GRANT/ LEWIS) IN-75
72675
29P.

INVESTIGATION OF BEAM-PLASMA INTERACTIONS

Final Report

NAG3-620

(NASA-CR-180579) INVESTIGATION OF BEAM-PLASMA INTERACTIONS Final Report (Alabama Univ.) 29 p Avail: NTIS HC A03/MF A01 CSCL 20I N87-22508
G3/75 Unclas 0072675

By

Richard C. Olsen, Ph.D.
Principal Investigator

Prepared For

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

Submitted by

The University of Alabama in Huntsville
College of Science
Huntsville, Alabama 35899

May, 1987

UAH Final Report on Grant NAG3-620 with NASA Lewis Research Center

R. C. Olsen
Physics Department
University of Alabama in Huntsville
Huntsville, AL 35899

May 19, 1987

I. INTRODUCTION

This grant has supported, over a two year period, the analysis of data from the SCATHA satellite pertinent to the problems of establishing electrical contact between a satellite and the ambient plasma. This work is in support of the NASA/LeRC efforts in tether technology, particularly for "plasma contactors". The original focus of the work was the electron gun experiments conducted near geosynchronous orbit, which resulted in observations which bore a startling similarity to observations of SEPAC experiments on SPACELAB 1. The study has evolved to include the ion gun experiments on SCATHA, a modest laboratory effort in hollow cathode performance, and preparation for flight experiments pertinent to tether technology. These areas are addressed separately in the sections which follow.

II. RESULTS

A. SCATHA electron gun experiments.

The SCATHA, or P78-2 satellite, was launched in 1979 with the purpose of studying satellite charging at high altitudes. It was heavily instrumented with particle and field experiments appropriate for that task, and included electron and ion sources for the purpose of actively modifying the satellite potential. It might have been thought that these data were irrelevant for tether technology development, a low altitude project, but observations from electron gun experiments at low and high altitudes in fact demonstrate a remarkable similarity. The initial impetus for this study was this similarity, as illustrated in Figures 1 and 2.

Figure 1 shows electron count rate from a spectrometer on SPACELAB 1, during SEPAC experiments with a 300 mA, 5 kV beam. Initially, the emitted current is balanced by positive current emitted from an MPD arc jet. As the 5 second electron beam firing continues, however, the MPD gas pulse fades, and the shuttle charges to a large positive potential. (about 1 kV). This charging was not in itself surprising. The curious observation was the enhanced flux of electrons at energies above the beam energy. (Wilhelm et al., 1984, 1986). Such features had previously been noted in the SCATHA data, as illustrated by Figure 2, from a typical SCATHA experiment (50 eV, 10 microampere). The peak in count rate was consistently observed above the beam energy (and satellite potential). One of the original objectives of the grant was to obtain distribution function plots of these data, and pursue the comparison further. This was done, and Figures 3 and 4 resulted, for the SEPAC and SCATHA data, respectively. The major feature of interest, enhanced fluxes above the satellite potential (and beam energy) remained evident, but the similarities seemed less clear after further study. Indeed, most of the subsequent consideration of the SEPAC data served only to make the comparison with SCATHA more obscure.

The SEPAC results have been further described by Taylor et al. (1985), Obyashi et al. (1984), and Sasaki et al. (1986, 1987). Similar experiments with the SPACELAB 1 PICPAB have been described by Torkar et al. (1986), and on a tethered rocket experiment by Oyama et al. (1986). Understanding of these observations is still limited, with possible interpretations along the lines of a beam-plasma discharge. It may be that the shuttle and rocket results are strongly affected by the neutral gas environment, which will limit our ability to draw analogies between shuttle and SCATHA. Katz et al. (1986) have suggested that space charge oscillations in the beam cause beam broadening, and have used this theory to model the SEPAC observations.

Proceeding with the analysis of the SCATHA data, it was found that the enhanced fluxes above the beam energy were a consistent feature of the electron gun experiments. The results were summarized for the 1986 NATO meeting (Olsen, 1986) and 1986 COSPAR meeting (Olsen and Cohen, 1986), and are in press. At present, it is felt that the data in Figure 4 result from either:

a) heating on the 'local' plasma by the beam, or

b) photoemission or secondary emission from differentially charged satellite surfaces.

If the former, the 'local' plasma is probably the local photoelectron cloud, or in eclipse, secondary emission electrons. A future task for a student is the modeling of the two possibilities.

If the local plasma is being heated by the electron beam, there should be a plasma wave signature of the heating process. A search of the available plasma wave data has only recently begun, and there are no results at this time. Previous reports by Koons and Cohen (1982) and Koons (1983) are inconclusive on this point.

B. Ion gun Experiments

Data from the ion gun experiments were more straight forward to analyze, due to the relative absence of spacecraft generated ions. It was quickly found that operation of the non-neutralized ion beam resulted in a satellite potential less than the beam energy. Operation at 1 kV, 1 to 2 mA resulted in typical potentials of -500 to -800 V, at equilibrium in sunlight. There were indications that the satellite initially charged to near the beam energy, and then rose to these equilibrium values in a period of a minute or so. This sort of temporal development was commonly observed during the electron emission experiments on ATS-5, and is puzzling. This area needs to be investigated using the NASCAP/SCATHA model, to determine if the mainframe current balance is being substantially distorted by differential charging on the insulating surfaces. Detailed results from analysis so far are described next.

1. Day 46 of 1979, Figure 5

The first day with UCSD data during the beam operations. The satellite charges to between -300 and -500 V during this period, with the beam on full. At 0934, the main discharge goes out, but the keeper remains on, and the high voltage remains on. The result is an operating mode called 'trickle mode', which emits a 20 microampere beam at 1 kV. The satellite potential which results is near - 10 V. Ions are seen below the charging peak during earlier portions of this operation, as seen at 0922 in the LO detector, where a thin line is seen just above the nominal charging peak. Spacecraft generated ions have been observed previously during negative charging on ATS6 and SCATHA.

2. Day 47 - 0800UT - Figure 6.

These data, taken at local midnight in the plasma sheet, show similar features. The spacecraft generated ions are again visible. This day also provides an opportunity to compare data with the SC2 experiment, which was on during this sequence. It shows a similar ion spectrum at and above the charging peak. At lower energies, however, differences are found. The body mounted SC2 detector shows ions down to much lower energies, and spin phase (pitch angle?) fluctuations. The SC2 data show ions down to the 40 eV channel

3. Day 47 - 1500 UT - Figures 7-12.

This is the most intensively analyzed segment, to date.

Figure 7 shows the spectrogram for 50 minutes of data. The turn-on transient at 1449 seems to show the satellite charging to near the beam energy (1 kV), and then dropping to near -500 V as the beam stabilizes. Ion gun telemetry show the gun current increasing or holding steady during this period, so the observation is counter-intuitive. The gun drops into trickle mode briefly, and a -10 to -20 V potential is found. The detailed look at the distribution functions shows:

Figure 8. The ion distribution function taken 7 seconds after the beam comes on shows a peak at 900 eV, suggesting a -900 V satellite potential. The UCSD detectors combine to give measurements several seconds apart, and it is found that 7 seconds later indicate a -800 V potential.

Figure 9. Ion distribution functions at steady state for beam off (top) and beam on (bottom). The satellite is at -400 V. This can be seen from the peak in the distribution function. Also, phase space invariance (Liouville's theorem) can be used to compare the off/on spectra and it is found that a 400 eV shift brings them into agreement.

Figure 10. Electron distribution functions for gun on and off (top panel) emphasize the latter point. Again, a 400 eV shift bring the spectra into agreement. The bottom panel is taken during trickle mode, as appropriate for the next figure.

Figure 11. Low energy ion distribution functions for gun off (top panel), and trickle mode at 1452 UT (bottom panel). The satellite is charged to near -20 V.

Figure 12. Summary of this operation. The energy of the charging peak is plotted versus time. This will be close to the satellite potential.

4. Day 95 - Figure 13.

In eclipse, the photocurrent is eliminated, and we would expect the satellite to charge to a value close to the beam voltage. On day 95, typical values were -800 to -1000 V. Figure 13, a distribution function for the high energy ion detector, shows the peak, and substantial fluxes below the satellite potential, indicating substantial generation of ions near or on the satellite surface.

