

MAY 21 1964

MASTER

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission: A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report. As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, approves, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PRELIMINARY RESULTS OF PLASMA MEASUREMENTS ON IMP-A

by

H. Bridge, A. Egidi, A. Lazarus, E. Lyon  
Laboratory for Nuclear Science and  
Department of Physics

L. Jacobson  
Lincoln Laboratory  
Massachusetts Institute of Technology  
Cambridge, Mass. U.S.A.

CONF-521-2

Facsimile Price \$ 1.60  
Microfilm Price \$ .80

Available from the  
Office of Technical Services  
Department of Commerce  
Washington 25, D. C.

-ABSTRACT-

Preliminary IMP-A plasma measurements made with a Faraday cup type

instrument are presented. The main results are as follows: a) A directed flux of positive plasma ions is always observed in regions beyond the influence of the earth. b) On each satellite pass two transitions in the plasma properties are usually observed, one transition can be identified with the magnetopause and one with a shock front created by the "supersonic" plasma stream. At the subsolar point, 12:00 Hrs. typical geocentric distances to these regions are  $10R_e$  and  $14R_e$  respectively; on the dawn side of the magnetosphere, 06:00 hr, the corresponding distances are  $14R_e$  and  $23R_e$ . c) In the transition region between the shock and the magnetopause a hot isotropic flux of positive plasma ions is observed.

Typical values of the directed plasma flux range from  $\phi = 1.10^8 \text{ cm}^{-2} \text{ sec}^{-1}$  to  $\phi = 1.10^9 \text{ cm}^{-2} \text{ sec}^{-1}$ . Typical values of the bulk velocity range from  $250 \text{ km sec}^{-1}$  to  $440 \text{ km sec}^{-1}$ . Data for the first three months of satellite operation will be presented and the significance of the results will be discussed.

This work has been supported by the National Aeronautics and Space Administration and by the Atomic Energy Commission.

5th International Space Science  
Symposium, Florence  
May 12-16

## DISCLAIMER

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

This paper presents preliminary results of plasma measurements carried out with a Faraday cup instrument on the IMP-A (Explorer 18) Satellite. The sensing device measures the flux of positive plasma ions between the limits  $(6 \times 10^6$  and  $6 \times 10^{10})$  particles  $\text{cm}^{-2} \text{sec}^{-1}$  and over an energy range (45 to 5400) e.v. The flux of electrons is also measured over a reduced energy range from 65 to 210 e.v.

The following characteristics of the satellite are pertinent to our discussion. IMP-A was launched Nov. 27, 1963 into a highly elongated orbit with an initial apogee of  $\sim 31 R_e$  (geocentric) and an initial perigee of 197 km altitude. The orbital period is  $\sim 3.9$  days. In describing the results we will use the solar ecliptic coordinate system shown in Fig. 1. In this reference frame the x axis is toward the sun; the z axis toward the north ecliptic pole, and the y axis is the third member of a right handed orthogonal set. The angles  $\phi$  and  $\theta$  respectively define the longitude measured eastward from the earth-sun line and the latitude measured in the conventional way. The initial direction of the line of apsides was in the general direction of the sun,  $\theta_a = -8^\circ$ ,  $\phi_a = 336^\circ$ . Fig. 2 shows the projection of the orbit onto the ecliptic plane; from this representation one can visualize roughly the position of the satellite relative to the sun-earth line as a function of time.

The satellite was spin stabilized with a period of rotation which has remained close to 2.4 seconds; precessional motion is negligible. The initial orientation of the spin axis was  $\theta_s = -50^\circ$ ,  $\phi_s = 238^\circ$ . The orientation of the spin axis as a function of time is shown schematically in Fig. 3. A further quantity of interest is the initial orientation of the orbit plane. The initial coordinates of

its normal are  $\theta_n = 46^\circ$ ,  $\phi_n = 257^\circ$ .

The type of plasma sensor used on the IMP satellite is shown schematically in Fig. 4. Very briefly its operation can be described as follows: A square wave voltage which oscillates at 1 KC between the limits  $V_1$  and  $V_2$  is applied to the modulator grid. Particles with a ratio of kinetic energy to charge,  $T/z$ , below  $V_1$  cannot reach the collector while those with  $T/z$  greater than  $V_2$  are not affected by the modulating voltage. The flux of particles with  $T/z$  between  $V_1$  and  $V_2$  is chopped at the modulator frequency and gives an alternating current at the collector which is amplified. Filtered and compressed logarithmically into an analog output voltage suitable for the telemetry system. This type of sensor has been described in previous publications <sup>1,2</sup> and its operation will not be considered in detail here. The plasma sensor and its response function are axially symmetric and maximum sensitivity occurs for particles which travel parallel to the axis of the sensor. The response falls to zero about 60 degrees off axis. The effective solid angle is about one steradian and the area solid angle product is about 25 cm<sup>2</sup> ster.

The instrument is mounted in the satellite with its axis of symmetry at right angles to the spin axis. Thus, as the satellite rotates the sensor scans a 360 degree field which extends  $\pm (60^\circ)$  with respect to the equatorial plane of the satellite. The telemetry format which governs the operation cycle is shown in Fig. 5. The format consists of four sequences each lasting 82 seconds. Each

1. Bridge, Dilworth, Rossi and Scherb, J. Geophys. Res. 65, (1960) 3053
2. Bright, Lazarus, Lyon, Rossi and Scherb, Space Research III, North Holland Publishing Co. (1963) 1113.

82 second sequence is divided into 16 equal frames 5.1 seconds in duration. One sequence in four is devoted exclusively to the rubidium magnetometer; during the remaining three sequences six 5.1 second intervals are allotted to the plasma measurements. The cycle of plasma measurements always begins in sequence 1 after the rubidium magnetometer measurement and is as follows: sequence 1, positive ions  $T/z = (45 - 105)$  e.v. and  $T/z = (95 - 235)$  e.v.; sequence 2, positive ions  $T/z = (220 - 640)$  e.v. and  $T/z = (560 - 200)$  e.v.; sequence 3, electrons  $T = (65 - 210)$  e.v. and positive ions  $T/z = (1700 - 5400)$  e.v. Approximately 3.5 seconds of each 5.1 second measurement interval is available to transmit the plasma signal. During this time the output is sampled every 160 m.s. corresponding to equal angular intervals of approximately  $20^\circ$ . These 22 measurements require about 1.5 revolutions. The energy window is then shifted and the process repeated. A complete energy scan requires 2.8 minutes and is repeated every 5.5 minutes.

At this point we summarize briefly the main results obtained to the present writing, and, in what follows, we give a more detailed description of the experimental evidence.

