# COSMIC RAY EVENT ASSOCIATED WITH THE JANUARY 10, 1997 MAGNETIC STORM

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ABSTRACT

We investigate the trend of the nucleonic intensity of the cosmic rays during the large geomagnetic storm occurred on January 10, 1997, in connection with the disappearance of a Hα filament on the Sun. We present also the results of a statistical analysis based on cosmic ray and solar soft X-ray observations performed during 10 storms, similar to the January 10 event, occurred during a period of high solar activity (January 1969-January 1972).

## 1. INTRODUCTION

Recent work on coronal mass ejections, flares, and geomagnetic storms for the period 1969-1974 (Ref. 1 and references therein), using as proxy for CME the daily indices of the solar soft X-ray activity (0.1 – 0.8 nm), showed that the magnetospheric events due to a sudden disappearance of a solar filament are not associated with a significant increase of the solar X-ray flux, while those associated with chromospheric flares, accompanied by type IV radio emission (Type IV-SFs), are well related with outstanding long duration X-ray events (LDEs). In this context the January 10, 1997 magnetic storm (Dst hourly minimum: -78 nT) seems to pertain to the first class, because the soft X-ray flux recorded by GOES satellites was particularly low, with a weak series of events (A class) from January 1 to 15, 1997 (Ref. 2). The event was extensively investigated (e.g. Refs. 3-8, http://www-istp.gsfc.nasa.gov/istp/cloud_jan97/event.html) and, even if it is always difficult to associate interplanetary and solar events univocally, there is strong evidence that the CME observed at SOHO (1997-01-06: LASCO C2 & C3 coronagraphs) and the magnetic cloud detected by WIND (1997-01-10) are indeed related to the disappearance of a Hα filament, occurred after noon of January 6 (~23°S, 3°W of the central meridian). In this report, using cosmic ray measurements from stations of the world-wide network of detectors and from the Antarctic Laboratory for Cosmic Rays (acronym: LARC, King George Island; Ref. 9-10), we discuss the cosmic ray features associated with this event and describe the results of a statistical analysis for a series of probable similar events occurred during solar cycle n. 20.

## 2. THE NEAR-EARTH INTERPLANETARY SPACE IN THE PERIOD JANUARY 6-15, 1997

A detailed description of the January 10, 1997 interplanetary perturbation can be found in Ref. 3. It was strongly geoeffective with two recorded storm sudden commencements (SSC: 1997-01-10 at 01.04 UT and SSC/SI: 1997-01-11 at 01.16 UT). The passage of the magnetic cloud occurred between the two SSCs and was followed by a stream interface and a corotating plasma stream. Figure 1 illustrates the nucleonic intensity recorded by several cosmic ray stations in the period January 6-15, 1997 along with values of the Kp index. Filled triangles give: - the shock arrival (1), the cloud passage (2-3) and the stream interface (4). It is seen that the associated cosmic ray event of January 10 does not resemble a *classical Forbush decrease* (i.e. a large depletion in cosmic ray radiation; see, for instance Ref. 11). Rather, as reported by Bieber and Evenson (Ref. 12), there is an evident enhancement of the cosmic ray anisotropy. On the other hand, from January 11 on, the medium-term cosmic ray modulation seems to be the classical one which follows the passage at the Earth of high-speed solar-wind stream coming from a coronal hole (Ref. 11).

WIND observations indicated that ~94% of the magnetic cloud was below the solar equatorial plane at 1 UA, moving southward at ~ 15 km/s and radially outward at ~ 450 km/s (Ref. 3). The multi-station analysis of neutron monitor data (Ref. 12) showed that:

- observed anisotropies “on January 10-11 resulted from rapidly changing gradients associated with a cosmic ray density enhancement inside the cloud ... the peak of this enhancement passed to the south of the Earth”,
- McMurdo neutron monitor (lower panel of Figure 1) registered a near constant radiation level from January 7 up to about 9 h before the shock arrival at WIND, when a sudden enhancement of the counting rate (~ 1%) occurred,

should it be identified as a shock precursor? or as cosmic rays reflection from the approaching shock? If this is the case, certainly cosmic ray measurements will be a useful tool for space weather forecasting and STP model simulations.

