STUDY OF COSMIC RAY INTENSITY MEASURED BY MARINER II AND BY GROUND NEUTRON MONITORS DURING THE FORBUSH DECREASE OF SEPTEMBER 30, 1962

by

U. R. Rao

Southwest Center for Advanced Studies
P. O. Box 30365
Dallas, Texas 75230

A letter

To be submitted to

JOURNAL OF GEOPHYSICAL RESEARCH

ACKNOWLEDGEMENT - This research has been supported by the National Aeronautics and Space Administration undaer grant NsG-269-62.

STUDY OF COSMIC RAY INTENSITY MEASURED BY MARINER II AND BY GROUND NEUTRON MONITORS DURING THE FORBUSH DECREASE OF SEPTEMBER 30, 1962

by
U. R. Rao
Southwest Center for Advanced Studies
P. O. Box 30365, Dallas, Texas

The planetary probe Mariner II which covered a radial distance of about 0.25 AU on its journey to the orbit of Venus contained instruments to measure cosmic ray intensity as well as a plasma probe to measure the flux and velocity of solar wind. The cosmic ray itensity measurements were carried out by an argon-filled integrating ionization chamber, a halogen quenched, glass Geiger-Mueller counter tube with a matched stainless steel shield and a second G.M. counter with a beryllium shield. All the three cosmic ray instruments had approximately the same threshold energy of 10 mev for protons. The description of the experiment and some of the results of both the cosmic ray measurements (Neher and Anderson, 1964; Anderson, 1964) and the plasma probe experiment (Snyder, Neugebauer, and Rao, 1964) have been published elsewhere.

The probe yielded useful data almost continuously from August 29 through the end of December, 1962. During this period, there was only one distinct Forbush decrease, which occurred on 30 September, 1962 (Day 273), when Mariner II was approximately 0.1 AU from the earth and oriented almost (within 5^{o}) along the earth-sun line. In this note we examine the data from various instruments on Mariner II and the data from ground neutron monitors during the above-mentioned Forbush decrease.

Figure 1 shows the time series of the hourly mean cosmic ray intensities measured by Mariner II ion chamber; the hourly mean neutron intensities at Deep River, Mt. Wellington, and Mawson; the hourly mean solar wind velocity, and the three hourly Kp indices for the period 29 September (Day 272) through 5 October, 1962 (Day 278). The onset of the Forbush decrease occurs at 0830 U.T. as seen by the ion chamber intensity on Mariner II. Due to the small decreases ($\sim$3.0%) and large statistical errors in the neutron monitor intensities, it is not possible to identify clearly the anisotropies and the onset time differences at the ground. However, the correlation between the changes in neutron intensity at ground stations such as Deep River and the changes in ion chamber intensity on Mariner II is very high (0.91 ± 0.02). The ratio of Forbush decrease observed by the ion chamber to that observed by the neutron monitor, obtained from the regression line is 3.88 ± 0.01. Since Mariner II is almost along the earth-sun line and is less than 0.1 AU from the earth, this ratio is truly representative of the ratio of primary intensity changes outside the earth's atmosphere to the changes of neutron intensity at Deep River. Lack of observation of any spatial gradient of intensity (Anderson, 1964) during the days 239 through 292 lends strong support to the above statement.

From balloon observations during the same period (1959-1963), Nerurkar and Webber (1964) have shown that the slope of the long term and short term variations observed at balloon altitudes over Minneapolis to the corresponding neutron intensity variations at Deep River is very much dependent on the level of observed intensity; the slope being larger when the level of intensity at Deep River is higher, indicating the presence of additional low energy radiation. For the level of neutron intensity at Deep River prevailing prior to the Forbush decrease of 30 September, 1962, a slope of 3.75 is derived for the long term variation, using the Nerurkar and Webber results. Comparing this with the observed slope of 3.88 ± .01 between ion chamber intensity on Mariner II and Deep River neutron intensity during the Forbush decrease of 30 September, 1962, we conclude that the spectrum of variation during the short term fluctuations, such as Forbush decreases, is similar to the spectrum of variation during long term changes. Anderson (1964), on the other hand, finds that the ratio of variation of the daily average Mariner ion chamber rates to variations of the daily average Deep River rate falls between 2 and 3 during different periods of observation. It must, however, be remembered that after day 292, Mariner II rapidly drifted away from the earth-sun line, and away from the earth toward Venus. A systematic intensity gradient of approximately 9%/AU has been estimated by Anderson (1964) from a comparison of ion chamber intensity with Deep River neutron intensity. Since these factors will clearly affect the observed ratios, the ratio obtained by

Anderson, even though less than that observed during the Forbush decrease or that obtained by Nerurkar and Webber, is not in contradiction with these results.

