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NEW MAUNDER MINIMUM IN SOLAR ACTIVITY AND COSMIC RAY FLUXES IN THE NEAREST FUTURE

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Abstract

During several years we have observed very low solar activity. As a result in 2009 the highest cosmic ray flux for the whole history of its monitoring was recorded. The analysis of the solar activity in the past and its relationship with the position of the center of the Sun relative to the center of mass of the solar system shows that with a high probability we are at the beginning of a new long-term solar activity minimum like Maunder or Dalton ones. Our prediction on very low solar activity in the current solar cycle was made in 2008 and since the data on sunspot number confirm our prognosis. So, we expect high cosmic ray fluxes and low modulation of galactic particles during 24-rd solar cycle and subsequent ones.

Introduction

One of the main characteristic of solar activity is quasi periodical changes of sunspot number with the average period of about 11 years. This periodicity is marked at least during ~ 2650 years [1, 2]. However, sometimes the long-term periods of very low solar activity occurred in the past. One of them is Maunder minimum with the duration of about 100 years from ~1620 till ~1720 [3]. There are several hypotheses explaining these phenomena. For example, stochastic fluctuations of parameters of solar dynamo are suggested to be the physical cause of the long-term solar activity minima occurred in the past [4].

Here we suggest a new mechanism which is responsible for the appearance of the long-term periods of very low solar activity and predict the beginning of a new long-term minimum like Maunder or Dalton ones.

The duration of the current solar activity minimum has been overextended and it could be compared with the long-term minimum observed in 1911-1913 (14-15 solar cycle). In Fig. 1 the solar activity minima observed in the beginning of 20 and 21 centuries are shown. In the 20 century solar activity minimum continued about 3 years. The current minimum started in 2007 and till now we have low solar activity.

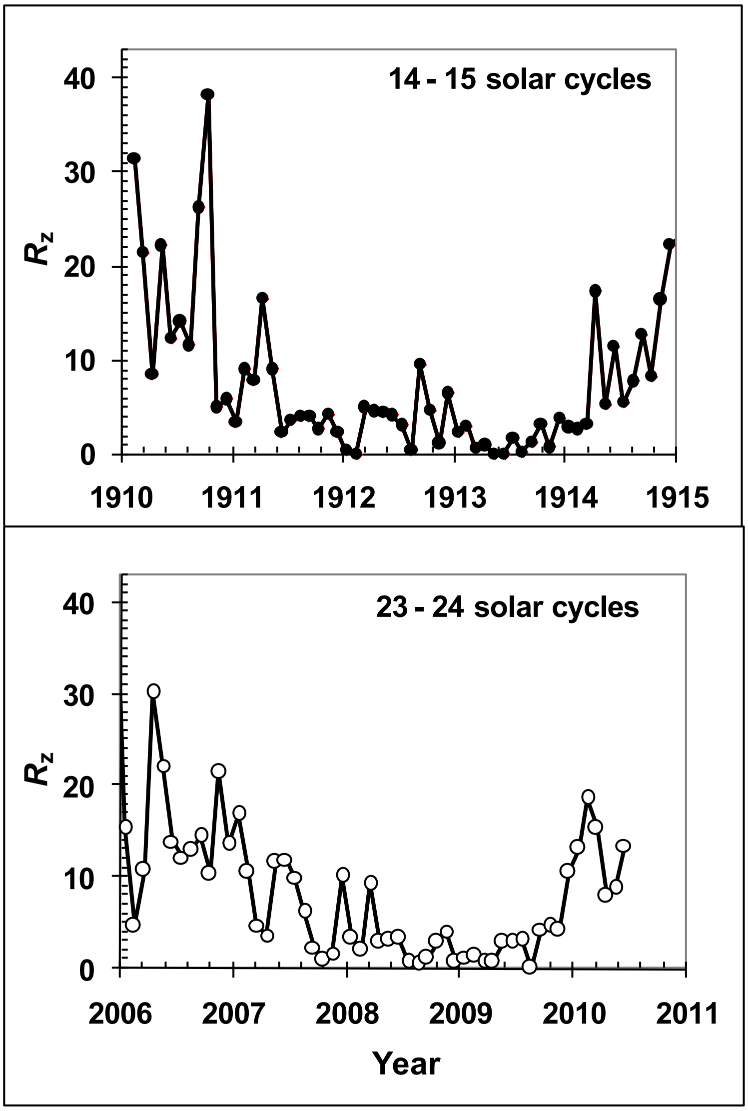

Fig. 1. Time dependences of the monthly sunspot number (R_z) at the end of 14-th and the beginning of 15-th solar cycles (upper panel, black points) and at the end of 23-rd and the beginning of 24-th solar cycles (bottom panel, open points). The data on sunspot number were taken from [8].