5. Day 293 - no figure.

During eclipse on day 293 of 1979, the satellite charged to near the beam energy for over 30 minutes. During a brief operation (̃5 minutes) at 2 kV, the satellite charged to between -1.8 and -2.0 kV.

C. Laboratory Experiments

As the analysis of the above data proceeded, and meetings were held at NASA/LeRC, it beame clear that tether technology development hinges on a successful "plasma contactor." In the context of tethers, this can mean electron guns, ion guns, plasma sources, or even large conducting surfaces. One result of the geosynchronous work described above is that hollow cathode plasma sources continue to be an excellent means of establishing effective and efficient electrical connection to the plasma. One problem with the hollow cathode technology is that it has traditionally been oriented toward use in and around ion engines, and hence has been optimized for an application which may not coincide with our requirements. The Lewis tether group has the premier hollow cathode expert (Paul Wilbur) to work on this area. He has focused his efforts on designing an optimum system for tether applications, resulting in the 'ring cusp' design. This leaves unresolved the basic parameter regime for standard designs, however. In order to fill this void, and develop basic experimental experience needed for successful flight experiments (in the next section), a modest laboratory effort was initiated. A bell jar vacuum system was acquired from a colleague, cleaned and made operational, and a hollow cathode system was installed. Successful operation of a commercial cathode (Ion Tech. Ft. Collins, Co.) was obtained. Unfortunately, at that point the PI, R.C. Olsen, closed up shop and moved to California. Results from this work are effectively delayed until he resumes experiments there.

D. Flight Experiments

A major element of this effort, though not addressed by the statement of work, is and has been the involvement with the Lewis tether group, working jointly toward resolution of basic technology issues such as plasma contactors. In the first two years of this work, the available flight data have been addressed, available laboratory data discussed and substantial theoretial development has occurred. It was determined that the next stage of this development must be a flight experiment to demonstrate/test the technology we have been discussing. With the slip in the TSS-1 schedule, it seems likely that a simple flight experiment using a sounding rocket could be accomplished prior to TSS-1. With this goal, the last portion of the grant period was spent working on HOCAT, a hollow cathode rocket experiment. The concept is illustrated in Figure 14. A definition phase effort was begun, and a follow on contract has recently been initiated by NASA/LeRC with R. C. Olsen at the Naval Postgraduate School, to continue this work. Engineering development at UAH will continue under the direction of Dr. Roy Torbert.

REFERENCES

Katz, I., G. A. Jongeward, D. E. Parks, D. L. Reasoner, and C. K. Purvis, Energy Broadening due to space-charge oscillations in high current electron beams, Geophysical Research Letters, 13, 64-67, 1986.

Koons, H. C., and H. A. Cohen, Plasma waves and electrical discharges stimulated by beam operation on a high altitude satellite, in Artificial Particle beams in space plasma studies, edited by Bjorn Grandal, pp 111-120, Plenum Press, New York, 1982.

Koons, H. C., Summary of environmentally induced electrical discharges on the P78-2 (SCATHA) satellite, Journal of Spacecraft and Rockets, 20, 425, 1983.

Obayashi, T., N. Kawashima, K. Kuriki, M. Nagatomo, K. Ninomiya, S. Sasaki, M. Yanagisawa, I. Kudo, M. Ejiri, W. T. Roberts, C. R. Chappell, D. L. Reasoner, J. L. Burch, W. L. Taylor, P. M. Banks, P. R. Williamson, and O. K. Garriott, Space Experiments with particle accelerators, Science, 225, 195-196, 13 July 1984.

Olsen, R. C., Ion beam experiment at high altitudes, presented at the 1986 fall meeting of the American Geophysical Union, San Francisco, California, 8-12 December 1986, EOS (abstracts) 67, 1180, 1986.

Olsen, R. C., Electron beam experiments at high altitudes, presented at the NATO AGARD symposium on the Aerospace Environment at high altitudes and its implications for spacecraft charging and communication, The Hague, The Netherlands, 2-6 June 1986 (proceedings in press).

Olsen, R. C., Electron beam experiments at high altitudes, Journal of Electrostatics, in press, 1987.

Olsen, R. C. and H. A. Cohen, Electron beam experiments at high altitudes, presented at the 1985 fall meeting of the American Geophysical Union, San Francisco, California, 9-13 December, 1985, EOS (abstracts) 66, 1053, 1985.

Olsen, R. C. and H. A. Cohen, Electron beam experiments at high altitudes, presented at the XXVI Plenary meeting of the Committee on Space Research (COSPAR), Toulouse, France, 30 June to 11 July 1986 (in press, Advances in Space Research).

Oyama, K. I., S. Sasaki, N. Kawashima, K. Hirao, and T. Obayashi, Results from tethered rocket experiment (Charge 11), presented at the XXVI Plenary meeting of the committee on space research (COSPAR), Toulosue, France, 30 June to 11 July 1986, (in press, Advances in Space Research).

Sasaki, S., N. Kawashima, K. Kuriki, M. Yanagisawa, T. Obayashi, Vehicle charging observed in SEPAC SPACELAB-1 experiment, Journal of Spacecraft and Rockets, 23, 194-199, 1986.

Sasaki, S., W. W. L. Taylor, N. Kawashima, K. Kuriki, M. Yanagisawa, T. Obayashi, K. Akai, W. T. Roberts, D. L. Reasoner, P. R. Williamson, P. M. Banks, and J. L. Burch, Neutralization of Beam-emitting spacecraft by plasma Injection, Journal of Spacecraft and Rockets, in press, 1987.

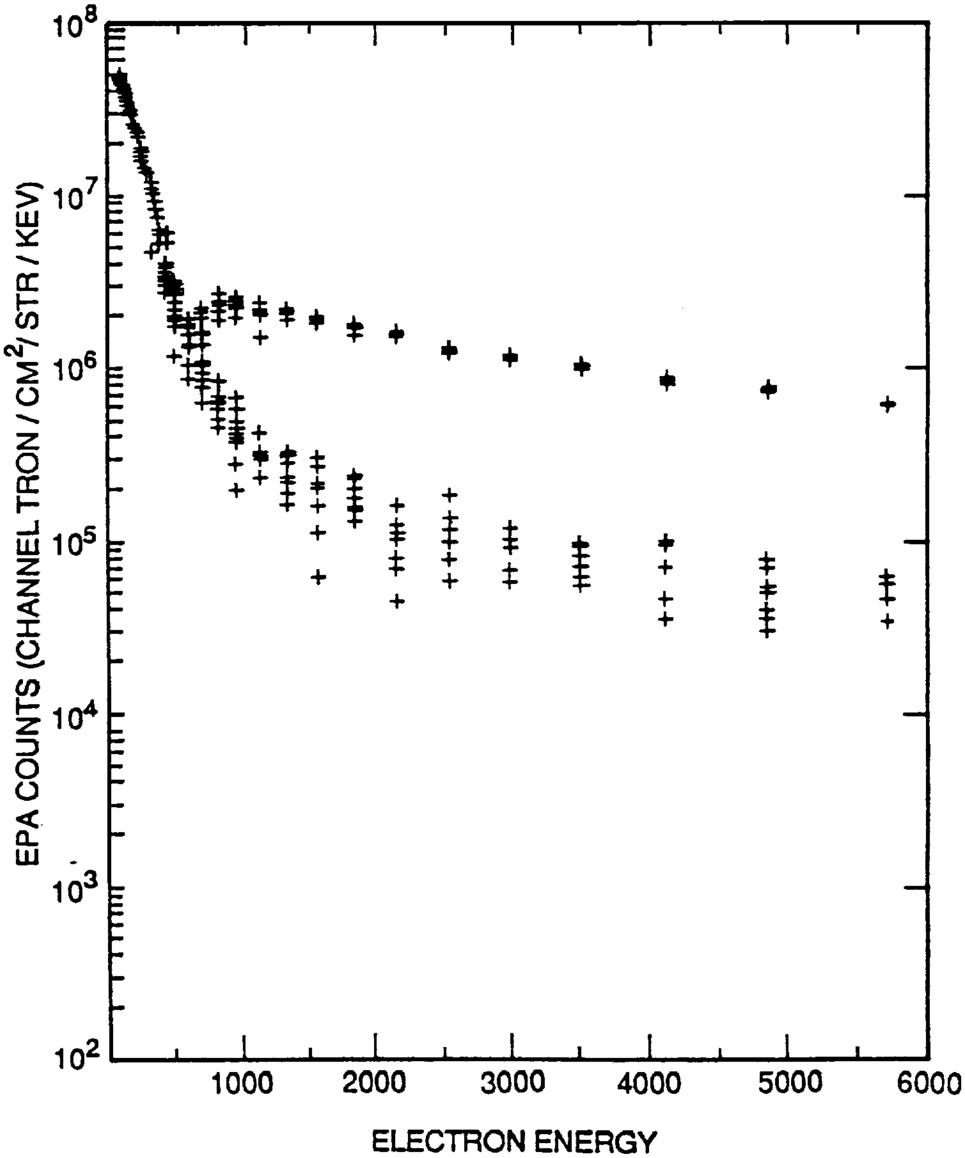
Taylor, W. W. L., T. Obayashi, N. Kawashima, S. Sasaki, M. Yanagisawa, J. L. Burch, D. L. Reasoner, and W. T. Roberts, Wave particle interactions induced by SEPAC on Spacelab 1: Wave observations, Radio Science, 20, 486-498, 1985.

