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AUTOMATED CALIBRATION OF A FLIGHT PARTICLE SPECTROMETER

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ABSTRACT

A system for calibrating both electron and ion imaging particle spectrometers was devised to calibrate flight instruments in a large vacuum facility in the Space Science Laboratory at MSFC. An IBM-compatible computer was used to control, via an IEEE 488 buss protocol, a two-axis gimbled table, constructed to fit inside the tank. Test settings of various diagnostic voltages were also acquired via the buss. These spectrometers constructed by the author at UCSD were calibrated in an automatic procedure programmed on the small computer. Data was up-loaded to the SSL VAX where a program was developed to plot the results.

Introduction

During the summer of 1985, the proposed automated calibration system was designed, constructed, and tested in the vacuum facility at MSFC. Due to failures of the vacuum vessel itself, no actual calibration was completed of the sounding rocket instrument. Fortunately, NASA delayed sounding rocket flight 35.014 for totally different reasons associated with payload weight and apogee requirements. The instrument will go back into the chamber in December for final calibration.

While waiting for chamber repairs, I devoted considerable time to a computer model of the Critical Velocity Effect , which the sounding rocket experiment will investigate. The first results of this work will be described.

Objectives

The objective of this summer's study was to construct an automated calibration system for instruments with many simultaneous channels. The instrument that I developed at UCSD can sample twenty different pitch angles at one time and do this for up to 64 different energies in 10 milliseconds. The manual calibration of such an instrument would exhaust at least 20 graduate students. We proposed to utilize the automatic gimbal table at MSFC for orienting the detector under computer control within the ion beam from a local source. Data would be collected by a ground station computer and transmitted to the SSL VAX 11/780 computer for analysis and display.

Calibration System

Figure 1 presents a block diagram of the automated calibration system that was constructed. Figure 2 is a photograph of the system being tested on the workbench before check-out in the chamber. The system host is a Compaq portable computer, which also serves as the ground station computer for the rocket instrument computer. A RS-232 link was used to transfer data files accumulated during calibration runs. This link was tested with dummy data and a student programmer produced line printer plots of the dummy data. I purchased a QuaTech MXI-241 plug-in board for the Compaq, which provide both a versatile 8255 peripheral interface and the required IEEE-488 port. Software was written that drove the stepper motors on the three-axis gimbal table, on which the detector was mounted in the vacuum chamber. An ion source provides a known ion species with a precise energy center and width, directed at the detector. The software listed in Figure 3, was written to control the angular orientation of the table. Other software was created to write controlled DC voltage sources that we would use to construct a analyzing high voltage for the detector itself and to provide diagnostic and labeling data for the particular calibration mode.

A custom bi-directional buss was designed to be controlled by the 8255 port on the QuaTech board. This allowed us to use the actual flight accumulator board to sample the count rate from up to 32 channels of the detector simultaneously. It also greatly simplifies the interface between the calibration system and the detector since this is exactly the flight configuration. Actual counter data was collected on the single pump down cycle that we were able to make before chamber failure. However, this data was later determined to be in error due to an electronic problem in our buss set-up. This problem was corrected and remains to be tested when we have the chamber again.

In summary, when the chamber is available again in December, the true test of this system will begin. Since the new launch date for 35.014 is May of 1986, the pressure still exists for a rapid calibration and we hope to be finished by March of that year.

Computer Simulation of Critical Velocity Effect

The project which is motivating the designed instrument and its calibration is fully described in the appendix. Alfven proposed in 1954 that, if a neutral gas flows at a velocity, perpendicular to the magnetic field, greater than a critical velocity,Vc,

$$V_c = \sqrt{2e\phi_{ion}/M}$$

then the gas would be anomalously ionized. The sounding rocket experiment will attempt to create these conditions in space. I undertook work to simulate the release of these neutrals from barium shaped charge releases. The following are the essential new features of this work.

First, the barium neutral density at a distance R from an instantaneous injection of particles with a velocity distribution, dN/dV, and angular distribution around a central polar angle, , is given by :

$$n(R) = \left(V\frac{dN}{dV}\right)_{V=R/t} \frac{1}{R^3} f(\theta)$$

where:

$$\int f(\theta)\, d\Omega = 1$$

The rapid fall-off of this density with R is a prime factor limiting the discharge, since the ionization rate and thereby the available free energy density are proportional to it. This later is given by:

$$\dot{N}_e (\Delta V)^2 \frac{M}{2}$$

where (ΔV) is the relative perpendicular velocity of the neutrals and the ambient plasma. This velocity, ΔV , may be deduced from equating the current that results from ionization(i.e. due to dNe/dt) to that which can be carried off in Alfven waves by the background plasma. If more current were generated by the burning process that this, then the cloud of neutrals and plasma would electrically polarize and then decrease the relative drift of the neutrals and plasma, thereby shutting off the effect. This provides a natural limit to the amount that can be ionized. Using this approach, we derived :

$$\Delta U = V_{Neutral} \Big/ \left(1 + \dot{N}_e M \ell_{11} / 2 \rho_A U_A \right)$$

Now, the ionization rate was computed using the following form of the impact ionization cross-section, which can be derived using the Born approximation:

$$\sigma(U) \propto \frac{1}{U^2} \ln(U^2)$$

Assuming an electron Maxwellian distribution with density,Ne, and temperature, Te, we derive the ionization rate:

$$\dot{N}_e = \sigma_{MAX} U_e N_n N_e Z(\phi_i / T_e) + Q \cdot N_n$$

where the function Z(ϕ_i / Te) is given by:

$$Z(\lambda) = \frac{8}{\sqrt{2\pi}} \lambda \left[Ei(\lambda) + 0.307 e^{-\lambda} \right]$$

The factor, Q, allows ionization by photoionization or some other 'free' source such as impact ionization from a high energy auroral electron beam. It could also model charge exchange. This is a critical factor since it provides the `seed' for the discharge to occur.