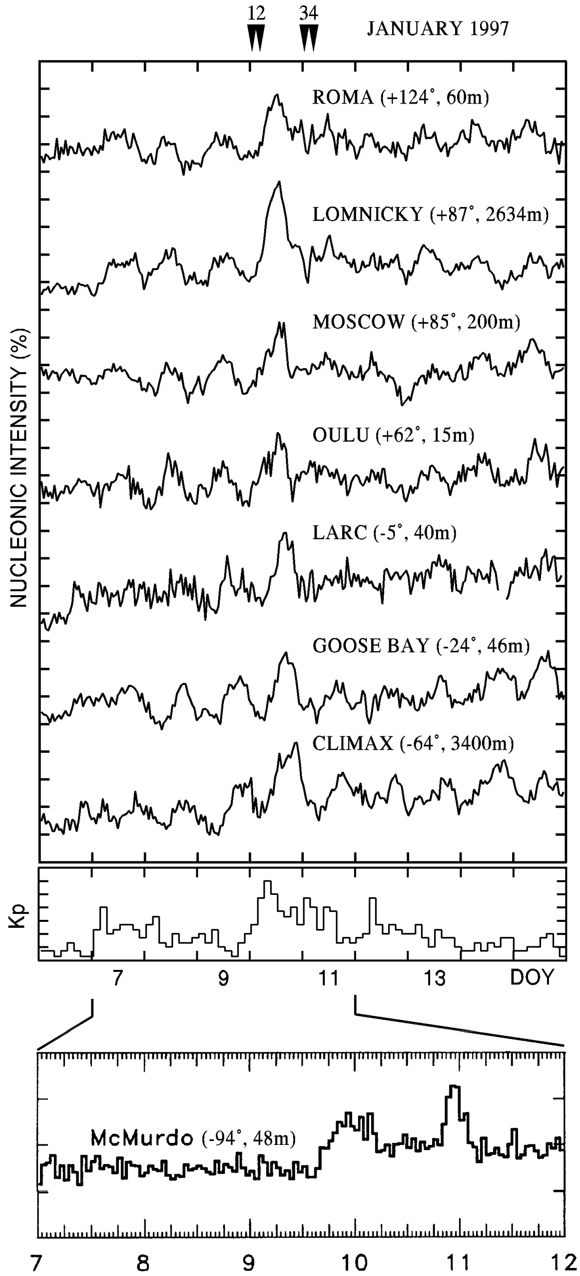


Figure 1. *Hourly nucleonic intensity recorded by 7 neutron monitors, sorted by the corresponding asymptotic eastern longitude (shown in parenthesis together with the altitude) as estimated for charged particles of 10 GV and assuming a quiet geomagnetic level (top); geomagnetic Kp-index (middle) and the nucleonic intensity recorded by the McMurdo detector (bottom, after Ref. 12). The y-axis tick markers for the nucleonic intensity correspond to 1%. Top triangles indicate:* 1 - *shock arrival,* 2 *and* 3 - *start and end of the magnetic cloud,* 4 - *stream interface.*

To this aim we compared the occurrence of the peak intensity detected on January 10 by the different cosmic ray stations. Going from Rome to Climax it is seen that the peak gradually delays, due to Earth rotation. Moreover, the peak occurs when the neutron monitor was looking about at 120°E from Sun direction, almost opposite to the theoretical direction of the Parker spiral at Earth (i.e. 45°W).

The above result reinforces Bieber and Evenson hypothesis. However, an accurate evaluation of the cosmic ray density and gradient in the near-Earth interplanetary space needs a detailed knowledge of the cosmic ray asymptotic directions during periods of different levels of geomagnetic activity: in fact, from Figure 1 it is clear that we have to take into account the strong variability of Kp level (between $3^-$ and 6). Moreover, Kudela et al. (Ref. 13) pointed out a possible increasing of the diurnal variability of the integral particle flux reaching a detector, when the geomagnetic activity level increases from a low level (Kp=0) to a high level (Kp>$5^-$). In conclusion, we stress the need to extend this type of analysis to events having similar characteristics (e.g. the July 28-29, 1977 event, Ref. 14) and to improve the evaluation techniques of cosmic ray anisotropies.

