NEW EVIDENCE FOR LONG-LIVED SOLAR STREAMS IN INTERPLANETARY SPACE

D. A. Bryant,* T. L. Cline, U. D. Desai, and F. B. McDonald
Goddard Space Flight Center, Greenbelt, Maryland
(Received 12 July 1963)

Explorer-XII measurements of the intensity of interplanetary protons of energy greater than 3 MeV provide a method of investigating long-lived solar plasma streams. On two occasions (27 October 1961 and 1 December 1961) we observed an increase of the intensity of these particles. The increases were unaccompanied by a solar flare but occurred at the beginning of a magnetic storm and Forbush decrease near the time of central meridian passage of a region responsible for a flare and a solar proton event during the previous solar rotation. These increases were very small and probably could not have been detected with riometers. Chapman and Ferraro[1] have shown that a stream of neutral plasma emitted from the sun could cause magnetic storms. The recurrence of small magnetic storms over many 27-day cycles of solar rotation led Bartels[2] to postulate that such streams were continuously emitted from long-lived regions on the sun which he called *M* regions. Recent Mariner-II measurements[3] have shown the existence of solar plasma with a 27-day structure. Magnetic fields carried by solar plasma are thought to be responsible for Forbush decreases of cosmic-ray intensity which often occur during magnetic storms. Although no direct measurements of such streams have been made on Explorer XII by our detectors, the intensity increases of these >3-MeV protons require streams of plasma and magnetic fields to carry the protons from the vicinity of the sun or to accelerate them locally or to trap interplanetary solar protons remaining from a previous solar event. We feel that the presence of protons of a few MeV in the plasma does not imply that they are an intrinsic feature of the plasma but rather that it is a consequence of latent trapping regions in the plasma being filled with solar protons from a preceding event.

The instruments on Explorer XII, designed to study galactic and solar cosmic rays, have been described.[4] The measurements reported here were made while the satellite was outside the magnetosphere on the sunlit side of the earth.

Figure 1 shows the intensity of interplanetary protons of energy greater than 3 MeV, whenever it was above the quiet-time value, from 30 September 1961 to 28 October 1961. A class-3 solar flare on 28 September 1961 initiated a solar proton event.[4] Two days later, long after the solar proton intensity had passed through a maximum, there was an increase to a level about 10 times greater than that of the solar proton maximum. At the same time there was a series of geophysical disturbances (including a magnetic storm with a sudden commencement and a midlatitude auroral display) and a Forbush decrease of relativistic protons observed both by Explorer XII and by neutron monitors. These events indicated the arrival of a stream of solar plasma carrying a magnetic field. The enhanced proton intensity and the geophysical disturbances had subsided by about 7 October. The proton intensity remained at its normal quiet-time value from 7 October until 27 October when there was again an increase in the proton intensity accompanied by a Forbush decrease and geomagnetic storms. (Table I summarizes these events.)

The intensity increase on 27 October is unlike a solar proton event: It is not immediately preceded by a solar disturbance and the time constants of rise and decay are only a few hours.

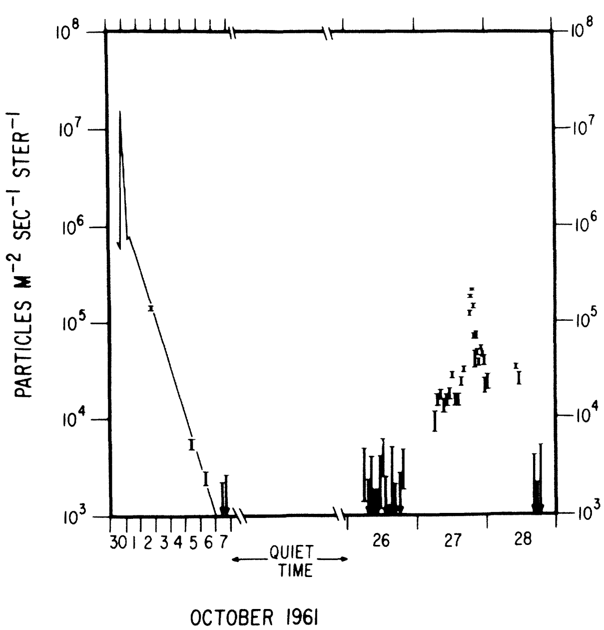

FIG. 1. Intensity of >3-MeV protons between 30 September and 28 October 1961. (Note that the time scales before and after the period during which the intensity remained at a quiet-time value are different.)

Table I. Summary of solar and geophysical events.

	Earlier group	Later group
Solar flare:		
Class	3 or 3+	>1
Time and date	2202 UT, 23 September 1961	1435 UT, 10 November 1961
Type-IV radio emission	2214 UT	1440 UT
Location	15°N, 29°E	19°N, ≈90°E
Forbush decrease:		
Duration	30 Sept. to ≈5 Oct.	No effects of two days' delay
Maximum amplitude: Explorer XII	8 %	
Deep River	2 %	
Geomagnetic storm:		
Duration	30 Sept. to ≈6 Oct.	No effects of two days' delay
Sudden commencement	2108 UT, 30 September	
Main phase	170 γ	
>3-MeV protons at Explorer XII:		
Onset time	1930 UT, 30 September	No effects of two days' delay
Maximum intensity	2×10^7/m^2 sec sr	
Recurrence phenomena associated with above events		
Forbush decrease:		
Duration	28 Oct. to ≈1 Nov.	1 Dec. to ≈4 Dec.
Maximum amplitude: Explorer XII	3 %	8 %
Deep River	2 %	4 %
Geomagnetic storms:		
Duration	26 to 27 October	1 Dec. to ≈4 Dec.
Sudden commencement	1940 UT, 26 October	...
Main phase	70 γ	145 γ
Duration	28 Oct. to ≈1 Nov.	
Sudden commencement	0820 UT, 28 October	
Main phase	280 γ	
>3-MeV protons at Explorer XII:		
Onset time	Between 26 and 27 Oct.	Before 0300 UT, 1 Dec.
Maximum intensity	2×10^5/m^2 sec sr	$>1.6\times10^5$/m^2 sec sr

