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The Solar Cycle in the heliospheric parameters and galactic cosmic ray intensity

M. B. Krainev[1] **and W. R. Webber**[2]

[1]Lebedev Physical Institute RAS, Leninsky Prospect, 53, 119991 Moscow, Russia
email: krainev@fian.fiandns.mipt.ru

[2]New-Mexico State University, Las-Cruces, NM, USA email: bwebber@nmsu.edu

Abstract. We consider the Solar Cycle - the variation in any solar, heliospheric or cosmic ray parameter, related to the well-known 22-year dynamo-like process on the Sun - and discuss how it is influenced by the inner (the transformation of the solar activity in the basement of the heliosphere) and the external (the interaction between the solar and interstellar winds) factors. The corresponding approaches to the description of the long-term variations (the Solar Cycle, secular and longer ones) in the galactic cosmic ray intensity are outlined.

1. Introduction

The long-term variations observed in the galactic cosmic ray (GCR) intensity, are the reflections of the similar variations in the heliospheric characteristics, which, in turn, are due to solar activity changes. However, for the heliospheric variations not only their inner source (the Sun itself), but also the heliospheric basement above the photosphere and the structure of the outer heliosphere could be important. Below the formation of the long-term variations in the heliospheric characteristics by the joint action of the inner and outer factors is discussed and the relevant approaches to the description of the long-term variations in the GCR intensity are briefly outlined.

2. The factors important for the heliospheric characteristics

When one considers the various heliospheric phenomena with the characteristic time, τ, between a few years and several decades, the main inner factor important for them is the dynamo process on the Sun which results in the well-known 11-year and 22-year solar activity cycles and controls the activity level, its position on the photosphere, and the magnetic field's polarity. Following Krainev, Webber (2005a) we call *a Solar Cycle* (with the capital initial letters) in any characteristic the smooth variation due to the above process and consider as a candidate for this role in the real data the initial (27-day or monthly averaged) data smoothed with a 2-year period.

On the left-hand panels of Figure 1 the development on the solar photosphere of the two branches of solar activity is shown: (1) the sunspot (or toroidal (T)) branch, characterizing the azimuthal magnetic field B_φ and (2) the large-scale magnetic field in the high-latitude regions (or poloidal (P) branch), observed in the radial magnetic field B_r. In the T-branch the powerful 11-year cycle is present and for this variation the useful division into the main phases - the minimum (m), ascending (A), maximum (M) and descending (D) ones - is introduced (see Obridko, Shelting 2003 and references therein). The duration of any main phase is about $\tau_{ph} = 2 - 4$ years which sets an important characteristic time of the Solar Cycle. In Figure 1, a, the sunspot area S in each hemisphere is multiplied by the sign of B_φ in the corresponding bipolar structures

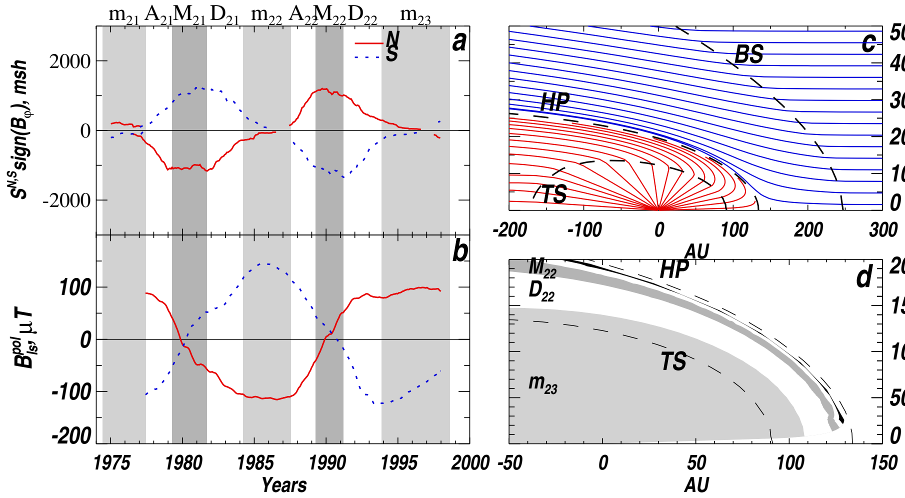

Figure 1. The factors, influencing the heliospheric characteristics and GCR intensity. The left panels - the Solar Cycle in both solar hemispheres in 1975-1997: (a) - the sunspot area S (from `science.nasa.gov/ssl/PAD/SOLAR/greenwch.html`, in the millionths of solar hemisphere), multiplied by the sign of B_φ of the corresponding bipolar sunspot groups; (b) - the line-of-sight projection of the polar magnetic field B_{ls}^{pol} (`sun.stanford.edu/~wso/wso.html`). The main solar cycle phases are indicated by the bands with different filling and the notation is shown above the panels. The right panels - the structure and time properties of the heliosphere according to Baranov, Malama (1993): (c) - the main surfaces of the heliosphere: the bow shock (BS), the heliopause (HP) and the termination shock (TS) of the solar wind, and the flow lines of the interstellar (to the right of HP) and solar winds; (d) - the distribution in $t = 1996.0$ of the solar wind plasma, that left the Sun in the previous moments, over the main solar cycle phases.

