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Momentary bursts of cosmic radiation

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Continuous records of cosmic ray intensity made by means of ionisation chambers containing gas at atmospheric pressure or at a pressure of several atmospheres as in the apparatus designed by Kolhörster, Hoffmann, Millikan, Compton and others show occasional and momentary, but quite marked increases of ionisation. This singular phenomenon has been known ever since Hoffmann first noticed it in 1927; in fact, it is usual to call these instantaneous bursts of ionisation *Hoffmann Bursts*. Quite a number of cosmic ray investigators have studied the phenomenon of Hoffmann bursts and, in spite of a natural scepticism, which in the early days tended to attribute their origin to some instrumental defect or to some unsuspected form of ionisation by collision, it is now recognised that they are indeed genuine and effectively measure the sudden increases in the intensity of cosmic radiation. It has been established that Hoffmann bursts are more frequent at high altitudes than at sea level and some investigators (Hoffmann himself among them) have found that they occur even when the ionisation chamber is shielded all round by 5 to 20 cm of lead. The most frequent bursts correspond to an energy of 10^8 eV, but there are bursts of higher energy reaching 10^{10} eV or even more. The source of these high-energy rays, however, remains as obscure as that of cosmic rays in general.

Although almost from the time of the discovery of cosmic radiation the sun has at times been considered to be one of the possible sources, the sun's contribution has generally been regarded as extremely small, particularly because of the smallness (or even the absence) of a diurnal variation with solar time. But during the last two decades there have been at least 5 occasions on which the sun has unquestionably emitted bursts of cosmic radiation in association with flares of great intensity. On four of these occasions prior to 1956 the bursts were recorded simultaneously by Compton-Bennett and other types of cosmic ray recorders functioning at a number of stations in the middle and high latitudes, but never with certainty at equatorial stations, thus indicating that the energy of the cosmic ray protons of solar origin did not on these occasions exceed 5×10^9 eV. However, during the flare of 23 February 1956 the shielded (11 cm of lead) Compton-Bennett meter at Huancayo (geomagnetic latitude : 0°·6 S) also recorded a relatively large increase of about 18 per cent; this showed that the sun could at times emit cosmic ray protons whose energies were greater than $1{\cdot}5 \times 10^{10}$ eV. Thus the sun's contribution to the general intensity of cosmic radiation, though presumably small, can during intense flares be considerable; in fact, it seems very probable that every solar flare is accompanied by emission of cosmic rays, which may not in every case strike the earth if they are mostly protons ejected from the flare region in a more or less radial direction. But if there be some truth in this conclusion then there ought to be a fairly frequent correspondence between solar flares and some aspects of cosmic ray observations. The continuous records of cosmic ray intensity made at the Kodaikanal Observatory, Kodaikanal (geomagnetic latitude : 0°·6 N, altitude : 2343 metres above msl) during the last few years appear to indicate the existence of such correspondence in respect of the Hoffmann bursts.

A standard Kolhörster cosmic ray apparatus with photographic recorder has been in continuous operation at this observatory since March 1956. The ionisation chamber is shielded with 12·5 cm of iron all round. During the $2\frac{3}{4}$ years upto the end of 1958 some 90 cases of sudden but momentary increases of ionisation with the usual characteristics of Hoffmann bursts have been recorded by the Kolhörster apparatus which has behaved perfectly normally leaving no room for suspecting that the momentary increases of ionisation may have been due to some unsuspected instrumental defect. The possibility of these jumps being due to C.T.R. Wilson's "run-away electrons" is also excluded since none of these cases can reasonably be linked with reported local or nearby thunderstorms; for, the observations of almost all cosmic ray workers have indicated that the effect of thunderstorms on shielded recorders is rather to decrease than to increase the ionisation. The sudden increases of ionisation recorded by our shielded apparatus are, therefore, to be considered as genuine Hoffmann bursts due to the hard component of cosmic rays. In Table 1 we have collected data on solar flares, solar radio emissions and radio fade-outs along with information regarding the Hoffmann bursts registered on the cosmic ray records of this observatory. The information on solar radio emissions and flares and on radio fade-outs has been derived mainly from the monthly bulletins of C.R.P.L., Boulder, U.S.A. and the I.A.U. quarterly bulletins on solar activity; in some cases the required data are not yet available. As far as can be judged from the available data a great majority of the bursts follow solar flares after a time-lag of 10 to 100 minutes which agrees very well with the time-lag of 10 to 150 minutes actually observed in the five unmistakable cases of cosmic ray emission by the sun during flares. A striking feature of the cosmic ray bursts evident from the table is that many of them occur simultaneously (in a few cases with only a small time-difference) with some outstanding occurrences, such as noise bursts or noise storms. This appears to support the hypothesis put forward by Ehmert (1947, 1948) and again in a slightly different form by Kwal (1951) that the generation of solar cosmic rays, the radio-electric emission of the sun and the production of solar flares are all due to a process of acceleration of protons in the fairly strong magnetic field of sunspots. This is also consistent with the conclusion reached by Wild *et al.* (1954) that the so-called Type III bursts of solar noise produced during flares are due to particles moving with velocities ranging from 3×10^{9} cm/sec to 2×10^{10} cm/sec, for such fast-moving particles can be indentified with low-energy cosmic rays.

