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# Effects of Coronal Mass Ejections on the Long Term Cosmic Ray Modulation

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**Abstract:** Recently, based on solar cycle 23 observations, we have proposed that the long term solar modulation of galactic cosmic rays (GCR) is influenced by coronal mass ejection (CME) activity. In this work, we extend the analysis of the effects of CMEs number and their latitudinal changes on the GCR flux during positive and negative magnetic cycles. We use CME data from both, recent observations by LASCO/SOHO and past observations by Solar Maximum Mission (SMM) and Solwind coronagraph on board the P78/ spacecrafts. On the other hand, we use GCR data from IMP-8 spacecraft. We found a high correlation between high latitude CMEs and GCR during positive cycles and a good correlation between low latitude CMEs and GCR is suggested during negative magnetic solar cycle. Finally, we discuss our results in terms of the magnetic irregularities transported by CMEs in to the heliosphere.

## Introduction

The long term modulation of Galactic Cosmic Rays (GCR) due to solar activity has been known since almost half century ago [1]. Many mechanisms have been proposed to explain the decreasing GCR flux in the inner heliosphere (see [2] and references therein), when the solar activity increases, during the ascending phase of the eleven year solar cycle and the corresponding increase of GCR flux during the descending phase of the cycle.

Recently ([3], here after paper 1), we have proposed that the agent which is transporting the solar activity information, in form of magnetic perturbations and causing major effect in the GCR flux, are coronal mass ejections (CMEs). Even more, we found that not only the the total number of CMEs is important, but their latitude behavior plays a major role in the GCR modulation.

In paper 1, we studied the GCR - CME relationship using both Climax and IMP8 GCR data and CME data from the Large Angle and Spectrometric Coronagraph Experiment (LASCO) on board of the Solar and Heliospheric Observatory (SOHO) spacecraft. We found a very good anti-correlation between high latitude CME activity and GCR flux during the ascending phase of solar cycle 23, which was positive ($qA > 0$) cycle. Based on these findings, we predicted that during negative ($qA < 0$) cycles the GCR flux will be modulated (at least during the ascending phase of the solar cycle) by low latitude CMEs, whereas for positive cycles the modulation will be done trough high latitude CMEs.

In order to test this idea, in this work we use CME data, available for solar cycles 21, 22 and 23 observed by different space craft experiments and compare the CME total number and latitude changes against the GCR flux measured by IMP-8 spacecraft.

## Data

We use data from:

- Solwind coronograph on board of the P78-1 satellite [4] during cycle 21 ($qA > 0$). From 1979 to 1985.
- The High Altitude Observatory Coronograph/Polarimeter on board the Solar Maximum Mission [5] during part of cycle 22 ($qA < 0$). From 1984 to 1989.
- LASCO during major part of cycle 23 ($qA > 04$). From 1996 to 2006.

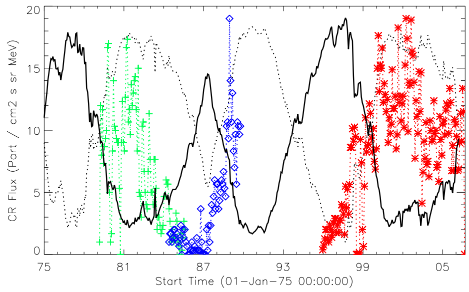


Figure 1: GCR (continuous line) and CMEs observed by Solwind (plus symbols) SMM (diamonds) and LASCO (stars) during solar cycles 21, 22 and 23. CME number is scaled to fit the GCR flux range. To facilitate comparisons, in this an following figures, we have plotted the inverse GCR flux as a dotted line.

It is important to note that the sensitivity of these experiments is different, making difficult a direct cooperation between them. Also note that in this study we are no taking into account the duty cycle of these instruments.

The GCR data comes from IMP-8 satellite, in this case we use proton flux in the 121 - 230 MeV energy range.

Figure 1 shows the mean IMP-8 proton flux per Carrington rotation, direct (continuous line) and, to make easy comparisons, we have plotted also the inverted flux (dotted line). Over-plotted and scaled to fit the GCR flux range, is the mean number of CMEs per Carrington rotation, measured by the three considered instruments.

