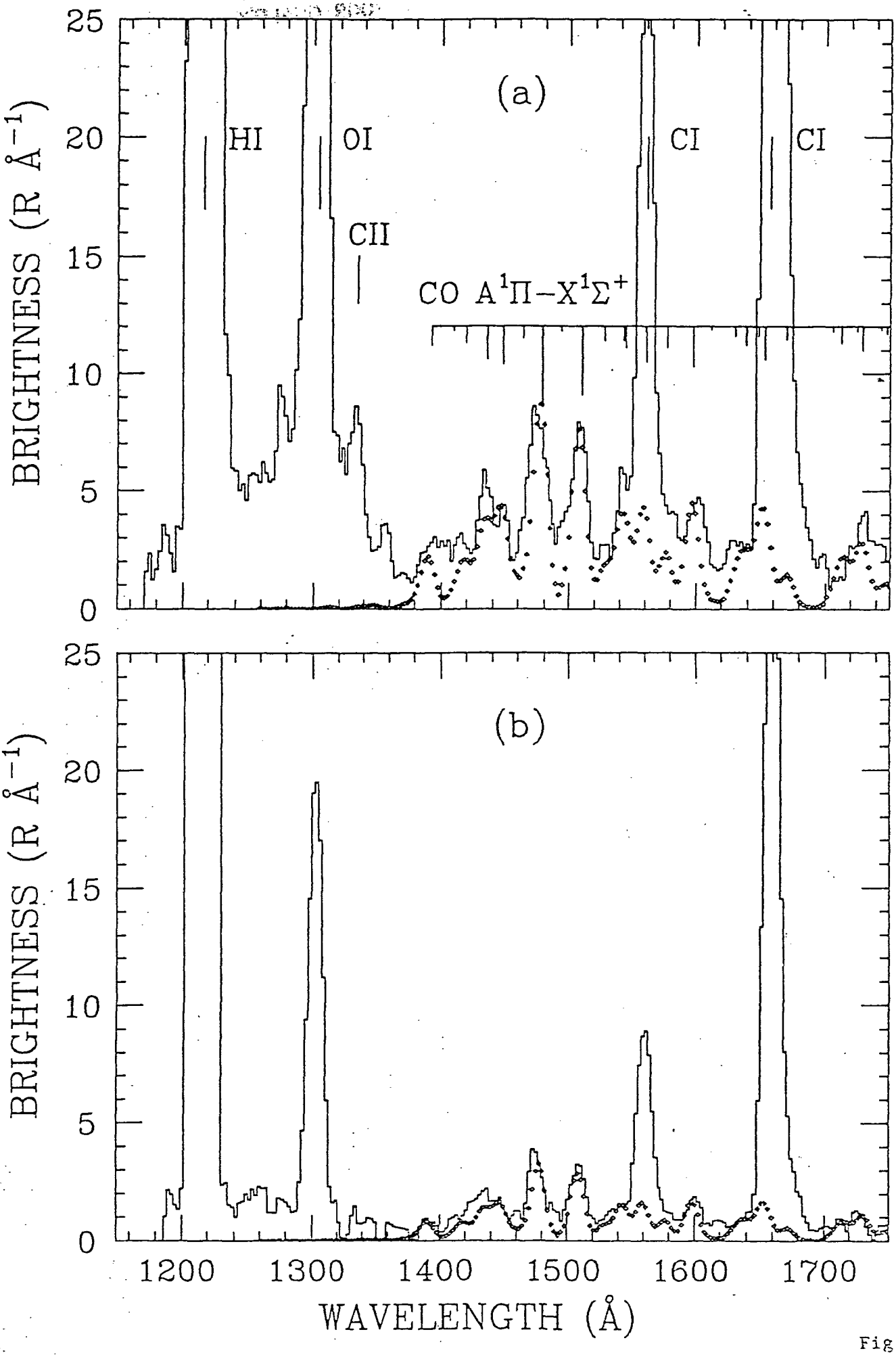

(a)
HI
OI
CII
CO A¹Π–X¹Σ⁺
CI
CI
BRIGHTNESS (R Å⁻¹)
25
20
15
10
5
0
(b)
BRIGHTNESS (R Å⁻¹)
25
20
15
10
5
0
1200
1300
1400
1500
1600
1700
WAVELENGTH (Å)

