1994 CEDAR Workshop

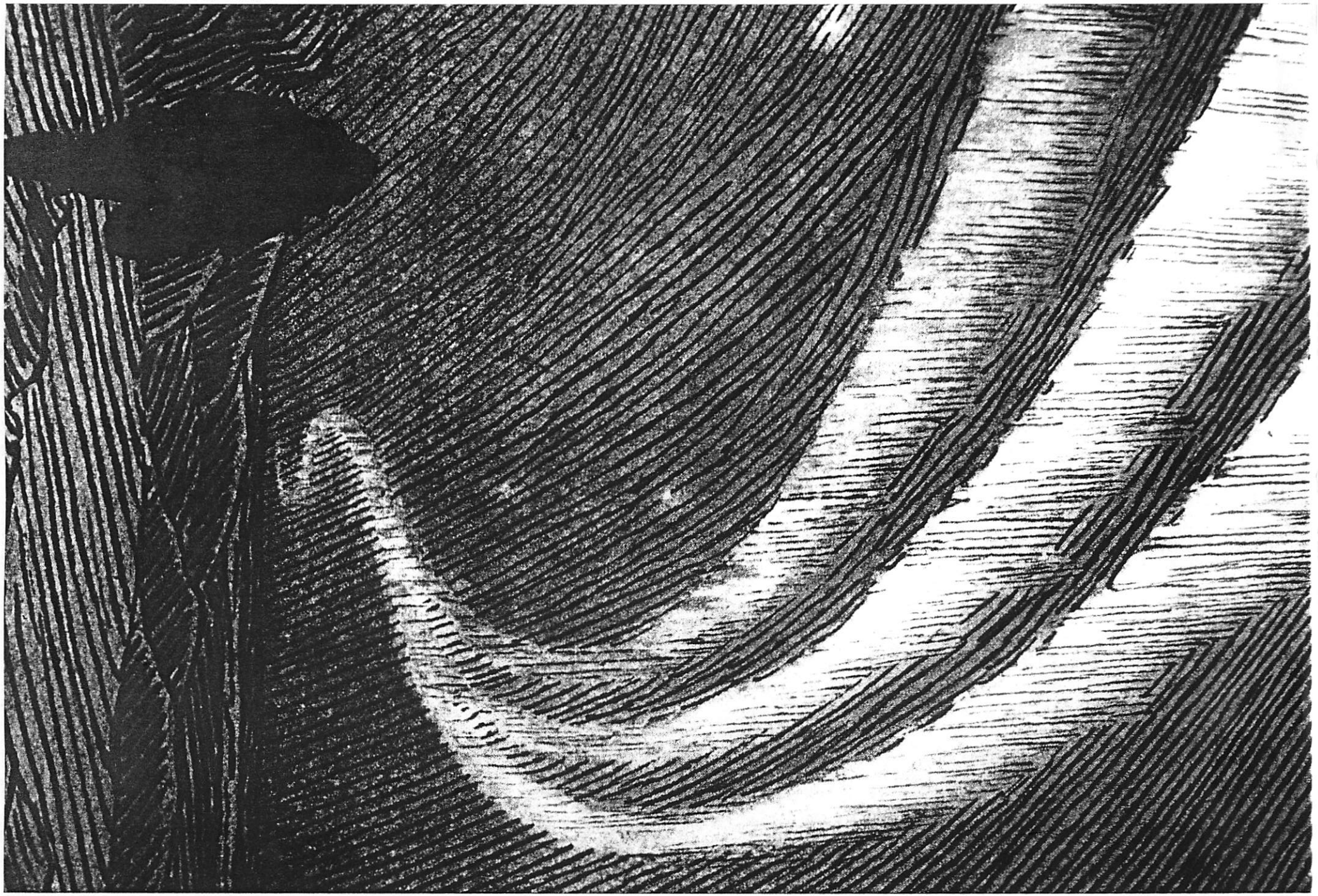
Boulder, Colorado
June 20-25, 1994

Tutorial Lecture

by Patricia Reiff
Rice University

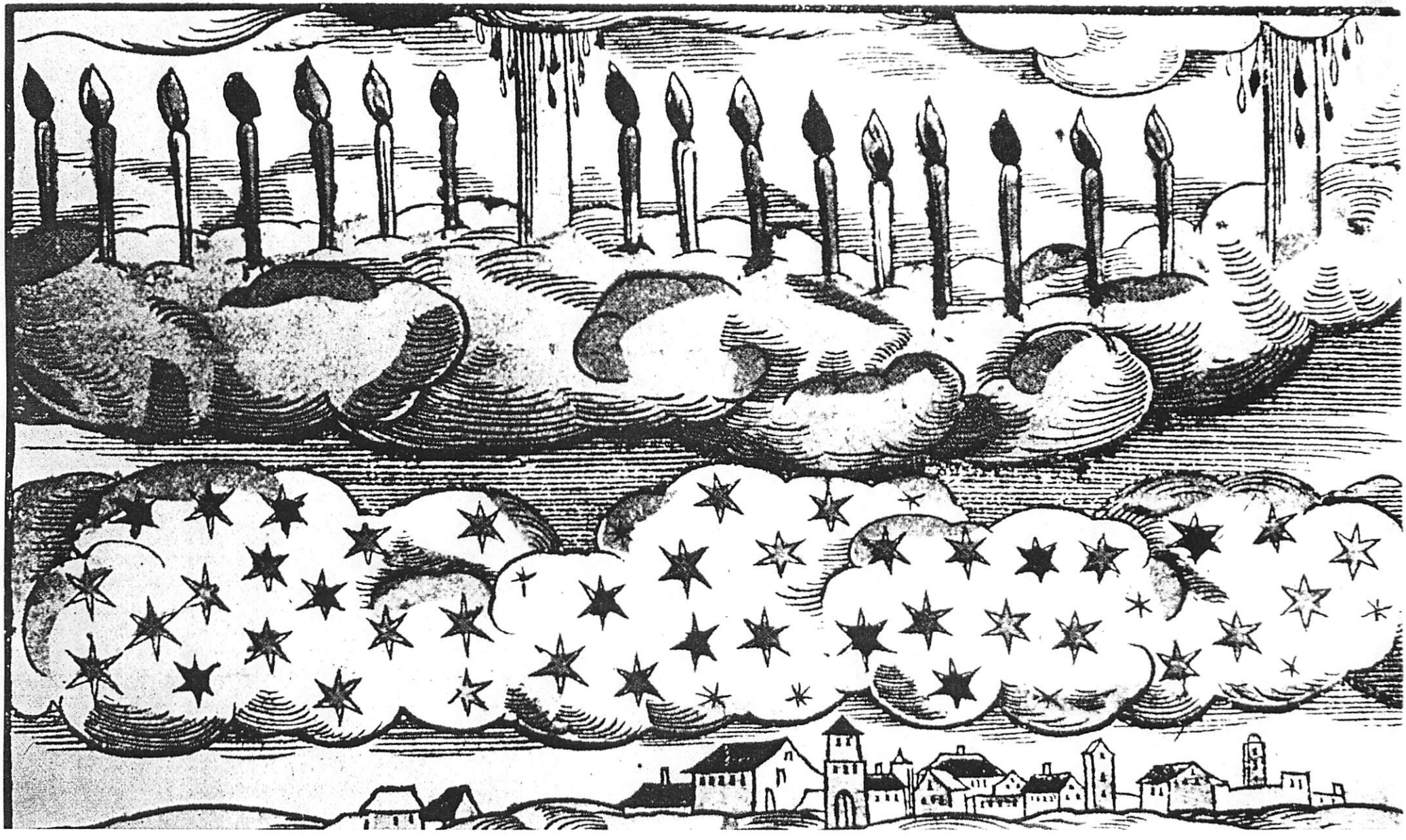
Auroral Acceleration Processes

NANSEN



Ein vnerhörtes Wunderzeichen/ welches ist gesehen worde

auff Kuttenberg/ in der Kron Böhem/ auch sonst in andern Stätten vnd Flecken herumb/ den 12. Januarij/ vier stund in die Nacht/ vnd gewehret biß nach 8. Inn der Wolcken des Himels stehen/ alß in disem Jar. 1570.



9 Figur.

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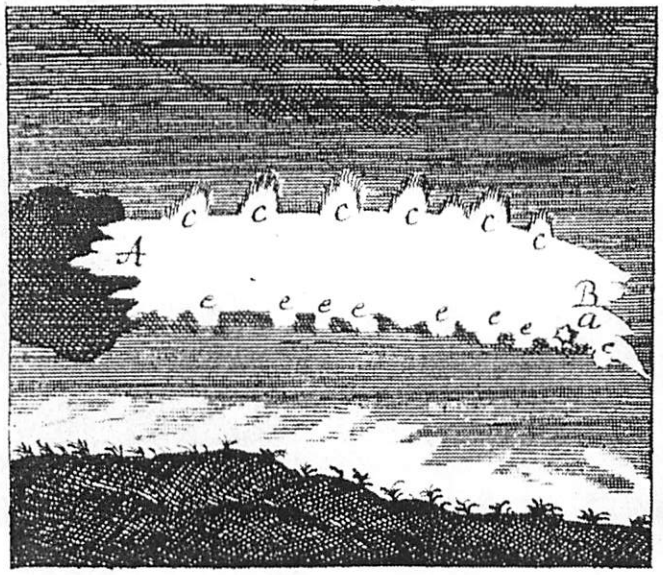

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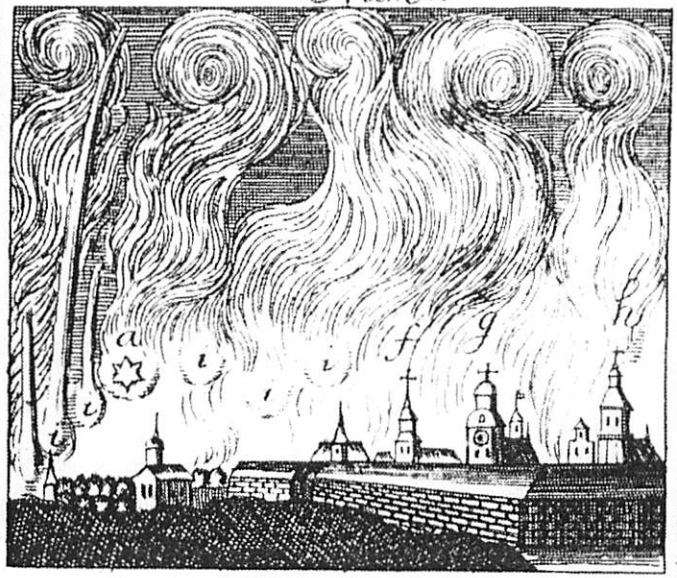

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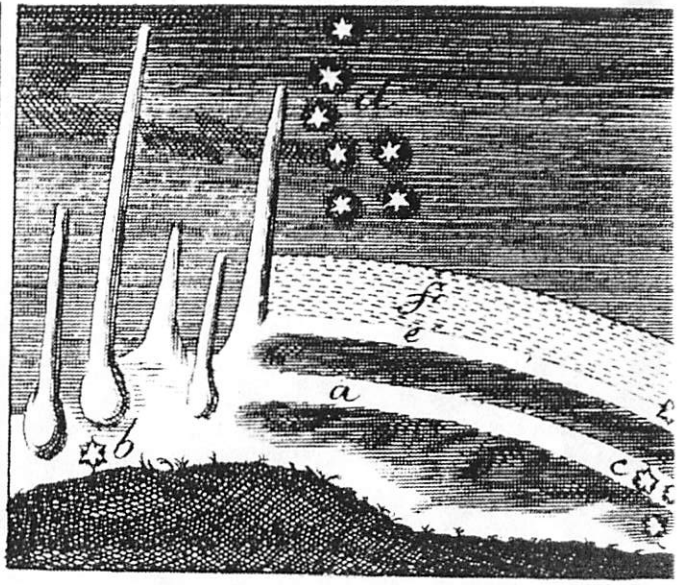

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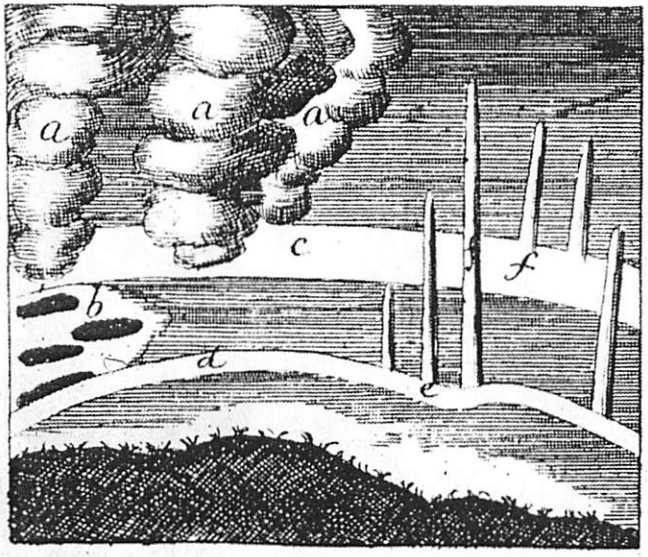

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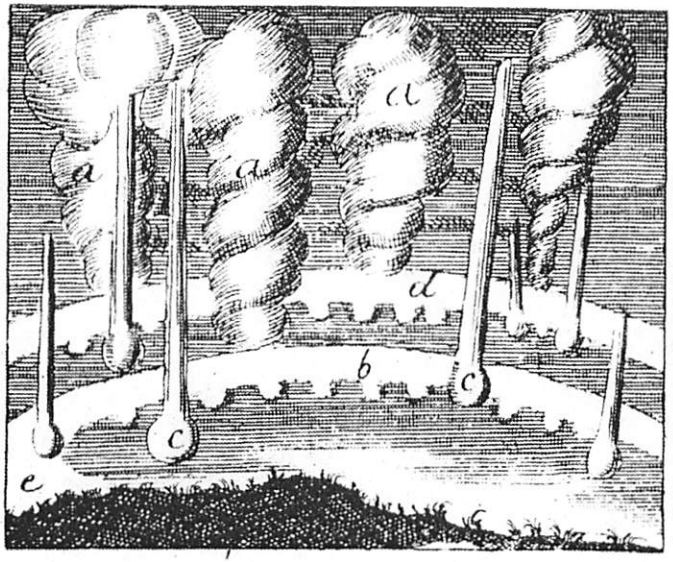

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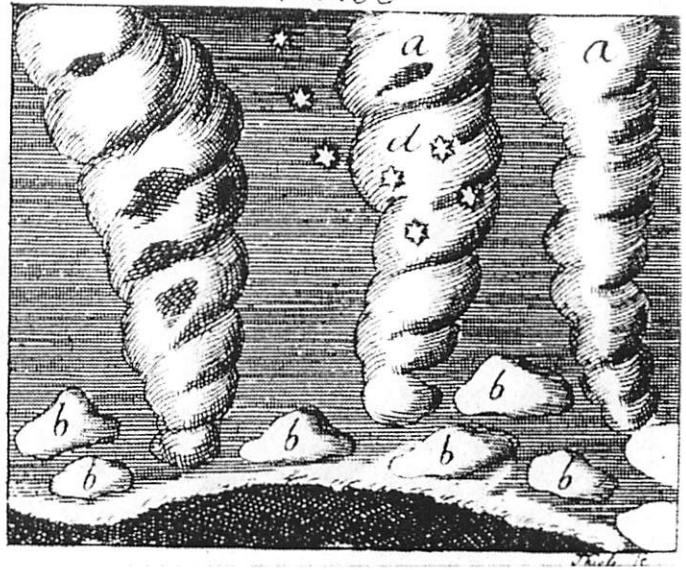
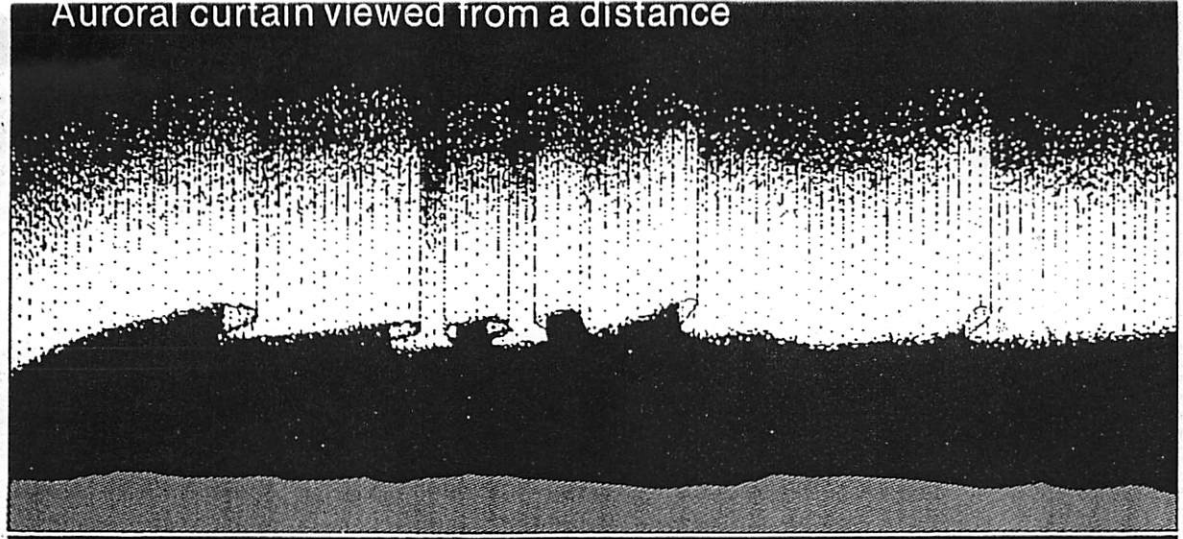
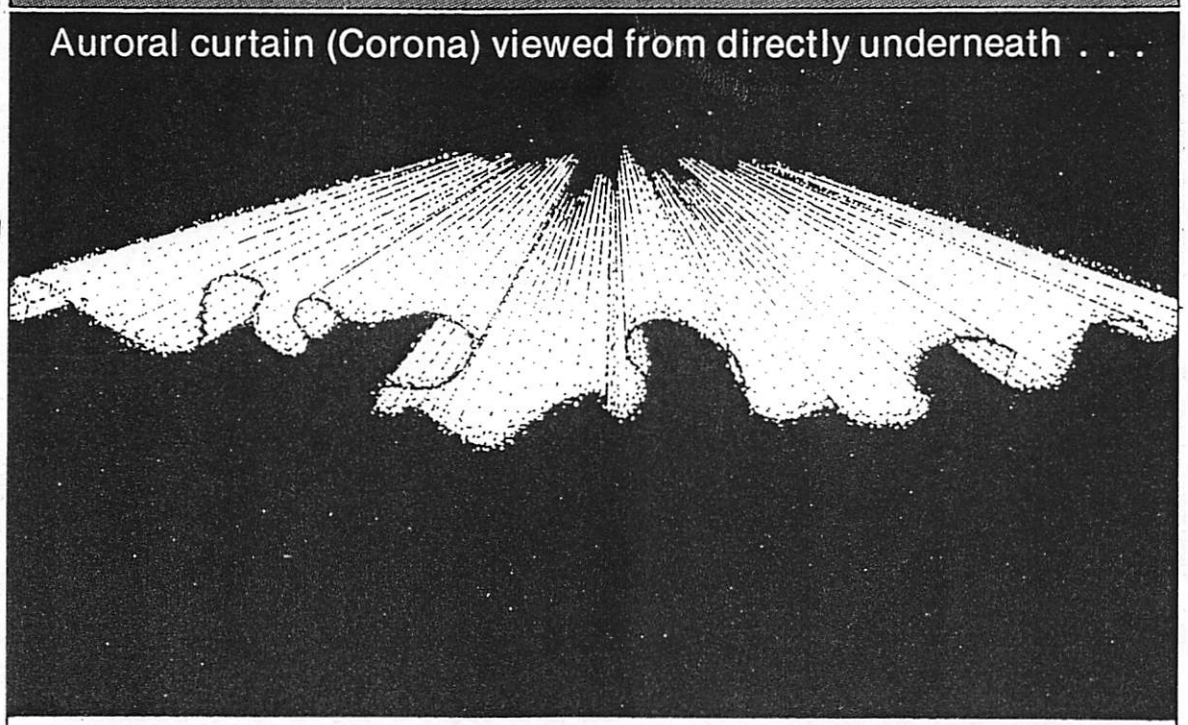
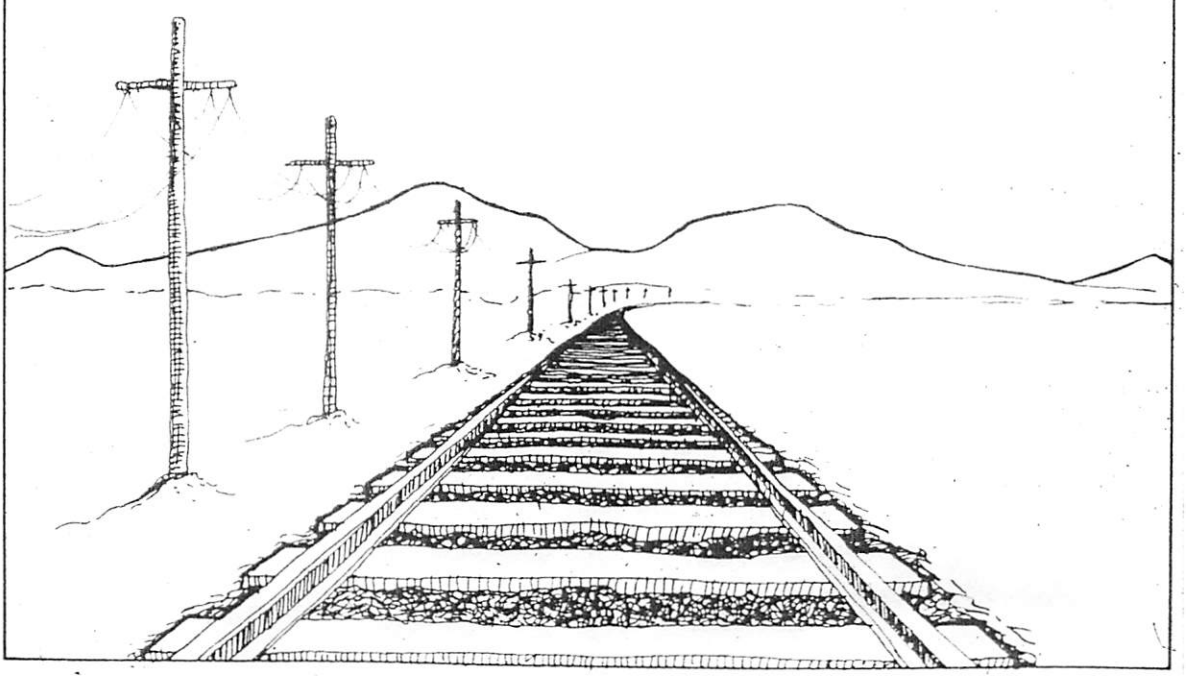
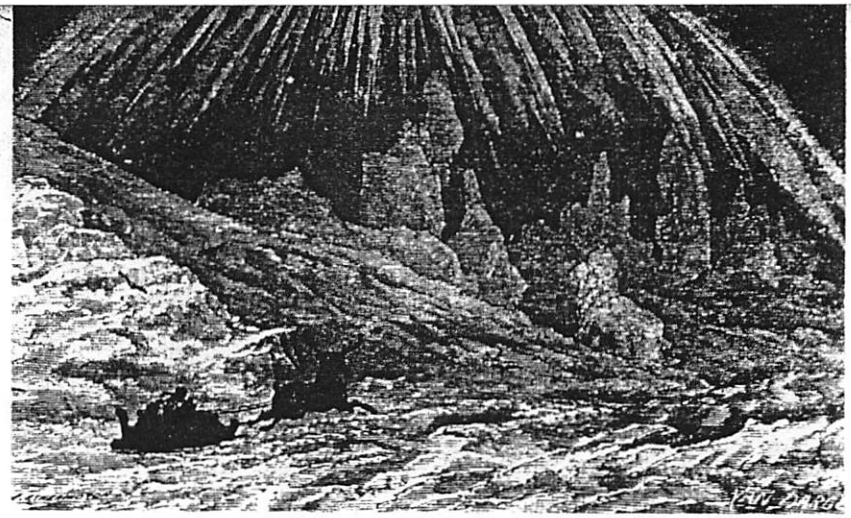




