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ELECTRON BEAM EXPERIMENTS AT HIGH ALTITUDES

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ABSTRACT

Experiments with the electron emitters on the SCATHA satellite produced evidence of beam plasma interactions, and heating of the low energy electrons around the satellite. These experiments were conducted near geosynchronous orbit, in the dusk bulge, and plasma sheet, with one short operation in the lobe regions, providing a range of ambient plasma densities. An electron gun was operated at 50 eV, with beam currents of 1, 10 and 100 µA. Also, a filament emitter was used in a mode where it was biased —100 V w.r.t. the satellite, at a current setting of 20 µA. Data from electrostatic analyzers show that the satellite charged to near the beam energy in sunlight, if the beam current was sufficient. Higher ambient electron fluxes necessitated higher beam currents. The electrostatic analyzers showed distribution functions which had peaks, or plateaus at energies greater than the satellite potential in the daylight experiments. These measurements indicate heating of the ambient plasma, at several Debye lengths from the satellite (several 10's of meters), with the heated plasma then accelerated into the satellite. It is likely that the source of the heated plasma is in fact the photoelectron sheath generated by the satellite.

INTRODUCTION

Electron Beam Experiments

Electron beam experiments have been conducted in the ionosphere and magnetosphere for almost two decades, in order to investigate basic plasma processes, vehicle charging, and magnetospheric fields and structures /1/. One element of such experiments which is of current interest is the occurrence of beam—plasma interactions. Most recently, such interest has been stirred by experiments with the Spacelab I SEPAC payload, both in flight and in ground tests. It has been suggested that a beam—plasma discharge is established in the region of the cargo bay /2/. In this work, we consider data from a high altitude satellite which also indicate interactions between an emitted electron beam and the ambient plasma.

Satellite and instruments

The P78—2 satellite was launched as part of the joint Air Force/NASA program to study Spacecraft Charging at High Altitudes and, is also called SCATHA /3/, SCATHA was launched on 30 January 1979 into a nearly geosynchronous orbit, with apogee at 7.8 RE.

The spin axis was nominally perpendicular to the earth-sun line, in the orbit plane, and the spin period was 59s. The satellite was cylindrically shaped, with a diameter of 1.7 meter, and a height of 1.75 meter. The satellite has a mixture of insulating and conducting surfaces. The 'top' of the satellite is a conducting surface, while the sides are primarily solar cell glass covers (insulators). There is a conducting belly band, and the 'bottom' is composed of insulators, particularly the injection motor cavity.

The electron gun experiment was designed to conduct studies of induced satellite charging and discharging. Its primary purpose was to counter the large negative potentials routinely encountered in the midnight to dawn sector by geosynchronous satellites, such as ATS-6 and the kilovolt potentials measured in eclipse by ATS5 and ATS6 /4,5/. The electron gun could be operated at currents from 1µA to lmA, at beam voltages of 50 eV to 3 keV. The electron gun was located on the belly band, and the beam directed radially away from the satellite. In addition to the electron gun, there was a filament neutralizer associated with the ion accelerator which could be operated independently. This package was located on the 'bottom' of the satellite. The neutralizer mode encountered in this article used a 100 V bias on the filament, and a current setting of 20 µA.

The UCSD particle detectors were mounted on the top of the satellite, on the side opposite the electron gun. The detector consists of 5 electrostatic analyzers (ESA's). Two sets of paired ion and electron ESA's are mounted in rotating detector assemblies. The HI detectors cover the 1-eV to 81-keV energy range in 64 steps, while the LO detectors cover the 1-eV to 1800-eV energy range. The rotating detectors may rotate over a 2200 range, including parallel to the spin axis, and radially away from the satellite. An energy sweep requires 16 seconds, and the detectors can be set to dwell on one energy step for up to 120 seconds. For practical purposes, pitch angle distributions are obtained by parking the detectors such that they point perpendicular to the spin axis, and high time resolution (of the 90° pitch angle particles) is obtained by parking a detector looking parallel to the spin axis. These detectors are similar to those flown on ATS-6 /6/.

