SATELLITE SURFACE POTENTIAL SURVEY*

Paul F. Mizera+ and G. M. Boyd
Space Sciences Laboratory
The Aerospace Corporation

SUMMARY

Results of Kapton differential voltage charging of the SSPM Kapton samples are presented for the first 100 days of P78-2 operations. Daily charging occurrences are plotted in magnetic local time and L-shell (altitude and magnetic latitude) space as a function of magnetic activity. Most of the low level charging occurs well into the dawn local time sector whereas the highest voltage levels occur in the premidnight local time sector. The probabilities of differential charging are extremely dependent on the local time sector, the altitude (or L-shell) and of course, the magnetic activity.

One of the critical engineering experiments flown on the USAF P78-2 satellite was the Satellite Surface Potential Monitor (SSPM). In order to properly characterize spacecraft charging the following observations are necessary: the three dimensional charged particle environment of both high and low energy ions and electrons; the resulting charging profiles of the spacecraft ground and dielectric materials; and electrostatic discharges when material charging levels are sufficiently high relative to adjacent objects. Various models of charging and discharing are currently being developed and used in the laboratory and their predictions must be validated by space data which can only be provided by in situ measurements. To date significant progress has been made in this direction by the SCATHA community using data from the P78-2 experiments. Two charging events, April 24, 1979 (ref. 1,2) and March 28, 1979 (ref. 2) have played a major role in the quantitative understanding of spacecraft differential charging both in sunlight and eclipse.

In addition to individual charging events, a long term statistical survey of spacecraft charging is necessary in order to provide the spacecraft community with information for design guidelines. Material characterization is an integral part of these design criteria. The work presented here is the first part of the SSPM charging survey currently underway at the Space Sciences Laboratory of The Aerospace Corp. To date a little over 100 days of data covering the time interval of Feb. 7 through May 26, 1979 have been processed and results of the differential charging will be discussed.

---

*Work performed under USAF Contract No. F04701-79-C-0080

+ On leave at Center for Astrophysics and Space Sciences, University of California, San Diego, La Jolla, CA

Since the inception of the SCATHA program, a back surface measurement was proposed and some results have been presented in references 1 and 2. The best way of judging the validity of the measurements is to analyze the results and interpret them correctly. The following data will show that the SSPM measurements of material charging are a valid technique to describe substorm injection events and the charging of spacecraft materials in space.

Figure 1 shows the response of the back surface potential measurement of the SSPM-2 Kapton sample to the charging environment in the post-dawn local time region on April 21, 1979. The energetic electron environment is primarily responsible for material charging as seen by the integrated flux of electrons with E from 5 KeV up to 80 KeV plotted in Figure 1. These data are averages over the 90° pitch angle spectra provided by the UCSD SC-9 spectrometer (P. Isenberg, personal communication 1980). The SSPM potentials are the maximum value attained in 64 sec time interval which is approximately one satellite rotation into and out of sunlight.

The correlation between the energetic charging current above the secondary electron crossover energy and the maximum SSPM-2 Kapton voltages reached during the same time intervals is remarkably good. The secondary electron crossover occurs below ~ 2 KeV where the secondary yield becomes greater than one. Therefore the results of the SSPM survey using the same measurements should be a valid indicator of substorm injection events and times when differential charging is occurring on the P78-2 satellite due to energetic electrons.

The first 104 days of the SSPM operation are used for these survey results. Since Kapton plays a major role in the SSPM experiment, one of the two Kapton plays a major role in the SSPM experiment, one of the two belly-band samples (SSPM-2) was used to indicate levels and probabilities of occurrence of differential charging of typical spacecraft materials. When levels greater than -50 Volts were observed during any 64 sec time interval of the 104 days survery, the measurements were recorded on an output tape along with all remaining SSPM outputs and selected environmental and geophysical parameters. Each 64 sec intervals was then examined for the maximum voltage attained and binned according to various geophysical parameters including L (drift shell), magnetic local time and magnetic activity as defined by the global index Kp.