However, we expect that the further development of this cycle will be different from the 15-th one in the last century. In the 15-th solar cycle the increase of sunspot number started in 1914 and took place till the end of 1917, when we had sunspot number maximum $R_z \approx 130$. In the current cycle we expect the maximum value of $R_z \leq 50$.

Prognosis of the development of the 24-th solar cycle

There are many papers devoted to the prediction of the development of solar activity in the current cycle [5-7]. As a rule, the maximum number of sunspots is suggested to be about R_z = (80-100). Our prognosis is different from others made earlier because we expect a new long-term period of very low solar activity, like Maunder minimum (1620-1720) or Dalton one (1790-1835) [8]. The bases of this prognosis are discussed below in the Section of "Discussion".

In Fig.2 monthly averages of R_z in 23-rd solar cycle and the prediction of solar activity in the current 24-th solar cycle are shown. The upper dashed curve corresponds to the Dalton minimum conditions and bottom thin curve corresponds to the Maunder minimum conditions. The maximum value of R_z will be in the limits of $3 < R_z < 50$ where Brussel number of sunspots is used.

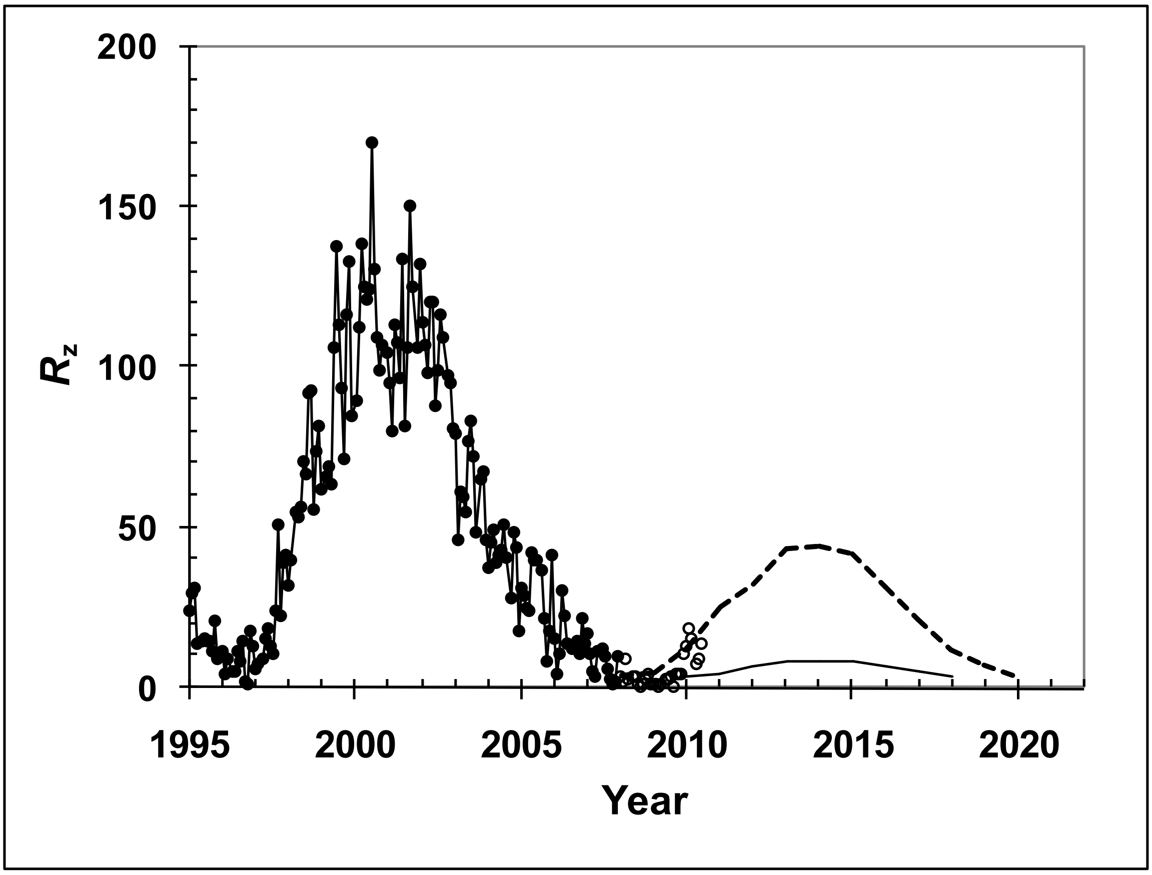