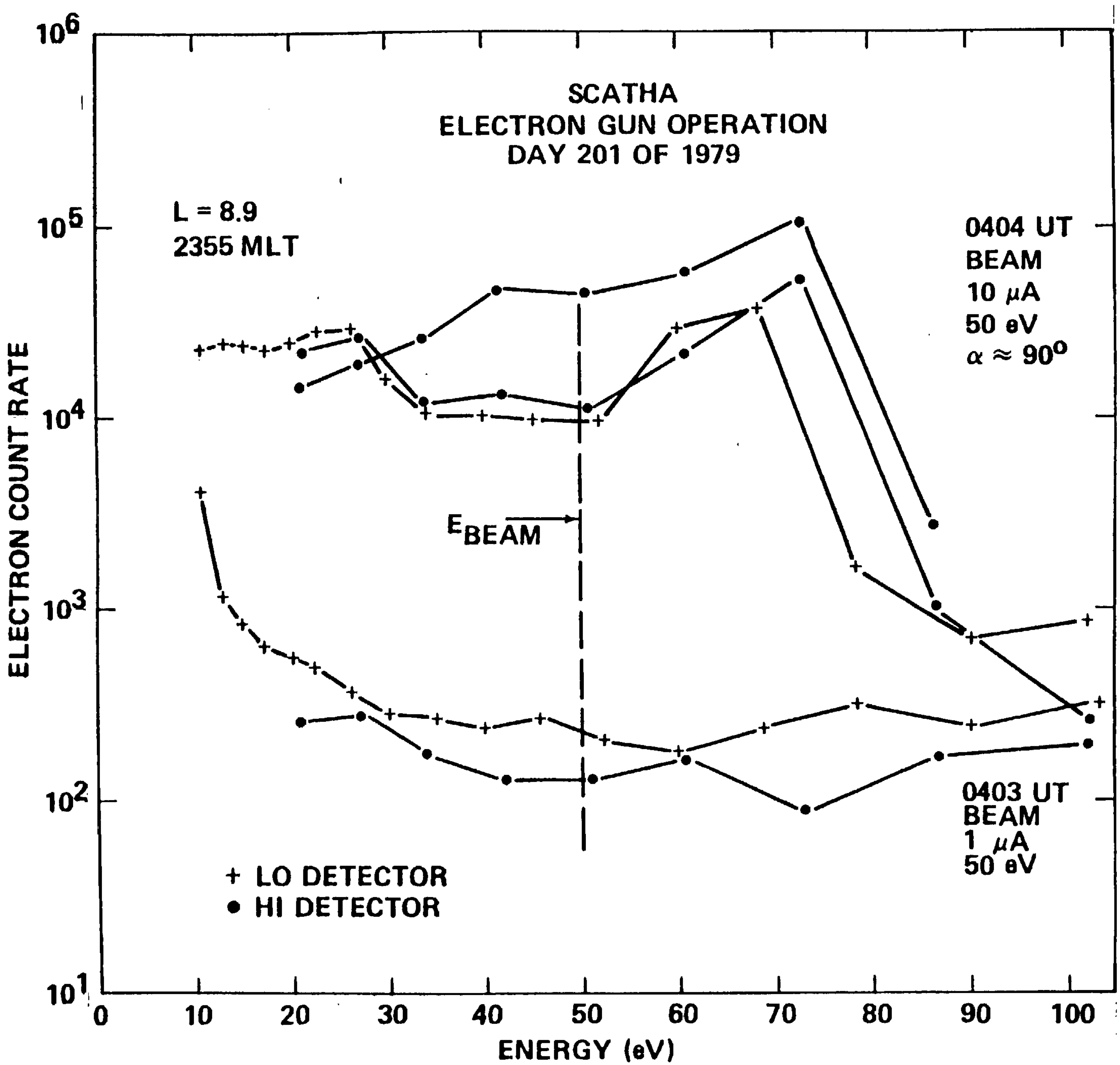
Torkar, K. M., W. Riedler, K. Wilhelm, J. Watermann, and C. Beghin, Return flux measurements in response to short-time electron beams aboard Spacelab 1, presented at the XXVI Plenary Meeting of the Committee on Sopace Research (COSPAR), 30 June to 11 July 1986.

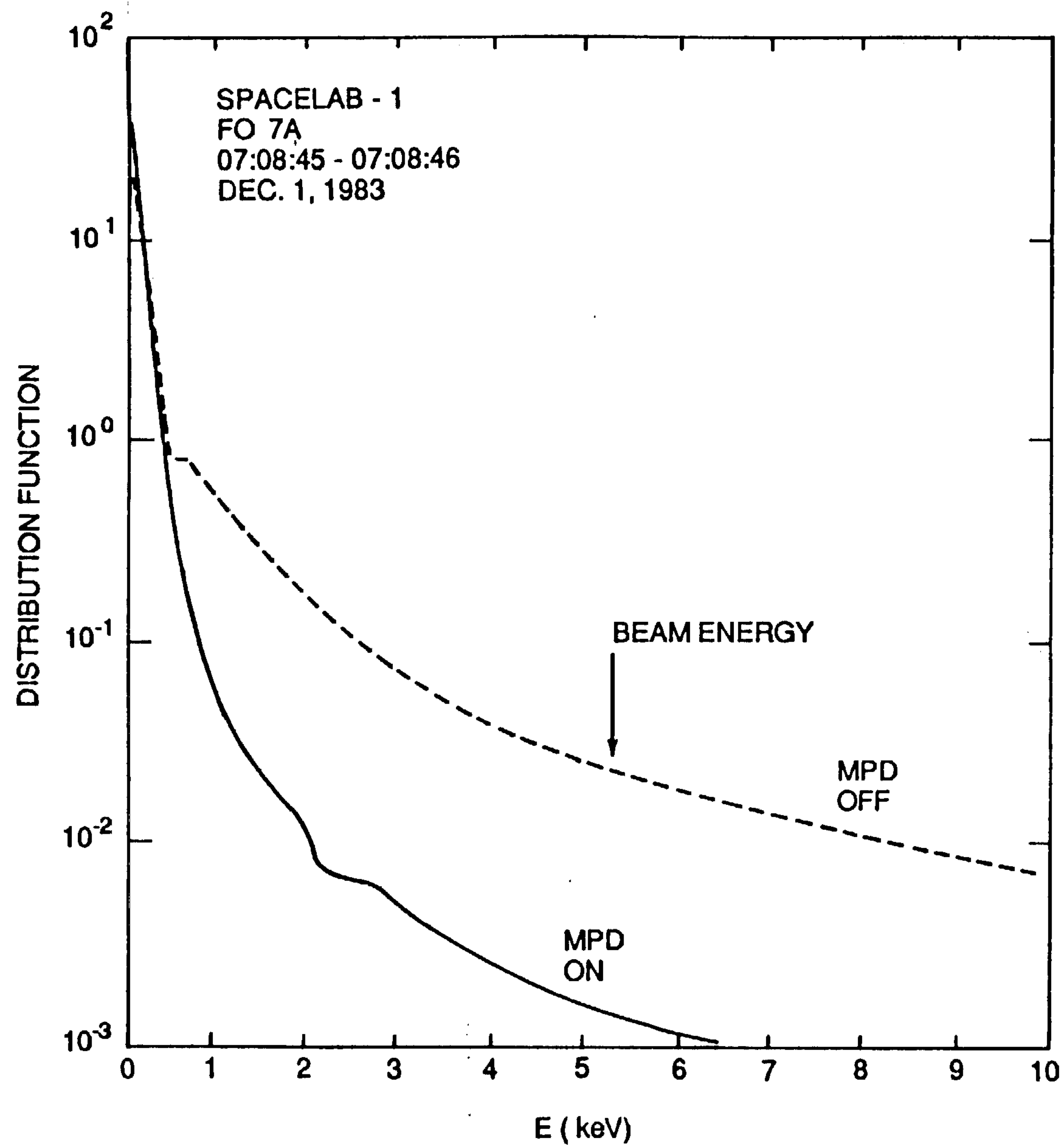
Wilhelm, K., W. Studeman, and W. Riedler, Electron flux intensity distributions observed in response to particle beam emissions, Science, 225, 186-188, 13 July 1984.