Figures 2a, b and c show a polar plot of the occurrence frequency greater than 100 Volts for quiet and disturbed magnetic conditions and greater than 1000 Volts for disturbed conditions respectively. Charging must have occurred at least 5 of the 64 sec intervals in a given 1 hour local time bin for the results to be valid.

The total number of days where this occurred are plotted in Figure 2. Figure 2a shows voltages greater than -100 Volts for quiet conditions defined as Kp < 2+. The separation at 2+ is arbitrary and more or less divides the total sampling intervals equally. Contours are indicated by the cross-hatching and represent levels of 5% and 10% probabilities of charging. [That is 5 days/104 ≈ 5%]. The results of Figure 2 are not meant to show exactly the probability of charging but to show the spatial regions where charging is most probable. Comparing Figure 2a and Figure 2b, one immediately sees the effect that magnetic activity has on differential charging. Only when Kp > 2+, does the probability of charging approach 20%. In addition, the maximum occurs in the dawn local time region and at high L shells which is a combination of altitude and magnetic latitude. That is, an L value > 7.5 means the satellite is off the equator and at high altitude.

Figures 2a and 2b show a differential charging threshold greater than -100 Volts, a relatively low level. Figure 2c shows levels greater than -1000 Volts and indicates a few interesting results. That is, highest levels of charging occur near local midnight during eclipse times and high magnetic activity. This is just because no solar UV is present to discharge the materials. There is an additional complication however; the entire spacecraft also charges to high voltages in the shadow and the SSPM measurement is the voltage of material relative to the spacecraft frame. This means the true absolute potential is the sum of the SSPM and the voltage of the spacecraft and is not taken into account here. Another interesting result is that the region of highest potentials reached is not the same as where the maximum probability of occurrence is found. That is, approximately 5% of the time in the 20-24 hours local time interval, greater than -1000 Volts differential charging occurred and almost no charging greater than -1000 Volts was recorded beyond 4-5 hours local time. This is just the opposite of the low level charging as seen in Figure 2b where up to 20% of the time, charging was observed in the 6-7 hours local time region. Another interesting contrast is that very little charging occurs for quiet magnetic conditions in the premidnight versus the postmidnight local time sectors.

The complete results of the Kapton charging survey are better presented in probabilities of occurrence above voltages from -100 volts to greater than -1500 volts. Before these results are discussed, a brief explanation of the satellite coverage is advisable. Table I shows the survey broken into bins of 64 sec intervals and separated into four local time intervals; 0-6, 6-12, 12-18, and 18-24 hours magnetic local time. In order to study the altitude dependence, the data were sorted into low (< $6.6R_E$) and high (>$6.6R_E$) L shells: 6.6 R_E is of course geosynchronous altitude. The last category used was quiet and disturbed magnetic conditions. (Kp = 2+ was used as the break point.)

One immediately sees from Table I the sampling bias in the data coverage over the the 104 days of the initial survey. Apogee of the P78-2 was initially in the dawn sector and local time changes only 1 degree or 5 minutes per day. Therefore apogee swings from dawn to dusk over a 1/2 year interval. Of particular importance is the poor coverage of the satellite in the dawn local time sector at L shells below geosynchronous altitude and above $6.6R_E$ in the dusk sector. This will be discussed later.

Figure 3a shows the percent probability of occurrence, P [>V], of Kapton charging above a given voltage level from -100 to -1500 Volts in a 64 second sampling interval. This value represents the maximum value reached in that interval. The accumulated results are divided into post-midnight to dawn (0-6 hours) and dusk to pre-midnight (18-24 hours) and disturbed (Kp>2+) and quiet (Kp< 2+) magnetic conditions. Figure 3a is for L shells above geosynchronous (6.6 R_E) altitude whereas Figure 3b is for L < 6.6 R_E. The average probability of low charging levels is approximately equal for post-midnight to dawn and dusk to pre-midnight and reaches values of 35-40% for Kp<2+. Above -500 Volts, however, the dawn probability decreases significantly while the dusk probability curve remains constant for quiet conditions (Kp< 2+) but drops by almost a factor of ten. Only at low voltages does the dawn quiet time charging results. One should note from Figs. 3a and 2a that the dusk probability curve is the result of charging just before local midnight.