The main results are as follows:

a) A directed flux of plasma ions is always observed in regions far from the earth where the plasma motion is unaffected by the geomagnetic field. We refer to this as region I.

b) For each orbit at least two transitions in the properties of the plasma are observed on the inbound pass and on the outbound pass of the satellite. One transition can be identified with magnetopause

and one with a shock front created by the supersonic plasma stream. At the subsolar point, 12:00 hours, typical geocentric distances to these regions are  $10R_e$  and  $14R_e$  respectively; on the dawn side of the magnetosphere, 6:00 hours, corresponding distances are  $14R_e$  and  $23R_e$ .

c) Between the shock front and the magnetopause, region II, a hot isotropic flux of plasma is observed.

In Fig. 6 the plasma flux is plotted on a linear scale as a function of rotation angle for the 5 positive ion levels and for the electron level. These data were taken on orbit 1 when the satellite was at a distance of  $21.7 R_e$ . It is clear that the signal is concentrated in energy window 3, (220-640) e.v., and that the plasma flow is essentially unidirectional. The arrows on the figure indicate the time at which the axis of the sensor pointed as closely as possible to the sun. Within the angular uncertainty of  $\pm 10^\circ$  it is clear that the longitude of the bulk velocity vector  $\phi_v$  is  $180^\circ$ . Data which should permit the simultaneous determination of  $\theta_v$  has not yet been reduced. The signals plotted in Fig. 6 are characteristic of region I.

In Fig. 7 the general plot is similar to that shown in Fig. 6; the data refers again to orbit 1, but the distance was  $15 R_e$ . It is clear that the angular distribution is essentially flat and that the energy spectrum extends from the lowest to the highest channel. (The noise level in Figs. 6 and 7 is about  $6 \times 10^6 \text{ cm}^{-2} \text{ sec}^{-1}$ ).

To permit a more ready inspection of the data we have chosen to plot appropriate 2.8 minute averages of the plasma properties every 5.5 minutes. A portion of such a plot for orbit 3 inbound is shown in Fig. 8. The abscissa is a linear time scale increasing to the right.

From top to bottom the first line represents the average energy flux per particle with the ordinate in e.v.; in the second graph the ordinate represents  $\log_{10}$  of the total positive ion flux; the third graph represents the  $\log_{10}$  of the electron flux, and finally the fourth graph gives a measure of the width of the energy distribution.

For the proton and electron fluxes two values are computed:

one "looking toward" and one "looking away" from the sun. Thus two levels are seen plotted for these fluxes in Fig. 8 and the separation between the maximum and minimum flux level is a measure of the anisotropy of the plasma flux. In the figure the proton flux at distances greater than  $15R_e$  has a value of  $\sim 10^8 \text{ cm}^{-2} \text{ sec}^{-1}$  and shows a high degree of anisotropy. The electron flux at this time is essentially at the noise level of the instrument. These conditions are characteristic of those we have identified with region I and persist until about  $15R_e$ . At this time the thermal energy of the protons increases, and the flux becomes close to isotropic. At the same time a relatively large flux of isotropic electrons is observed. These conditions are characteristic of region II and persist with some variations until about  $10R_e$  when there is an abrupt decrease of the proton and electron fluxes to the noise level. In this pass  $10R_e$  corresponds to the boundary of the magnetosphere. The space within the magnetosphere is defined as region III.

The data in Fig. 8 were obtained during orbit 3 when the satellite was close to subsolar region. With the exception of 3 passes which have not yet been examined, similar results have been obtained for 43 traversals of the boundary region (up to orbit 23, Feb. 24). These

data are plotted in Fig. 9; the solid lines indicate the portions of the orbit in which the flux observed was essentially isotropic. (Fig. 2 is useful in interpreting this figure). In constructing the figure, points on the trajectory have been rotated about the earth-sun line into the plane of the ecliptic.

The most striking feature evident from Fig. 9 is that the shape of the magnetospheric boundary and the shape of the shock front are in full agreement with the well known theory of supersonic aerodynamic flow around a blunt body. On the average at least, regular boundary surfaces are observed for the magnetosphere and the shock front during an extended period of time. This observation suggests that a stable boundary surface exists. There are, however, features of the data which are as yet unexplained and the details of the interaction between the plasma and the geomagnetic field are as yet not obvious. Initial attempts to check the conservation equations for particle density, momentum flux and energy density across the shock transition are encouraging and results will be reported in due course. Finally, we would like to emphasize that rapid transitions in the properties of the plasma are a characteristic feature of the data.

This can be seen by a close inspection of Fig. 9. In this representation broken regions of the orbit traces indicate regions in which a transition was observed from a nearly isotropic flux of positive ions to a directed flux. Typically conditions change in the following sequence on an inbound pass: I  $\rightarrow$  II  $\rightarrow$  I  $\rightarrow$  II...  $\rightarrow$  III. Transitions between these conditions are observed to take place in times less than 5 seconds and the time during which region I is observed in the sequence II  $\rightarrow$  I  $\rightarrow$  II is frequently of the order of 5 or 10 minutes. For this reason, the transitions tend to be "washed out" by the 2.3 minute averages used in Fig. 8. Fig. 10 shows a portion of the orbit in which data for the maximum and minimum flux observed during one revolution of the

satellite is plotted for energy level 3 (220 - 640) e.v. Transitions between regions I and II are clearly evident. Detailed spectra for a transition of this sort are as shown in Fig. 11. Here the transition has taken place with a time uncertainty of  $\sim$  80 seconds defined by the magnetometer sequence which occurs between the two plasma measurements shown.

We acknowledge with gratitude the close and effective collaboration with our many colleagues at the Goddard Space Flight Center. Without their help, this work would not have been possible.

In the analysis of the data we have profited by the work of Dr. G. Moreno and by discussions with Prof. S. Olbert; Mr. R.H. Baker of Lincoln Laboratory contributed in an essential way to the design and construction of the experiment.

