The Gnevyshev Gap Effect in Galactic Cosmic Rays

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Abstract

During the last three solar cycles and in a wide energy range of galactic cosmic rays both the modulation and the variability of the intensity demonstrate effects related to the Gnevyshev Gap (GG) — a substantial decrease once or twice during the maximum phase of each solar cycle of a parameter that generally varies in phase with the cycle. The GG-effect also manifests itself in the behaviour of both the strength of the average interplanetary magnetic field and the power of its fluctuating component. The energy dependence of the GG-effect in the modulation and in the variability of the cosmic ray intensity was found to be different. The start of the GG-effect in the cosmic ray modulation practically coincides with a change in the energy dependence of the cosmic ray modulation.

1 Introduction:

The double-peak structure (DPS) of the maximum phase of the 11-year solar cycle has been a subject of interest for solar physicists since the investigations made by M. N. Gnevyshev during the 1960s (Gnevyshev, 1963, 1967). Data for more than thirty years showed that DPS manifests itself in many solar and heliospheric parameters (e.g., Feminella & Storini, 1997; Bazilevskaya et al., 1998, and references therein).

In this paper special attention is paid to the valley between the peaks (we call it the Gnevyshev Gap, or GG, according to Storini & Pase, 1995) rather than the peaks themselves during the maximum phase of the solar cycle. We consider that a certain parameter $\mathcal{P}$ demonstrates a GG-effect if a) it varies approximately in phase with the solar cycle and b) it decreases substantially once or twice for short periods of time during the maximum phase of solar activity. One outstanding feature of the GG-effect on the Sun is that the GG amplitude is greater for the more energetic parameters (Gnevyshev, 1963, 1967).

A few years ago we found that the GG was a property also of the variability of the galactic cosmic ray (GCR) intensity in a wide range of characteristic times. This variability can be expressed in terms of the power spectrum density, the wavelet spectrum or the simple standard deviation (SD) of the daily intensities with respect to the monthly mean (Storini & Pase, 1995; Bazilevskaya et al, 1995a; Astaf'eva et al., 1997; Storini et al., 1997). As it is well known the GCR intensity itself varies in a counterphase with the solar cycle. However, its modulation varies in phase with the solar cycle and demonstrates the GG-effect (Storini, 1995). Besides, it was noted from long ago (see references in Moraal, 1975, and also Krainev et al., 1983a, 1983b; Bazilevskaya et al., 1995b) that the temporary change in modulation of GCR intensity during the maximum phase of each solar cycle strongly depends on the energy of particles. In this paper we discuss GG-effects in GCR intensity modulation and variability, with special emphasis on their energy dependence, and show that these effects are also present in the time behaviour of the interplanetary magnetic field, both in its regular and fluctuating components.

2 Data Processing, Analysis and Discussion:

To analyse the energy dependence of the GG-effect in the GCR modulation and SD we consider the long time series of the daily counting rates of the neutron monitors at Huancayo/Haleakala (N_{Hu}, effective vertical cutoff rigidity $R_c \cong 13GV$), Rome ($N_{Ro}, R_c \cong 6.2GV$) and Climax ($N_{Cl}, R_c \cong 3GV$) as well as the balloon data in the transition maximum in the stratosphere at Murmansk ($N_{Mu}, R_c \cong 0.6GV$) (Bazilevskaya et al., 1991; Bazilevskaya & Svirzhevskaya, 1998, and references therein). Days with particle contribution from the Sun were excluded from the data series. All the data were monthly averaged and the SD of daily data with respect to monthly mean was determined. The resulting time series were normalized to the May 1965 count rate and smoothed on 3–7 month scale.

We define the relative GCR modulation as $M \equiv (N(05.1965) - N(t))/N(05.1965) \cdot 100, \%$. In Figure 1 the time profiles of the 7-month smoothed SD (upper panel) and the relative modulation (middle panel) for all four GCR series and for the last three solar cycles (20–22) are compared with the time profiles of the regular and fluctuating components of the interplanetery magnetic field (IMF) (lower panel).

For the boundaries of the maximum activity phases we use those reported by Ivanov (1995). Nevertheless, the response of the GCRs to solar changes could be delayed by about one year, as they are sensitive to the conditions in the heliosphere as a whole. Hence, we looked for GG-effects in GCRs during what we will call the "heliospheric maximum phase" (HMP). Its extent is the one of Ivanov (1995), prolonged by one year, and it is shown for each cycle by vertical dashed lines in Figure 1. From the SD trends we observe: (i) the SD is in phase with the eleven year cycle, and at neutron monitor energies its amplitude decreases with the GCR energy (the SD for the stratospheric data is not shown after 1991 because of the relatively poor statistics); (ii) all SD series demonstrate the GG-effect (see arrows and labels). One can also notice that the relative amplitudes of GG ($A^{GG}_{\mathcal{P}} \equiv (\mathcal{P}_b - P_g)/\mathcal{P}_b \cdot 100, \%$, where $\mathcal{P}_b$ and $\mathcal{P}_g$ are the values of $\mathcal{P}$ immediately before and at the bottom of the gap, respectively) are approximately the same for all SD series. For example, for the GG in the cycle 21 the $A^{GG}_{SD} =$ 54.9, 53.3, 53.5, 52.0 % and for the GG in the cycle 22 the $A^{GG}_{SD} =$ 51.2, 58.0, 57.7, 52.3 % for Murmansk, Climax, Rome and Huancayo, respectively.

