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In two recent rocket-borne photometer experiments strong contamination signals were observed by the airglow photometers at 5577 Å, 6300 Å and 7619 Å. On the second flight the payload was equipped with two wide-band, wide-angle photodiode detectors which also detected the contamination glow. On both flights the contamination, which was modulated at the spin rate of the rocket, decreased exponentially with height, becoming negligible above a height of about 88 km. The glow was observed only in the ram direction except in the case of one of the photodiode detectors, which observed an unmodulated glow in the wake direction for a few seconds after the photometers were deployed. The relative intensities measured by the wide-band and narrow-band detectors suggest that the contamination glow was a continuum emission. It is suggested that the contamination glow was not caused by outgassing, but most probably had its origin in reactions involving atomic species produced by thermal dissociation in the shock wave in front of the photometers.

OBSERVAÇÕES/REMARKS

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"CONTAMINATION GLOW OBSERVED DURING TWO ROCKET SOUNDING EXPERIMENTS"

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CONTAMINATION GLOW OBSERVED DURING TWO ROCKET SOUNDING EXPERIMENTS

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ABSTRACT. In two recent rocket-borne photometer experiments strong contamination signals were observed by the airglow photometers at 5577 Å, 6300 Å and 7619 Å. On the second flight the payload was equipped with two wide-band, wide-angle photodiode detectors which also detected the contamination glow. On both flights the contamination, which was modulated at the spin rate of the rocket, decreased exponentially with height, becoming negligible above a height of about 88 km. The glow was observed only in the ram direction except in the case of one of the photodiode detectors, which observed an unmodulated glow in the wake direction for a few seconds after the photometers were deployed. The relative intensities measured by the wide-band and narrow-band detectors suggest that the contamination glow was a continuum emission. It is suggested that the contamination glow was not caused by outgassing, but most probably had its origin in reactions involving atomic species produced by thermal dissociation in the shock wave in front of the photometers.

1. INTRODUCTION

In many rocket-borne photometer experiments the data have been found to be contaminated by unexpected emissions. These emissions have been observed mainly in the 90 - 120 km height range in the wake direction, (Heppner and Meredith, 1958, Wallis and Anger, 1968, Evans et. al., 1973, Ogawa et. al., 1987). On those occasions when the contamination was also seen in the ram direction (Stegman et. al., 1982, Lopez-Moreno et. al., 1985, Greer et. al., 1983) it was invariably found to be weaker in this orientation. The observation of the contamination glow mainly in the wake direction has led to the suggestion that it is caused by outgassing from the payload or the rocket motor (O'Neil et. al., 1979).

Interest in vehicle induced atmospheric emissions has increased considerably since it was discovered that surfaces of the Space Shuttle facing the ram direction are clothed in a light-emitting layer some tens of centimetres thick, an effect with important implications for optical experiments based on the Shuttle platform (see, for example, Torr, 1983). Prior to the observations of Shuttle glow, a similar effect had

been seen on the AE-C satellite (Yee and Abreu, 1983). The observed characteristics of the Shuttle and satellite glows seem to be quite different to those of the contamination signals observed in the rocket experiments referenced above, the main difference being that the shuttle and satellite glows have been seen exclusively in the ram direction, whereas, in rocket experiments, the glow has been seen mainly in the wake direction. The purpose of this report is to present the results of two recent rocket experiments in which vehicle-induced glow was observed. The vehicle glow observed in these experiments appears to be closer in nature to that observed on the Space Shuttle than to the contamination glow observed in previous rocket experiments.

2. OBSERVATIONS

The vehicle glow reported in this paper was observed in two experiments designed to measure, simultaneously, the vertical distributions of the emissions of $\text{OI } 5577 \text{ \AA}$ and $\text{O}_2 \text{ } 7619 \text{ \AA}$ (first experiment) and $\text{OI } 5577 \text{ \AA}$ and $\text{OI } 6300 \text{ \AA}$ (second experiment). A SONDA III solid fuel rocket carried the same basic payload, consisting of two deployable airglow photometers and two plasma probes, to a height of 516 km in the first experiment, and to 444 km in the second. The layout of the payload is shown in Figure 1. The rather unusual technique adopted for deploying the photometers from the sides of the payload was dictated by the unavailability of an ejectable nose-cone. In the second payload two wide-angle, wide-band photodiode detectors were included in addition to the airglow photometers. Of these photodiode detectors, not included in the first payload, one looked in the ram direction and the other looked towards the wake. Brief specifications of the payloads and the launch parameters are shown in Tables I, II and III.