Fig. 2. The monthly averages of sunspot number R_z in 23-rd solar cycle (black points) [8]. The upper dashed curve corresponds to the Dalton minimum conditions and bottom thin curve corresponds to the Maunder minimum conditions [9, 10]. Open points are real data on R_z obtained after the end of 2007.

The prognosis was made ~ 2 years ago in the beginning of 2008 [9]. In Fig. 2 the data on R_z obtained after this time are shown by open points. There is a good coincidence between prognosis and real data.

Physical bases of solar activity prognosis

It is a well established fact that in the history of solar activity there were long-term periods when solar activity was very low during the several tens of years. These periods were called grand solar activity minima. Fig. 3 shows the yearly sunspot number as the function of time. Here the data of Shove set and real data have been used [1, 8]. One can see the long-term periods with severe decreases of solar activity. In Table 1 the approximate durations of these grand solar activity minima occurred in the past are given [3, 5].

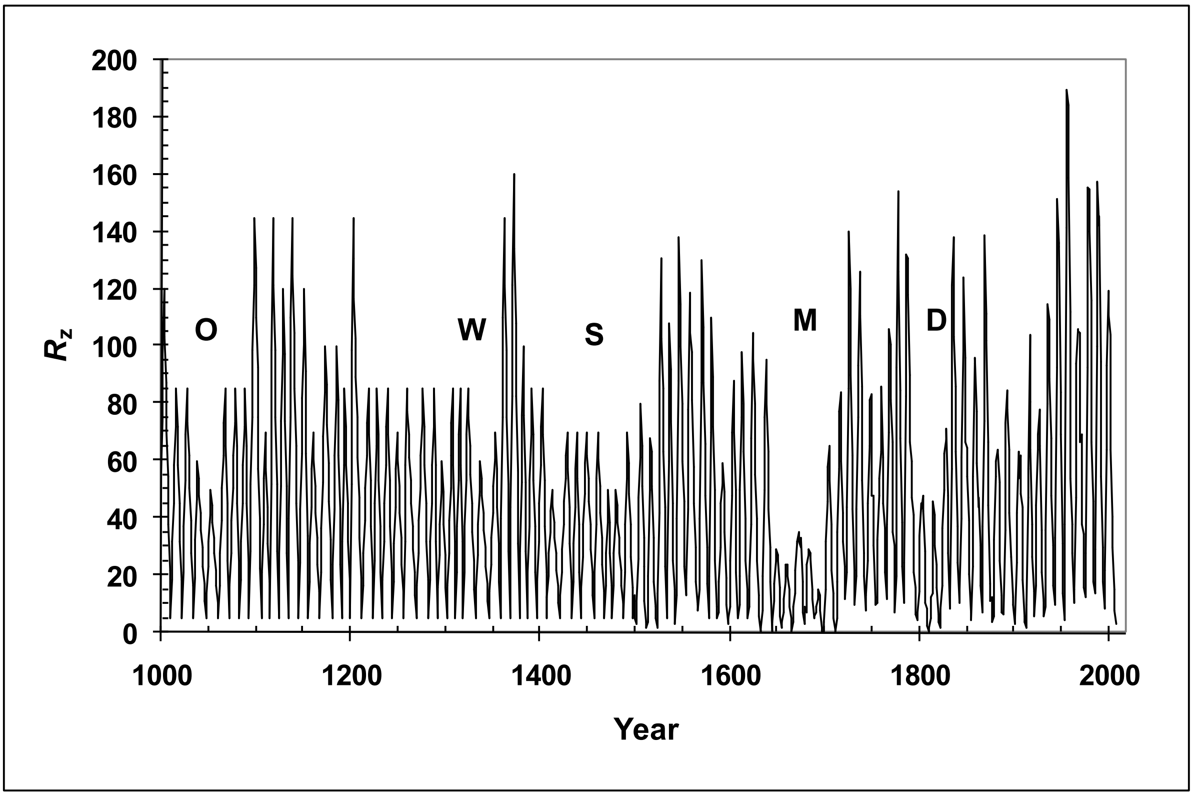

Fig. 3. Time dependence of solar activity (yearly sunspot number R_z) [1, 8]. The drastic long-term decreases of R_z were called as grand solar activity minima: O – Oort minimum, W – Wolf minimum, S – Spörer minimum, M – Maunder minimum, and D –Dalton minimum.