OBSERVATIONS

50 eV - 10 μA - Sunlight

Data from a sequence of operations on 20 July 1979 (Day 201) are presented here. Data from 0600 UT are shown, illustrating experiments in the plasma sheet, near local midnight (0130 LT). This is a disturbed day; ΣKp = 24+, Kp = 2+ for 3-6 UT. The satellite is in the plasma sheet at 7.4 R_E, 17°λ_m . The plasma sheet electrons can be characterized with a density of 0.7 cm $^{-3}$. and temperature of 8.6 keV. The electron gun was operated at a beam energy of 50 eV, and a current of 10μA.

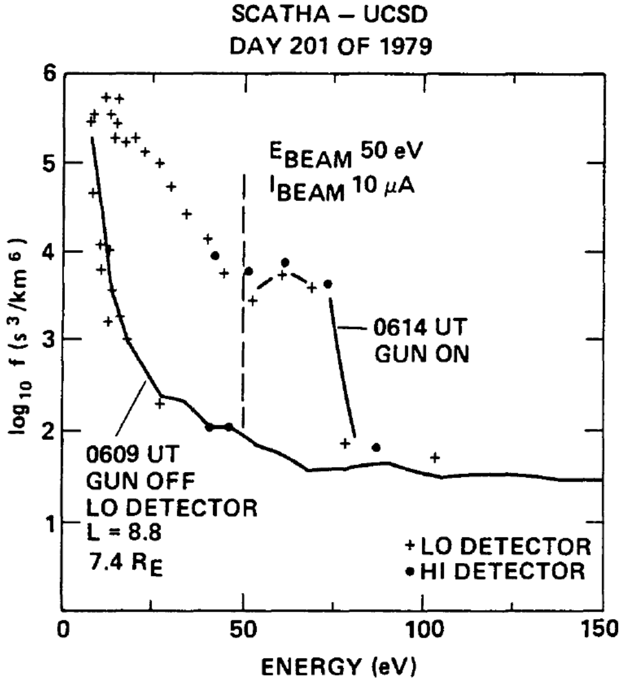

Figure 1

The 0-150 eV, 90° pitch angle, electron data are shown as a distribution function in Figure 1. In this format Maxwellian (e.g., thermalized) distributions will appear as straight lines. When the gun is off (0609 UT), the boundary between spacecraft generated photo electrons and ambient plasma at 10 to 15 eV suggests a satellite potential of +10 to +15 V /7/. When the gun is switched on, a different equilibrium is quickly established. SCATHA charges to near the beam energy (50 eV), and enhanced fluxes appear both above and below 50 eV. There is not, however, a peak at 50 eV, as would be expected if the mono-energetic beam electrons returned to the satellite; nor is there a peak which could be attributed to cool (T ~ 1 eV) ambient electrons which have fallen through a 50 eV potential drop. Instead, there is a local minimum at 52 eV, and a peak above 50 eV, or at least a plateau from 55 to 75 eV. If the 0609 (gun off) data are shifted upwards in energy by 35 eV and if the only changes in the plasma measurements are those due to the increase in satellite potential, Liouville's theorem requires that the distribution functions overlap. They do so above about 80 eV, for the unperturbed magnetospheric plasma. It is clear from this comparison, however, that the 55 to 75 eV data represent a ‘new’ population, and do not simply represent a charging effect. The density in the 55 to 75 eV portion of the distribution function is about 1 cm^{-3}. This is comparable to the ambient density. The 20-45 eV electron data show a density of 124 cm^{-3}, and temperature of 6.3 eV.

Dusk bulge - sunlight

During experiments later on this day, in the dusk bulge, higher currents were required to charge the satellite. A current of 10~A charged the satellite to about +30 V, but there was no peak in the distribution function above that energy. When the beam current was increased to 100 µA, the satellite potential increased to +50V, and a peak appeared above 50 eV. These data indicated a dependence of the satellite potential on ambient plasma density and beam current, which is expected. Also, there is a dependence of the ‘plateau’ effect on the ambient plasma conditions, and beam current.

