A SOLAR FLARE TYPE INCREASE IN COSMIC RAYS AT LOW LATITUDES

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ON 23rd February 1956, the occurrence of a large solar flare was associated with a number of remarkable events observed at different stations on the earth. In addition to ionospheric disturbance, a spectacular increase of cosmic ray intensity has been reported by a number of observing stations situated in the middle latitudes.

The Physical Research Laboratory has for some years been conducting a systematic study of the ionosphere and of cosmic ray intensity at low latitudes. Continuous measurement of cosmic radio noise has been started recently. A report by Ramanathan *et al.*[1] of the events observed at Ahmedabad on 23rd February by an ionospheric recorder and a 25 Mc/s cosmic radio noise monitor is published separately. We give here the results of measurements of cosmic ray meson intensity made with standard telescopes at

1. Ahmedabad	..	A	—73° E,	23° N,	13° N	geomagnetic,	sea-level
2. Kodaikanal	..	K	—77° E,	10° N,	1° N	,,	2,343 m.
3. Trivandrum	..	T	—77° E,	8° N,	1° S	,,	sea-level

Ahmedabad and Trivandrum are stations at sea-level.

Trivandrum and Kodaikanal are stations on the geomagnetic equator, the latter being situated at a mountain elevation. Details of the standard telescopes have been published elsewhere.[2] The telescopes measure triple coincidences of cosmic rays that can penetrate 10 cm. of lead, and which arrive in directions inclined with the vertical at an angle not exceeding 22° in the E-W plane, and 37° in the N-S plane.

I. SOLAR FLARE TYPE INCREASE ON 23RD FEBRUARY 1956

During the period 21–2–1956 to 25–2–1956, three independent instruments were functioning satisfactorily at Ahmedabad, while at Kodaikanal and Trivandrum there were at each station one or two independent telescopes in operation. In Fig. 1 are shown the per cent. hourly deviations of meson intensity measured by each telescope on 22nd, 23rd and 24th February. No corrections of any kind have been applied to the data. For each station hourly data from the different telescopes have been combined and the average per cent. hourly deviations are plotted. The average per cent. hourly deviations of all 7 telescopes at the three stations are also shown. In Table I we give

TABLE

Per cent. average hourly deviations of meson intensity at Ahmedabad, Kodaikanal

75° E.M.T.	21—2—1956				22—2—1956			
	A	K	T	Ave.	A	K	T	Ave.
0330 to 0030 ..	+1·58		+0·26	+0·92	−0·02	−1·17	+0·98	−0·07
0030 to 0130 ..	+0·42		−2·23	−0·91	+0·05	+0·66	+4·35	+1·68
0130 to 0230 ..	−0·02		−0·70	−0·36	+1·56	+0·83	+1·10	+1·16
0230 to 0330 ..	−0·05		−3·07	−1·56	−1·19	−0·33	+0·55	−0·32
0330 to 0430 ..	−1·86		−1·92	−1·89	+0·44	+1·50	−0·43	+0·50
0430 to 0530 ..	+0·53		−1·67	−0·57	+0·11	−1·00	−0·51	−0·46
0530 to 0630 ..	+1·01		−0·10	+0·46	+1·17	+0·34	+4·31	+1·94
0630 to 0730 ..	+0·68		−1·51	−0·42	−3·06	+0·67	+0·74	−0·55
0730 to 0830 ..	−2·36		−0·64	−1·50	−0·84	+0·34	+3·47	+0·99
0830 to 0930 ..	−2·13		+2·70	+0·29	+1·23	+1·17	+0·25	+0·88
0930 to 1030 ..	−1·09		+3·51	+1·21	+0·49	+4·33	+2·75	+2·52
1030 to 1130 ..	+0·96		−1·25	−0·15	+0·19	−0·33	+5·76	+1·87
1130 to 1230 ..	+2·38		+0·22	+1·25	−2·47	+2·34	+0·58	+0·15
1230 to 1330 ..	+0·85		−1·75	−0·45	−1·58	−0·83	+0·41	−0·66
1330 to 1430 ..	−1·12		+0·27	−0·43	+1·74	+2·67	+3·06	+2·49
1430 to 1530 ..	−2·18		−1·75	−1·97	+1·79	+3·00	−1·61	+1·06
1530 to 1630 ..	−0·60		+0·93	+0·17	−1·73	+1·00	+0·83	+0·03
1630 to 1730 ..	+0·37		−0·57	−0·10	−0·52	−3·83	−4·08	−2·81
1730 to 1830 ..	−3·17		−1·49	−2·33	−1·80	+0·50	−1·52	−0·94
1830 to 1930 ..	+1·80		−0·02	+0·89	−1·90	+2·67	−1·96	−0·39
1930 to 2030 ..	−0·95		−0·32	−0·64	+0·06	−2·35	−1·96	−1·41
2030 to 2130 ..	−1·50		−1·38	−1·44	−2·13	+1·00	−2·39	−1·50
2130 to 2230 :	−2·98		+3·08	+0·05	+2·08	−0·34	−5·16	−1·14
2230 to 2330 ..	+0·24		−2·91	−1·22	+2·40	+0·84	−2·50	+0·25