Table 1. The grand minima of solar activity.

Minimum	Oort	Wolf	Spörer	Maunder	Dalton
Period (years)	1010 - 1050	1280 - 1350	1460 – 1540	1620 - 1720	1790 - 1835

Analysis of the appearance of grand minima shows that they arise when the distance between the center of the Sun and the center of mass of the solar system is exceeds one solar radius. It follows from the inspection of Fig. 4. From the 5 periods of very low solar activity given in Table 1 only the Oort minimum period violated the conclusion made above. But Oort minimum took place about 1000 years ago and our knowledge on solar activity during this time is unreliable.

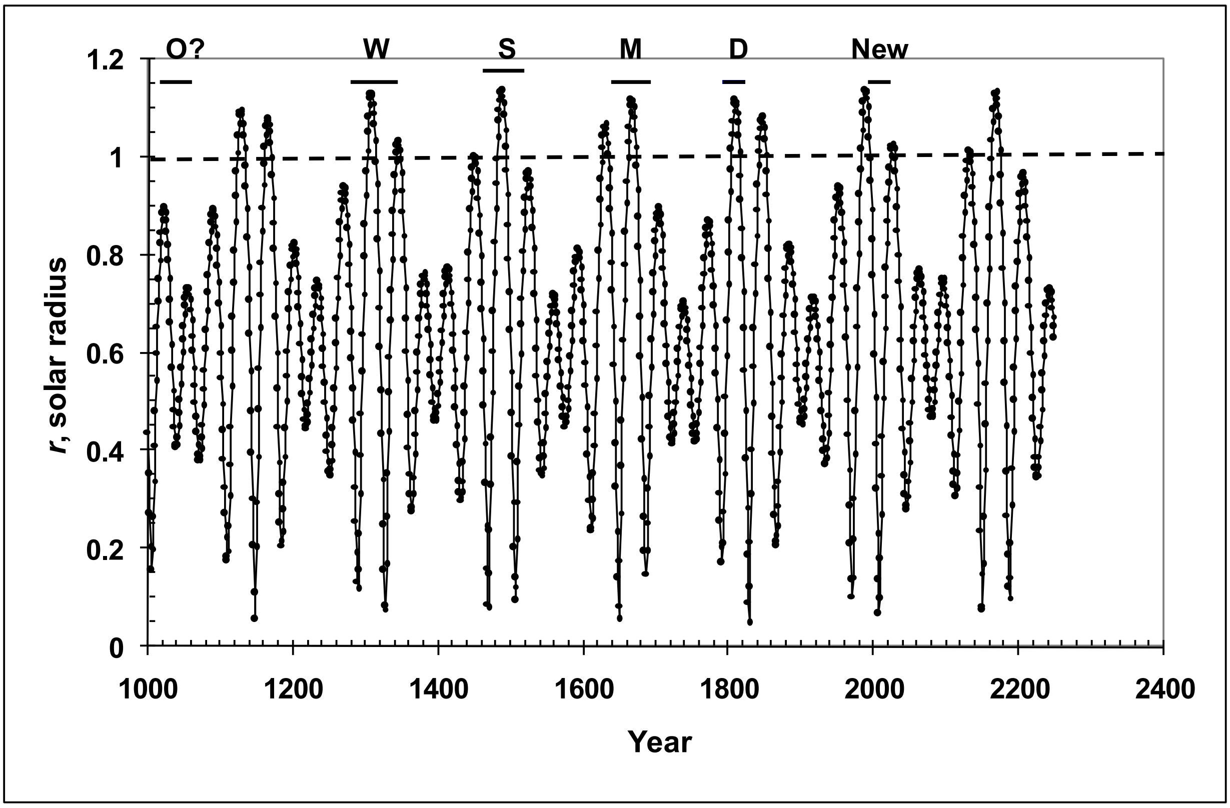

Fig.4. The distance r between the center of the Sun and the center of mass of the solar system vs. time. Calculations were made for external planets excluding Jupiter. The upper horizontal bars show the grand solar activity minima in the past. Their names are given in Fig. 3. New is a new solar grand minimum that was started ~3 years ago.