Fig. 2

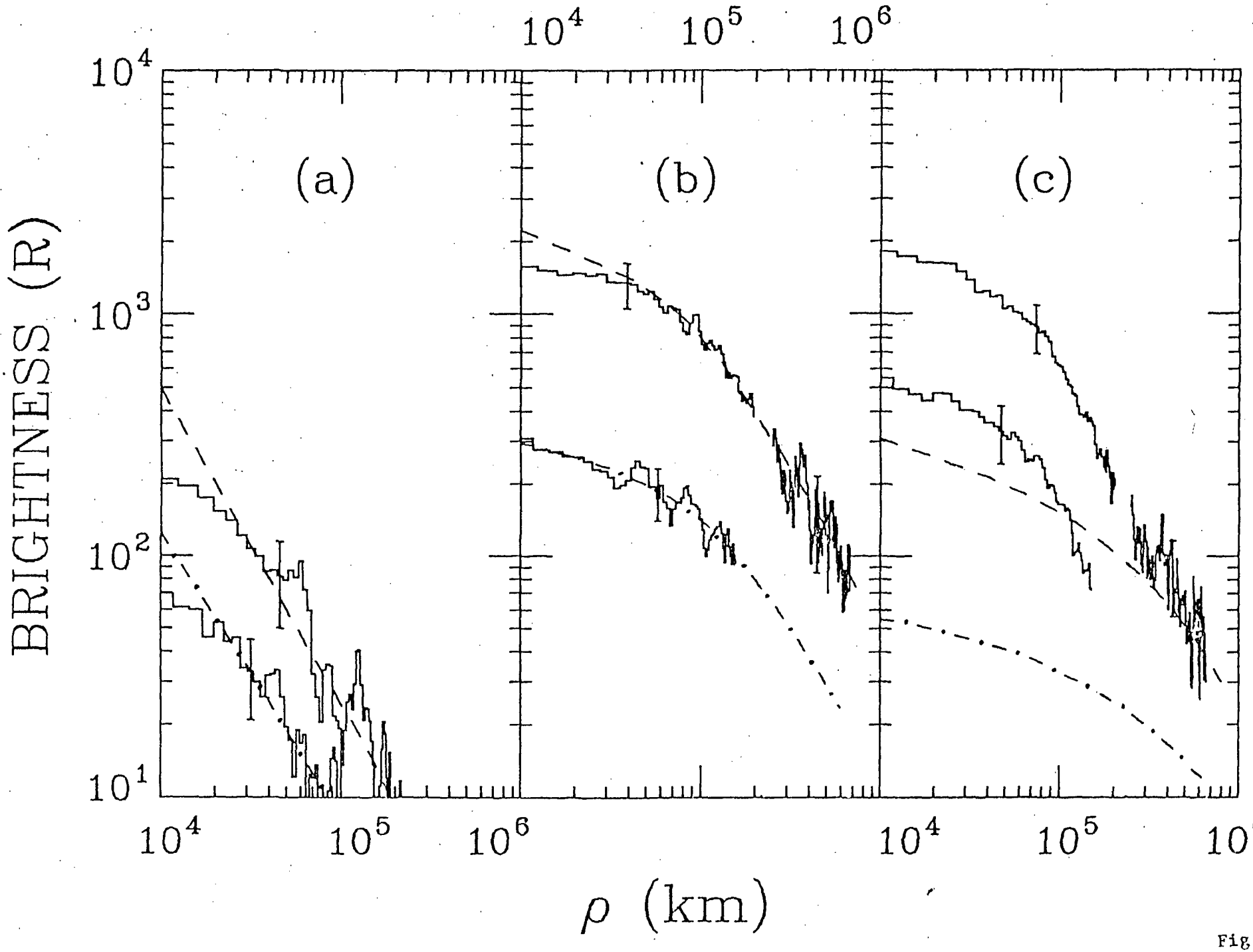


Fig. 3

APPENDIX B

Search for Ultraviolet Shuttle Glow

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Search for Ultraviolet Shuttle Glow