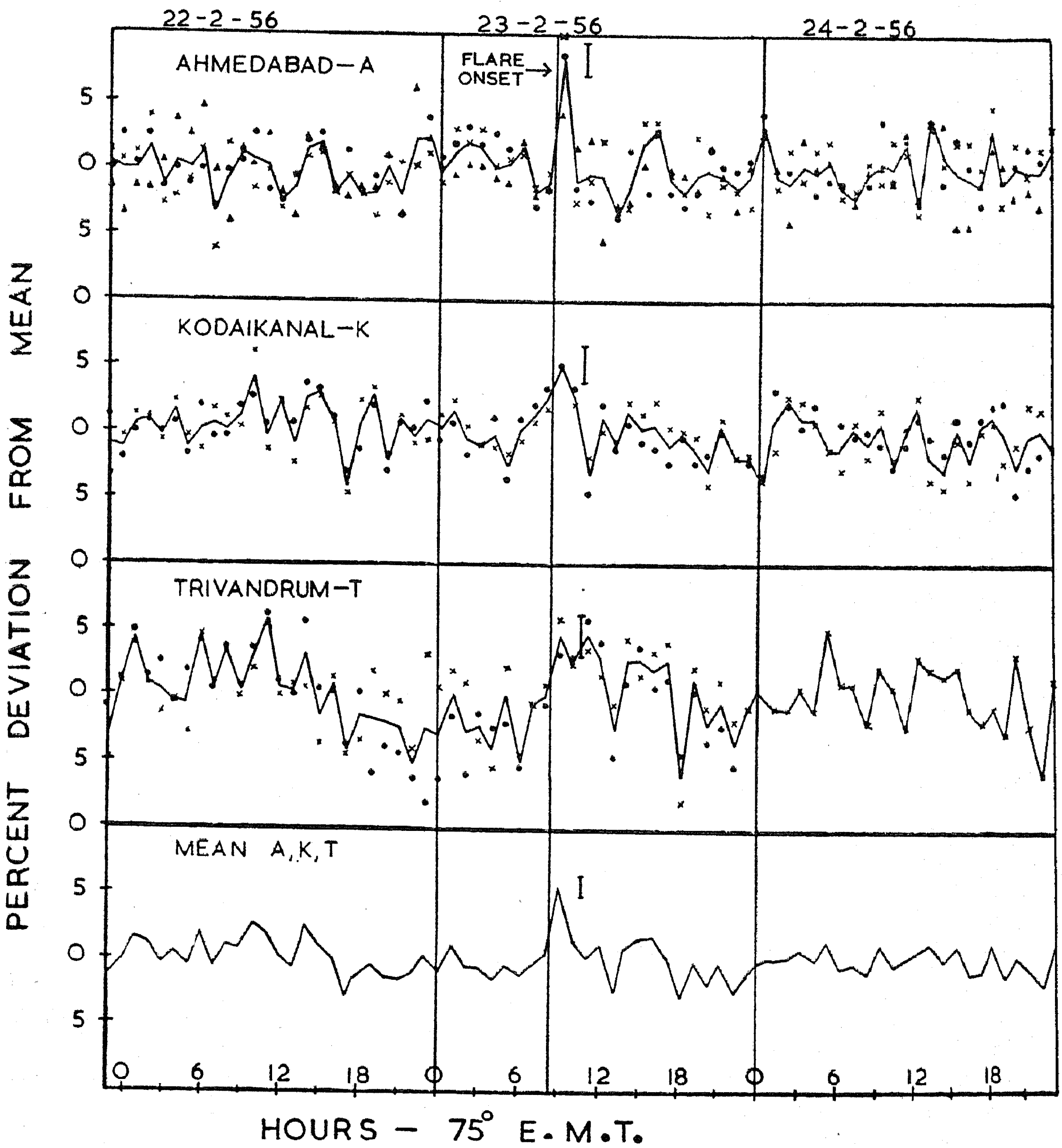
the average hourly deviations at A, K and T as well as the combined average hourly deviations for all three stations. Data commence from two days prior to the day of the solar flare and end two days following the flare. Since the