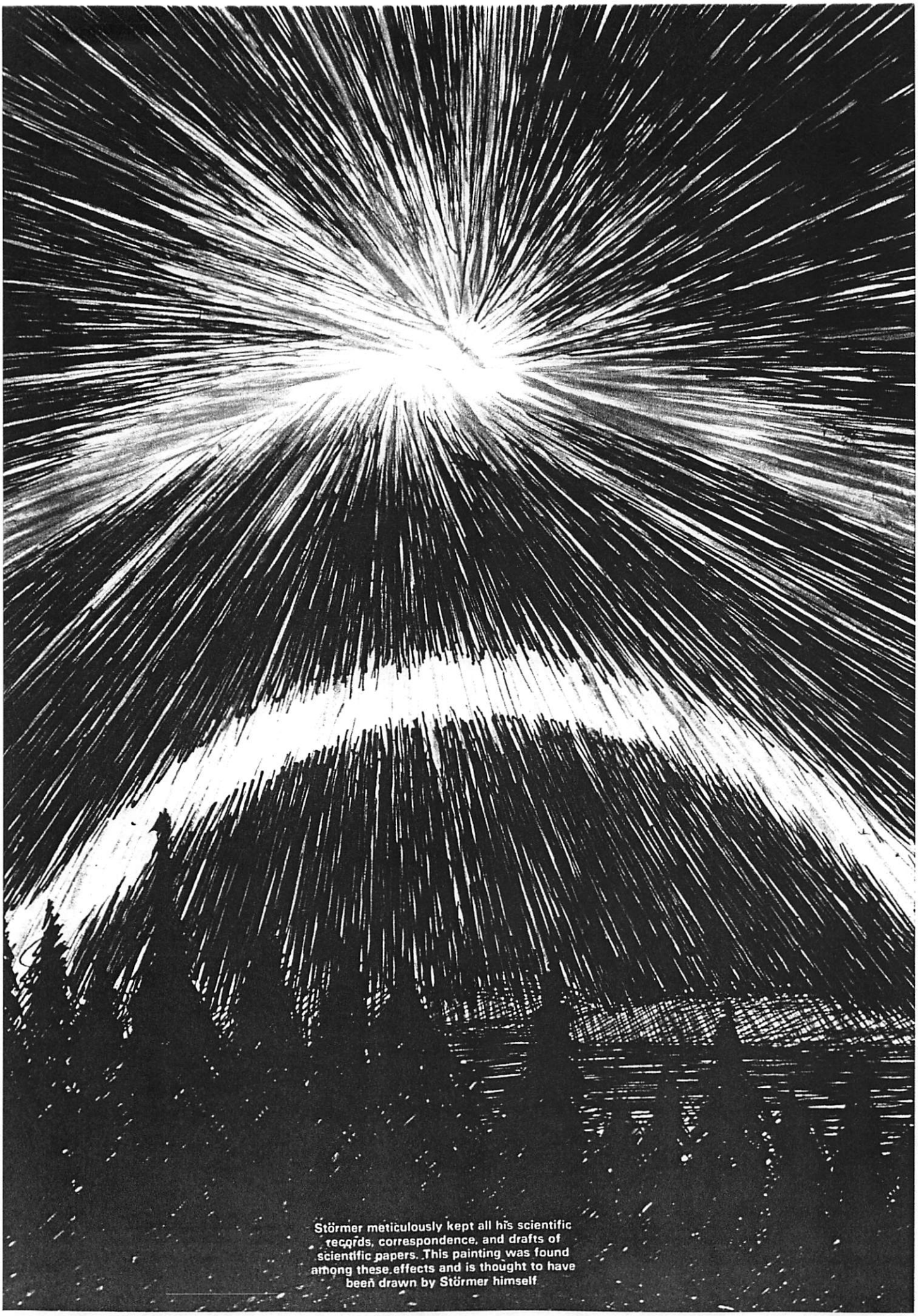


. . . affected by the same principle as these railroad tracks and telegraph poles.



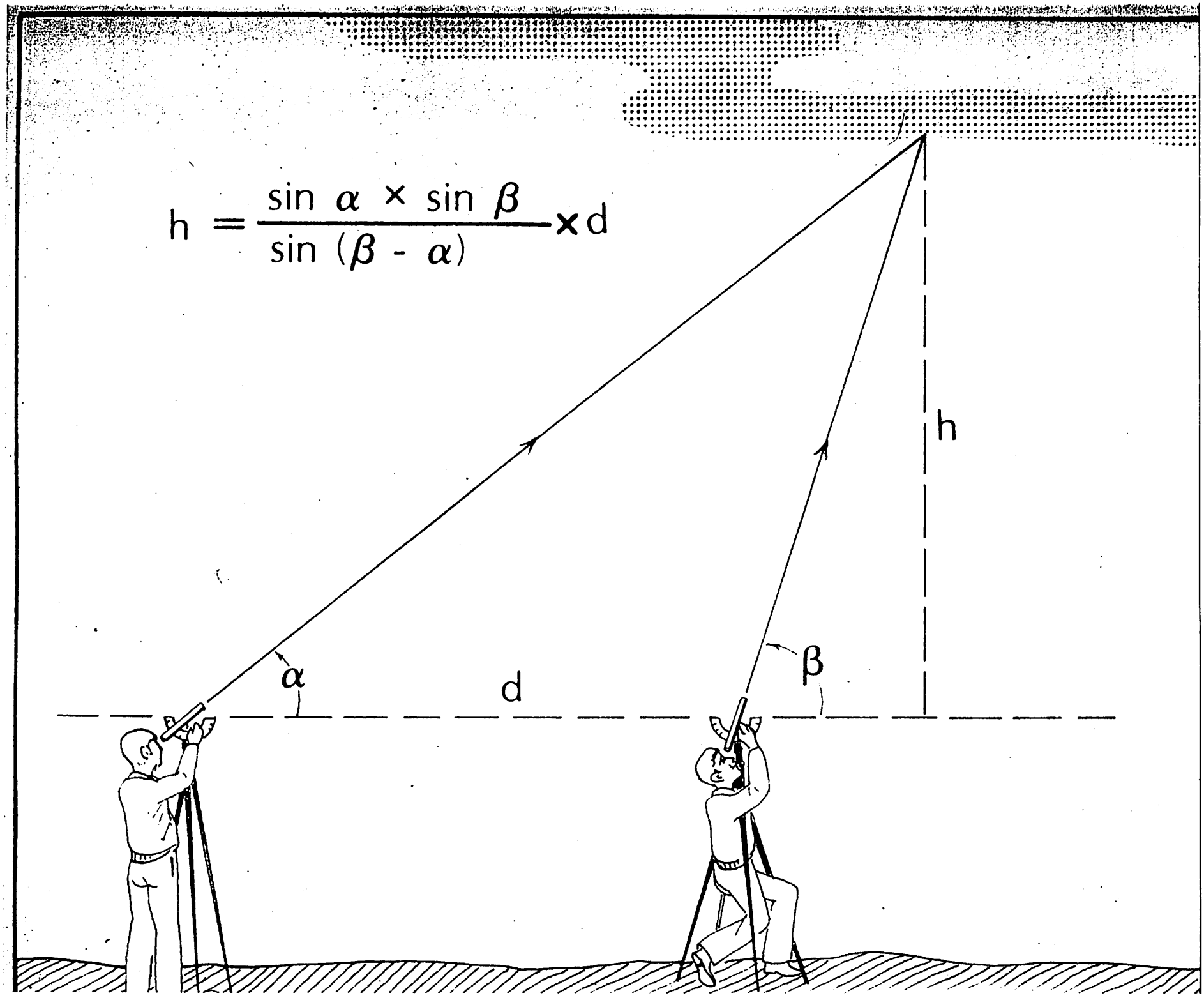


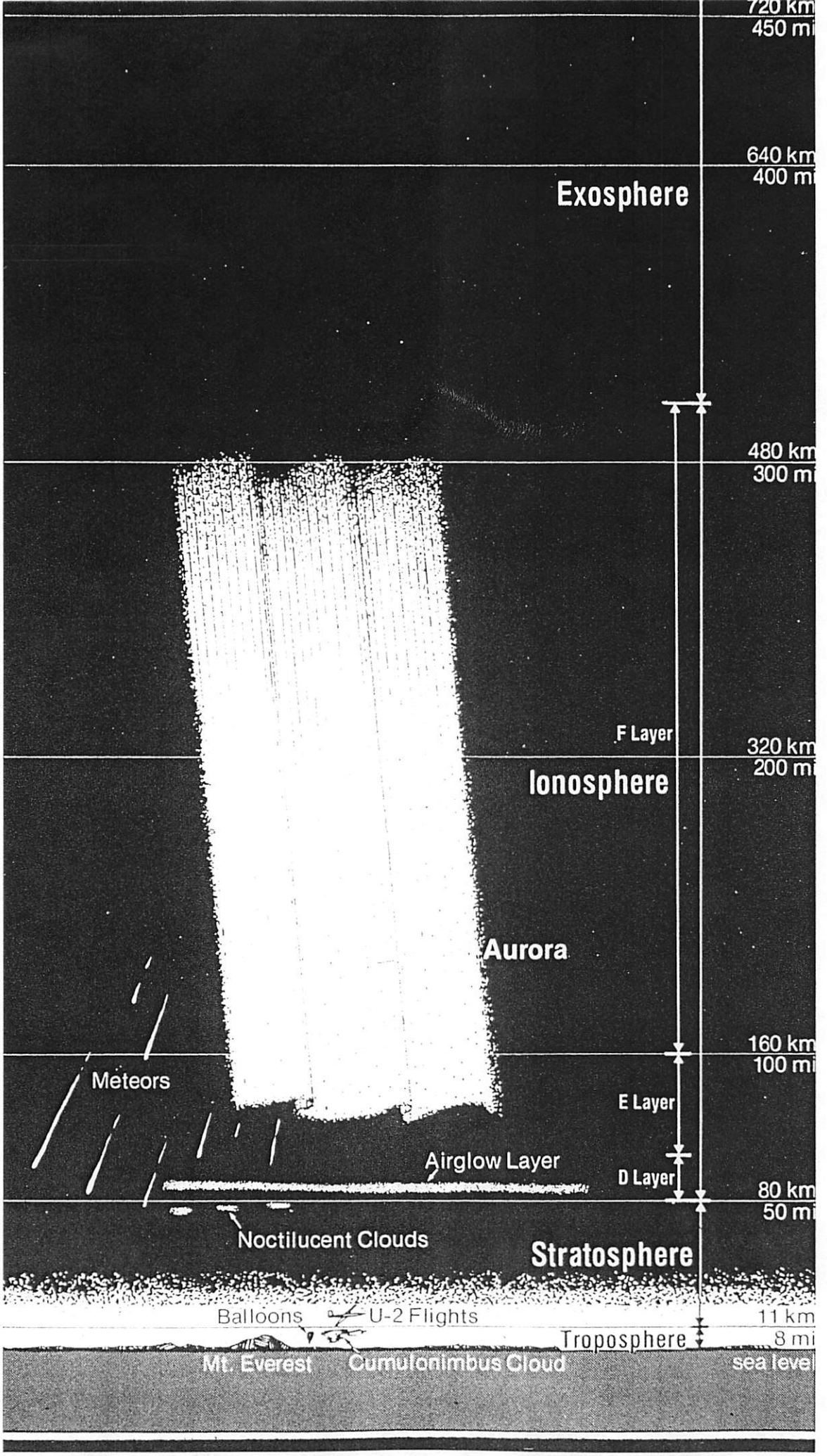
ABOVE — *The shape of the aurora in this 19th century engraving may look very distorted and abstract. This particular form is called the corona, seen when the aurora curtain is located near its zenith. (From* Under the Rays of the Aurora Borealis *by Sophus Tromholt, 1885, courtesy of S.-I. Akasofu)*
RIGHT — *This photograph proves that the above engraving is an accurate rendering of the coronal form. (S.-I. Akasofu)*

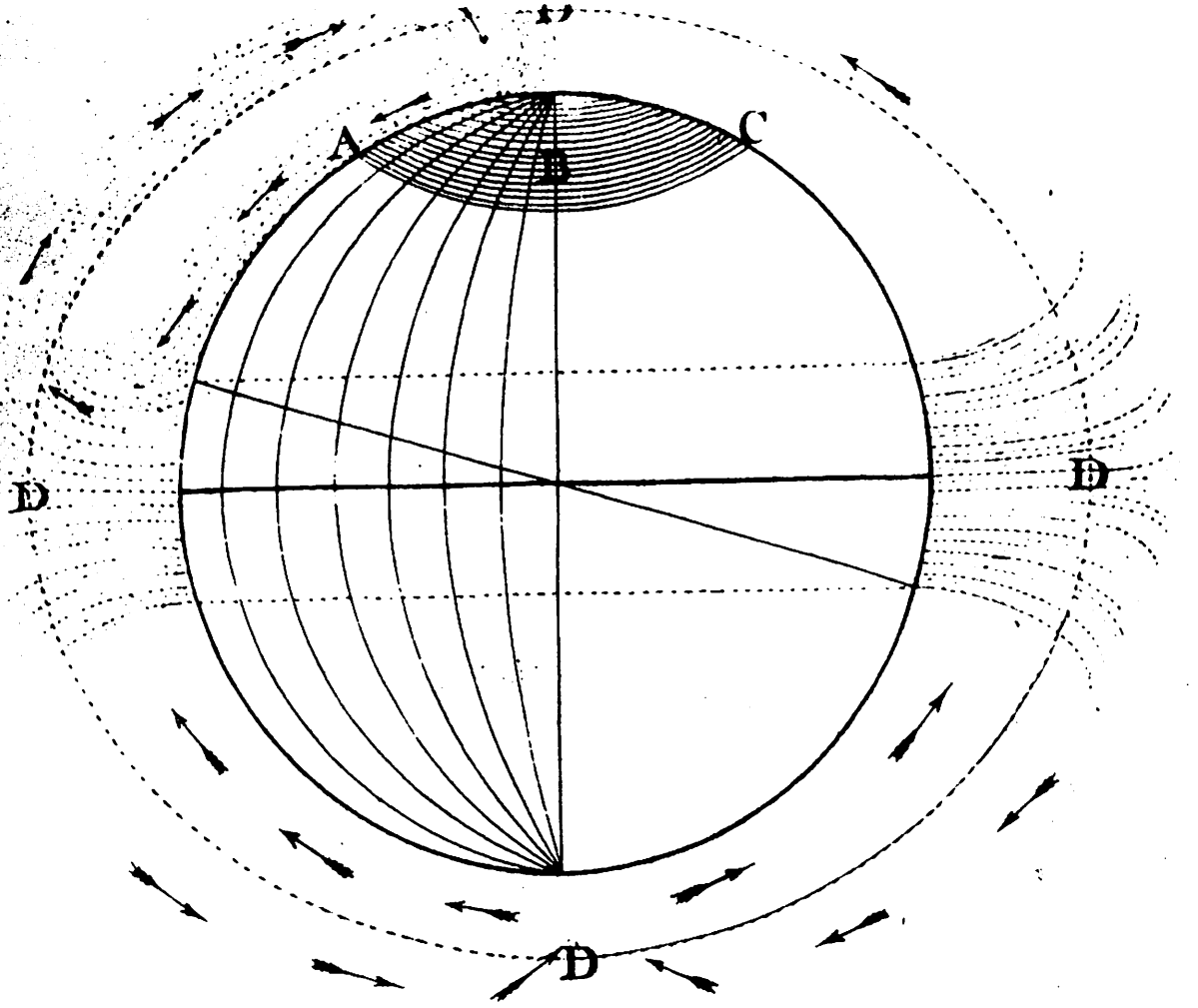


Störmer meticulously kept all his scientific records, correspondence, and drafts of scientific papers. This painting was found among these effects and is thought to have been drawn by Störmer himself

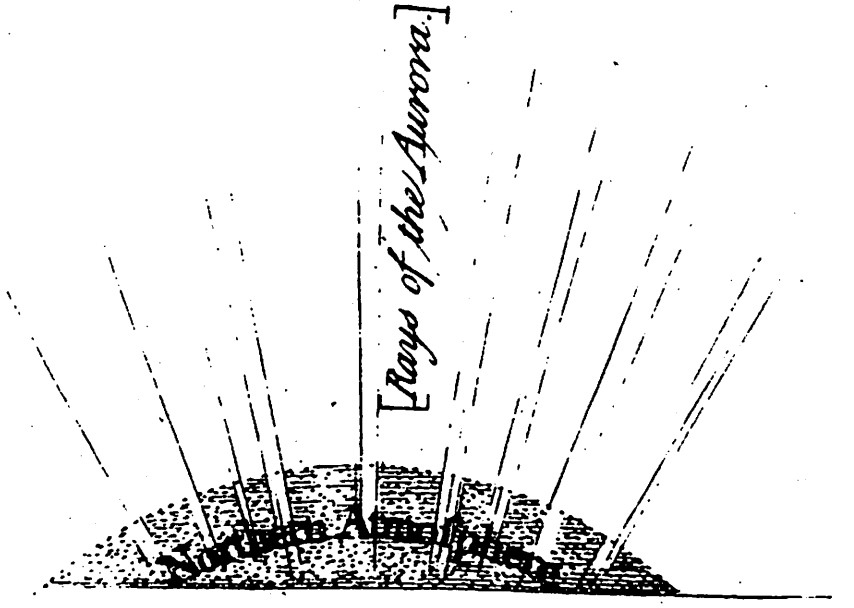
$$h = \frac{\sin \alpha \times \sin \beta}{\sin (\beta - \alpha)} \times d$$




720 km
450 mi
640 km
400 mi
Exosphere
480 km
300 mi
F Layer
320 km
200 mi
Ionosphere
Aurora
160 km
100 mi
Meteors
E Layer
Airglow Layer
D Layer
80 km
50 mi
Noctilucent Clouds
Stratosphere
Balloons
U-2 Flights
11 km
Troposphere
8 mi
Mt. Everest
Cumulonimbus Cloud
sea level



The Arrows represent the general Currents of the Air.
ABC. the great Lake of Ice & Snow in the Polar Regions.
DDDD. the Medium Height of the Atmosphere.
The Representation is made only for one Quarter and one Meridian of the Globe; but is to be understood the same for all the rest.



BEN FRANKLIN

STÖRMER

Kristian Birkeland

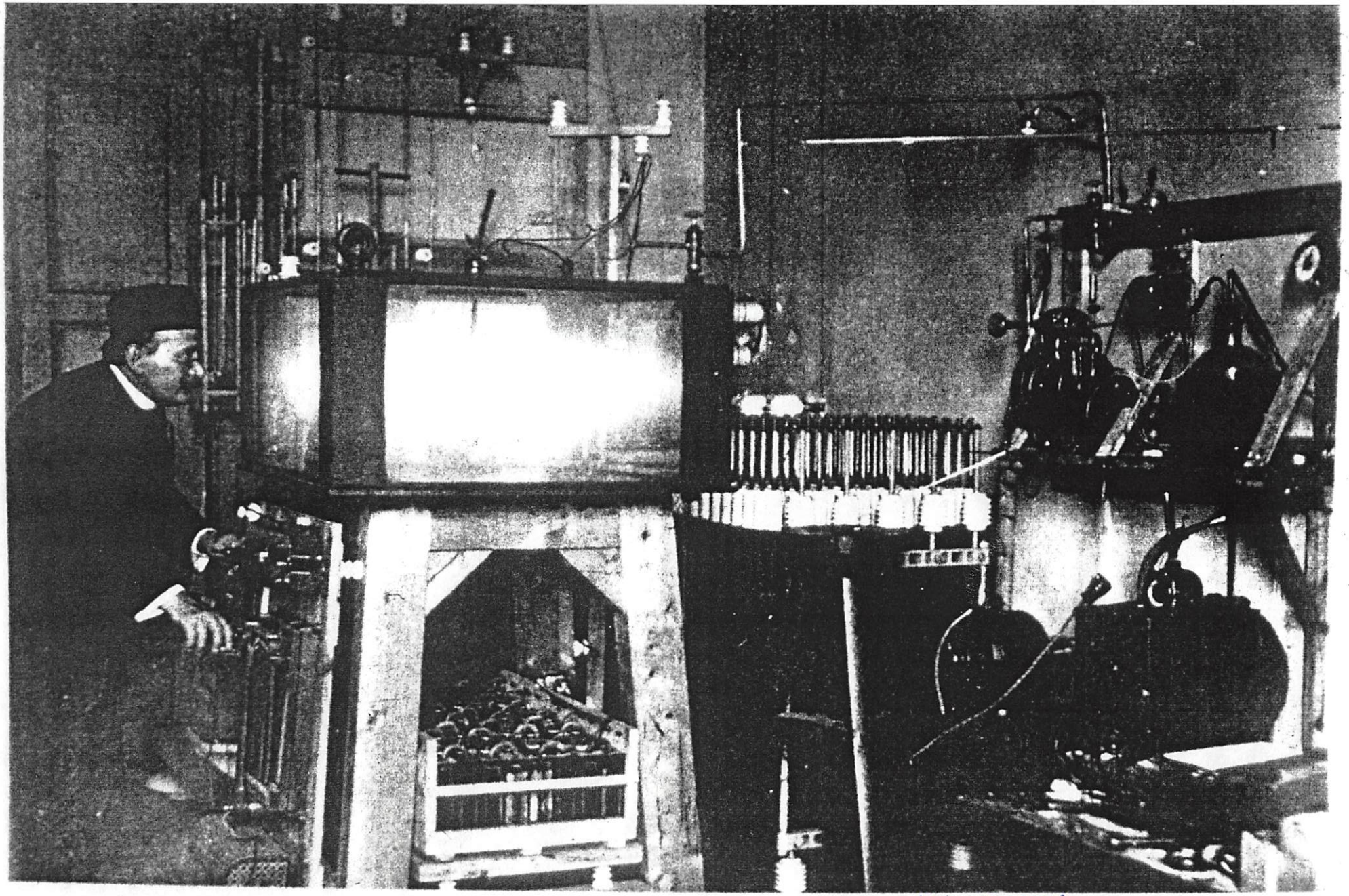
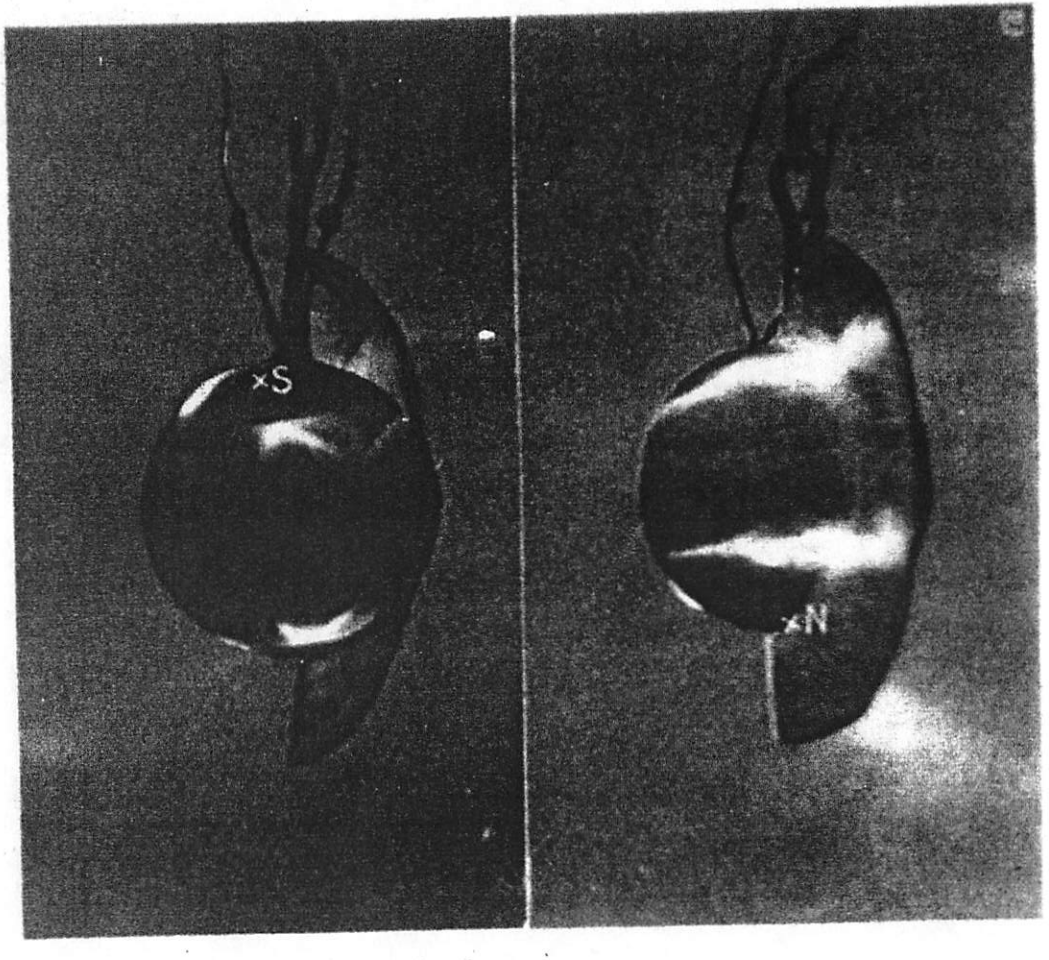