Finally, the total energy balance for this electron population may be computed as follows:

$$\begin{aligned} \frac{d}{dt}\left(\tfrac{3}{2} N_e T_e \right) = \eta \left[\dot{N}_e (\Delta U)^2 M/2 \right] & \\ - \dot{N}_e \phi_{ion} & \\ - \alpha_{Ba} N_e N_n \phi_B & \\ - \alpha_0 N_e N_0 \phi_0 & \end{aligned}$$

where the positive term is the above energy input and the negative terms are due to energy loss from the impact ionization itself and from electron excitation of barium and the background oxygen.

All the ingredients of the simulation are now in place and the computer was used to compute the evolution of Ne and Te at successive R's along the beam path. A typical profile that resulted is given in Figure 4, where these parameters are plotted versus time for an injection distance of 2 km. Clearly, the electrons are heated and the population grows. However, we never found the large yield that Haerendel and colleagues claim in their earlier work (Haerendel,1982). We are presently working to revise the model to include convection effects and a better charge exchange model.

Conclusions and Recommendations

The calibration project should and will continue and, perhaps during the second year of this project, will be functional as a reliable and useful facility for calibrating space-flight particle spectrometers.

References

1. Alfven,H.,On the Origin of the Solar System,Oxford at the Clarendon Press,London,1954.

2. Haerendel,G.,Alfven's Critical Velocity Effect Tested in Space,Z.Naturforsch,A.37,728 ,1982.

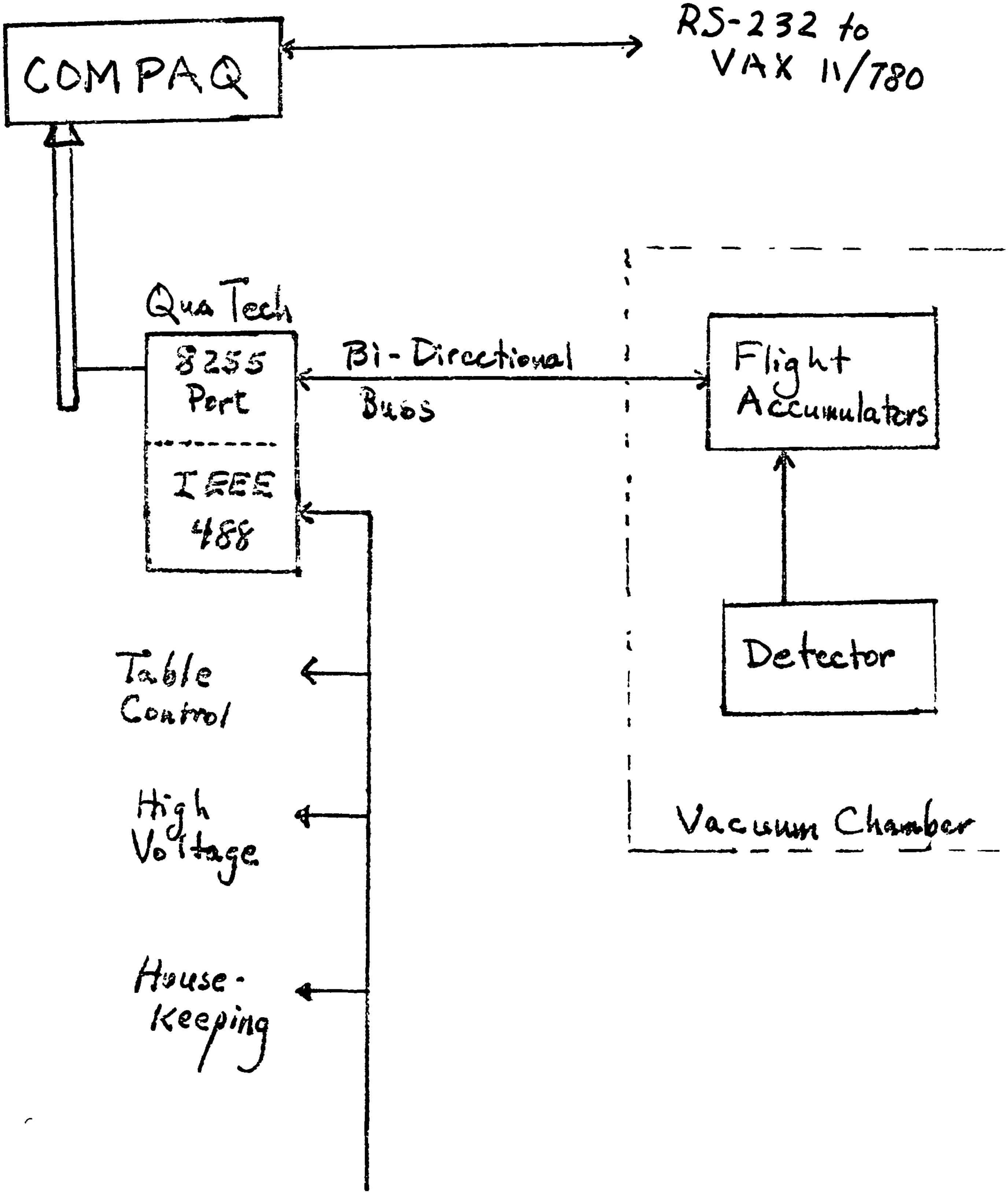

COMPAQ
RS-232 to
VAX 11/780
QuaTech
8255
Port
IEEE
488
Bi-Directional
Buss
Flight
Accumulators
Detector
Vacuum Chamber
Table
Control
High
Voltage
House-
Keeping