I

and Trivandrum and the per cent. average hourly deviations for the three stations

23—2—1956				24—2—1956				25—2—1956			
A	K	T	Ave.	A	K	T	Ave.	A	K	T	Ave.
−0·08	+0·33	−2·92	−0·89	+3·19	−3·45	+0·81	+0·18	+1·90	+0·83	+2·04	+1·59
+1·40	+1·50	+0·11	+1·00	−0·47	+1·00	−0·81	−0·09	−4·06	+0·83	−2·10	−1·78
+1·80	−0·67	−2·86	−0·57	−0·98	+2·33	−1·02	+0·11	+2·41	−0·66	−1·53	+0·07
+1·60	−1·00	−2·32	−0·57	+0·10	+1·33	+0·61	+0·68	−1·78	−2·00	−1·52	−1·77
0·00	−0·16	−4·15	−1·43	−0·16	+1·23	−1·22	−0·01	+3·16	+0·49	−2·40	+0·41
+0·30	−1·67	−0·02	−0·46	+0·70	−1·33	+4·89	+1·42	+1·23	+2·66	−2·13	+0·58
+1·60	+0·17	−5·10	−1·11	−1·48	−1·16	+0·81	−0·67	+0·38	+1·00	+0·06	+0·48
−1·70	+1·33	−0·75	−0·37	−2·15	+0·16	+0·81	−0·39	+0·73	−0·50	+1·18	+0·47
−1·30	+2·50	+0·06	+0·42	−0·32	−0·99	−2·24	−1·18	+0·46	+0·49	+0·69	+0·54
+7·60	**+4·83**	**+4·57**	**+5·66**	+0·94	+0·33	+2·24	+1·17	+0·43	+2·33	+3·62	+2·12
−0·91	+2·66	+2·60	+1·45	+0·07	−2·33	+0·61	−0·53	−0·35	−2·00	+4·76	+0·80
−0·47	−3·33	+4·61	+0·27	+2·08	−0·33	−2·44	−0·23	−1·22	+0·83	+1·97	+0·52
−0·59	+1·00	+2·89	+1·10	−2·68	+1·83	+2·85	+0·67	−0·47	−2·00	−0·17	−0·88
−3·31	−1·00	−2·60	−2·30	+3·02	−1·99	+2·24	+1·09	−0·92	−0·83	−0·66	−0·80
−1·40	+1·50	+2·60	+0·90	+0·86	−2·99	+1·43	−0·23	+1·19	+2·17	+3·91	+2·43
+1·86	+0·33	+2·66	+1·61	−0·01	+0·17	+2·24	+0·80	−1·88	+2·00	+0·98	+0·37
+2·95	+0·50	+1·86	+1·77	−0·72	−2·12	−1·02	−1·29	+1·00	+1·83	+0·25	+1·03
−0·84	−1·00	−2·61	+0·26	−1·24	+0·50	−2·24	−0·99	+3·89	+2·00	+0·74	+2·21
−1·78	−0·16	−6·26	−2·73	+2·94	+1·33	−1·02	+1·08	−0·40	+1·49	+2·36	+1·15
−0·38	−1·33	+1·24	−0·16	−1·00	+0·01	−2·85	−1·28	+1·37	−4·17	−1·46	−1·30
−0·15	−2·83	−2·13	−1·70	+0·11	−2·84	+3·05	+0·10	+0·30	+0·83	−3·15	−0·67
−0·53	−0·50	−0·54	−0·19	−0·11	−0·34	−2·44	−0·96	−0·10	−1·83	−0·73	−0·88
−1·65	−2·00	−3·56	−2·40	−0·24	−0·01	−6·11	−2·12	−0·47	−0·83	−2·31	−1·20
−0·68	−2·00	−0·81	−1·16	+1·58	−1·16	+1·99	+0·80	−0·80	+0·05	+1·55	+0·27

