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Forbush decreases of cosmic ray intensity without a shock wave

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Abstract: Forbush decreases of the cosmic ray intensity are produced either from a sudden solar eruption, as a CME, or from a high speed solar wind stream that comes from the Sun as a result for example of a coronal hole. The first events, in the most cases, are connected with a sudden storm commencement that reaches the Earth and creates a Forbush decrease of the cosmic ray intensity. The second ones can also create Forbush decreases of smaller amplitude but without the appearance of a sudden storm commencement. In this study the Forbush decreases that do not orientate by a SSC will be studied for the total time period that cosmic ray intensity data recorded at the neutron monitors are available (1957-2016). An analysis of these ground recorded events with solar and interplanetary associated parameters will be performed. Finally the possibility of observing precursory signals before the beginning of these cosmic ray decreases without a shock wave will be examined.

I. Introduction

As it is known Forbush decreases (FDs) are short time (from several hours to several days) decreases in galactic cosmic ray (CR) intensity within one to two days followed by a slow recovery typically lasting several days. Interplanetary shock waves, high-speed solar wind streams and magnetic clouds can be responsible for the registered variations of the CR intensity (Papailiou et al., 2012a). This study will be focused on the FDs that came from high-speed solar wind streams. The most possible source of these streams are the coronal holes. But there are some cases in which one's CME's arrival does not produce a sudden storm commencement (SSC) in the upper magnetosphere, so they are studied also.

The study of the precursors (pre-decreases or pre-increases) in the cosmic ray intensity usually preceding Forbush decreases, has served as the main subject for many investigations (e.g. Dorman, 2005, Kudela & Storini, 2006). Pre-decreases apparently result from the "loss cone" effect, in which the neutron monitor station is magnetically connected to the cosmic ray depleted region downstream of the shock (Belov et al., 1995), while pre-increases are caused by galactic cosmic ray acceleration at the front of the advancing disturbance, as the particles are being reflected from the approaching shock (Kudela & Storini, 2006).

A/A	Date - Time	Ampl (%)	Dst min (nT)	IMF (nT)	Vsw_max (km/s)	Axy_max (%)	Solar Source
1.	1998.08.26 07.00	7.2	-188	18.9	847	4.85	X 1.0 flare
2.	2000.11.22 11.00	3.2	-22	8.6	406	1.12	-
3.	2003.02.01 14.00	3.9	-72	13.1	787	2.39	Part. Halo CME
4.	2003.10.21 18.00	6.9	-61	11.8	744	1.99	CH_63
5.	2012.05.30 17.00	3	-5	9.9	444	1.96	Part. Halo CME
6.	2013.08.24 00.00	3.1	-23	8.8	521	3.45	CH_580
7.	2014.12.01 05.00	3.7	-11	14	592	1.83	CH_644

Table: FDs of the last two solar cycles 23 and 24 that presents precursors signs.

III. Selected Event of 21 October 2003

In this work one characteristic event will be presented that followed all the criteria and appeared precursor signs at the cosmic ray intensity. This Forbush decrease occurred at 21 October 2003 at 18.00 UT and had an amplitude of 6.9% at 10GV, by using the GSM method. It was the most active period that had ever been observed at the Sun (only one week after this event the most extreme FD occurred), but this specific FD came from a coronal hole, with the front of the Sun being quiet for about a week. It is about the coronal hole CH_63 (Fig. 1) that appeared at the solar disk from 12 to 18 of October 2003 and orientated as southern and trans equatorial hole.