Wilhelm, K., J. Waterman, K. Torkar, W. Riedler, Spacelab 1 observations of suprathermal electrons induced by artificial electron beans, presented at the XXVI Plenary Meeting of the Committee on Space Research (COSPAR), 30 June to 11 July, 1986 (In press, Advances in Space Research).

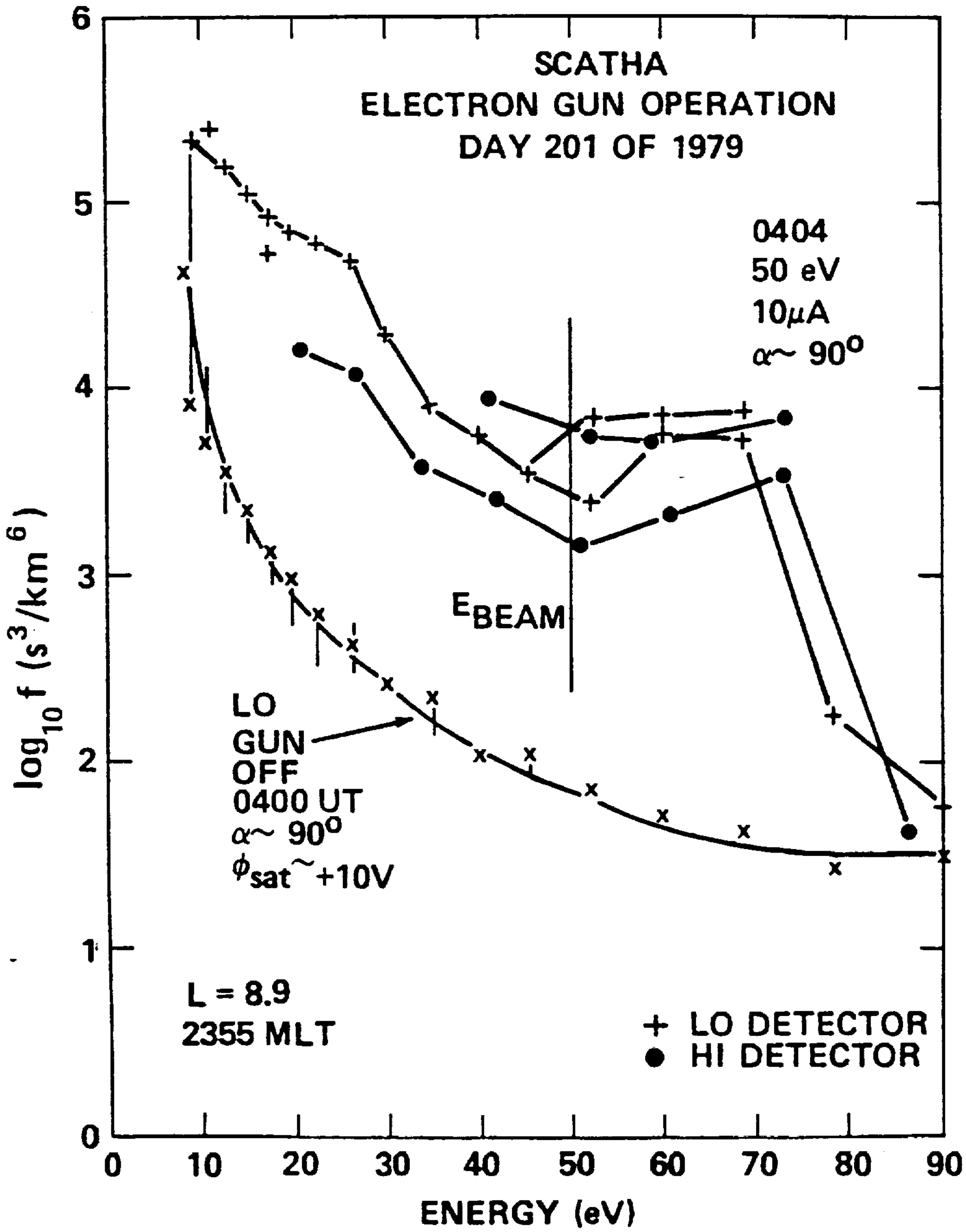
SPACELAB - 1 FO 7A FROM - 07:08:45.500 TO - 07:08:46.000
DEC. 1, 1983




SCATHA
ELECTRON GUN OPERATION
DAY 201 OF 1979
L = 8.9
2355 MLT
0404 UT
BEAM
10 μA
50 eV
α ≈ 90°
E_{BEAM}
0403 UT
BEAM
1 μA
50 eV
+ LO DETECTOR
● HI DETECTOR
ELECTRON COUNT RATE
10^6
10^5
10^4
10^3
10^2
10^1
0
10
20
30
40
50
60
70
80
90
100
ENERGY (eV)