Fig. 451

BIRKELANDS TERRELA

In order to obtain a clear conception of the conditions, we will once more have recourse to my experiments with the terrella. The experiments shown in fig. 46, *a*, *b* and *c*, follow directly on to those in fig. 38, *a*, *b* and *c*. In fig. 46 *a*, the terrella is so turned that the screen forms an angle of 135° with its first position (fig. 38 *a*). In the next experiment (fig. 46 *b*), the angle is 180°. The angles are here measured from west to east. Fig. 46 *c* shows how the cathode rays strike the terrella; when the latter is not magnetic, but is in the same position as in the experiment given in fig. 46 *b*, only the half that is turned towards the cathode becomes luminous with phosphorescence.



It will be seen from figs. 46 *a* & *b* how the cathode rays behave when the terrella is very powerfully magnetised.

We will here especially direct our attention to the luminous wedge that is thrown upon the screen at about the 70th parallel of latitude north.

In figs. 47 *a* & *b*, we have a confirmation of the way in which the rays whirl round

CONCERNING THE CAUSE OF THE PERTURBATION.

36. The cause of the great magnetic disturbance at Dyrafjord, and subsequently at Axeløen also, must mainly be sought in the effect of a horizontal current. This follows from the fact that the places of the greatest effect are found for a long distance in the direction of the current-arrow, while in the direction perpendicular to it, the effect very quickly diminishes. At $1^h\ 45^m$, for instance, the perturbing force at Dyrafjord is 240 γ, at Axeløen 193 γ, and the direction about the same, reckoned from the meridian of the place. At the same time, the strength at Kaafjord and Matotchkin Schar is respectively 39.6 γ and 20.6 γ, and the distance between Dyrafjord and Axeløen is 1809 kilometres, while between Axeløen and Kaafjord it is only 896 kilometres (see fig. 11).

In the district between Dyrafjord and Axeløen we must assume a horizontal current, which ought to flow fairly close to the earth for a long distance; for, owing to the rapid diminution in the effect out towards the sides, the current must flow rather low in relation to the earth's dimensions. We shall return to this later on.

We may conclude from the vertical intensities that it must be a current above the earth's surface. This is proved in the case of similar storms (see February 10th and March 31st, 1903), also by a consideration of the earth-current curve; but this is unfortunately waiting for the day under discussion.

With regard to the further course of the current, there are two possibilities that may be considered.

(1) The entire current-system belongs to the earth. The current-lines are really lines where the current flows upon the earth's surface, or rather at some height above it.

(2) The current is maintained by a constant supply of electricity from without. The current will consist principally of vertical portions. At some distance from the earth's surface, the current from above will turn off and continue for some time in an almost horizontal direction, and then either once more leave the earth, or become partially absorbed by its atmosphere.

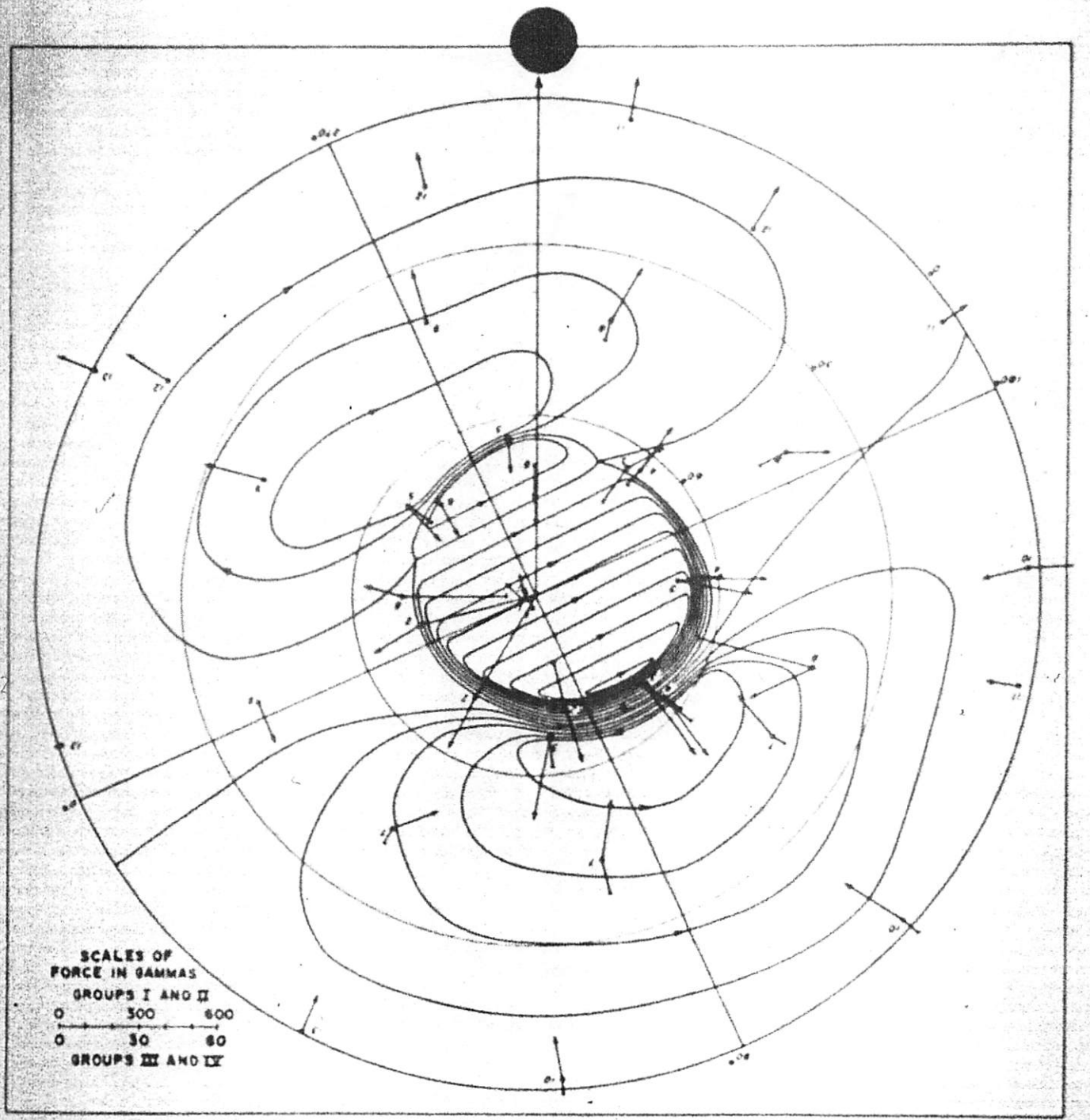


Fig. 31a. Equivalent current system for an average polar magnetic substorm (Silsbee, H. C. and E. H. Vestine: *Terr. Magn.* **47**, 195, 1942).

THE POLAR ELEMENTARY STORMS.

33. One cannot look long at the curves for the registered magnetic elements without observing a regularity in a number of details, especially in the behaviour of the great storms. This, strange to say, is not least apparent at the stations round about the auroral zone, and especially in the storms that have occurred at our Norwegian stations during the period in which the magnetic conditions have been observed by us. In the first place, it appears that the great majority of storms of short duration are at their height at our stations at about midnight by local time; and when they make their appearance at that time, it is found that they nearly always cause oscillations in the same direction for the horizontal intensity and declination. We further find that the direction of the oscillation in the vertical curve, especially in the case of Axel Island and of Kaafjord, is also repeated time after time. We get a direct impression that, notwithstanding little accidental circumstances, the magnetic storms, in their formation and course, are controlled by very limited conditions, and that these conditions are pre-eminently fulfilled in very limited areas in the polar regions. This impression is opposed to the theory upheld by Ad. SCHMIDT[1] and other terrestrial-magnetists — that the magnetic storms are produced by free cyclonic electric current-systems.

FROM BIRKELAND's BOOK

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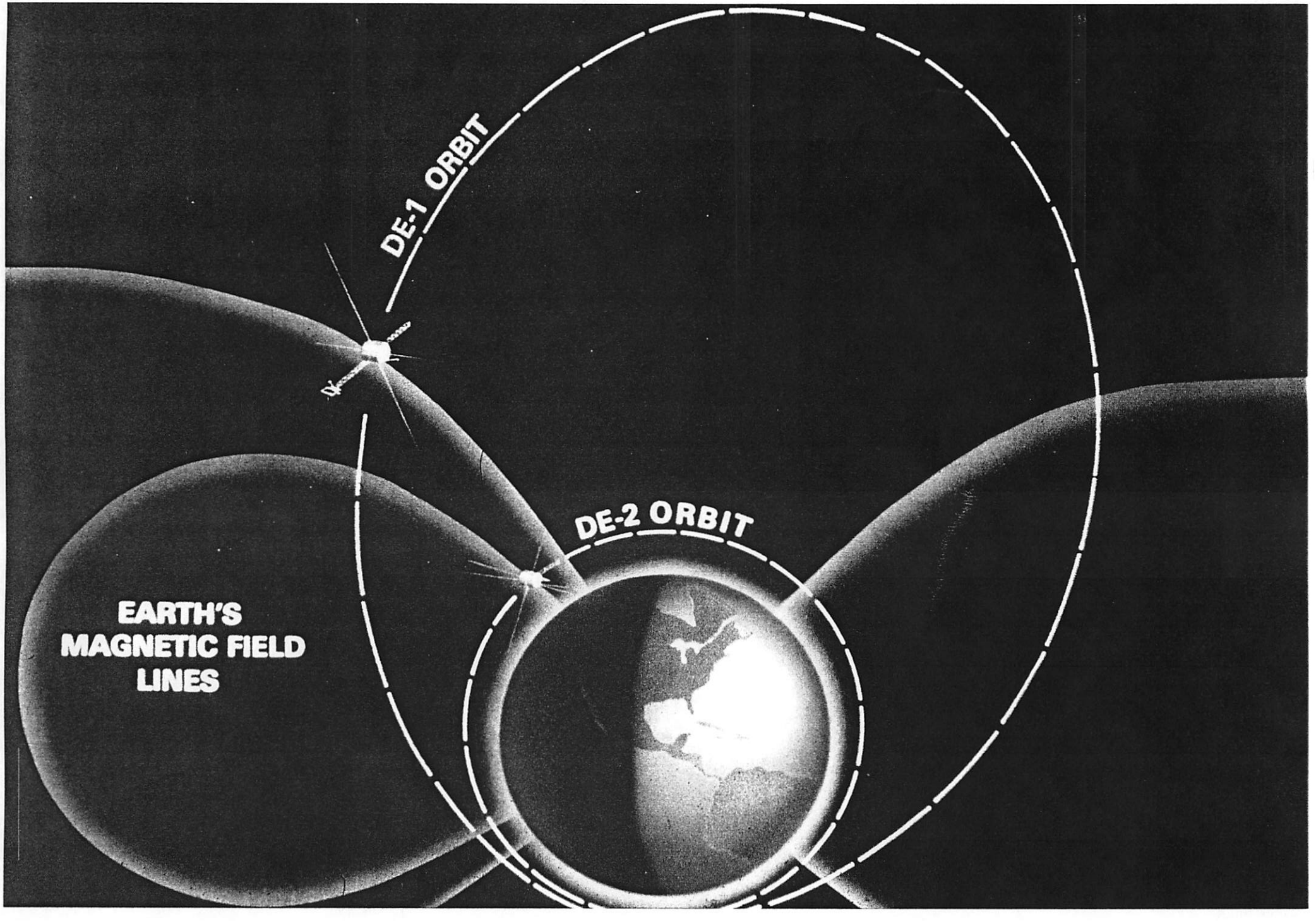
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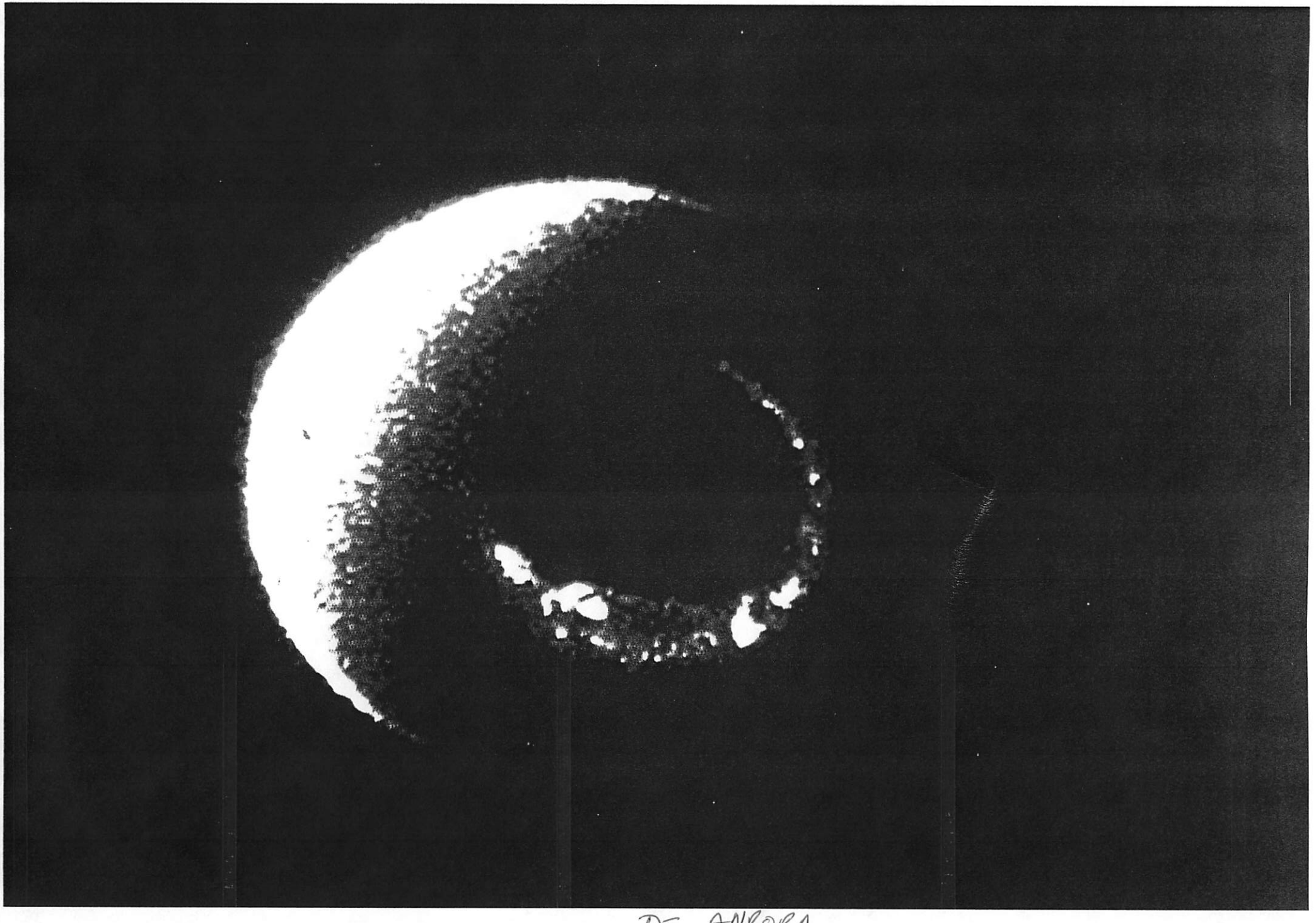
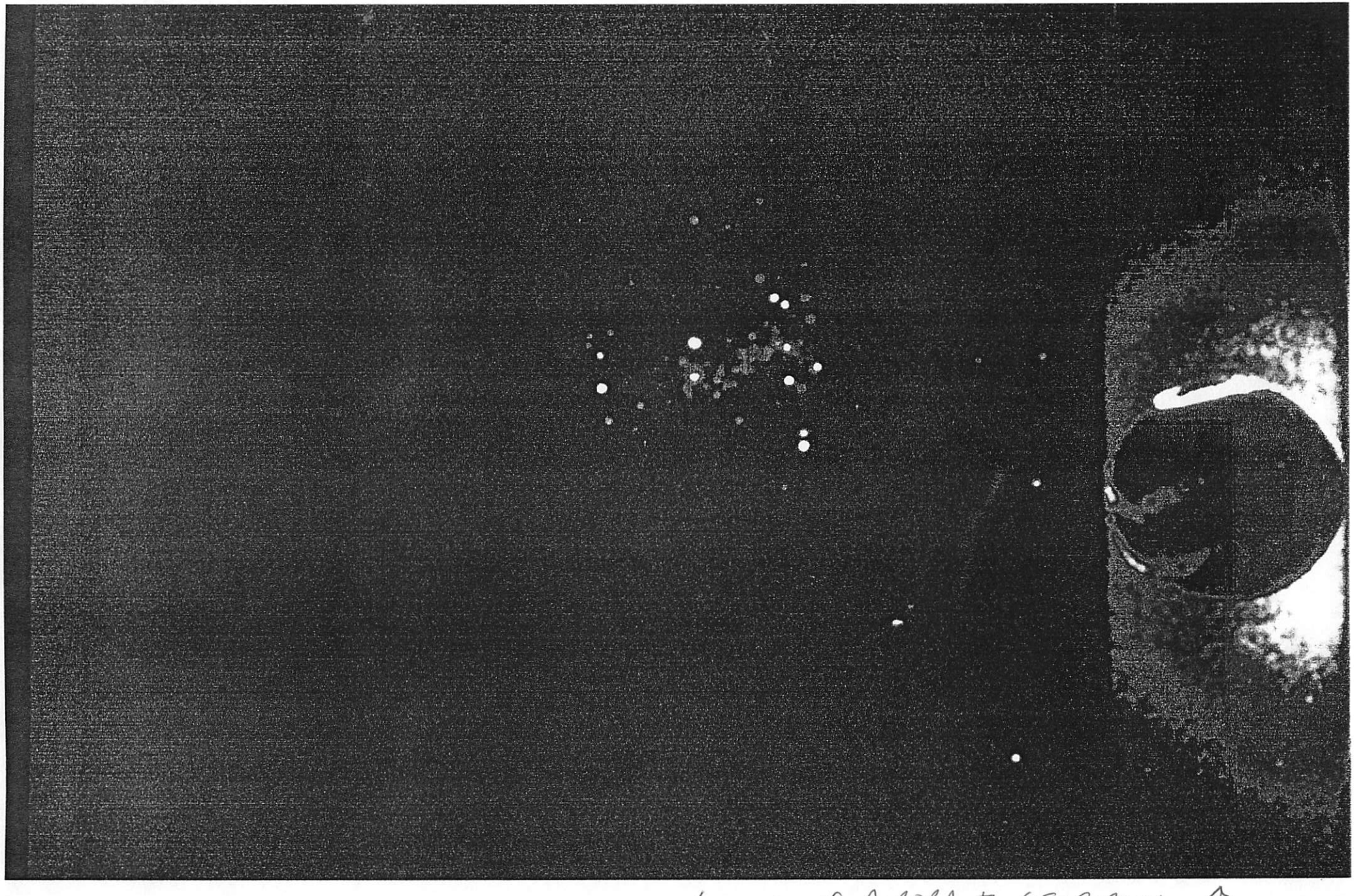
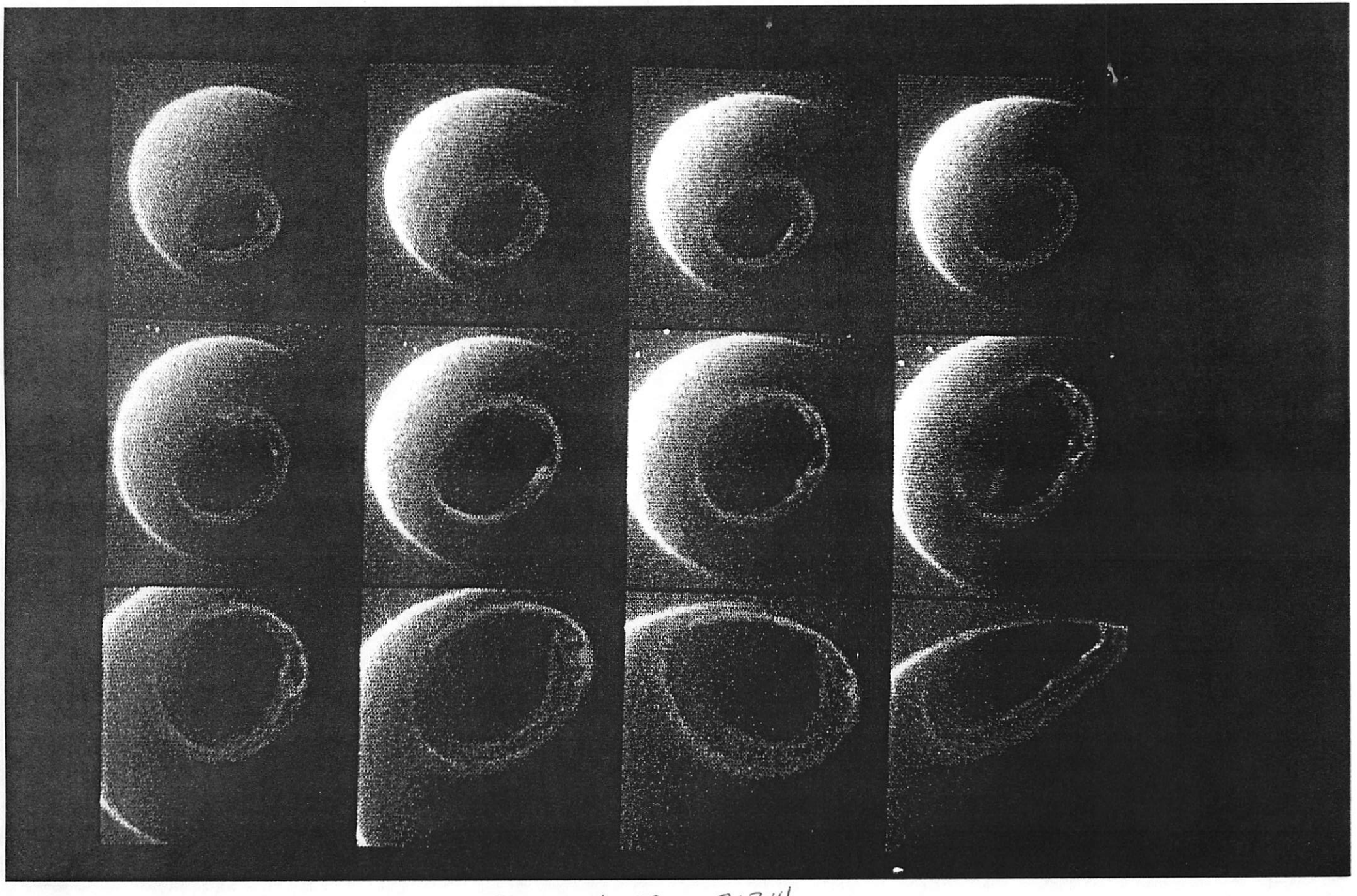