## Analysis

### Cycle 21

Figure 2 shows the CME - GCR relationship during solar cycle 21. Similar to Fig. 1 we have plotted the direct (continuous line) and inverse (dotted line) GCR flux, plus symbols denote the total (top panel), low latitude (middle panel) and high latitude (bottom panel) number of CMEs observed by solarwind. Unfortunately, Solwind started observations on 1979, on the middle of the ascending

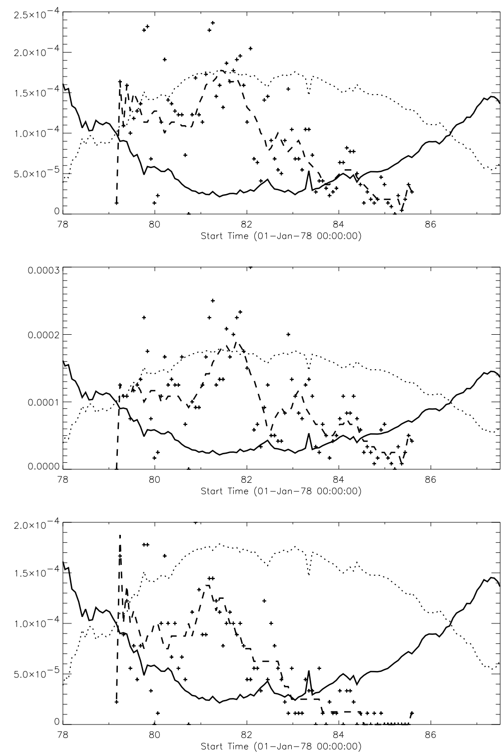


Figure 2: IMP - 8 proton flux (120 - 230 MeV) during solar cycle 21. Plus symbols, from top to bottom represent the total, low latitude and high latitude number of CMEs observed by Solwind.

phase of the cycle. This makes difficult to compare the effects of CMEs on this phase of the GCR flux. Although, there seems to be an anti-correlation between both parameters in the 1980 and 1981.5 time range.

### Cycle 22

Figure 3 shows the IMP-8 proton flux during part of cycle 22 when SMM was in operation. Again in this case the data covers only part of the cycle, Fortunately we have the ascending part of the solar cycle. The top panel (all CMEs) show a similar behavior between the CME number, which is increasing in this phase, and the decreasing GCR flux. It is necessary a deep analysis, although it is clear that the low latitude CME number is better anti-correlated with the GCR flux than the high

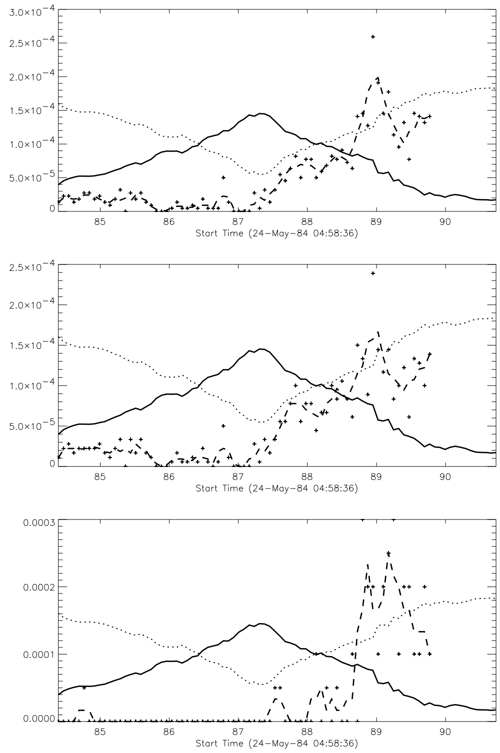


Figure 3: Same as Figure 2 but for cycle 22. The CME data was observed by SMM spacecraft.