Another feature of the cosmic ray bursts collected in the table is that more than half of them were recorded at Kodaikanal during the night hours; but the solar flares, solar noises and radio fade-outs with which we believe them to be associated were recorded at various observatories necessarily during their day-light hours. This may, at first sight, appear to be rather strange. But there is really nothing untenable about this association. Some of the unquestionable cases of emission of cosmic rays during solar flares have shown the same peculiarity, thereby indicating that the cosmic rays emitted by the flare region are greatly dispersed by the local magnetic field of spots and are further deviated by the magnetic field of the earth so that they can strike the dark hemisphere of the earth.

It will also be noticed from the table that we associate the Hoffmann bursts recorded at Kodaikanal—a station almost on the geomagnetic equator—with solar flares of various importances ranging from 3 to sub-flares. One might be inclined to think that the very high-energy particles which could reach an equatorial station ought to have been produced only by flares of very high importance. But actual observation in absolutely unequivocal cases indicates that there is no proportionality between the importance of a flare and the energy of the cosmic ray particles or the importance of the geomagnetic storm for which it is responsible.

Although no certainty can be claimed in the very incomplete and uncertain state of our present knowledge of the mechanism of solar flares and of the physical process through which they emit both cosmic rays and radio radiation and cause geomagnetic storms, yet the data presented in our table appear to us to suggest that the momentary bursts of cosmic radiation recorded by the Kolhörster apparatus of this observatory are attributable to solar flares. If this view be correct, then one may also expect a similar correspondence to be apparent between solar flares and Hoffmann bursts recorded at other latitudes.

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TABLE 1

Date	Time of burst (U.T.)	Voltage drop during burst	Solar Flares			Solar Radio Emissions outstanding occurrences (U.T.)	Radio fade-outs (U.T.)
			Start (U.T.)	End (U.T.)	Importance		
1956							
Mar 9	0740	10					
15	1150	20				Burst at 1150	
17	0005	15				Noise storm from 1312 (16th) to 0050 (17th) off scale	0010, 0030, S–SWF
22	2200	10					
Apr 19	2215	2·5				Noise storm	
May 6	2100	7·5	2030	2040	sub		
7	1750	5	1705		sub		
11	0035	10	2045	2220 (10th)	1	Type III burst at 0034; Noise storm from 2314 (10th) to 0534 (11th)	
24	2005	5	1800	1850	1		
Jun 11	2015	5	1935	1940	1+		
Jul 3	0330	5	after	0006	2	Type III burst at 0330	
7	0830	10	0545	1000	2		
18	2310	7·5	2040	2147	2	Bursts at 2107, 2312, 2318 off scale; and noise storm	
Aug 5	1340	5	1338	1358	1	From 3rd-11th, most energetic noise storm, 1202–1900	
6	0810	5	0510	0635	1	,,	
10	1210	5	1150	1205	1+	From 3rd-11th, most energetic noise storm, 1207–2548	1058–1119, S–SWF
31	1815	10	1655	1850	sub	Most energetic noise storm 1430–1730; off scale	1725–1815, G–SWF
Sep 4	2335	7·5	after	2145	1	Noise storm (1230–2510) off scale	S–SWF
15	1415	5	1405	1453		Noise storm	G–SWF
Oct 4	2115	5	1950	2020		Noise storm 1414–2420	S–SWF
5	2255	12·5		2115	sub	Noise storm 1300–2419	
6	1930	10	before	1958	,,	Noise storm 1301–2211	SWF
23	1910	5		1850	,,	Data not available	

TABLE 1 (*contd*)

