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Observations with University of Iowa Equipment on Mariner IV, November 1964--February 1965* (Preliminary Report)

by

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1. Scientific Objectives

(a) Detection and exploratory survey of intensity, composition, and distribution of magnetically-trapped charged-particles (radiation belts) around the planet Mars.

(b) Study of the occurrence of energetic particles in interplanetary space (with special reference to low-energy solar cosmic ray events): identification of such particles, and measurement of their absolute intensities, their approximate energy spectra and their angular distributions with respect to the probe-sun line, all as a function of time throughout the flight. Comparative analysis will be made with observations by similar Iowa equipment on earth satellites Injun IV and OGO-I.

2. Interpretative Areas

(a) Vector magnetic moment (magnitude and orientation of Mars.

(b) Mechanics of a radiation belt on a planet of quite different properties than those of the earth and at a heliocentric distance 1.5 times as great as that of the earth.

(c) Further studies of the emission of charged particles from the sun and correlation with optical and radio observations of the sun (the latter by ground observatories).

(d) Study of the propagation conditions for charged particles in interplanetary space (magnetic fields, diffusion mechanisms, and energy loss mechanisms).

3. <u>Apparatus</u> (See Figure 1)

(a) <u>Geiger-Mueller Tubes A, B, and C</u>

The basic detectors are Geiger-Mueller tubes of end-on, thin mica window type (EON 6213), arranged as follows:

Detector	Conical Field of View (Full Angle)	Angle of Axis to Probe-Sun Line	Directional Geometric Factor	Particles to Which Sensitive
			cm^2 sterad	
A	60°	135°	0.044 ± 0.005	Electrons, $E_e > 40$ keV Protons, $E_p > 0.5$ MeV
B	60°	70°	0.055 ± 0.005	Same as A
C	60°	70°	0.050 ± 0.005	Electrons, $E_e > 150$ keV $E_p > 3.1$ MeV (added foil on C detector)

Omnidirectional geometric factor about 0.15 cm^2.

Side Shielding: Approx. range of 50 MeV protons.

Dynamic Range: From galactic cosmic ray background of ~ 0.65 counts/sec to 10^7 counts/sec.

(b) Thin (35 microns) Surface Barrier Solid State Detector with Two Discrimination Levels D_1 and D_2 (Figure 1)

The detector's collimator is of conical form with a full angle of 60°. Its axis is parallel to the axes of detectors B and C, at an angle of 70° to the probe-sun line (the "fixed", stabilized axis of the spacecraft). The directional geometric factor is 0.065 ± 0.003 cm^2 sterad. The experimentally calibrated sensitivity to protons is as follows:

D_1: $0.50 \leq E_p \leq 11$ MeV

D_2: $0.88 \leq E_p \leq 4.0$ MeV.

Both channels are quite insensitive to electrons of any energy. The nominal side shielding corresponds to the range of ~ 50 MeV protons. The detector is equipped with an Am^{241} source of alpha particles which gives fixed background rates of approximately 0.07 and 0.06 counts/sec on D_1 and D_2, respectively. The dynamic range extends up to ~ 10^6 counts/sec by use of the laboratory calibration curves.

(c) Observational Cycle

The Iowa detectors are part of a sequence of eight commutated data channels. The duty cycle is as follows:

A, C, D_1, and D_2 accumulate counts in turn on a shift register (whose contents are subsequently read out and transmitted over the spacecraft telemetry system to the earth) 12.5% of the time each and B, 25% of the time. The accumulation interval per sample is 11.25 seconds for each segment of the commutator at the spacecraft bit rate of $33\frac{1}{3}$ bits/sec and 45 seconds at $8\frac{1}{3}$ bits/sec.

(d) Remarks

The G.M. detectors are similar to the one in the Iowa experiment in Mariner II which operated properly for over four months in interplanetary flight and yielded valuable data on energetic particles in interplanetary space [J. A. Van Allen and L. A. Frank, "The Iowa Radiation Experiment" (on Mariner II), Science, Vol. 138, No. 3545, pp. 1097-1098 (December 7, 1962)] and gave upper limit information on the existence of a radiation belt of the planet Venus and on its magnetic moment [L. A. Frank, J. A. Van Allen, and H. K. Hills, "Mariner II: Preliminary Reports on Measurements of Venus--Charged Particles", Science, Vol. 139, No. 3558, pp. 905-907 (March 8, 1963)].

4. Passage Through the Earth's Magnetosphere

During traversal of the earth's magnetosphere on 28 November 1964, a comprehensive body of data was obtained by detectors A, B, C, D_1, and D_2 on both electrons and protons. Results are plotted in Figures 2, 3, and 4. Special interest attaches to the nature of the electron distribution in the outer fringes of the magnetosphere at sun-earth-probe angles of about 112° (on the dawn side of the earth). The outer boundary of the transition region was found to be at 23 R_E (earth radii geocentric distance) and there was a single detached spike of low energy electrons at 25.7 R_E. Thereafter, no influence of the earth was evident. The Fredricksburg magnetic A index during this period was 6 (relatively quiet). A detailed study of both the electron and proton data is in progress.

5. <u>General Interplanetary Conditions</u>

Since 28 November 1964 all detectors have been operated on a substantially continuous basis. The daily average counting rates of detectors A, B, and C are shown in Figure 5. By comparison with the corresponding data from similar equipment on Mariner II (1 September 1962 to 30 December 1962), as reported in previously cited references, there is a marked reduction in the abundance of low energy particles in interplanetary space, though a general qualitative similarity in the temporal variations. The overall reduction is presumably associated with the reduced solar activity during tate 1964--early 1965 period.