photographic records were made hourly at the half hours according to 75° EMT, which is almost local time at the three stations, and the onset of the flare was observed at Ahmedabad by the sudden absorption of cosmic



TEXT-FIG. 1. Per cent. hourly deviations of cosmic ray meson intensity at Ahmedabad, Kodaikanal and Trivandrum and the average of the hourly deviations at the three stations on 22nd, 23rd and 24th February 1956. The hcurly deviations of each individual telescope are also indicated with appropriate symbols.

radio noise at about 0832 hours 75° EMT, we are fortunate in having the onset of the flare almost coincide with the commencement of the hourly interval over which the cosmic ray intensity is averaged.

At Ahmedabad during the hour immediately following the flare the average deviation is $+ 7 \cdot 6 \pm 1 \cdot 3\%$. During the same hour at Kodaikanal and at Trivandrum the average deviations are $+ 4 \cdot 8 \pm 1 \cdot 45\%$ and $+ 4 \cdot 6$

$\pm 1 \cdot 64\%$ respectively. The average hourly deviation at Ahmedabad rarely exceeds $\pm 3\%$ and therefore the increase of $7 \cdot 6\%$ after the solar flare on 23–2–1956 stands out clearly. At Kodaikanal and Trivandrum the hourly deviations are much larger than at Ahmedabad and consequently the increases during the hour following the flare are not equally striking even though at both stations there are large significant positive deviations. In the average of deviations of all seven telescopes we get the advantage of suppressing deviations which are not simultaneously present at all three stations. We then have a prominent average increase of $+ 5 \cdot 7 \pm 0 \cdot 8\%$ during the hour immediately following the solar flare. This is considerably larger than other hourly deviations throughout the period. The difference between the increase at Ahmedabad and the average increase at all three stations is not significant. It is therefore not possible to comment on the difference in the flare effect due to change from 0–13° geomagnetic North latitude. There is also no significance difference between the increases at Kodaikanal and Trivandrum, in spite of the difference in elevation of about 2,343 m. But in view of the standard error of the determination at each place, the existence of a difference cannot be excluded.

II. Interpretation

The present evidence establishes for the first time the existence of a solar flare increase in cosmic rays at low latitudes near the geomagnetic equator. During the four earlier observed instances of solar flare increases in cosmic ray intensity, no significant increase was noticed at stations in latitudes less than 25°. It is difficult to say whether the present flare is unique in producing measurable effects at the Equator, since equipment comparable to ours was not operating during earlier occasions at low latitudes. As discussed later in this communication, solar cosmic rays emitted during large flares can arrive only from certain restricted directions from the sky above the instrument. This effect becomes more pronounced at low latitudes and therefore the chance of recording a significant flare type event with an ionisation chamber with omnidirectional sensitivity is rather less favourable than with a telescope pointing to an appropriate direction. It is not known so far whether the Carnegie Institution ionisation chamber at Huancayo has registered an increase after the recent flare. A negative answer will leave ambiguous the position regarding the uniqueness of the present flare since its occurrence at a time when all three stations in India were near the impact zone appropriate to positive particles originating from the sun has perhaps favoured the observation of the increases at the Indian stations as compared to Huancayo.