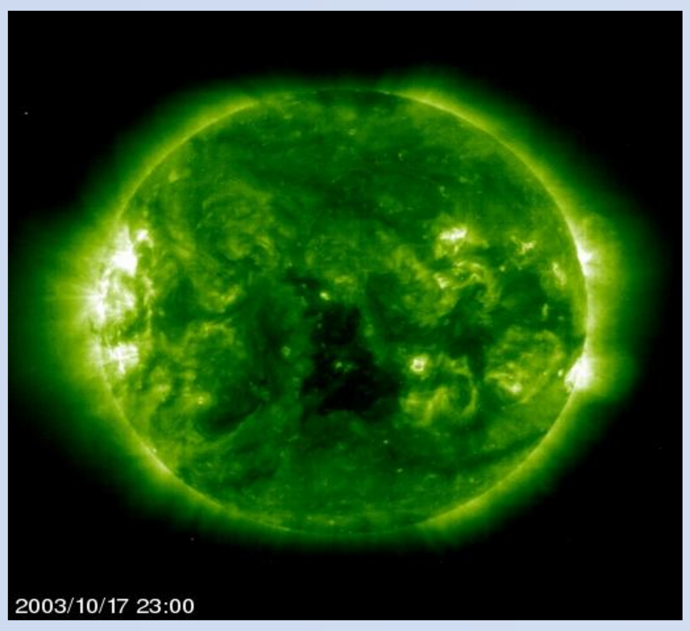

Fig. 1: The Sun on 2003.10.17 (sohodata.nascom.nasa.gov)

The high speed stream that had been created by the coronal hole traveled on the interplanetary medium for about three days and reached Earth at 21.10. The solar wind velocity had been disturbed with its maximum value at 744km/s (Fig. 2 upper panel), but typically the interplanetary magnetic field stayed regular at 11.8nT, as it is happened in the coronal holes (Fig. 2 lower panel).

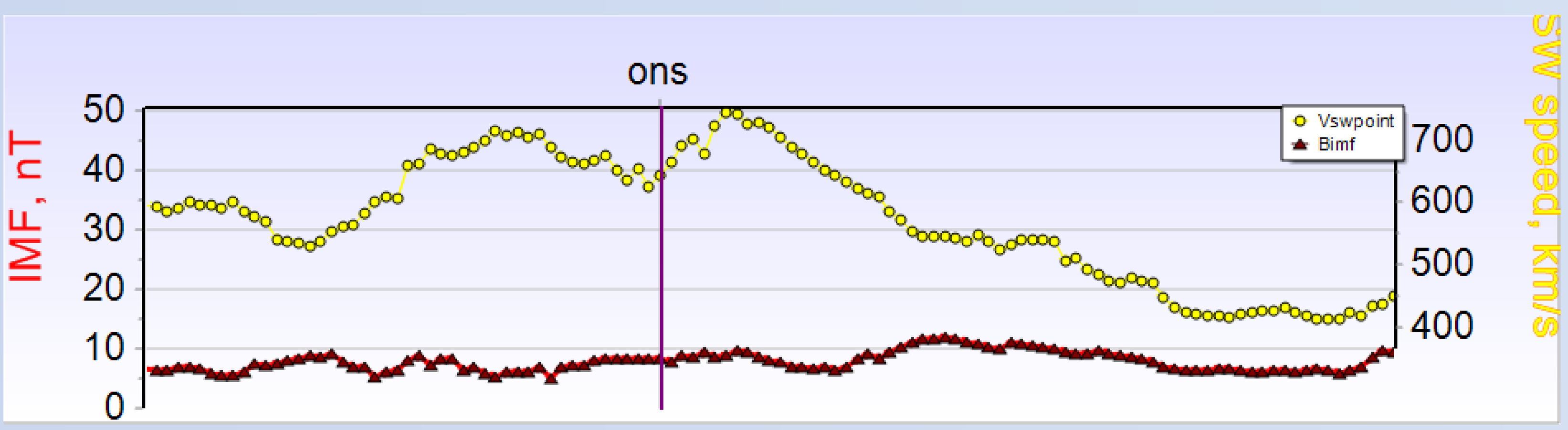

Fig.2: The variation of the solar wind velocity (upper panel) and of the interplanetary magnetic field (lower panel) before and after the FD start.

The precursors sings appeared as the study proceeding and the use of neutron monitor data was started. In Fig. 3, orange dots are hourly cosmic ray variations, green diamonds depict cosmic ray variations averaged within the sector ±20° and the curve is the fitted first harmonic of anisotropy (solar-diurnal variation) for data under consideration. There is a shift of pre-increase area from east to north. (orange points slightly below 90deg).

