Observations with University of Iowa Equipment
on Mariner IV--February, March, April, May 1965 (Preliminary)*

by

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1. Introduction

This report is an extension of the earlier research report U. of Iowa 65-5 of 22 February 1965, entitled "Observations with University of Iowa Equipment on Mariner IV, November 1964--February 1965 (Preliminary Report)" by J. A. Van Allen, S. M. Krimigis, and L. A. Frank. Reference should be made to that report for description of the scientific objectives and equipment and for a summary of earlier results. The present report shows measurements up to Day 125 (5 May) of 1965 and discusses the sensitivity of the apparatus for the detection and measurement of the magnetic moment of Mars.

2. Operation of Equipment, etc.

All four U. of Iowa detectors continue to function properly through the latest date (5 May) for which telemetry data (users' listings) have been received. The temperature of the package has declined gradually and in the expected manner from a flight maximum value of +29.4° C on Day 334 of 1964 to +12.2° C on Day 132 of 1965.

All data analysis up to the present has been done "by hand" from the JPL users' listings. Very helpful preliminary reports on the rolling motion of the spacecraft during
traversal of the magnetosphere have been received from
E. J. Smith of JPL and D. E. Jones of Brigham Young University.

Three oral, illustrated papers were presented at the
Mariner IV symposium of the American Geophysical Union meeting
in Washington, D. C. on 19 April 1965:

(P4) S. M. Krimigis and T. P. Armstrong -- "Observations of
Protons in the Magnetosphere with Mariner IV".

(P5) L. A. Frank, J. A. Van Allen, and H. K. Hills --
"Magnetospheric Electron Measurements with Mariner IV".

(P6) J. A. Van Allen -- "Interplanetary Particle Measurements
with Mariner IV".

and D. Schneiderman of JPL in briefing President Johnson, Vice
President Humphrey, and others on the progress of the Mariner IV
mission.

Two master data extract tapes have been received from
JPL: the first for Days 333-340 of 1964 and the second for
Days 340-347 of 1964. Both of these have been error-corrected
and listed on our IBM 7044/1401 and are satisfactory. Further
extract tapes are awaited.

3. Diffusion Analysis of
5-13 February 1965 Solar
Cosmic Ray Event

The principal solar cosmic ray event of the period
28 November 1964 to 5 May 1965 is the one previously reported
in U. of Iowa 65-5 during the period 5-13 February 1965.

Detailed analysis of the data from this period is being made in conjunction with data from our near-earth satellite Injun IV. Figure 1 shows an analytical plot of the intensity-time history for protons \( E_p > 55 \text{ MeV} \) derived from the corrected differences of counting rates of detectors B and Dₚ. The best-fit value of the parameter \( \beta \) is 0.9. A similar analysis of the data from detector C, with appropriate subtraction of the portion of the spectrum which can penetrate the window of detector C, yields \( \beta = 0.67 \). This mild discrepancy is not yet understood. The scheme of analysis is that of U. of Iowa 65-7 "An Interplanetary Diffusion Model for the Time Behavior of Intensity in a Solar Cosmic Ray Event" by S. M. Krimigis (1 April 1965) (in press, Journal of Geophysical Research).

4. **Weak Solar Cosmic Ray Event of 20 April 1965**

A weak proton event was found in data from the low energy channel D₁ of the solid state detector \( 0.50 < E_p < 11 \text{ MeV} \) on 20 April 1965 (Figure 2). The maximum directional intensity was \( 0.4 \pm 0.1 \left( \text{cm}^2 \text{ sec sr} \right)^{-1} \) at about 10:00 on 20 April and the duration was apparently less than 10 hours. This is an apparently valid event, though only slightly above the level of statistical significance. No measurable intensity occurred in
channel D$_2$ ($0.88 < E_p < 4$ MeV). The spacecraft was at a heliocentric radial distance of 1.39 A.U. and at a heliocentric angle of 24.5° "behind" the earth (i.e., clockwise as viewed from the north ecliptic pole). There is no clear association with any reported solar flare, though there was significant solar flare activity on 16 April and a peak of 48 in the daily mean Fredricksburg A-index occurred on 18 April. It is barely plausible that the detected particles were trapped in a slow-moving plasma cloud which reached the spacecraft at 1.39 A.U. two days later. No other events have been detected during the period 13 February--5 May 1965.

5. Summary of Solar Cosmic Ray Events 26 November 1964--5 May 1965

<table>
<thead>
<tr>
<th>Date</th>
<th>Day 1965</th>
<th>Heliocentric Radial Distance</th>
<th>Earth-Sun Probe Angle</th>
<th>Time Interval between Successive Onsets</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-12 January</td>
<td>9-12</td>
<td>1.055</td>
<td>+ 1.8°</td>
<td>---</td>
</tr>
<tr>
<td>5-13 February</td>
<td>36-44</td>
<td>1.140</td>
<td>- 1.3</td>
<td>27 days</td>
</tr>
<tr>
<td>20 April</td>
<td>110</td>
<td>1.389</td>
<td>- 24.5</td>
<td>74 (= 27 + 27 + 20)</td>
</tr>
</tbody>
</table>

As noted previously, there was a 27 day interval (1.0 synodic rotation period of the sun) between the first two of the above events. No recurrence was observed during two
subsequent rotations. The 20 April event occurred about 7 days early (or about 5 days early if corrected for the -24.5 earth-sun-probe angle) to be identified with a persistent 27 day cycle.

The time averaged intensity of solar cosmic rays during the period 28 November 1964 to 5 May 1965 is one to two orders of magnitude less than that during the Mariner II flight period, 1 September to 30 December 1962.