From evidence prior to the recent flare, the generally accepted interpretation of the solar flare increase in cosmic ray intensity was that it is caused by a burst of positively charged particles from the sun which for the purpose of this effect, appears to have a diameter of about 30° as viewed from the earth. The particles were believed to have a maximum energy of about 10 Bev and an energy distribution much steeper than the distribution of the normal primary cosmic rays. Even though increases at stations at high latitudes, such as Godhavn, Resolute and Thule have presented difficulties, since the stations lie outside normal impact zones for particles of these energies from the sun, attempts have been made to retain the postulate of solar origin by invoking the aid of interplanetary magnetic fields. The discovery of the increase at low latitudes now makes it necessary to revise some of our thinking on this subject. If the effect is caused by positively charged particles from the sun, the following conclusions would appear to result from our observation of the increase at the magnetic equator and at 13° North geomagnetic latitude where the minimum cut-off rigidity for vertical particles is about 17·0 and 16·2 Bev/Zc respectively. In order to correct for the deflection in the geomagnetic field, and to determine the energies of positive particles originating from the sun which could play a role in causing the increase of intensity, we can use the most valuable results of Brunberg and Dattner.[3]

On 23rd February 1956, the declination of the sun was − 10°. At 0900 hours local time the position of the sun, with an angular diameter of 30° as viewed from the earth, is indicated in the diagrams kindly prepared by Brunberg and Dattner for Ahmedabad and Kodaikanal and reproduced in Figs. 2 (A) and (B) respectively. It will be observed that at Ahmedabad solar protons must have energies between 35 and 65 Bev. Furthermore these particles are incident at the top of the atmosphere at directions in the N-S plane which make angles with the zenith from about 16° S–50° S. Correspondingly at Kodaikanal or Trivandrum the solar particles would have to be within an energy range 35–70 Bev and would be incident in directions from about 8° S–45° S inclined to the vertical in the N-S plane. At all three stations no particles from the sun could arrive in the E-W plane. Between the stations at the magnetic equator and at 13° N geomagnetic latitude, there is no marked change in the limits of directions of arrival of the trajectories or of the energies of allowed protons of solar origin. Moreover we have not established a significant difference between the per cent. increase of meson intensity at the three stations after the flare. It is therefore appropriate to consider the average conditions for solar protons in low latitudes in conjunction with the average increase of 5·7%.