Date	Time of burst (U.T.)	Voltage drop during burst	Solar Flares Start (U.T.)	Solar Flares End (U.T.)	Solar Flares Importance	Solar Radio Emissions outstanding occurrences (U.T.)	Radio fade-outs (U.T.)
1956							
Nov 10	2010	5	1915	1940	1	6th-14th Noise storm	
11	2330	7·5	2055	2219	1+	,,	
15	2250	5	2150	2220	2	Noise storm 1340–2218	
17	1950	5	1844	1901	1	Major bursts at 1721, 1848, 2035	SWF
28	0350	5					
Dec 1	0325	5				Bursts at 0247, 0250	0249–0329, SWF
19	2010	7·5	2008	2129	1	Major burst at 2005	
1957							
Jan 1	0720	7·5					
3	1755	5					1610-1640, SWF
18	1145	5	1139	1213	1		SWF
Feb 15	0440	5				Type III burst at 0440	
27	1630	7·5		1700	sub	Noise storm from 1621	
Mar 29	2225	7·5				Noise storm from 1438 of 28th for 2 days	
Apr 9	1235	5				Noise storm 1235-1935; burst at 1138	
10	1850	7·5		1800	sub	Noise storm from 1820; bursts at 1739, 1804	
15	1410	5	1410	1430	2	Major bursts at 1351, 1410	G-SWF
19	0040	10				Major bursts at 2253, 2303 on 18th	
25	1420	5	1313	1414	2	Bursts at 1313	SWF
27	0605	10	0401	0415	1		
27	1430	10				Noise storm 1205–2505	
May 1	1950	5					
15	1350	5	1245	1330	2	Type III burst 1347, bursts 1330; 1405 off scale	
17	1850	5	1726	1746	1	Bursts 1743—off scale	
30	1915	5	1848	2249	1+	Major bursts at 1742, 1816	1735–2000, SWF

TABLE 1 *(contd)*

Date	Time of burst (U.T.)	Voltage drop during burst	Solar Flares			Solar Radio Emissions outstanding occurrences (U.T.)	Radio fade-outs (U.T.)
			Start (U.T.)	End (U.T.)	Importance		
1957							
Jun 4	1415	5				Bursts between 1123–1243	
18	1510	10	1436	1440	1+	Burst at 1327	SWF
19	1250	5	1040	1203	2−	Noise storm	
20	2050	5	1834	1924	1	Type III bursts 2049, 2050, 2052, 2053	SWF
Jul 1	1635	5					
23	0910	10	0849	0945	1		0853–0906, SWF
27	2055	5	2050	2124	1+	Burst at 2055	
Aug 16	1410	5	1347	1410	1+		
24	1315	5	1240	1246	1+		
Sep 17	1840	7·5	1638	1745	1+		
Oct 9	2135	5	Earlier	2122	1		
27	2100	10	1931	2030	1	Noise storm 1300–2345	Slow S–SWF
Nov 2	1850	5				Noise storm 1500–2345, burst 1758	
5	2105	5		2054	sub	Noise storm 1947–2340	
12	0910	5	0830	0849	1		
24	1315	5	E0900	1123D	3		S–SWF
				1153	sub		
Dec 9	1415	12·5	0559	0907D	1	Burst at 1415	
				1457	sub		
11	0220	7·5	0210	0259	2		
14	2120	5		2040	sub	Series of bursts between 1420–2310	
26	1330	5	1300	1328	1+	Burst at 1329	1305–1342, slow S–SWF
1958							
Jan 12	2355	10				Series of bursts between 1425–2340	
13	0825	5	0737	0750	1		0742–0754, SWF

TABLE 1 *(contd)*

Date		Time of burst	Voltage drop during burst	Solar Flares			Solar Radio Emissions outstanding occurrences	Radio fade-outs
		(U.T.)		Start (U.T.)	End (U.T.)	Importance	(U.T.)	(U.T.)
	1958							
Feb	8	0550	35	0502	0708	1+	Bursts at 0407, **0551**	SWF 0407–0428; 0437–0648
	12	2255	10	2215	2322	1+		S-SWF
	13	1419	5	1309	1313	1		
	20	1605	5	1500	1510	1		
	27	1805	10	1741	1755	1		
Mar	8	2350	10	2336	2340	1	Burst at 2235; rise in base level from 2200–2440	
Apr	16	0540	10	0538	0551	1	Bursts at 0541, 0551	0534–0608, SWF
	19	1740	5	1724	1735	1+		
	30	1930	5				Bursts between 1928–1951	
May	26	0745	5	E0720	0801	1		
Jun	4	0055	5	0055	0108	1+	Bursts 0050, 0055; Noise storm 0047–0048	
	8	0415	5	0200	0500	1+		
Aug	7	1005	10		0853	sub		
	25	1035	10	0956	1042	2		
	31	1630	5	1544	1602	1	Noise storm 1535–1651; bursts 1545, 1701	
Sep	15	1135	10	1016	1040	1+		
	18	2235	10		2200	sub		
	27	1855	5				Type III bursts at 1829, 1847	
Oct	2	1015	10	1013	1042	1		
	3	1300	5	1140	1200	1		
Dec	31	1400	5	1312	1400	1+	Noise storm 1350–1400	