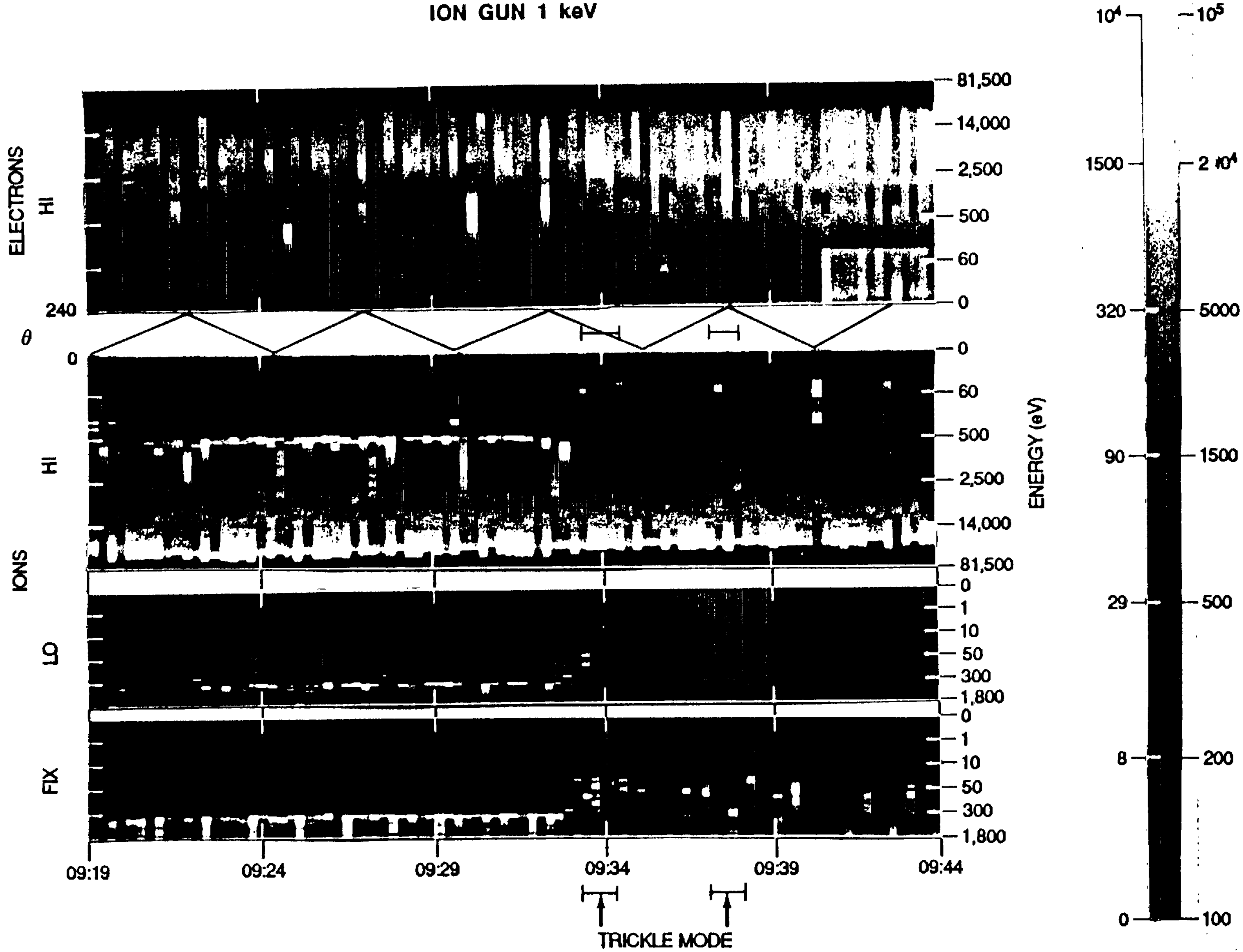

SPACELAB - 1
FO 7A
07:08:45 - 07:08:46
DEC. 1, 1983
BEAM ENERGY
MPD
OFF
MPD
ON
DISTRIBUTION FUNCTION
E (keV)

3



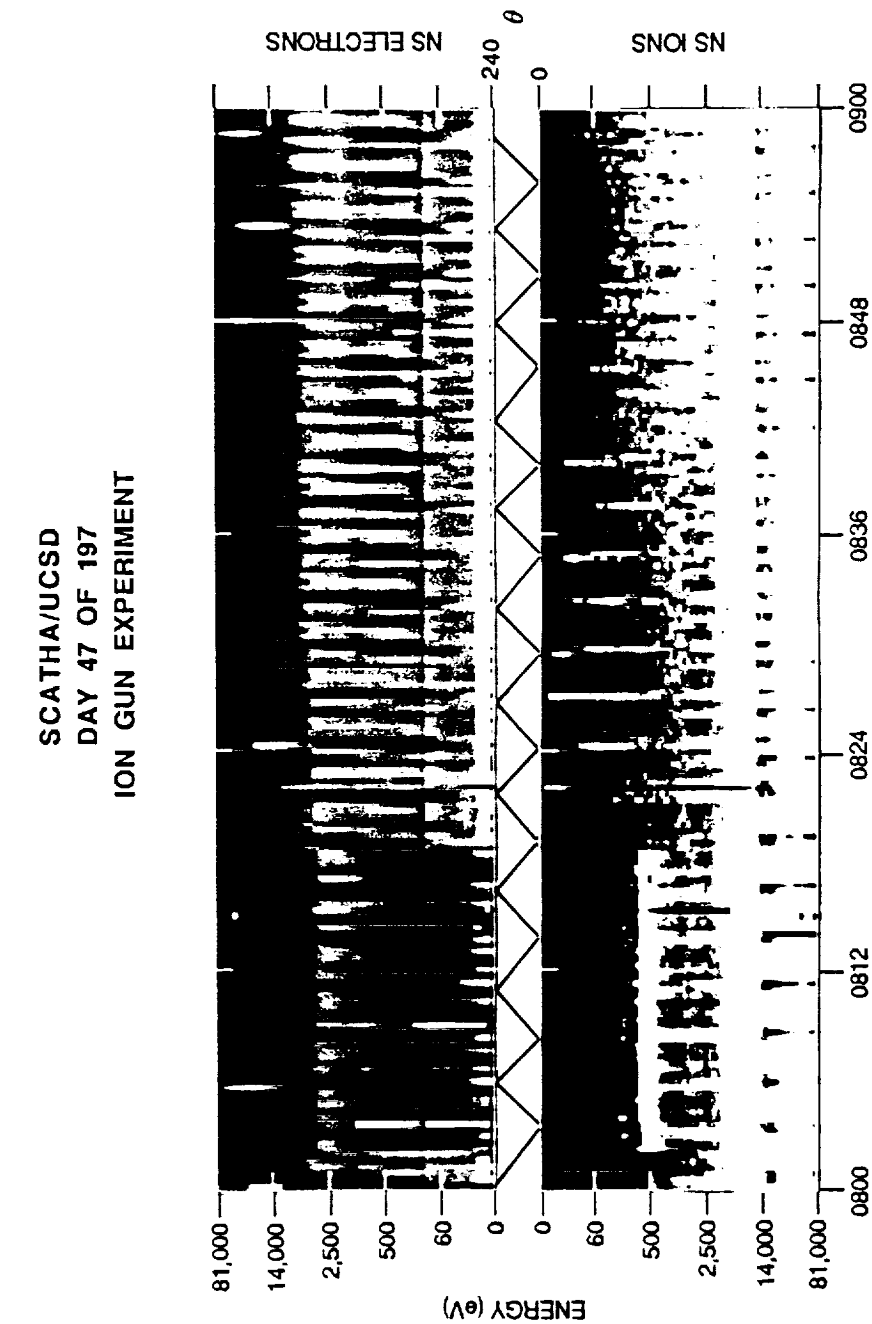
SCATHA
ELECTRON GUN OPERATION
DAY 201 OF 1979
0404
50 eV
10μA
α~ 90°
E BEAM
LO
GUN
OFF
0400 UT
α~ 90°
φsat ~+10V
L = 8.9
2355 MLT
+ LO DETECTOR
● HI DETECTOR
log10 f (s^3/km^6)
ENERGY (eV)
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90