DE AURORA



Ly-α OF AURORA & GEOCORONA ↗



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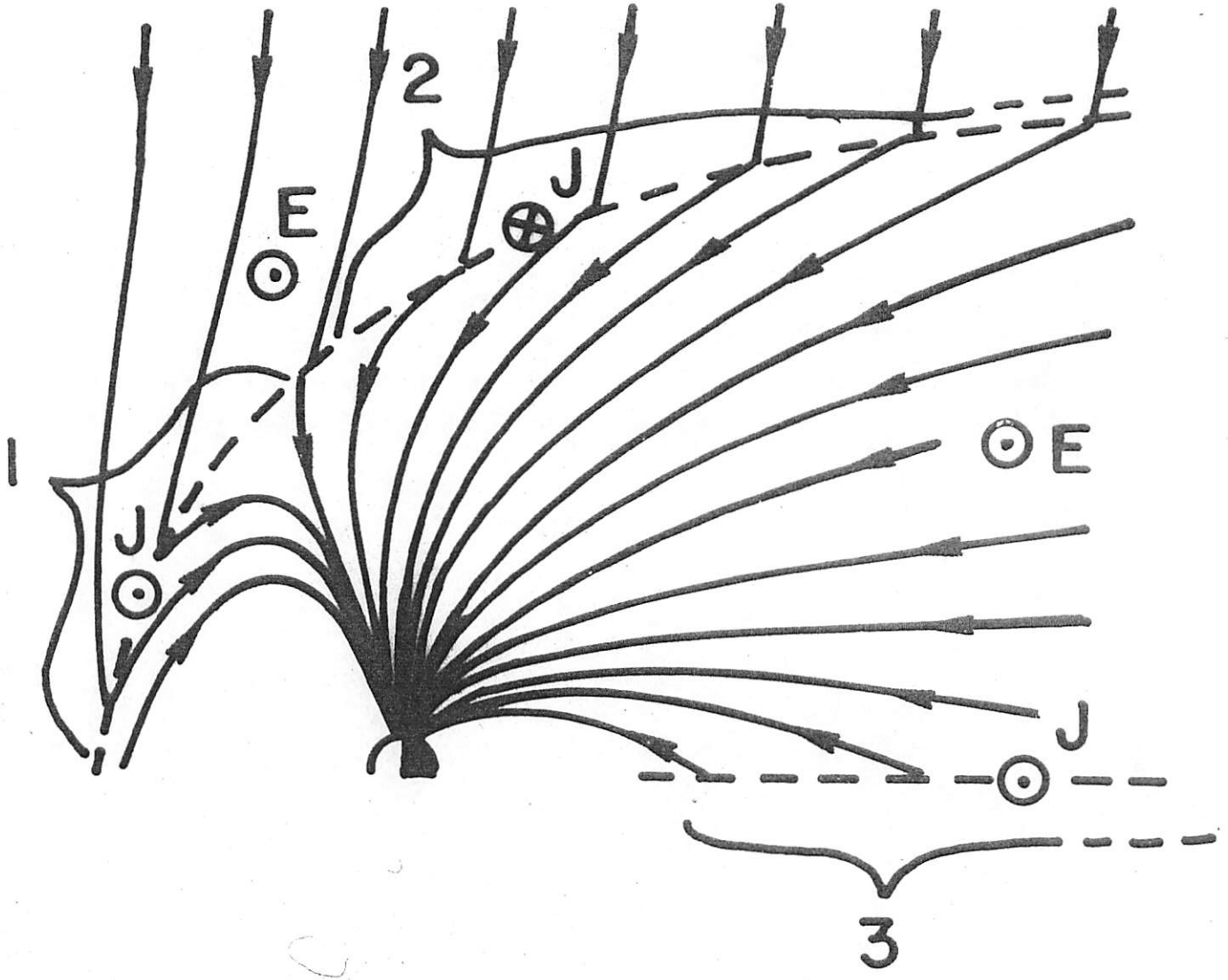
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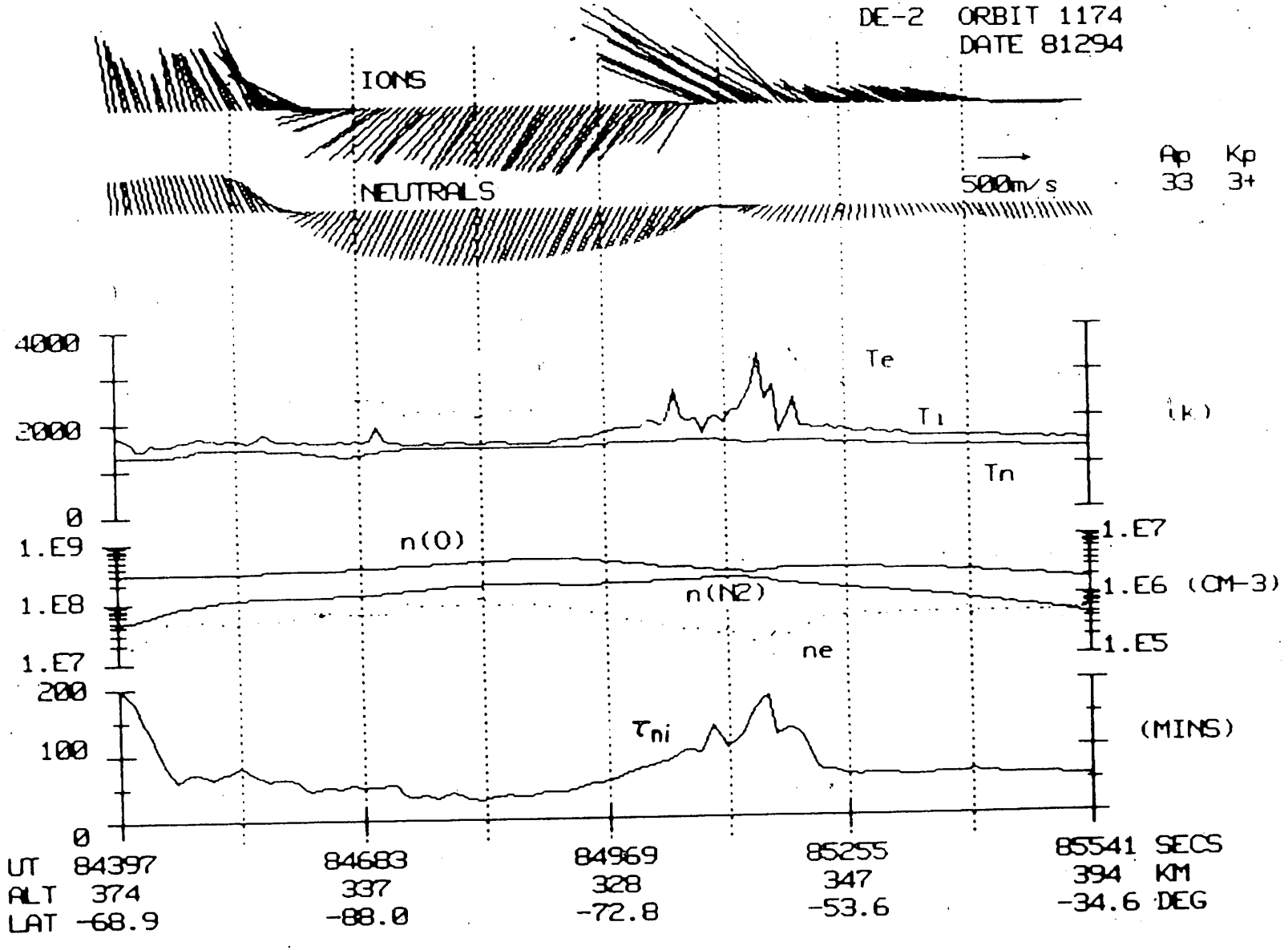
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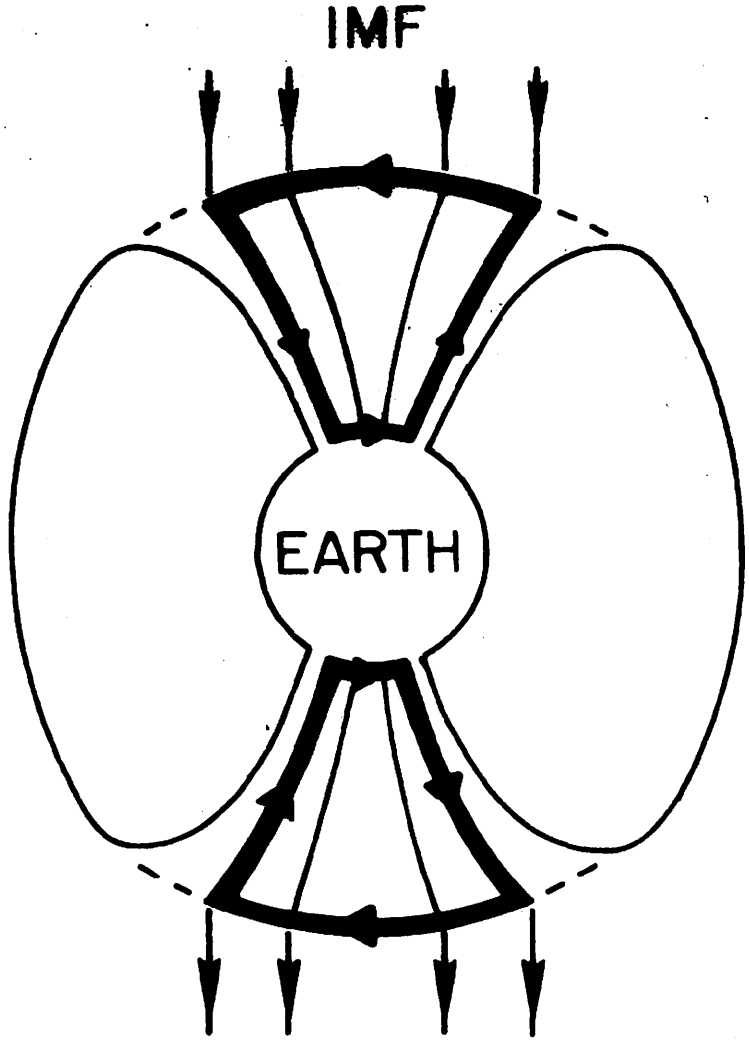

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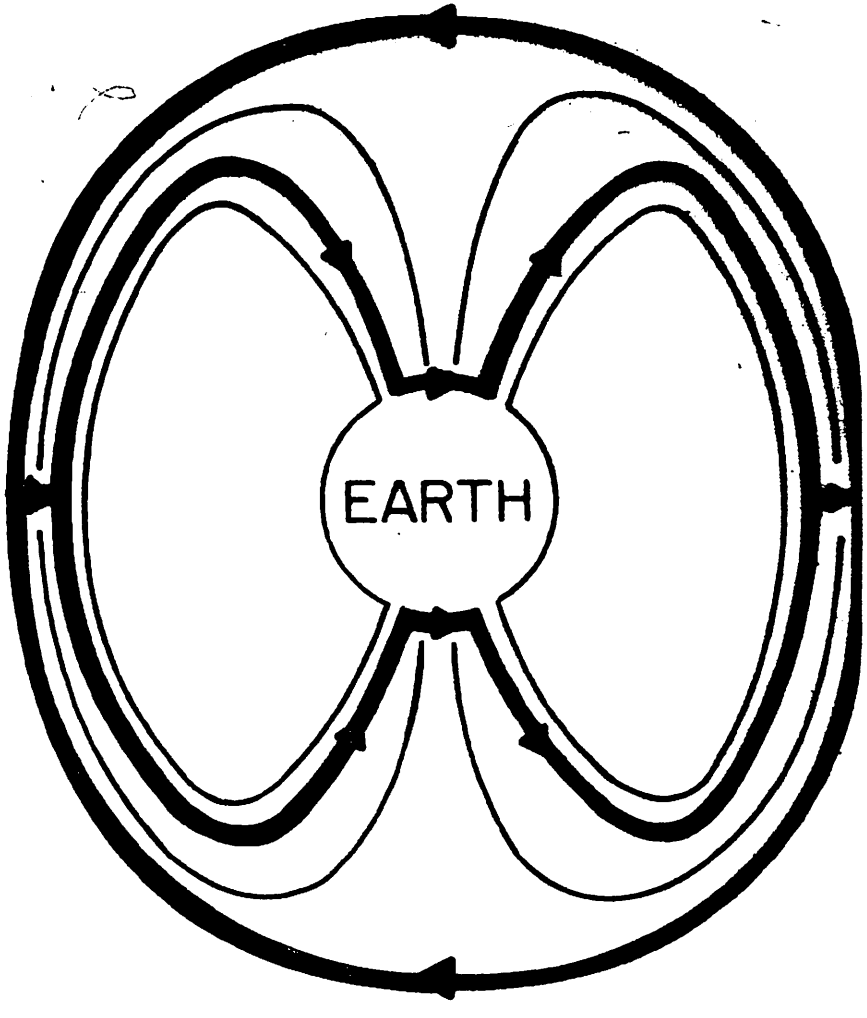