## 3. GEOMAGNETIC STORMS NOT ASSOCIATED TO TYPE IV-SF EVENTS.

Landi et al. (Ref. 1), looking for the connection between soft X-ray events and geomagnetic storms, found that events associated with Type IV-SF behaved quite differently than the others (Figure 2). In fact, the superposed epoch analysis, shown in Figure 2, reveals that a well defined peak in LDE index (2 days before the SSC) exists only for this kind of events. The associated average cosmic ray modulation (Forbush decrease) was of the *classical type*.

We investigate here, in more detail, the behaviour of the LDE index for the geomagnetic storms not associated with Type IV-SF, by selecting a subset of 10 events out of the 52 considered in the upper panel of figure 2. The choice was done considering only those events associated with short duration interplanetary streams, which were certainly not related to chromospheric flares and thus possibly associated to the disappearance of a filament (in performing this selection, we used the results shown in Fig.4 of Ref. 15). In addition, to study the X-ray characteristics during high levels of solar activity, our analysis was restricted to the period January 1969 - January 1972.

The results of the superposed epoch analysis of the 10 selected events are shown in Figure 3. The upper panel confirms that the level of the soft X-ray flux is low for both the LDE and IMP (impulsive) events (data source: Ref. 16) even in the maximum phase of solar activity. In fact, within the errors, no significant signals occur before the SSC.

