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INTRODUCTION

The NASA satellite Explorer 33 was launched from the Eastern Test Range, Cape Kennedy, Florida on 1 July 1966 at 1602:25.375 UT by a Thrust Augmented Improved Delta vehicle. The primary objective was to place the 57.1 Kg. spin-stabilized IMP type spacecraft into a captured lunar orbit and investigate the magnetic field, plasma and energetic particle environment of the Moon. Unfortunately the injection velocity following third stage burnout was slightly in excess of the nominal required by 0.2% and no stable orbit anchored to the lunar gravitational field was possible. The decision was made at 2100 UT to abort the primary mission by firing the fourth stage retro-rocket at 2233 UT and thus switch to the alternate mission. This was planned in advance for those few cases of trans-lunar trajectories which precluded successful lunar orbits.

The alternate mission selected was to place the satellite into a highly elliptical earth orbit with apogee near 450,000 Km. well beyond the moon's orbital distance of 385,000 Km. In addition the line of apsides was to initially begin at a solar ecliptic longitude of approximately $\phi = 240^{\circ}$, which corresponds to 120° West of the Sun. Thus during its first six months the satellite would sweep through the entire antisolar portion of the magnetosphere and investigate the geomagnetic tail at distances up to 80 R_E (1 R_E = 6378.2 Km).

The retro firing was successfully performed and placed Explorer 33 in the highest Earth orbit yet achieved for any satellite. The initial orbital parameters were: apogee = 440,300 Km. at $\phi_{SE} = 242^{\circ}$, $\theta_{SE} = -1^{\circ}$ on July 7; perigee = 51,000 Km. and orbital period = 12 days. The initial spin rate was 26.5 rpm and the spin axis orientation was $\phi_{SE} = 129^{\circ}$, $\theta_{SE} = -4^{\circ}$. The orbital parameters were severely perturbed by a close lunar approach at a selenocentric distance of 36,300 Km. on July 9. Both apogee and perigee have continued to increase since that time due principally to lunar perturbations and in Orbit No. 4 apogee was 514,100 Km on August 24 at $\phi_{SE} = 187^{o}$ and $\theta_{SE} = -3^{o}$ with perigee at 79,100 Km on September 2.

This note presents preliminary results of a study of the geomagnetic tail from data obtained by the NASA-Goddard Space Flight Center magnetic field experiment during the first 55 days of satellite lifetime. A separate report by Van Allen and Ness (1966) discusses simultaneous particle and magnetic field observations of an interplanetary shock wave detected on 8 July when the spacecraft was located in interplanetary space outside the earth's bow shock wave.

MAGNETOMETER EXPERIMENT

The GSFC magnetic field experiment employed a triaxial fluxgate sensor located at the end of a boom 2.2 meters from the spin axis to eliminate spurious contributions to the measurements from spacecraft generated magnetic fields. Two axes of the sensor are oriented perpendicular to the spin axis and hence the rotation of the satellite permits the inflight determination of the zero level of these two sensors since they are physically reversed by 180° each spin. A thermo-mechanical "flipper" device reorients the triaxial sensor set by 90° around the boom axis once each 24 hours. This places the third axis of the sensor set perpendicular to the spin axis to permit its zero level determination.

Preliminary investigation of the post-flight zero levels of the three sensors indicate nominal accuracy of approximately $\pm 0.25\ \gamma$ (1 gamma = 10^{-5} oersted). The dynamic ranges of the sensors are approximately $\pm$ 64γ which with the 8 bit analog-digital converter of the experiment electronics provides a quantization uncertainty of $\pm 0.25\gamma$. An in-flight calibration of the sensitivity and linearity is provided by temporarily adding an accurately known magnetic field increment to the sensors twice each day. The performance of the magnetic field experiment for the first 60 days of operation has been completely consistent with preflight calibrations of accuracy and precision.

A three component measurement and digitization is performed by the instrument in 10 milliseconds. Sixteen such vector measurements of the magnetic field are obtained at 5.11 second intervals in each telemetry sequence of 81.808 seconds. From these data a sequence average magnetic field is computed by linearly averaging the separate orthogonal components in a non-rotating payload coordinate system. The component averages are then rotated into a solar ecliptic coordinate system for interpretation and additional analysis. These components then determine the direction of the field in terms of solar ecliptic latitude θ and longitude ϕ. The magnitude average is computed by linearly averaging the magnitudes of the 16 separate samples in each sequence.

The data presented in this report include also hourly averages which are computed in a manner similar to that used for the sequence averages. That is, the hourly averaged components are computed to determine the average field direction and the magnitude averaged directly as before. If the magnetic field fluctuated rapidly with large amplitudes, then such average fields might not well represent the instantaneous field at any moment. However, for the fields measured previously in the geomagnetic tail by Ness (1965) and for those reported herein the direction and magnitude are generally very steady and only slowly changing except during traversals of the neutral sheet or at times of geomagnetic activity. Since most of the data included in this note were obtained during periods of low geomagnetic activity, the field averages can be physically interpreted as being a good representation of the instantaneous magnetic field.