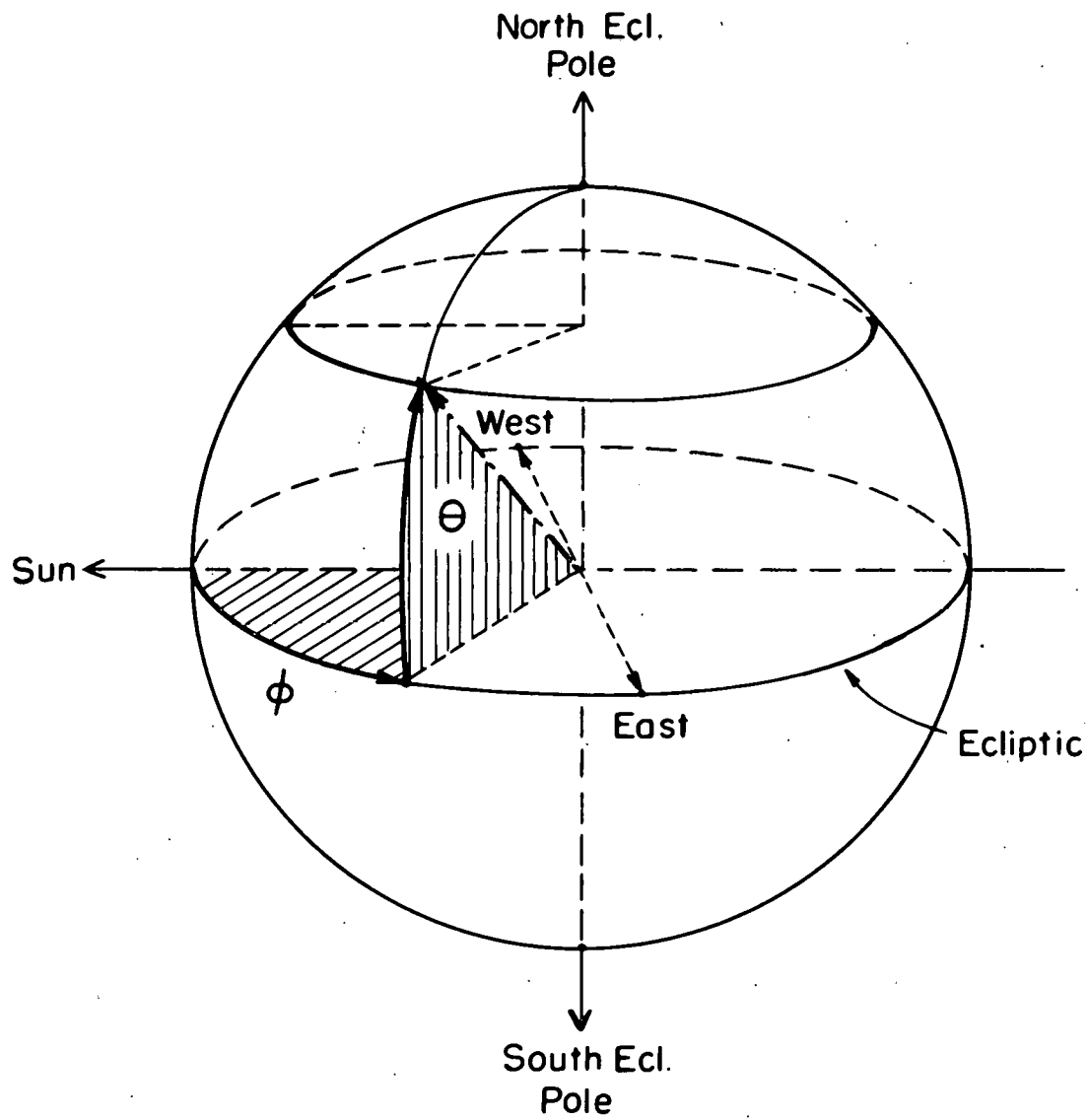


Fig 1

### IMP I ORBIT-EARTH - SUN RELATIONSHIP

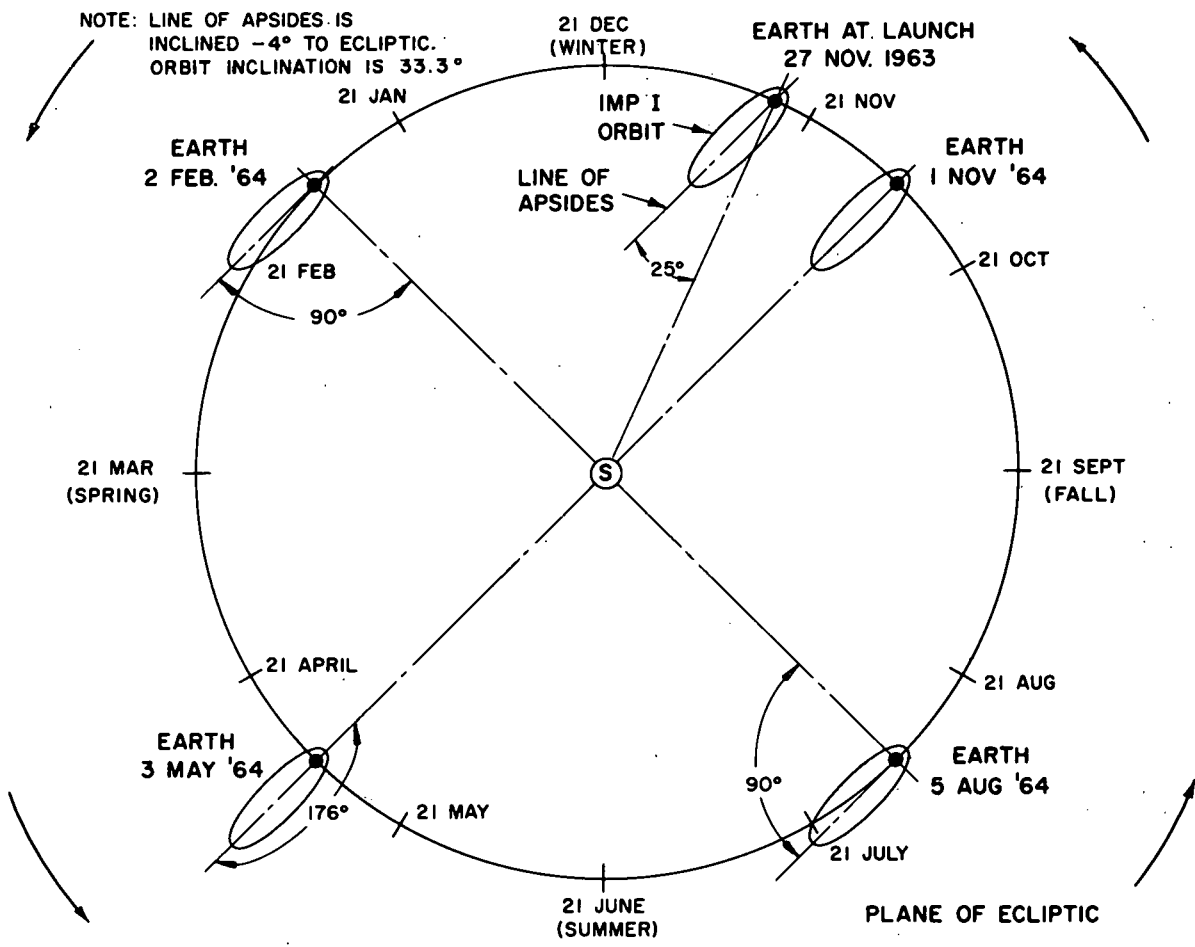