6. Solar Cosmic Ray Event Beginning on 8 January 1965

The first significant interplanetary "event" began on 8 January and extended through 12 January 1965. A comparative plot of the data from detectors A, B, C, D_1, and D_2 is shown on Figure 6. The particles responsible for the "event" are conclusively identified as protons (or possibly alpha particles) and not electrons. The maximum directional intensities of 4.3 ± 0.3 on detector D_1 and 1.0 ± 0.15 $(cm^2 \text{ sec sterad})^{-1}$ on detector D_2 occurred at 18:00 UT on 9 January. Generally confirmatory, though less clear, results were obtained by detectors A, B, and C. The low background and the specific properties of the solid state detector are especially advantageous in the study of solar cosmic ray events [cf., J. A. Van Allen, L. A. Frank, and D. Venkatesan, "Small Solar Cosmic-Ray Events Observed with Mariner II", Trans., Amer. Geophysical Union, 45, 80, 1964]. No solar activity has yet been identified with this event.

7. Search for the Earth's Magnetospheric Wake at 3020 R_E

On 28 January 1965, the earth was at inferior conjunction with the spacecraft. The spacecraft was at an antisolar distance of 19,233,000 km (3020 R_E) and was 50 R_E above the sun-earth line at the time of the conjunction.

The data from all detectors have been searched for a possible effect of the magnetospheric wake during a 17 day period centered on the time of conjunction. Plots of the counting rates of the sensitive electron detectors A and B and of pertinent orbital data are given in Figure 7. The quantitative sensitivity is as follows: During a one day period approximately 12,500 counts are accumulated on detector B. The daily mean counting rate is about 0.58 counts/sec with a statistical accuracy of 1%. Hence, an added counting rate of say 0.04 counts/sec for a full day's period would be clearly detectable. This rate corresponds to a directional intensity of ~ 0.8 electron ($E_e > 40$ keV) $(\mathrm{cm}^2\ \mathrm{sec\ sterad})^{-1}$. This threshold intensity is about 4 orders of magnitude less than the intensities commonly seen in the earth's magnetospheric wake at radial distances up to 30 R_E.

No effect whatever was detected.

(The Fredricksburg magnetic A index was 1 to 4 during most of the conjunction period and had its highest value of 20 on 22 January.)

8. Solar Cosmic Ray Event Beginning on 5 February 1965

The principal activity which has been observed with the Iowa equipment up to the date of writing (22 February 1965) is the solar cosmic ray event which began on 5 February and was still detectable on 13 February (latest data available). The onset of the event was at 18:40 ± ten minutes on 5 February. The data from detectors A, B, C, D_1, and D_2 are shown on Figure 8. No detailed study of the spectrum and angular distribution as a function of time has been made yet, but it is immediately clear that the spectrum was much "harder" (higher proportion of energetic particles) during the early few hours of the event than it was later. The event is a complex one. The maximum omnidirectional intensity, J_o ($E_p >$ 50 MeV) $\approx$ 220 $(cm^2 \text{ sec})^{-1}$, occurred at about 22:00 UT on 5 February. There were several relative maxima in the directional intensity of $0.5 \leq E_p \leq 11$ MeV protons, as shown on Figure 8. The greatest value was ~ 130 $(cm^2 \text{ sec sterad})^{-1}$ at 09:00 on 7 February.

This event is worthy of a substantial study, including the correlation with solar and geophysical data. Injun IV data are also available on the particle intensities near the earth and especially over the polar caps during this event.

It may be of significance that the February event followed the January event by about 27 days. There was substantial solar and geophysical activity during the February event.

9. The Mars Encounter

The Mars encounter in mid-July continues to be a primary objective of the Iowa study with Mariner IV. In preparation for this encounter a family of "radiation signatures" have been computed for a variety of hypothetical Martian radiation belts and orientations of the magnetic moment of the planet.

