Variations in cosmic ray intensity and interplanetary parameters on the onset of coronal mass ejections

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Abstract. Coronal Mass Ejections (CMEs) are plasma eruptions from the solar atmosphere involving previously closed field regions, which are expelled into the interplanetary medium. Such regions and the shocks, which they may generate, have pronounced effects on cosmic ray intensities both locally and at some distance away. The present study deals with the influence of different types of CMEs on cosmic ray intensity and interplanetary parameters. The data of ground based neutron monitor and CME events observed with instruments onboard and Wind spacecraft have been used in the present analysis. The method of superposed epoch (Chree) analysis has been used to the arrival times of these CMEs. Further a correlative analysis has also made so as to study the correlation between different heliospheric parameters along with cosmic ray intensity during the onset of different types of CMEs. The role of CMEs in long term modulation will also be discussed.

Keywords: Coronal mass ejections, cosmic ray, sun

1 Introduction

Earlier, it was thought that solar flares were responsible for major interplanetary particle events and geomagnetic storms. However, recently we have seen an important paradigm shift such that now coronal mass ejections (CMEs), not flares, are considered the key causal link with solar activity. CMEs are plasma eruptions from the solar atmosphere involving previously closed field regions, which are expelled into the interplanetary medium. Such regions, and the shocks which they may generate, have pronounced effects on cosmic ray densities both locally and at some distance away. These energetic particle effects can often be used to identify CMEs in the interplanetary medium, where they are usually called ‘ejecta’. When both the ejecta and shock effects are present the resulting cosmic ray event is called a ‘classical, two-step’ Forbush decrease.

Bieber and Evenson [1] noticed strong enhancements of the cosmic ray anisotropy before and during the January 1997 CME/magnetic cloud. From a multi-station analysis of neutron monitor data, they conclude that B×□n drift is a primary source of CME-related anisotropies for 5 GeV cosmic rays. Evolution of the cosmic ray density and density gradients is closely linked to magnetic properties of the ejecta, and provides information on the magnetic cloud and related
features as they approach and pass Earth. Strong enhancement of the field-aligned anisotropy was observed primarily during the 9 hours prior to shock arrival condition of Earth. Cane et al. [2] reported a significant relationship between CMEs and cosmic ray variations.

Shrivastava [3] argued that the coronal mass ejections in association with B-type solar flare might be the reason for the enhancement of geomagnetic field variation and CMEs indicate its better role in cosmic ray modulation.

The intensity of galactic cosmic rays measured on Earth is related to the Sun's cycle of activity, which is well known by astronomers. The solar magnetic field flips every 11 years and the number of sunspots and 'coronal mass ejections' 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. Cliver and Ling [4] have discovered a quirk in this pattern - and they believe that coronal mass ejections could be responsible for it.

Cliver and Ling [4] propose that when cosmic rays impinge on the solar poles early in an 11-year cycle, they do not encounter CMEs. But cosmic rays do meet CMEs when they approach the equator at this time in the solar cycle. This means that the interaction of cosmic rays with the strong magnetic fields of CMEs affects the intensity of cosmic rays on Earth. There are many uncertainties inherent in predicting long-term trends from relatively short-term measurements, as Cliver and Ling point out. But the pattern is clearly evident from the data so far.

### 2 Data and analysis

CME events observed by instruments onboard SOHO and Wind spacecraft for the period 2003-08 have been considered for the present work. We have analyzed sixty-seven CMEs during 2003-08. The temperature and pressure corrected hourly data (counts of neutrons) of cosmic ray intensity from Kiel neutron super monitor have been used, where the long-term change from the data has been removed by the method of trend correction. Chree analysis of superposed epoch has been applied on the pressure corrected daily average cosmic ray intensity data with respect to full halo CMEs, partial halo CMEs, Asymmetric and Complex 'Full' Halo CMEs and asymmetric halo CMEs. Statistical significance of the results so obtained is evaluated by using a method suitable for Chree analysis.

### 3 Discussion

We have selected CMEs and divided into four groups (1) Asymmetric 'Full' Halo CMEs, (2) Partial Halo CMEs (3) Asymmetric and Complex 'Full' Halo CMEs and (4) 'Full' Halo CMEs during 2003-08. We have adopted the Chree analysis of superposed epoch to study the effect of these CMEs on cosmic ray intensity using the daily average cosmic ray intensity of Kiel neutron monitor during 2003-08.

We have plotted (Figs not shown here) the frequency of occurrence of four different types of CMEs identified during the period 2003-08. It is clearly noticed that frequency of occurrence of Asymmetric
'Full' Halo CMEs is significantly high, whereas frequency of occurrence of Asymmetric and Complex 'Full' Halo CMEs is low compared to other CMEs identified during the period of investigation. It is also noticed that frequency of occurrence of full halo and partial halo CMEs is almost equal.

To study the effect of these CMEs on cosmic ray intensity, we have adopted the Chree analysis of superposed epoch for days – 10 to + 10 and plotted (not shown here) as a percent deviation of cosmic ray intensity data of Kiel neutron super monitor for 2003-08. Deviation for each event is obtained from the overall average of 21 days. Epoch day (zero day) correspond to the starting days of CMEs.

From these investigations we observed that all the four types of CMEs studied here produced significant disturbances in cosmic ray intensity. However, the deviations in cosmic ray intensity are more pronounced in case for asymmetric and complex full halo CMEs. Short term modulation in cosmic ray intensity are caused by interplanetary shocks, which are driven by matter that is expelled from the Sun during a reorganization of the solar magnetic field i.e. CMEs. Most of CMEs are related with a specific solar flare and generate an interplanetary shock. The ejecta known to be the driver of interplanetary shocks. Magnetic cloud is also investigated as ejecta. These ejecta have a magnetic enhancement, which shows a clear rotation in the field direction. The CMEs have considerable influence on particle propagation and the interaction of these flows with quite solar wind create regions of compressed, heated solar wind and shocks, which are responsible for the modulation of cosmic rays.

We have also plotted the scattered diagram between cosmic ray intensity and IMF strength (B) along with regression line, correlation coefficient (r) to find out the possible correlation between these parameters during the onset of four different types of CMEs in Fig 1-4. The correlation coefficient between these two parameters is also calculated. As depicted in the plots and observed correlation coefficient, the cosmic ray intensity shows nearly good anti-correlation with IMF strength (B) during asymmetric full halo CMEs (r = - 0.44) and partial halo CMEs (r = - 0.46), whereas a poor correlation is seen between these two during asymmetric and complex full halo CMEs (r = - 0.14) and full halo CMEs (r = 0.24).

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5 Conclusions
The cosmic ray intensity shows
Fig 2: Cosmic ray intensity along with the variation in associated value interplanetary magnetic field strength (B), regression line and correlation coefficient (r) for Partial Halo CMEs. Nearly good anti-correlation with IMF strength (B) during asymmetric full halo CMEs and partial halo CMEs, whereas it shows poor correlation with B during other CMEs.

Fig 4: Cosmic ray intensity along with the variation in associated value interplanetary magnetic field strength (B), regression line and correlation coefficient (r) for (a) Asymmetric 'Full' Halo CMEs, (b) Partial Halo CMEs, (c) Asymmetric and Complex 'Full' Halo CMEs and (d) 'Full' Halo CMEs transit speed, magnetic field enhancements etc. are needs to be studied in more detail for establishment a better model.

6 References