The low altitude results in Figure 3b show some additional interesting trends. For disturbed magnetic times, the dusk probability has a similar shape as both the disturbed and quiet, high altitude results with the probability values closer to those at the quiet times. In contrast, the dawn curve in Figure 3b is distinctly different from those in Figure 3a. Perhaps as striking is the null result for the dawn charging at quiet times for L < 6.6. Referring to Table I, the poorest satellite coverage is in this region of space. Nevetheless, the sampling is sufficient to suggest a very strong decrease in the charging probability near dawn during quiet times and at low altitude. We would estimate an upper limit of 0.1% probability of charging to -100 Volts for the post-midnight to dawn sector in Figure 3b.

SUMMARY OF SURVEY RESULTS

Based on the first 100 days of P78-2 operations, the SSPM charging results provided some extremely interesting preliminary results, both engineering and scientific. Using the Kapton voltage measurement as a monitor of the hot charging plasma environment, a number of preliminary conclusions can be reached. For those interested in differential charging in the earth's outer radiation belts, Figures 2a and 2b show some interesting patterns. That is, at a local time near 06 to 07 hrs at L > $7.5R_E$, there is a 20% chance of charging Kapton greater than -100 Volts in magnetically disturbed conditions. The probabilities drop to approximately 10% and are located more toward post midnight as the magnetic conditions become quiet. However the highest charging levels occur in the dusk local time regions.

Figure 3 shows this a little clearer (especially Figure 3a) during disturbed conditions. The dawn local time shows the mot variability in charging conditions. This is most likely related to dynamic plasma transport processes at work in this region fo the earth's magnetosphere.

The final results should be most applicable to the engineering community interested in overall charging occurrences. If we combined all of the SSPM survey results into two categories, quiet (Kp< 2+) and disturbed (Kp>2+) magnetic conditions, the probability of differential charging of Kapton greater than -100 Volts is 8.4% and 19.9% respectively. For levels greater than -1000 Volts, the probabilities drop 0.064% and 0.80% respectively. This means on the average for a spacecraft flying in a high altitude orbit similar to the P78-2 satellite, when the global magnetic 3 hour index Kp is greater than 2+, there is almost a 20% chance of charging a dielectric similar to kapton to voltages over -100 Volts if that material is shadowed by the spacecraft.

We must caution the reader, however, that most of the satellite coverage for this time period is biased toward high altitude dawn local time samples. There are regions in space and magnetic activity that are not covered by these 104 days and would require at least a year's worth of processed data to begin to provide adequate statistics of spacecraft charging for long term space missions.

REFERENCES

1. Mizera, P. F., Koons, H. C., Schnauss, E. R., Croley, D. R., Jr., Kan, H. K. A., Leung, M. S., Stevens, N. John, Berkopec, F., Staskus, J., Lehn, William L., Nanewicz, J. E.: First Results of Material Charging in the Space Environment. Appl. Phys. Lett., 37, 276, 1980.

2. Mizera, P. F., Leung, M. S., Kan, H. K. A.: Laboratory and Space Results from the SSPM Experiment. Accepted for Pub., J. Spacecraft and Rockets, 1980.

TABLE I SSPM SURVEY COVERAGE FOR THE FIRST 104 DAYS

NUMBER OF SAMPLES (64 SEC)

MLT (hrs)	L< 6.6		L>6.6		TOTAL
	Kp< 2+	Kp>2+	Kp< 2+	Kp>2+	
0-6	908	1,202	18,836	22,427	43,373
6-12	2,910	4,512	15,500	18,449	41,371
12-18	9,785	12,816	1,399	2,252	27,252
18-24	9,304	9,695	4,128	5,277	28,404