Figure 1. Payload configuration. Note that the photodiode detectors were not included in the first experiment.

TABLE I. PHOTOMETER CHARACTERISTICS
FOR THE FIRST EXPERIMENT.

PHOTOMETER	1	2
DETECTOR	EMI9924NA	EMI9798NA
WAVELENGTH	5577 Å	7619 Å
BANDWIDTH	10 Å	60 Å
FIELD ANGLE	4 Deg.	4 Deg.

TABLE II. PHOTOMETER CHARACTERISTICS FOR THE SECOND
EXPERIMENT.

PHOTOMETER	1	2	3	4
DETECTOR	EMI9924NA	EMI9798NA	HUV1100BG	HUV1100BG
WAVELENGTH	5577 Å	6300 Å	2000 TO 12000 Å	
BANDWIDTH	15 Å	15 Å		
FIELD ANGLE	4 Deg.	4 Deg.	150 Deg.	150 Deg.

TABLE III. LAUNCH PARAMETERS

PARAMETER	EXPERIMENT 1	EXPERIMENT 2
VEHICLE	SONDA III	SONDA III
DATE	11/12/85	31/10/86
LOCAL TIME	2030	2359
LAUNCH ELEVATION	81.4 Deg.	79.0 Deg.
2nd.STAGE BURNOUT	52 km	50 km
PHOTOMETER DEPLOYMENT	76 km	72 km
APOGEE	516 km	444 km

Both experiments provided good airglow profiles, which are being presented elsewhere (Takahashi et. al., 1987). An analysis of the vehicle glow observed in the first experiment is also being published elsewhere (Clemesha et. al., 1987). In this paper we will summarise the results of the first experiment and present the additional information obtained from the wide-band photodiode detectors in the second.

In the first experiment the photometers were deployed at a height of 76 km. Immediately after deployment the photometer signals increased rapidly to values many times the expected airglow levels. These

signals, which were modulated at the spin rate of the rocket, decreased in amplitude with height, reaching negligible levels by about 88 km.

The spin-modulation of the photometer signals showed a 180 degree phase difference between the 2 instruments, which were situated on opposite sides of the rocket, and bore a fixed phase relationship to the signal from the transverse magnetometer. This relationship can be seen in Figure 2., where we show the upleg signals from the two photometers and the transverse magnetometer for the first experiment. On the down-leg, the spin-modulated contamination signals were again seen, but not until the rocket turned over at about 78 km. In this situation both the phase and amplitude of the modulation were found to change with the large coning angle of the re-entering vehicle.

Figure 2. Upleg data for the first experiment.

On the basis of the results outlined above, we concluded, in Clemesha et. al., (1987), that the glow is produced only in the ram direction. It was further suggested that the glow resulted from thermal dissociation of atmospheric species in the shock front ahead of the photometers, and that the spin-modulation was caused by periodic "shadowing" of the photometers by the nose-cone of the rocket.

In considering the mechanism responsible for the emission it was suggested that the excitation could originate in the recombination of atomic oxygen produced by thermal dissociation. Various mechanisms starting with atomic oxygen have been suggested for producing the observed Shuttle glow. Slanger (1983) suggested that reactions between atomic oxygen and water or hydrocarbons adsorbed on the surface of the Shuttle could produce excited OH, leading to the Meinel bands, and Torr (1983) suggested that reactions with odd nitrogen could result in excited NO_2 , with consequent emission of the NO_2 continuum. In Clemesha et. al., (1987) we suggested that it is not inconceivable that the

3-body recombination of atomic oxygen could lead to the same atomic and molecular emissions as are seen in the natural airglow, and that the contamination glow seen in our first experiment might have consisted of the OI 5577 Å and O₂ 7619 Å emissions. Although the long lifetimes of the O(¹S) and O₂(b¹Σg⁺) states, together with the high collision frequencies in the shock front, make this mechanism appear somewhat improbable, it might be significant that, in spite of the 12 second lifetime of the O₂(b¹Σg⁺) state, strong O₂ atmospheric band emissions have been observed in shock tube experiments (Torr, 1983). For this reason it seemed unwise to discard the mechanism without further investigation. We included the two photodiode detectors in the second experiment in an attempt to determine whether the contamination glow consists of a number of lines, or whether it is a continuum emission.