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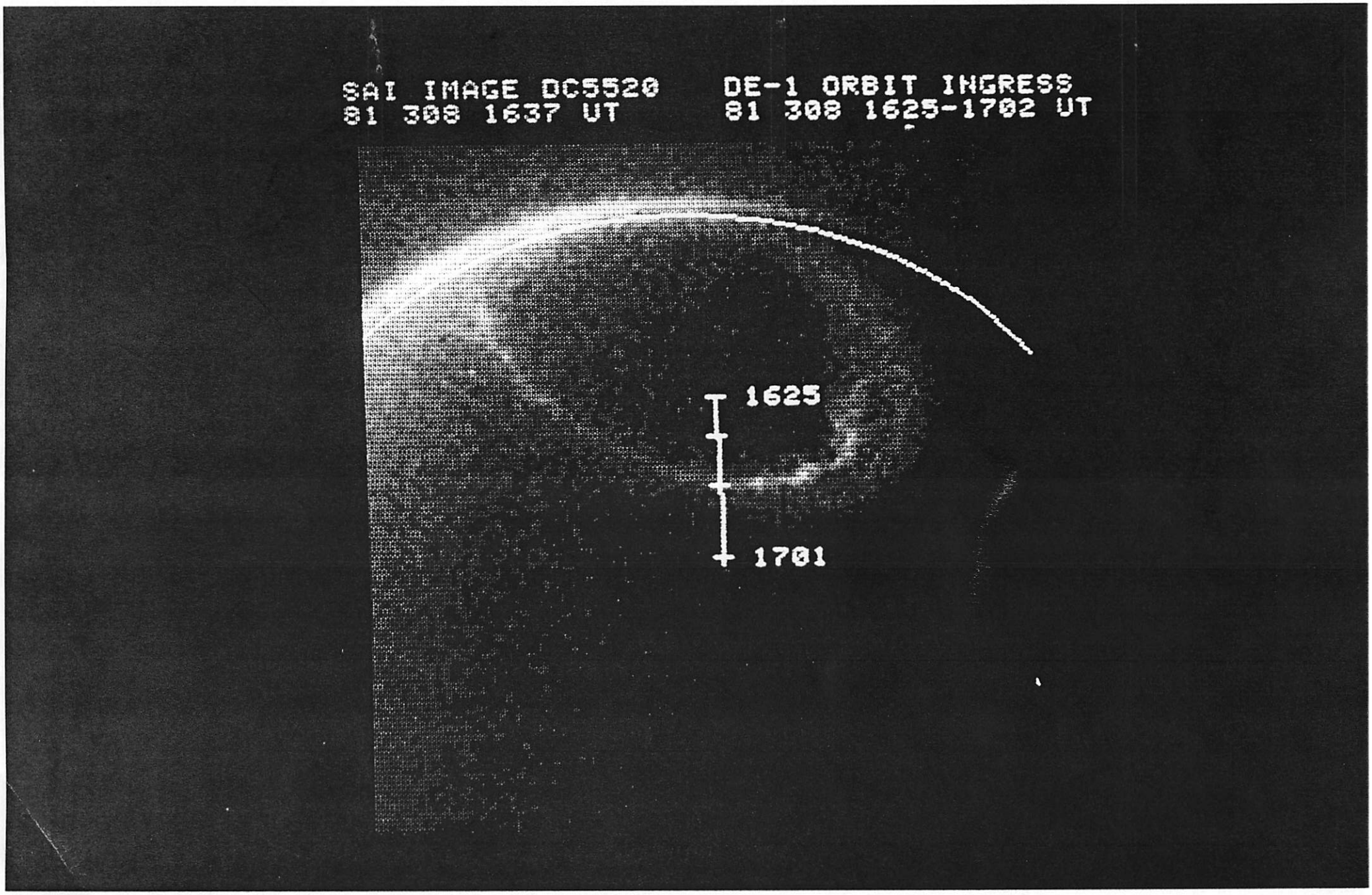
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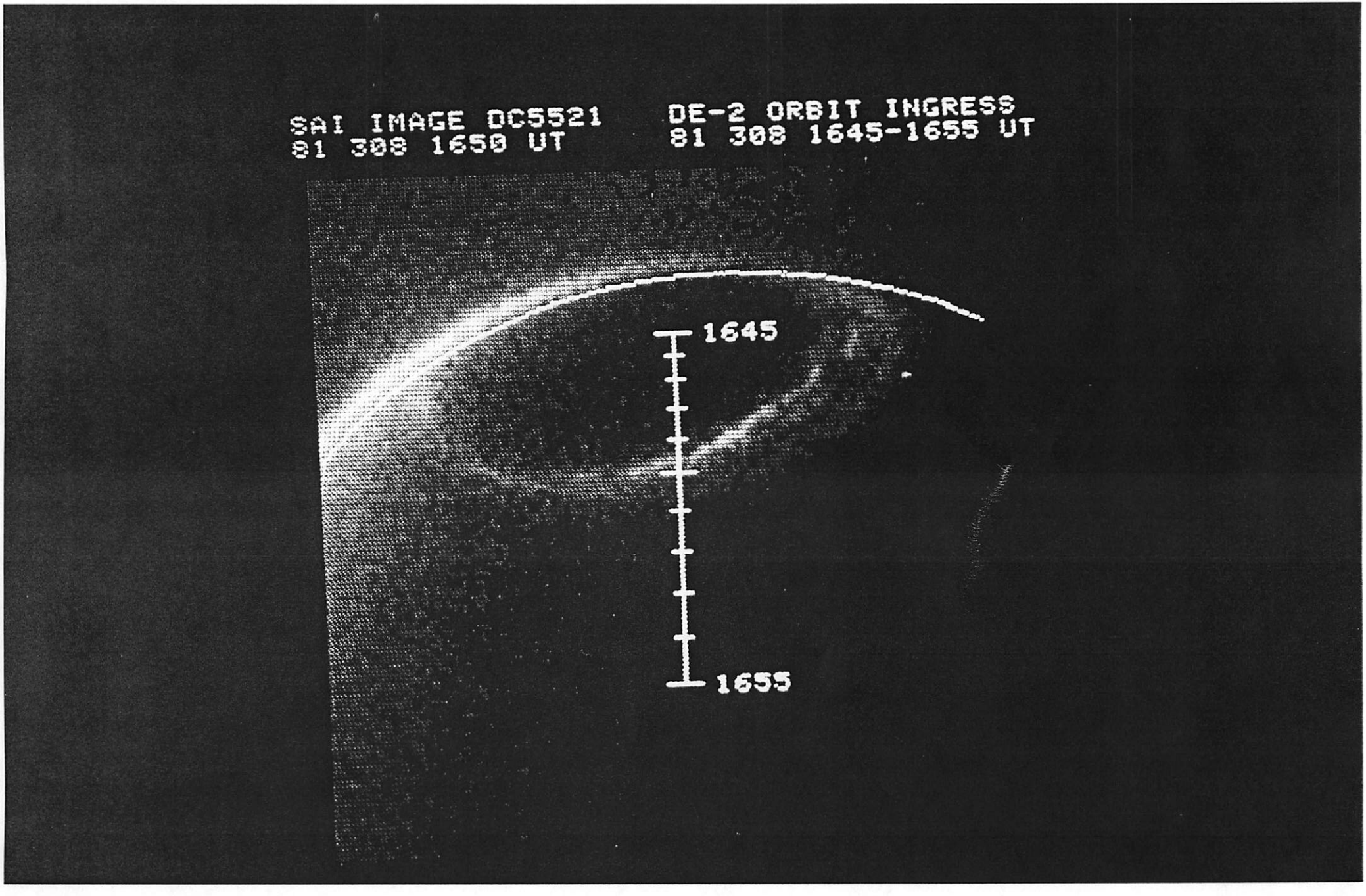
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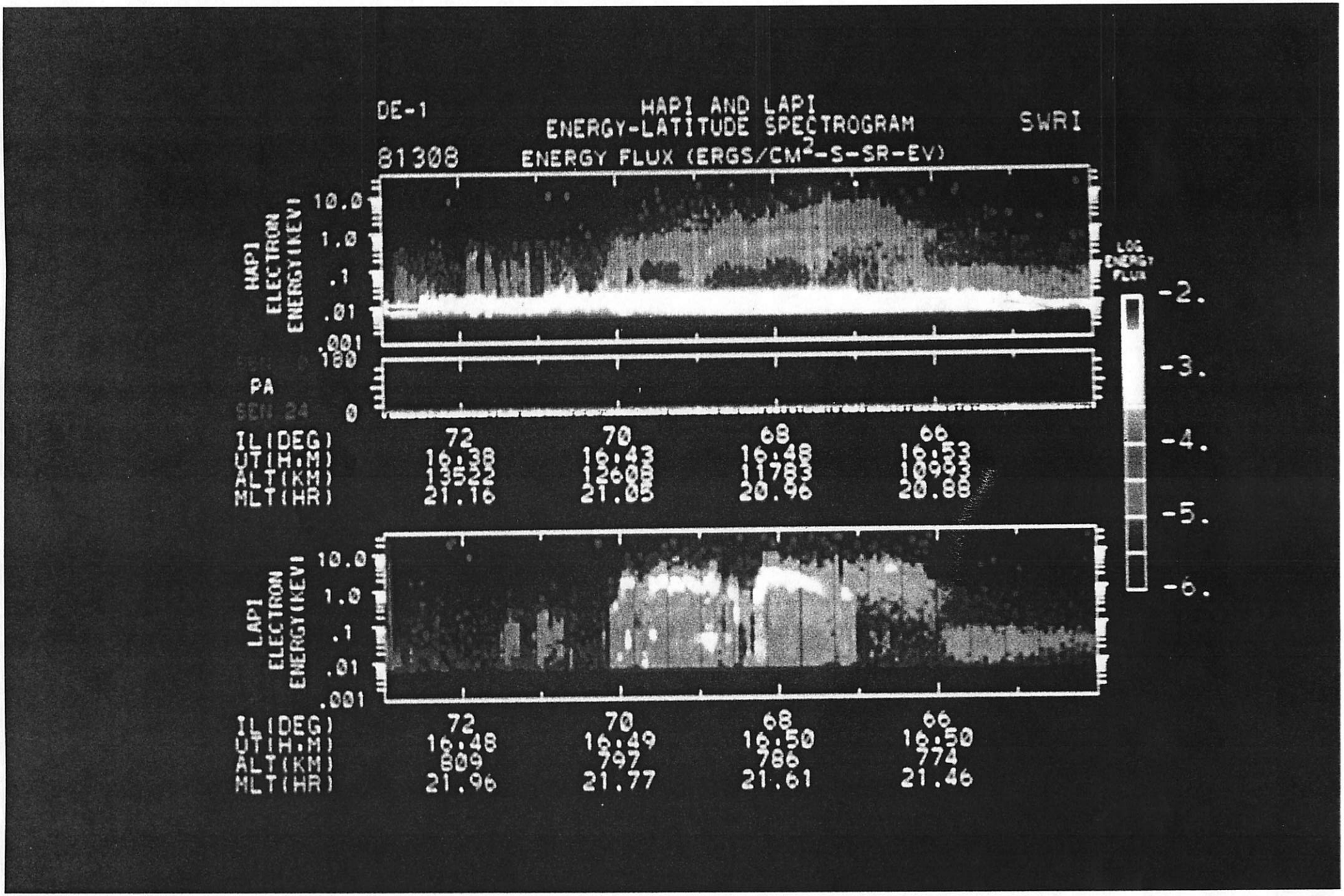
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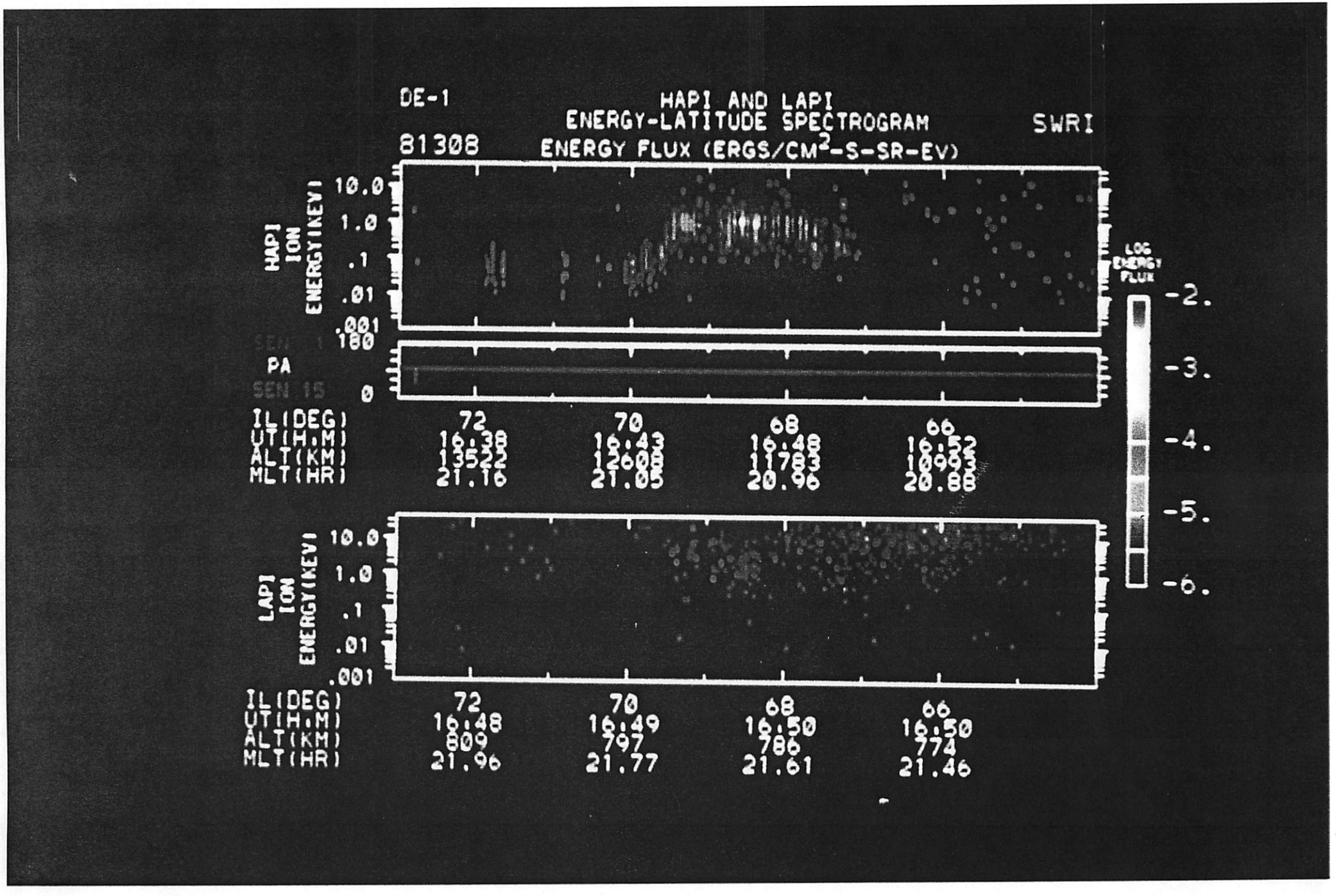
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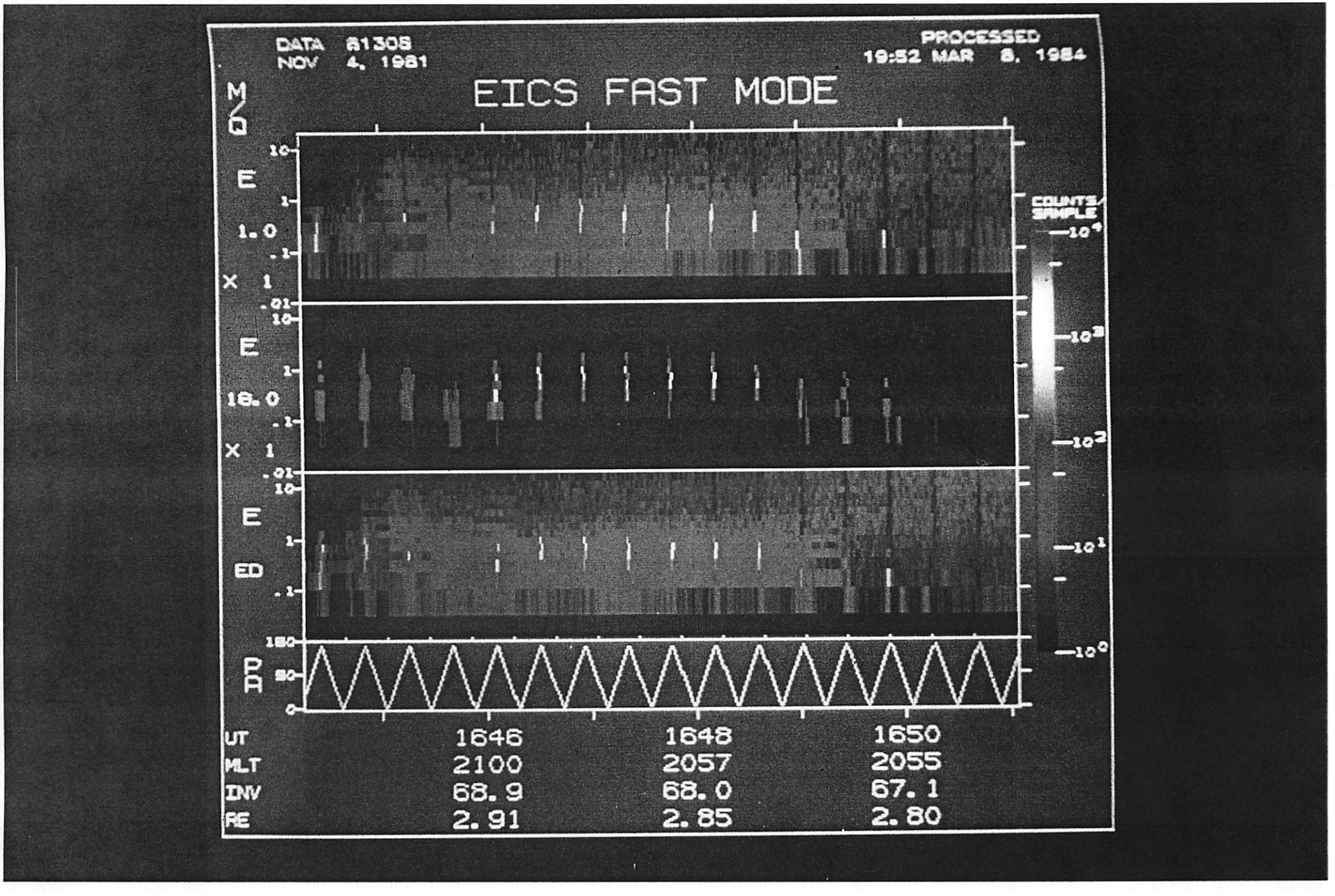
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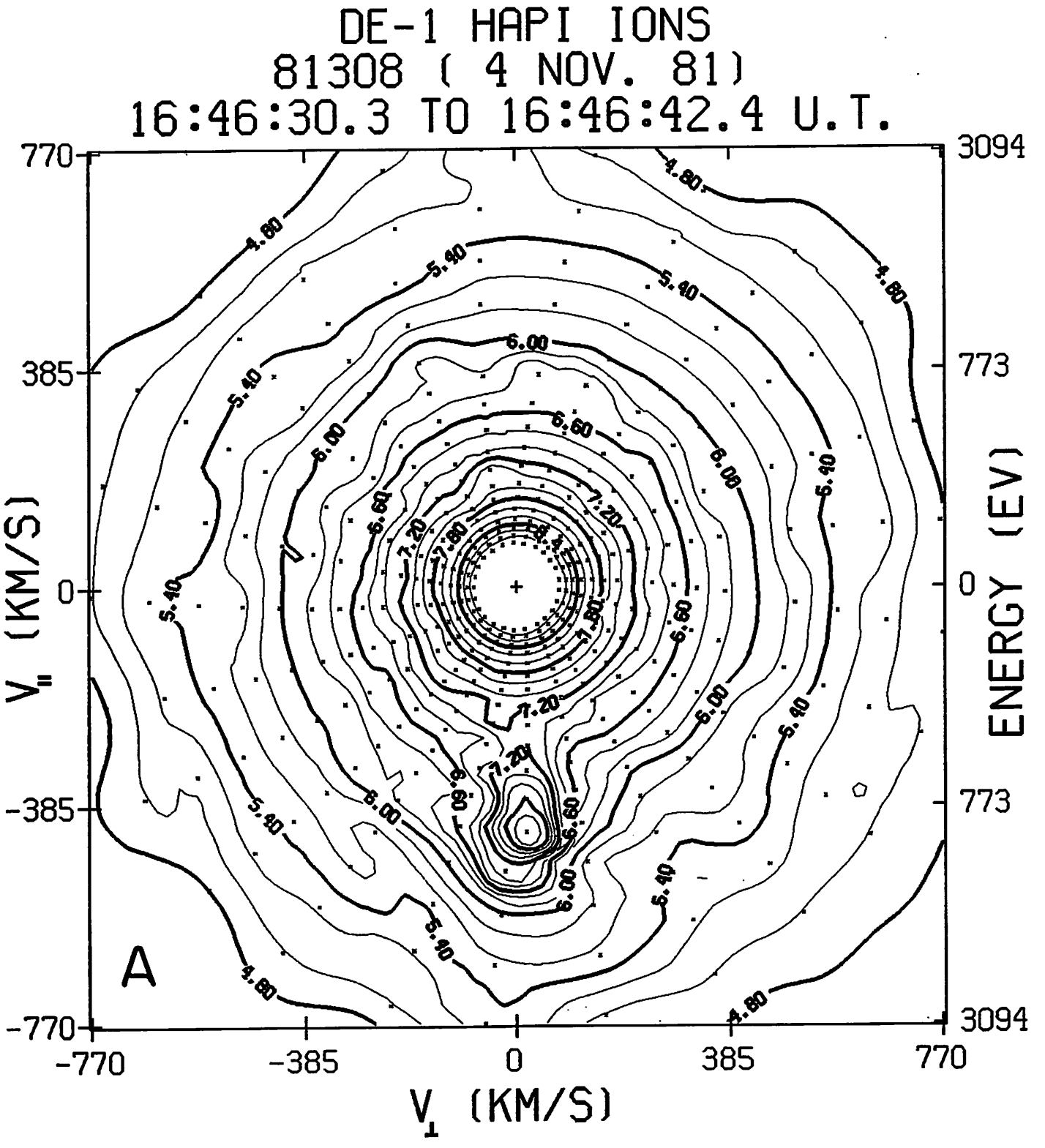