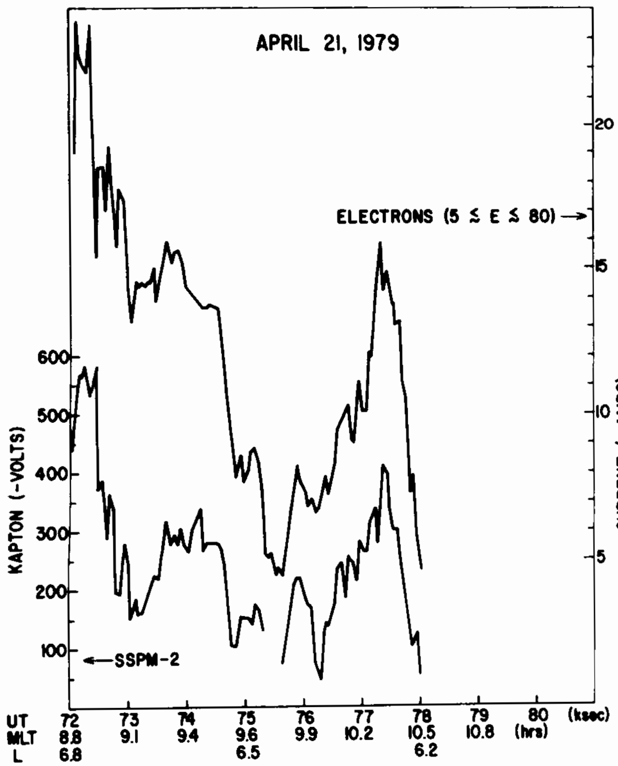

Fig. 1 -- Charging current from electrons with 5 <E <80 KeV and Kapton voltages for a post-dawn pass on April 21, 1979. The electron current is calculated from the average 90° pitch angle spectrum and the SSPM-2 Kapton voltage is the maximum value reached in a 64 sec sampling interval.

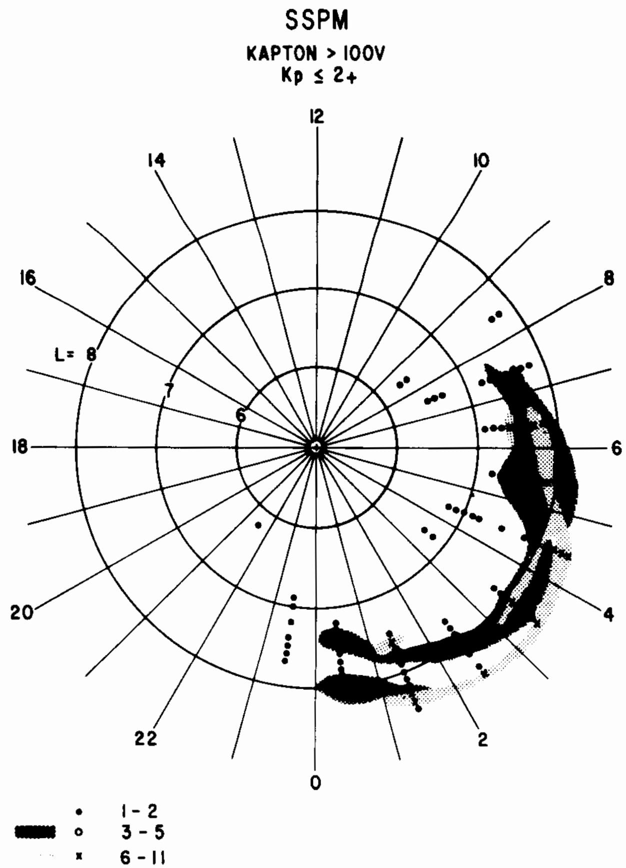

Fig. 2a -- The symbols represent the number of days when the SSPM-2 Kapton sample charged above -100 Volts sorted into 1 hour local time and 0.1 L shell bins. Only events where there was charging at least 5% of the time were considered valid observations. The cross-hatched contours represent approximately a 5% and 10% probability of charging.