OBSERVATIONS

During the first two orbits of Explorer 33 in July 1966, the cislunar portion of the geomagnetic tail was found to have a topology ($\theta = 0^{\circ}$, $\phi = 0^{\circ}$ or 180°) and field magnitude (15-25γ) consistent with the previous results of the IMP 1 satellite (Ness, 1965). This spacecraft had previously mapped the magnetic tail extensively out to $32R_E$ during the period March 15 to May 30, 1964. In addition the position of the magnetopause and bow shock wave have been measured by Explorer 33 to be in approximately the same relative positions as observed by IMP-1.

The high apogee has extended the dawn side observations of the magnetosheath at a solar ecliptic longitude of approximately 225° to $70R_E$. A future publication will discuss these and subsequent data obtained on the magnetosheath when Explorer 33 sweeps through the dusk side region. Note that the perigee of the satellite (8-12 R_E) is ideal for studying the magnetosheath and its boundaries for the first six months of its lifetime. Thereafter the high perigee will permit a detailed study of the night side magnetosphere where it changes from approximately a dipolar field geometry to the tail configuration, a region referred to by Anderson and Ness (1966) as the particle "cusp".

During the outbound portion of the third orbit, Explorer 33 spent 36 hours in the magnetic tail beyond the lunar orbital distance. Except for a brief encounter with the near-earth end of the neutral sheet, the satellite remained well above the sheet for the remainder of the pass through the tail.

The magnetic field well away from the neutral sheet was very steady, with magnitudes ranging between 10 - 18 γ at distances less than 50 R_E. The field magnitudes are consistent with relatively quiet geomagnetic conditions during most of August. On IMP-1 enhanced tail field magnitudes of up to 40γ were found to be positively correlated with geomagnetic activity (Behannon and Ness, 1966). The field direction was almost always within a few degrees of being parallel to the earth-sun line. The data are possibly suggestive of a slight divergence of the tail field lines from the tail axis.

The magnetic field magnitude gradually decreased as Explorer 33 moved out to the vicinity of the moon's orbit, (60R_E) while the field continued to be directed approximately toward the sun. Figure 1 shows the magnetic field vectors measured on August 2 and 3 by Explorer 33 during orbit 3 at distances beyond the Moon. These vectors were constructed from hourly averages of the field. The tails of the vectors trace out the position of the satellite during the 30-hour orbital segment onto the ecliptic plane and perpendicular to it (the X_{SE} - Z_{SE} plane). The Z_{SE} scale has been expanded for purposes of clarity of presentation but no change has been made on vector magnitudes or directions. The day numbers shown (213-214) represent day-of-the-year numbers relative to January 1 as day 0.

It is to be noted that the observed magnetic field topology is characteristically that of the earth's magnetic tail above the neutral sheet. The minimum hourly average field magnitude was 4 γ with a subsequent increase again to >14γ before the tail boundary was reached. The median field magnitude was 8.4γ. Identification of the boundary crossing into the magnetosheath is based on the change in the character of the observed magnetic field from that of a steady, well-ordered tail field to that of the turbulent and fluctuating field characteristic of the magnetosheath (Ness et al. 1964). Because of motion of the magnetopause the spacecraft usually crosses the boundary more than once during a single traversal of the boundary region. The magnetopause was first detected on this orbit at a distance of 17.4 R_E from the earth-sun line. If an aberration of the geomagnetic tail axis of 4^o is assumed, then this yields a tail radius of $17.4+4 = 21.4$ R_E. The effect of the proximity to the magnetopause is seen in the directional changes of the last three hourly average field vectors shown in figure 1. The magnitude increase in day 214 may be correlated with an increase of the A index (Preliminary report No. 783 HAO) from its lowest value in August on day 213.

Figures 2 and 3 show orbit 4 of Explorer 33 in solar magnetospheric coordinates (Ness, 1965), in which the true orbital motion is modulated by the daily wobble of the geomagnetic dipole axis. Z_{SM} in Figure 3 is indicative of the perpendicular distance from the neutral sheet to the spacecraft. On this basis it can be seen from figure 3 that numerous close approaches with the neutral sheet should have been expected during orbit 4.

The hourly average field components for a period of more than nine days from August 16-26 when Explorer 33 was in the magnetic tail are shown in figure 4. Because of continued close proximity to the neutral sheet throughout this pass, the observed field was much less steady than is typical of the tail field. Although geomagnetic activity was relatively low throughout most of August, during this period (days 227-237) there was a higher level of geomagnetic disturbance on days 229,230 and 234 than on the other days.

This is supported by the A-index and also from inspection of the Fredericksburg and Tucson magnetograms. On these three days the highest average fields (10-18γ) were observed in the tail. This correlation is consistent with the earlier IMP-1 results showing positive correlation between geomagnetic activity and field strength (Behannon and Ness, 1966).

