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MEASURED ELECTRON CONTRIBUTION TO SHUTTLE PLASMA ENVIRONMENT: ABBREVIATED UPDATE

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The differential energy spectra of electrons between 1 and 100 eV were measured by an electron spectrometer flown on an early shuttle. This energy range was scanned in 64 incremental steps with a resolution of 7%. The most striking feature that was observed throughout these spectra was a relatively flat distribution of the higher energy electrons out to 100 eV. This is in contrast to normal ambient spectra which consistently show a rapid decline in quantitative flux beyond 50-55 eV. The lower energy (1-2 eV) end of these spectra showed steep thermal trails comparable to normal ambient spectral structure. In general, daytime fluxes were significantly higher than those obtained during nighttime measurements. Quantitative flux excursions which may possibly be associated with thruster firing were frequently observed. Spectral structure suggestive of the N_2 vibrational excitation energy loss mechanism was also seen in the data from some measurement periods. Examples of these spectra are shown and possible correlations are discussed.

INTRODUCTION

The purpose of this experiment was to examine the role of low energy electrons in the interaction between large vehicles and the space environment, and to assess the extent of contamination presented by these electrons. For this purpose, an electron spectrometer was flown on an early shuttle. This instrument was a 127° cylindrical electrostatic deflection analyzer essentially identical to that described in reference 1. Differential energy spectra between 1 and 100 eV were obtained by applying the analyzer voltage in 64 incremental steps. The analyzer resolution was 7% and the stepping increments were set at 7% to match this and thus avoid gaps in the spectral data. Dwell time per step was set at 1.0 sec, thereby requiring 64 secs to scan a full spectrum; this was found to be an undesirably long time period, as will be later discussed. The instrument was mounted near the rear of the shuttle bay with a look direction out over the right wing, along the -Y axis and tilted 12° upward from it.

Before showing the shuttle data it will be useful to first show, by way of contrast, what the ambient or relatively uncontaminated spectra look like. The examples shown in figure 1 are spectra of ambient daytime photoelectrons which were obtained on a rocket flight using an instrument identical to that used on the shuttle. The highest altitude shown, however, is about 80 km below shuttle altitude. These are typical of many hundreds of spectra obtained during several rocket flights

and show four chief characteristics: There is first a steep thermal tail at very low energies (<2eV), only the lower parts of which are seen in these particular spectra. Second is the valley-like structure between 2-5 eV caused by energy loss due to resonant vibrational excitation of N_2 by electron impact -- the so-called nitrogen bite-out. It should be noted, for later reference, that this feature diminishes in the ambient spectra as altitude increases toward 200 km and disappears above this, well below shuttle altitude. Third, in the 20-30 eV region for daytime spectra only, there are several closely spaced peaks due to photoionization of N_2 and O by the intense solar He II line at 304A; this structure is shown here as combined by the limited analyzer resolution to form one broadened peak. And fourth, there is a rapid quantitative decrease in photoelectrons above about 55 eV due to a pronounced decrease in the solar euv flux at higher energies (wavelengths less than about 170A).

MEASUREMENTS

The shuttle spectra showed departures from the ambient characteristics noted above, some of which were expected and some of which were not. Figure 2 shows a typical spectrum which is actually the average of all spectra obtained during this particular data acquisition period. In common with ambient spectra, a thermal tail below 2 eV is seen, as was expected. There is no apparent structure in the 2-5 or 20-30 eV regions which was not unexpected. What was quite unexpected, however, is the continued relatively flat distribution of electrons having energies greater than 50 eV, out to the highest energy measured (100 eV). This was the most striking characteristic of these measurements; it was present in every spectrum taken during the flight. The source of these higher energy electrons is, as yet, unexplained. But it clearly indicates the need for one experimental change for the next flight: that is to extend the energy range coverage out to 500 or 1000 eV to see where, or if, the expected shoulder can be found. Figure 3 shows three individual spectra obtained in this same measurement period during which the vehicle went from daylight to darkness. As shown, the quantitative electron flux decreases significantly at night, clearly suggesting that locally generated solar photoelectrons contribute in large measure to the daytime electron environment of the shuttle. Two of these spectra also show considerable scatter or data point excursions. In an attempt to correlate this scatter with other vehicle events, periods of thruster firing are shown, although this cannot be considered a direct source of electrons in the energy range shown here. It should be noted that thruster firings mentioned herein refer to all cases to the verniers. There was very little firing of the primary thrusters during any of these data acquisition periods, and what little there was appeared to have no effect on the data. Thruster operation involves a hypergolic reaction between monomethylhydrazine (MMH) and nitrogen tetroxide (N_2O_4) and while this generates what might be called a hot plasma, it cannot directly contribute electrons having energies much greater than about 2 eV. Some subsequent accelerating mechanism would clearly be required if thruster activity is to be associated with these flux excursions.