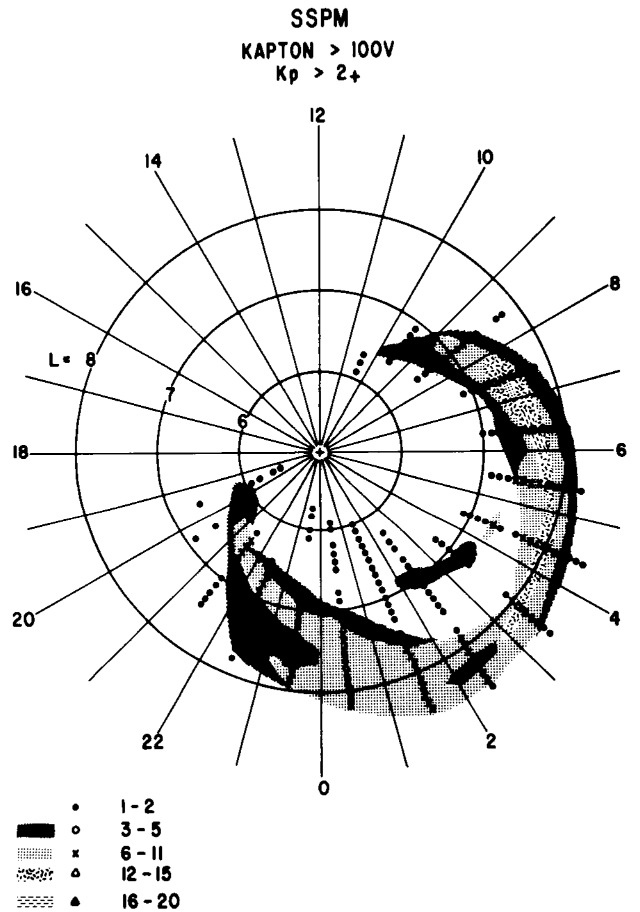

Fig. 2b -- Same as Fig. 2a but for disturbed times defined as Kp >2+. The charging probabilities increase to 20% in the 6-7 hr. local time region.

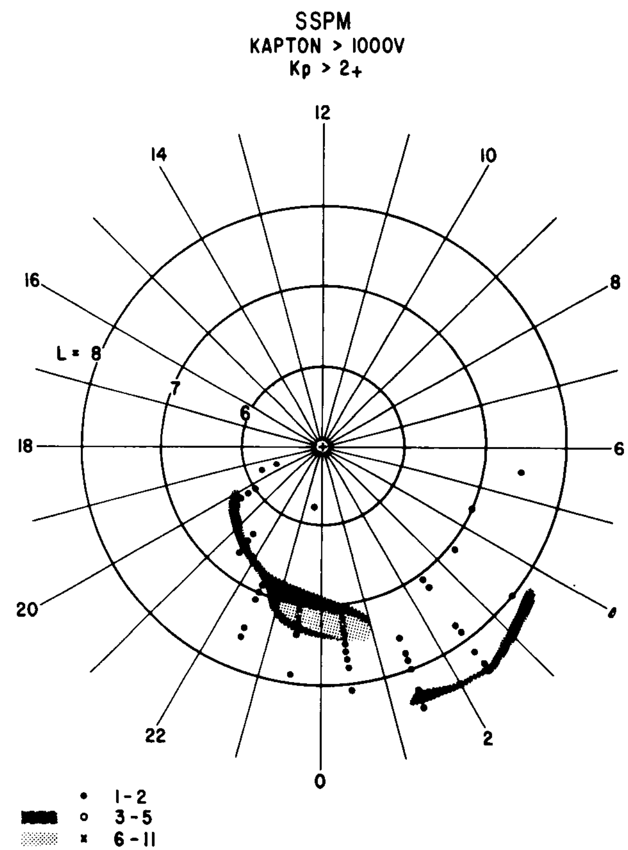

Fig. 2c -- The number of days when the SSPM-2 Kapton charged to greater than -1000 Volts during disturbed magnetic conditions. The maximum occurrence is ≈ 10% near local midnight and includes eclipse passes.