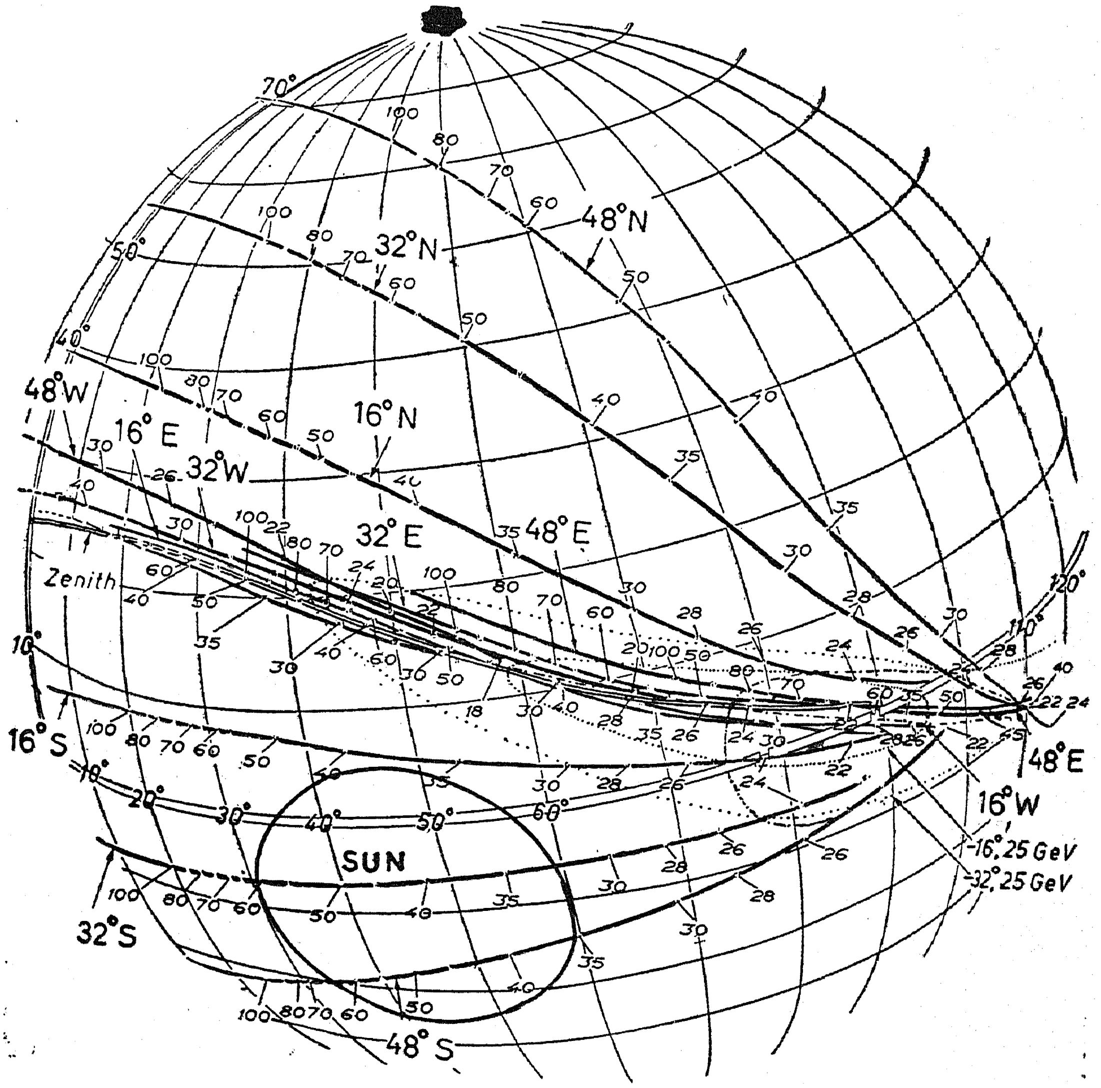
III. The Intensity of 50 Bev Solar Flare Protons

If N* be the number of primary solar protons in the energy range 35–67·5 Bev per sec. per cm.^{2} area normal to the direction of incidence, and N be the number of background cosmic rays in the same energy range per sec. per cm.^{2} per steradian, we would like to calculate the ratio $x = N^*/N$. At the present moment there are a number of uncertainties involved in relating N* and N to the corresponding counting rates n^* and n in our telescopes due to solar particles and background intensity respectively of primaries in the energy range 35–67·5 Bev. This is mainly because the published results of Brunberg and Dattner relate only to the E-W and N-S planes. We have therefore no precise way of determining the limiting directions in other azimuths which define the extent of cone which is available to the solar protons during this flare. From the interceptions of the cone on the N-S plane through zenith, and from the semi-angle of the telescopes in the same plane we estimate that solar protons can have not more than a fifth of the cone available to background intensity measured in our telescopes. Thus at the present moment we can calculate only a lower limit to the ratio x, indicative of the order of its magnitude. Under these circumstances it is appropriate to disregard a correction for the difference in the effective aperture of the telescope for solar protons and background intensity. Furthermore, since the mean primary energy for background intensity is comparable to the mean energy of 50 Bev for solar protons, we can also assume that the same multiplicity factor can be applied in each case to derive the sea-level intensity in terms of the intensity at the top of the atmosphere. Thus we have $x = N^*/N \approx 5\, n^*/n$. If n' be the counting rate due to background in the entire energy range from geomagnetic cut-off to infinity, and we assume an integral spectrum of the form $E^{-1\cdot7}$ for the primaries of background intensity, the proportionate increase of intensity