II. Data and Analysis

Hourly values of the CR density and anisotropy, obtained from the neutron-monitor network, were combined with solar, interplanetary and geomagnetic parameters in the database of the interplanetary disturbances and FDs created at the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation RAS (IZMIRAN; Belov, 2008). This database of FDs currently includes more than 7000 events over the period 1957 – 2016 and allows the selection of events with regard to different parameters and various statistical estimations. Using the global survey method (GSM), the density and first harmonic of anisotropy for the CR of rigidity 10 GV have been calculated (Asipenka et al., 2009) and entered into this database. Solar-wind parameters and geomagnetic indices were obtained from the OMNI database (http://omniweb.gsfc.nasa.gov). For studying the precursor effects in different Forbush events, the "Ring of Stations" (RS) method has been applied (Asipenka et al., 2009) to the hourly data of CR intensity recorded by the neutron-monitor stations of the worldwide network with cutoff rigidity Rc < 4 GV and latitudes <70°.

For this work, the whole period for that there is data from the neutron monitors available, was been examined. The events of FDs through the time period 1957 – 2016 have been studied and from them have been selected these which hadn't caused by a SSC. The amplitude of these events had to be greater than 2.99% and the anisotropy before the start of the FD was Axy > 0.9%. The chosen anisotropy can be considered as anomalous, since it exceeds the mean statistical value significantly (Belov et al., 2008).

Finally the interplanetary environment has to be quiet or with little disturbances before the FD's appearance. From 154 events that followed the first two criteria only 21 of them took place in a quiet interplanetary medium and the 80% of them present characteristic precursors signs. The Fds that followed the above criteria and obtained in the last two solar cycles presented in the Table on the left.