A 2.5 hour interval during day 233 (August 22) is shown in Figure 5 on an expanded time scale. Individual sequence averages are shown for this period, which includes the complete but rather gradual traversal of the neutral sheet near 1000 UT. Note the many occasions during which the neutral sheet appears to have been crossed for relatively short periods of time. From these data the conclusion is reached that the neutral sheet at $80R_E$ is still relatively thin and very well defined within the geomagnetic tail. In addition the multiple traversals of the sheet clearly indicate that it is in motion back and forth across the satellite. These results are in good agreement with the previous IMP-1 results of Speiser and Ness (1966).

Figure 6 represents an interpretation of the data based on the relative orientation of the neutral sheet appropriate to the time of year. As viewed from the earth, it projects the region swept out by the daily wobble of the sheet and of the tail portion of orbit 4 onto the Y_{SE}-Z_{SE} plane. As seen from the characteristic behavior of ϕ, changing abruptly from ϕ approximately 360° to 180° in figure 4, Explorer 33 approached the neutral sheet once each day while in the magnetic tail. In order for this to have been possible the axis of the neutral sheet must have been 2-3 R_E above the ecliptic plane. Assuming that the neutral sheet or field reversal region had a thickness of approximately 1 R_E at this time, then the features seen in figure 4 can be understood in terms of the relative positions and motions of Explorer 33 and the neutral sheet as interpreted from the orbital data of Figure 3. The neutral sheet is expected to be located somewhat above the X_{SM} - Y_{SM} plane during this time because the neutral sheet is rooted at 10$\pm$3 R_E (see discussion by Speiser and Ness, 1966) in the geomagnetic equator.

At about 2200 UT on day 232 the spacecraft penetrated the neutral sheet at its highest daily position on the -Y_{SE} side of the tail. The neutral sheet then moved downward with the satellite, reaching its lowest daily position between 1000 and 1100 UT on day 233. It then moved above Explorer 33, leaving the satellite clearly in the antisolar-directed fields below the sheet. Finally a daily encounter of a prolonged nature occurred on each of the remaining days until the magnetopause was traversed late on day 236.

CONCLUSIONS

In summary it has been clearly established by the GSFC magnetic field measurements made on Explorer 33 that the magnetic tail of the earth extends well beyond the orbit of the Moon. The geomagnetic tail has the same general characteristics both away from the neutral sheet and through the neutral sheet that were observed previously by the IMP-1 satellite at half the lunar distance.

These experimental results and analyses are contrary to those reported by Dolginov et al. (1966) from the Lunik 10 magnetometer results obtained in the vicinity of the Moon during the period April 3- May 4, 1966. From their results they concluded that the geomagnetic tail did not extend to the distance of the Moon. The uncertainty of their measurements placed an upper limit of 5γ to any possible contribution of a tail field to the measured fields (23-40γ).

However on the same Lunik 10 Gringauz et al. (1966) with charged particle traps sensitive to low energy electrons and protons interpreted their results as indicating clearly the effect of the geomagnetic tail at 60 R_E. They measured anisotropic fluxes of protons with energy >50ev when the Moon was outside the magnetic tail region and electron fluxes with E_e>70ev when within the magnetic tail. Additional data from Lunik 10 by Grigorov et al. (1966) reports isotropic fluxes of presumably electrons with energy E_e>40Kev in the region of the assumed magnetosphere boundary.

We suggest that the measurements of Dolginov et al (1966) were performed when Lunik 10 was near to or located within the neutral sheet and very weak fields should be expected. Thus the apparent conflict between the absence of a detectable tail from the Lunik 10 data and the clear indication of a well developed tail and neutral sheet from Explorer 33 can be resolved. The results of Gringauz et al. (1966) support this interpretation.

The question of how far beyond $80R_E$ the geomagnetic tail extends (Dessler, 1964; Dungey, 1965; Van Allen, 1965) is not yet answered by these preliminary studies. Temporal and spatial variations of magnetic field strength within the tail for all of the Explorer 33 data will have to be carefully analyzed before an attempt to deduce a radial gradient is successful. The transverse width of the tail appears to be consistent with the 40-44 R_E value established previously by the IMP-1 satellite at half the distance to the Moon (Ness, 1965).

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FIGURE CAPTIONS

Figure 1 Measurements of the Earth's magnetic tail field on orbit No. 3 projected on the X_{SE} - Y_{SE} and X_{SE} - Z_{SE} planes during August 2-3, 1966. The vectors represent hourly averages obtained while the satellite was above the neutral sheet and beyond the orbital distance of the Moon.