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ABSTRACT

The Space Shuttle Columbia flown in January 1986 carried two ultraviolet experiments (UVX) designed to observe very weak diffuse emission from various astronomical sources at wavelengths below 3200 Å with moderate spectral resolution. Such observations are extremely sensitive to the presence of any shuttle induced ultraviolet glow, since the wavelength range, 1200-3200 Å, includes strong emission lines or bands of species such as O, NO, and OH which are predicted to radiate strongly by models of the shuttle glow. The UVX spectrometers are sensitive to emission features as faint as 0.1 Rayleighs. Emissions from O_2, O and NO are detected and shown to be consistent with an atmospheric origin.

INTRODUCTION

The phenomenon of shuttle glow is of great concern to astronomers who will be flying instruments on the space shuttle and on spacecraft in low earth orbit. The presence of a visible shuttle glow has been known since the flight of STS-3 /1/ and its spectral shape has been measured at moderate resolution /2-4/. The intensity of the shuttle glow seems to vary strongly with shuttle altitude /5,6/. The measured spectral shape shows a decrease in intensity towards shorter wavelengths, verifying the earlier spacecraft glow results from the Atmosphere Explorer series of satellites /7/, and has led to various theoretical analyses of the spacecraft glow. Several species of molecules have been suggested to explain the glow (OH, NO, NO_2, O_2, N_2) /8-14/. These theories also attempted to explain the enhancement of the shuttle glow in the orientations where surfaces were normal to the shuttle velocity direction by utilizing a surface to catalyze the excitation reactions. Some of the suggested emitting species have transitions in the ultraviolet spectral region observed by the present experiment, so these uv emissions are searched for in the data.

INSTRUMENT AND OBSERVATION

The ultraviolet experiment (UVX) is a joint project of the Johns Hopkins University (JHU) Department of Physics and Astronomy, University of California, Berkeley (UCB) Space Sciences Laboratory and the Goddard Space Flight Center (GSFC) Applied Engineering Directorate whose aim is to study the intensity and spectral distribution of the diffuse cosmic ultraviolet background. The experiment demonstrated the feasibility of low cost astronomy from the space shuttle using Get Away Special (GAS) canisters. The experimental package utilized three of the GAS cans, one from each of the participating organizations. The scientific instruments were contained in two GAS cans with motorized door assemblies. The UCB package consisted of a single spectrometer covering the spectral range from 600 to 1900 Å with a gap from 1150 to 1300 Å to exclude HI Ly-α /15/. The GSFC avionics package (GAP) was mounted in a sealed canister to protect the tape recorder and telemetry formatter. The third GAS can contained the JHU UVX experiment.

The JHU experiment package used two Ebert monochromators to cover the spectral region from 1200 to 3200 Å. Each of the instruments observed the same 0.°26 by 4.°0 area on the sky to within the co-alignment error of less than 30 arc - seconds. The JHU package was co-aligned to the UCB instruments to within 0.°1. The spectral resolutions of the monochromators were 17 Å between 1200 and 1700 Å and 29 Å between 1600 and 3200 Å. Strong atmospheric emission and second-order radiation were rejected by use of filters (CaF_2 and BaF_2) placed behind the entrance slits. The sensitivity of the instruments was cosmic ray dark count limited to $\sim$ 80 photons cm^{-1} sr^{-1} $Å^{-1}$ s^{-1} for continuum emission and 0.05 Rayleighs for line emission.

The UVX experiment was flown on mission STS-61C launched on 12 January 1986 aboard the Space Shuttle Columbia. The three GAS cans were mounted on the GAS bridge in the aft portion of the cargo bay shielded from the cabin lights by a satellite thermal shroud. The GAS cans were open to space 12 hours after launch to allow for instrumental outgassing. At 36 hours into the mission, the observational sequence was started.