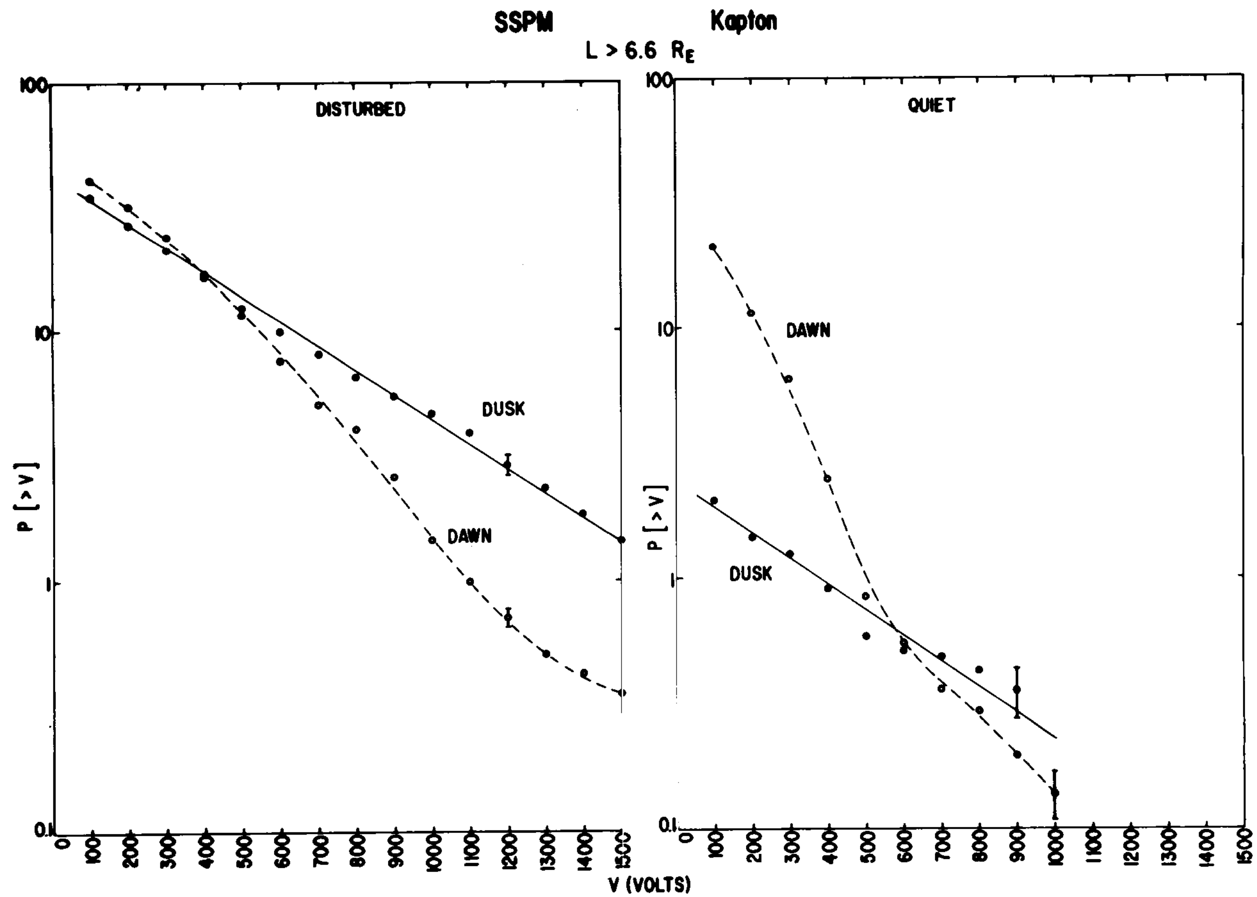

Fig. 3a -- Percentage probability of charging greater than V for high altitudes (>6.6 R_E) sorted into disturbed (Kp >2+) and quiet (Kp ≤2+) magnetic times covering 0-6 hrs postmidnight and 18-24 hrs premidnight local times. The curves are labelled dawn and dusk respectively.