$$\cdot 057 = \frac{n^*}{n'} \approx \frac{x}{5} \frac{[E^{-1\cdot7}]_{35}^{67\cdot5}}{[E^{-1\cdot7}]_{16\cdot5}^{\infty}}.$$

We then have $x \approx 1\cdot5$, indicating that averaged over one hour following the flare, the flux of solar protons in the energy range 35–67·5 Bev is about 1·5 times the flux of background cosmic rays in the same energy range.

Visual records indicate that the flare on 23–2–1956 was of magnitude 3 and occurred at 22·5° heliographic north and 73° heliographic west. One of the four earlier flares which produced increases of cosmic ray intensity was also located about 70° W heliographic longitude. We do not know much about the nature of magnetic fields between the sun and earth during such intense disturbances. If there is no magnetic focussing effect, we have to

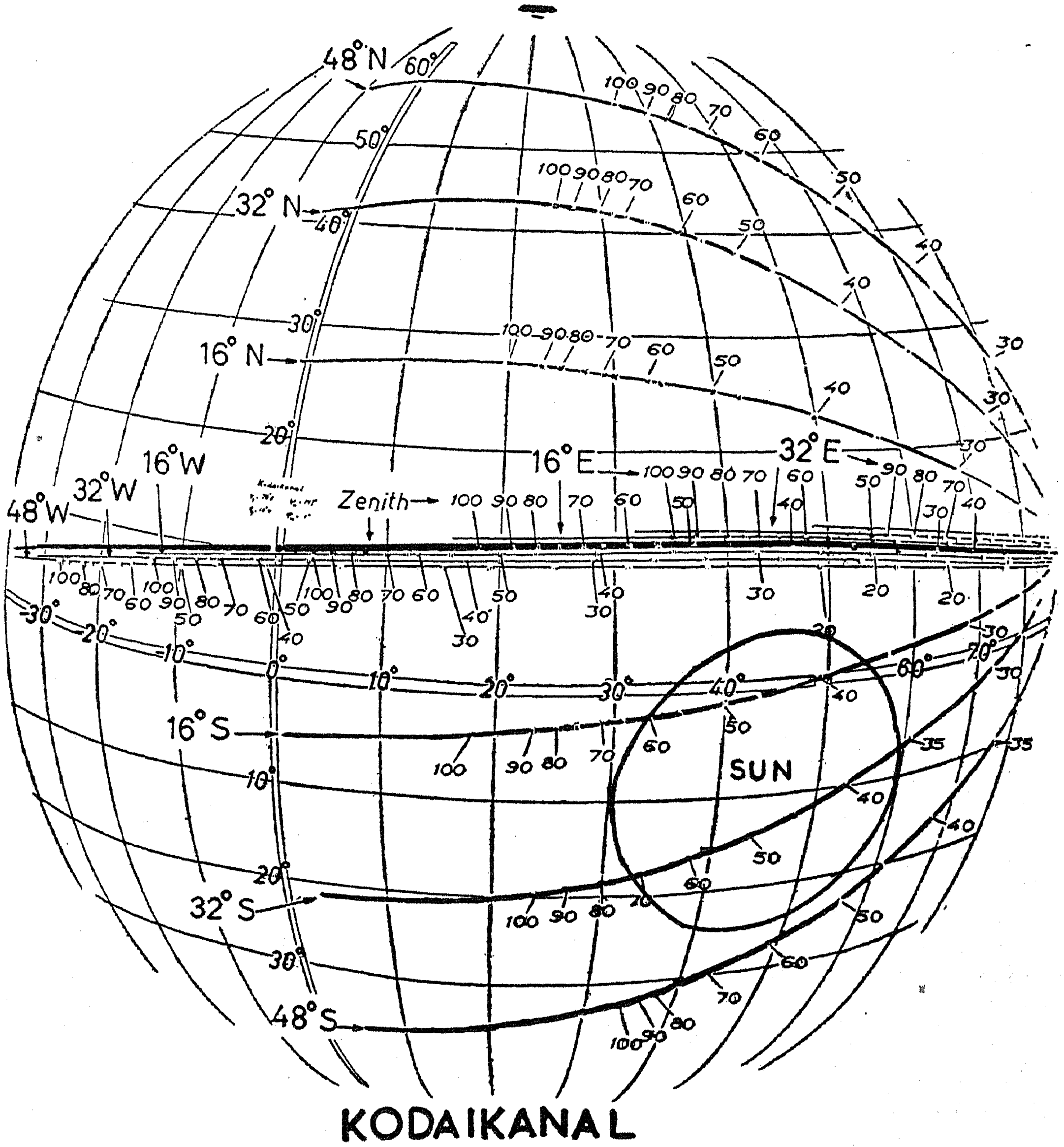


AHMEDABAD

A

TEXT-FIG. 2. Dagrams prepared by Brunberg and Dattner, showing the asymptotic co-
to the zenith in the North-South and East-West Planes at (A) Ahmedabad, (B) Kodaikanal.
at 0900 hours 75° EMT is marked in the diagrams. For further explanation, reference may be

accept the rather remarkable conclusion that protons of energies as great as 35–67·5 Bev can be ejected from the sun in a cone of semi-angle as large as 75°. A consequence of assuming throughout the cone a flux of solar protons as large as is observed near the earth would be that during the hour following the solar flare of magnitude 3 the sun emitted about 10^{28} protons of an energy ut 50 Bev. This may be compared with the estimate made by Simpson



B

ordinates of velocity vectors of protons of different energies incident in various directions inclined
The position of the sun on 23-2-1956 with an assumed diameter of 30° as viewed from the earth,
made to the original paper.[3]

et al.[4] of 2×10^{23} protons per second of mean energy 4 Bev averaged over a solar cycle due to flares of magnitude equal to or greater than 1+.

