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Characteristics of cosmic ray intensity on the onset of coronal mass ejections

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Abstract - Coronal Mass Ejections (CMEs) are large, energetic expulsions of mass and magnetic fields from the Sun; they can significantly affect large volumes of the heliosphere and appear to be a key cause of geomagnetic storms. The present study deals with the influence of Asymmetric 'Full' Halo CMEs, Partial Halo CMEs, Asymmetric and Complex 'Full' Halo CMEs and 'Full' Halo CMEs on cosmic ray intensity during 2005. The data of ground based neutron monitor of Inuvik 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. It is noteworthy that the occurrence of Asymmetric 'Full' Halo CMEs is greater than the other CMEs during the period of investigation. The cosmic ray intensity found to decrease 10 days before the onset of CMEs and reaches to its minimum 3 days after the event for Asymmetric 'Full' Halo CMEs, Partial Halo CMEs and Asymmetric and Complex 'Full' Halo CMEs. On the onset of asymmetric and complex full halo CMEs the intensity of cosmic ray fluctuates quite frequently as compared to other CMEs. Significant enhancement is seen in the cosmic ray intensity two days after the onset of 'Full' Halo CMEs, which is continue for two days then decreases rapidly.

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Keywords: cosmic ray, coronal mass ejections, anisotropy, solar wind, interplanetary magnetic field and geomagnetic activity.

1. Introduction

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 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 $\mathbf{B}\times\nabla n$ 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. Edward Cliver, of the Air Force Research Laboratory in Massachusetts, and Alan Ling, of Redex Inc in Massachusetts, compared numbers of sunspots dark patches on the disk of the sun caused by local magnetic fields and measurements of galactic cosmic rays dating back to 1951. The sharp fall in cosmic ray intensity that occurs every 11- year is closely related to the rise in the number of sunspots. They studied this relationship and noticed that the cosmic ray curve lagged behind the rise in the number of sunspots by about a year but only during alternate solar cycles. In the intervening cycles, the two trends occur almost simultaneously.

The researchers suspect that the alternating pattern is rooted in the reversal of the Sun's magnetic field every 11 years. Cosmic rays preferentially approach the Sun from the direction of its poles when the magnetic field lines are pointing out of the Northern hemisphere. When the magnetic field flips, cosmic rays tend to approach equatorial regions of the Sun. But astronomers also know that coronal mass ejections (CMEs) colossal streams of gas that erupt from the Sun's surface tend to occur close to the Sun's equator early in the solar cycle, and later migrate towards the poles.

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.

We present a study of the short-term evolution of coronal mass ejections observed by the Large Angle and Spectrometric Coronograph (LASCO) on board SOHO during 2005 and their relation with the modulation of galactic cosmic-ray (GCR) intensity observe at 1 AU by the Inuvik neutron monitor and IMP-8 spacecraft. We compare the short-term GCR modulation with the CME occurrence rate at all, low, and high latitudes, as well as the observed CME parameters.

Data and analysis

CME events observed by instruments onboard SOHO and Wind space craft during the 2005 have been considered for the present work. We have analyzed 46 CMES in the year 2005. Chree analysis of superposed epoch has been applied on the presure corrected daily average cosmic ray intensity and interplanetary parameters data with respect to full hallo CMEs, partial hallo CMEs and asymmetric hallo

CMEs. Statistical significance of the results so obtained is evaluated by using a method suitable for Chree analysis.

Results and Discussion

We have selected CMEs and divided in to four groups (1) Asymmetric 'Full' Halo CMEs, (2) Partial Halo CMEs (3) Asymmetric and Complex 'Full' Halo CMEs and (4) 'Full' Halo CMEs during 2005. 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 Inuvik neutron monitor during 2005.