Figure 1

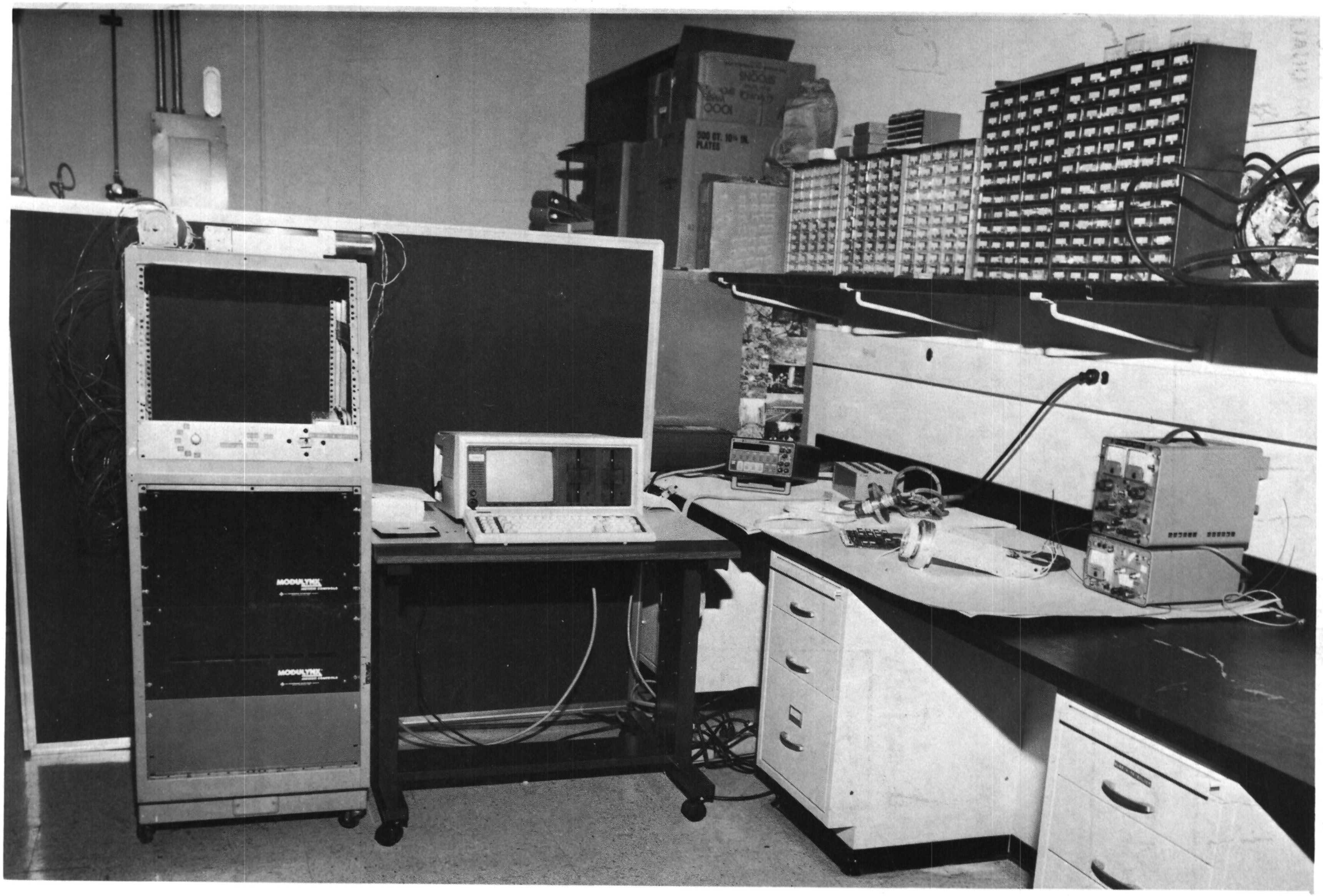
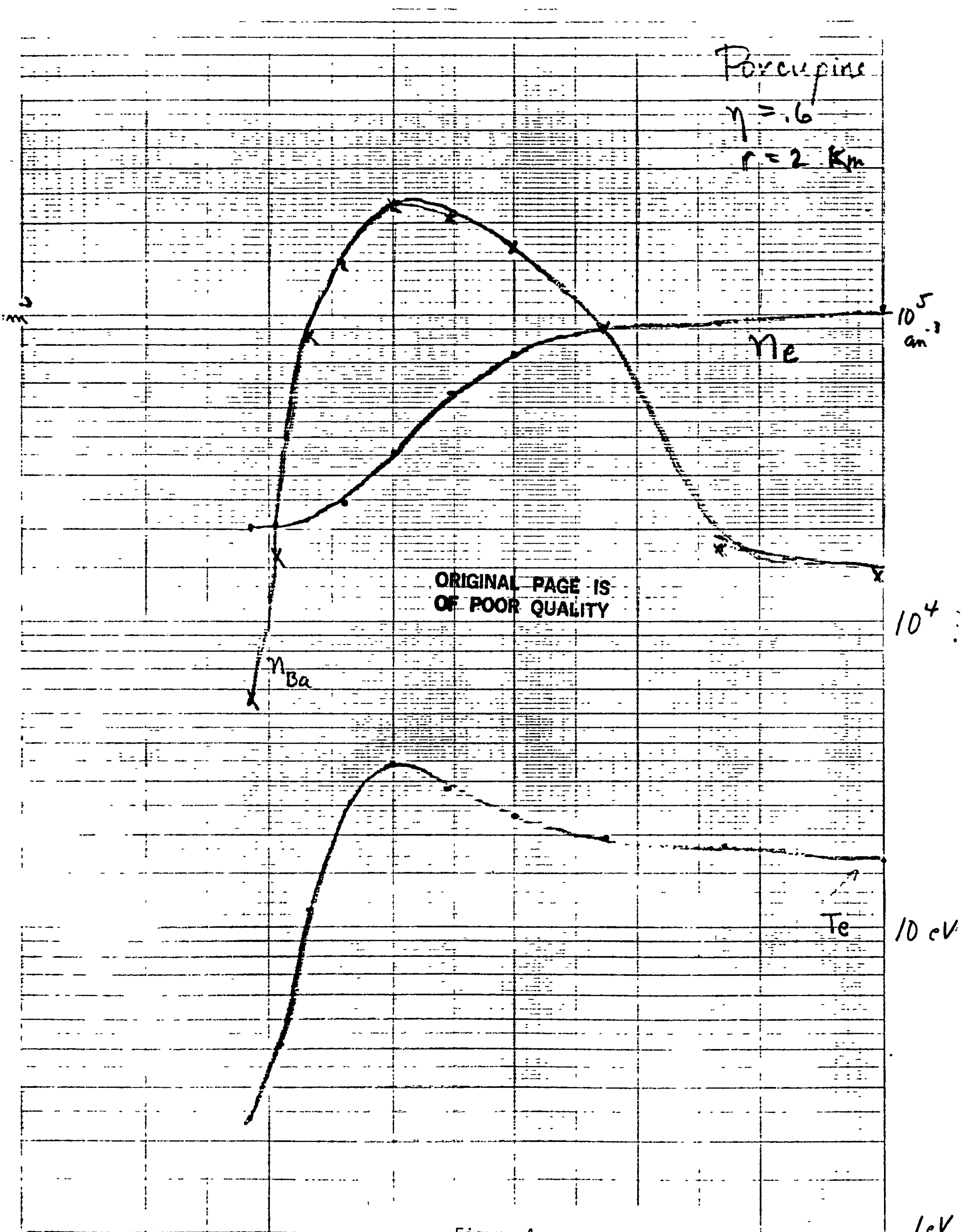