The percent change in intensity of a secondary component of type i, recorded at latitude λ and height h can be expressed as

$$\frac{100\ \delta N_\lambda^i(h)}{N_\lambda^i(h)} = \frac{100 \int_{E_\lambda^c}^{\infty} \frac{\delta D(E)}{D(E)}\ w_\lambda^i(h,E)\ dE}{\int_{E_\lambda^c}^{\infty} w_\lambda^i(h,E)\ dE} \qquad (1)$$

where E_λ^c is the vertical cutoff energy at latitude λ , $w_\lambda^i(h,E)$ is the coupling constant for secondary component i defined as $\frac{D(E)m^i(E,h)}{N_\lambda^i(h)}$ where D(E) is the differential energy spectrum of primaries and $m^i(E,h)$ is the "multiplicity function." Similarly, we can express the percent change in intensity of primary radiation such as the one measured by Mariner II ion chamber as

$$\frac{100\ \delta N_p}{N_p} = \frac{100 \int_{E_{min}}^{\infty} I(E)\ \frac{\delta D(E)}{D(E)}\ D(E)dE}{\int_{E_{min}}^{\infty} I(E)\ D(E)dE} \qquad (2)$$

where I(E) is the ionization rate per unit omnidirectional flux of particles with energy E. [I(E) equals unity for Geiger counters.]. E_{min} is the threshold of the Mariner II instruments (10 Mev for protons). Assuming the spectrum of variation to be of the form AE^β and using the coupling coefficients for sea level neutrons at 50° latitude given by Webber and Quenby (1959) and the recent IMP-1 results on primary spectrum (McDonald and Ludwig, 1964), we have calculated the ratio of percent change of cosmic ray intensities measured by Mariner II ion chamber and Geiger counters to that observed by Deep River neutron monitor for different exponents of the spectrum of variation. Figure 2 shows the theoretically calculated ratio of the percent change observed by Mariner II ion chamber and the Geiger counters to the percent change of cosmic ray intensity measured by Deep River neutron monitor for various values of the exponent β.

In Figure 3 is plotted the time series of the 6 hourly mean cosmic ray intensities measured by Mariner II ion chamber, Be, and steel shielded G-M counters aboard Mariner II and the Deep River neutron intensity for the period 29 September (272) through 13 October 1962 (286). The onset of the Forbush decrease, as well as the changes of intensity in various instruments, correlate very well as seen from Figure 3, the correlation coefficient between any two intensities being at least $0.85 \pm .05$. However, the slopes of the intensity changes observed by the two G-M counters, both having similar energy response to the neutron intensity change at Deep River, do not agree very well, the slopes being $2.39 \pm .02$ and $3.05 \pm .02$. Similar discrepancies have been noted by Anderson (1964). Hence, we have considered the mean of the two values, namely $2.72 \pm .02$, as the proper ratio of the changes of G-M counter intensity at Mariner II to the changes of neutron intensity at Deep River.

Using the two observed ratios, one between the ion chamber and Deep River neutron intensities ($3.88 \pm .01$) and the other between G-M counter and Deep River neutron intensities ($2.72 \pm .01$), we obtain from Figure 2, two estimates for β, namely -0.41 ± 0.01 and $-0.48 \pm .01$ respectively. We conclude that the energy spectrum of variation during the Forbush decrease was of the form $AE^{-0.45 \pm .04}$. Due to lack of good agreement between the two Geiger counters, we are, however, unable to determine whether the intensity changes during this Forbush decrease was energy or rigidity dependent.