SCATHA/UCSD
DAY 46 OF 1979
ION GUN 1 keV



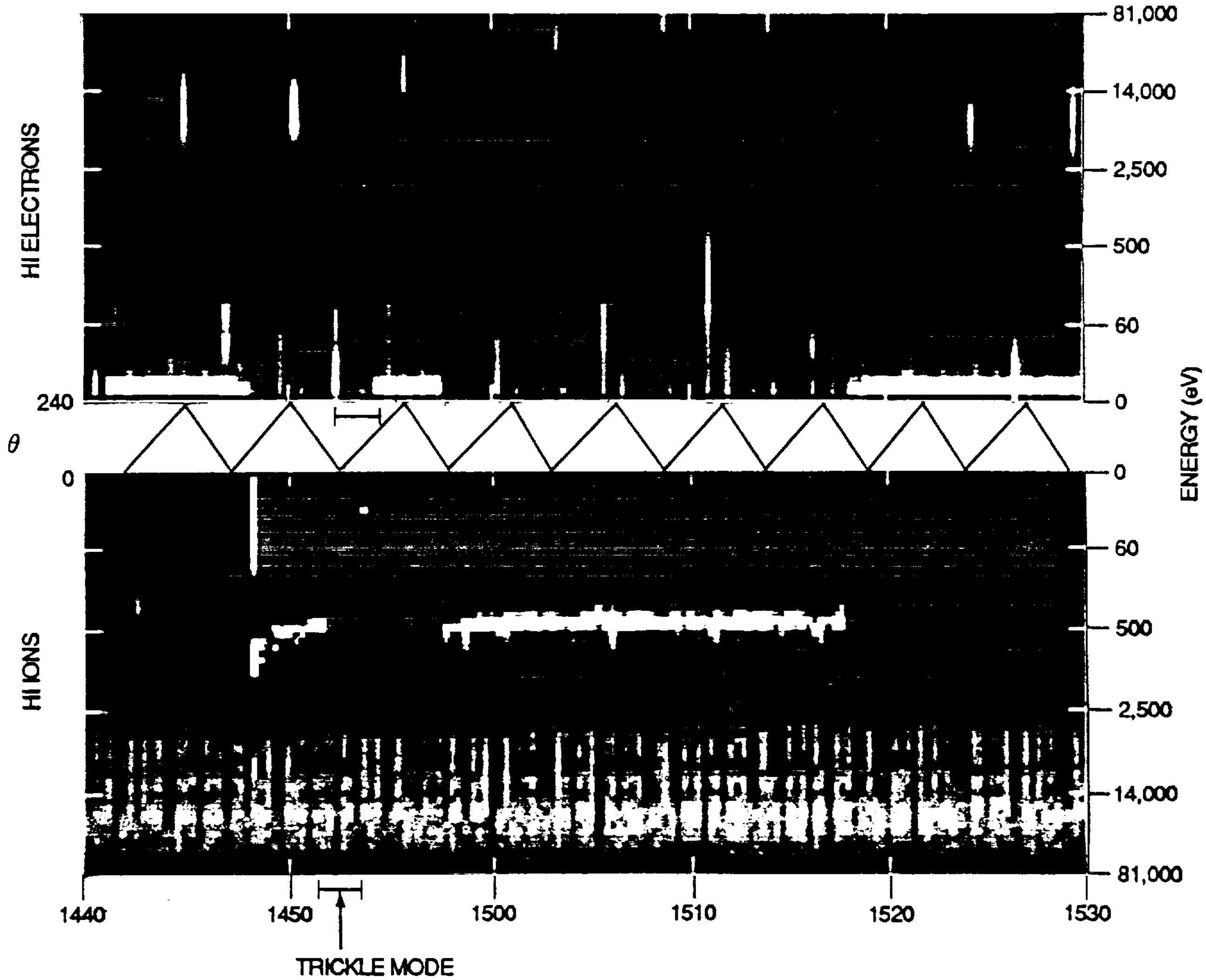
ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY



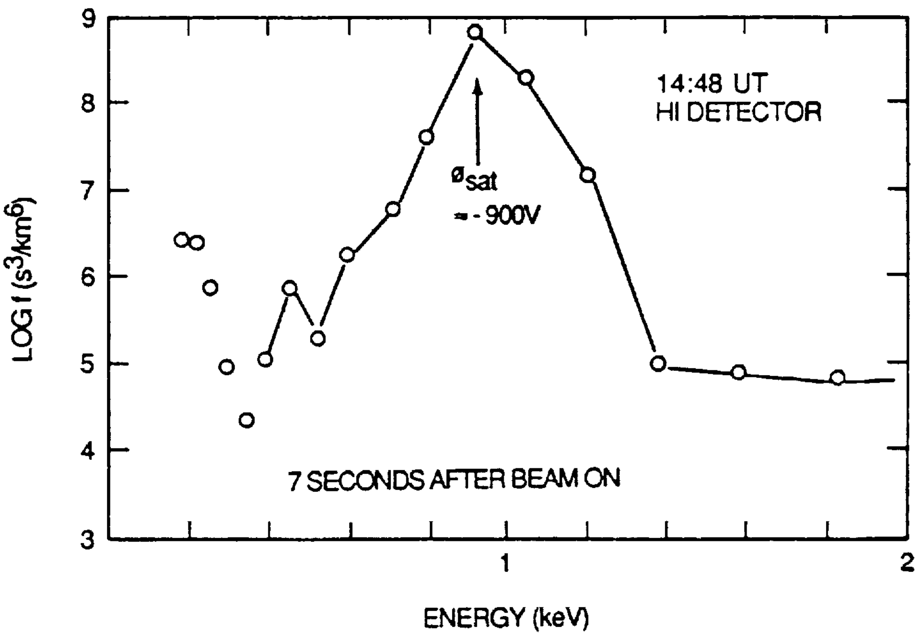
ORIGINAL PAGE IS
OF POOR QUALITY

SCATHA/UCSD
DAY 47 OF 1979



SCATHA/UCSD
DAY 47 OF 1979

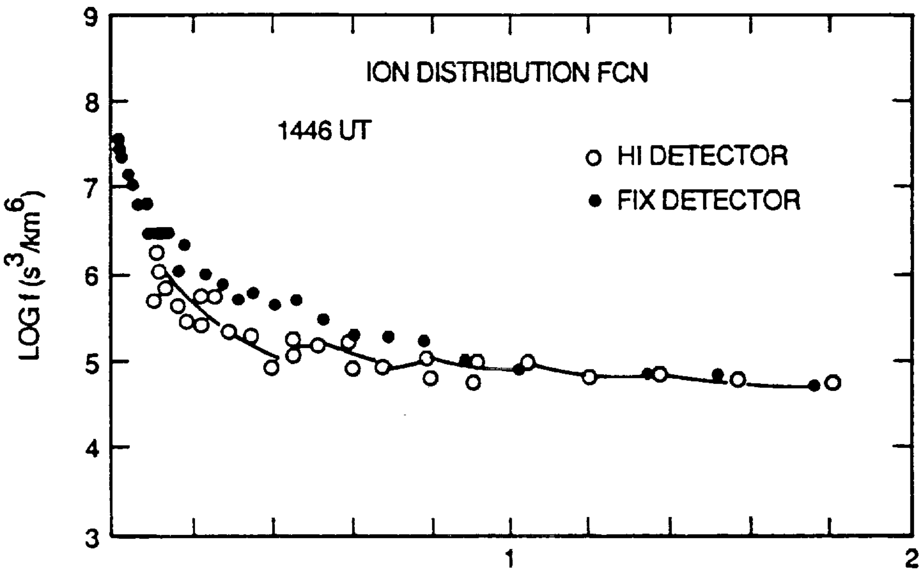
ION DF

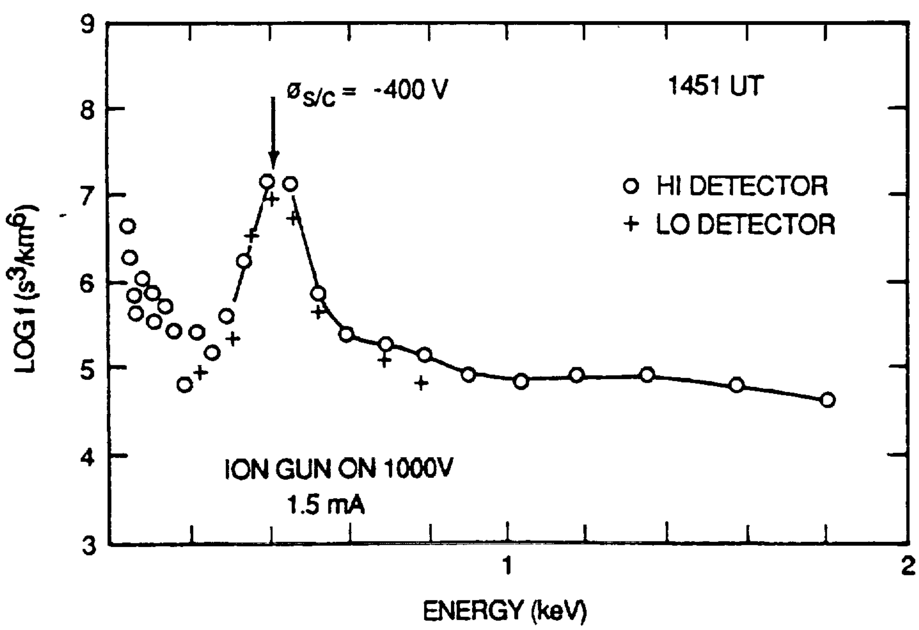


PEAK COUNT RATE IS @ 915 eV (815,000 c/s)
AND 1050 eV (315,000 c/s)
14:48:09 ∼ 10^3 x NORMAL CR

