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Relationship between speed of Full Halo Coronal Mass Ejections and Cosmic ray intensity

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Abstract

Halo and Full Halo CMEs (Coronal Mass Ejections) events observed by Solar and Heliospheric observatory (SOHO) mission are used to study their effects on cosmic ray intensity variations during 2009 to 2012, which correspond to ascending phase of recent solar cycle 24. It is found that the speed of HCMEs (Halo Coronal Mass Ejections) are significantly negative correlated with cosmic ray intensity. All the FHCMEs (Full Halo Coronal Mass Ejections) having the linear speed ≥ 1000 km/s produce transient decrease in cosmic ray intensity on short-term basis. The results of analysis indicated that the magnitude of decrease in cosmic ray intensity is large for high speed FHCMEs (Full Halo Coronal Mass Ejections) in comparison with low speed FHCMEs (Full Halo Coronal Mass Ejections).

Key word: Full Halo Coronal Mass Ejection, Cosmic rays, Transient decrease, Solar activity.
PACS Nos. 96.50S; 96.60 ph; 96.50Wx

1. Introduction

Coronal Mass Ejections (CMEs) in which large-scale expulsion of plasma are seen as bright arcs in coronagraph images are the most stunning activities of the solar corona. These episodic expulsions of mass and magnetic fields from the solar corona into the interplanetary medium may have masses of the order of 10^{15} gram and may liberate energies up to 10^{30}-10^{32} ergs[1-2]. CMEs (Coronal Mass Ejections) which appear to surround the occulting disk of the observing white light coronagraphs in the sky plane projection and expand rapidly are known as HCMEs (Halo Coronal Mass Ejections). As a special type, those surrounding the occulting

disk i.e. with an apparent angular width of 360^0 are called the full halo CMEs[3]. It has been observed that the average apparent velocity of halo CMEs is fairly higher than that of normal CMEs[4-5]. After the identification of CMEs in 1974 and observations of CME events from 1996, it is accepted its role in interplanetary disturbances and perturbation in interplanetary magnetic field. Now it is essential to study the role of CMEs in cosmic ray modulation. Cane[6] reported a significant relationship between CMEs and cosmic ray intensity variations. Shrivastava[7] argued that the CMEs in association with major solar flares play a better role in short-term cosmic ray decreases. The relationship found between HL CMEs and the reversal of global solar magnetic field and the relationship of the latter with the drift of galactic cosmic rays in to the heliosphere suggest that HL CMEs may play an important role in long-term cosmic ray modulation. It is known that the cosmic ray intensity measured on the Earth is related to solar activity cycle. The solar magnetic field flips every 11 years and the number of sunspots and CMEs rises and falls twice in each complete 22 year cycle. The cosmic ray intensity on earth also peaks twice every 22-years in time with the solar cycle. The cosmic ray researchers suspect that the alternating pattern is rooted in the reversal of the sun's magnetic field every 11-years. Cosmic rays preferentially approaches the sun from the direction of its poles at the epoch of A > O, when the magnetic field line are pointing out of the northern hemisphere, when the magnetic field flips (A < O), cosmic rays tend to approach equatorial region of the sun.

Cliver and Ling[8] have discovered a quirk in this pattern and they believe that CMEs could be responsible for it. They suggest that anti-correlation between low latitude open magnetic flux and cosmic ray intensity occurs because CMEs open new flux to the interplanetary medium. Lara *et al*.[9] found a high correlation between high latitude CMEs and GCR during positive cycles. Their finding is in agreement with the Galactic Cosmic Ray (GCR) transport theory, which states that the inflow of GC rays dependent on the solar magnetic polarity. cosmic rays interact with CMEs when they approach the equator. This indicates that the interaction of cosmic rays with the strong magnetic fields of CMEs affects the cosmic ray intensity at neutron monitor energies.

Our aim of this work to examine the relationship of occurrence of halo/full halo CMEs with cosmic ray intensity during 2009 to 2012 correspond to ascending phase of solar cycle 24. linear speed of full halo CMEs are considered, in this work to derive the effects of full halo CMEs on cosmic ray intensity.