In Figure 1 is also plotted the time series of the hourly mean solar wind velocity (reversed scale), measured by the plasma probe in Mariner II, and the three hourly K_p indices. For the analysis presented here we have approximated the plasma bulk velocity, by the value for the channel with the largest measured current. The error arising from this approximation (Snyder, Neugebauer, and Rao) is negligible. From the figure it is clear that the inverse time series of the solar wind velocity follows the time series of ion chamber cosmic ray intensity very closely. The inverse correlation between the changes in plasma velocity and the changes in ion chamber cosmic ray intensity is very high, being $-0.98 \pm .01$. A comparison of the plasma velocity changes with the changes of ion intensity reveals that each decrease in ion chamber intensity is correlated with a corresponding increase in plasma velocity, as if each individual burst of plasma cloud interacts with the interplanetary medium to produce a corresponding decrease of cosmic ray intensity. Similarly, the correlation between K_p indices and the ion chamber intensity is very high. Even though the correlation of ion chamber intensity with plasma velocity, or K_p, is very high during the Forbush decrease, the correlation is practically nonexistent on a long term basis, (Snyder, Neugebauer, and Rao). Assuming that the Forbush decrease has made a complete recovery when the intensity reaches within 0.5 percent of the pre-event value, it can be seen from Figure 1 that even though both K_p and plasma velocity recover to their normal value in about two days (i.e, on day 276), the cosmic ray intensities continue to remain depressed. The neutron intensities at various stations recover on day 277. The ion chamber intensity and the G-M counter intensities on Mariner II, however, recover only on day 285 or 286 (Figure 3), showing that the recovery is energy dependent, the low energy cosmic rays recorded by the Mariner II ion chamber and G-M counters recovering last.

In summary, we draw the following important conclusions:

(1) The changes in ion chamber intensity measured in space during the Forbush decrease of 30 September 1962 are very well correlated with the changes of neutron intensity at Deep River and at other neutron monitor stations. The neutron intensity at the ground, however, recovers much faster than the ion chamber intensity, indicating that the intensity of low energy cosmic rays has still not recovered to its pre-decrease value.

(2) Both the short term variations, such as Forbush decreases, and the long term variations have a similar spectrum of variation.

(3) The spectrum of variation during the Forbush decrease may be represented by $AE^{-0.45 \pm 0.04}$

The changes in cosmic ray intensity are very well correlated with the changes in solar wind velocity during the Forbush decrease. The effect is as though each individual burst of plasma cloud interacts with the interplanetary medium to produce a corresponding decrease in the cosmic ray intensity.

ACKNOWLEDGMENTS

I am grateful to Drs. H. Anderson, C. W. Snyder, and M. Neugebauer of the Jet Propulsion Laboratory, Pasadena, California, for permission to use the Mariner II data. I am also indebted to Dr. K. G. McCracken for helpful suggestions. The work reported here was supported by the NASA Research Grant NSG-269-62.

REFERENCES

Anderson, H. R.; "Ionizing Radiation Measured Between Earth and Venus by Mariner II," paper presented at the International Space Science Symposium (COSPAR), Florence, 1964. (In Press)

Fenton, A. G., K. G. McCracken, D. C. Rose, and B. G. Wilson; "The Onset Times of Forbush-type Cosmic Ray Intensity Decreases," Can. J. Phys; 37, 970-982, 1959.

McCracken, K. G.; "The Cosmic Ray Flare Effect," J. Geophys. Research, 67, 447-458, 1962.

McDonald, F. B., and G. H. Ludwig; "Measurement of Low Energy Primary Cosmic Ray Protons on IMP-1 Satellite," 1964. (In Press)

Neher, H. V., and H. R. Anderson; "Cosmic Ray Intensity at Thule, Greenland, during 1962 and 1963 and a Comparison with Data from Mariner II," J. Geophys. Research, 69, 807-814, 1964.

Nerurkar, N., and W. R. Webber; "Observations of Primary Cosmic Ray Variations Using Ion Chambers and Geiger Counters," J. Geophys. Research, 69, 815-830, 1964.

