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RELATION OF COSMIC-RAY VARIATIONS TO INTERPLANETARY PLASMA OBSERVATIONS FOR THE EXPLANATION OF THE EVENT OF FEB. 15, 1978

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ABSTRACT

The very rapid, almost symmetric,spike-like cosmic-ray depression occurred on 15 February 1978 is also detected by the Athens neutron monitor at a cut-off rigidity of 8.7 GV. Combined neutron monitor measurements with interplanetary plasma and magnetic field data are used for the study of this event. It is suggested that this rare cosmic-ray depression was related with the solar flares on 13 February 1978, and was caused by one forward interplanetary shock wave rather than a shock pair.

1.- Introduction

During the common Forbush decrease starting with a SSC on 14 February 1978 at 21:35 UT (SGD, 1978a), an anusual very rapid and large cosmic-ray intensity decrease occurred.The total duration was 10 to 11 hours only. Surprisingly, north polar N.M. (Neutron Monitor) stations, f. ex. Alert, did not measure large depressions as other stations distributed at higher geografic latitudes, indicating in this way strong North-South anisotropies (Duggal and Pomerantz, 1978). The feature of these anisotropies was very similar to that persisted during the cosmic-ray storms on 4 August 1972 (Geranios, 1978).

In this analysis, we are not occupied with rigidity spectrum calculations or with cosmic-ray intensity gradients, done already successfully by other authors (Wada et al, 1978 and Iucci et al, 1978, respectively). We attempt to intercorrelate the cosmic-ray data with the interplanetary data recorded by Helios-1 and Helios-2 in order to find the shock conditions responsible for this Forbush decrease.

2.- Data analysis

As, in the rule, large cosmic-ray decreases originate from solar flares, we searched for such eruptions before the detection of the reported SSC on 14.2.1978. Flares accompagnied by type IV radiobursts are considered since this type of flares produces Forbush decreases (Iucci et al, 1977). The two considered here flares of this type occurred about two days prior the event. Both were in the McMath region 15139 and started almost simultaneously. The main characteristics are shown in Table I (SGD, 1978b). For the immediately following period up to six days we were able to find only one SSC (14.2.78 at 21:35 UT), after which the world-wide cosmic-ray depression begun. This sharp cosmic-ray depression for 12 neutron monitor stations covering a rigidity spectrum from 0.0 to 8.7 GV is shown in Figure 1.

TABLE I

FLARES, IV			S S C	FORB. DECREASE		SHOCK				SPACE CRAFT
DATE UT	REGION	IMP. OPT.	DATE UT	ATHENS N.M. DATE	MINIMUM MAGN.	DATE UT	SPEED KM/S	DIRECT. Φ(1)	-θ	
13.2.78 01:39	N13-W24	1B	14.2.78 21:35	15.2.78 17:00	12.4%	15.2.78 03:00	630	—	—	H-1
13.2.78 01:40	N19-W14	1B				15.2.78 02:55	650(2) 800	50(3) 55(4)	13 —	H-2

(1) Φ is the angle between the projection of the shock plane onto the ecliptic and the projection of the SUN-EARTH direction.
(2) Mean speed.
(3) Derived from the Coplanarity theorem.
(4) Estimated geometrically.

For a more accurate estimation of the minimum depression we took into account the depression due to the Dst variation. The maximum value occurred simultaneously with the cosmic-ray minimum and was of -118γ (SGD, 1978c). Applying the method proposed by Dorman (1974) we have found that 1% of the depression was due to the Dst decrease.

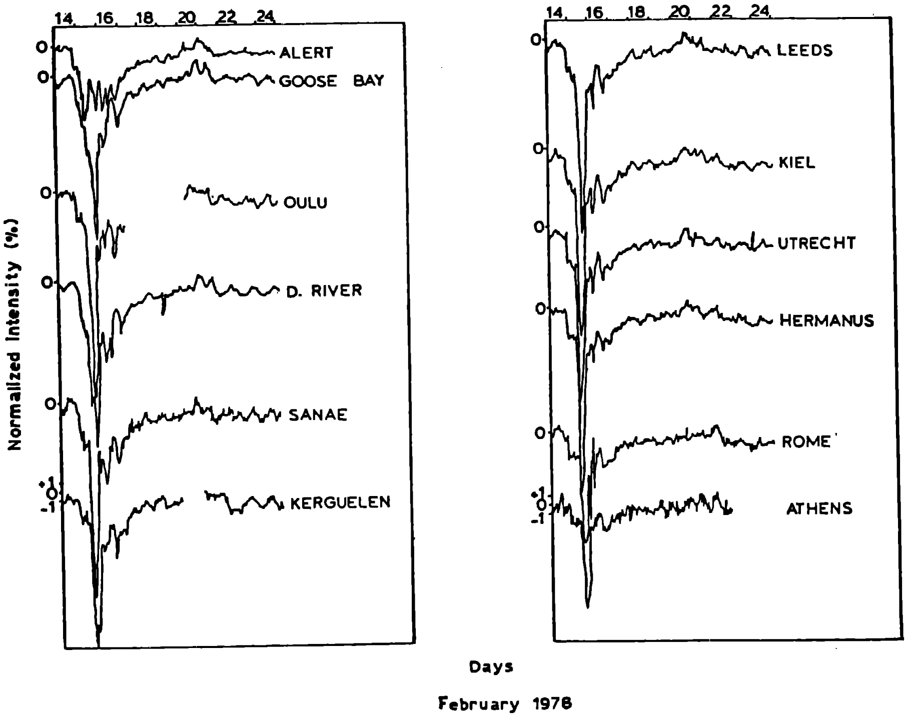

Fig. 1. The rapid cosmic-ray depression detected at neutron monitor stations covering a rigidity spectrum from 0.0 to 8.7 GV

Consequently, the cosmic-ray depression due to the interplanetary origin should be -11.35% instead of -12.4% at the Athens N.M.