Fig. 2

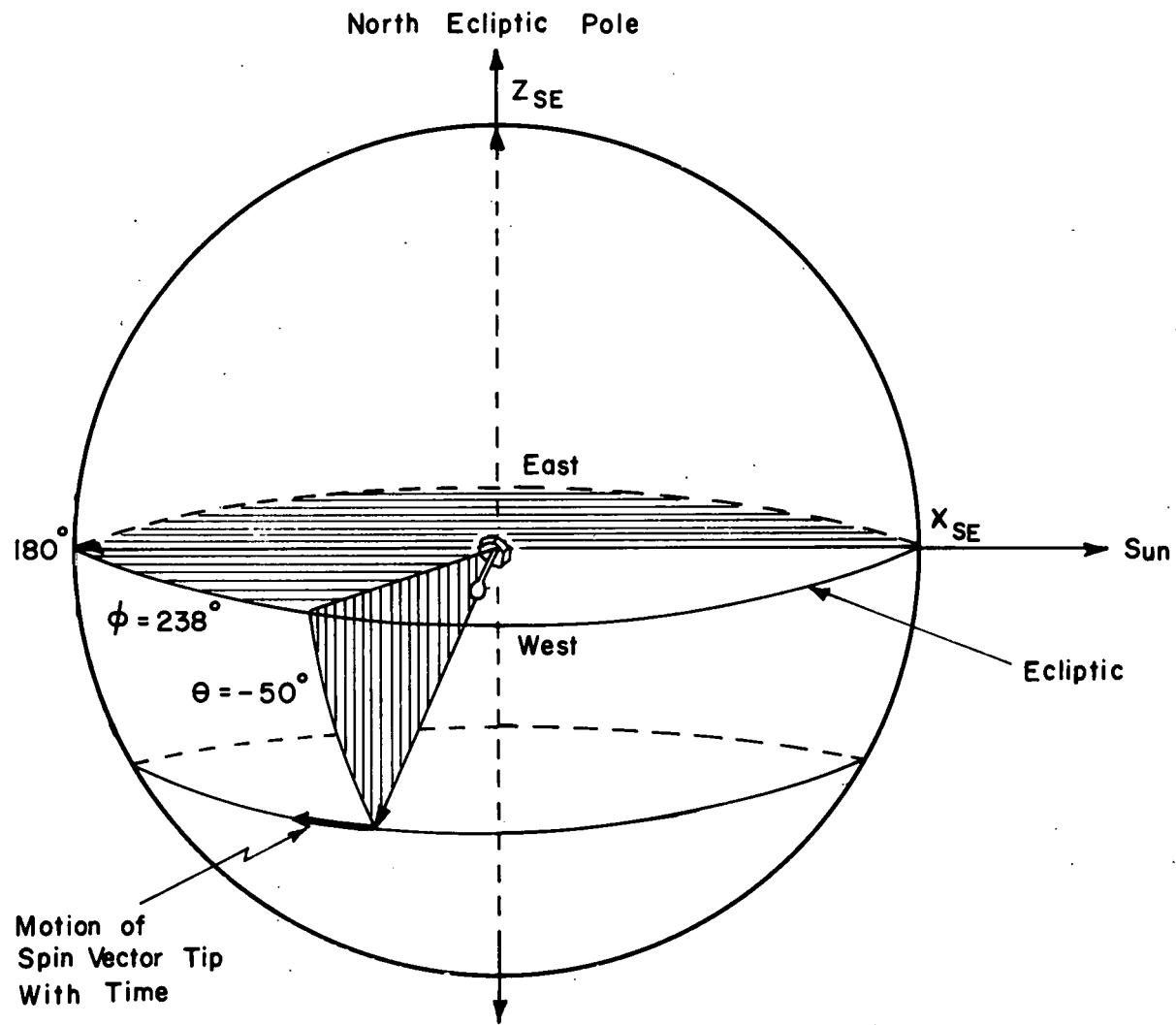


Fig. 3 - ORIENTATION OF SATELLITE AT TIME OF LAUNCH  
(NOV. 27, 1963)