6. Long Term Rates of Detectors A, B, C, D1, and D2

With the exception of the "events" summarized in section 5, the rates of the solid state detector channels D1 and D2 have been indistinguishable from those due to the Am241 inflight calibration source, namely 0.071 and 0.059 (sec)-1, respectively.

In Figure 3 are shown the daily mean counting rates of the three Geiger tubes A, B, and C, omitting the high intensity of the early February event.

It appears that the rate of A has declined some 10% from Day 340 of 1964 to Day 125 of 1965 and that the rate of B has declined some 7% (though in a different way) but that the rate of C has remained constant.
The declines in the rates of A and B are much beyond that to be attributed to the observed cooling of the instrument on the basis of the preflight temperature tests (6 ± 6% over the temperature range +50° to -25° C). Hence these declines may be due to some subtle aging effect or they may be due to a real spatial and/or temporal change in astrophysical conditions, e.g., a slight decrease in the intensity of low energy electrons which can cause counts in A and B but not in the heavier-window tube C.

The counting rate trends will be followed with interest in future data; meanwhile they are noted as being present but not understood. The overall temporal change of galactic cosmic ray intensity at the earth as measured by the Deep River neutron monitor is in the opposite sense and about 2.5% over the same time period.

7. Sensitivity of U. of Iowa Equipment for Detecting the Magnetic Moment of Mars

The data from Mariner IV's traversal of the earth's magnetosphere provided a direct calibration of the sensitivities of the various instruments in detecting the presence of the earth's magnetosphere, and hence its magnetic moment. The outer fringe of the magnetospheric transition region was
traversed on the dawn side near the geomagnetic equator at a sun-earth-probe angle of about 112°. The proton detectors $D_1$ and $D_2$ showed no clear difference above background beyond 10.6 and 7.0 $R_E$ (earth radii), respectively, though there seemed to be a slight "afterglow" of augmented counting rate in $D_1$ which persisted for some hours. The rates of detectors $A$, $B$, and $C$ dropped to their interplanetary rates at 23, 23, and 21 $R_E$, respectively, but there was an apparently significant burst of electrons at 25 to 26 $R_E$ in detectors $A$ and $B$.

For the present purpose, 23 $R_E$ is adopted as the outer edge of the magnetosphere as detectable by $A$ or $B$ near the geomagnetic equator. The 3 hour range index $K_p$ was 1+ for 21:00 to 24:00 U.T. on 28 November and 0+ for 00:00 to 03:00 U.T. on 29 November. Hence the geomagnetic situation was "quiet".

The sensitivity of detectors $A$ and $B$ for detecting a Martian radiation belt may be assessed according to the physical similitude argument which we used originally in discussing the significance of the negative results of our Mariner II measurements in the vicinity of Venus [L. A. Frank, J. A. Van Allen, and H. K. Hills, "Mariner II: Preliminary Reports on Measurements on Venus--Charged Particles"].

Use is made of the diagrams prepared by H. R. Anderson [Private Communication, February 1965] for the "solar magnetospheric" coordinates in the vicinity of Mars on 14-15 July 1965. These diagrams are based on the predicted encounter ephemeris and assume that the magnetic moment of Mars is body-centered and has its axis parallel to the rotational axis of the planet.

We further assume
(a) [Cf. Science, 139, 905-907, 1963] "that the processes leading to the development of the radiation belts of Earth also occur in the magnetospheres of other magnetized planets and that the important processes scale in some continuous manner and not discontinuously with the magnitude of the magnetic moment of the planet in question."
(b) That the detectable outer fringe of the Martian magnetosphere has the same geometric shape as that of the earth.
(c) That the physical scaling law is
\[
\frac{r_M}{r_E} = \left( \frac{M_M}{M_E} \right)^{1/3} \left( \frac{S_E}{S_M} \right)^{1/6}
\]  
\text{(1)}

where \( \frac{M_M}{M_E} \) is the ratio of the magnetic moment of Mars to that of the earth and \( \frac{S_M}{S_E} \) is the ratio of the solar wind pressure at Mars to that at the earth. The average value of \( \frac{S_M}{S_E} \) is presumably 0.5. Hence we use the scaling law:

\[
\frac{r_M}{r_E} = 1.1 \left( \frac{M_M}{M_E} \right)^{1/3}
\]  
\text{(2)}

On the basis of a preliminary study it appears that the conditions for detection of a Martian radiation belt will be the most favorable about an hour after the time of closest approach and just before occultation. Thus, using the diagrams of Anderson, we find that at 02:05 U.T./15 July, \( R = 21,000 \text{ km, } \lambda = -36^\circ, \text{ } L = 30,000 \text{ km (a local minimum), and LOS-LOP = } -132^\circ \). Using equation (2) and the preceding body of assumptions, we estimate that a Martian magnetic moment as small as

\[
M_M \approx 0.002 \ M_E
\]
may be detected by the presence of low energy electrons. A somewhat more conservative estimate is

\[ M_M \approx 0.01 \ M_E. \]
SOLAR PROTON EVENT
OBSERVED BY MARINER IV AT 1.14 A.U.
ON FEB. 5, 1965
$t_0 = 1801 \text{ UT}$
$E_p \geq 55 \text{ MeV}$
SOLAR PROTON EVENT ON MARINER IV
AT 1.38 AU, ESP = 25°

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

MAX. FLUX = 0.4 ± 0.1 (CM$^2$/SEC-SR)$^{-1}$

BACKGROUND DUE TO INFLIGHT CALIBRATION SOURCE

$D_2$
$0.88 \leq E_p \leq 4$ MeV

06 12 18 06 12 18 06 12 18
APRIL 19, 1965 APRIL 20 APRIL 21

Figure 2