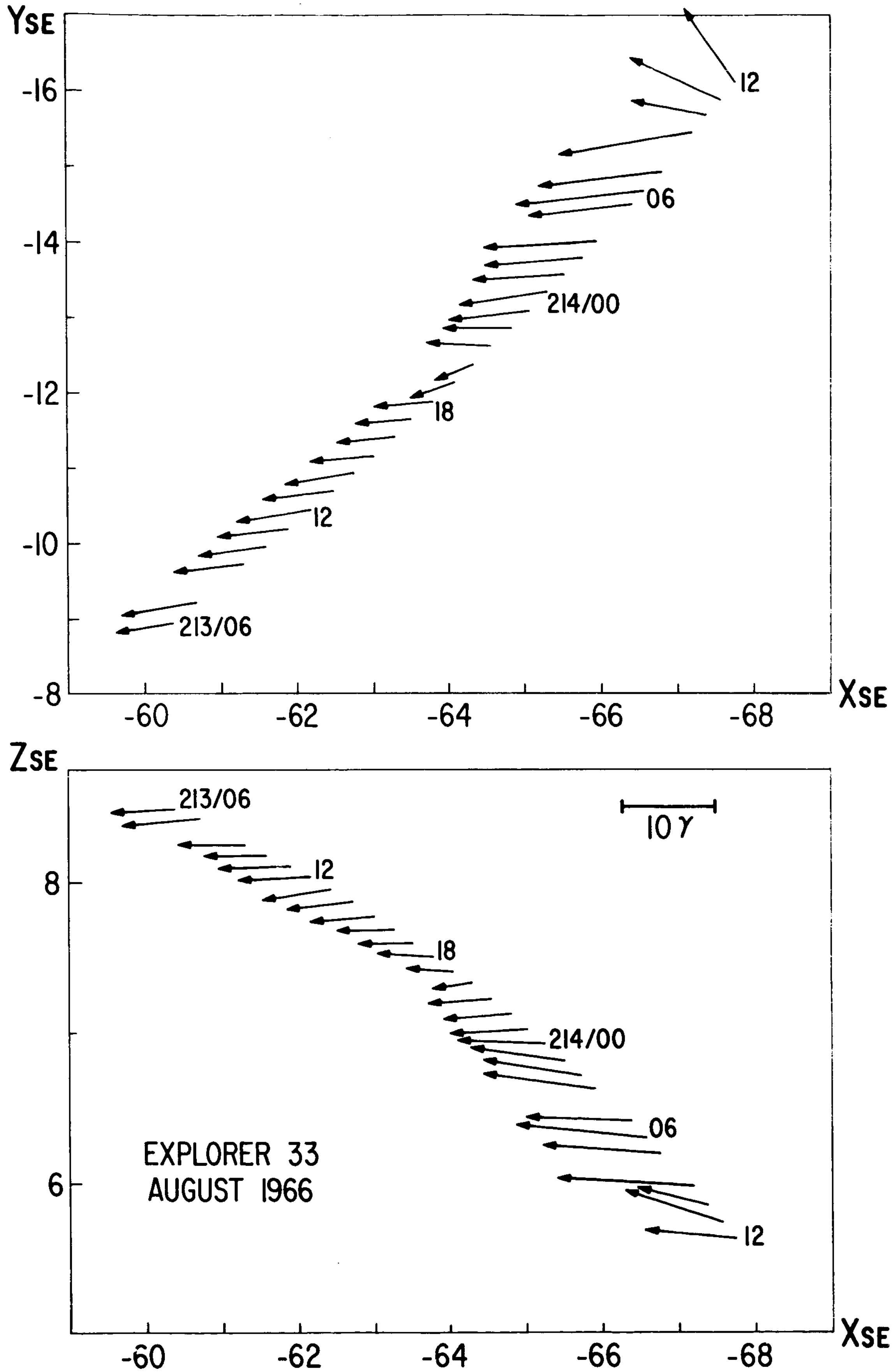
Figure 2 Projection of satellite trajectory on the X_{SM} - Y_{SM} equatorial plane. From August 16-26 (days 227-237) the satellite was located within the geomagnetic tail.

Figure 3 Projection of satellite trajectory on the X_{SM} - Z_{SM} noon-midnight meridian plane. An expanded scale from X_{SM} = -78 to 80 R_E is shown to clearly illustrate the diurnal oscillation of the relative position of the satellite to the neutral sheet near apogee.

Figure 4 Hourly averaged measurements in solar ecliptic coordinates of the Earth's magnetic tail field for 9 days in August 1966. Explorer 33 was imbedded within the geomagnetic tail and periodically in close proximity to the neutral sheet. A complete traversal of the neutral sheet occurs on day 233 between 0600 -1200 UT.

Figure 5 Detailed telemetry sequence averages of the geomagnetic tail field in solar ecliptic coordinates during the traversal of the neutral sheet in the Earth's Magnetic tail when the satellite was well beyond the lunar orbital distance. The multiple and rapid crossings indicate motion of a thin field reversal region.