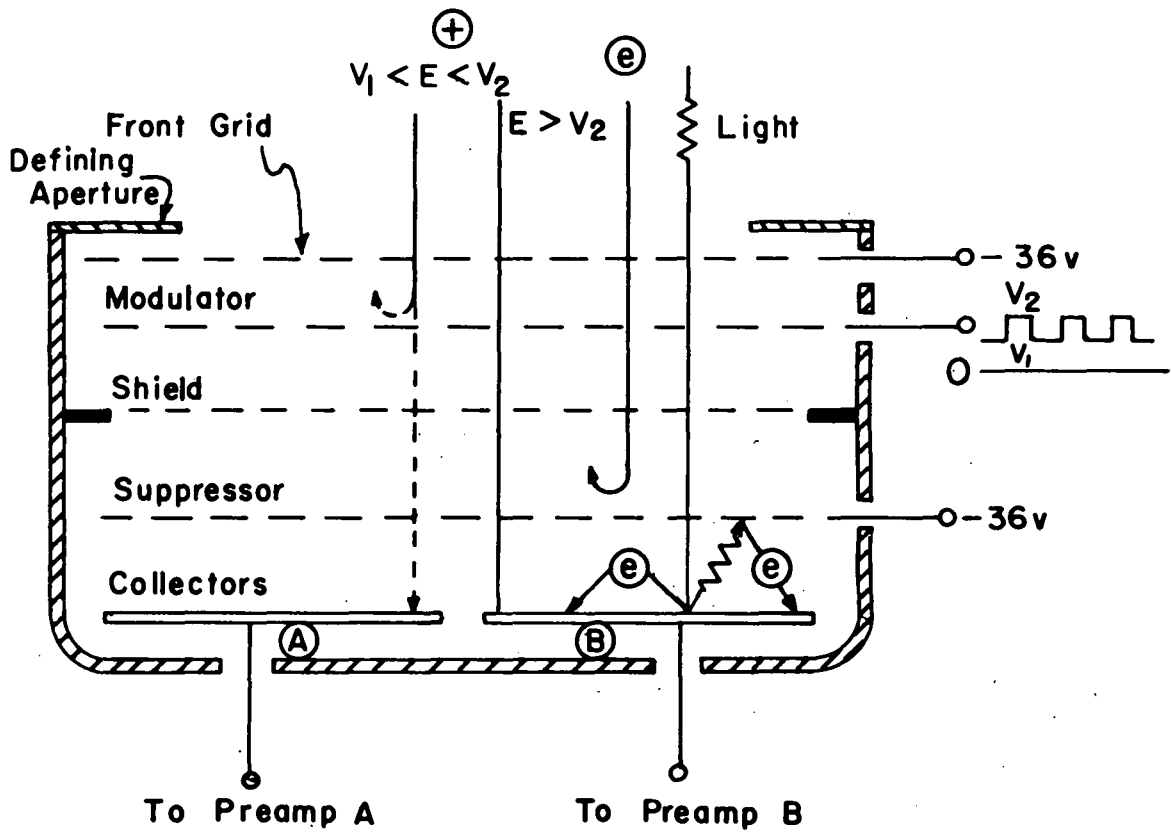
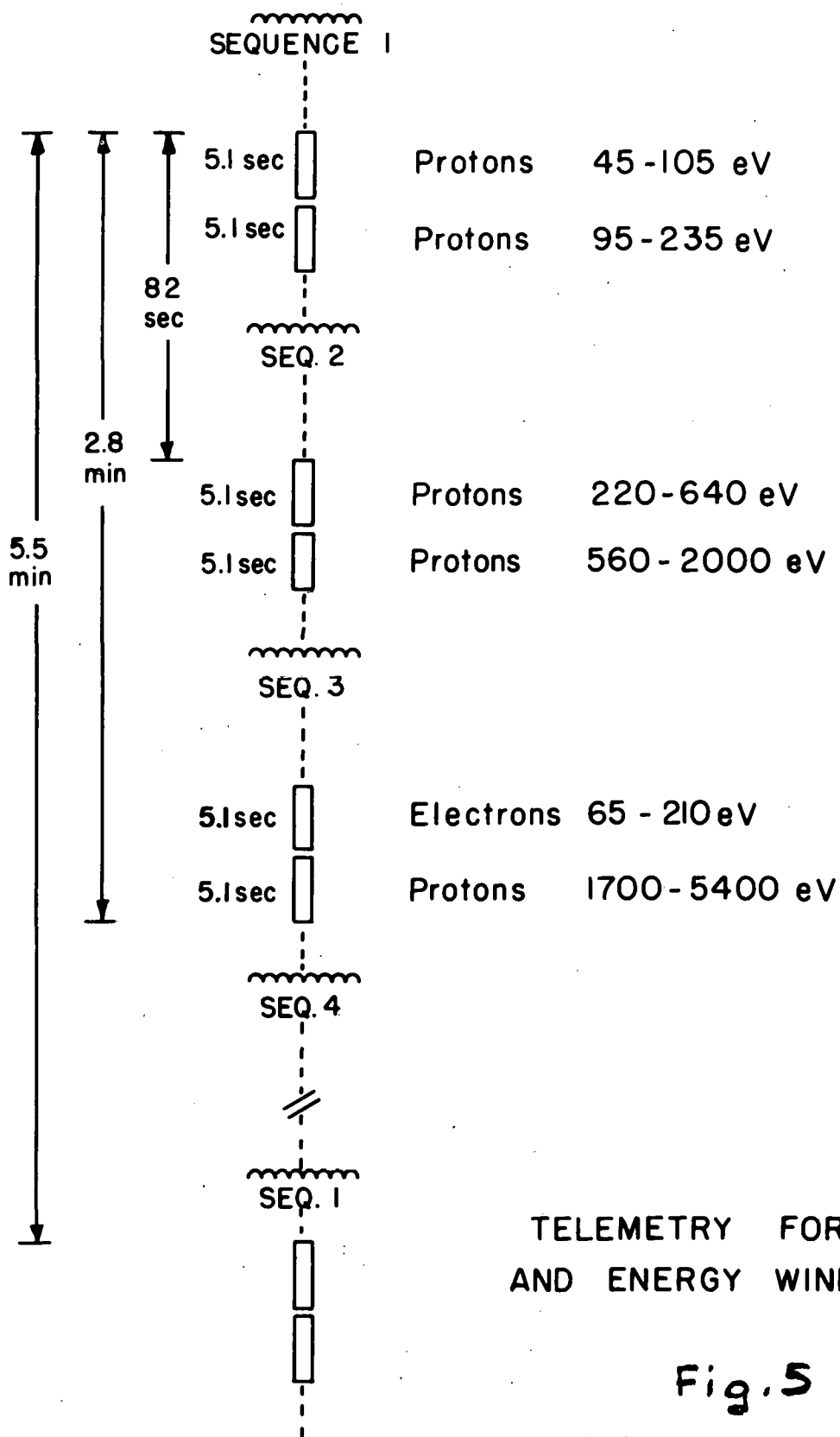