UVX observed nine regions of the sky which were selected to enhance components of the diffuse cosmic ultraviolet background. These targets were observed on days two, three and four of the shuttle's mission. The ninth target, a slow spatial scan, ($\alpha = 13^h$, $\delta = +15^\circ$) was selected as the candidate in which to look for shuttle glow as the look direction of the spectrometers was along the velocity vector of the shuttle. This target was a region at high galactic latitude where the presence of line emission of the galactic halo had been reported /16/. This target was not above the horizon until the latter portion of a night pass but the orbiter was positioned so that the target would be visible by the instruments when it rose above the horizon. The target was observed in the northern hemisphere at latitudes greater than 10° N and thus avoided the tropical arcs regions. Since the orbit of the shuttle for this mission was circular at 320 km, the ram direction was at a zenith angle of 90°. The design of the instruments was such that no surfaces of the shuttle were in the field of view and in order to look at any surfaces exposed to the ram the look direction must be along the ram and then the telescope mirror provides a surface on which the glow might form. Thus, we examined the data for enhanced emission from expected shuttle glow species when the observation was in the ram direction.

DATA

The large scale features of the spectrum are obvious in figure 1. The extended bright region is the enhanced emission at the earth's limb due to atmospheric species. The narrow horizontal bands are due to stars crossing through the instruments' fields of view. Also present in these data is zodiacal light which is indicated by the two faint diffuse vertical bands in the long wavelength data.

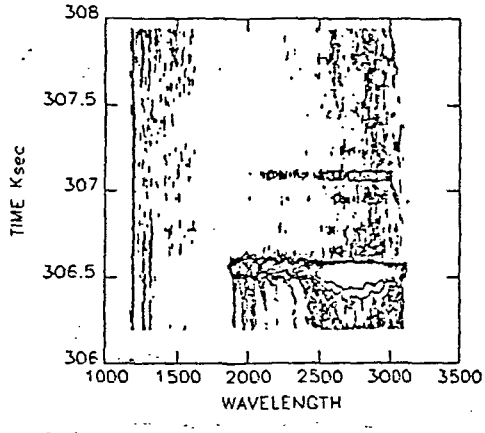

Figure 1: Contour plot of the spectrometer data. The data is arbitrarily scaled raw count rates. Time is counted from instrument turn-on. Both spectrometers are displayed in the horizontal direction. Hydrogen Ly-α emission is present at wavelength 1216 Å. OI 1356 Å and OI 1304 Å emissions are also present. Nitric oxide δ and γ band emission lies in in wavelength range from 1900 Å to 2700 Å. O_2 Herzberg emission dominates the long wavelength data at around time 306.5 Ksec. Several star crossings are present in the data, for example, at 307 Ksec. The zodiacal light signal, present in long wavelength instrument, increases with time as the look direction approaches the sun.

As atomic oxygen is the predominant constituent of the atmosphere at shuttle altitudes, its emissions should be present in the shuttle glow. Emissions from three identified oxygen multiplets (^3P-$^5S^0$ (1356 Å), ^3P-$^3S^0$ (1304 Å), and ^3P-^1S (2972 Å)) are present in these data but they do not show enhancement in the ram direction. It may also be argued that these emissions cannot be shuttle related because of optical depth considerations. The 1304 Å emission is extremely optically thick in the Earth's atmosphere, while the 1356 Å emission is optically thin. The 1304 Å emission shows very little change at the Earth's limb while the 1356 Å emission is greatly enhanced; thus this emission must be atmospheric in origin. The 2972 Å emission must also be atmospheric in origin since it has a long lifetime (approximately 1 sec.) and any excited atoms would move out of the spectrometers' field of view before radiating. The time traces from the oxygen emissions are shown in figure 2.