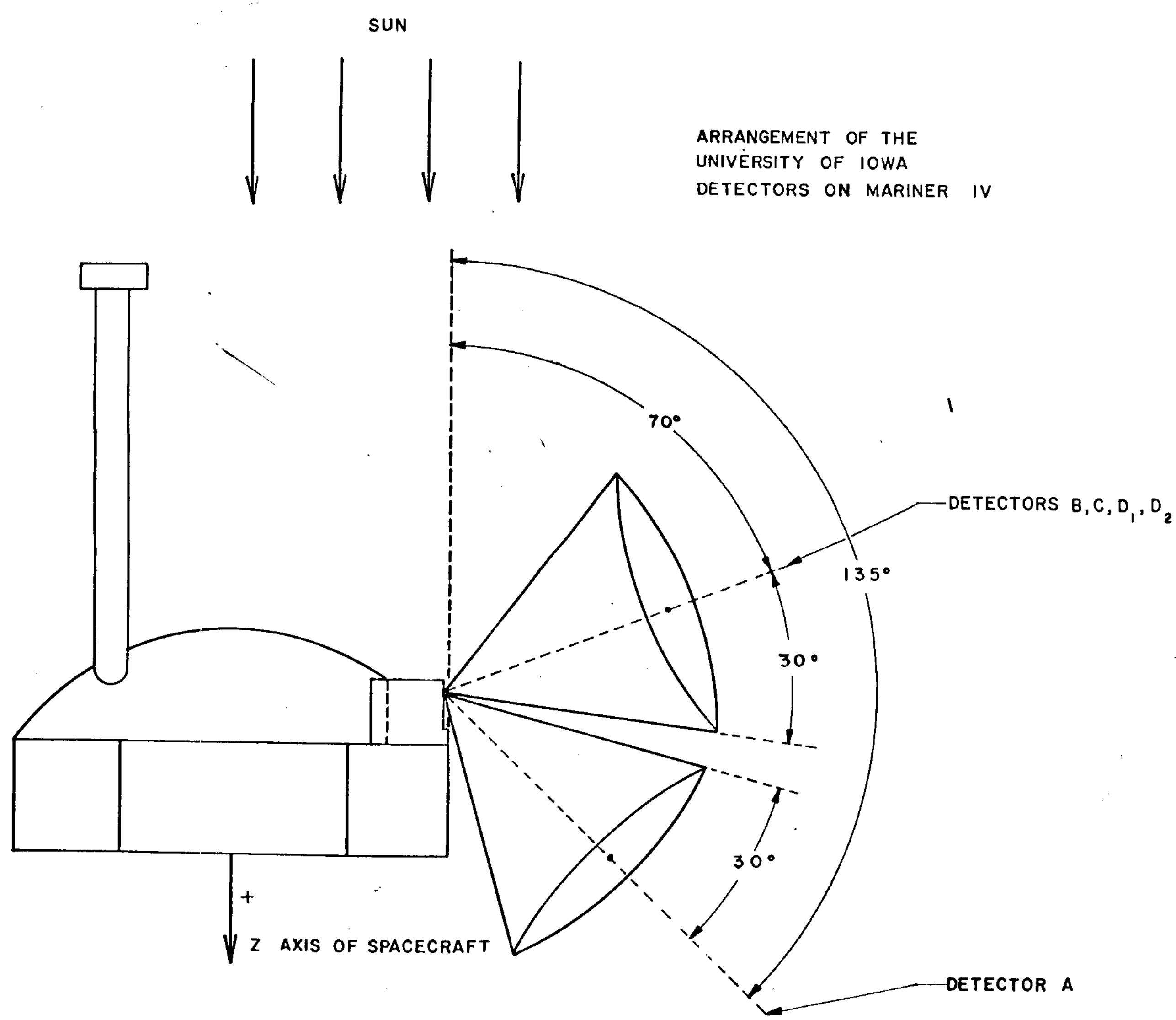
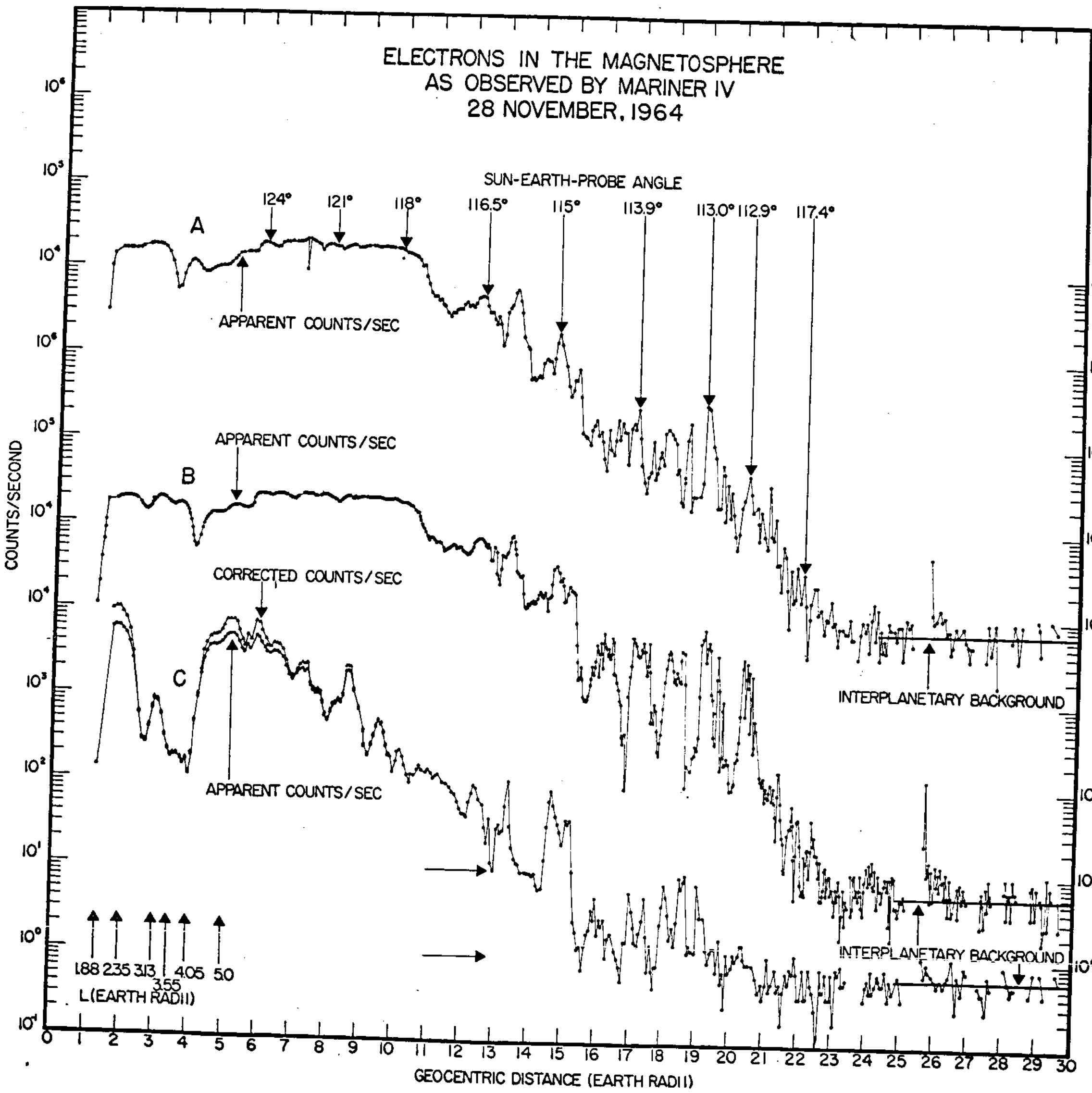