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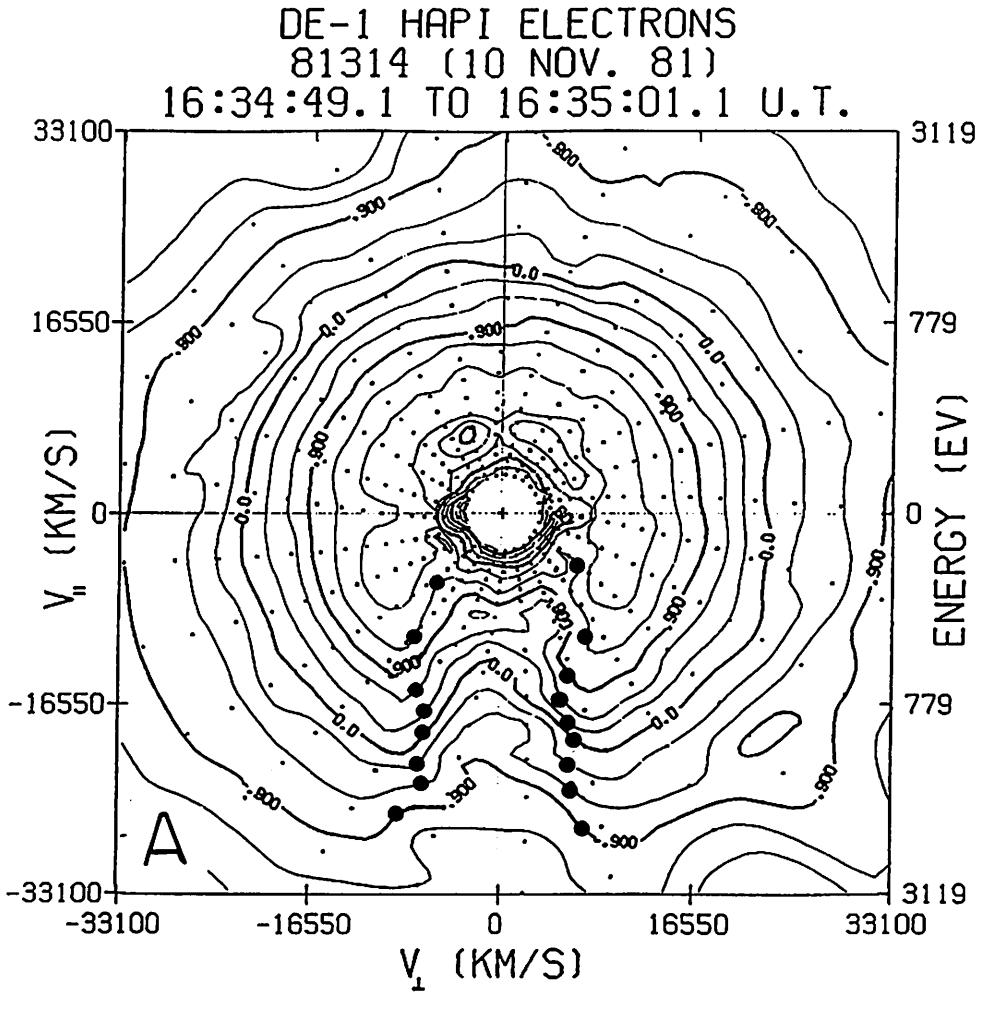
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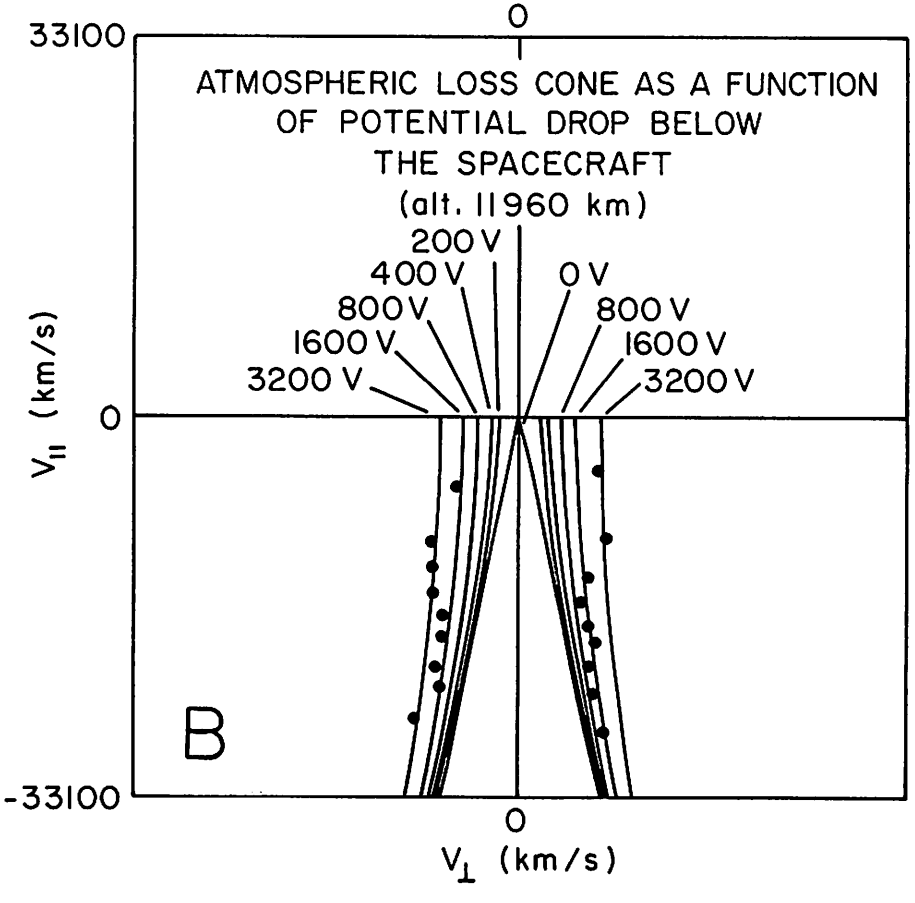
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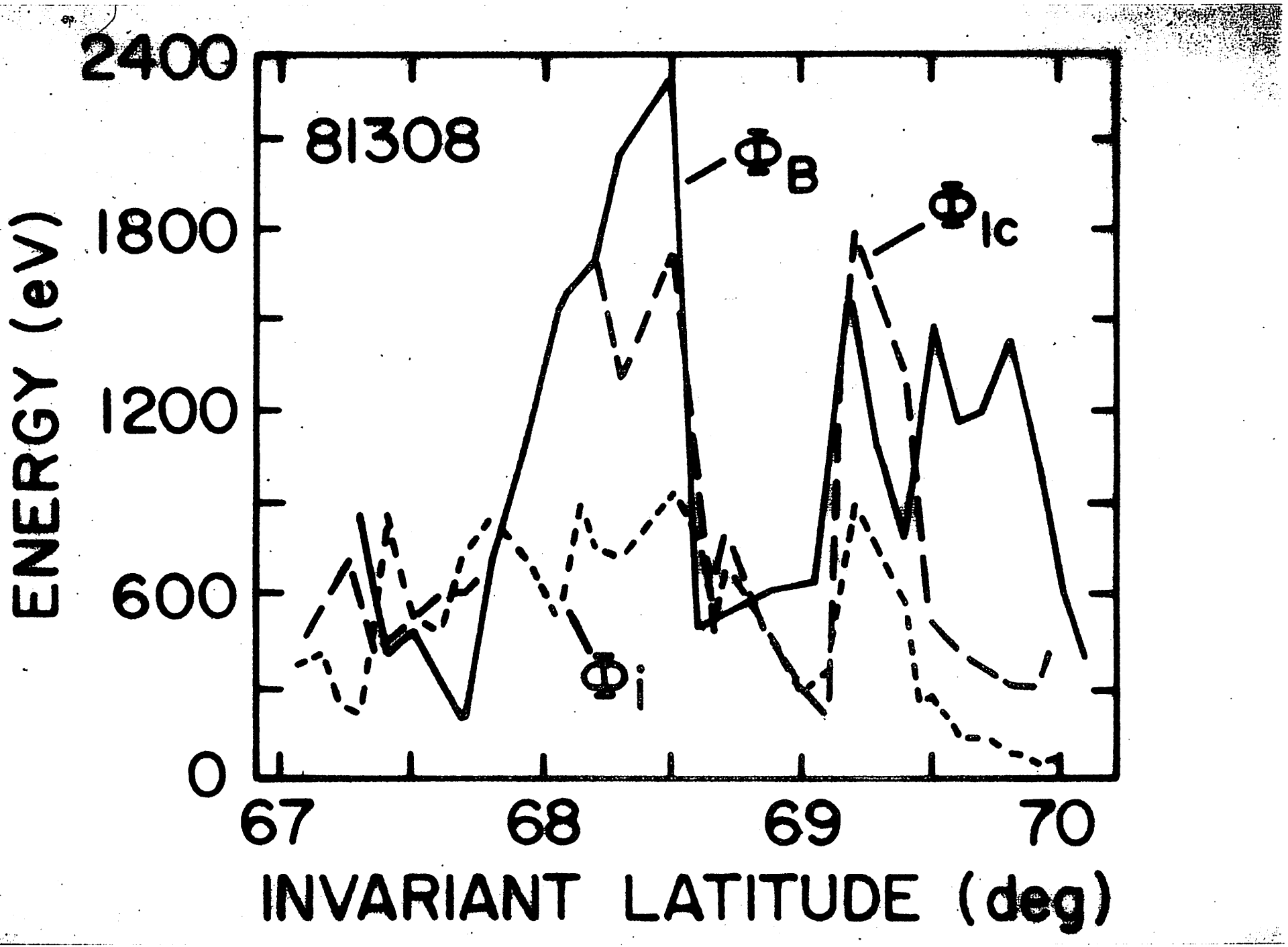
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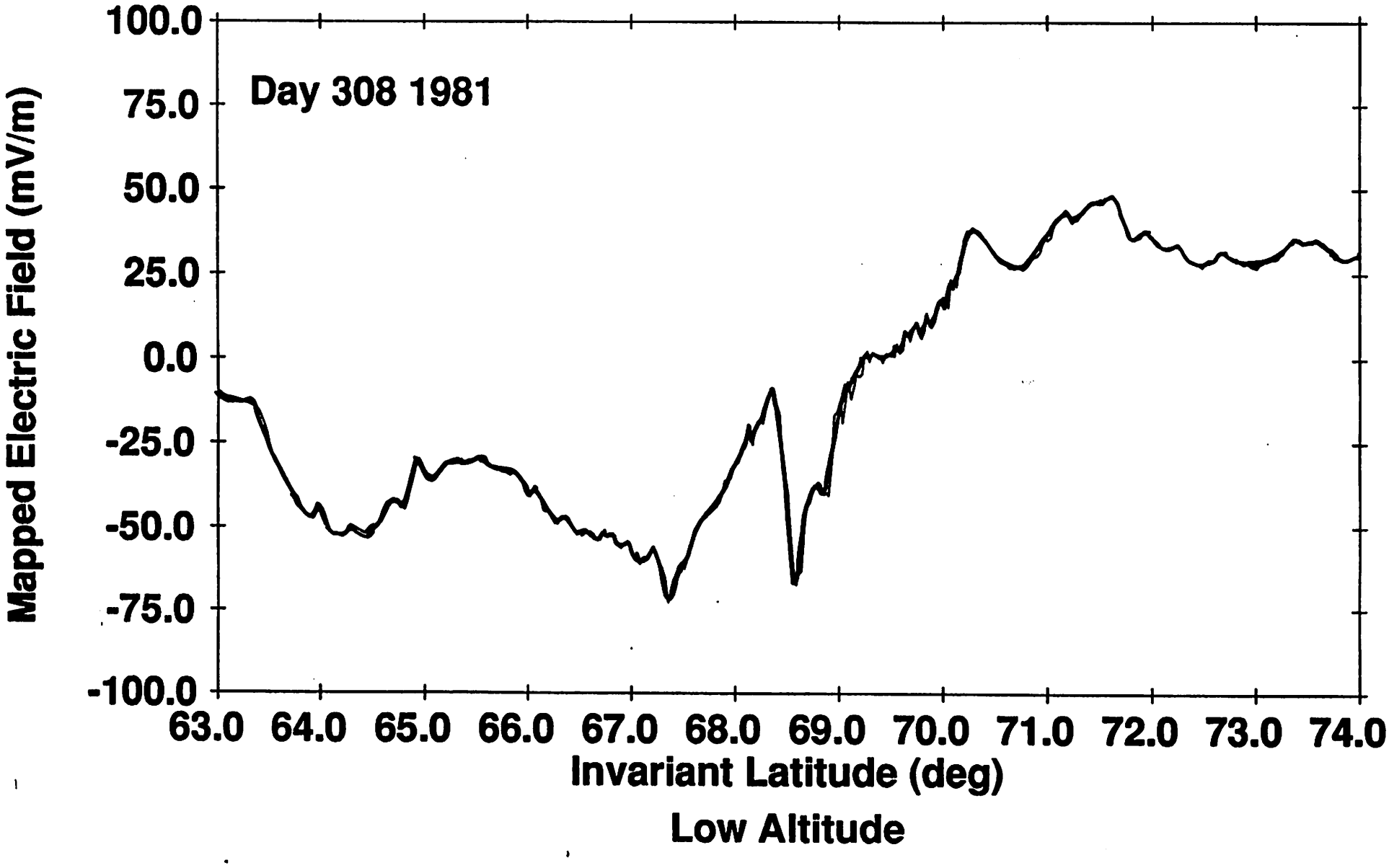
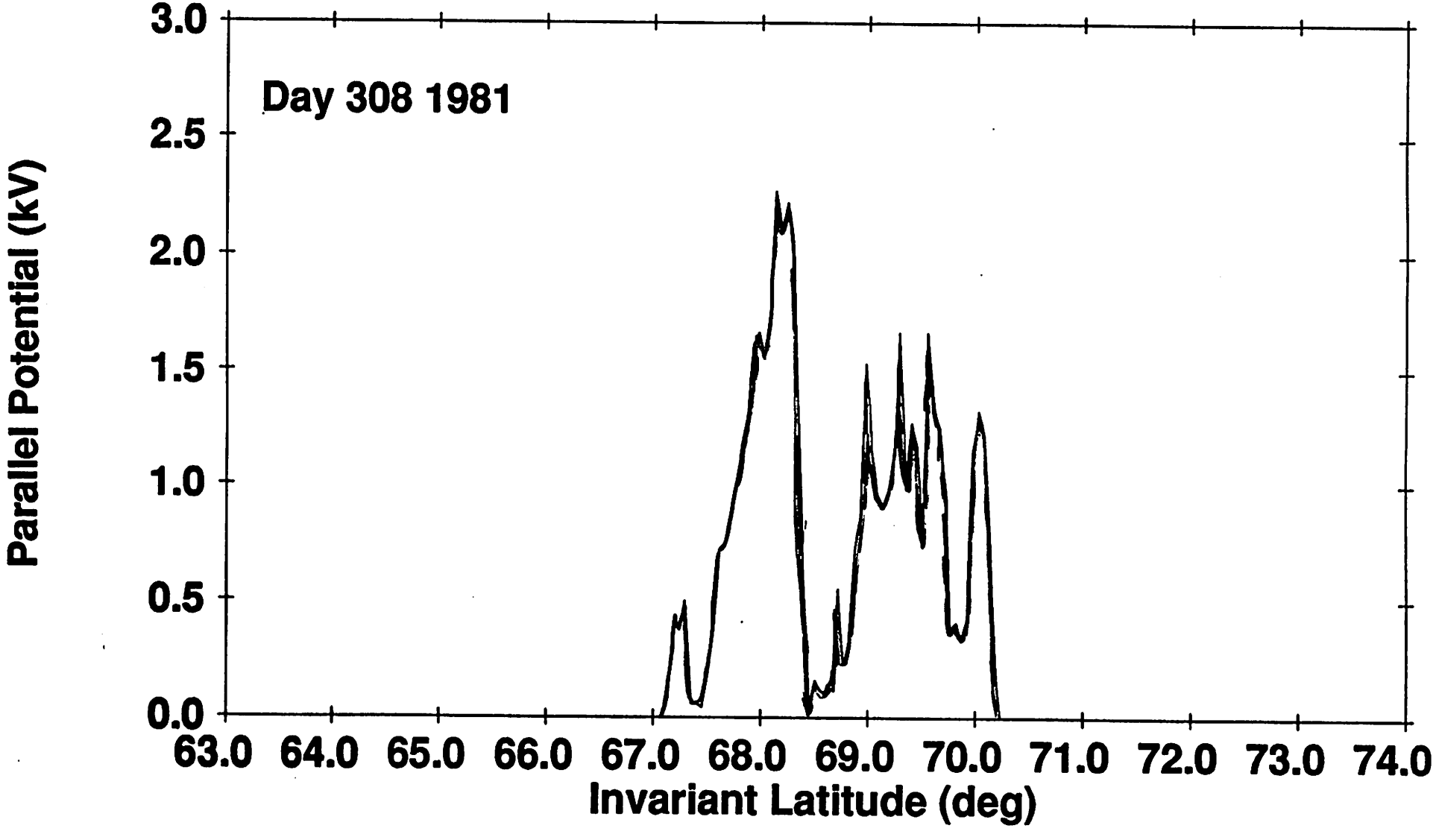
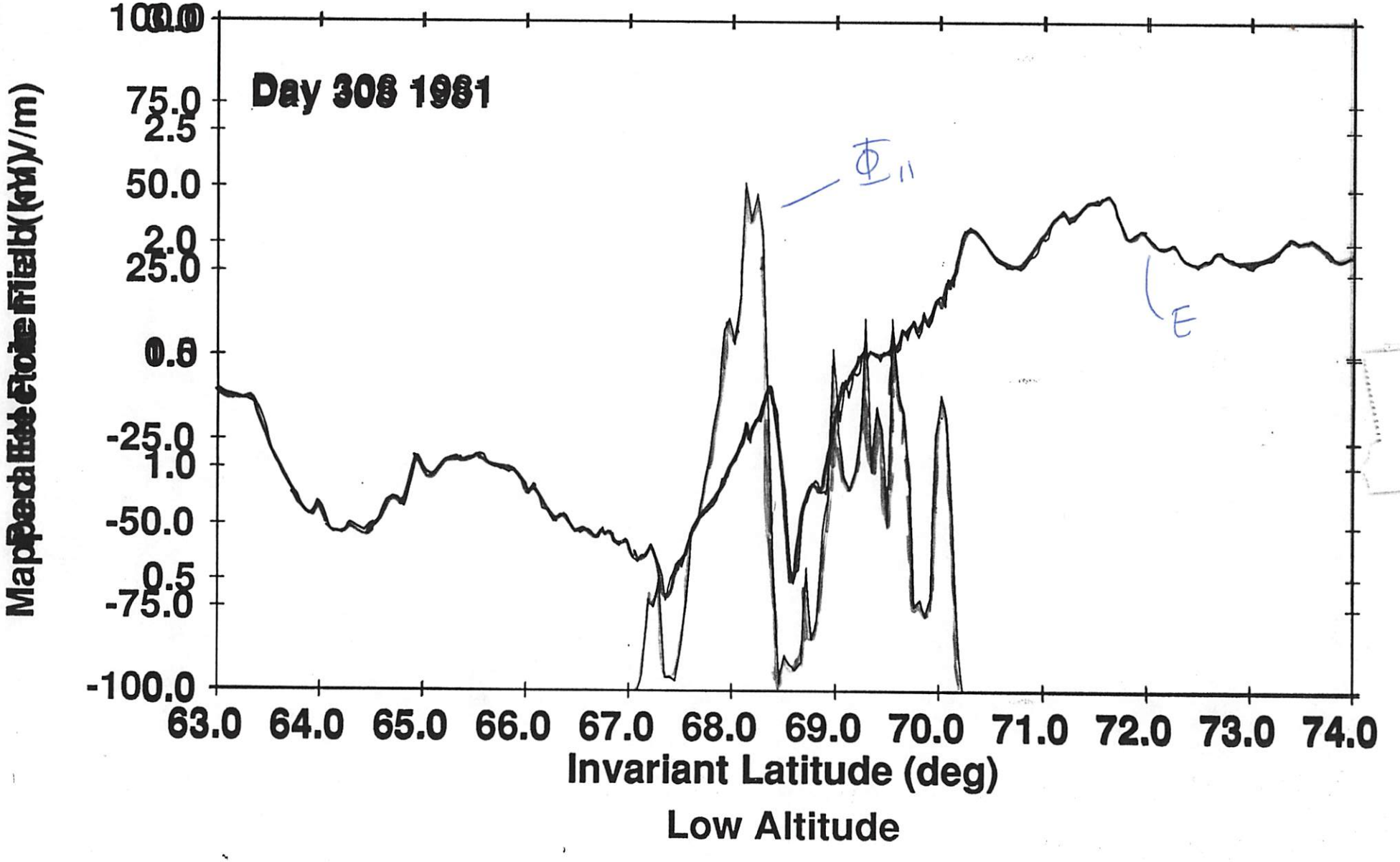
70
INVARIANT LATITUDE (deg)


Day 308 1981
Mapped Electric Field (mV/m)
100.0
75.0
50.0
25.0
0.0
-25.0
-50.0
-75.0
-100.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
Invariant Latitude (deg)
Low Altitude


Day 308 1981
Parallel Potential (kV)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
Invariant Latitude (deg)


Day 308 1981
Φ11
E
Invariant Latitude (deg)
Low Altitude

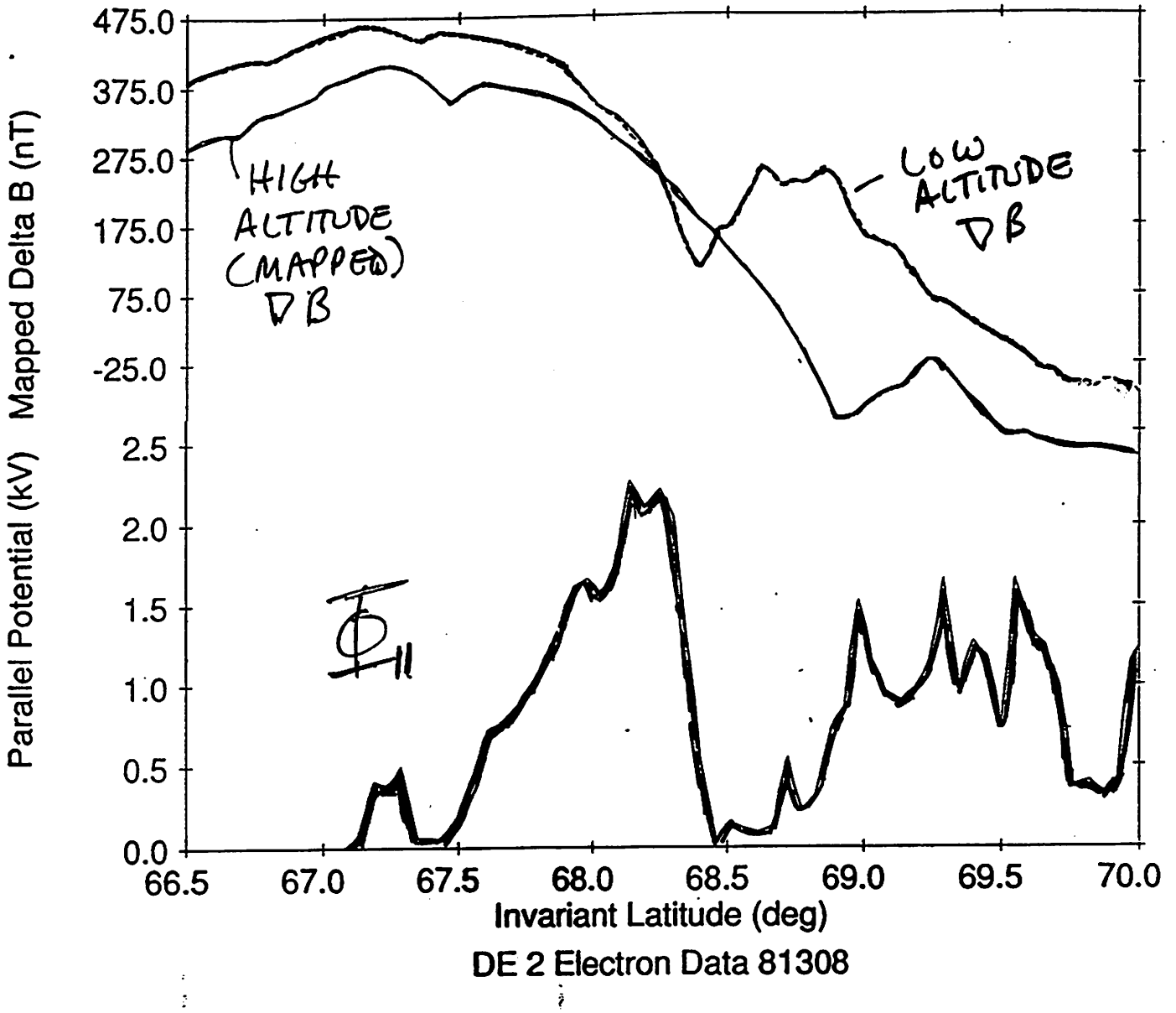
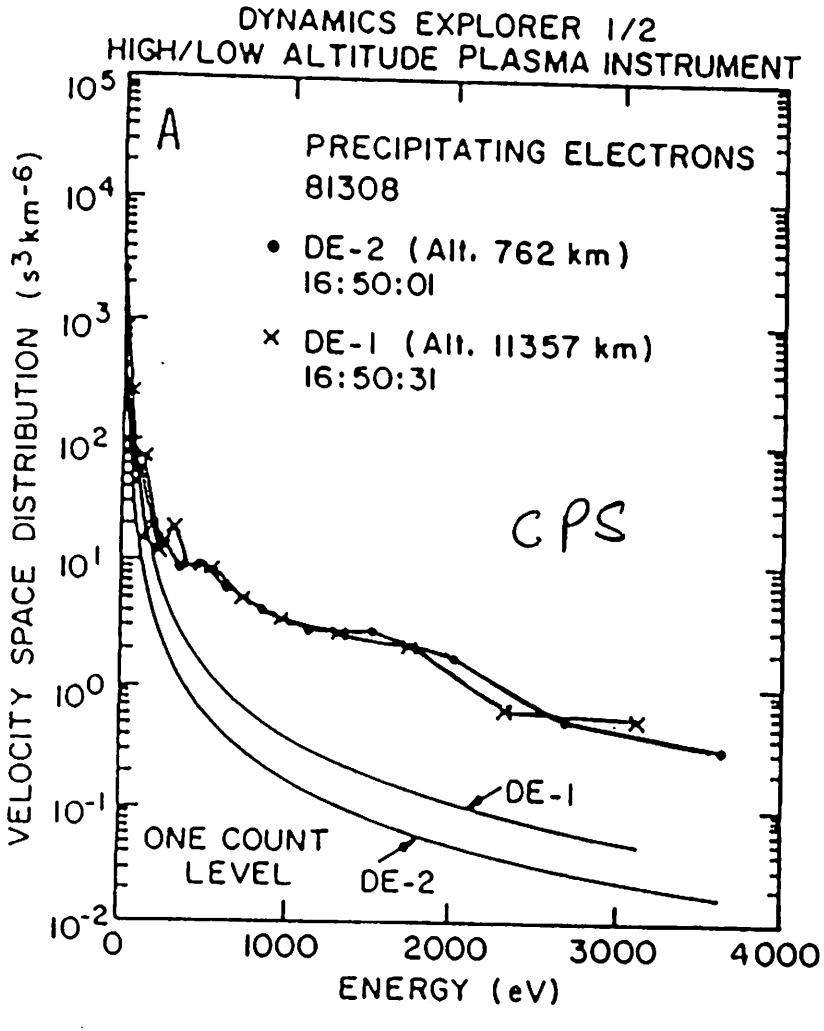
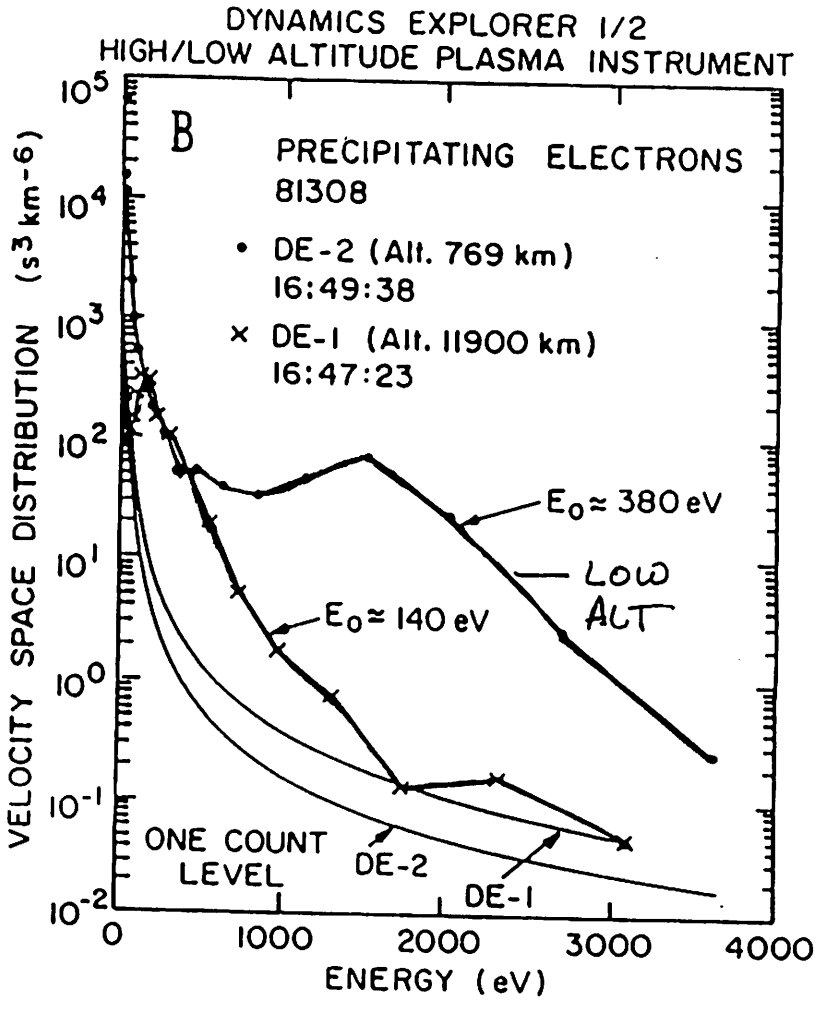
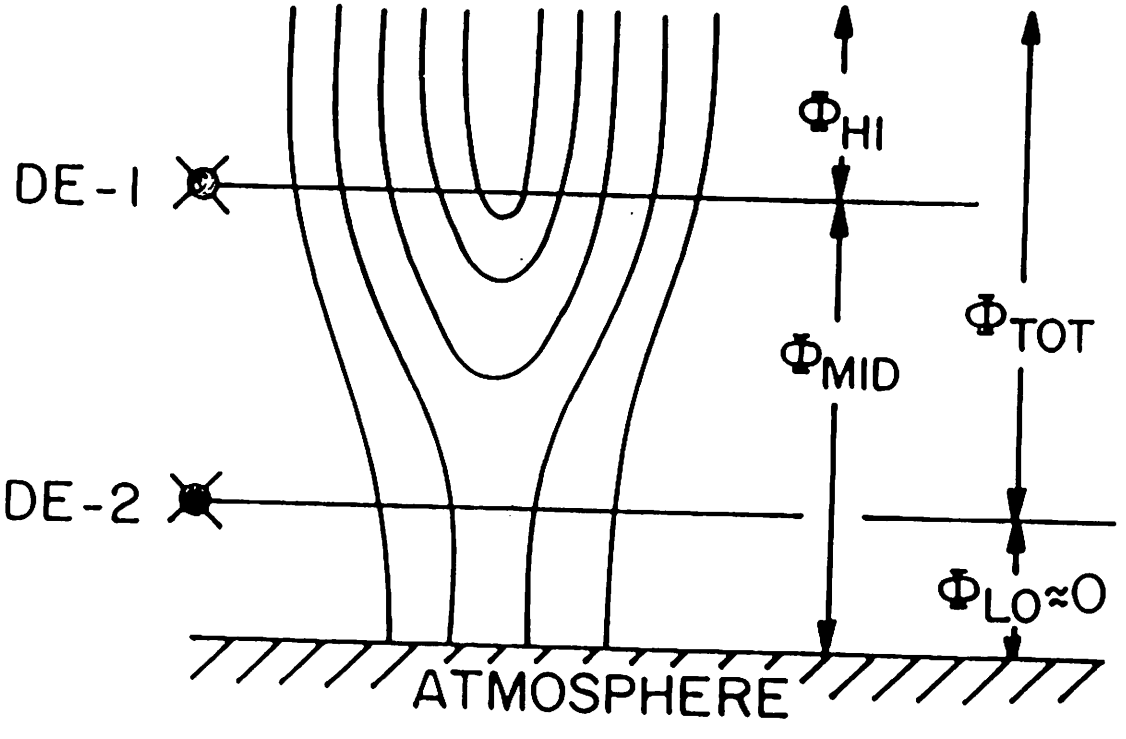
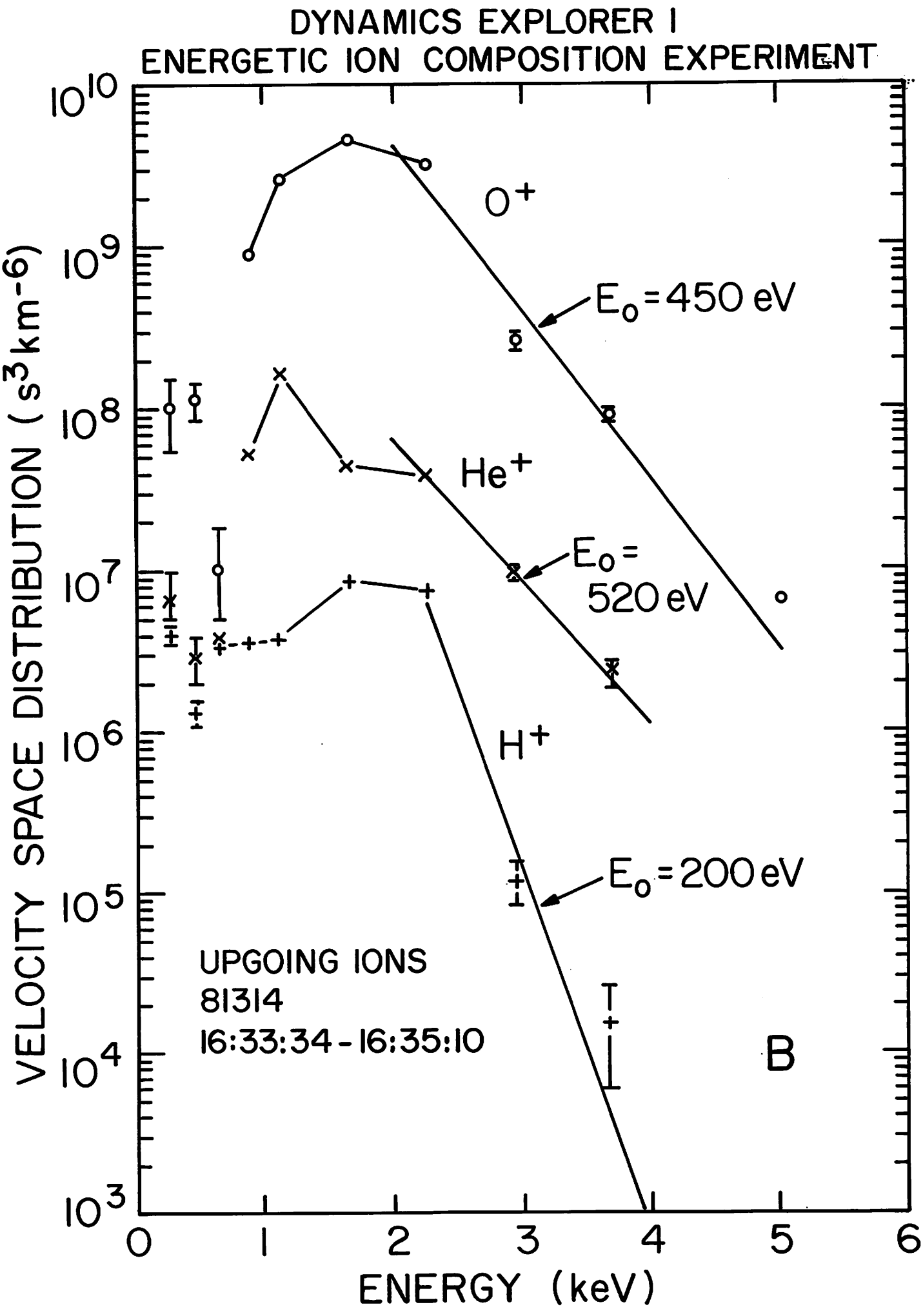