The upleg signals for the two airglow photometers, the two photodiodes and the transverse magnetometer are shown in Figure 3. As can be seen from the figure, the airglow photometers exhibited spin-modulated contamination signals very similar to those observed in the first experiment. Of the photodiode detectors the forward-looking diode produced a spin-modulated signal in the same phase as that from the 5577 Å photometer, to which it was physically adjacent. The rear-looking diode saw strong contamination immediately after deployment, but the signal dropped rapidly to zero between the heights of 80 and 83 km, without showing any spin-modulation.

Figure 3. Upleg data for the second experiment.

The amplitudes of the contamination signals, shown in Figure 4, exhibit an approximately exponential variation with height. Note that the parameter plotted in Figure 4 is the peak intensity of the contamination signal occurring during each rotation of the rocket, plotted on a logarithmic scale and with the airglow subtracted. The intensity is expressed in Rayleighs per Angstrom; to obtain the absolute values observed, the values shown in Figure 4 should be multiplied by the filter bandwidths given in Tables I and II. The observed e-folding distances are 1.27 km for the 5577 Å emission in experiment 1, 1.67 km for the same emission in experiment 2, 1.66 km for the 6300 Å emission in experiment 2 and 2.65 km for the 7619 Å emission in experiment 1. A tendency for the e-folding distance to increase towards the red, observed in the first experiment, was not confirmed in the second. In view of the large scatter in the data for 7619 Å emission in the first experiment, we must consider the evidence for an increase in the e-folding distance towards the red to be weak.

Figure 4. Height dependence of the peak contamination intensities.

3. DISCUSSION

In order to discuss the implications of the relative intensities observed by the two photometers and the forward-looking photodiode it is necessary to explain how they were calibrated. The photodiode detectors

were calibrated by comparison with the airglow photometers (themselves calibrated by means of a secondary standard) using an extended white light source. This source consisted of a white screen illuminated by an incandescent lamp with a filament temperature of about 2850 K. In Figure 3, where we show the upleg signals from the two airglow photometers and two photodiodes, the scales are chosen in such a way that the white light calibration source would give equal signals from a photodiode and its corresponding photometer: i.e., the 5577 Å photometer in the case of the forward-looking photodiode, and the 6300 Å instrument in the case of the backward-looking one. The effective optical powers producing equal signals in Figure 3 are, of course, very different. The emission spectrum for the 2850 K filament temperature of the calibration source is shown as curve (b) in Figure 5. This spectrum has its maximum at around 10000 Å, close to the peak of the sensitivity curve for the photodiode, shown in the figure as curve (a). If we define the effective incident power as the integral, with respect to wavelength, of the product of the source spectrum and the relative response of the detector (curve (c)), then we get effective incident powers of 0.39 for the photodiode and 0.0005 for the 5577 Å photometer. Thus we can see that, to produce equal signals in Figure 3, the total power within the passband of the photodiode would have to be about 780 times that within the 15 Å bandwidth of the 5577 Å photometer. This, of course, is only true for a source whose spectrum corresponds to that of a blackbody at 2850 K. We can, however, use this value as an order of magnitude when discussing the experimental results.

Figure 5. Spectral data for photodiode calibration: (a) photodiode response; (b) 2850 K black-body spectrum; (c) product of (a) and (b).

The photodiode signal amplifiers used a dynamic range compression scheme which did not work very well in practice. For this reason the calibration is unreliable except at low signal levels. At such low

levels, and using the relative scales established in the manner described above, the signal from the forward-looking photodiode was about 5 times greater than that from the 5577 Å photometer. Using the factor of 780, we find that there was about 3900 times as much power within the passband of the photodiode as there was in the 15 Å bandwidth of the photometer.

If the observed contamination consisted of line and band emissions resulting from excited states of atomic and molecular oxygen, produced in the 3-body recombination of atomic oxygen, then we can get a very rough idea of the expected relative amplitudes from the known intensities of the natural airglow emissions. Within the passband of the photodiode we would have the Herzberg I and II, Chamberlain and Atmospheric bands of molecular oxygen, and the 5577 Å emission of atomic oxygen. Amongst these emissions the main contribution to the photodiode signal would come from the O₂ atmospheric band, with an intensity of about 6000 R. The U.V. emissions might count for as much as 1000 R., but their contribution to the photodiode signal would be reduced by the latter's low sensitivity at shorter wavelengths (the strong O₂(a¹Δg) 1.27μ emission is outside the passband of the photodiode). On this basis, the ratio between the intensities registered by the photodiode and the 5577 Å photometers respectively would be of the order of 70:1. As explained above, the experimentally determined ratio is about 4000:1, or about 60 times the expected value. Thus we have two factors which argue against the possibility that the contamination signal was caused by the emissions produced by the 3-body recombination of atomic oxygen and seen in the natural airglow. Firstly we have the fact that roughly the same contamination intensities were seen by the 7619 Å and 5577 Å photometers, instead of the 70:1 ratio seen in the airglow and, secondly, the wide-band detector saw about 60 times as much signal as would be expected from the atomic and molecular oxygen emissions.