Figure 2

```
10 BUSSTA=&H4A5:CLR=&H9F0:DCL=&H388:EOI=&H2A5:GTL=&H482
20 GTS=&H295:IFC=&H2B9:INIT=&H308:LISTEN=&H6C7
30 LLO=&H3A8:LON=&H2A9:PASSCONT=&H5DB:PPDS=&H4B7
40 PPEN=&H3D8:PPOL=&H56E:PPU=&H3B8:READS=&H7CE
50 READB=&H7B0:RECECONT=&H617:REMOTE=&H6A0:SDC=&H398
60 SPOL=&H4D9:TALK=&H775:TCA=&H235:TCS=&H285
70 TON=&H2B1:TRIG=&H493:ULON=&H2AD:UNL=&H34D
80 UNT=&H378:UTON=&H2B5:WRITES=&H89D:WRITEB=&H88D
90 XFER=&H969
100 DEF SEG = 0
110 CSEG=(256*PEEK(&H3C7))+PEEK(&H3C6)
120 DEF SEG=CSEG
130 RDATA$="+2000,F,C,X49406                              "
140 SYSCON%=1
150 I488ADDR%=&H338
160 DEVADDR%=1
170 CALL INIT(SYSCON%,I488ADDR%,DEVADDR%)
180 CALL REMOTE
190 CALL LLO
200 COMM$="XD"          'TURN ON POWER TO X-MOTOR
210 EOI$="10"
220 LISTEN$="24"
230 CALL WRITES(LISTEN$,EOI$,COMM$)
240 COMM$=" CPT "          'GIVE STATUS OF INTIAL X-AXIS POSITION
250 CALL WRITES(LISTEN$,EOI$,COMM$)
260 TALK$="24"
270 LISTEN$=""
280 CALL READS(TALK$,LISTEN$,EOI$,RDATA$,STATUS%)
290 PRINT "RDATA",RDATA$
300 LISTEN$="24"
310 TALK$=""
320 COMM$="XM1000G;"          'MOVE MOTOR
330 CALL WRITES(LISTEN$,EOI$,COMM$)
340 COMM$=" CPT "          'GIVE STATUS OF X-AXIS AFTER MOVEMENT
350 CALL WRITES(LISTEN$,EOI$,COMM$)
360 TALK$="24"
370 LISTEN$=""
380 CALL READS(TALK$,LISTEN$,EOI$,RDATA$,STATUS%)
390 PRINT "RDATA",RDATA$
400 COMM$="XE;YE;ZE;UE;"          'TURN OFF POWER FOR ALL AXES
410 LISTEN$="24"
420 TALK$=""
430 CALL WRITES(LISTEN$,EOI$,COMM$)
440 CALL GTL
450 CALL UNL
460 STOP
```

Figure 3



Porcupine
$\eta = .6$
r = 2 Km
10^5
cm^{-3}
n_e
ORIGINAL PAGE IS
OF POOR QUALITY
10^4
n_{Ba}
Te
10 eV
1 eV
.4

Figure 4

Critical Velocity Experiments

Two complete sounding rocket experiments are planned for flight from Wallops Flight Facility in October, 1985, to study the Critical Velocity Effect in space plasmas. The international research team consists of investigators from University of California, San Diego (R. B. Torbert, P.I.), Cornell University (M. C. Kelley, P.I.), University of Alaska (E. M. Wescott, P.I.), Max Planck Institute for Extraterrestrial Physics, Garching, West Germany (G. Haerendel, P.I.), Royal Institute of Technology (C.-G. Falthammar, P.I.), and Utah State University (C. Howlett and J. Foster , P. Is.).