Figure 6 Orbit 4 pass of Explorer 33 through the magnetic tail as viewed from the Earth. Clearly evident is the continued close proximity to the neutral sheet.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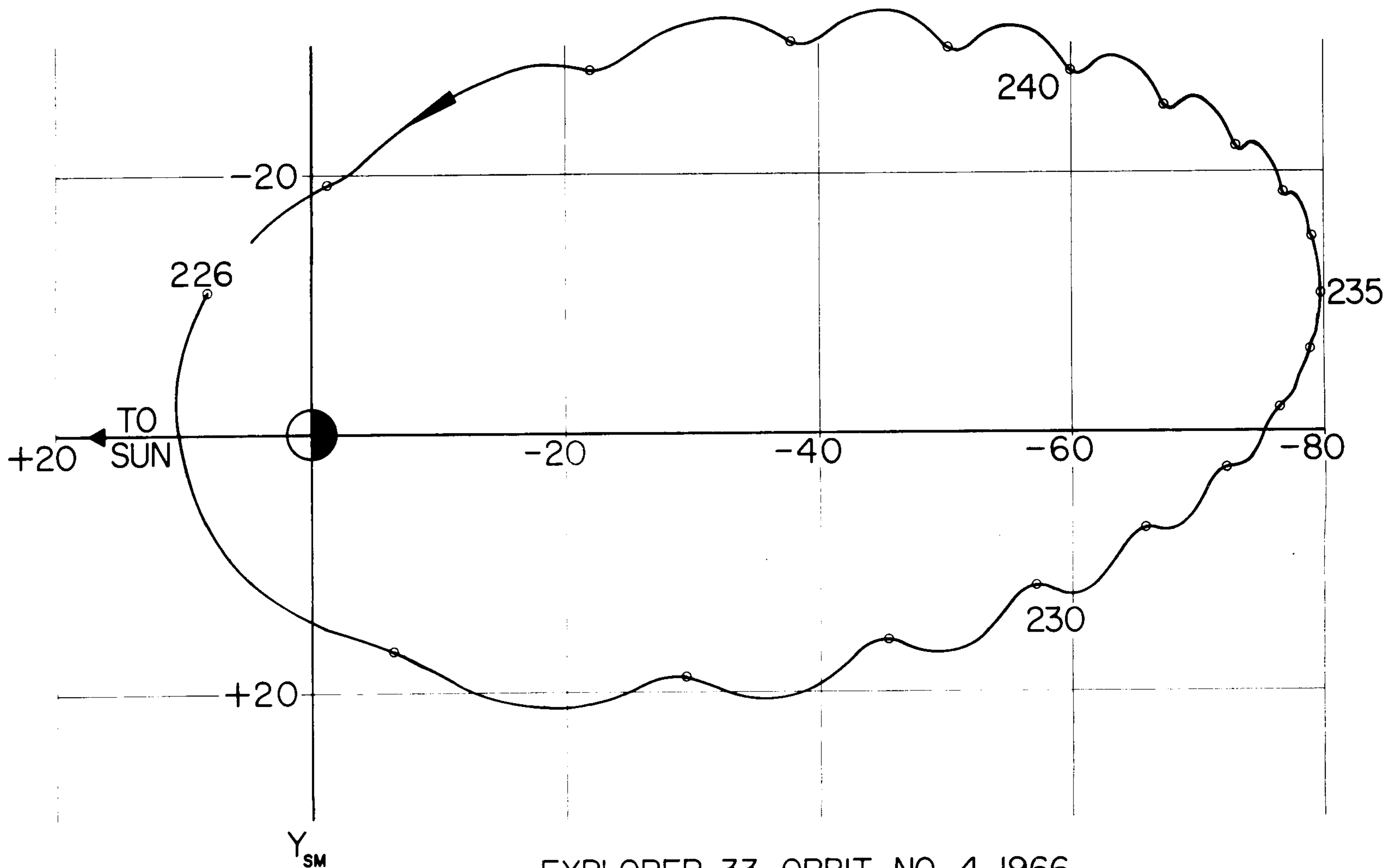