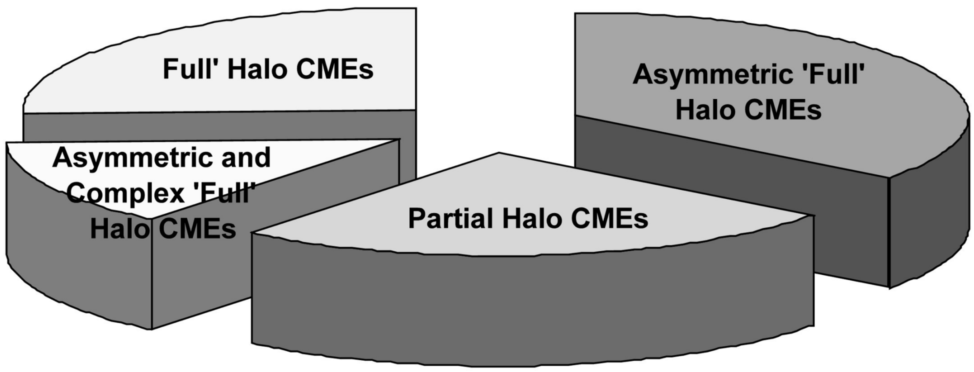

Fig 1: Frequency of occurrence of (1) Asymmetric 'Full' Halo CMEs, (2) Partial Halo CMEs (3) Asymmetric and Complex 'Full' Halo CMEs and (4) 'Full' Halo CMEs during 2005.

The occurrence of four types of CMEs during the period 2005 has been plotted in Fig 1. It is clearly seen from the Fig that number of Asymmetric 'Full' Halo CMEs is greater than the number of other CMEs during the period of investigation. 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 in Fig 2 -5 as a percent deviation of cosmic ray intensity data of Inuvik neutron monitor for the year 2005.

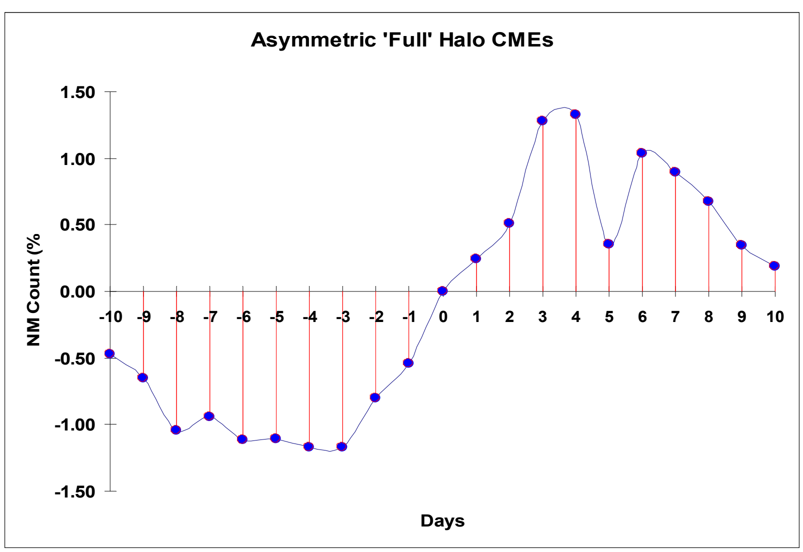

Fig 2: The results of Chree analysis of superposed epoch from –10 to +10 days with respect to zero epoch days for Asymmetric 'Full' Halo CMEs.

Deviation for each event is obtained from the overall average of 21 days. Epoch day (zero day) correspond to the starting days of Asymmetric 'Full' Halo CMEs. As depicted in Fig 2 the decrease in cosmic ray intensity starts from – 10 day and reaches to its minimum on – 3 day and then start increasing upto +3 day. The cosmic ray intensity shows a significant decrease on + 5 day and recovered on + 6 days and then decreases sharply upto + 10 day.