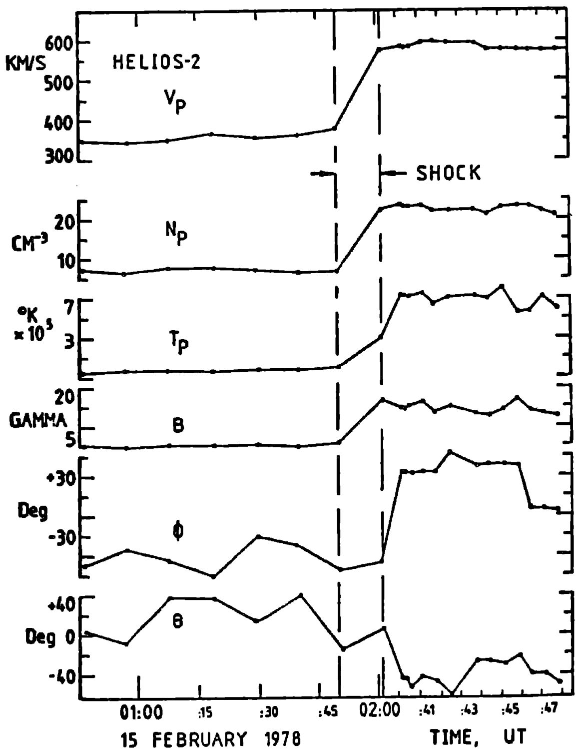

Fig. 2. The interplanetary plasma and magnetic field parameters at the shock front. Φ angles between -90° and +90° indicate fields toward the sun. Positive θ angles indicate fields directed above the ecliptic plane. The shock front passage should be placed between 01:50 and 02:02 UT.

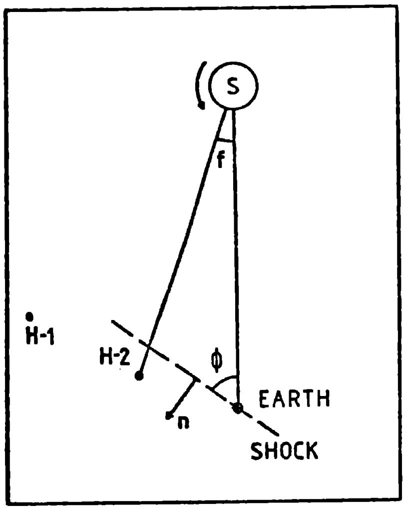

Fig. 3. The geometry for the estimation of the shock direction in the ecliptic plane

For the explanation of the spike-like Forbush decrease we have searched in interplanetary plasma and magnetic field data for possible shocks or shock pairs (Rosenbauer and Schwenn, 1979; Neubauer, 1979). At the time of the SSC (assumed as the signature of the passage of an interplanetary shock wave) both Helios were almost 1 AU (Astronomical Unit) far from the Sun and we were able to find one shock front only detected by these spacecraft five hours after the SSC. Any apparent shock pair related to this shock was not found. According to the hourly available plasma data of Helios-1 the shock was detected at 03 UT on 15 February 1978, while the time of the shock passage at Helios-2 was estimated more accurately (02:55, 15 February) since the available plasma and magnetic data were in a more detailed time scale. For Helios-2 the profile of the solar wind parameters just before and after the shock is shown in Figure 2. Assuming conservation of mass in the solar wind we calculated the shock speed separately accrding to Helios-1 and Helios-2 data

$$U = (n_2 v_2 - n_1 v_1) / (n_2 - n_1)$$

Where U the shock speed,
n the number density of protons,
v the solar wind speed

Indices 1 and 2 refer to values just prior and just after the shock, respectively. The calculated speeds are shown in Table I with the mean also hock speed estimated from the onset time of the flare and the shock detection by Helios-2.

Although both Helios were nearer to the Sun (0.95 AU) than the earth (1 AU) the shock front seemed to pass first the earth and then the Helios. From the time delay of the shock detection between the Earth and the Helios-2 we calculated the direction of the shock in the ecliptic plane. Because of the detailed magnetic field data we could indepentely calculate the shock direction applying the Coplanarity theorem according to which for a plasma with isotropic pressure, the direction of the shock propagation and the directions of the interplanetary magnetic field on both sides of the shock lie in the same plane (Colburn and Sonett, 1966)

$$\overline{\Delta B} \times (\bar{B}_1 \times \bar{B}_2) = \bar{q}$$

where $\overline{\Delta B} = \bar{B}_2 - \bar{B}_1$ and $\bar{q}$ the unit vector of the shock plane.

3.- Conclusions

According to the shortly described analysis it came out that the two simultaneous solar flares produced one and the same shock wave. The calculated shock speeds according to Helios-1 and Helios-2 plasma data are very close to each other indicating the common speed of the shock at two different observational points. This shock should have been decelerated in its way from the Sun to the interplanetary space since the mean speed clearly exceeds the momentary speed (Table I). Both methods, geometrical and Coplanarity, give the same direction of the shock propagation being westward from the Sun; this accordance fits also to the western location of the causitive flares.

The rapid recovery phase of the discussed cosmic-ray decrease may be due first to the western location of the related flares, as flares in the western limb give decreases with shorter recovery times than flares lying in the eastern or central limbs (Geranios, 1980), and second to the possible sharp defined trailing edge of the shock front.

This last point should further be searched taking into account detailed magnetic data from other also spacecraft (geocentric too).

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