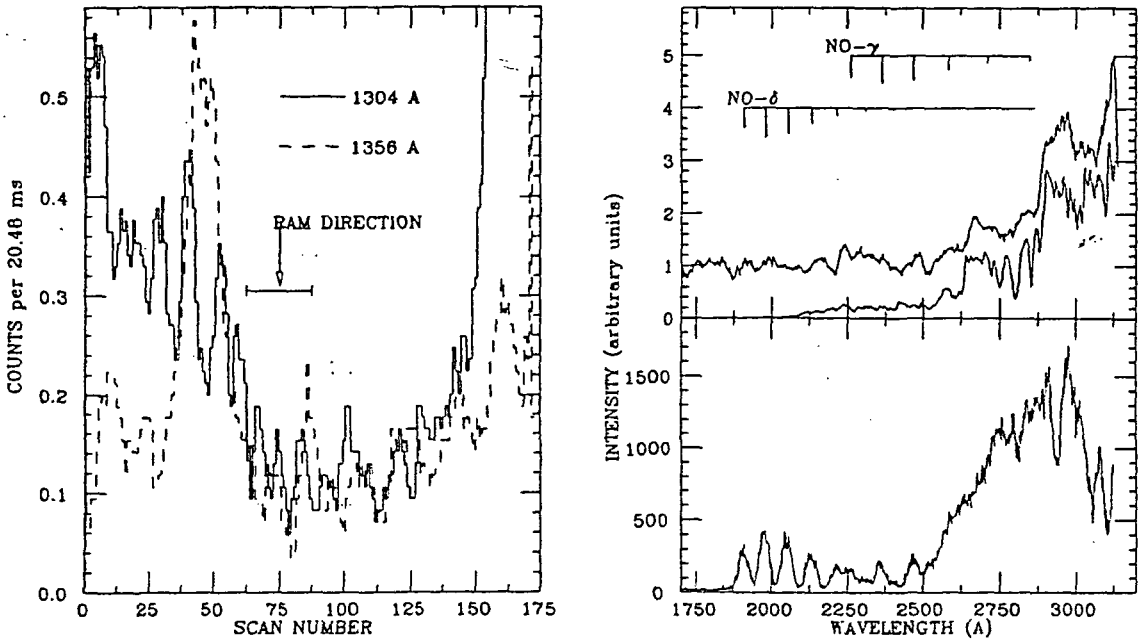

Figure 2 (left): Time traces for 17 Å wide bandpass centered on the brightest OI emission lines in the data. The 1356 Å emission shows limb brightening around scan 45, while the 1304 An emission does not. Star crossings are the 3 scan wide increases in brightness. The 1304 Å emission shows intensity variation with solar zenith angle and a large increase in brightness as solar illuminated atmosphere is observed.

Figure 3 (right): Upper panel: The observed 1600 to 3200 Å in the ram direction. The wavelengths of the NO δ and γ bands are identified. The solar spectrum /18/ is overplotted to show the level of zodiacal light. Lower panel: The limb spectrum in the same spectral region showing the presence of NO and O_2 emission bands.

The presence of nitric oxide emission is also seen in the limb data. Emissions in the nitric oxide band progressions to the ground state have been suggested as a likely source for shuttle glow /17/ and an observation of an enhancement at the NO (1,0) γ band has been reported/2/. The signature of this emission would be an enhanced signal in the NO β (B$\rightarrow$X) transitions due to a surface reaction that excites the incoming $N(^4S)$ into $N(^2D)$. Emission in the NO δ (C$\rightarrow$X) bands and NO γ (A$\rightarrow$X) bands would also be present. The NO emissions observed in this experiment are consistent with an atmospheric origin from the radiative recombination of $N(^4S)$ with $O(^3P)$ without a resonance fluorescence component whichs indicates that the observed atmosphere was not illuminated by sunlight. Nitric oxide emission is present in the limb data, disappears before the zenith angle of the ram direction is reached and is not detectable above the zodiacal light background in the ram direction.

Emission from the OH Meinel bands were originally postulated as the source of the vehicle glow detected by the Atmospheric Explorer satellites /10/ but now seems implausible on the basis of radiative lifetime of the vibrational levels /11/. Two of the OH electronic (A$\rightarrow$X) bands, the (0,0) band at 3064 Å and the (1,0) band at 2811 Å, lie within the UVX spectral range. Neither of these bands are seen above the zodiacal light background. The long wavelength spectrum of the ram direction is shown in Figure 3 along with the wavelengths of expected NO emissions identified and with the solar spectrum /18/ overplotted to indicate the zodiacal light.

The bright emission from the O_2 Herzberg bands is seen in figures 1 and 3 between 2400 and 3200 Å. This emission is due to the three body recombination of O and occurs at an altitude of about 95 km in the atmosphere. Again, as with the nitric oxide, all traces of the O_2 emissions disappear before the zenith angle of 90° is reached. The relative intensities of each of the bands agrees quite well with the intensities predicted from previous nightglow observations of O_2 /19/.