Fig. 4-IMP-A PLASMA CUP



TELEMETRY FORMAT  
AND ENERGY WINDOWS

Fig. 5

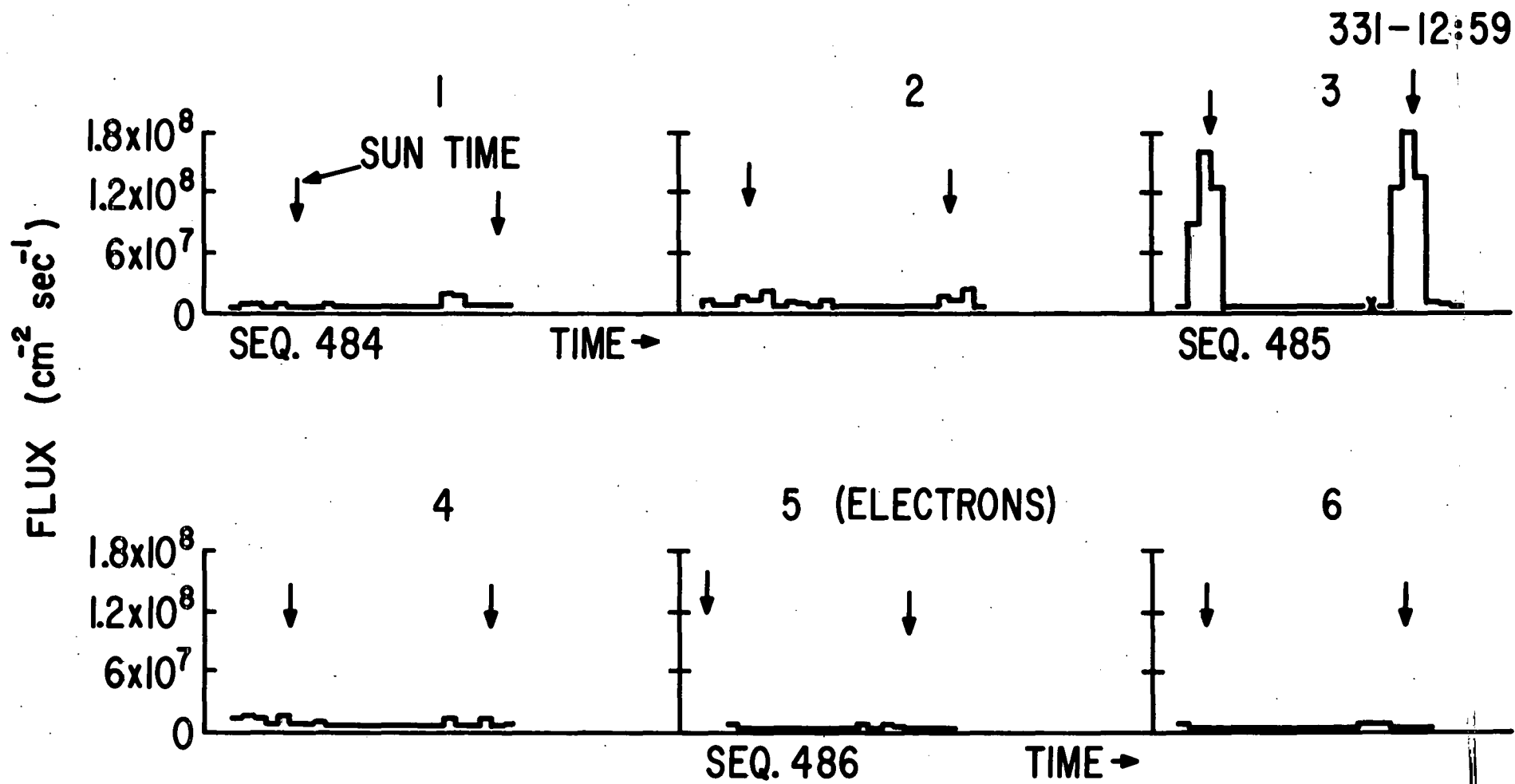


Fig. 6

331-10:48