Thruster firings occur for a minimum of 80 msec, although in many cases one or more were active for considerably longer periods of time. But this points up another way in which the experiment should be changed for a subsequent flight: The present scan timing sequence (1sec/step, 64sec/scan) is simply too long to observe, over the better part of a spectrum, any short term phenomenon which may have occurred. Very short term phenomenon could therefore appear as the excursion of a

single data point, or a few consecutive points, which may account for the apparent scatter effect. For the present data to be associated with thruster firing, however, requires that some sort of delayed reaction or response time be inferred -a seemingly plausible concept. But the apparent response time involved is not manifested in any constant manner. The topmost spectrum of figure 3, for example, shows a sharp drop in flux levels approximately 2 seconds after thruster firing ceased while the middle spectrum shows a delay of 13-14 seconds before a similar response is observed. Additional illustration of this is seen in figure 4 which shows three individual spectra taken during a common nighttime period. The lowest spectrum shown (C) was completely free of thruster firing during its measurement and for a period of 15 minutes prior to that. The topmost spectrum (A) was taken following a period of moderate thruster activity and in one during which there was nearly continuous firing of all six vernier thrusters. The middle spectrum (B) was taken immediately following this but represents a largely thruster-free measurement; firing occurred during the very early (low energy) segment of this spectrum and then ceased for all data points taken above 3.4 eV. This spectrum seems to indicate a tendency to return to the normal lower nighttime flux levels, but has not reached this point some 50 seconds after thruster firing ceased. These apparent variations in response time, therefore, tend to obscure the possible association of thruster firings with data perturbations.

An enhanced view of the steep thermal tail below 2 eV is seen in the spectrum of figure 5. This suggests that the generally negative (1-3 volts) vehicle potential had decreased or gone positive at this time, allowing more of the very low energy electrons to enter the analyzer, thus allowing more of this tail to be observed. This is supported by independent measurements from a companion experiment (ref. 2), the data from which indicates a vehicle potential of about +0.8 volts at the time this spectrum was taken.

That thruster firings may contribute to higher flux levels is consistent with the data shown next in figure 6. This relates to a 35 second orbital maneuvering system (OMS) burn which occurred during this period. The OMS employs the same hypergolic reeaction as described for the thrusters except that each of the two engines in this system generates 6000 pounds of thrust as compared to only 24 pounds for each of the vernier thrusters. This figure shows two typical individual spectra, the lower of which was taken prior to the OMS burn, and the upper taken during and immediately after the burn. Only a little over two minutes separated these individual spectra in time and yet a difference of an order of magnitude or more is seen in the flux levels.

A substantial number of spectra were obtained while the shuttle was in a bottomto-the-sun attitude and while these were almost exclusively daytime data, their flux levels were among the lowest of the flight. Typically, these spectra were indistinguishable from nighttime measurements. It seems likely that the term "bottom-to-the-sun" can explain these low fluxes: There was almost certainly large numbers of solar photoelectrons being generated at the sunlit bottom surfaces of the wings and fuselage during these periods. The subsequent trajectories of these electrons would largely be governed, exclusive of collision processes, by the geomagnetic field lines. And no matter what the orientation of these lines, it seem unlikely that many of these electrons could migrate into the shuttle bay area and enter the acceptance cone of the analyzer.