In 1954, Alfven proposed that, if an element in a nearly neutral plasma was ionized when it attained a flow velocity which depended on its ionization potential, then several facets of the structure of the solar system could be explained. With remarkable conviction, he maintained that there should therefore be a 'Critical Velocity effect,' whereby a neutral atom of mass M drifting perpendicular to the ambient magnetic field at a velocity greater than

$$Vcr = sqrt(2e \ \phi_{ion}/M)$$

would be anamolously ionized.

At the time, this speculation was greeted with some skepticism, since the classical cross-section for impact ionization at this velocity was exactly zero and only reached some reasonable probability at very large energies. However, a series of laboratory experiments showed that just such an effect occurs in plasma fusion devices (for a review, see Danielsson, 1973). The best explanations of what occurs all go something like this. Imagine, for some reason, that a few neutrals are ionized. This could be due to photoionization or some residual thermal ionization. The resulting ions, traveling with a large velocity perpendicular to B, can easily be shown to create lower hybrid waves, a type of plasma wave with a large phase velocity parallel to B. Electrons are resonantly accelerated along B in this wave to energies of the order of the ionization potential of the original neutral. These electrons have a large cross-section for ionizing the remaining neutrals. The effect snowballs into a discharge as more and more ions produce more and more hot electrons and so on. This result aroused the interest not only of astrophysicists, but also fusion physicists who needed to heat plasmas in their machines.

In applying these results to the case of the solar system, two difficulties arise. Namely, although its clever that somehow the energy of the ion (poor at ionizing) gets transfered to the electron (great at ionizing), what happened to the momentum? The standard answer in the laboratory is that the walls of the device absorb the momentum. There are no walls in space, however. Secondly, what keeps the hot electrons from leaving the interaction region? Again, the sheath fields near the walls accomplish this in the laboratory. Since there are many other possible applications in space besides Alfven's theory of the solar system (the formation of the inner coma cometary plasma [Formisano et. al., 1981], and the ionization of the plasma torus of Io in Jupiter's magnetosphere, [Galeev and Chabibrachmanov, 1983]) it is of great interest to determine the exact conditions under which the effect might occur in space. The best resolution to these problems was to directly test the hypothesis in space, using chemical release experiments where the ejection velocities of around nearly 10 km/sec exceed the critical velocity of barium (2.7 km/sec) and strontium (3.5 km/sec).

Although there had been tantalizing hints of some sort of prompt ionization in previous barium release experiments (Deehr, et. al., 1982), the first conclusive evidence was reported from one of the Porcupine flights by G. Haerendel (1982). In this experiment, the shaped-charge barium beam traveled upwards at an angle of 28 degrees to the magnetic field at a height of 450km, which was below ionizing UV radiation. Any barium ionized while still below the uv terminator would travel up along field lines and appear above the terminator at the horizontal distance that ionization occured. Figure 1 shows a densitometer trace taken just after the cloud emerged into sunlight. A heavy ionization in the first few seconds after the explosion (while the cloud was still in darkness) is indicated by the ionization peak extending out to 10 or 15km from the explosion. Haerendel estimates approximately 30% of the barium cloud which had $V_{perp} > Vc$, was ionized. Haerendel also showed how the background plasma was capable of absorbing the lost momentum of the ions by carrying away Alfven waves from the beam region. Electric field obsevations from a remote payload confirmed his hypothesis.

To directly measure the plasma properties of the discharge, a new set of experiments, flown from Peru, were designed to both provide a stringent test of the critical velocity hypothesis, and to determine the range of pitch angles over which the critical velocity operated. In the Star of Condor (34.009) experiment ,a strontium radial shaped-charge was placed in the plane of the magnetic field lines, so that all ranges of pitch angles, from parallel to B to perpendicular to B were covered. The limiting value of perpendicular velocity for which the effect was observed, could have been used as a measure of the efficiency with which the kinetic energy of the newly created ions is transferred to the electrons. Strontium does not ionize in sunlight; hence any appreciable ionization observed (the initial explosion ionizes less than 10E-4) could be attributed to the critical velocity effect. However during the flight in March, 1983, essentially no ionization whatsoever was observed by E. M. Wescott, the principal investigator. Figure 2 is a photograph of the strontium neutrals from that observation.

The companion experiment, Star of Lima (34.010), placed an instrumented payload directly in a barium neutral beam directed almost directly downwards (hence almost perpendicular to the magnetic field lines) from an altitude of 450km. Figure 3 shows data from the UCSD electron analyzer near the time of the ignition. Quasi-dc electric field results from the Cornell University are included for comparison.