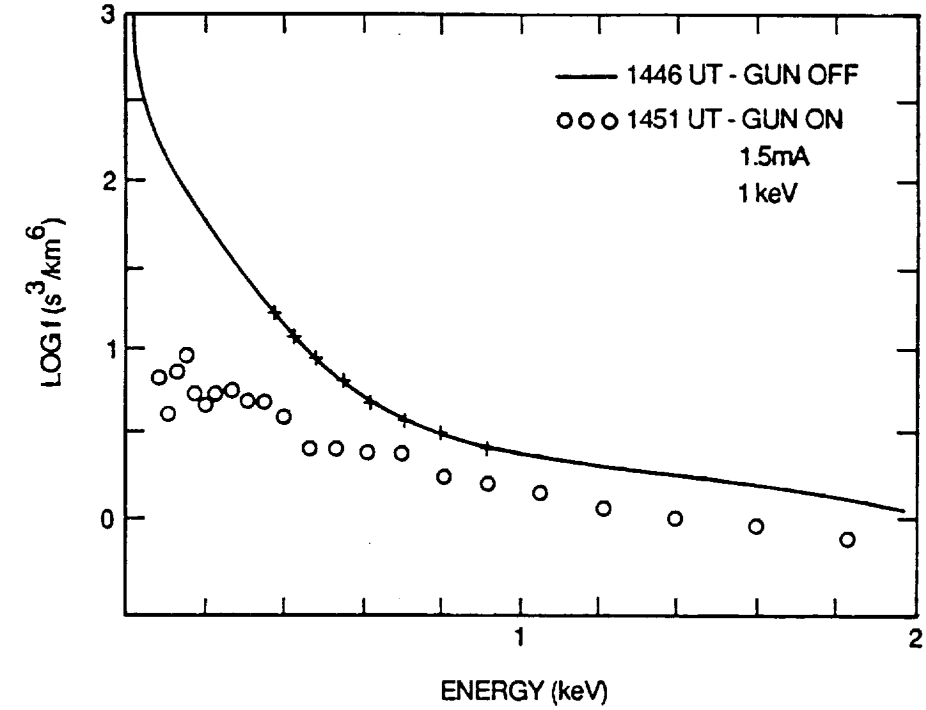
7 SECONDS LATER (14:48:16)
PEAK IN EW DETECTOR IS IN
788 AND 902 eV CHANNELS
PEAK IN FIX DETECTOR IS IN
688 AND 788 eV CHANNELS