There was little or no thruster activity during all measurements of this mode and there was very little variation between individual spectra obtained during these periods; this is again consistent with the possible correlation data perturbations and thruster firing. There was a passage from day to night in the 10 minute bottom-to-the-sun run illustrated in figure 7 which did not appear to have any effect on spectra except at very low energies. This is an averaged spectrum but it very closely represents all those obtained, both day and night, except for the 1-3 eV region where an enhanced view of the thermal tail again appears. The maximum data point for this tail was a factor of 2 or more higher than shown in this averaged spectrum, and was fairly constant in the daytime spectra. Following eclipse, this dropped immediately by a factor of 8 to 10 and remained quite constant in all of the night spectra. This again suggests a diminished vehicle potential and, again, this was supported by the independent measurements of reference 2. It also indicates the influence of daytime solar photoelectrons on the low energy (1-3 eV) region of these spectra but not elsewhere which, in turn, indicates the influence of collision processes since most of these electrons must have come from the sunlit side. Note also that the data points in the extreme low energy region of this spectrum are seen to be reduced substantially below the maximum point, an effect observed in all the spectra of this run. This was due, almost certainly, to geomagnetic shadowing. The orientatin of the geomagnetic field lines throughout the run was toward the aft quarter and downward with respect to the vehicle, or to the right and downward with respect to the analyzer look direction. This means that some electrons spiraling about field lines in trajectories that would normally bring them within the acceptance cone of the analyzer could, in some cases, be intercepted by vehicle or payload components and thus be lost to collection. The lower energy electrons are most vulnerable to such shadowing effects because of their shorter Larmor radii. In the case of the high termal tail seen earlier in which no such effect was observed, the field lines were oriented to the left, or forward, and above, where no vehicle or payload components existed to obstruct the electron paths.

Figure 8 shows a spectrum typical of all those obtained during two of these bottom-to-the-sun periods. These were daytime measurements during which there were no thruster firings and virtually no difference between individual spectra. Note the valley-like structure in the 2-4 eV region. This feature was present in all spectra of these two consecutive runs and is strongly suggestive of the N_2 vibrational excitation energy loss mechanism (the nitrogen bite-out) mentioned earlier as a characteristic of ambient spectra below 200 km. This would not be expected to appear in ambient spectra at the shuttle altitude (300 km). But if sufficient N_2 were present, the mechanism that produces this structural feature should prevail. Residual N_2 from the MMH/N_2O_4 thruster reaction might possibly have provided this. The question of why this feature was seen only in these data, but seen consistently throughout them, has no immediate answer.

SUMMARY/CONCLUSIONS

Undoubtedly, the most remarkable feature of these measurements is the relatively flat spectral distribution of higher energy electrons which was consistently observed but remains essentially unexplained. And while the data associating quantitative electron flux excursions with thruster and OMS firings can be considered pursuasive, it cannot be considered conclusive based on these data alone. The data do seem conclusive in indicating that locally generated solar

photoelectrons contribute substantially to the daytime electron environment of the shuttle. Other observed departures from the general characteristics of these spectra also lend themselves to explanations as, for example, geomagnetic shadowing or the N_2 bite-out mechanism. And the occasional enhanced observations of the steep thermal tail is probably explained by departures in vehical potential levels. Many questions remain, however. A reflight of this experiment, modified as earlier described, should provide very useful additional data and, possibly, some answers.

REFERENCES

1. McMahon, W.J. and Heroux, L., Rocket Measurement of Thermospheric Photoelectron Energy Spectra, J. Geophys. Res., 83, 1390 (1978).
2. Smiddy, M; Sullivan, W.P. Girouard, D.; and Anderson, P.B., Shuttle Electrical Environment, Proceedings of Spacecraft Environmental Interactions Conference, Paper I-4, NASA Lewis Research Center, (1983).