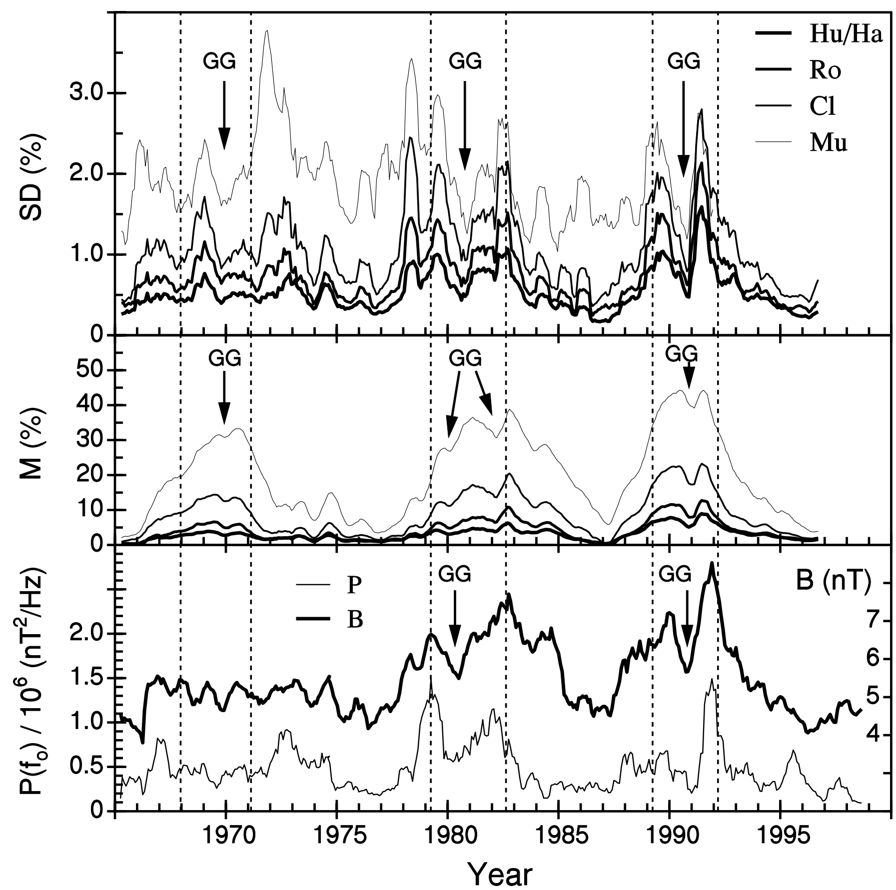

Figure 1: The time profiles of the 7-month smoothed SD (upper panel), the GCR modulation (middle panel), the regular strength B and the power spectrum density $P(f_0 = 2 \cdot 10^{-6} Hz)$ of the interplanetary magnetic field (lower panel). The HMP periods are shown by the vertical dashed lines and the GGs are marked by arrows and labels.

Obviously, the modulation of the GCR (middle panel of Figure 1) also follows the solar cycle and there are gaps (indicated by arrows) during the HMP for all the intensity series considered. Besides, the GGs in modulation are more narrow than in the SD and the relative amplitude of the gaps in M grows with GCR energy. For the first GG in the cycle 21 the $A^{GG}_{M} =$ 0.7, 7.7, 23.4, 23.8 % and for the GG in the cycle 22 the

$A_M^{GG} = 10.5, 22.6, 29.2, 26.2$ % for Murmansk, Climax, Rome and Huancayo, respectively.

The IMF parameter was obtained by using hourly and 5-minute averaged magnetic field intensity, provided in the "omni"-files by GSFC. The data were processed to obtain the monthly values of both the mean strength B and the power spectrum density $P(f)$ in the frequency range $10^{-6} < f < 10^{-3} Hz$ (Blackman & Tukey, 1958). The lower panel of Figure 1 shows the behavior of the 7-month smoothed B and $P(f_0)$ ($f_0 = 2 \cdot 10^{-6} Hz$). It is easily seen that both IMF parameters, relevant for cosmic ray propagation in the heliosphere — B, describing the regular IMF, and $P(f_0)$, relating to its fluctuating component — vary in phase with the solar cycle and demonstrate the GG-effect (at least in cycles 21 and 22).