100 eV - 20 ~A - Eclipse

One possibility for the enhanced flux of (apparently) heated electrons is that these are heated photoelectrons. To shed some light on this idea, data taken in eclipse were sought for comparison. The data which are closest in nature to those shown above are for an experiment with the filament electron emitter associated with the ion gun. On 1 April 1979 (Day 91), the satellite was in eclipse, and charged to near zero volts when the filament was turned on. The filament was biased —100 V with respect to the satellite, effectively generating a 100 eV electron beam, with a current setting of 20~A. The result was that the satellite charged to near, but apparently less than 100 V. The resulting electron distribution functions are shown in Figure 2. A peak, or plateau is found between 80 and 100 eV. The environment is much cooler on this day, and the ambient plasma density should be higher than in the first example. If the “emitter off” data are shifted in energy by ~80 eV, the distribution function overlaps the “emitters on” data. Hence, it is possible that there are no changes in the plasma around the satellite due to the gun operation, simply an increase in satellite potential to about +80 V. Unfortunately, the energy resolution ($\Delta E/E$ = 20%) for the instrument makes it difficult to determine if the peak is truly accelerated low energy ambient electrons, or locally generated plasma, as inferred for the daylight events. In addition to the cold ambient plasma, there will be a substantial flux of low energy secondary electrons generated at the spacecraft surface by the ambient plasma.

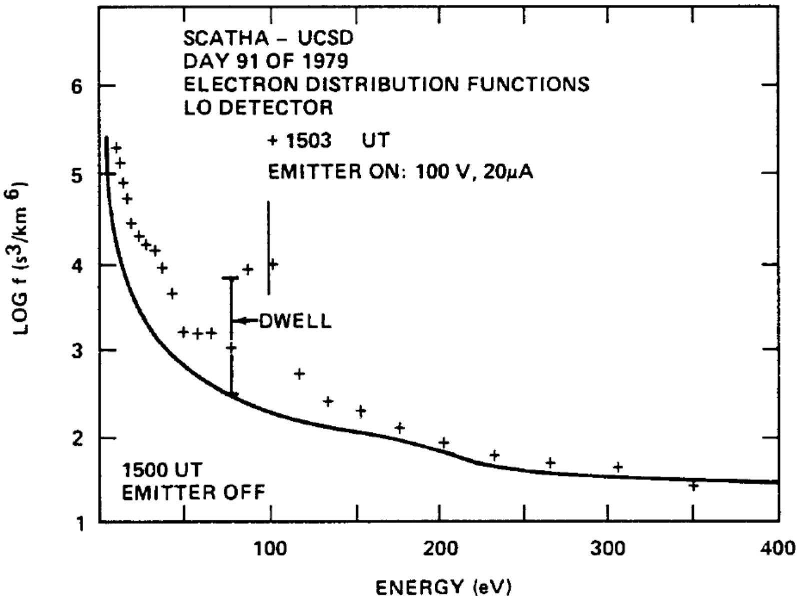

Figure 2

CONCLUSIONS

The electron gun operations on SCATHA conducted in July, 1979, resulted in charging of the satellite to potentials up to the beam energy, at beam currents which depended on the ambient plasma parameters. If the beam current is not high enough, the satellite charges to a potential below the beam energy. During the 10µA experiment in the dusk bulge, no additional effects are inferred. At 10 µA in the midnight region, and 100 µA in the dusk bulge, an additional feature appeared - a peak in ghe distribution function above the satellite potential.

The electrons in the peak are neither from the grounded satellite surfaces, by conservation of energy, nor from the ambient plasma, by the shape of the distribution function. These electrons must be the result of interactions between the electron beam and the other electrons around the satellite. This latter population includes not only the ambient plasma, but the spacecraft generated photoelectron, which represent a higher plasma density than the ambient (~100 cm^{-3} vs. 1 cm^{-3}**)** in the region near the satellite. If the beam interacts with these other electrons, then scattering of the beam electrons could produce the plateau in the distribution function above the satellite potential. Also, the enhancement below the satellite potential can be explained as the result of heating the ‘local’ photoelectrons, in sunlight. This hypothesis is supported by an apparent lack of similar features in the eclipse data. It is possible that differentially charged insulating surfaces are a source of photoelectrons or secondary electrons which at least have the proper energy to act as a source for the electrons above the charging peak.

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