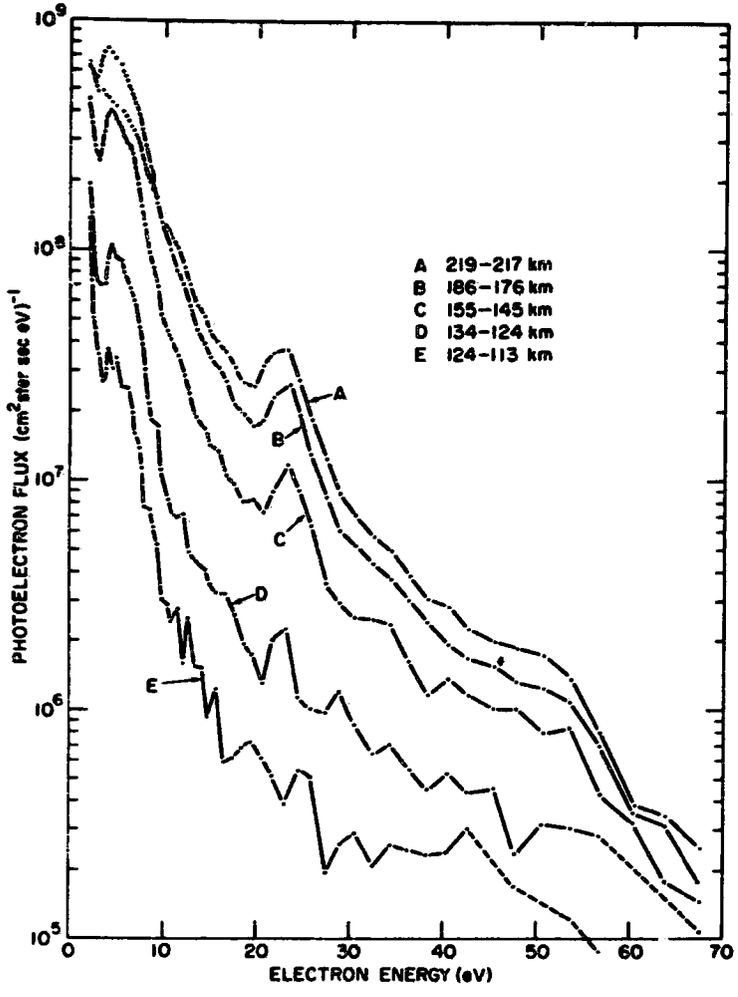

Fig. 1 Examples of typical ambient electron spectra, obtained under conditions of minimal contamination, for comparison with shuttle measurements.

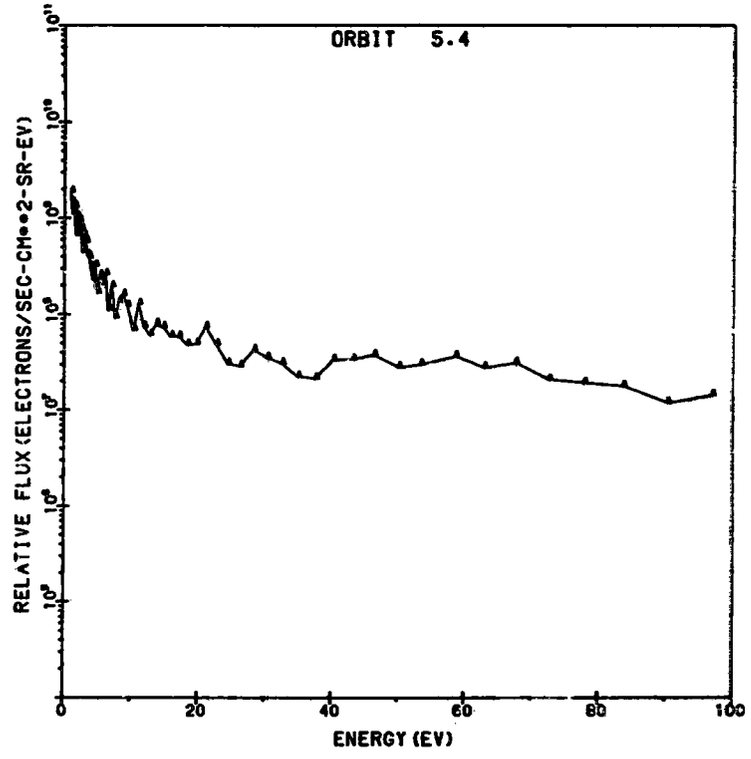

Fig. 2 Electron energy spectrum typical of all shuttle measurements. The paramount feature is the relatively flat distribution for energies greater than 50 eV out to the highest measured. The coordinates of all figures showing shuttle spectra are common to facilitate comparisons between them.