475.0
375.0
275.0
175.0
75.0
-25.0
2.5
2.0
1.5
1.0
0.5
0.0
66.5
67.0
67.5
68.0
68.5
69.0
69.5
70.0
Parallel Potential (kV) Mapped Delta B (nT)
Invariant Latitude (deg)
DE 2 Electron Data 81308
HIGH ALTITUDE (MAPPED) DB
LOW ALTITUDE DB
Φ∥

Figure 17


DYNAMICS EXPLORER 1/2
HIGH/LOW ALTITUDE PLASMA INSTRUMENT
A
PRECIPITATING ELECTRONS
81308
• DE-2 (Alt. 762 km)
16:50:01
× DE-1 (Alt. 11357 km)
16:50:31
CPS
DE-1
DE-2
ONE COUNT LEVEL
VELOCITY SPACE DISTRIBUTION (s³km⁻⁶)
ENERGY (eV)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
0
1000
2000
3000
4000

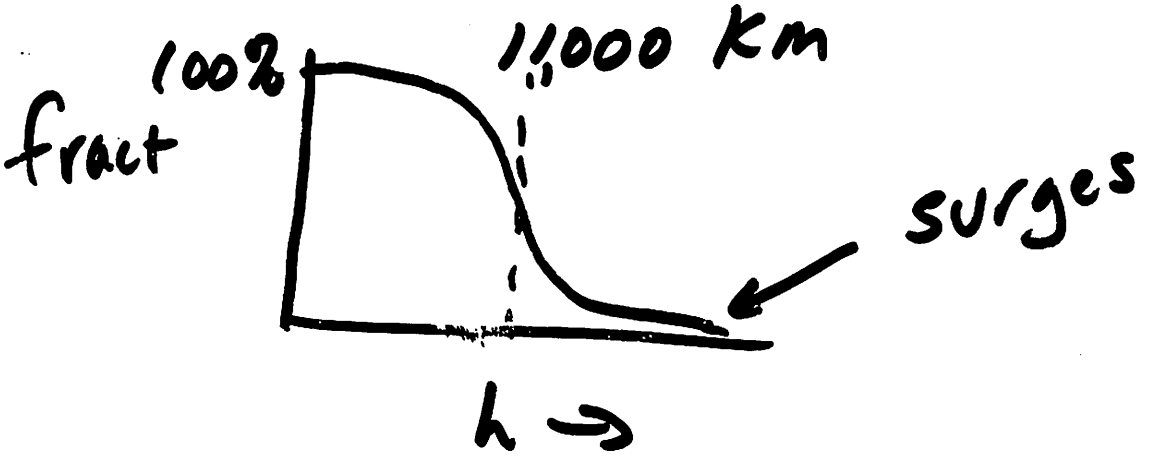

DYNAMICS EXPLORER 1/2
HIGH/LOW ALTITUDE PLASMA INSTRUMENT
B
PRECIPITATING ELECTRONS
81308
• DE-2 (Alt. 769 km)
16:49:38
× DE-1 (Alt. 11900 km)
16:47:23
E₀ ≈ 380 eV
LOW ALT
E₀ ≈ 140 eV
DE-2
DE-1
ONE COUNT LEVEL
VELOCITY SPACE DISTRIBUTION (s³km⁻⁶)
ENERGY (eV)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
0
1000
2000
3000
4000

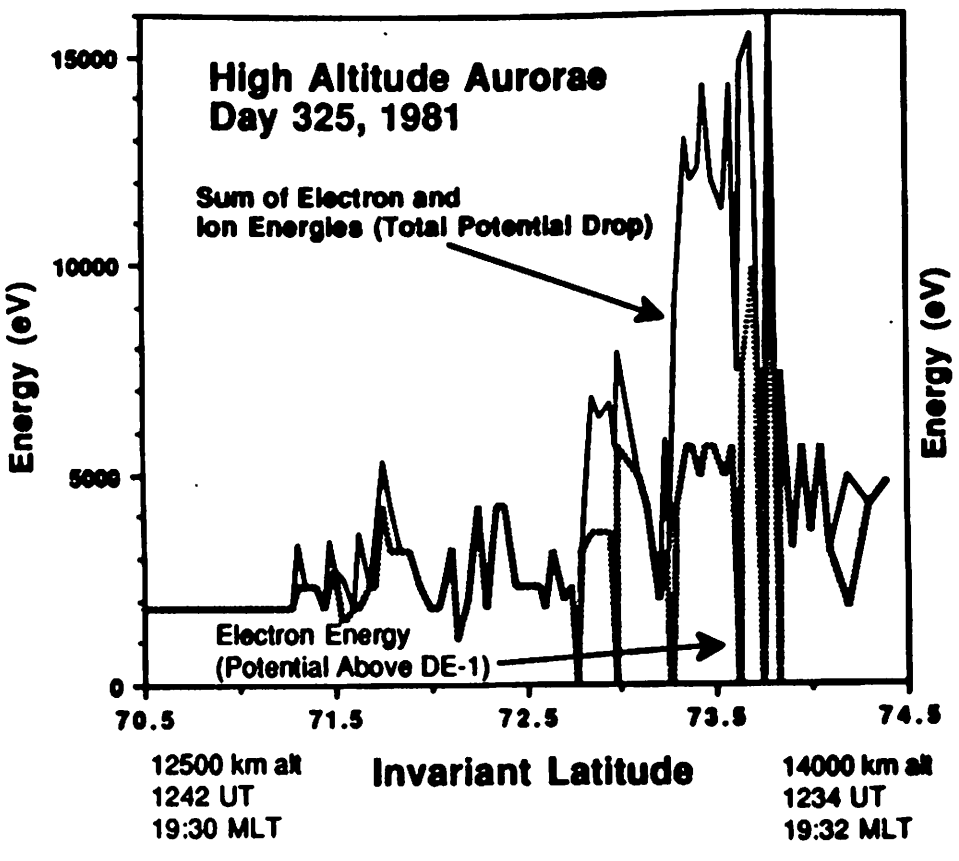

DE-1
DE-2
Φ_{HI}
Φ_{MID}
Φ_{TOT}
$\Phi_{LO} \approx 0$
ATMOSPHERE

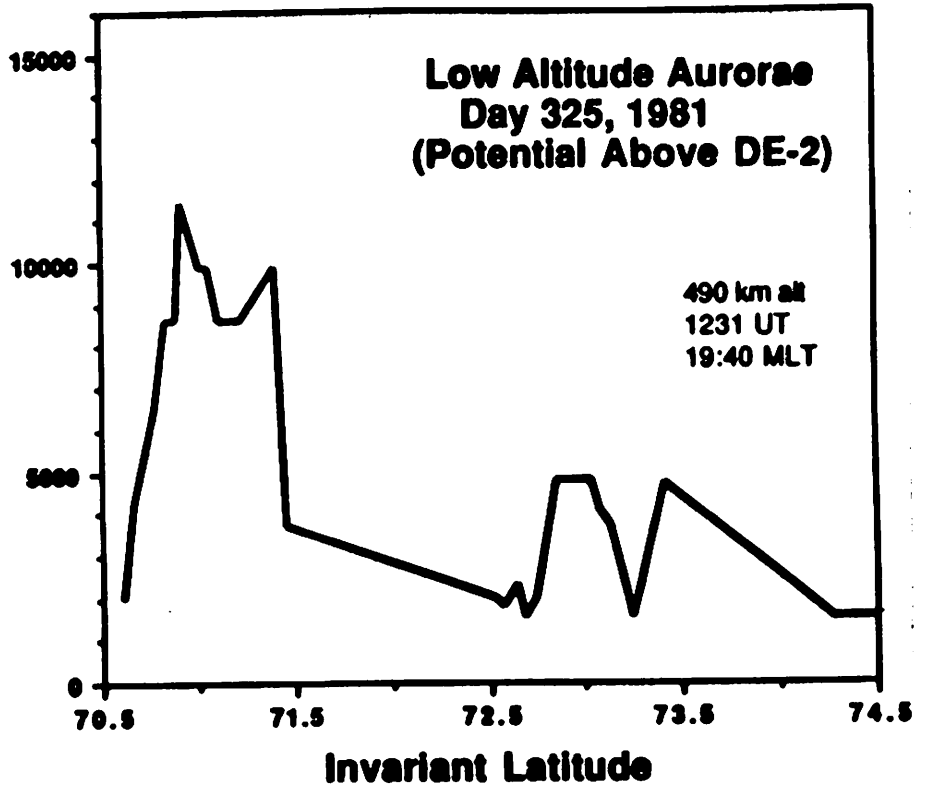

DYNAMICS EXPLORER I
ENERGETIC ION COMPOSITION EXPERIMENT
VELOCITY SPACE DISTRIBUTION ($s^3 km^{-6}$)
10^{10}
10^9
10^8
10^7
10^6
10^5
10^4
10^3
O^+
E_o = 450 eV
He^+
E_o = 520 eV
H^+
E_o = 200 eV
UPGOING IONS
81314
16:33:34 - 16:35:10
B
0
1
2
3
4
5
6
ENERGY (keV)

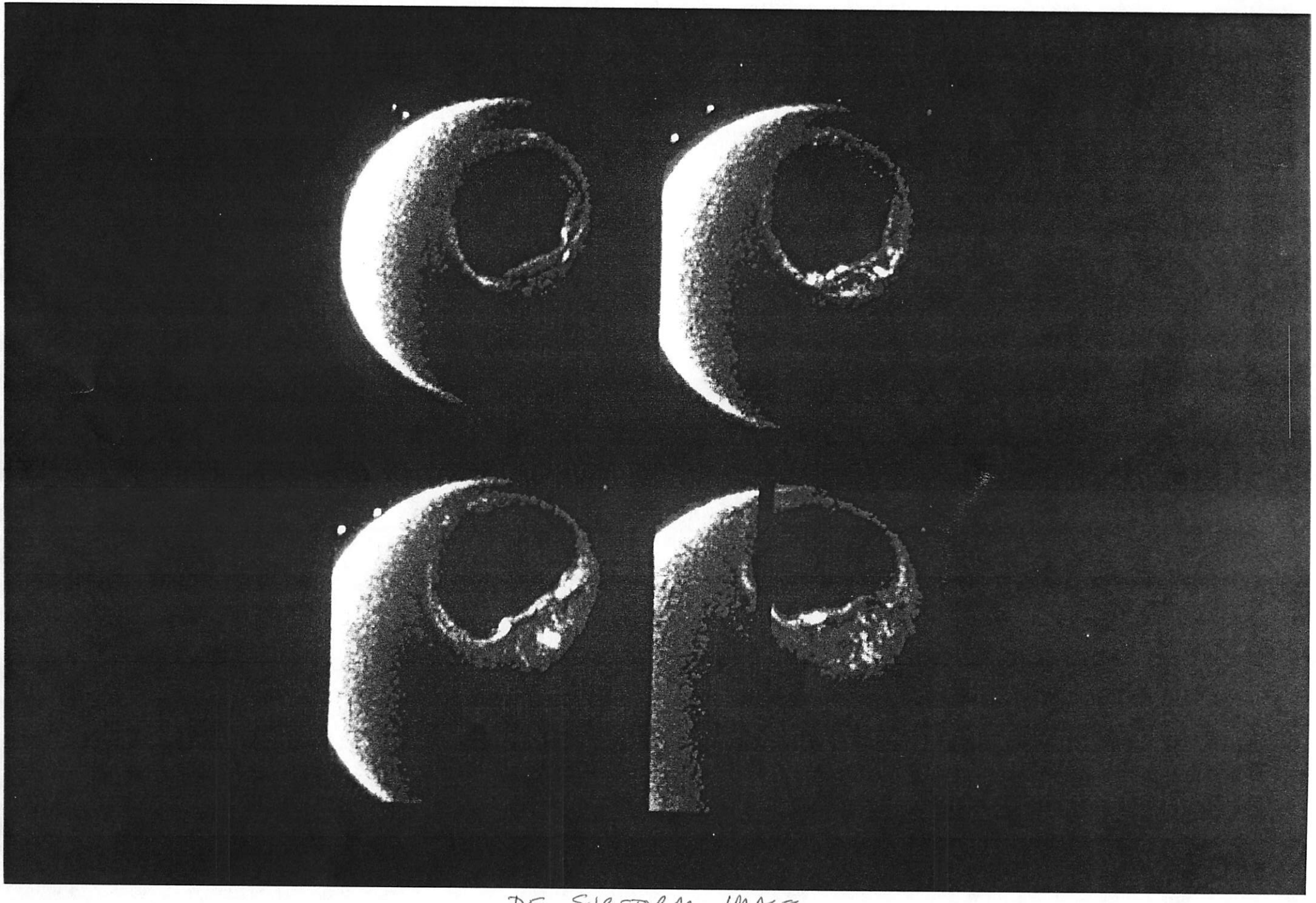
Low Altitude Limit
(balancing fluxes)
~ 1100 - 1500 km

High Altitude Limit
(statistical, DE data)




High Altitude Aurorae
Day 325, 1981
Sum of Electron and
Ion Energies (Total Potential Drop)
Electron Energy
(Potential Above DE-1)
Energy (eV)
15000
10000
5000
0
70.5
71.5
72.5
73.5
74.5
12500 km alt
1242 UT
19:30 MLT
Invariant Latitude
14000 km alt
1234 UT
19:32 MLT

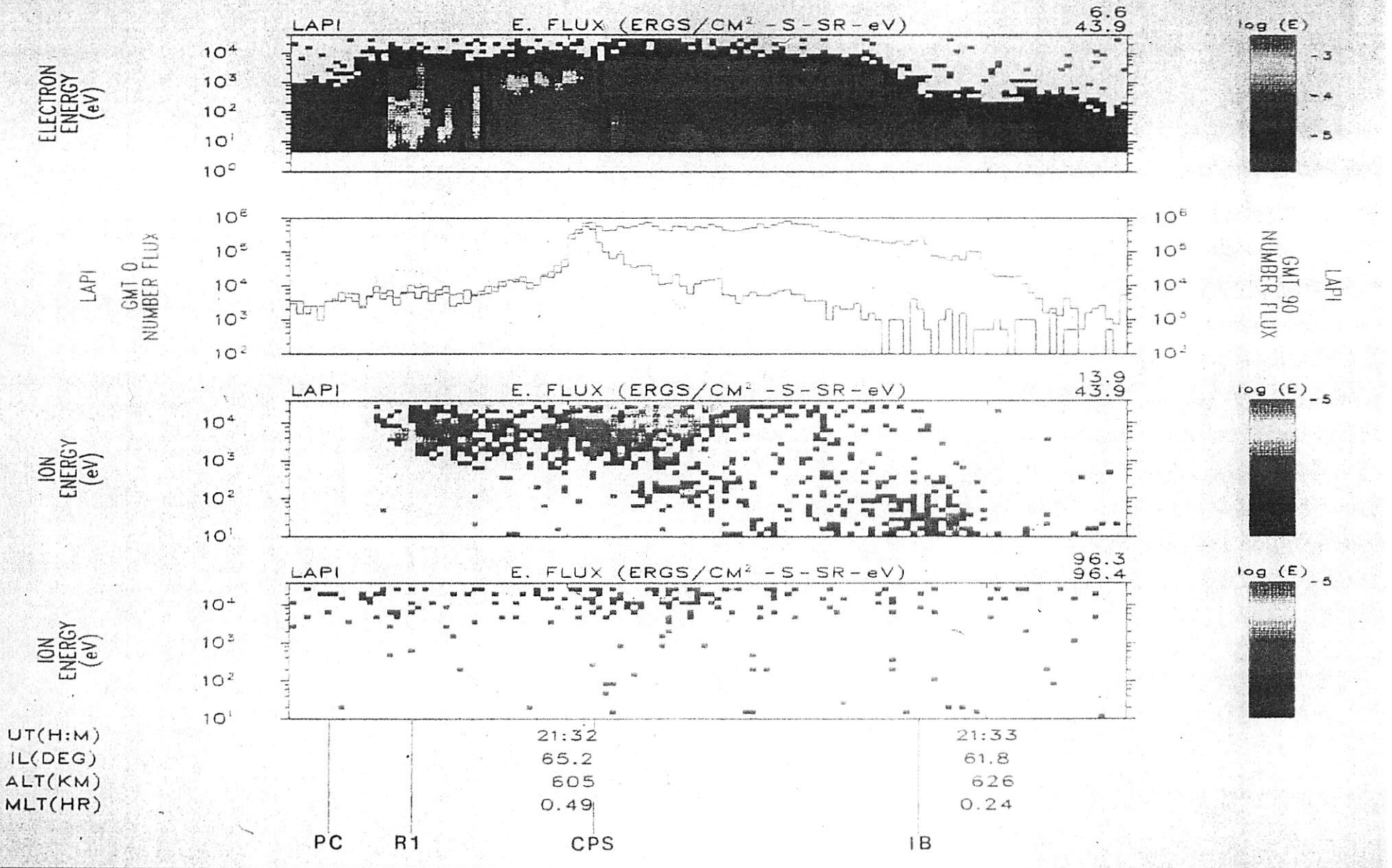

Low Altitude Aurorae
Day 325, 1981
(Potential Above DE-2)
490 km alt
1231 UT
19:40 MLT
Energy (eV)
15000
10000
5000
0
70.5
71.5
72.5
73.5
74.5
Invariant Latitude