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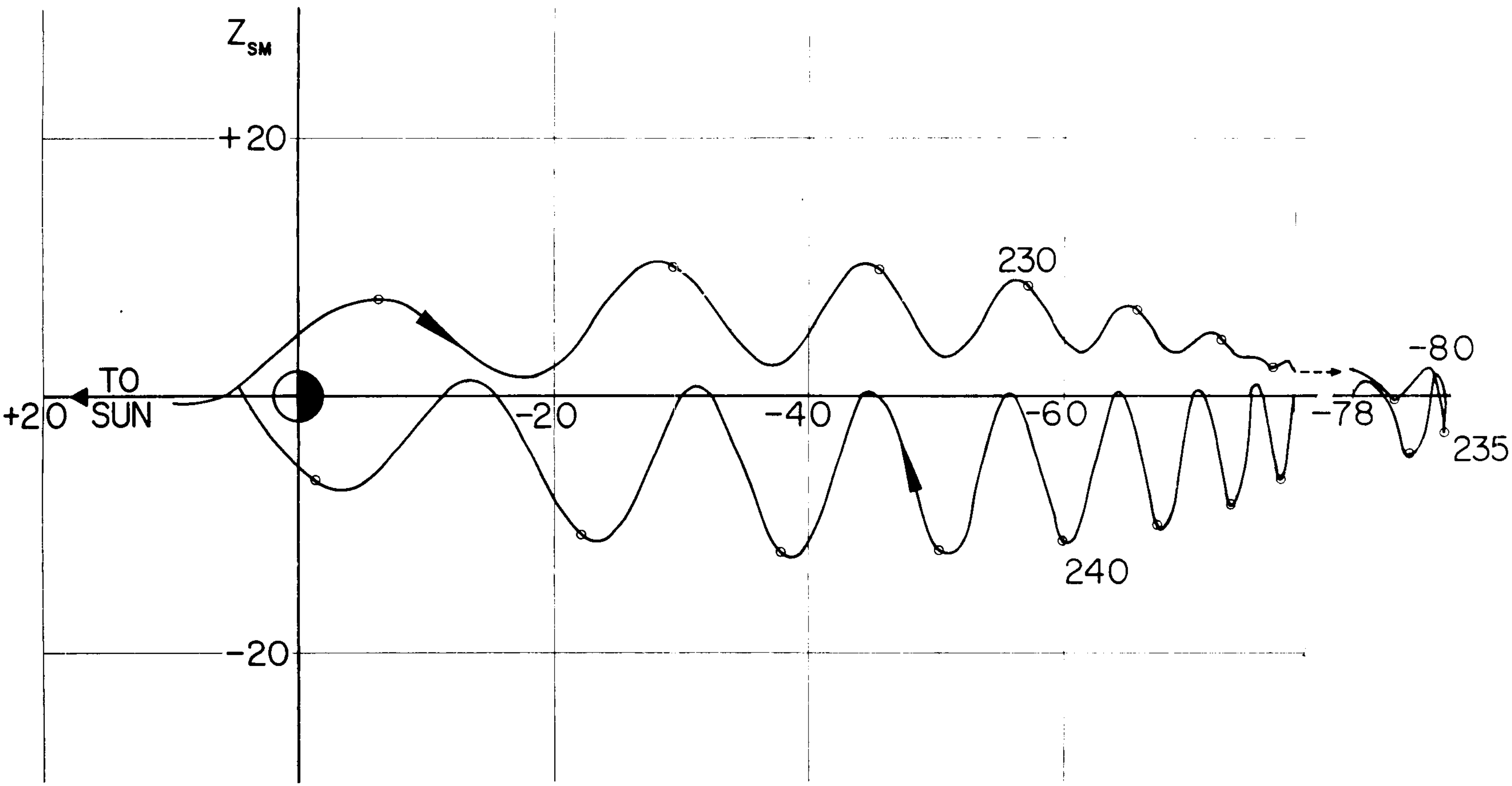