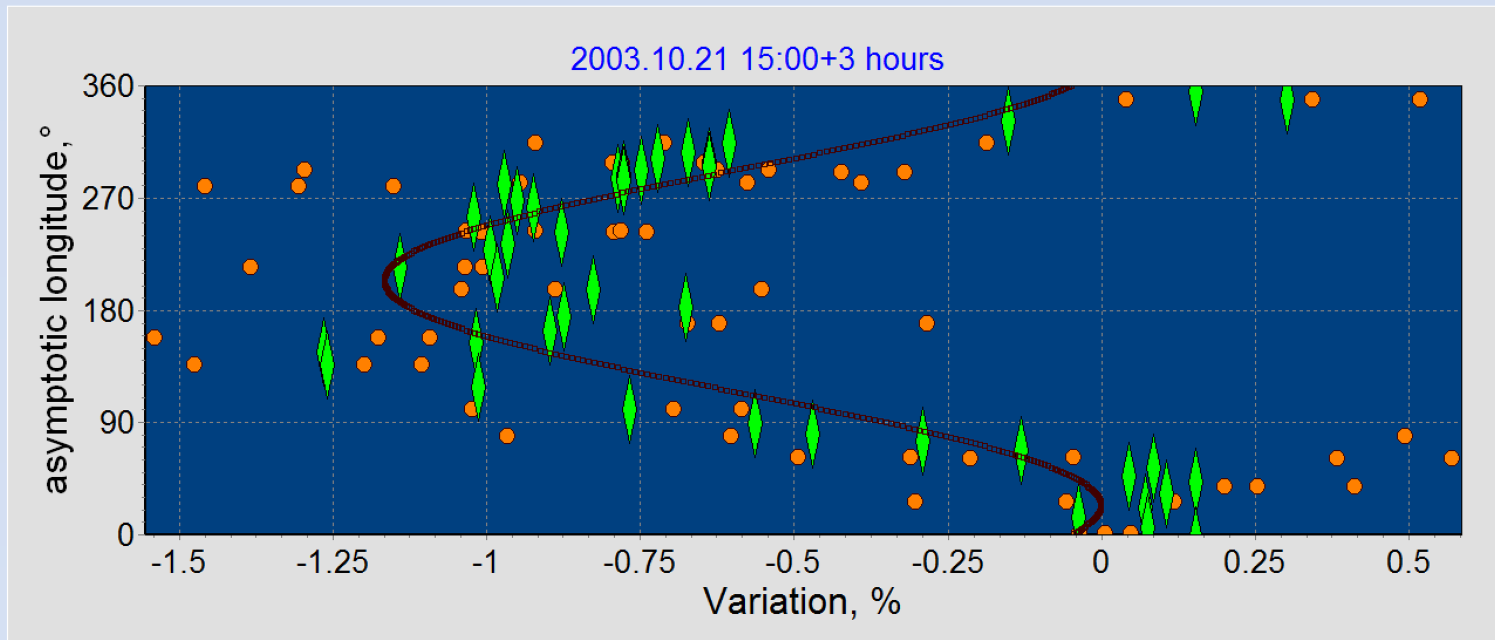

Figure 3: Dependence of cosmic ray variations on the asymptotic longitude of neutron monitors during the event on 21 October 2003.

The asymptotic longitudinal CR distribution diagram for this event is presented in Fig. 4. Here the CR intensity decreases, as measured by all neutron monitor stations used by the RS method, are depicted with red circles, while yellow circles refer to CR intensity increases relative to a quiet fixed period. The size of the circles is proportional to the size of the variation (Papailiou et al., 2012b). The precursor is a pre-decrease in the longitudinal zone 180°–360° before the onset of the event.