2. Data analysis :

The halo CME data used in this analysis downloaded from NASA websites (http://gsfc.nasa.gov/CME_list/halo/helo html). Similarly full halo CME data downloaded from website (http://www.lmsal.com/cgi-dlapason/www-get cme-list.sh). In this study we have also used data of the mean monthly/yearly sunspot numbers (Rz). The temperature and pressure corrected daily values of cosmic ray intensity from Moscow neutron monitor (latitude 55.47 N, Longitude 37.32 E, Altitude 200 m, geomagnetic cut-off rigidity 2.43GV) have been used. Chree analysis of superposed epoch method has been applied on the pressure corrected average cosmic ray intensity data with respect to full halo CMEs. The days of Forbush decreases have also been removed from the analysis to avoid their influence in cosmic ray variation. The full halo CMEs are divided into three categories on the basis of their linear fit speed.

(i) Nine events possess their linear speed ≤ 1200 km/s and are called low speed FHCMEs (Full Halo Coronal Mass Ejections).

(ii) Ten events possess their linear speed $1200 \leq V_{Fhcme} \leq 1800$ km/s and are called medium speed FHCMEs (Full Halo Coronal Mass Ejections).

(iii) Seven events possess their linear speed ≥ 1800 km/s and are called high speed FHCMEs (Full Halo Coronal Mass Ejections).

3. Results and Discussion

Coronal Mass Ejections (CMEs) traveling at different speeds tends to merge into what are known as

complex ejecta, which are seen often in the interplanetary medium during times of high solar activity[10], Increase of the magnetic field during the passage of an ejecta of 1 AU is related to the decrease in cosmic ray intensity[11]. The halo CMEs, may be directed towards or away from the Earth and appear as expanding, circular brightening surrounding the occulted of the coronagraph.

LASCO coronagraph due to their improved sensitivity and larger field of view have recorded several halo CMEs. Halo CMEs which are associated with major solar flares are generally showed higher speeds and smaller accelerations[12]. High speed CMEs generally create shocks, which are found to be responsible in Forbush type cosmic ray decreases. Recently Shrivastava et al[13] studied the association of Halo and Partial Halo CMEs and their effects on cosmic rays for the period of 2001 to 2006, which cover the declining phase of solar cycle 23. They have reported that the major solar flares in association with CMEs and located in western hemisphere of solar disk are more effective in producing Fds. In recent studies, it has been found that the speed of CMEs are also play an important role in cosmic ray modulation[14].

Parnahaj *et al.*[15] clearly investigated a connection between halo CME speed and CR forbush decrease amplitudes. In the present work first we have derived the relationship of speed of halo and full halo CMEs with cosmic rays and solar activity on long-term basis. We have choose all the events of FHCMEs for the period of 1996 to 2012, covering the solar cycle 23 and ascending phase of solar cycle 24. Out of 539 HCMEs. 150 are identified as full halo CMEs which have angular with 360^0. Figure 1 shows the frequency distribution annual number of halo and full halo CMEs. In can be inferred from the figure 1 that two types of CME events show large increase during the period of high solar activity period. FHCMEs are observed less number in comparison to HCMEs.