Although our measurements do not allow us definitely to conclude that the contamination was caused by a continuum emission, the fact that the intensities observed by the 3 different airglow photometers flown in the two experiments were of the same order of magnitude, in terms of Rayleighs per Angstrom, strongly suggests that this was the case. The bandwidth of the photodiode detector is of the order of 400 times that of the 5577 Å photometer, but the ratio between the intensities measured by the two detectors is about 10 times this value. This suggests that the contamination emission increases in intensity towards longer wavelengths. The relative intensities measured by the airglow photometers support this conclusion to some extent. In the second experiment the 6300 Å photometer measured a contamination signal about 2.5 times that seen by the 5577 Å instrument. On the other hand the signal measured at 7619 Å in the first experiment was slightly less than that measured at 5577 Å. It must be admitted, however, that the data from the 7619 Å photometer during the interval where the contamination signal was seen is not entirely reliable. At the very high signal levels encountered during this phase of the flight the 12-bit signal counters over-ranged many times, and there is some ambiguity in reducing the data from the 7619 Å instrument.

In our earlier paper (Clemesha et. al. 1987), it was pointed out that, although the 1.1 eV kinetic energy of the O_2 molecules, relative to the rocket, is insufficient to cause dissociation (unlike the case of orbital vehicles), the mean free path at the heights in question is small enough for the molecules to become thermalized in the shock wave in front of the photometers. An r.m.s. energy of 1.1 eV corresponds to a Maxwell-Boltzmann distribution for a temperature of 4000 K, at which temperature approximately one millionth of the molecules would have energies greater than the 5 eV binding energy of the O_2 molecule. If this process is, indeed, taking place, then the rapid decrease in the observed intensity of the vehicle glow with height (with an e-folding distance of about 1.5 km, as compared with an atmospheric scale height of around 5 km) would be explained by the rapidly increasing mean free path, decreasing the number of collisions and thus the degree of thermalization of the incoming molecules.

It is interesting to note that, in our second experiment, both the 5577 Å and the 6300 Å contamination signals showed the same, quasi-sinusoidal, variation with height, with a vertical wavelength of about 7 km. This does not correspond to the coning period of our rocket, and most probably resulted from the variations in angle of attack caused by horizontal winds.

One final question which arises is that of why the sort of vehicle glow which we report here has not been seen in other rocket photometer experiments. The vehicle which we used, the SONDA III rocket, developed by the Institute of Space Activities (IAE) of the Brazilian Air Force, has an apogee of about 500 km. At a height of 80 km it has a velocity of about 2.7 km/s. Most, if not all, rocket photometer experiments aimed at measuring D and E-region emissions have used rockets with much lower apogees. At the much lower velocities of these vehicles, in the height range in question, the temperature in the shock wave would be too low to produce appreciable dissociation of molecular oxygen.

4. CONCLUSIONS

Strong optical emissions produced by interaction between vehicle and atmosphere were observed in two rocket sounding experiments. These emissions, seen at 5577, 6300 and 7619 Å, and by a wide-band silicon photodiode were detected at heights up to 90 km. The emissions were observed only in the ram direction, and their intensities decreased approximately exponentially with height with an e-folding distance of about 1.5 km. Maximum intensities of about 3000 Rayleighs/Angstrom were observed at 78 km, immediately after the photometers were deployed. The forward-looking photodiode detector, sensitive to radiation between approximately 2000 and 11000 Å, measured about 4000 times the intensity seen by the 15 Å bandwidth 5577 Å photometer. On the basis of this ratio, we conclude that the vehicle-induced glow is most probably a continuum emission whose intensity increases towards longer wavelengths. It seems likely that the emission is the result of reactions involving atomic species produced by thermal dissociation in the shock wave in front of the photometers.

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