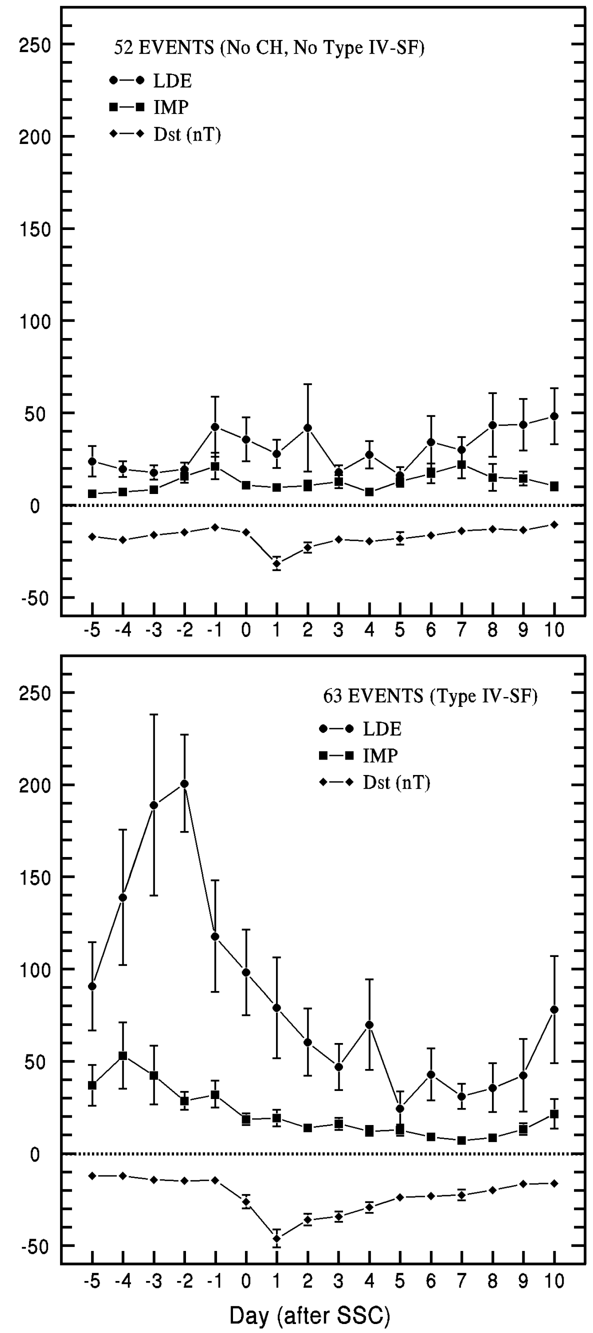


Figure 2. *Superposed epoch trends of the flare index for LDE, IMP (impulsive), and Dst indices versus time during 52 geomagnetic perturbations not associated with Type IV-SFs and coronal holes on the Sun (upper panel) and during 63 storms related to Type IV-SFs (lower panel). The zero day in each plot corresponds to the SSC occurrence (after Ref. 1).*

The lack of any peak in the chromospheric flare index (Hα-FI; data source: Ref. 17) shown in the bottom panel, confirms that we have indeed eliminated Type IV-SF events. The bottom panel shows also the trend of the isotropic cosmic ray intensity (ISO-CR) derived from polar-looking detectors (data source: Ref. 18). Here, only a signal of about 0.7% can be observed for three days after the SSC. Moreover, the low level of Hα-FI lasting from days 3 to 7 suggests that several of the events considered here are of the type "magnetic cloud preceding an interaction region" (Ref. 19), i.e. of the January 10, 1997 type.

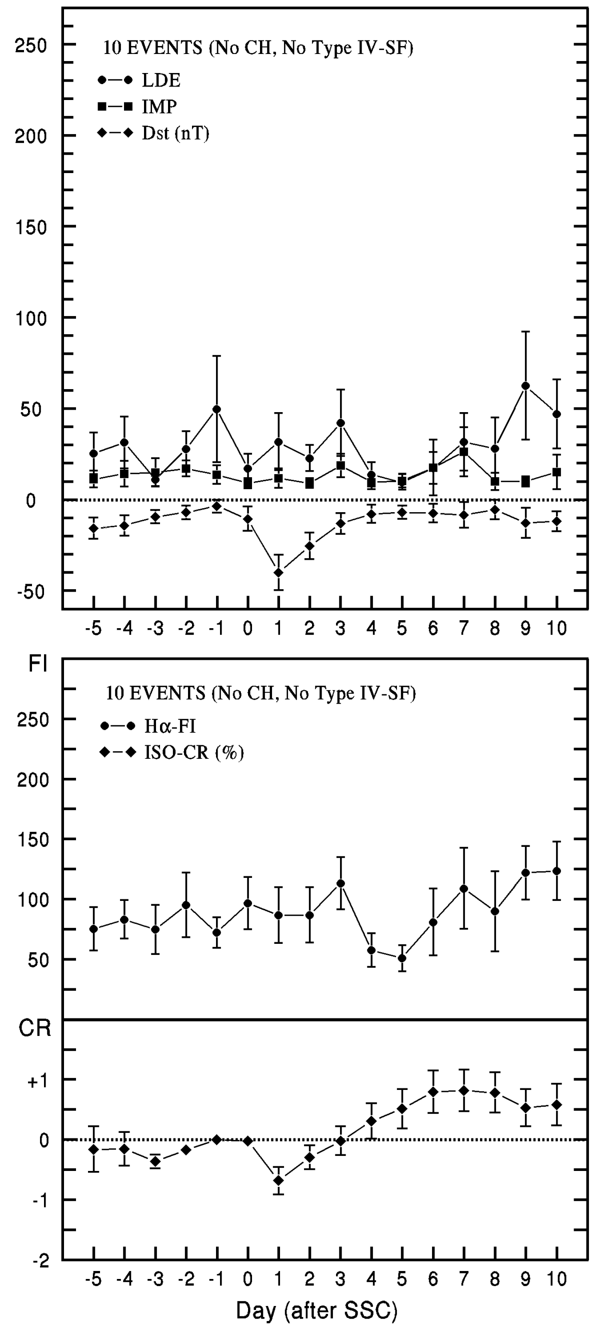


Figure 3. *Superposed epoch trends of the flare index for LDE, IMP, and Dst (upper panel) and for the Hα-FI and ISO-CR (lower panel) versus time during 10 geomagnetic perturbations not associated with Type IV-SFs or coronal holes on the Sun.*

4. CONCLUDING REMARKS

In this paper we emphasise the relevance of cosmic ray measurements for a better understanding of Space Weather. Moreover, we suggest that soft X-ray events can help in identifying different categories of geomagnetic storms.