SUN
ARRANGEMENT OF THE
UNIVERSITY OF IOWA
DETECTORS ON MARINER IV
70°
135°
30°
30°
DETECTORS B, C, D1, D2
DETECTOR A
+
Z AXIS OF SPACECRAFT

FIGURE 1



ELECTRONS IN THE MAGNETOSPHERE
AS OBSERVED BY MARINER IV
28 NOVEMBER, 1964
SUN-EARTH-PROBE ANGLE
124°
121°
118°
116.5°
115°
113.9°
113.0°
112.9°
117.4°
A
APPARENT COUNTS/SEC
B
APPARENT COUNTS/SEC
CORRECTED COUNTS/SEC
C
APPARENT COUNTS/SEC
INTERPLANETARY BACKGROUND
INTERPLANETARY BACKGROUND
1.88 2.35 3.13 3.55 4.05 5.0
L (EARTH RADII)
COUNTS/SECOND
GEOCENTRIC DISTANCE (EARTH RADII)

FIGURE 2

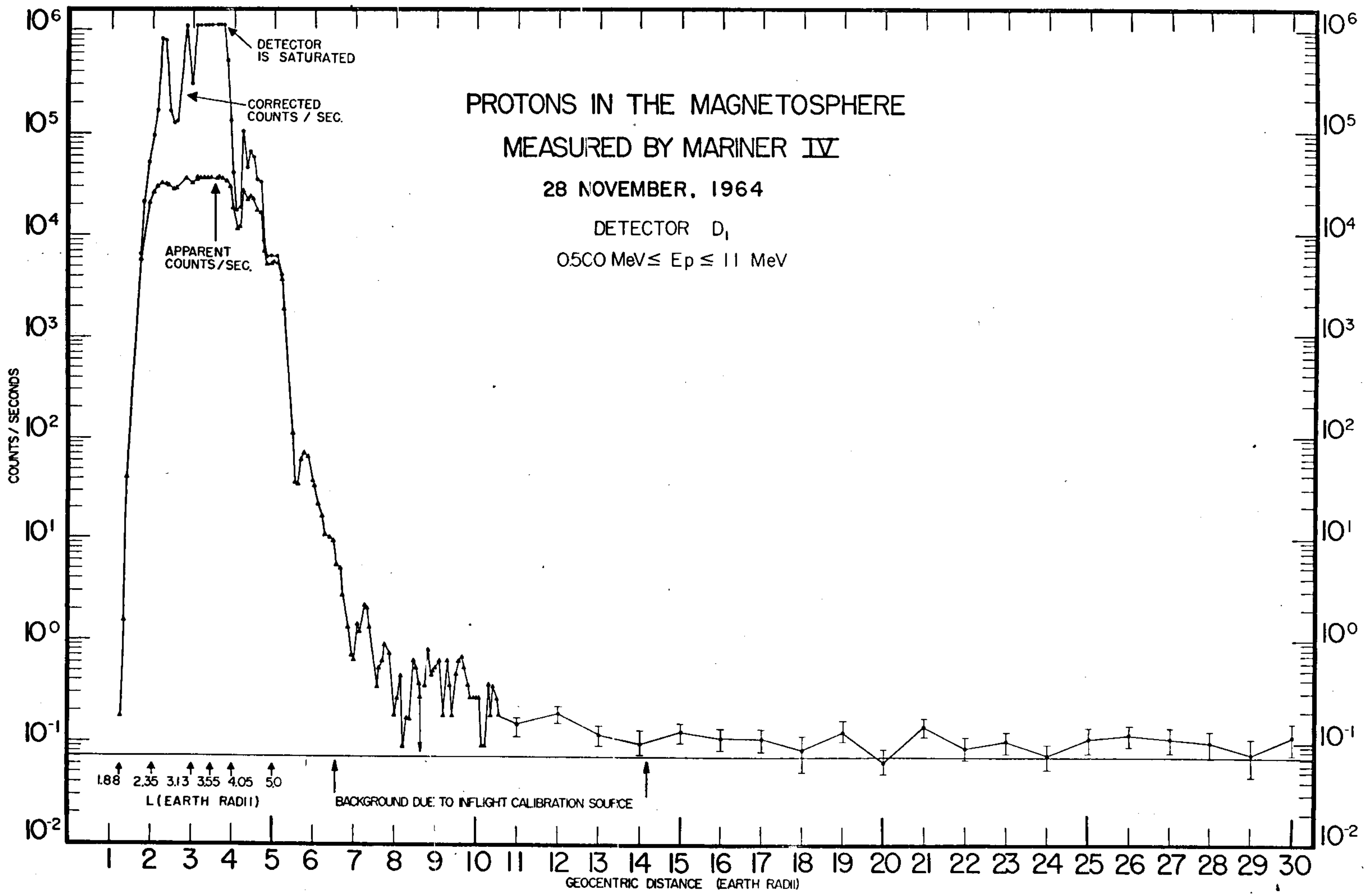
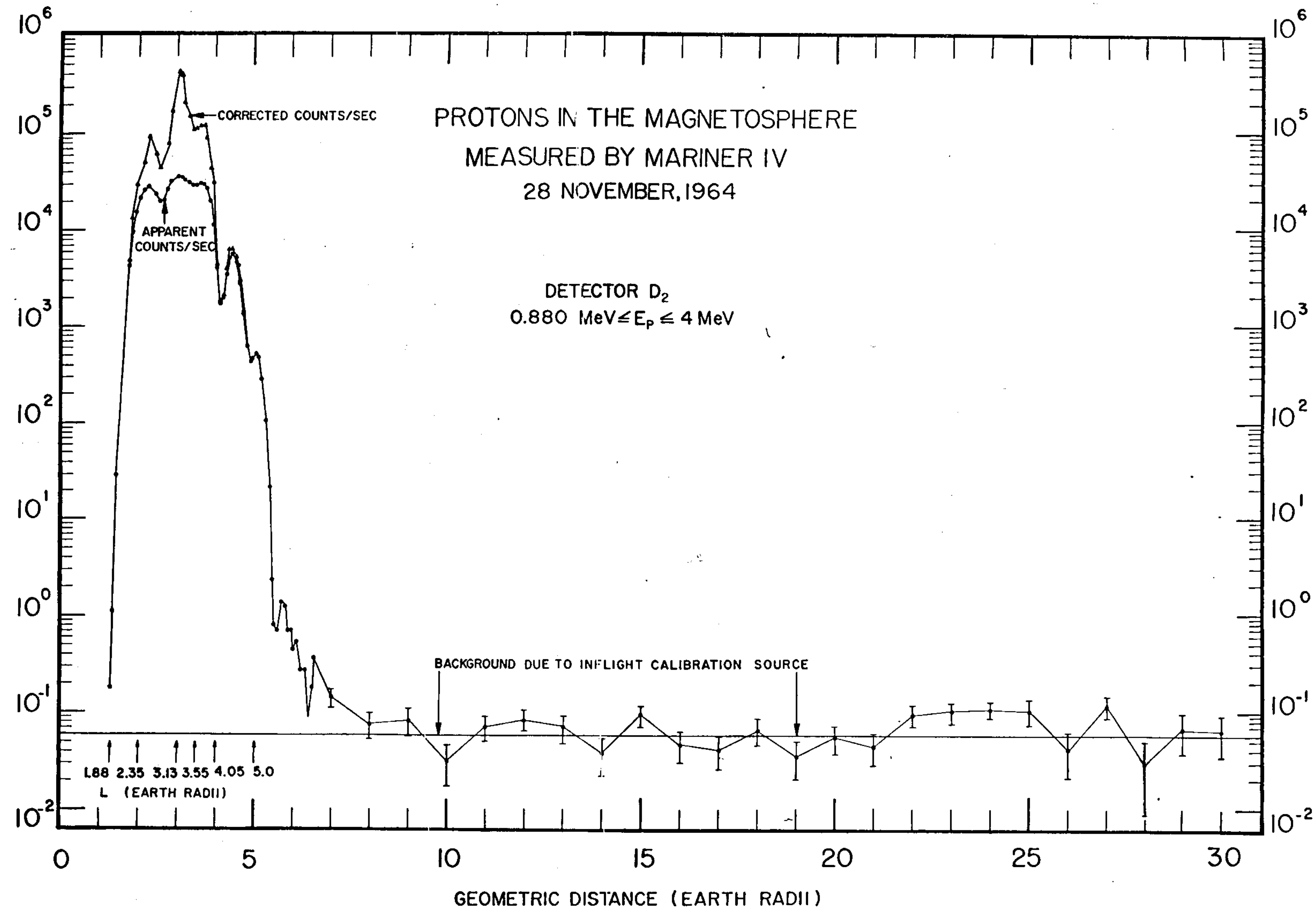