Further, the arrival times are not a function of proton velocity since the shapes of the differential kinetic-energy spectra at onset and at maximum intensity are nearly the same, both having a power-law exponent between -4 and -5 in the range 3 to 10 MeV. We suggest that the active region of the sun responsible for the 28 September flare was the origin of a long-lived plasma stream that we encountered on 27 October, a full rotation of the sun after 30 September. If the continuous emission of this long-lived stream began during the active life of the region either on or before 28 September, the >3-MeV proton-intensity increase on 30 September was also caused by an encounter with that stream, but to ascribe the 30 September and 27 October proton increases to an identical phenomenon may be an oversimplification, since the earlier event may have been a result of a different and transient phenomenon (such as the shock wave postulated by Parker[5] or the magnetic bottle postulated by Gold[6]) caused by the solar activity of 28 September. During the rotation of the sun following October 27, the region stopped emitting plasma, since neither our records nor geophysical observations show an event 27 days later in November.

It seems likely that our observations of 27 October are closely related to the phenomenon of R rays as proposed by Müstel.[7,8] Müstel considers R rays which are thin and filamentary extensions of the outer corona above activity centers to be responsible for recurrent magnetic storms. Figure 2 is a schematic drawing made by Müstel showing these R rays. The fine structure in the proton-intensity increase on 27 Oc-

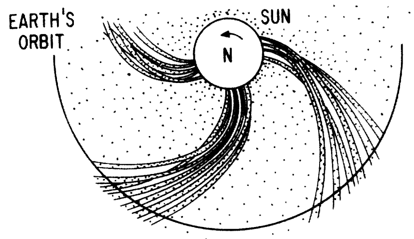

FIG. 2. Schematic drawing of R rays after Müstel.[8]

tober may have been a direct consequence of the filamentary structure of the rays.

The second of the two events we wish to mention occurred on 1 December 1961. It is similar to that of 27 October, and the relevant sequence of events is also outlined in Table I. On 10 November 1961 a flare accompanied by Type-IV emission occurred on the extreme west limb of the sun and initiated a solar proton event which was observed by Explorer XII. No magnetic storm, Forbush decrease, or >3-MeV proton increase was seen after the usual one- to three-day plasma transit time from the sun to the earth. Three weeks later on 1 December 1961, after 3/4 of a solar rotation, there was a Forbush decrease, a magnetic storm, and a >3-MeV proton event similar to that of 27 October, indicating the arrival of a solar plasma stream. The occurrence of the event of 1 December closely coincided with the central meridian passage of the active region which produced the flare on 10 November. This event again substantiates the picture of a long-lived plasma stream emanating from an active region of the sun, but in this case the timing was different owing to the different position of the parent flare on the sun.

There is another occurrence which could be the same phenomenon. On 7 September 1961 a solar proton event having an anomalously slow intensity decay was observed by Explorer XII, the details of which will be reported in a later paper. There was no observation at that time of a large flare or of Type-IV emission which can definitely be associated with this event, and there was no geophysical disturbance two days later. Eleven days later on 18 September there was a small increase of the intensity of >3-MeV protons similar in spectrum to those of 27 October and 1 December and unaccompanied by a flare. We speculate from these observations that the flare responsible for the solar proton event of 7 September occurred on the remote side of the sun and that the increase on 18 September was the same phenomenon as that observed on 27 October and 1 December.

---

*NAS-NASA Resident Research Associate.

[1]S. Chapman and V. C. A. Ferraro, Nature 126, 129 (1930).
[2]J. Bartels, Terrest. Magnetism Atm. Elec. 37, 48 (1932).
[3]C. W. Snyder and M. Naugebauer, Fourth International Space Science Symposium, COSPAR, Warsaw, Poland, 1963 (unpublished).
[4]D. A. Bryant, T. L. Cline, U. D. Desai, and F. B. McDonald, J. Geophys. Res. 67, 4983 (1962).
[5]E. N. Parker, Space Science Reviews 1, 62 (1962).
[6]T. Gold, J. Geophys. Res. 64, 1665 (1959).
[7]E. N. Müstel, Astron. Zh. 39, 418 (1962) [translation: Soviet Astron.–AJ 6, 333 (1962)].
[8]E. N. Müstel, Astron. Zh. 39, 619 (1962) [translation: Soviet Astron.–AJ 6, 488 (1963)].

QUANTITATIVE STUDIES OF OPTICAL HARMONIC GENERATION IN CdS, $BaTiO_3$, AND KH_2PO_4 TYPE CRYSTALS

R. C. Miller, D. A. Kleinman, and A. Savage
Bell Telephone Laboratories, Murray Hill, New Jersey
(Received 2 July 1963)

Recent theoretical discussions[1-4] of second-harmonic generation (SHG) have raised two questions which can be answered only by quantitative measurements of the second-order polarization tensor d. The first question is whether or not the d tensor obeys the symmetry proposed by Kleinman,[2] which would follow from the general symmetry derived by Armstrong et al.[5] if the nonlinear mechanism is lossless and dispersionless. The second question is whether or not large values of d result when the second-harmonic frequency ν_2 approaches the intrinsic absorption edge of the crystal as proposed by Lax et al.[3,4] The crystals chosen for this quantitative study are among the strongest known for SHG.[6]

We have measured the allowed components $d_{14} = d_{25}$ and d_{36} for KH_2PO_4, KD_2PO_4, and $NH_4H_2PO_4$