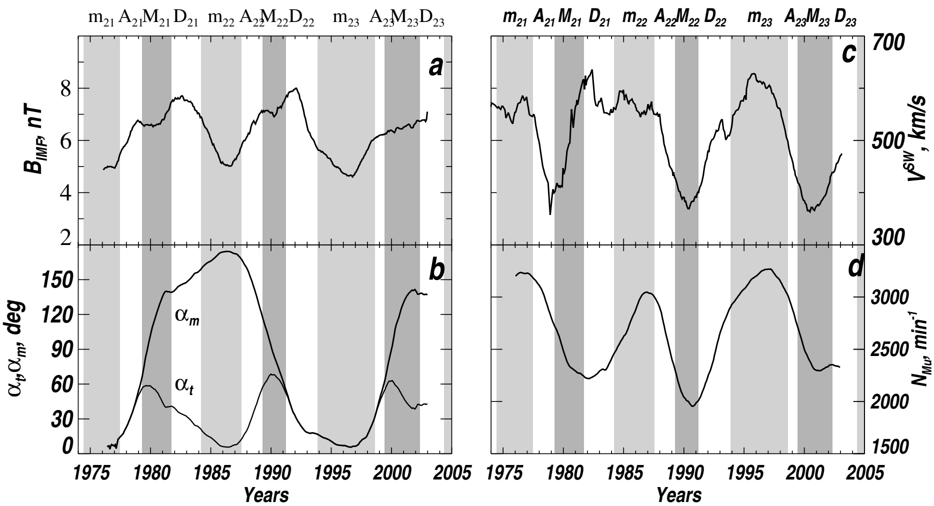

Figure 2. The Solar Cycle in the heliospheric characteristics and GCR intensity in 1975-1997 near the Earth's orbit : (a) - the IMF strength B_{IMF} (`nssdc.gsfc.nasa.gov/omniweb/ow.html`); (b) - the half-width of the IMF sector-structure zone α_t (`sun.stanford.edu/~wso/wso.html`) and the magnetic tilt α_m; (c) - the solar wind velocity V^{SW} (`stesun5.stelab.nagoya-u.ac.jp/pub/vlist/`) in the $50 \leqslant \lambda < 60$ latitude range; (d) the count rate of the omnidirectional Geiger counter in the Pfoetzer maximum in the stratosphere at Murmansk. The main solar cycle phases are shown like in Fig. 1.

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and one can see that the T-branch also demonstrates the distinct 22-year cycle, and the reversal of the toroidal magnetic fields occurs during the solar cycle minimum phase. Contrary, P-branch peaks during the minimum phase and the inversion of its magnetic fields occurs in the maximum phase of solar cycle. The very important feature of the inner source of the heliospheric variations is the layer between the photosphere and the heliosphere where the magnetic field is the main energetic factor (see, e.g., Gibson 1973). Owing to this *basement* of the heliosphere the magnetic fields of the P-branch gain advantage over those of T-branch in the penetration into the heliosphere. Besides, the processes in this layer provide the effective interaction between the activity of T- and P-branches, so that all heliospheric characteristics are shaped under the influence of both branches of solar activity. Of course, the Sun as the inner factor for the heliospheric variations is characterized also by the secular and longer variations of solar activity.

By the external factor, important for the heliospheric characteristics, we mean the interaction between the magnetized solar wind and the matter and fields of the interstellar medium, which forms the structure of the outer heliosphere. Our present view of this structure is based mainly on the modelling of the above interaction (see., e.g., Baranov 2003). In Fig. 1, c, the flow lines of the solar and interstellar winds and the form of the specific surfaces are depicted, calculated by Baranov, Malama (1993) for the typical set of parameters. The solar wind moving radially out of the Sun with the velocity $V_1^{SW} \approx 450$ km/s, is strongly decelerated in the inner heliosheath between the termination shock ($r = r_{TS} \approx 100AU$) and the heliopause ($r = r_{HP} \approx 150AU$), particularly in the lobe sector of this layer. Near the heliopause the solar wind speed is about 20 km/s and the average speed in the mentioned sector is $V_2^{SW} \approx 50$ km/s. Then the characteristic time of the solar wind propagation in the layer inside the termination shock $\tau_1 = r_{TS}/V_1^{SW} \approx 1$ year, and in the lobe sector of the inner heliosheath $\tau_2 = (r_{TS} + r_{HP})/2V_2^{SW} \geqslant 10$ years. We call the first of these layers *monophase* layer, and the second one *polyphase* layer, as the first layer is always related to the period less than one phase, $\tau_1 < \tau_{ph}$, while the second one is always covered by the plasma and magnetic fields of several previous phases of the solar cycle, $\tau_2 > \tau_{ph}$. The Fig. 1, d, illustrates the aforesaid for $t = 1996.0$.