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6. REFERENCES

1. Landi R & al 1998, Coronal mass ejections, flares, and geomagnetic storms, *J. Geophys. Res.*,**103**, A9, 20553-20559

2. *Solar Geophysical Data* 1997, NOAA, U.S. Depart. of Commerce, Boulder, U.S.A.

3. Burlaga L & al 1998, A magnetic cloud containing prominence material: January 1997, *J. Geophys. Res.*, **103**, A1, 277-285

4. Lu G. & al 1998, Global energy deposition during the January 1997 magnetic cloud event, *J. Geophys. Res.*, **103**, A6, 11685-11694

5. Webb D F & al 1998, The solar origin of the January 1997 coronal mass ejection, magnetic cloud, and geomagnetic storm, *Geophys. Res Ltr.*, **25**, 14, 2469-2472

6. Goodrich C C & al 1998, An overview of the impact of the January 10-11, 1997 magnetic cloud on the magnetosphere via global MHD simulation, *Geophys. Res Ltr.*, **25**, 14, 2537-2540

7. Tsurutani B T & al 1998, The January 10, 1997 auroral hot spot, horseshoe aurora and first substorm: A CME loop?, *Geophys. Res Ltr.*, **25**, 15, 3047-3050

8. Wu S T & al 1997, Dynamical evolution of a coronal mass ejection (CME) to magnetic cloud: A preliminary analysis of the January 6-10, 1997 CME observed by LASCO/SOHO, Proc. V SOHO Workshop on "The Corona and Solar Wind near minimum activity" *ESA SP-404*, 739-744.

9. Storini M & Cordaro E G 1997, Italia/Chile collaboration for LARC, *Nuovo Cim.*, **20C**, 6, 1027-1032

10. Storini M & al 1995, Cosmic ray asymptotic directions for Chilean neutron monitors, *Proc. 24th Int. Cosmic Ray Conf.*, **4**, 1074-1077

11. Storini M 1990, Galactic cosmic-ray modulation and solar-terrestrial relationships, *Nuovo Cim.*, **13C**, 1, 103-124

12. Bieber J W & Evenson P 1998, CME geometry in relation to cosmic ray anisotropy, *Geophys. Res Ltr.*, **25**, 15, 2955-2958

13. Kudela K & al 1998, Access of cosmic rays to Lomnický Štít and Rome stations, in J. Medina (ed.), *Proc. 16th European Cosmic Ray Symposium*, Alcalá, Spain (in press)

14. King J H & al 1982, On the complex state of the interplanetary medium of July 28-29, 1977, *J. Geophys. Res.*, **87**, A8, 5881-5887

15. Iucci N & al 1979, High-speed solar-wind streams and galactic cosmic-ray modulation, *Nuovo Cim.*, **2C**, 4, 421-438

16. Antalová A 1996, Daily soft X-ray flare index (1969-1972), *Contr. Astron. Obs. Skalnaté Pleso*, **26**, 2, 98-120

17. Knoška Š & Petrášek J 1984, Chromospheric flare activity in solar cycle 20, *Contr. Astron. Obs. Skalnaté Pleso*, **12**, 165-260

18. Pase S & Storini M 1993, Isotropic intensity and axial cosmic-ray anisotropy derived from polar-looking neutron-monitor stations, *Report CNR/IFSI-93-24*, Istituto di Fisica dello Spazio Interplanetario, Frascati, Italy

19. Klein L W & Burlaga L F 1982, Interplanetary magnetic clouds at 1 AU, *J. Geophys. Res.*, **87**, 2, 613-624