The percentage ionization observed in this experiment as determined either by ground based optical observations by E.M. Wescott, the principal investigator, or from UCSD ion detectors was quite low : about 10E-4 of the released cloud ionized. Even this could plausibly be accounted for by a slight exposure to photoionizing uv (about 1/40 of full exposure). However the instrumented payload detected many of the phenomena associated with the critical velocity effect, including broad band electric field waves around the

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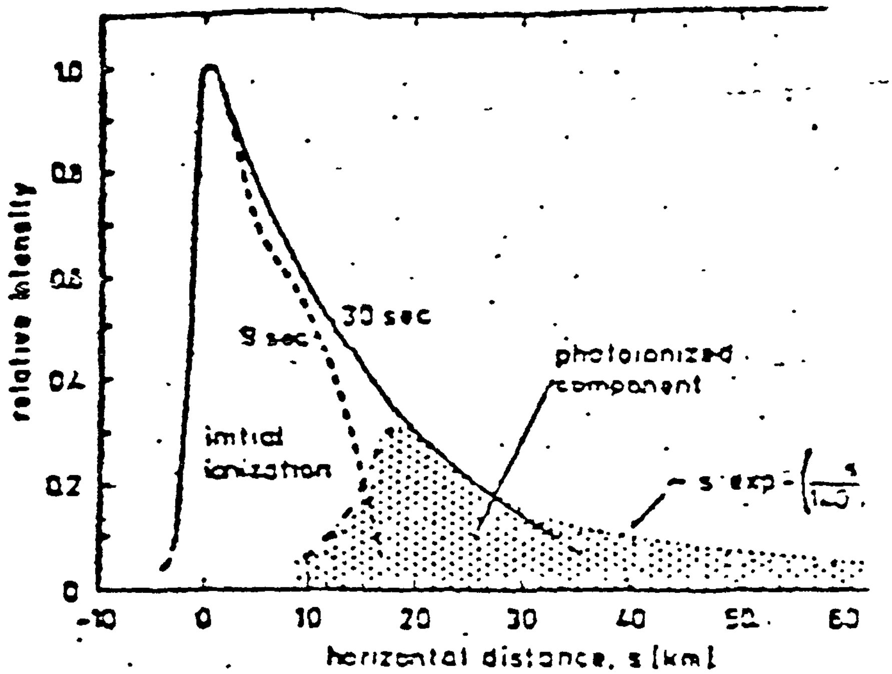


Fig 1 Densitometer traces of the ionized barium appearing above the terminator. The dotted part i of the data to the expected contribution from photo- tion. Nearly all ions to the left of $s = 15$ km are the of an initial ionization in darkness.

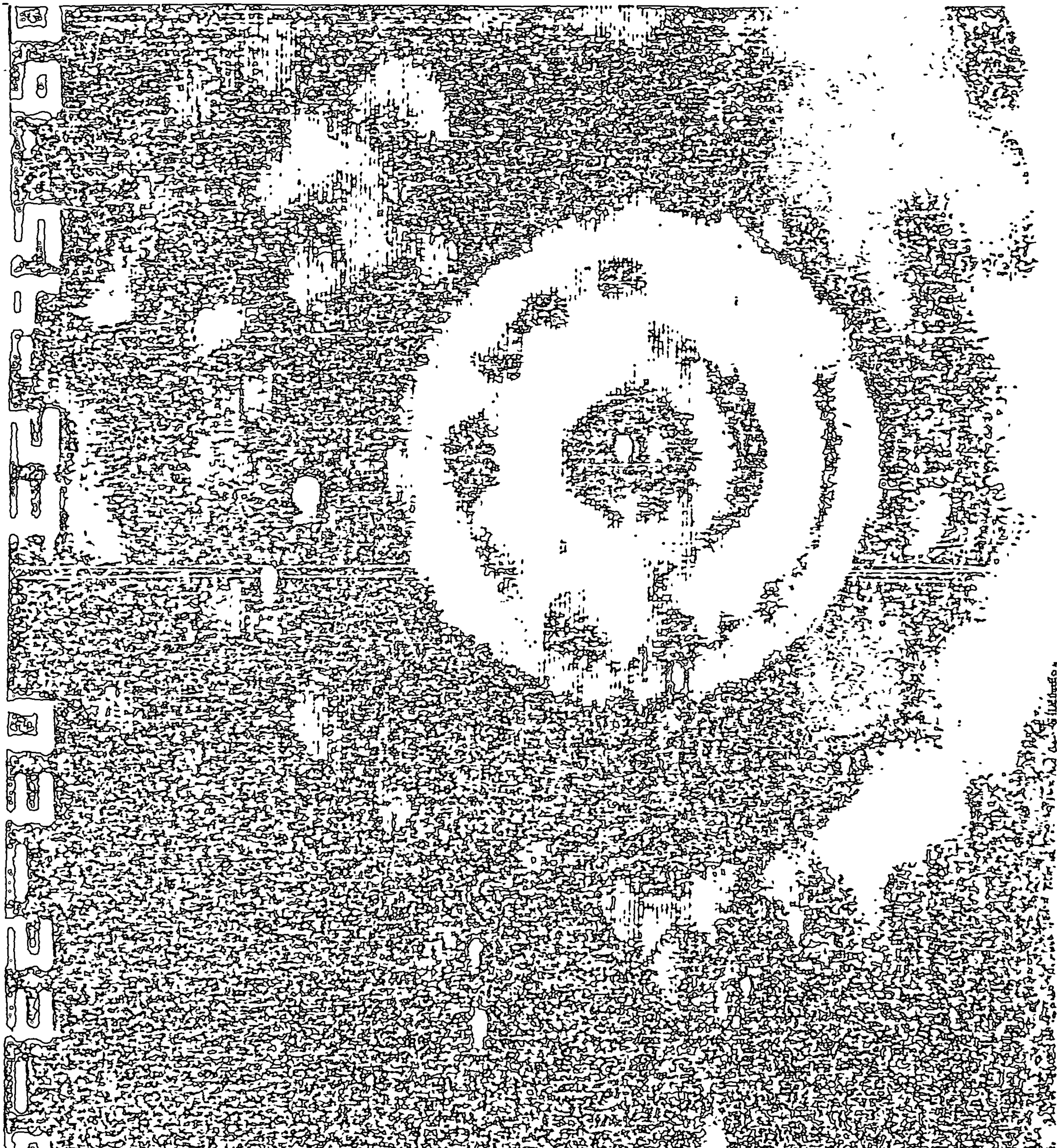


Figure 2. TV picture of neutral strontium vapor at +15 seconds, viewed from Paracas, Peru. Magnetic field line runs from center of