3. The long-term variations in the heliospheric characteristics and GCR intensity

First let us consider the Solar Cycle in the layer between the heliospheric basement and the termination shock (or the monophase layer). As we mentioned before, two branches of solar activity, penetrating into the heliosphere, influence each other and loose their identity. So they transform into two groups of the heliospheric characteristics, changing with the 11-year and 22-year periods, respectively. For the characteristics important for GCRs the first group includes the interplanetary magnetic field (IMF) strength B_{IMF}, the half-width of the IMF sector-structure zone α_t, and also the solar wind speed V^{SW}. The second group includes the *magnetic tilt* α_m - the introduced by Webber, Krainev (2003) characteristic of the IMF polarity distribution, equal to the angle between the angular velocity of the Sun and the IMF magnetic moment. In Figure 2, a - c, the Solar Cycle in the listed characteristics is shown for 1976-2002 at the Earth's orbit. Note that they are rather smooth (except solar wind velocity), so they satisfy the requirement we impose on the variation to be called the Solar Cycle. The measurements aboard the spacecraft PIONEER-10, VOYAGER-1, 2 demonstrated (see the reviews in Velli et at. 2003), that inside the monophase layer the Solar Cycle in the heliospheric characteristics of both groups develops in phase with their variation near the Earth (more precisely, with the time shift $\triangle t_1 \leqslant \tau_1 \ll 11$ years). In Fig. 2, d, both the 11-year and 22-year

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variations in the smooth GCR intensity time profile are clearly seen, which are in more details discussed in Krainev, Webber (2005a). Here we note that, considering the Solar Cycle in the GCR intensity, one can ignore in the first approximation both the time of the GCR propagation through the monophase layer of the heliosphere ($\triangle t_D \approx 1$ year) and the time shift in the variations of the heliospheric characteristics $\triangle t_1$ in this layer.

As the secular and longer variations of the solar activity and GCR intensity are beyond the scope of the paper, we shall not discuss them in details. We only mention that, as in the polyphase layer the plasma and magnetic field, which left the Sun during a few previous phases of the solar cycle, coexist, the modulating property of this layer (for example, the strength of the magnetic field there) could be determined by the solar activity averaged over several previous phases. Then the simplest modulation model (see Krainev, Webber 2005b) can reproduce in general the behavior in 1600-2000 of the ^{10}Be concentration in the polar ice, which is expected to be the proxy of the GCR intensity with the energy $T \approx 2$ GeV (see McCkacken, McDonald 2001).

4. Conclusions

1. Beside the Sun itself there are also two factors, which actively influence the long-term variations in the heliospheric parameters and the galactic cosmic ray intensity: (1) the layer adjacent to the Sun through which the solar activity penetrates into the heliosphere and (2) the interaction between the solar and interstellar winds, forming the two-layer heliospheric structure with quite different time characteristics of the layers.

2. In the first approximation the smoothing of the initial data in the first layer (inside the termination shock) with a two-year period allows one to study the Solar Cycle – the variation due to the well-known 22-year dynamo-like process on the Sun – in almost any characteristics there. The heliospheric parameters throughout the first layer vary approximately without time shift which could be taken into account in describing the Solar Cycle in the GCR intensity there.

3. The second layer (between the termination shock and heliopause) memorizing the previous solar activity may have a bearing on the secular and longer variations in the GCR intensity.

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References

Baranov, V.B. 2003 in *Solar Wind Ten*, Velli, M. et al (eds.), NY, Mellville, 21–29

Baranov, V.B., Malama, Yu.G. 1993 *J. Geophys. Res.* **98**, 15157–15163

Gibson, E.G. 1973 *The quiet Sun* Washington, NASA

Krainev, M. B., Webber, W. R. 2005a *Proccedings of RAS, ser. phys.* V. 5. in print (in Russian)

Krainev, M. B., Webber, W. R. 2005b *Geomagnetism and Aeronomy* sent to the editor (in Russian)

McCracken, K.G., McDonald, F.B. 2001 *Proc. 27th Int. Conf. Cosmic Rays*, 3753

Obridko, V. N., Shelting, B. D. 2003 *The Astron. Journal,* **80**, 1034-1045 (in Russian)

Velli, M. et al (eds.) 2003 *Solar Wind Ten*, NY, Mellville, 860 p.

Webber, W.R., Krainev, M.B. 2003 In *The climatic and ecological aspects of solar activity* ,St-Petersburg, Main Astronomical Observatory RAS, 65–70

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