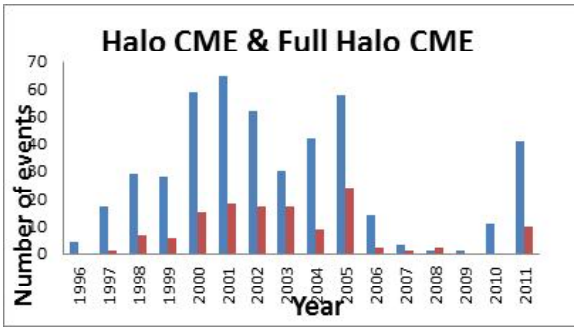
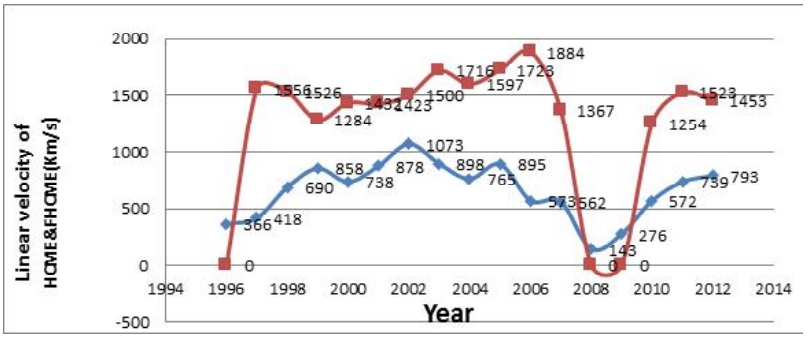


Figure 1: Shows the frequency histograms of number of events of HCMEs and FHCMEs.

Figure 2 shows the yearly mean values of linear speed of halo and full halo CMEs. Figure shows the linear plot to annual mean values of cosmic rays in percent deviation along with sunspot numbers Rz. As usual sunspot shows anti phase with cosmic rays. In same figure, speeds of HCMEs and FHCMEs follow the trend of solar activity.



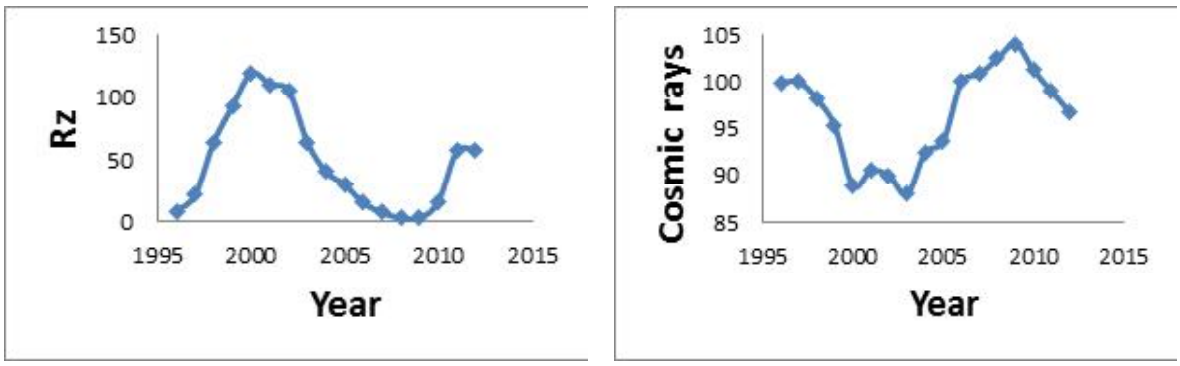


Figure 2: Shows the yearly mean values of cosmic rays, sunspot numbers (Rz), linear velocities of HCME and FHCMEs.

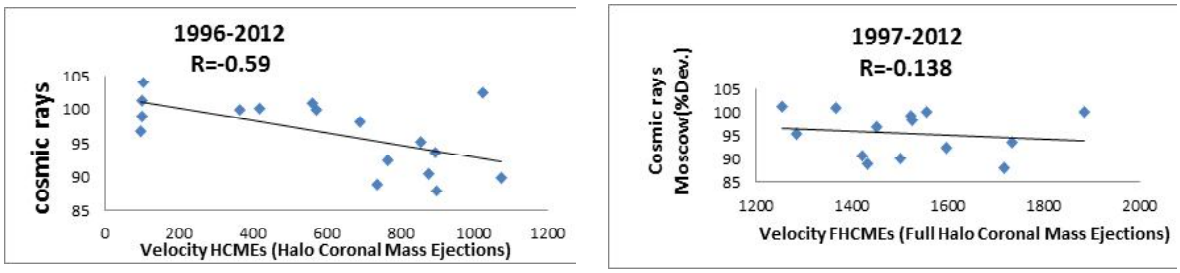


Figure 3: Crossplot between the yearly mean values of HCMEs and FHCMEs speed with cosmic rays (Moscow neutrons).