To study the energy dependence in the GCR intensity modulation in more detail we, as Krainev (1991), normalized the 3-month smoothed modulation of Huancayo/Haleakala, Rome and Climax counting rates to that of Murmansk for the ascending (As) phases of each solar cycle, using a power regression.

In the three panels of Figure 2 the 3-month running means of the GCR modulation normalized to $M_{Mu}(t)$ are shown separately for each solar cycle. Due to the mathematical technique applied, all four curves lie very close to each other during the As–phases of solar cycles. In the descending (Ds) phases the curves progressively come apart, indicating a different energy dependence of the GCR modulation during the Ds-phases, as found in the past (cf. Popielawska, 1992), after the high-latitude heliomagnetic field reversals. During the HMP the deviations between the curves are pronounced, the amplitude of the GG growing (as it was emphasized from Figure 1) with the GCR energy. From Figure 2 we can also derive that the change in the energy dependence starts with the GG-effect but it does not always return to the previous dependence with the end of the GG-effect. In fact, for cycle 20 a pronounced difference exists between the modulation of high and low energy GCRs up to the end of 1971, well beyond the GG and HMP. A similar feature was present during the entire HMP of cycle 21, even in between the gaps. Contrary, during cycle 22 the effects are very localized and practically there is no energy effect outside the GG.

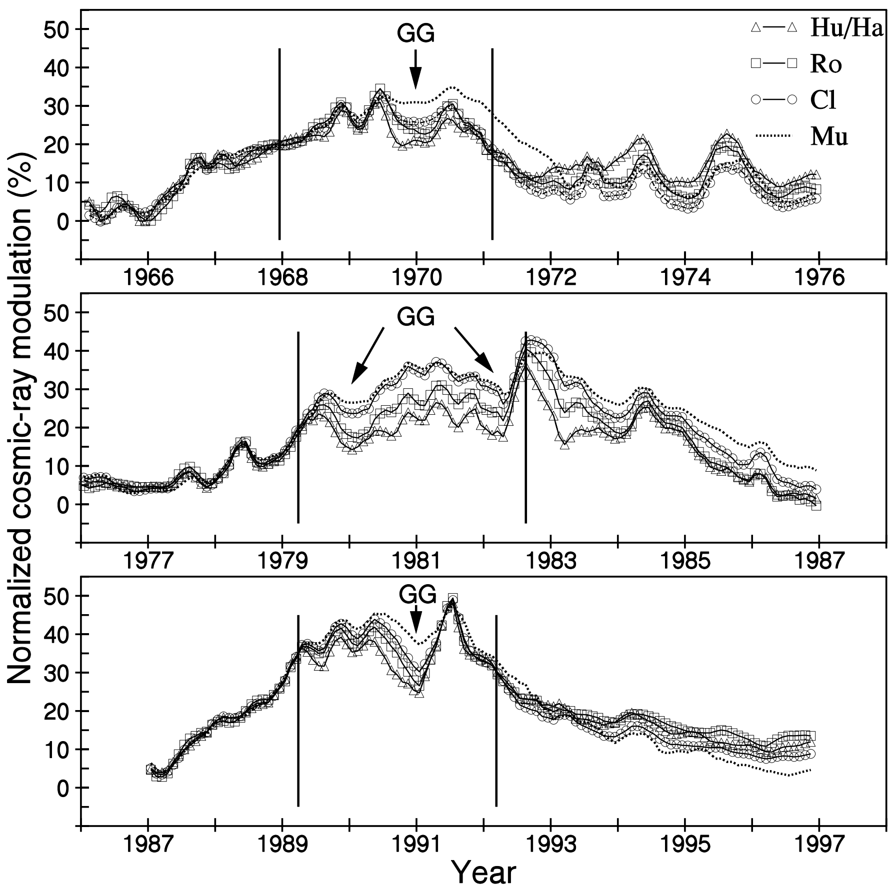

Figure 2: The GCR modulation normalized to M_{Mu} for solar cycles 20 (upper panel), 21 (middle panel) and 22 (lower panel). The HMP periods are shown by vertical lines in each panel.

3 Conclusions:

1. It is evident that the GG-effect — a decrease just in the maximum phase of the 11-year cycle — is definitely a specific feature both in the GCR modulation and in their variability (SD) in a rather wide energy range (from several to tens of GeV). For the aim of the GG-effect understanding it is essential that the heliospheric parameters best related to cosmic ray propagation in the heliosphere — the strength of the regular magnetic field and the power spectrum density of its fluctuating component — vary in phase with the solar cycle and demonstrate the GG-effect.

2. The energy dependence of the GG-effect in GCR modulation and variability (SD) seems to be different, the relative amplitude of the former growing with the particle energy, while that of the latter is energy independent.

3. For all the three cycles considered the start of the GG-effect in the GCR modulation practically coincides with a change in the energy dependence of the modulation, which may last for some time after the end of the GG-effect.

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