barium lower hybrid frequency and associated heating of electrons (the energetic electrons in Figure 3 could not have been produced directly from photoionization). It is clear that the processes believed to occur in critical ionization velocity experiments were in fact observed. The question arises: why was discharge not reached in Peru, yet was on Porcupine? Certain obvious candidate explanations can be ruled out; for example, the suggestion that the electrons escape from the system along field lines before they can have an ionizing collision can be ruled out, because of the electron pitch-angle isotropy observed. At present, the most likely explanation for the difference in the two barium release experiments is that the stronger magnetic field and higher plasma density in the Porcupine experiment allowed the background plasma to more effectively take up the momentum of the newly ionized barium atoms (enabling them to transfer their kinetic energy to heating electrons). The question of when the critical velocity effect will occur in space plasmas remains very open however.

The present set of experiments will be conducted with a complete set of instrumentation capable of resolving some of these questions. In one of the two Wallops flights, we will use barium as the neutral jet, and in the other, strontium, thereby exploring the differences between the two Condor experiments. As shown in Figure 4, there will be two instrumented payloads, so that both the electron thermal flux escaping from the beam and the size of the Alfven wave radiating from the interaction region (related to the efficiency of momemtum transfer) can be directly measured. Each rocket will consist of a main payload, a daughter payload attached to the ejected nose cone, and the chemical release module. The daughter payload will be ejected along the magnetic field by orienting the vehicle with an Attitude Control System (ACS). The ACS will then reorient the main payload to eject the chemical canister nearly perpendicular to the local magnetic field. There will be a slight upward cant to the injection velocity so that ions and neutrals preferentially move upward toward the terminator for 320 nanometer solar ionizing radiation. Thus, the conditions for both Porcupine and Condor will simultaneously be realized. The main payload will measure directly the ionizing front. However, now the daughter payload will be able to determine not only the amplitude of the Alfven wave created by the interaction, but also the amount of escaping superthermal electrons from the interaction the region. Thus, the two largest imponderables in both theoretical and experimental discussions of the effect will be directly measured. An extra bonus can be realized from the mother-daughter configuration in this case. Namely, if the lower-hybrid plasma waves are observed on both electric field detectors, the parallel phase velocity of the waves can be measured by correlating the two signals. The parallel wavelenth of 10 km is ideal for this sort of measurement. The high phase velocity along B is the feature of these waves that results in the large electron resonant heating responsible for maintaining the ionization process. Thus, we believe that some detailed plasma physics can be learned from this experiment.

The instrumentation includes 3-axis electric field and electron density measurements on both the mother and daughter (Cornell and Royal Institute), a fast ion and electron spectrometer measuring complete ion and electron energy and pitch angle distributions 500 times per second during the iqnition period by means of a burst-capture on board (UCSD), a precise plasma density measurement (Utah State), and search coil magnetometers (RIT). The chemical release modules are constructed by the University of Alaska and Max