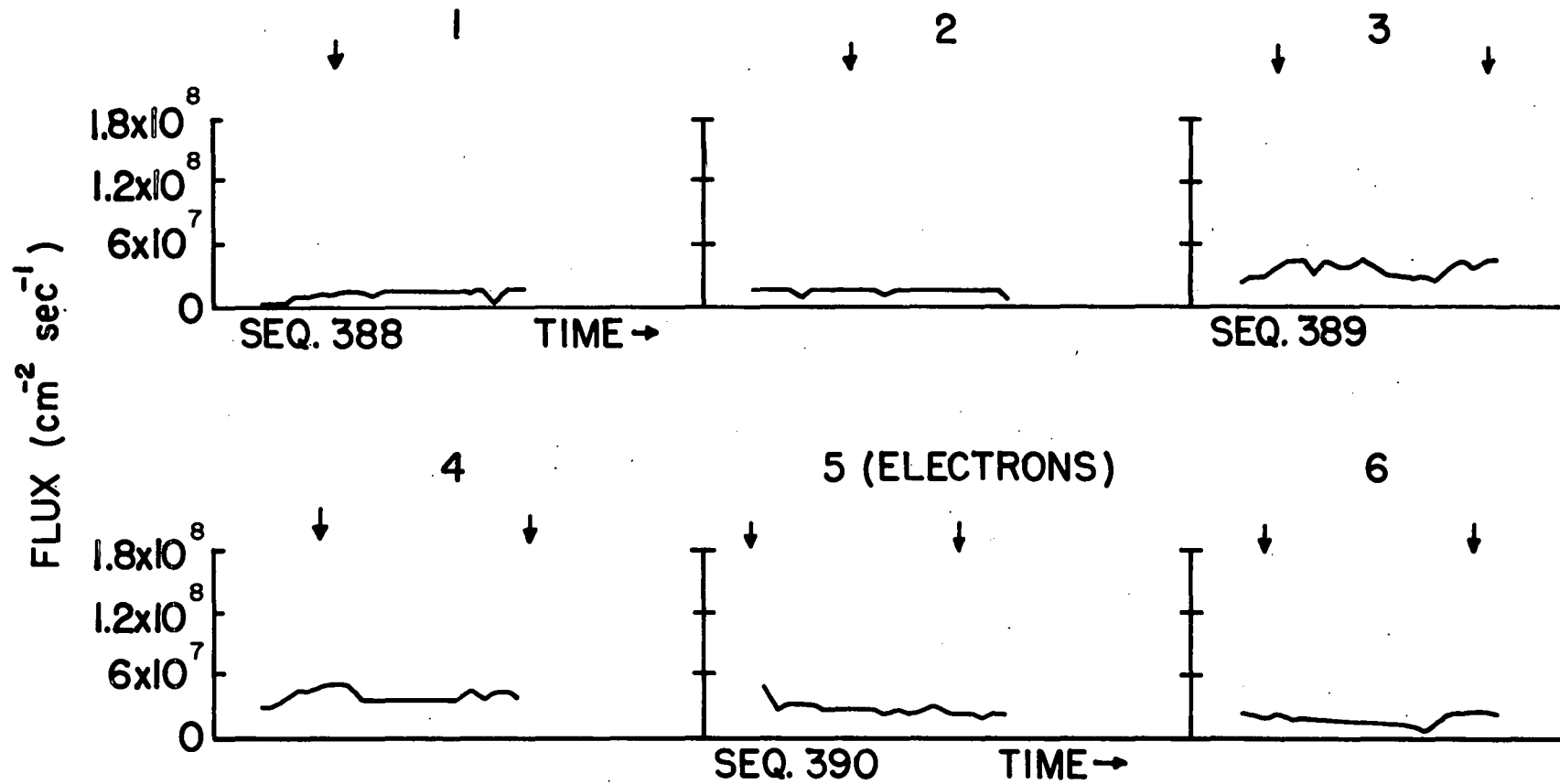


Fig. 7

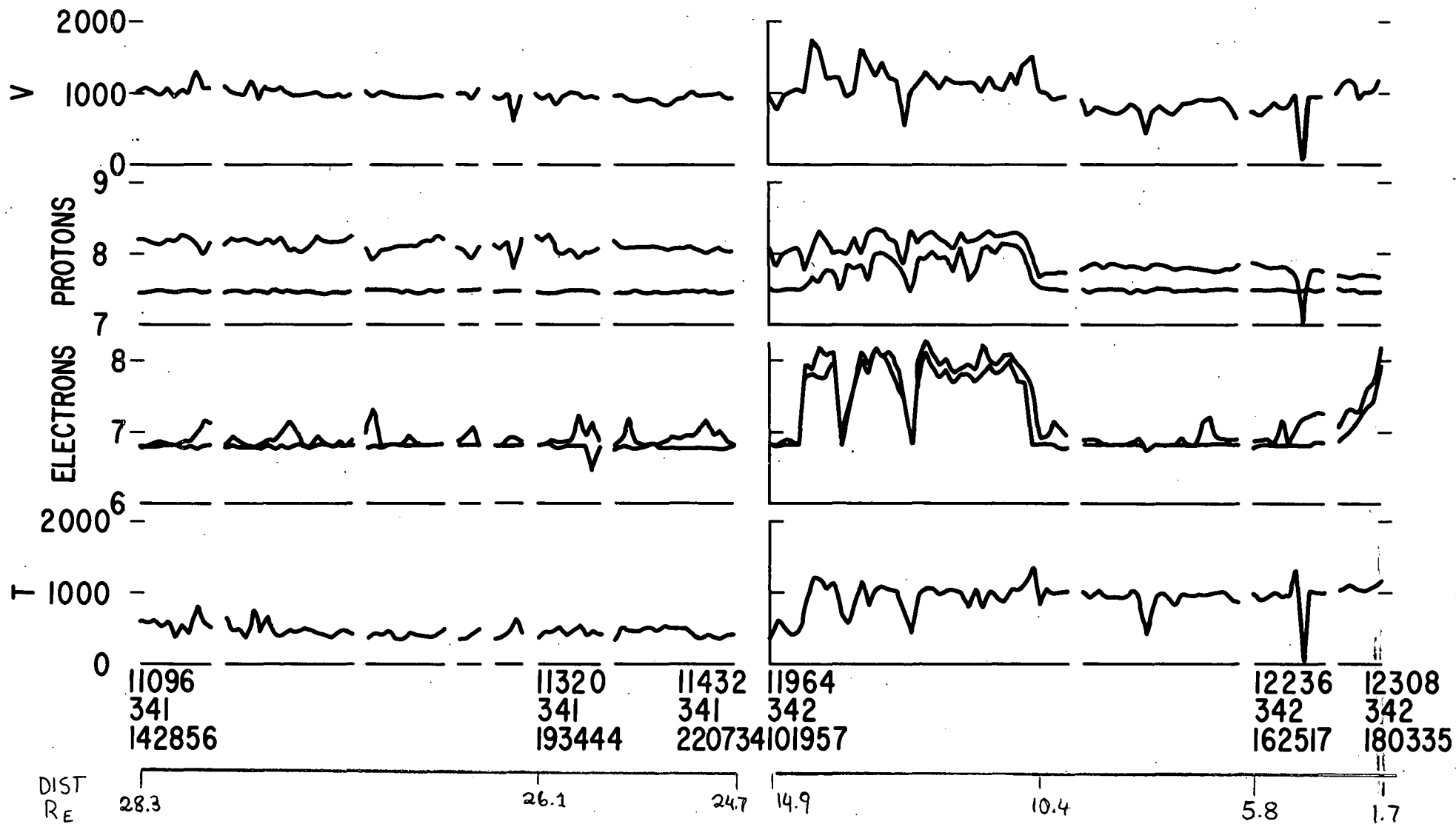
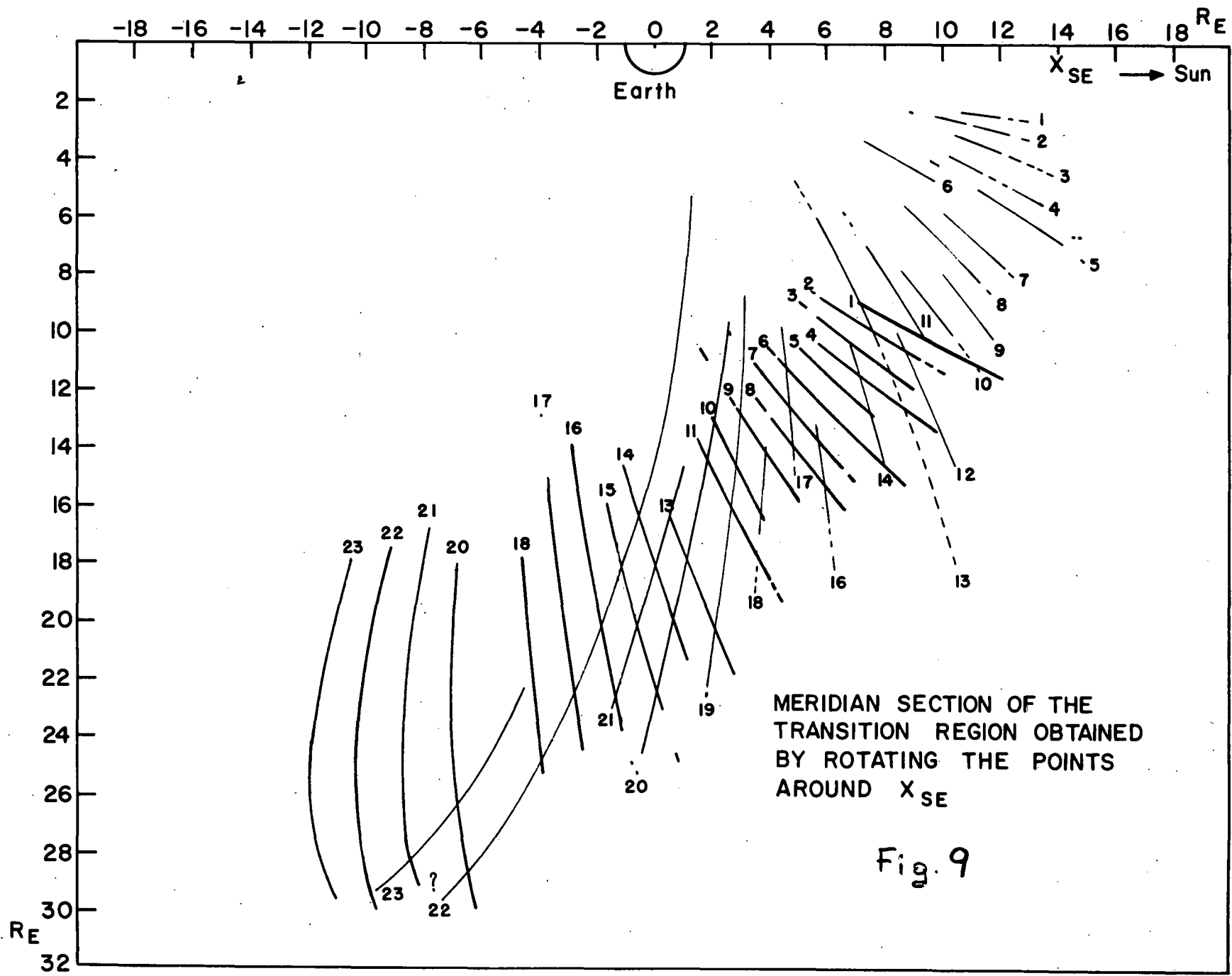