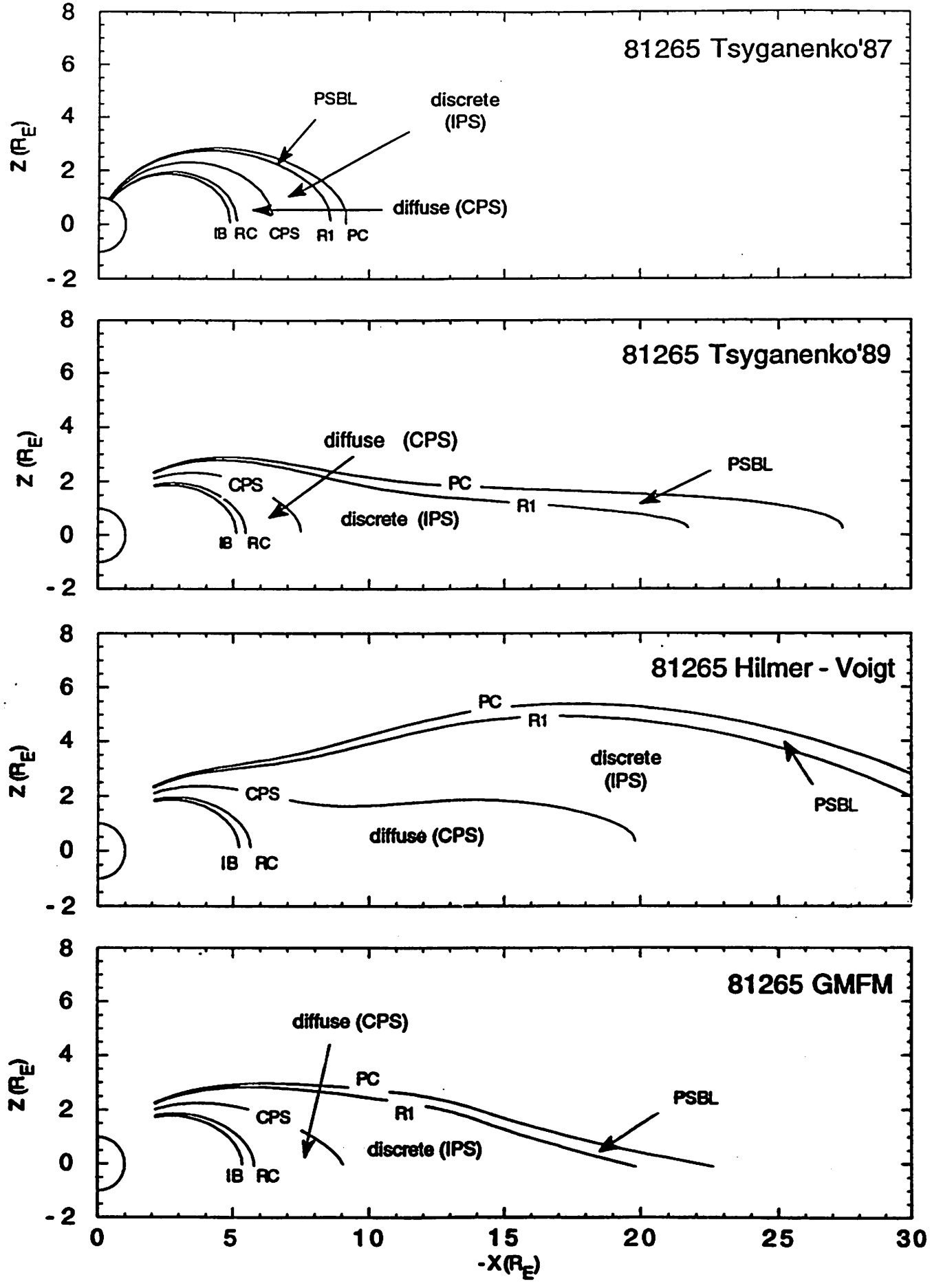
DE SUBSTORM IMAGES

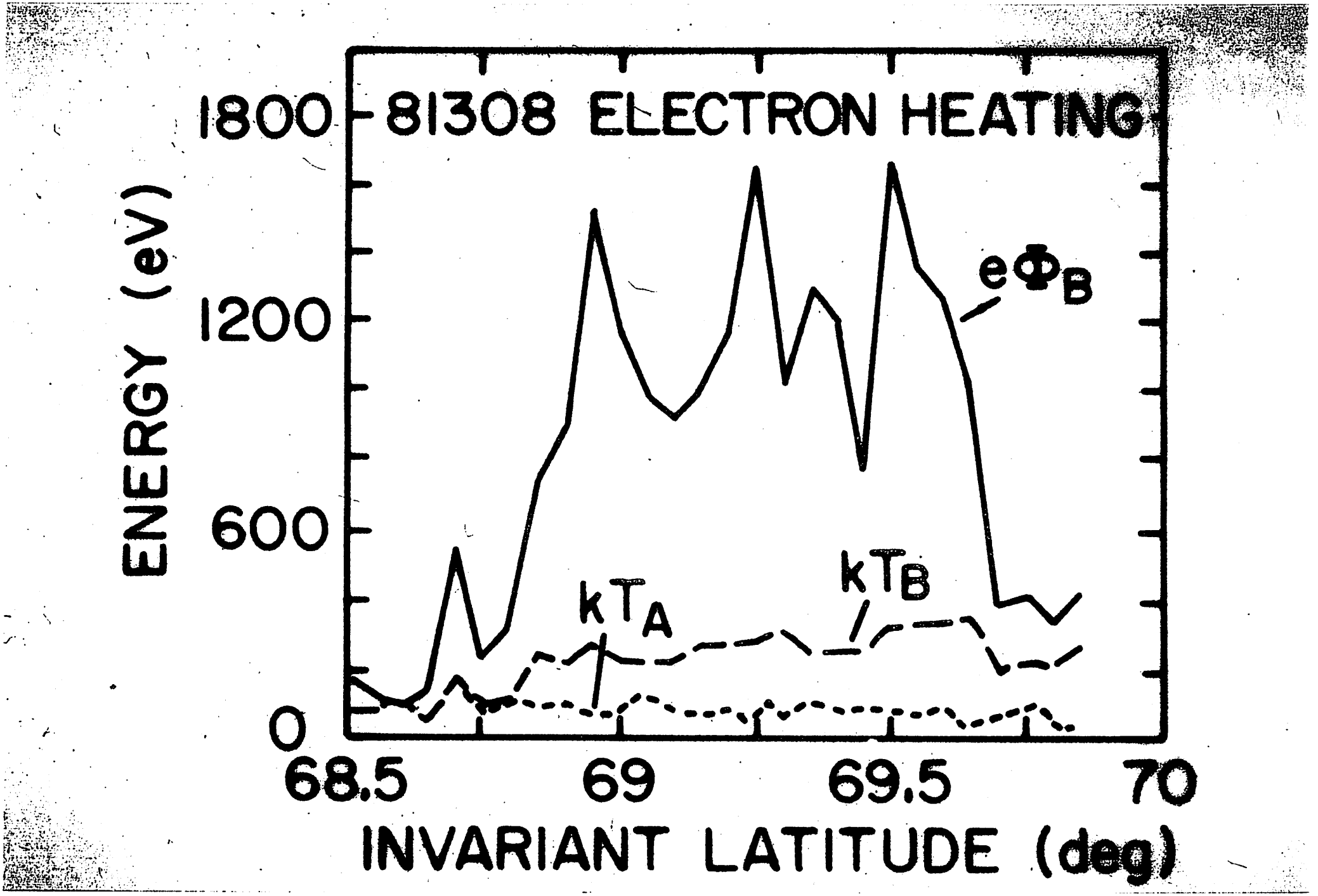
DYNAMICS EXPLORER
JOINT DATA PRESENTATION

YR/DAY: 81/265



SIMF


81265 Tsyganenko'87
PSBL
discrete
(IPS)
diffuse (CPS)
IB RC CPS R1 PC
81265 Tsyganenko'89
diffuse (CPS)
PSBL
CPS
PC
R1
discrete (IPS)
IB RC
81265 Hilmer - Voigt
PC
R1
discrete
(IPS)
CPS
PSBL
diffuse (CPS)
IB RC
81265 GMFM
diffuse (CPS)
PC
PSBL
CPS
R1
discrete (IPS)
IB RC
Z (R_E)
-X(R_E)
8
6
4
2
0
-2
0
5
10
15
20
25
30

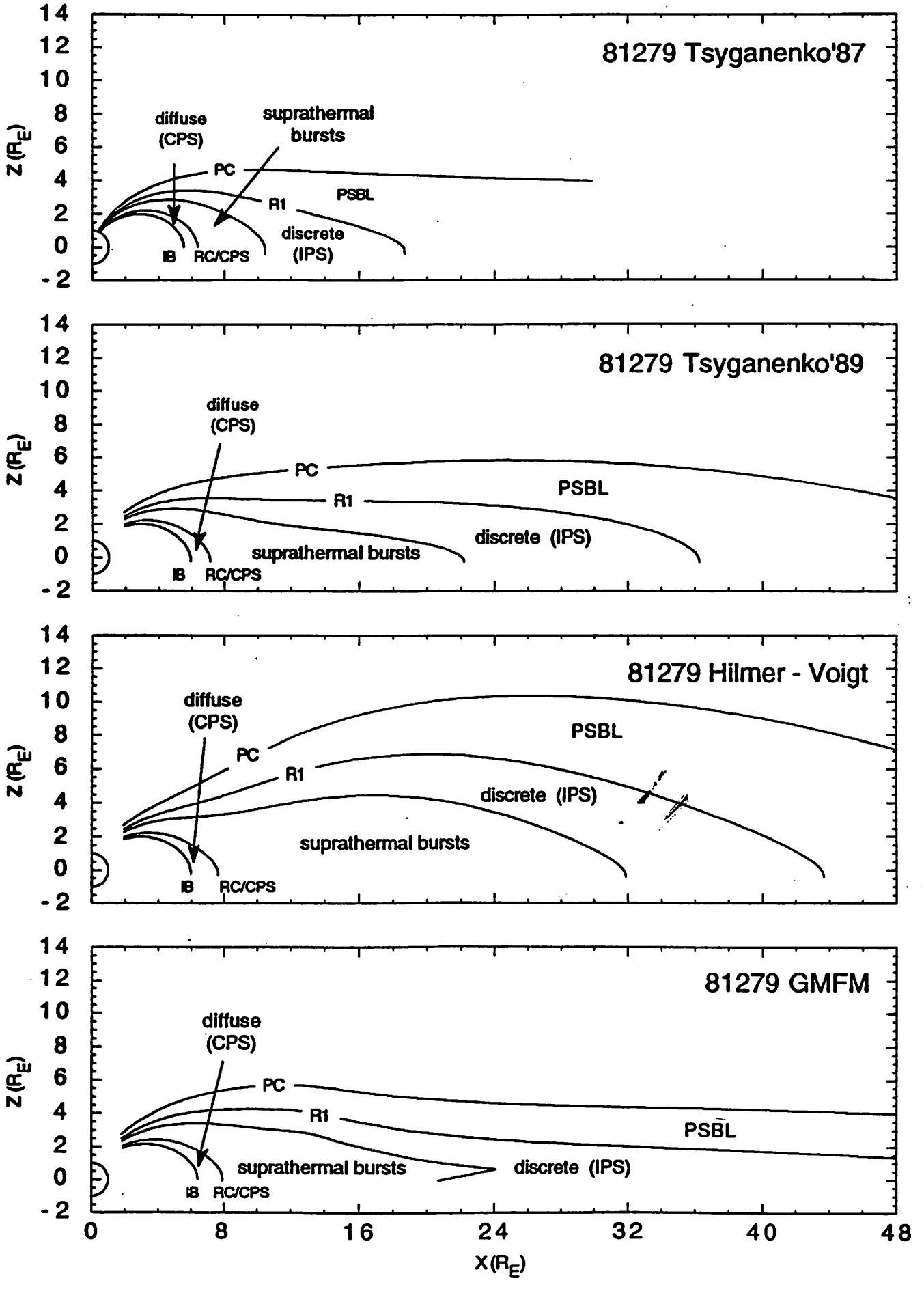

81308 ELECTRON HEATING
1800
1200
600
0
ENERGY (eV)
eΦB
kTA
kTB
68.5
69
69.5
70
INVARIANT LATITUDE (deg)

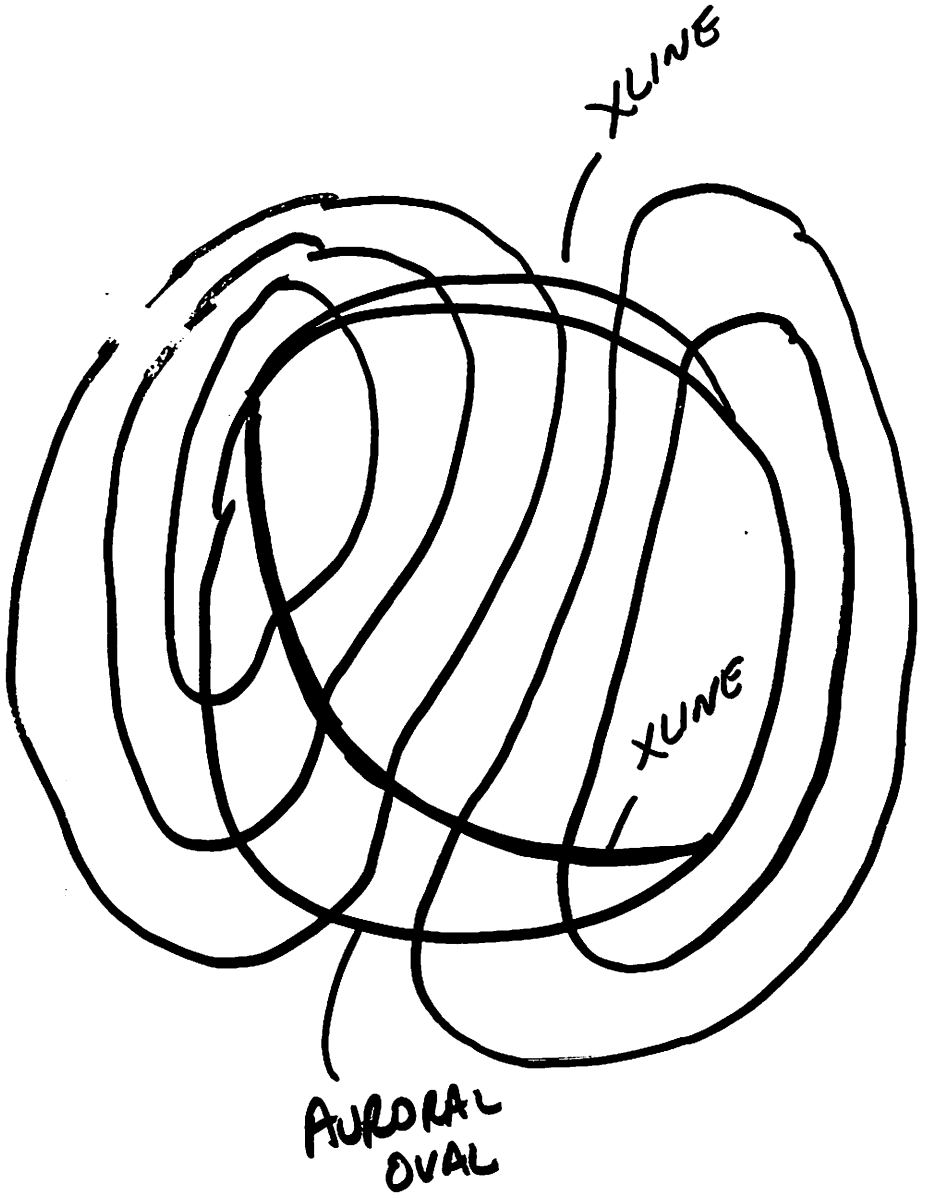
Low Latitude Aurora

Related to noise in Equator - P.a. Scattering (CRRES, Johnstone)

"Suprathermal Bursts" may be spatial as well as temporal

SIMF


81279 Tsyganenko'87
diffuse (CPS)
suprathermal bursts
PC
R1
PSBL
discrete (IPS)
IB
RC/CPS
81279 Tsyganenko'89
diffuse (CPS)
PC
PSBL
R1
discrete (IPS)
suprathermal bursts
IB
RC/CPS
81279 Hilmer - Voigt
diffuse (CPS)
PC
PSBL
R1
discrete (IPS)
suprathermal bursts
IB
RC/CPS
81279 GMFM
diffuse (CPS)
PC
R1
PSBL
suprathermal bursts
discrete (IPS)
IB
RC/CPS
Z (R_E)
X (R_E)
14
12
10
8
6
4
2
0
-2
0
8
16
24
32
40
48


XLINE
XUNE
AURORAL
OVAL

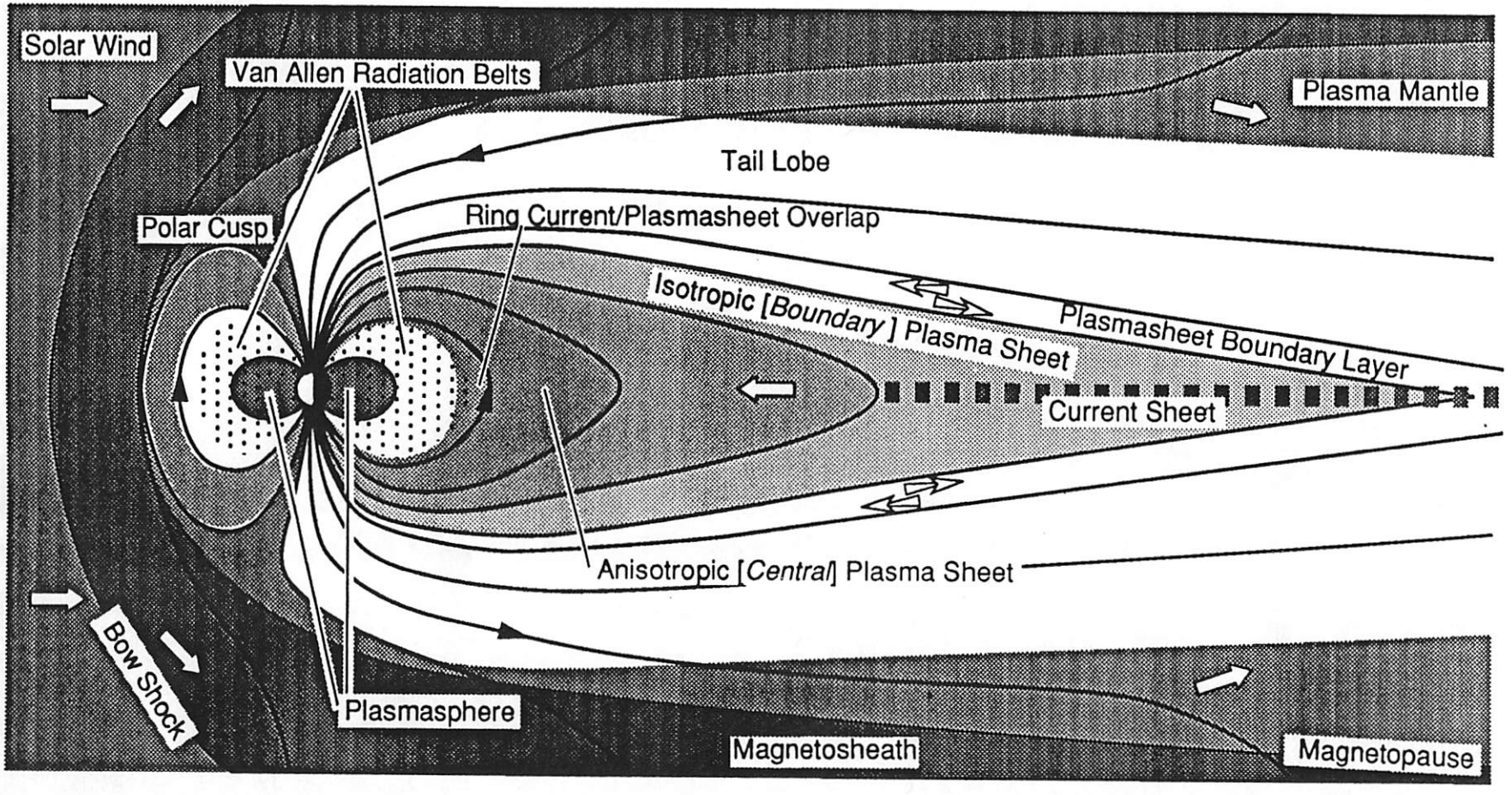
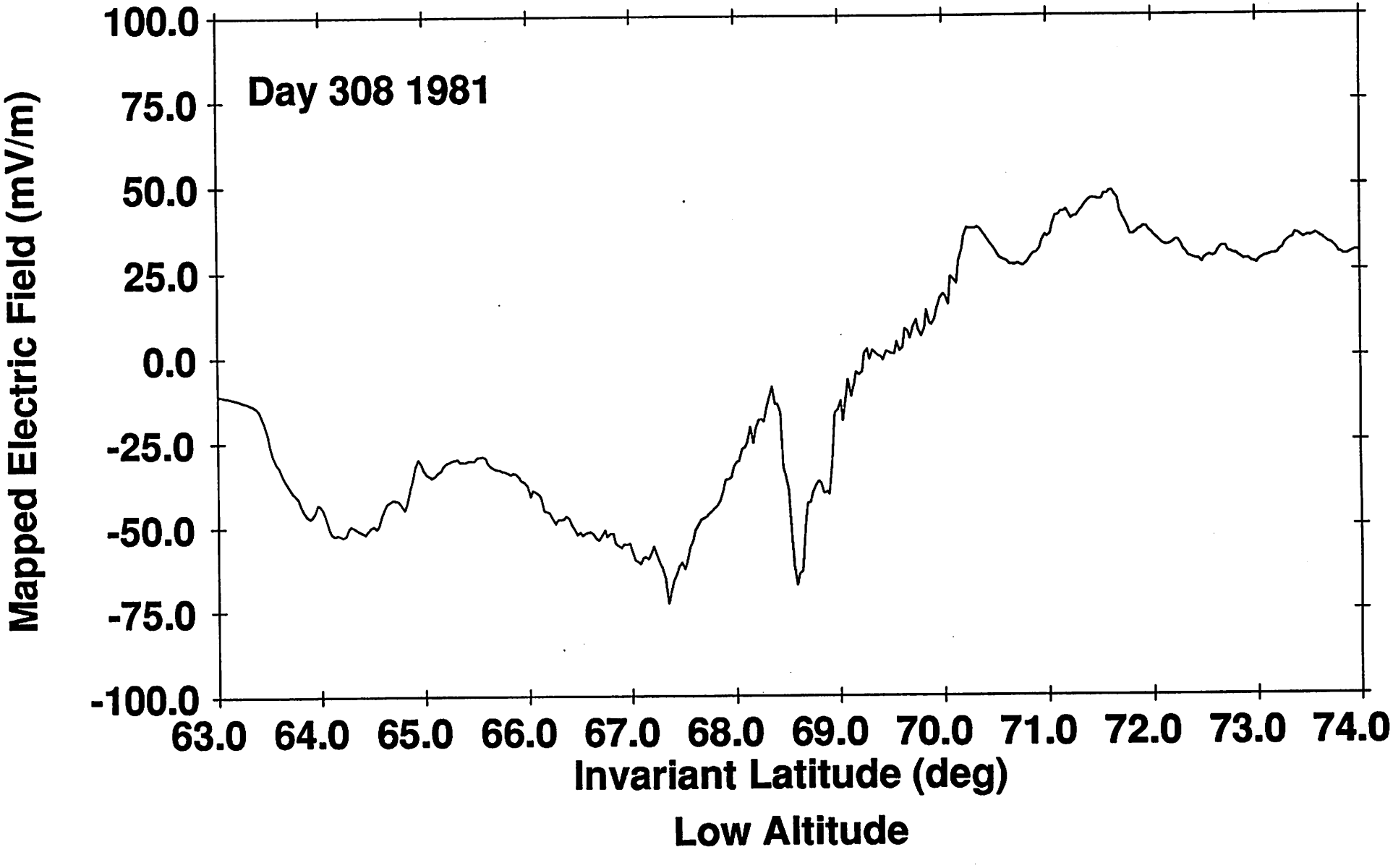

Solar Wind
Van Allen Radiation Belts
Plasma Mantle
Tail Lobe
Polar Cusp
Ring Current/Plasmasheet Overlap
Isotropic [Boundary] Plasma Sheet
Plasmasheet Boundary Layer
Current Sheet
Anisotropic [Central] Plasma Sheet
Bow Shock
Plasmasphere
Magnetosheath
Magnetopause

Figure 11


Day 308 1981
Mapped Electric Field (mV/m)
100.0
75.0
50.0
25.0
0.0
-25.0
-50.0
-75.0
-100.0
63.0
64.0
65.0
66.0
67.0
68.0
69.0
70.0
71.0
72.0
73.0
74.0
Invariant Latitude (deg)
Low Altitude