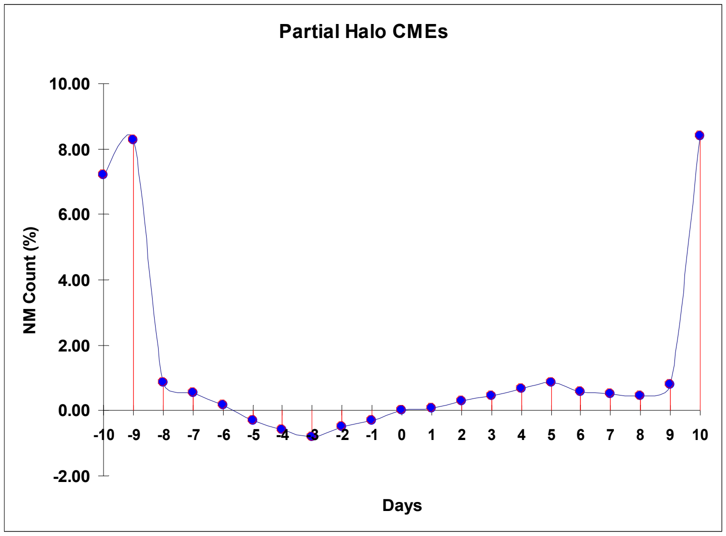

Fig 3. The results of Chree analysis of superposed epoch from –10 to +10 days with respect to zero epoch days for Partial Halo CMEs.

One can clearly see from Fig 3 that the decrease in cosmic ray intensity starts from – 10 day and reaches to its minimum on – 3 day and then start increasing slowly upto +9 day. The cosmic ray intensity shows a significant increase on + 10 day. The cosmic ray intensity seems to statistically constant before and after 8 days of the onset of partial halo CMEs.

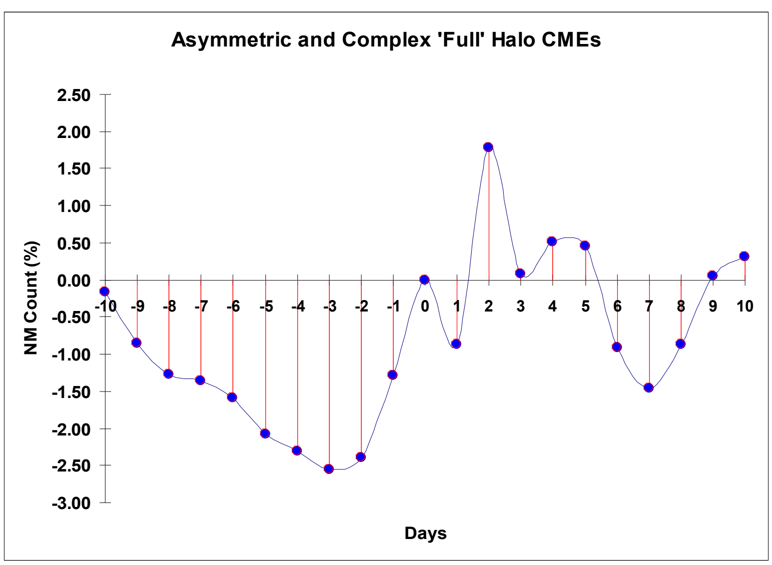

Fig 4: The results of Chree analysis of superposed epoch from –10 to +10 days with respect to zero epoch days for Asymmetric and Complex 'Full' Halo CMEs.

It is quite observable from Fig 4 that the decrease in cosmic ray intensity starts from – 10 day and reaches to its minimum 3 days before the onset of CMEs and then increases upto zero epoch days i.e. on the onset of asymmetric and complex full halo CMEs. It is clearly seen that the cosmic ray intensity shows a significant increase on + 2 day and significant decrease on + 7 day. It is also evident that on the onset of asymmetric and complex full halo CMEs the intensity of cosmic ray fluctuate quite frequently.