Fig. 8



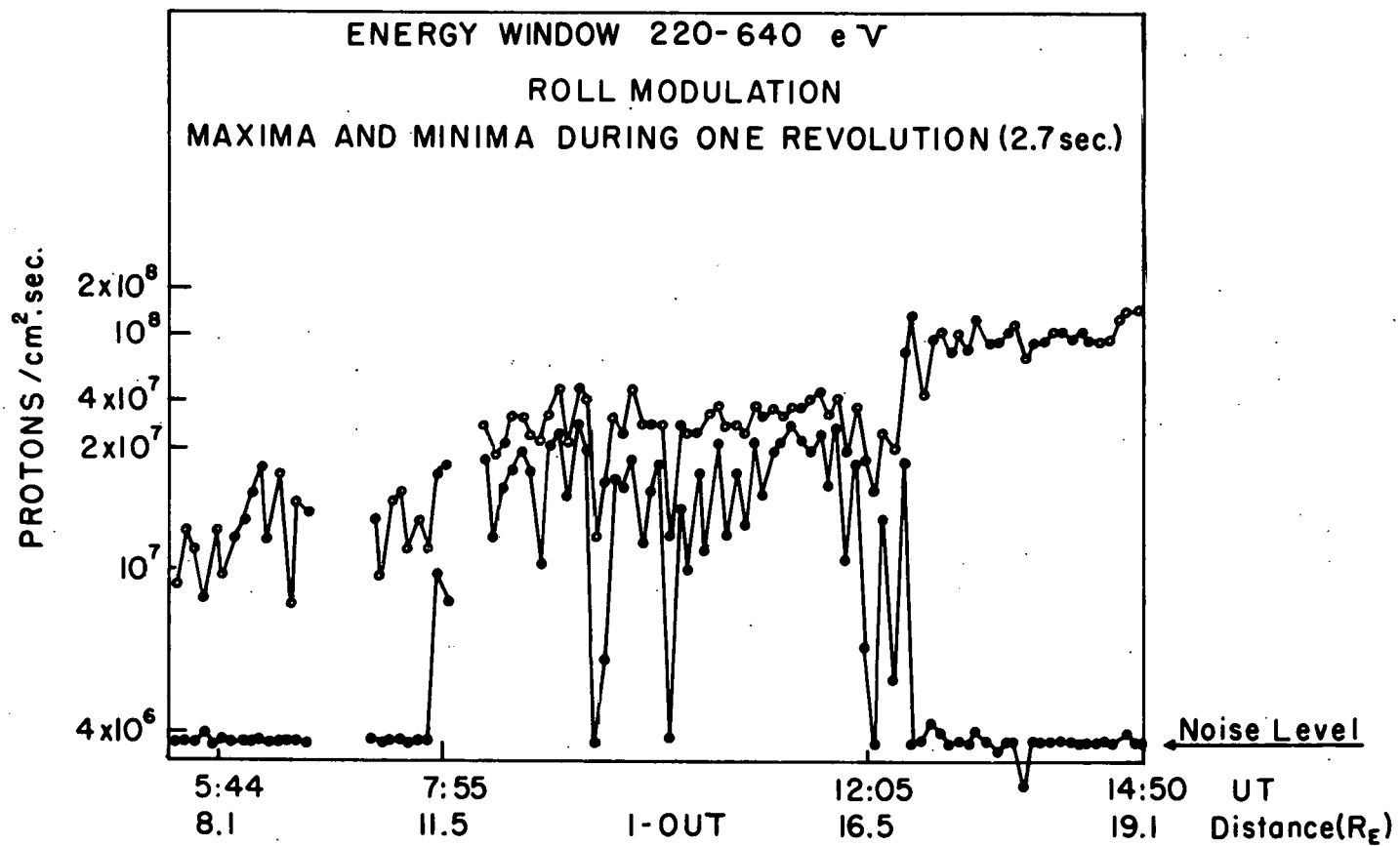
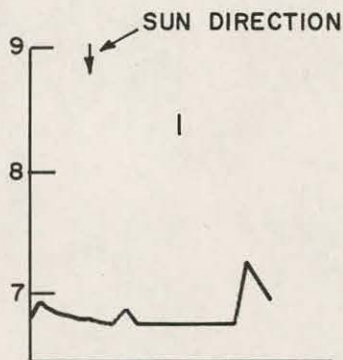


Fig. 10 - IMP I - 1<sup>st</sup> PASS OUTBOUND (NOV. 27<sup>th</sup>, 1963)

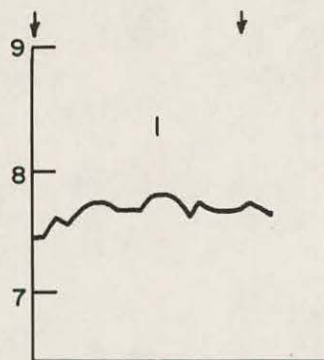
Fig. II

ORBIT I INBOUND - DIST. 13.1  $R_E$  - NOV. 30, 1963 (DAY 334)  
 TRANSITION FROM REGIME I TO REGIME II

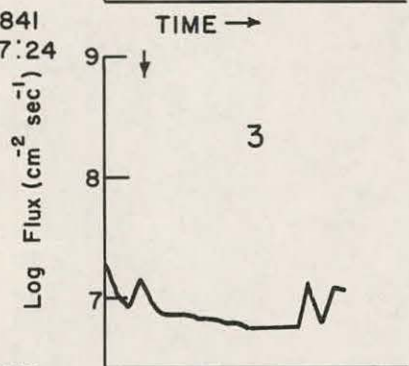
SEQ 3840  
 TIME 17:22



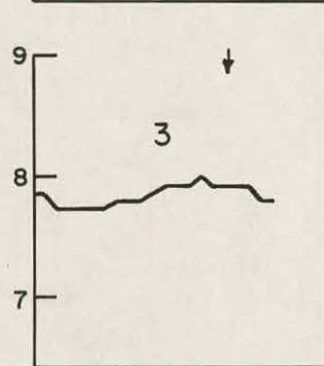
SEQ 3844  
 TIME 17:28



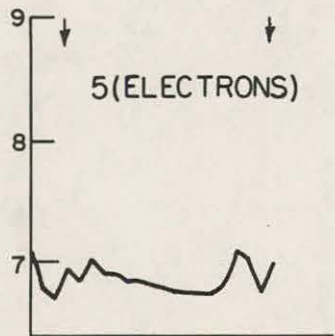
SEQ 3841  
 TIME 17:24



SEQ 3845  
 TIME 17:29



SEQ 3842  
 TIME 17:25



SEQ 3846  
 TIME 17:30