PROTONS IN THE MAGNETOSPHERE
MEASURED BY MARINER IV
28 NOVEMBER, 1964
DETECTOR D1
0.5CO MeV ≤ Ep ≤ 11 MeV
DETECTOR IS SATURATED
CORRECTED COUNTS / SEC.
APPARENT COUNTS/SEC.
COUNTS / SECONDS
1.88 2.35 3.13 3.55 4.05 5.0
L (EARTH RADII)
BACKGROUND DUE TO INFLIGHT CALIBRATION SOURCE
GEOCENTRIC DISTANCE (EARTH RADII)

FIGURE 3



PROTONS IN THE MAGNETOSPHERE
MEASURED BY MARINER IV
28 NOVEMBER, 1964
DETECTOR D_2
0.880 MeV $\leq E_p \leq$ 4 MeV
CORRECTED COUNTS/SEC
APPARENT COUNTS/SEC
BACKGROUND DUE TO INFLIGHT CALIBRATION SOURCE
1.88 2.35 3.13 3.55 4.05 5.0
L (EARTH RADII)
GEOMETRIC DISTANCE (EARTH RADII)

FIGURE 4

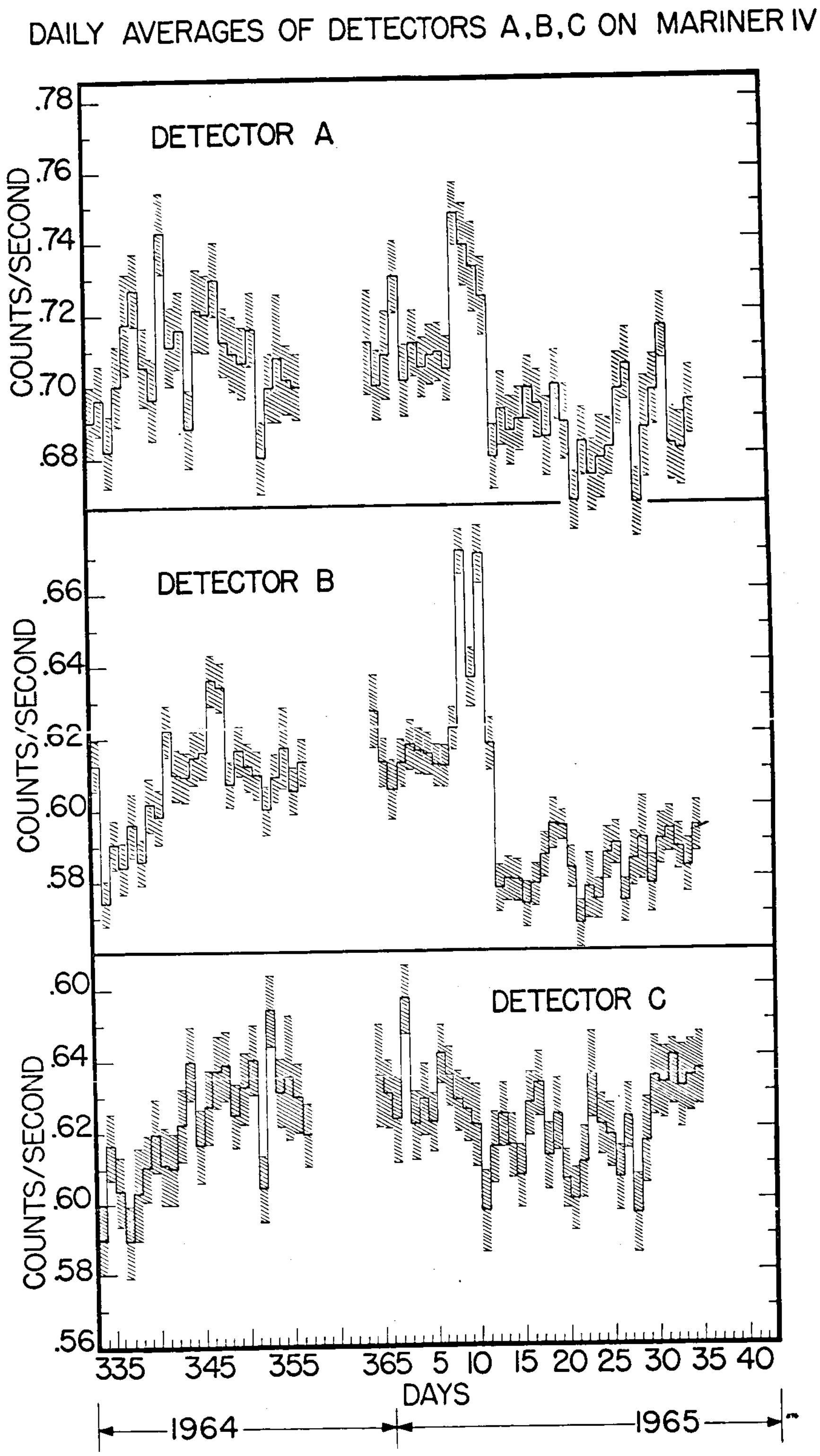
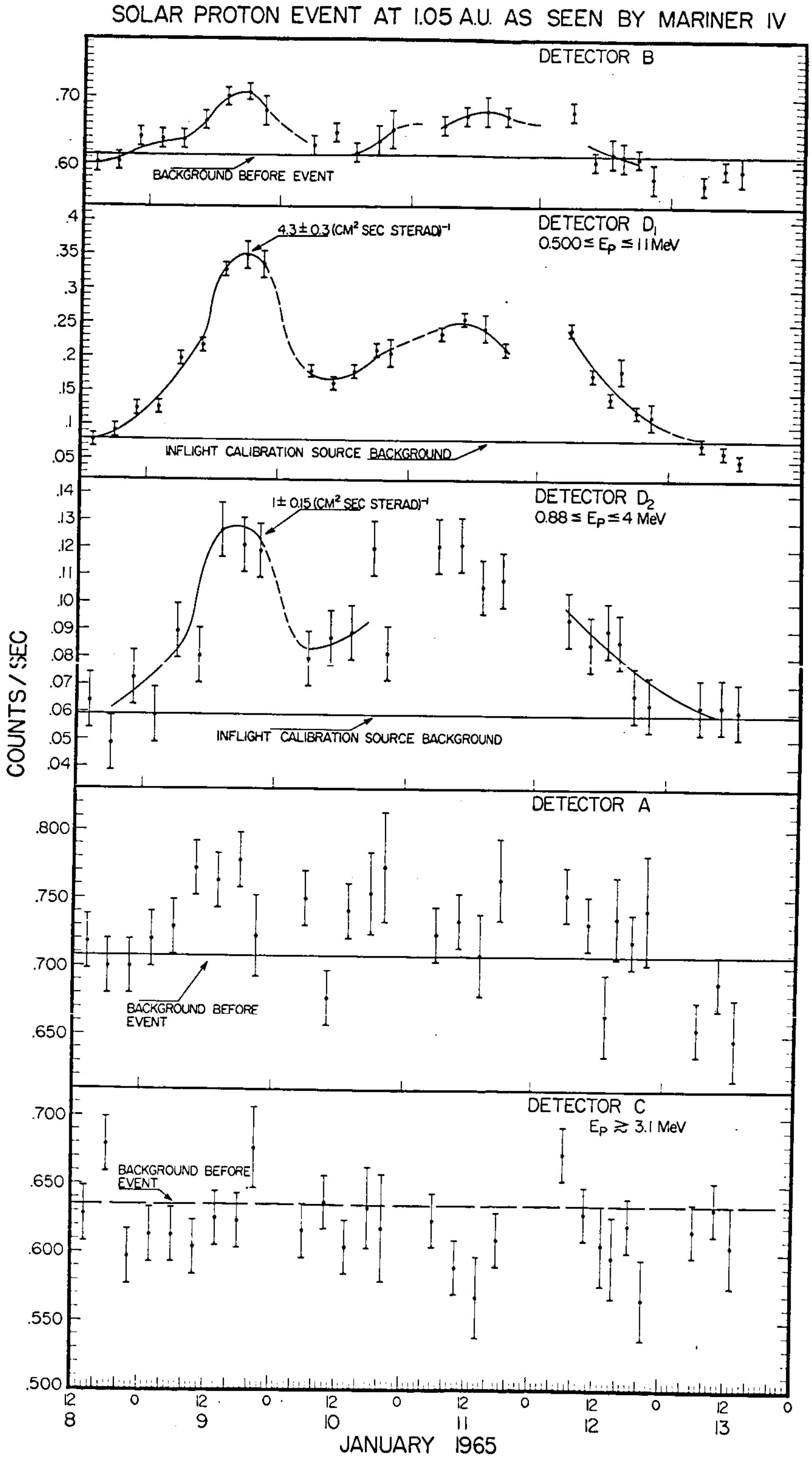