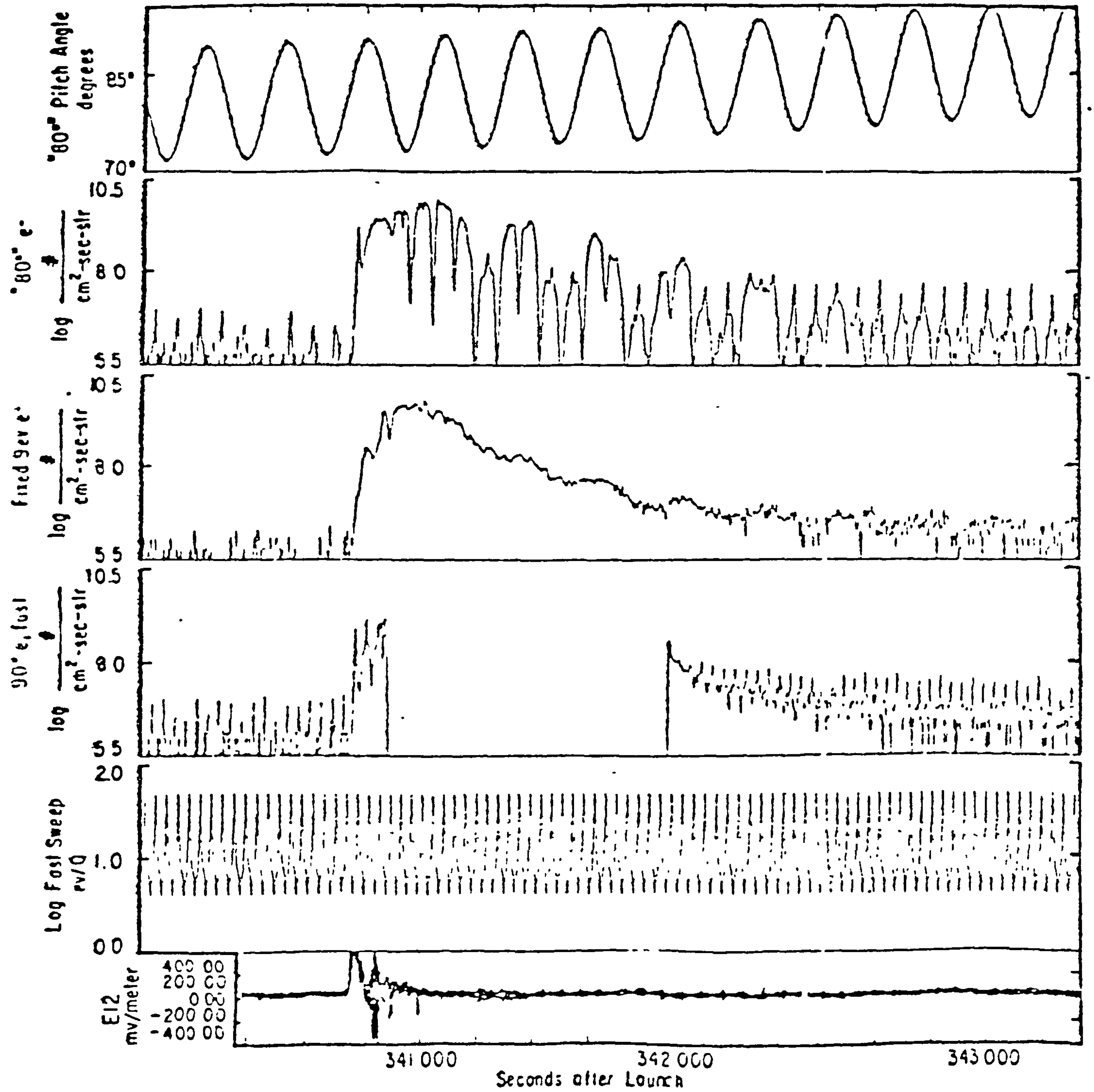
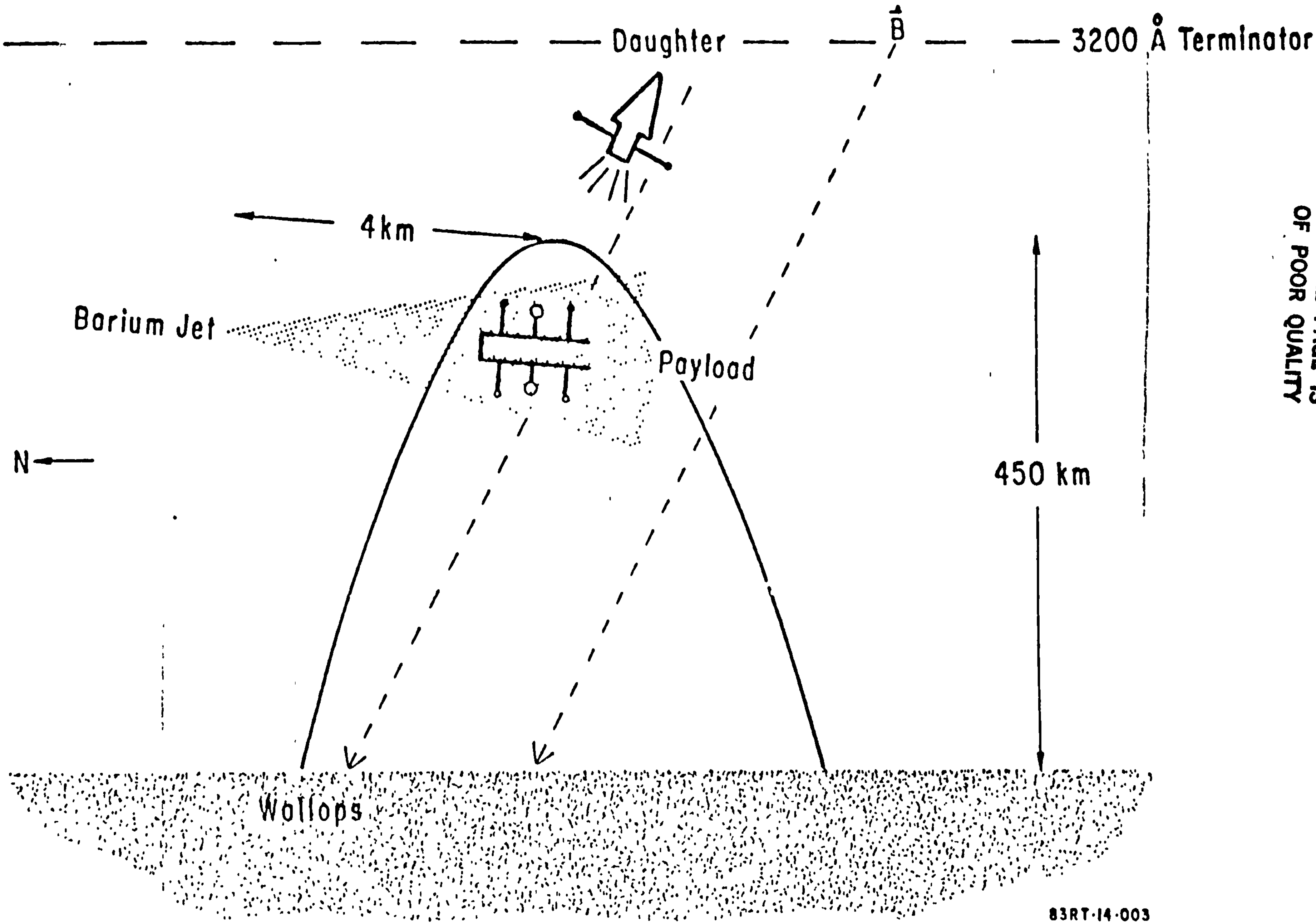


Fig. 3 Energetic electron fluxes measured by UCSD RPAS near the Ba release event at 340 658 flight time.



Daughter
$\vec{B}$
3200 Å Terminator
4km
Barium Jet
Payload
N
450 km
Wallops
83RT-14-003

Fig. 4