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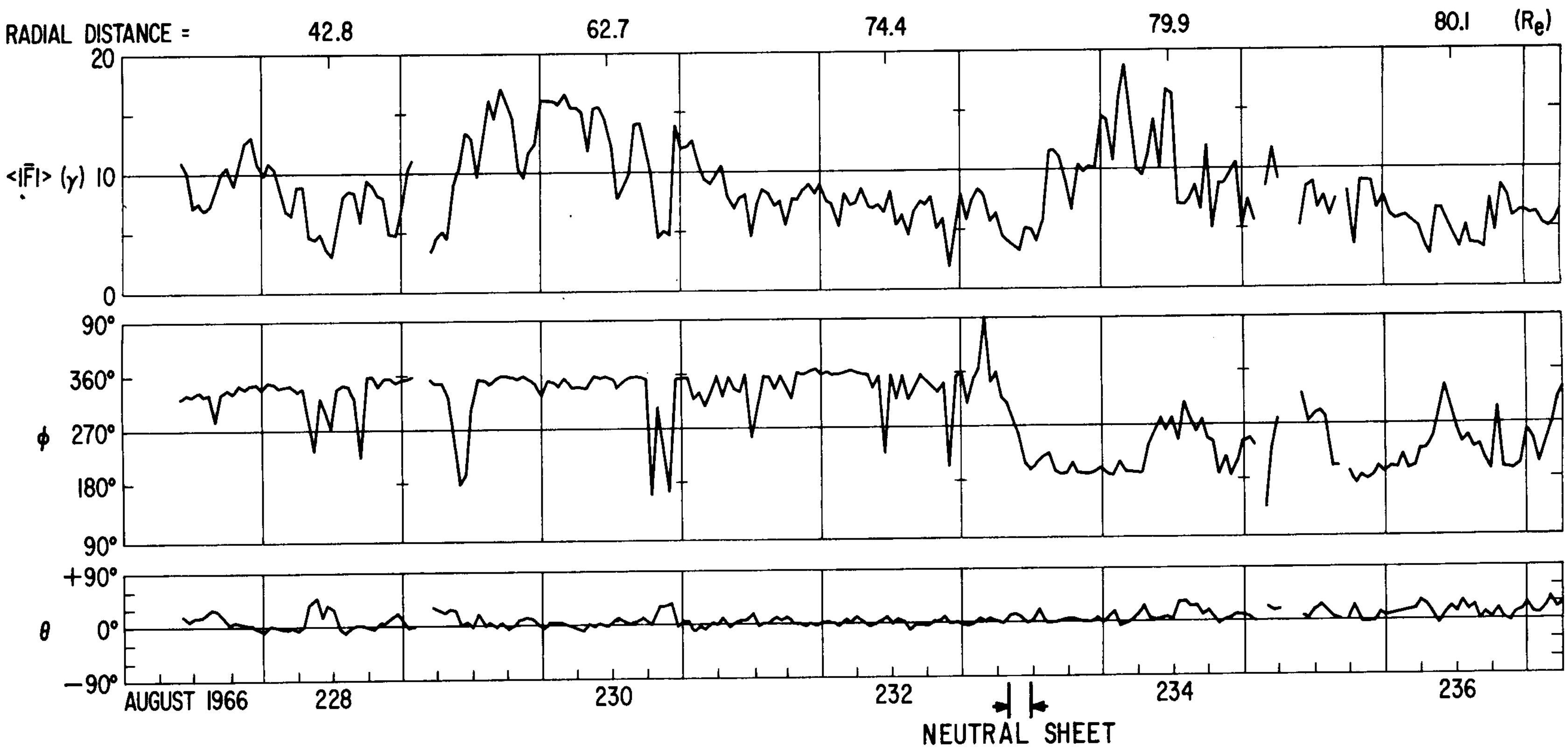
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AUGUST 1966
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