DAILY AVERAGES OF DETECTORS A,B,C ON MARINER IV
DETECTOR A
DETECTOR B
DETECTOR C
COUNTS/SECOND
.78
.76
.74
.72
.70
.68
.66
.64
.62
.60
.58
.56
335 345 355 365 5 10 15 20 25 30 35 40
DAYS
1964
1965

FIGURE 5



SOLAR PROTON EVENT AT 1.05 A.U. AS SEEN BY MARINER IV
DETECTOR B
BACKGROUND BEFORE EVENT
DETECTOR D1
0.500 ≤ Ep ≤ 11 MeV
4.3 ± 0.3 (CM² SEC STERAD)⁻¹
INFLIGHT CALIBRATION SOURCE BACKGROUND
DETECTOR D2
0.88 ≤ Ep ≤ 4 MeV
1 ± 0.15 (CM² SEC STERAD)⁻¹
INFLIGHT CALIBRATION SOURCE BACKGROUND
COUNTS / SEC
DETECTOR A
BACKGROUND BEFORE EVENT
DETECTOR C
Ep ≳ 3.1 MeV
BACKGROUND BEFORE EVENT
JANUARY 1965

FIGURE 6

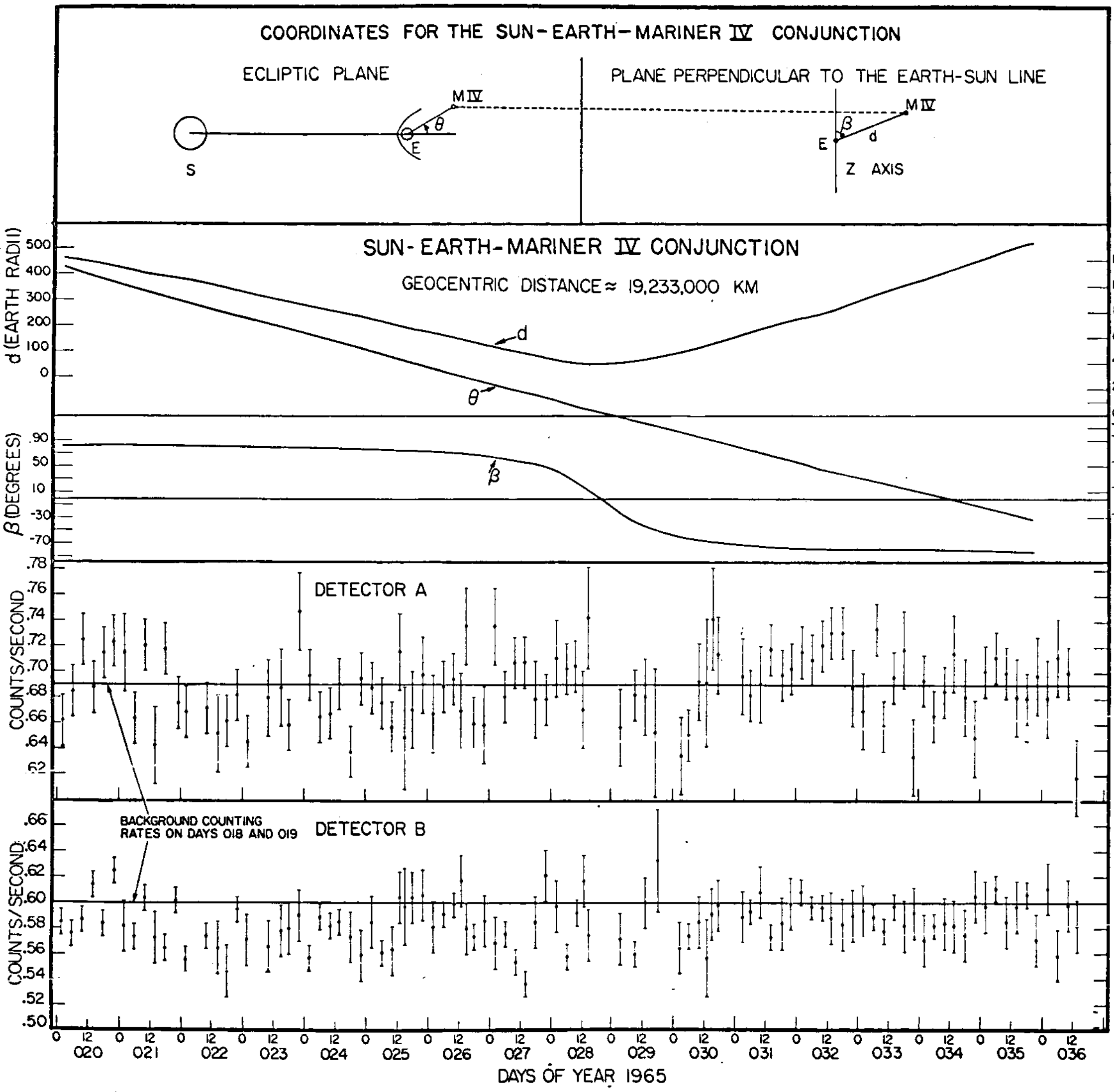