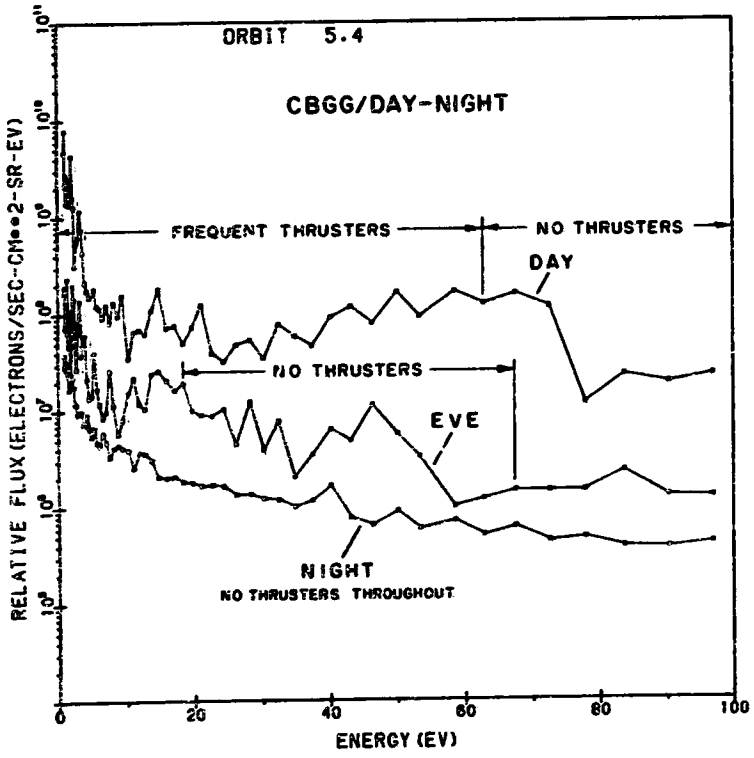

Fig. 3 Individual spectra from day-night measurement period showing daytime fluxes considerably higher than those of nighttime spectra. Data point excursions and their possible correlation with thruster firings are discussed in the text.

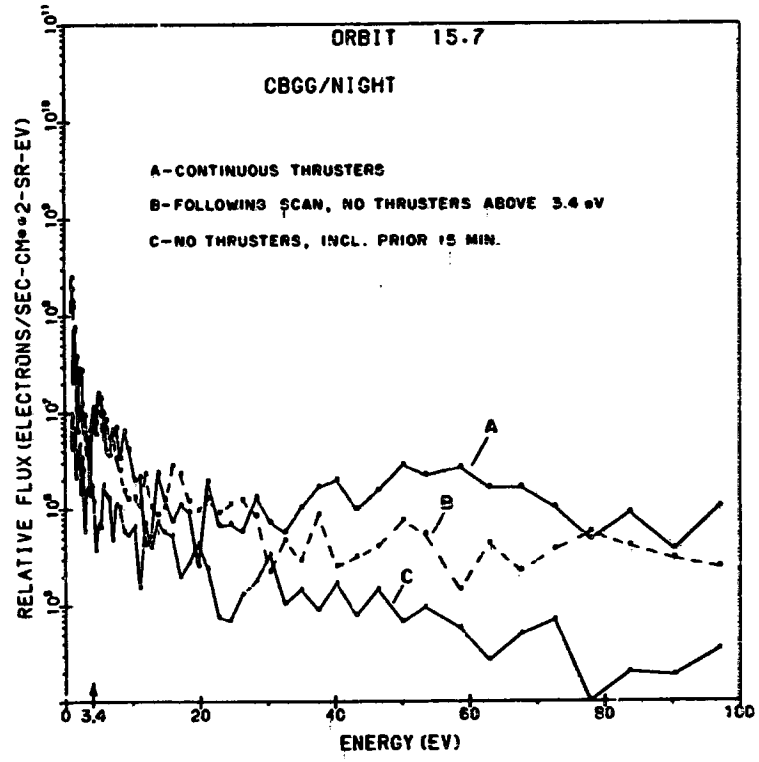

Fig. 4 Additional comparison of individual nighttime spectra with thruster firing periods.