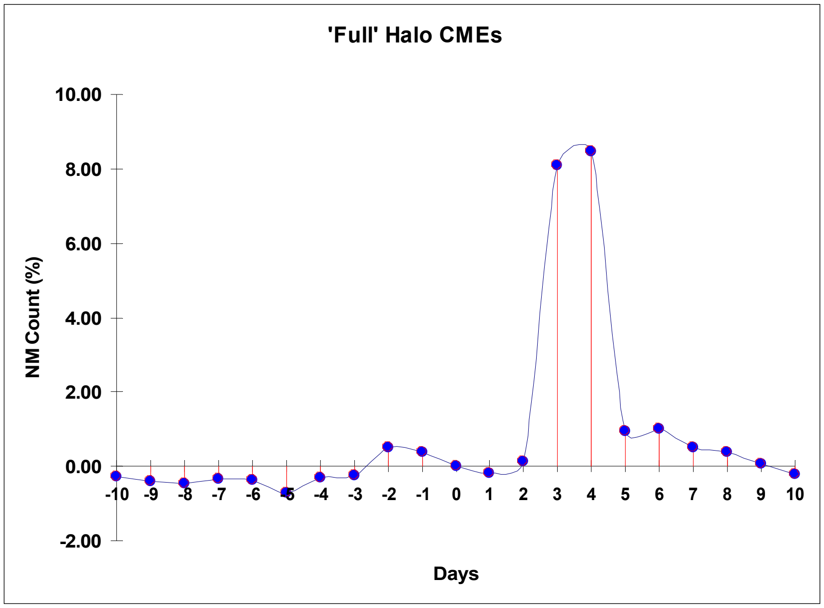

Fig 5: The results of Chree analysis of superposed epoch from –10 to +10 days with respect to zero epoch days for 'Full' Halo CMEs.

It is quite observable from Fig 5 that the deviations in cosmic ray intensity are very slow 10 days before the onset of 'Full' Halo CMEs up to the two days after the event. The intensity is seems to be statistically constant for this period. It is clearly seen that the cosmic ray intensity shows a significant increase on + 2 and + 3 day and significant decrease on + 5 day and then remains statistically constant.

Badruddin and Singh [6] studied the influence of CMEs; halo CMEs and partial halo CMEs on cosmic ray intensity and modulators as compared to the other CMEs. Lara et al. [7] studied the long-term evolution of CMEs observed by LASCO on board *SOHO* during the ascending, maximum, and part of the descending phases of solar cycle 23 and their relation with the modulation of galactic cosmic-ray (GCR) intensity observed at 1 AU by the Climax neutron monitor and *IMP-8* spacecraft. They observed a general anti-correlation between GCR intensity and the CME rate, which is relatively high (~-0.88), a lower anti-correlation between the low-latitude the CME rate and GCR intensity (~-0.71) and a very high anti-correlation between the high-latitude CME rate and GCR intensity (~-0.94). Their results suggest that all CME properties show some correlation with the GCR intensity, although there is no specific property (width, speed, or a proxy of energy) that definitely has a higher correlation with GCR intensity.

Significant increase in cosmic ray intensity for asymmetric full halo and full halo CMEs are evident. The cosmic ray intensity peak up to 2 to 3 days after the onset of CME. However in case of Partial Halo CMEs the cosmic ray intensity peak up to 8 to 9 days before and after the onset of CME. In contrast, it is difficult to draw any conclusion in case of asymmetric and complex full CMEs. Thus we may conclude that asymmetric full halo, full halo and partial halo CMEs are more effective in producing disturbances in cosmic ray intensity as compared to complex CME. 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.

Conclusions

From the present investigations following conclusions may be drawn:

- The occurrence of Asymmetric 'Full' Halo CMEs is greater than the Partial Halo CMEs, Asymmetric and Complex 'Full' Halo CMEs and 'Full' Halo CMEs during the period of investigation.
- The cosmic ray intensity found to decrease 10 days before the onset of CMEs and reaches to its minimum 3 days after the event for Asymmetric 'Full' Halo CMEs, Partial Halo CMEs and Asymmetric and Complex 'Full' Halo CMEs.
- On the onset of asymmetric and complex full halo CMEs the intensity of cosmic ray fluctuates quite frequently as compared to other CMEs.
- Significant enhancement is seen in the cosmic ray intensity two days after the onset of 'Full' Halo CMEs, which is continue for two days then decreases rapidly.

Thus we can say that CMEs are more effective transient modulators of cosmic ray intensity. However, study of the simultaneous deviations in solar wind plasma field parameters during the passage of these CMEs, their transit speed, magnetic field enhancements etc. are needs to be studied in more detail for a better model.

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