CONCLUSION

The success of the UVX experiment in measuring the extremely low light levels is evidence that the shuttle glow in ultraviolet does not adversely affect UV astronomy. UVX, although not optimized for glow observation, failed to detect an enhanced signal in the ram direction at wavelengths associated with candidate shuttle glow species. It would thus appear that a properly baffled UV astronomy payload observing during the night portion of the shuttle orbit has nothing to fear from shuttle glow.

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REFERENCES

1. Banks, P. M., Williamson, P. R., and Raitt, W. J., Space shuttle glow observations, *Geophys. Res. Lett.*, 10, 118-121, (1983)
2. Mende, S. B., Garriott, O. K., and Banks, P. M., Observations of optical emissions on STS-4, *Geophys, Res. Lett.*, 10, 122-125, (1983)
3. Torr, M. R. and Torr, D. G., A preliminary spectroscopic assessment of the Spacelab 1/shuttle optical environment, *J. Geophys. Res.*, 90, A2, 1683-1690, (1985)
4. Mende, S. B., Swenson, G. R. and Clifton, K. S., Atmospheric emissions photometric imaging experiment, *Science*, 225, 191-193, (1984)
5. Mende, S. B. and Swenson, G. R.,Vehicle glow measurements on the space shuttle, 1985, in *Second Workshop on Spacecraft Glow*, NASA CP-2391, ed. J. H. Waite and T. W. Moorehead, 2-17.
6. Mende, S. B., Banks, P. M. and Klingesmith III, D. A., Observation of orbiting vehicle induced luminosities on the STS-8 mission, *Geophys. Res. Lett.*, 11, 527-530, (1984)
7. Yee, J.-H. and Abreu, V. J., Visible glow induced by spacecraft-environment interaction, *Geophys. Res. Lett.*, 10, 126-129, (1983)
9. Torr, M. R., Optical emissions induced by spacecraft-atmosphere interactions, *Geophys. Res. Lett.*, 10, 114-117, (1983)
10. Slanger, T. G., Conjectures on the origin of the surface glow of space vehicles, *Geophys. Res. Lett.*, 10, 130-132, (1983)
11. Yee, J.-H. and Dalgarno, A., Radiative lifetime analysis of the shuttle optical glow, in *AIAA Shuttle Environment and Operations Meeting*, AIAA CP838, paper no. 83-2660, 191-197, (1983)
12. Abreu, V. J., Skinner, W. R., Hays, P. B. and Yee, J.-H., Optical effects of spacecraft-environment interaction: spectrometric observations by the DE-B satellite, in *AIAA Shuttle Environment and Operations Meeting*, AIAA CP838, paper no. 83-26587, 178-182, (1983)
13. Green, B. D., Atomic recombination into excited molecular states - a possible mechanism for shuttle glow, *Geophys. Res. Lett.*, 10, 576-579, (1984)
14. Prince, R. H., On spacecraft-induced optical emission: a proposed second surface luminescent continuum component, *Geophys. Res. Lett.*, 12, 453-456, (1985)
15. Martin, C. and Bowyer, S., The Berkeley extreme ultraviolet/far ultraviolet shuttle telescope, *BAAS*, 16, 518, (1984)
16. Feldman, P. D., Brune, W. H., and Henry, R. C., Possible detection of a far-ultraviolet line emission from a hot galactic corona, *APJ*, 249, L51-L54, (1981)
17. Kofsky, I. L. and Barret, J. L., Infrared emission from desorbed NO_2^* and NO^*, in *Second Workshop on Spacecraft Glow*, NASA CP-2391, ed. J. H. Waite and T. W. Moorehead, 155-164.
18. Mount, G. H. and Rottman, G. J., The solar spectral irradiance 1200-3184 An near solar maximum: July 15, 1980, *J. Geophys. Res.*, 86, A11, 9193-9198, (1981)
19. Degen, V., Nightglow emission rates in the O_2 Herzberg bands, *J. Geophys. Res.*, 82, 2437-2438, (1977)