Figure 3 shows the cross plot between speeds of HCMEs (Halo Coronal Mass Ejections) and FHCMEs (Full Halo Coronal Mass Ejections) with cosmic ray intensity in percent deviation. Moscow cosmic ray intensity has been assumed to be 100% for the year 1986. The figure quite clearly reveals the anti correlation of linear speed of Halo CMEs with cosmic rays. However FHCMEs speed shows poor correlation with cosmic rays. The results of this correlative analysis indicates a possible role of CMEs speed in cosmic ray modulation process. Correlative analysis also indicates that short-term effects of FHCMEs should be also investigated for this interval. Further, we have divided all the FHCMEs into three categories on the basis of their linear speed. These categories are (i) $V_{fhcme} \leq 1200$ km/s (ii) $1200 \leq V_{fhcme} \leq 1800$ km/s and (iii) Vfhcme ≥ 1800 km/s. To determine the average behaviour of short-term changes in cosmic ray intensity, we have adopted the chree method of superposed epoch and on carried out the analysis for selected events Events associated with Fds or GLEs are excludrd from the analysis. Zero days are taken as the onset days of FHCMEs. The results of chree analysis for days -4 to 8 days have been plotted in figure 4 as a percent deviation of data from Moscow neutron monitor. The deviation for each event is obtained from the overall averages of 13 days. Significant transient decrease in cosmic ray intensity is observed. A maximum decrease is observed after 6 days after the onset days of FHCMEs. It indicates a significant effect of FHCMEs on cosmic ray intensity variation on short-term basis.

Further we have performed the similar chree analysis on the considering of Full Halo CMEs in three categories on the basis of their linear fit speed earlier. Figure 5 shows the results of chree analysis of first category of Full HCMES, which have linear speed d”12000 km/s. As depicted in figure 5, the decrease in cosmic ray starts from +1 day and reaches a maximum decrease immediately on 2nd and 3rd days after the onset of

CMEs. Similar analysis is also done for the second category of Full halo CMEs. Result of analysis is shown in figure 6 which almost support the finding of first category. The decreases in cosmic rays are confined only three days, just after the onset day of CME. However, slight larger decreases are noticed in comparison to first category. Results of bigger Halo CMEs are depicted in figure 7. As depicted in figure 7., the decrease in cosmic ray intensity starts +2 days and reaches a maximum decrease +5 day after the onset of Full halo CMEs. It is seen from the comparison of figures 5, 6 and 7 that the higher speed range full halo CMEs produce larger decrease in cosmic ray intensity.

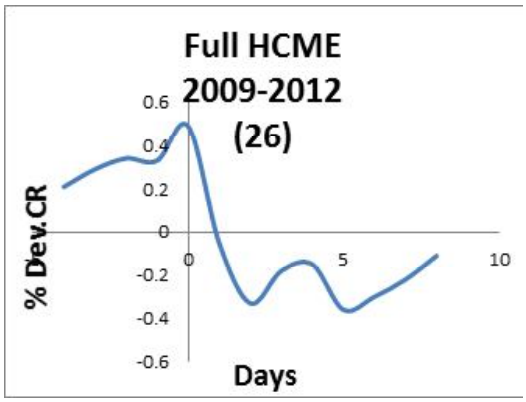


Figure 4: Results of Chree analysis of superposed epoch from -4 to 3 days with respect to zero epoch days for the period of 2009 to 2012. The percent deviation of daily mean cosmic ray intensity (Moscow neutron) for a number of events (noted in parantheses). Zero day correspond to onset day of FHCMEs events.