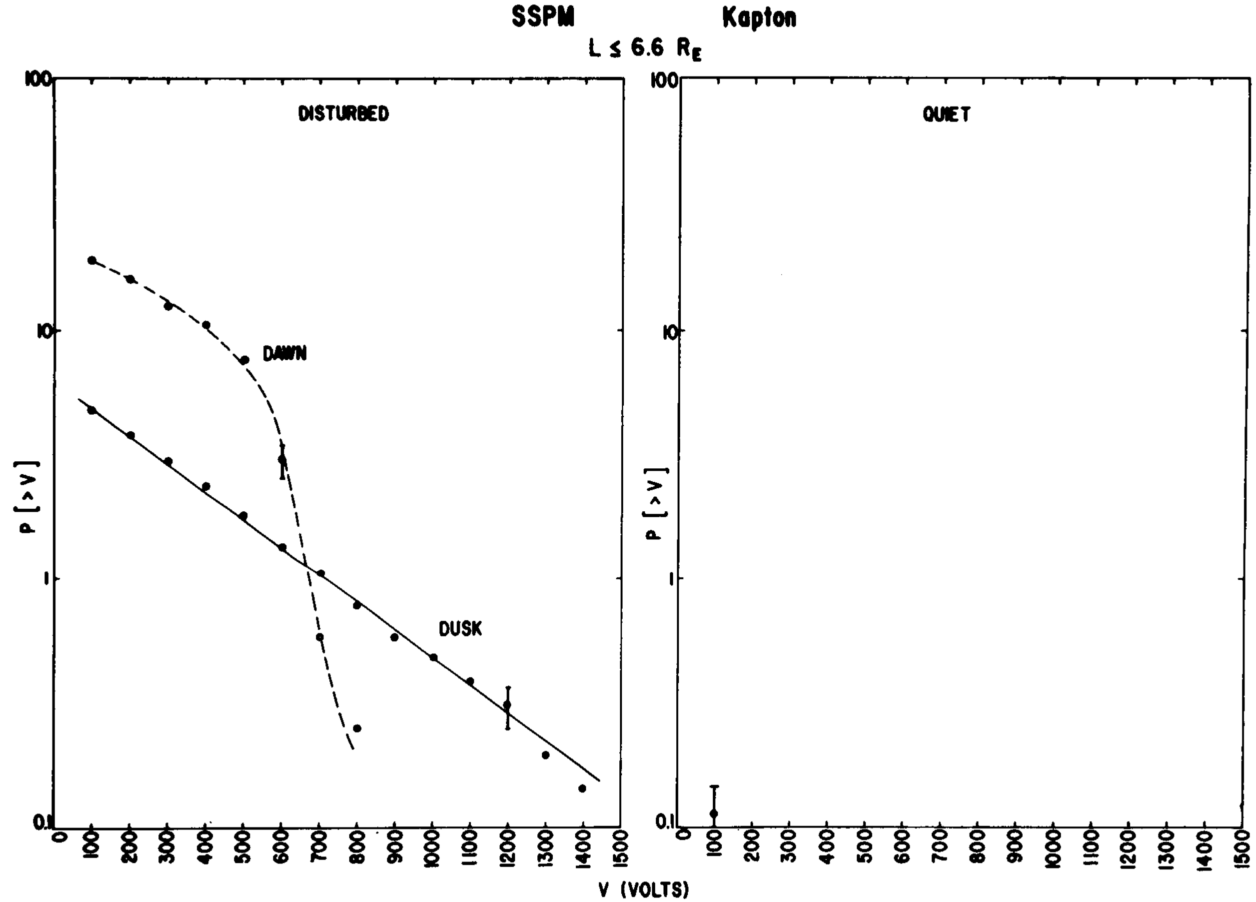

Fig. 3b -- Low altitude ($\lesssim$6.6 R_E) charging probabilities for postmidnight and premidnight local times again sorted into disturbed and quiet times and labelled dawn and dusk respectively.