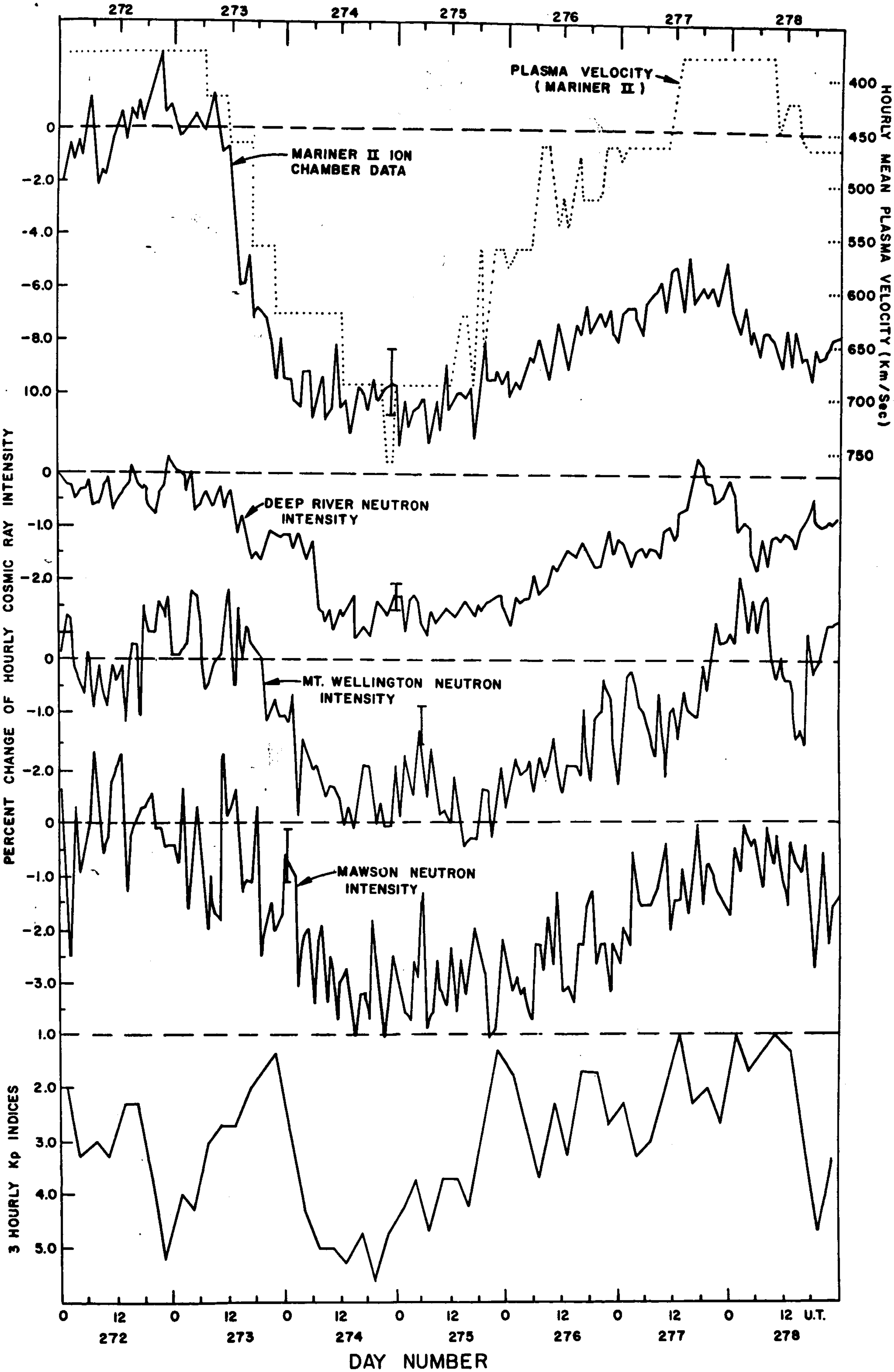
Snyder, C. W., M. Neugebauer, and U. R. Rao; "The Solar Wind Velocity and Its Correlation with Cosmic Ray Variations and with Solar and Geomagnetic Activity," J. Geophys. Research, 68, 6361-6370, 1963.