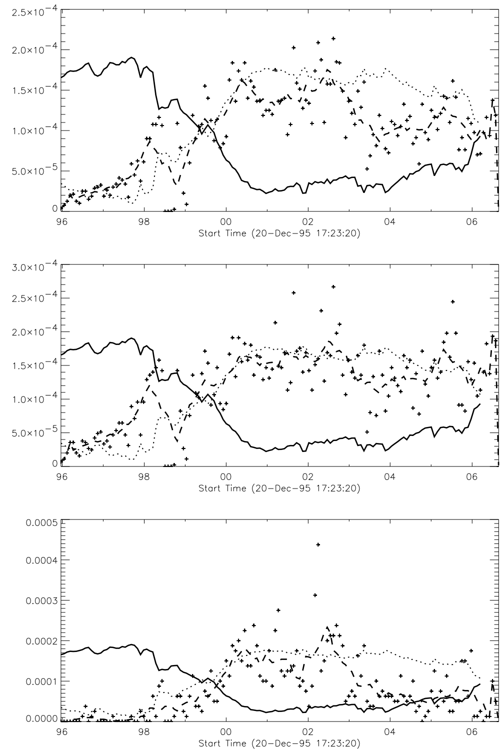


Figure 4: Same as Fig 2 but for solar cycle 23, in this case, CME data comes from LASCO experiment.

latitude number. In this case, low latitude CME activity started early in 1987 few months before than the GCR decreasing phase. Whereas high latitude CME activity seems to start towards the end of 1988.

### Cycle 23

In this case CME data is available for the whole cycle, except for two major data gaps during 1998 and 1999 (Figure 4). As we stated in Paper 1, the number of low latitude CMEs start increasing early in 1996, at that time, the GCR flux were unaffected. On the other hand, high latitude CME activity started at 1998, almost at the same time that the GCR long term modulation. In this case, the anticorrelation between the number of high latitude CMEs and GCR flux is very high.

As an example, in Figure 5 we show the dispersion plot of the mean number of CMEs Vs the mean GCR flux, for total (diamonds), low latitude (plus symbols) and high latitude (squares) CMEs. It is clear that there is an anticorrelation between the number of CMEs and GCR flux. Although, the dispersion is high for the case of all latitude CMEs, is better for low latitude CMEs and is really low for high latitude CMEs.

## Discussion and Conclusions

This preliminary analysis of the GCR flux and CME number relationship, shows that CMEs play a fundamental role in the eleven year GCR modulation. Even more, we show that this modulation is carried out by high latitude CMEs during positive ($qA > 0$) cycles and by low latitude CMEs during negative ($qA < 0$) cycles. This finding is in agreement with the GCR transport theory, which

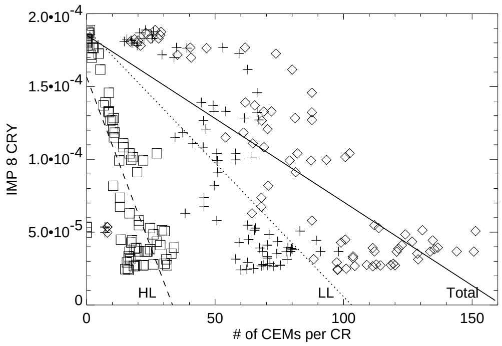


Figure 5: Dispersion plot between total (diamonds), low (plus symbols) and high (squares) latitude CMEs and GCR during cycle 23.

states that the inflow of GCRs depends on the solar magnetic polarity. During $qA > 0$ epoch, (where the heliospheric magnetic field is directed outward in the north polar region and inward in the south polar region, as in the first half of cycles 21 and 23), the GCRs drift inward from the polar regions to the equatorial plane and then outward along the HCS; during $qA < 0$ epochs (first half of cycle 22), the drift is inward through the HCS, from the equatorial plane to the poles (see figure 2 in [6]). Therefore, the effect of CMEs on the GCR modulation must be different depending on the CME latitude and $qA$ sign during the cycle. Our analysis strongly suggest that this scenario is correct although, it is necessary better CME data as which will be provided by the STEREO mission.

Finally, we note an interesting behavior by analyzing Figure 1 (or Figures 2 and 4): The CME - GCR flux seems to be well correlated during the ascending phase and the first maximum of the cycle. After that there is no apparent relationship between them.

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