COORDINATES FOR THE SUN-EARTH-MARINER IV CONJUNCTION
ECLIPTIC PLANE
PLANE PERPENDICULAR TO THE EARTH-SUN LINE
S
E
M IV
θ
β
d
Z AXIS
SUN-EARTH-MARINER IV CONJUNCTION
GEOCENTRIC DISTANCE ≈ 19,233,000 KM
d (EARTH RADII)
θ (DEGREES)
β (DEGREES)
DETECTOR A
DETECTOR B
BACKGROUND COUNTING RATES ON DAYS 018 AND 019
COUNTS/SECOND
DAYS OF YEAR 1965

FIGURE 1

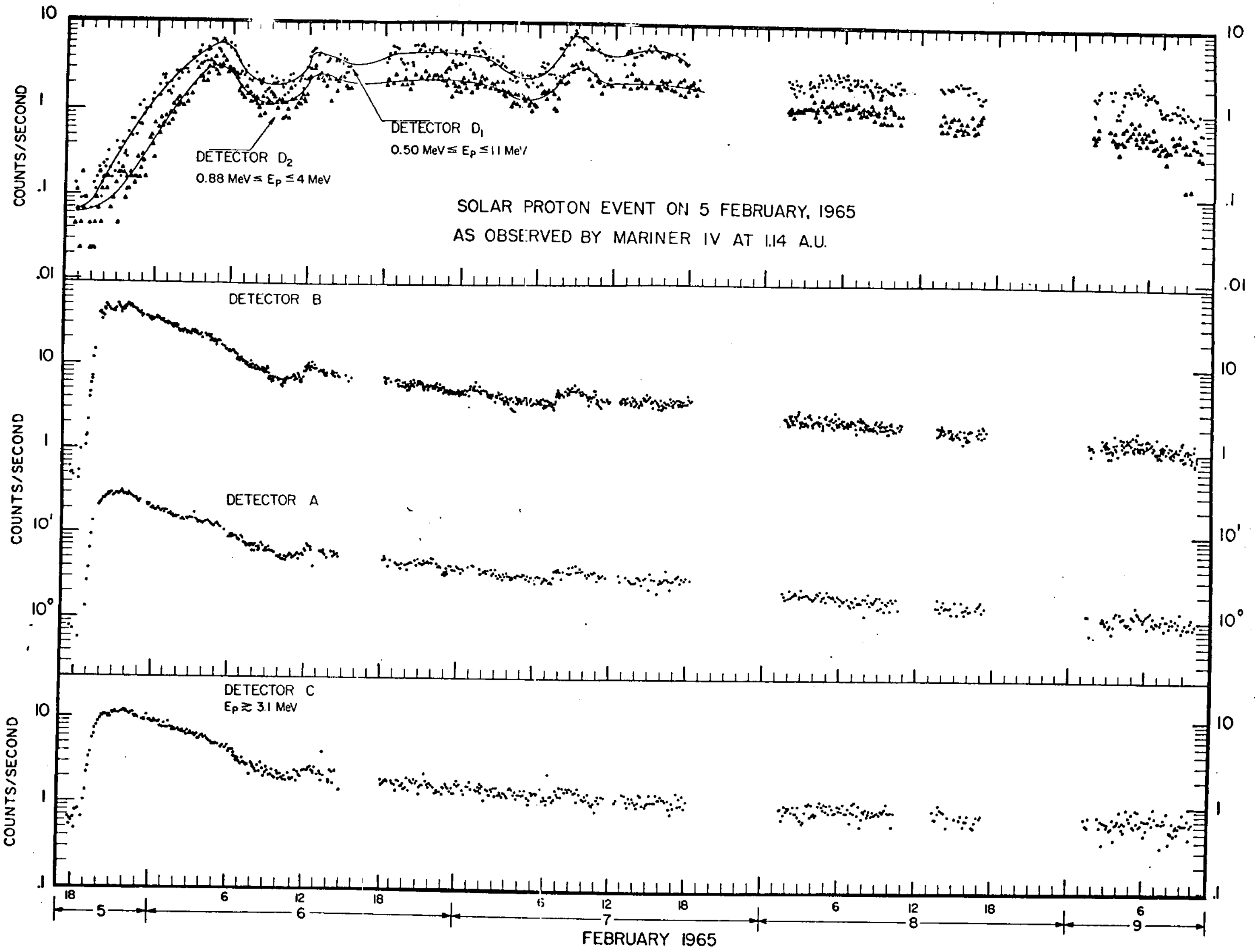

SOLAR PROTON EVENT ON 5 FEBRUARY, 1965
AS OBSERVED BY MARINER IV AT 1.14 A.U.
DETECTOR D_1
$0.50\ MeV \le E_p \le 11\ MeV$
DETECTOR D_2
$0.88\ MeV \le E_p \le 4\ MeV$
DETECTOR B
DETECTOR A
DETECTOR C
$E_p \gtrsim 3.1\ MeV$
COUNTS/SECOND
FEBRUARY 1965

FIGURE 8