IV. Conclusion

When we consider the sharp increase of intensity and its short mean life reported by other workers who have made continuous ionisation chamber records, we are forced to conclude that events occur on the sun which involve the acceleration of a very large number of particles to much higher energies than has been hitherto suspected or indeed thought possible. The alternative to such a conclusion might involve the abandoning of our present belief that during such events particles are actually emitted from the sun. Any modulation theory would run into the difficulty, amongst others, that the interval between the observed maximum of visual intensity of the flare and the maximum of cosmic ray intensity is only of the order of about 10–15 minutes.

We are indebted to Drs. Brunberg and Dattner for their proton-energy diagrams and to Professor H. V. Neher and Mr. Nerurkar, for helpful discussions. We are also grateful to Mr. Thakore and Mr. Vishwanath, for computational assistance. The present work is generously financed by the Atomic Energy Commission of India.

SUMMARY

During the hour following the big solar flare on 23–2–1956, an average increase of $+5\cdot7 \pm 0\cdot8\%$ has been observed in meson intensity measured with standard telescopes at Ahmedabad, Kodaikanal and Trivandrum. This is the first report of a significant solar flare type increase in cosmic rays near the geomagnetic equator. If the increase is due to solar protons travelling in approximately direct paths, the energy of the protons must extend from about 35–67·5 Bev. It is estimated that the average flux of such protons is approximately equal to 1·5 times the flux of general cosmic ray intensity in the same energy range. During the hour, the sun is estimated to have emitted more than 10^{28} protons of about 50 Bev energy.

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