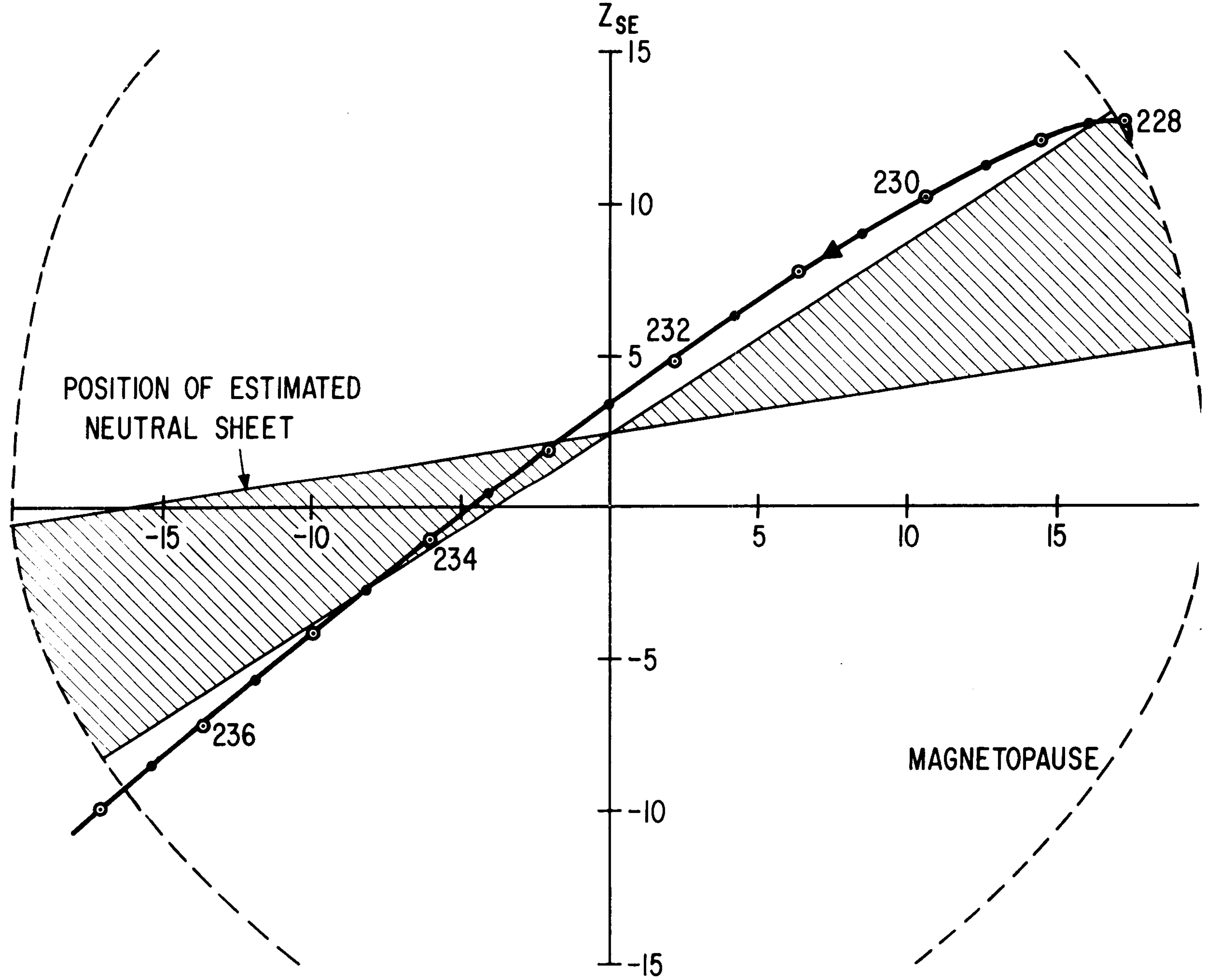
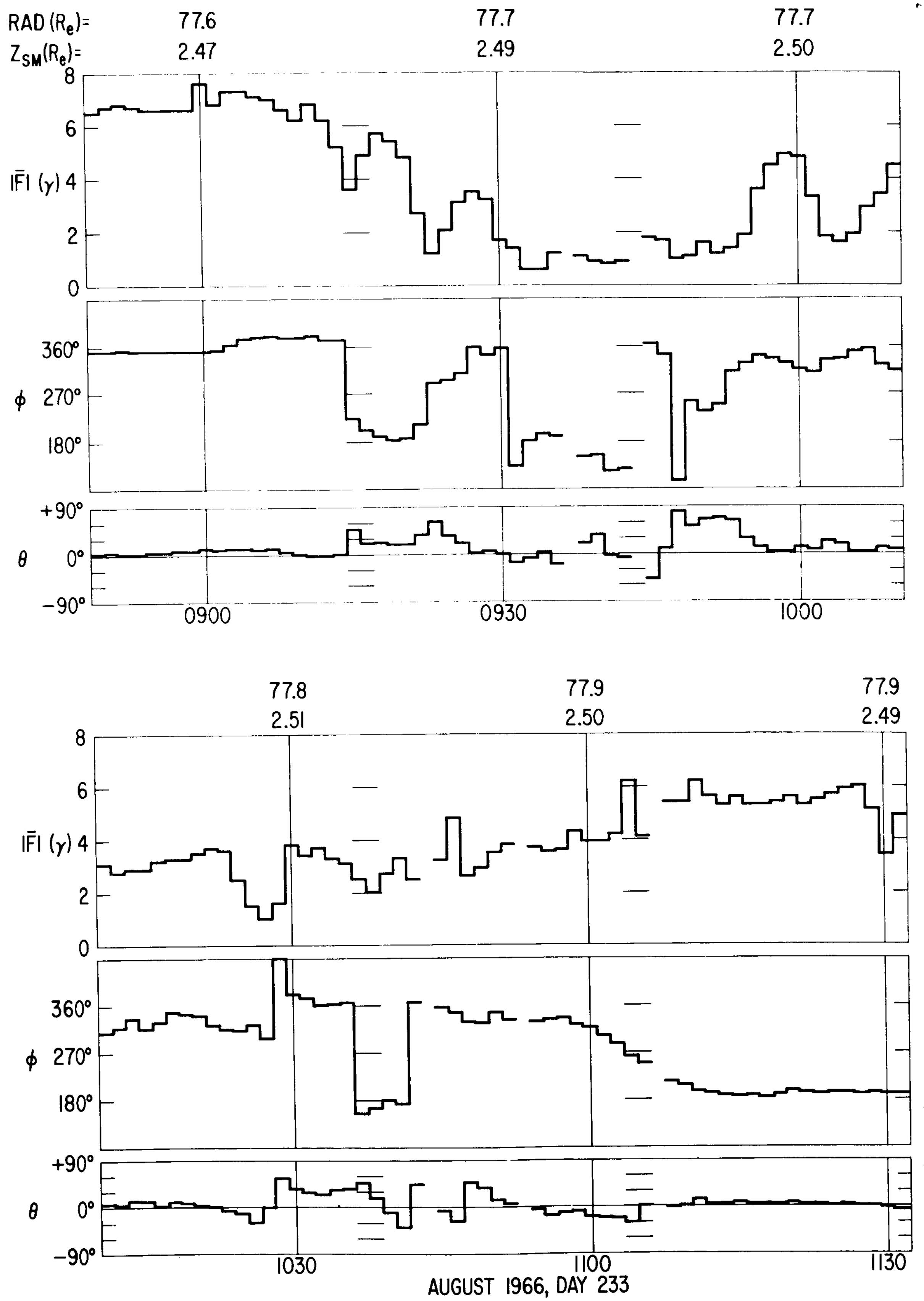
NEUTRAL SHEET



EXPLORER 33 1966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