CAPTIONS FOR FIGURES

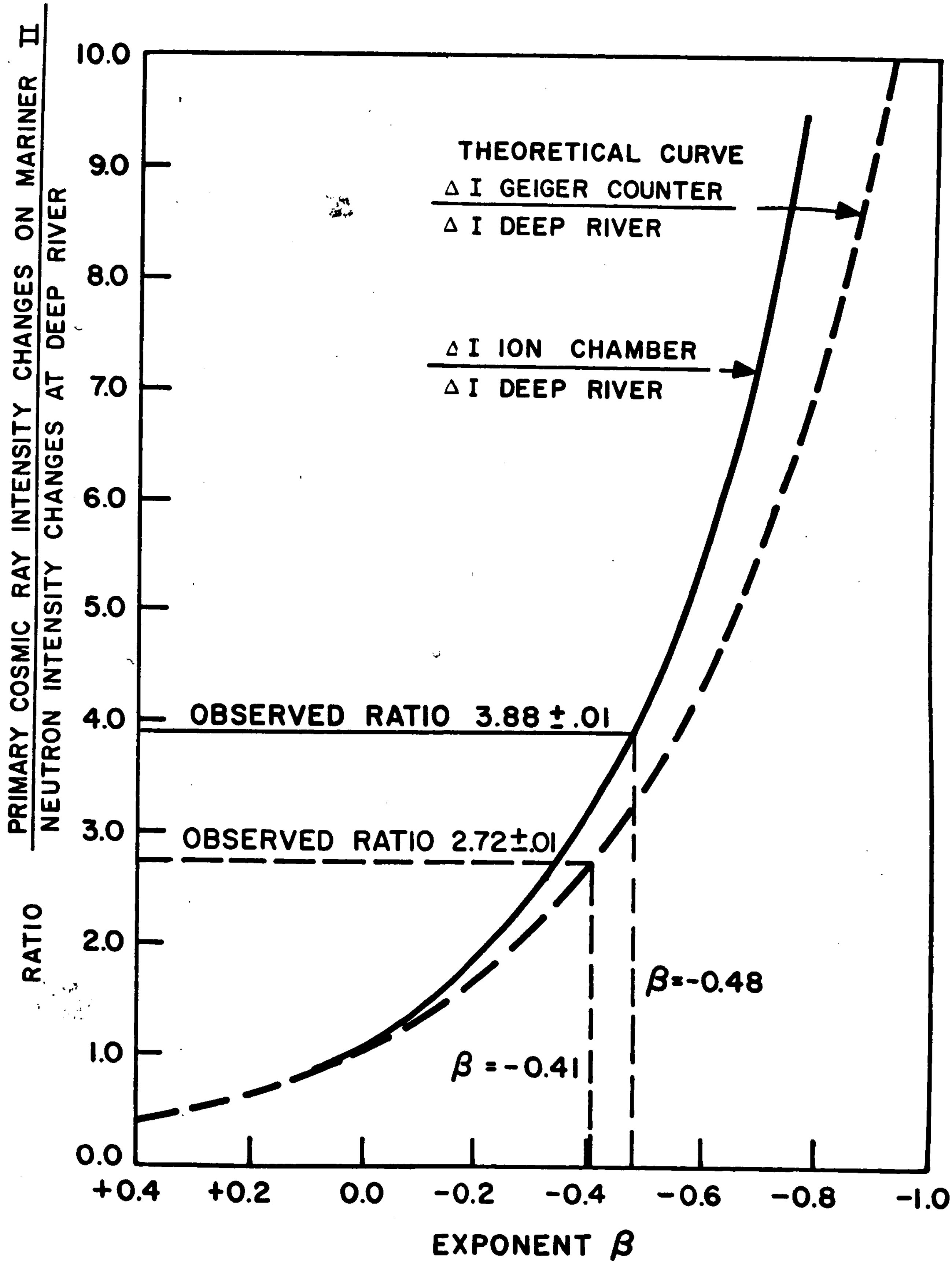
Figure 1 Time series showing the (a) hourly mean cosmic ray intensity recorded by Mariner II ion chamber (b) hourly mean solar wind velocity, (c) hourly mean neutron intensities recorded at Deep River, Mt. Wellington and Mawson, and (d) the 3 hourly Kp indices for the period September 29 (272) through October 5, 1962 (Day 278).