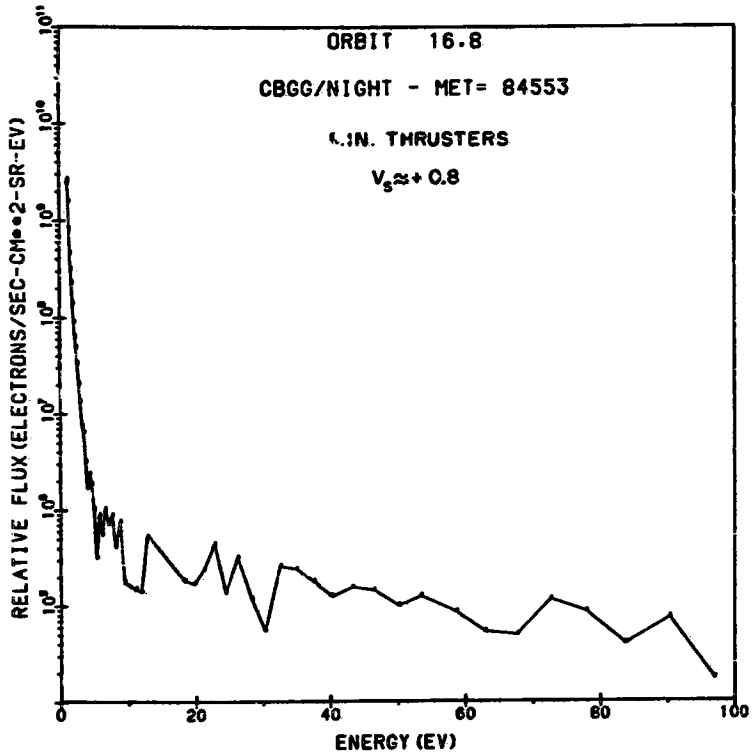

Fig. 5 Enhanced view of thermal tail, apparently due to varying vehicle potential. This potential had departed from its usual slightly negative value to about +0.8 volts at the time this spectrum was taken.

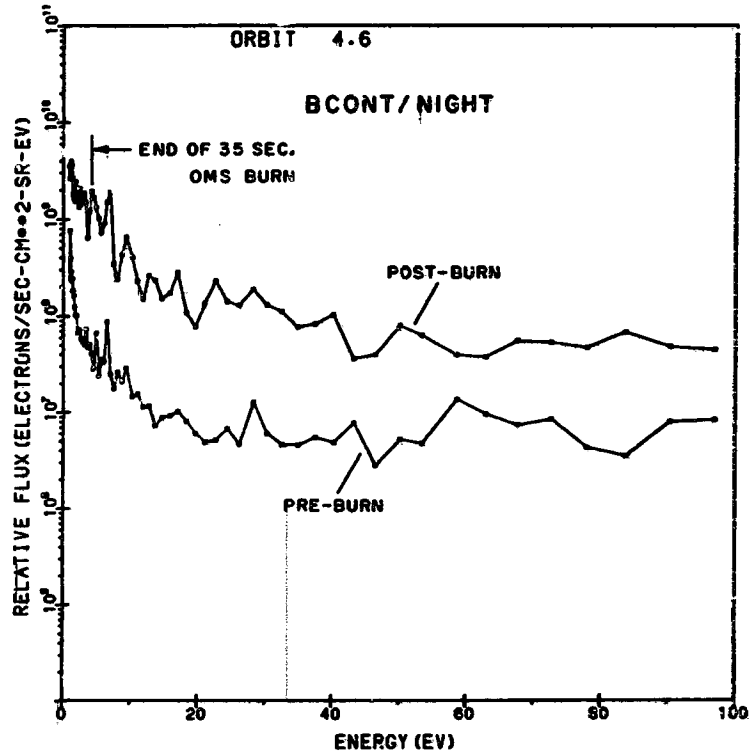

Fig. 6 Before and after spectra related to short OMS burn. The apparent delayed response of flux levels to the burn is seen. These spectra were obtained about two minutes apart.