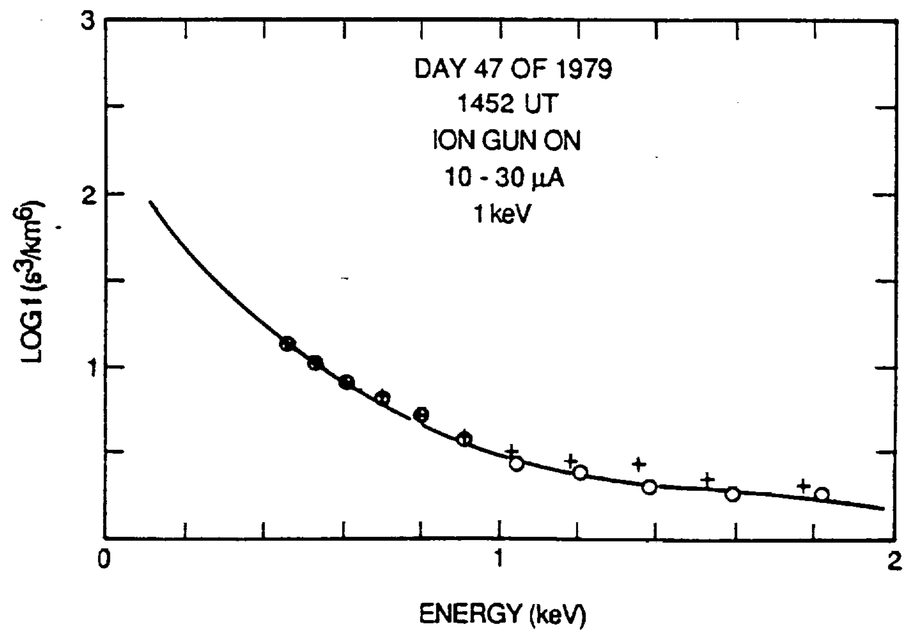
SCATHA/UCSD
DAY 47 OF 1979





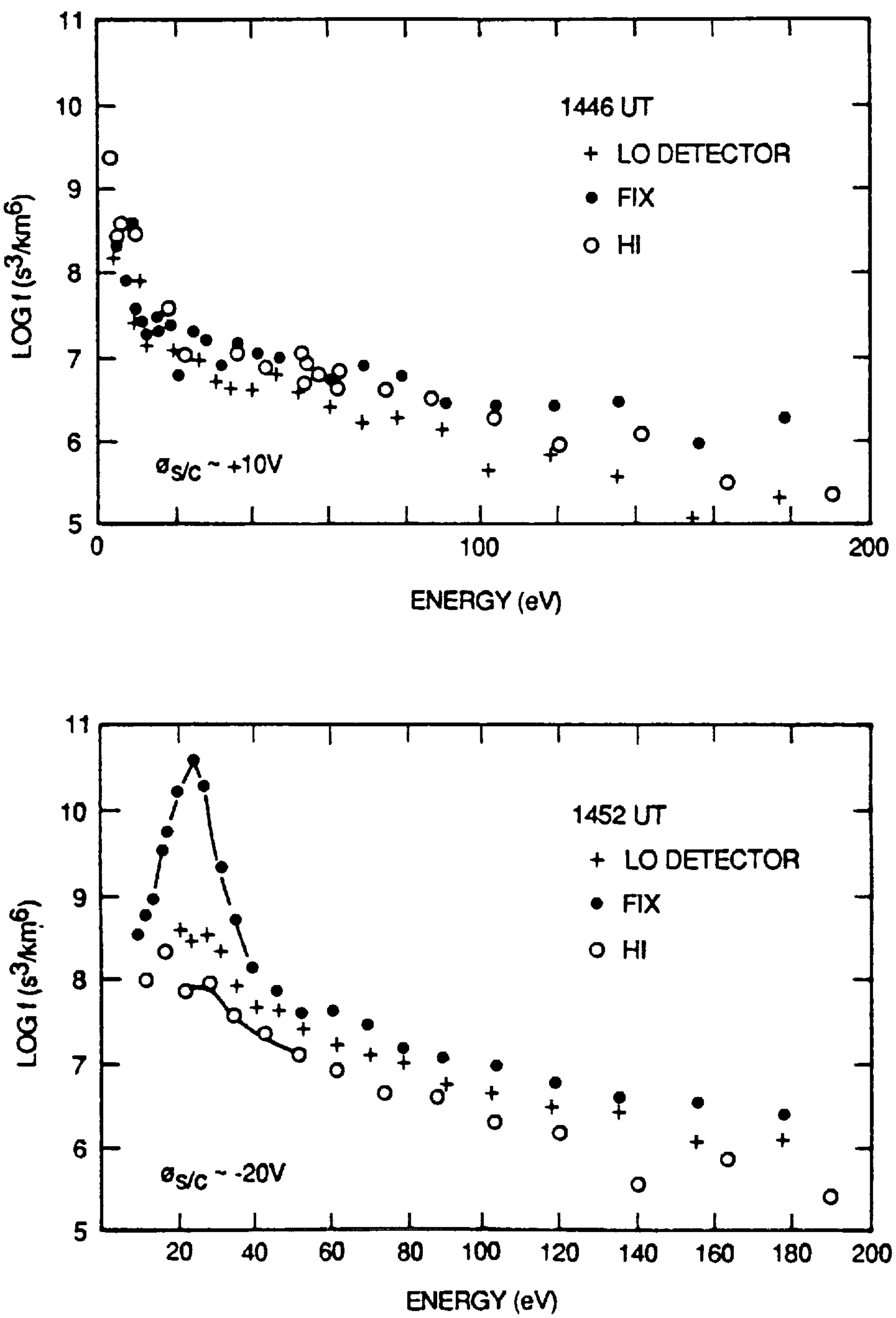
SCATHA/UCSD-ELECTRONS
DAY 47 OF 1979

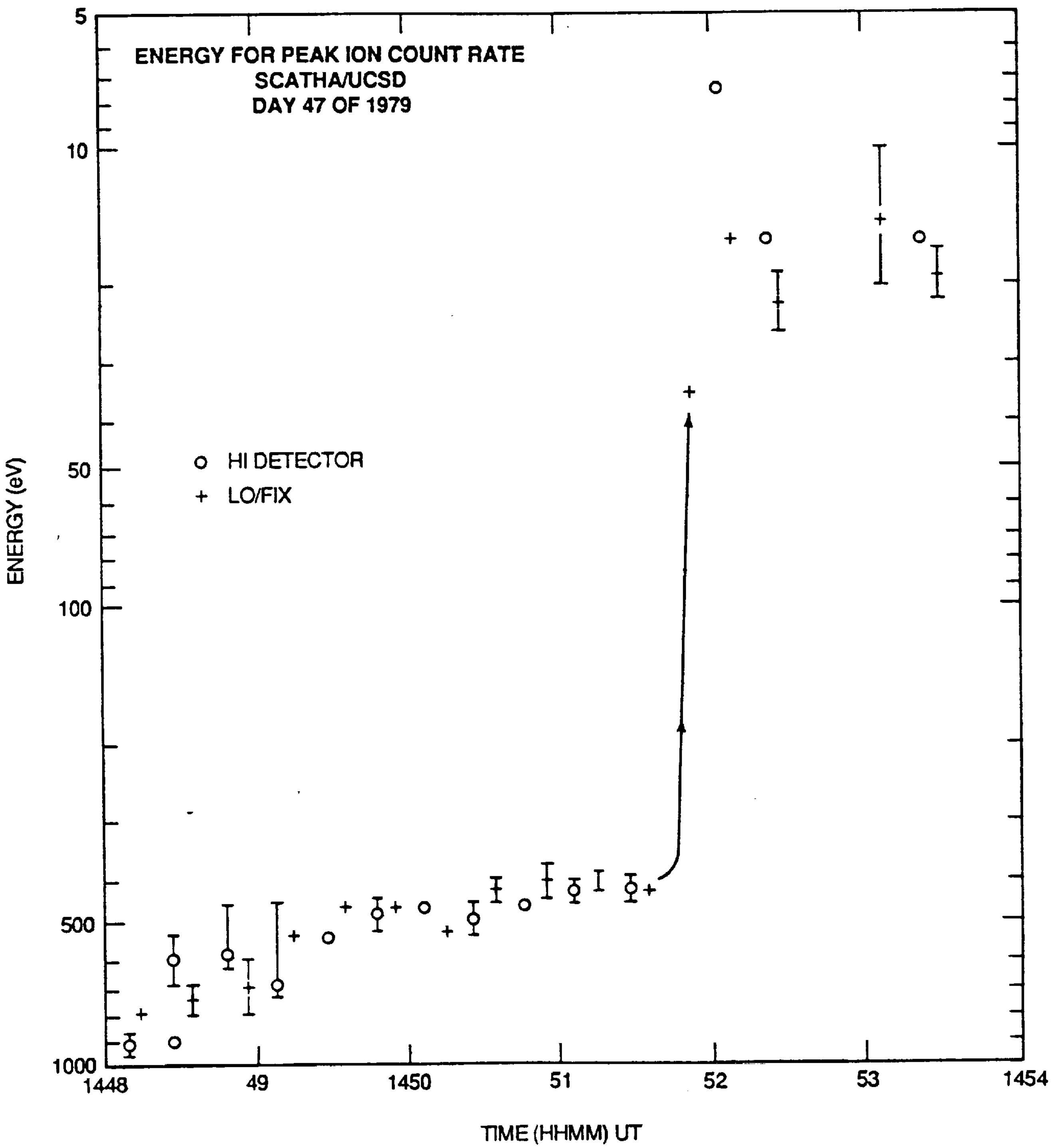




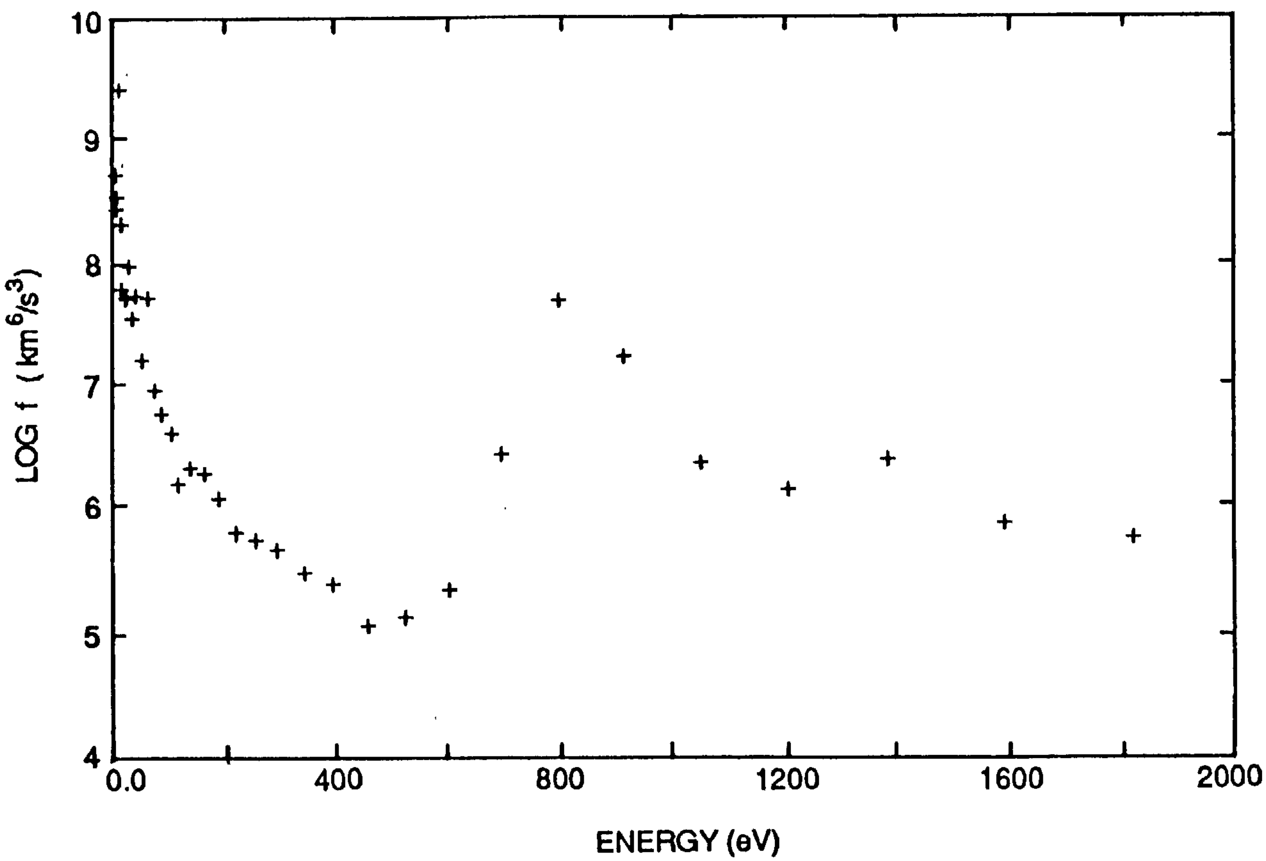
DETECTORS LOOKING PARALLEL TO SPIN AXIS ⊥B

SCATHA/UCSD
DAY 47 OF 1979
ION DISTRIBUTION FUNCTIONS




ENERGY FOR PEAK ION COUNT RATE
SCATHA/UCSD
DAY 47 OF 1979
HI DETECTOR
LO/FIX
ENERGY (eV)
5
10
50
100
500
1000
1448
49
1450
51
52
53
1454
TIME (HHMM) UT

SCATHA UCSD DAY 95 OF 1979
13:38:04 HI IONS



HOLLOW CATHODE ROCKET EXPERIMENT (HOCAT)