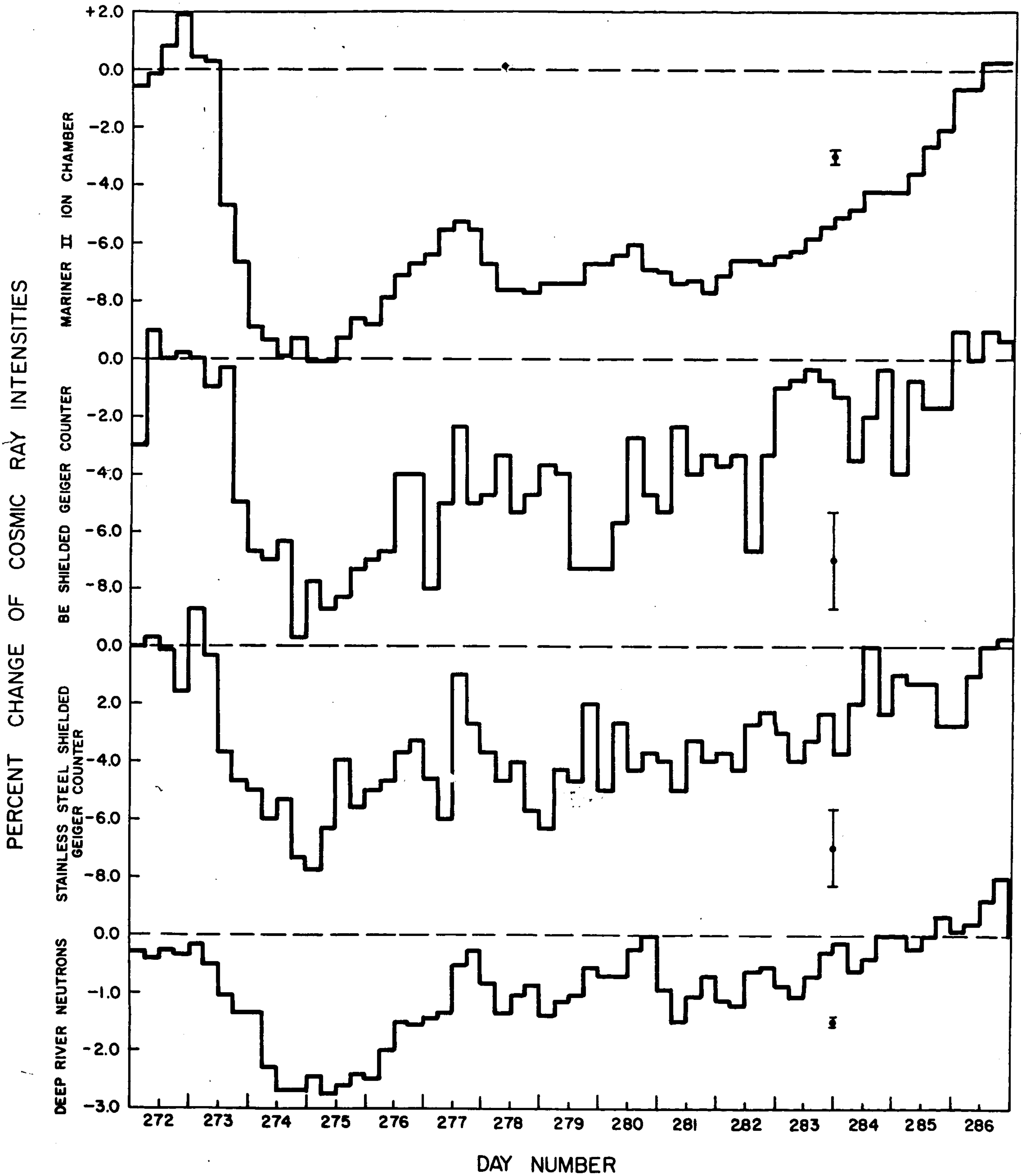
Figure 2 Theoretical curve showing the ratio of percent change cosmic ray intensity observed by Mariner II ion chamber and geiger counters to the percent change neutron intensity at Deep River as a function of β, for a spectrum of the type AE^{β}.

Figure 3 Time series of hourly mean cosmic ray intensities measured by (a) Mariner II ion chamber, (b) beryllium and stainless steel shielded geiger counters aboard Mariner II, and (c) the neutron intensity at Deep River for the period September 29 (272) through October 13, 1962 (286).



PLASMA VELOCITY (MARINER II)
MARINER II ION CHAMBER DATA
DEEP RIVER NEUTRON INTENSITY
MT. WELLINGTON NEUTRON INTENSITY
MAWSON NEUTRON INTENSITY
PERCENT CHANGE OF HOURLY COSMIC RAY INTENSITY
HOURLY MEAN PLASMA VELOCITY (Km/Sec)
3 HOURLY Kp INDICES
DAY NUMBER
U.T.
272
273
274
275
276
277
278


THEORETICAL CURVE
Δ I GEIGER COUNTER / Δ I DEEP RIVER
Δ I ION CHAMBER / Δ I DEEP RIVER
OBSERVED RATIO 3.88 ± .01
OBSERVED RATIO 2.72 ± .01
β = -0.48
β = -0.41
RATIO PRIMARY COSMIC RAY INTENSITY CHANGES ON MARINER II / NEUTRON INTENSITY CHANGES AT DEEP RIVER
EXPONENT β
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
+0.4
+0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0


PERCENT CHANGE OF COSMIC RAY INTENSITIES
MARINER II ION CHAMBER
BE SHIELDED GEIGER COUNTER
STAINLESS STEEL SHIELDED GEIGER COUNTER
DEEP RIVER NEUTRONS
+2.0
0.0
-2.0
-4.0
-6.0
-8.0
2.0
-1.0
-2.0
-3.0
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
DAY NUMBER