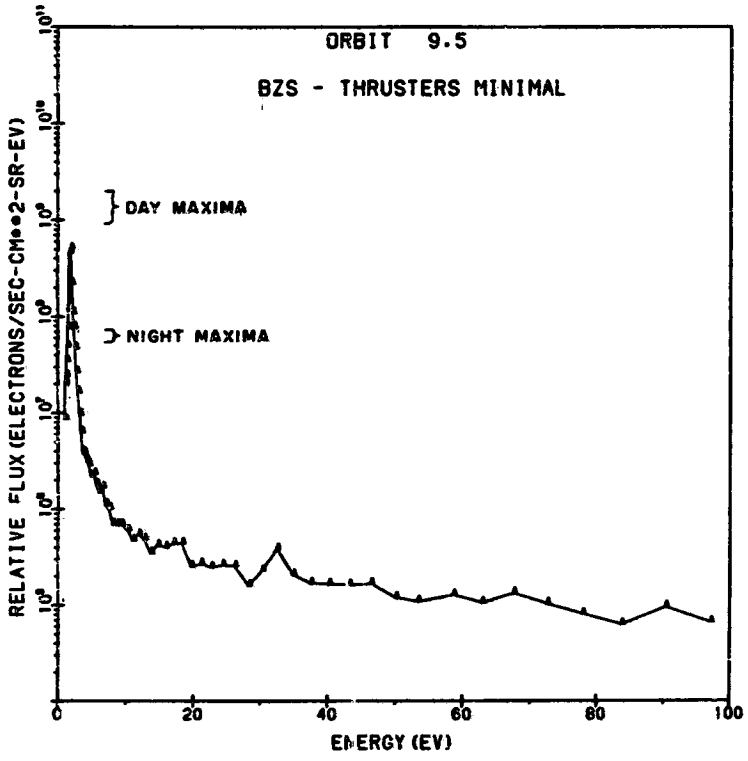

Fig. 7 Bottom-to-sun spectrum representative of those obtained during day-to-night measurement period. Beyond about 3 eV there was no day/night difference in any of these spectra. A diminished but constant vehicle potential coincided with an enhanced view of the thermal tail, the maximum point of which was seen to drop rapidly following eclipse. The effect of geomagnetic shadowing is also seen in the extreme low energy region.

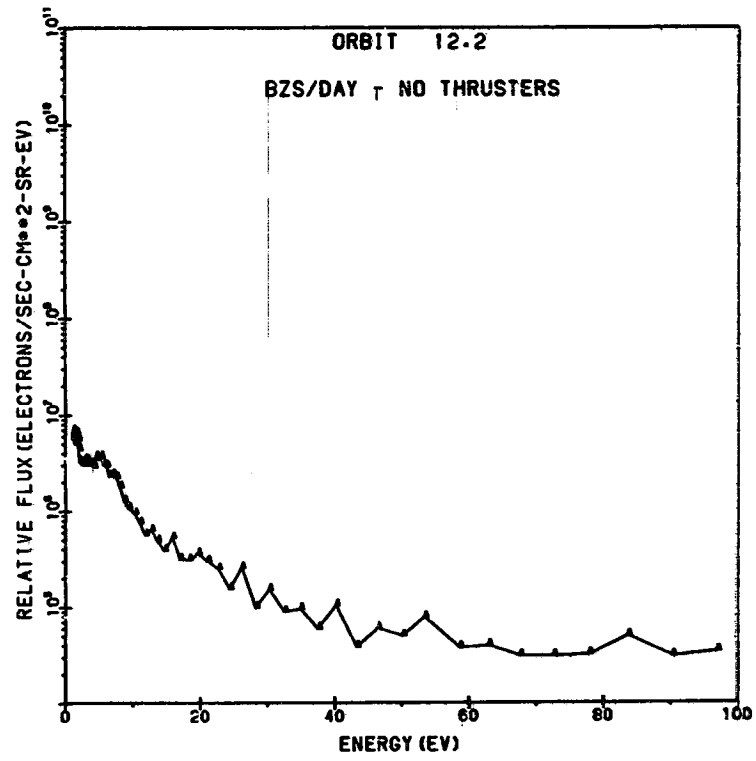

Fig. 8 2-4 eV spectral structure suggestive of the N_2 vibrational excitation energy loss mechanism.