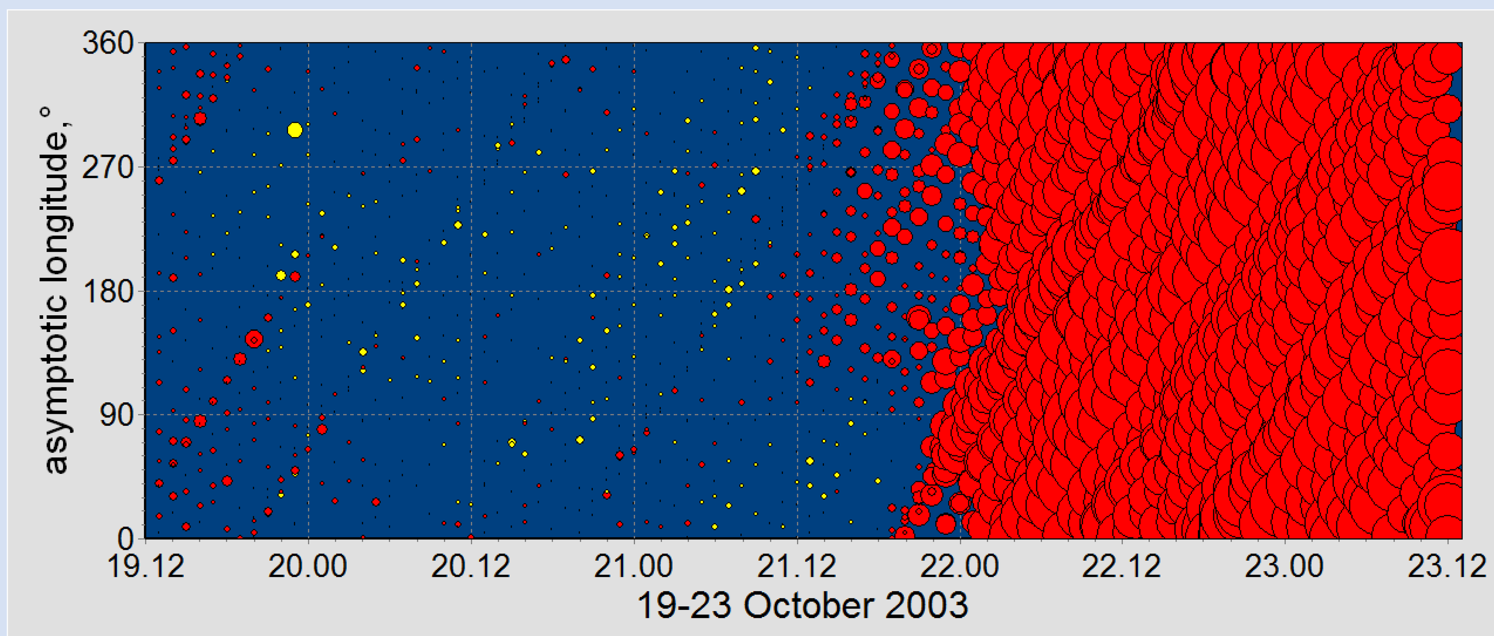

Fig. 4: The longitude-time distribution of the event on 21 October 2003.

The FD occurred on 21 October 2003 at 18.00 UT with an amplitude of 6.9% at 10GV, by using the GSM method. The CR intensity variation during this FD is presented in Fig. 5. As a result of the high speed stream a disturbed geomagnetic environment was observed (Dstmin=-61nT).

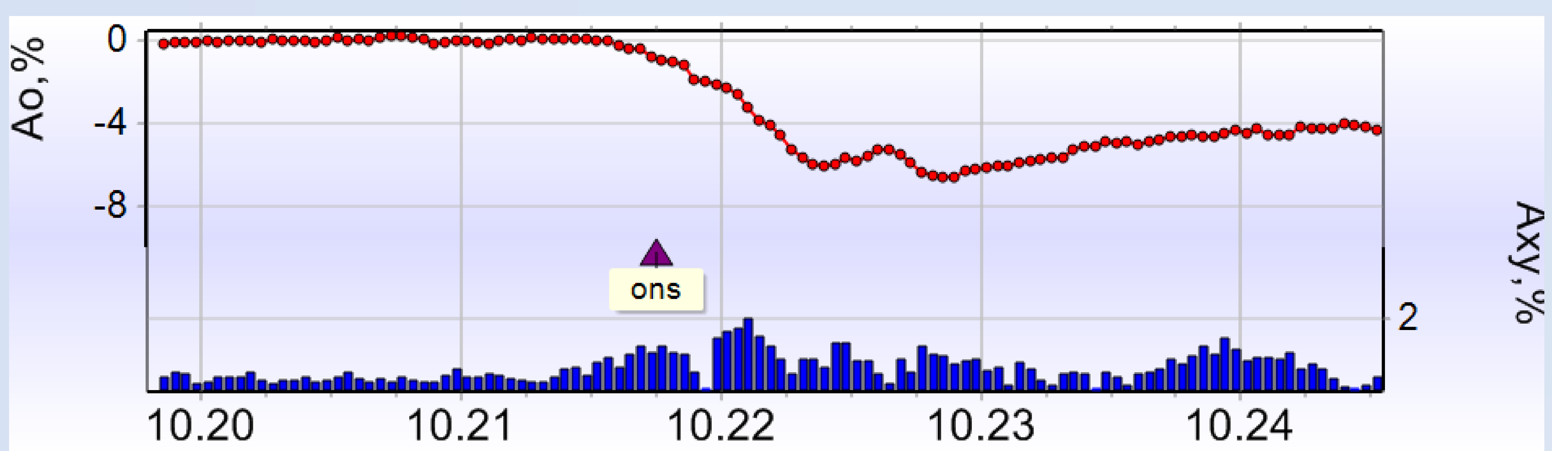

Fig. 5: The variation of the cosmic ray intensity of the FD of 21 October 2003.

IV. Conclusions

- The solar sources of the most FDs without a shock wave are coronal holes.
- The direction of the anisotropy was restricted. Maybe it was a quick acceleration inside a high speed stream, with a very abrupt interplanetary magnetic field with more radius lines. The B usually is regular inside a Coronal Hole as here.
- Untypical precursor sign as it was a pre-increase from east to north.
- Typically it is noted a quick transport from the movement of the structure in the interplanetary medium. As a result a disturbed geomagnetic environment was observed.

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