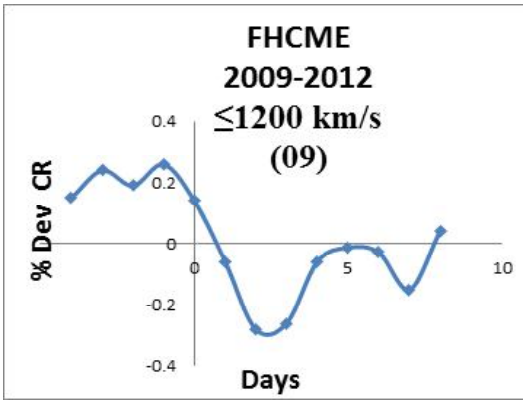


Figure 5: Same as Figure 5 but for the FHCMEs having speed ≤1200 Km/s

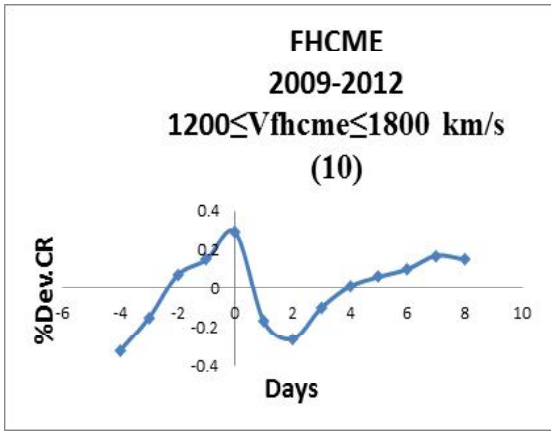


Figure 6: Same as Figure 5 but for the FHCMEs having speed $1200 \leq V_{FHCME} \leq 1800$ Km/s

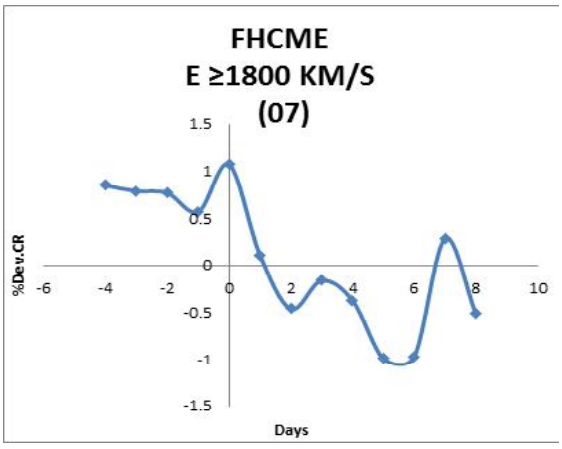


Figure 7: Same as Figure 5 but for the FHCMEs having speed ≥ 1800 km/s

It is expected that large transient decreases are caused by Full Halo CMEs and their associated shocks. Full HCMEs have large linear speed (≥1000 km/s). In front of such a high speed mass ejection, a strong shock wave must develop. It has been suggested that shock waves play an important role in cosmic ray modulation by acting a barrier in path of cosmic ray particles. Thus it may be interred that speed of halo and full halo CMEs are more effective modulators of cosmic ray intensity.

4. Conclusions

From the above discussion of results, the following conclusion can be drawn.

(i) The linear speed of Halo and Full Halo CMEs follow the long-term 11-year variation trend of sunspot solar activity cycle. As per Figure 2, speeds of HCMEs (Halo Coronal Mass Ejections) and FHCMEs (Full Halo Coronal Mass Ejections) follow the trend of solar activity

(ii) A significant negative correlation is observed between linear speed of HCMEs (Halo Coronal Mass Ejections) and cosmic ray intensity. However FHCMEs (Full Halo Coronal Mass Ejections) speeds are poorly correlated with cosmic rays on long-term basis.

(iii) FHCMEs (Full Halo Coronal Mass Ejections) produce short-term decreases in cosmic ray intensity.

(iv) FHCMEs (Full Halo Coronal Mass Ejections) having linear velocity ≥ 1800 km/s are to be more effective in producing cosmic ray transient decrease.

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