In Fig. 4 the values of r were calculated for the Sun and external planets of the solar system excluding Jupiter. The period of Jupiter rotation around the Sun is T_J = 11.86 y and high frequency oscillations will appear if we take into account of this planet. The calculations made for all planets including Jupiter give the same but less distinct result.

The inspection of Fig. 4 shows that now we have start of a new grand solar activity minimum. The next grand one is expected at the end of 22-nd century.

The spectral analysis of the set of R_z for the long period of time shows the existence of spectral lines. In Table 2 and in Fig. 5 the results of spectral analysis of R_z data for the period (1500-2008) are given [2]. The spectral lines with the significance level more than 98% are only presented.

Table 2. Periods of spectral lines, T, obtained from the set of sunspot number R_Z covered the period (1500 – 2008) and periods of two or more planet beating.

Period in R_z data (year)	600	205	106	22.13	19.96	18.35	11.06	10.76	10.49	10.02
Period of planet beating (year)	-	198	-	22.20	19.86	-	11.07	10.86	10.49	10.02

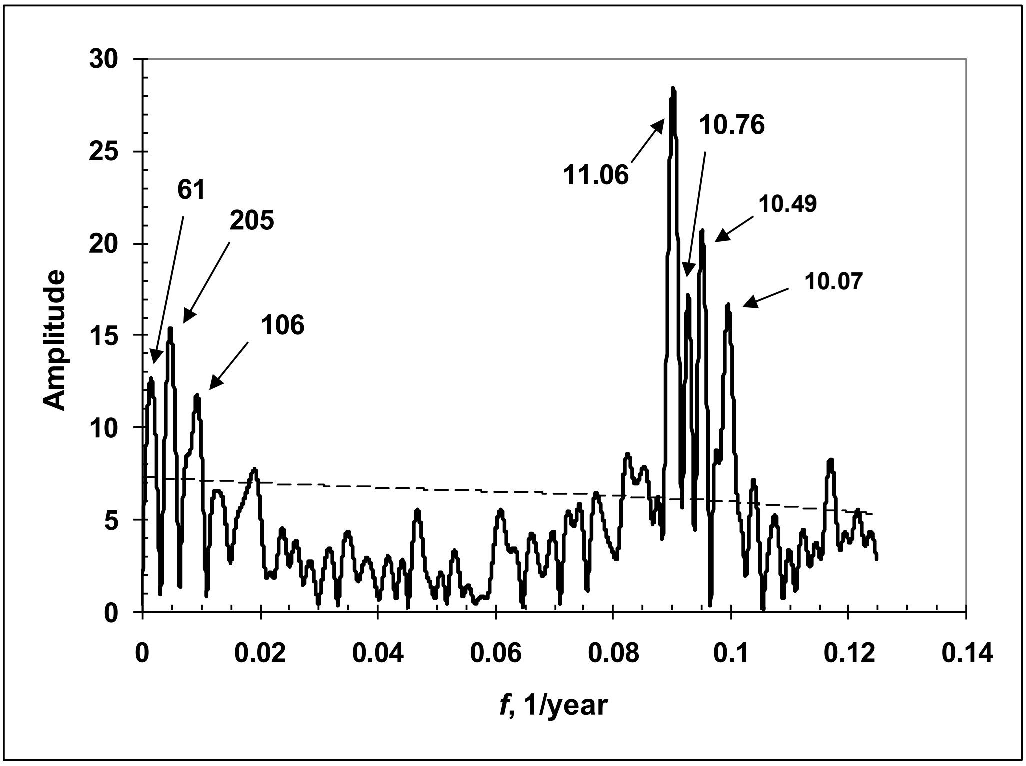

Fig. 5. The results of spectral analysis of R_z data covered the time interval (1500-2008). The dashed line shows 98% level of significance. The periods (years) of the significant spectral lines are given.

The spectral analysis of the set of R_z data covered the time interval of 2654 years confirms the existence of Theo spektral lines given in Table 2 [1, 11-13]. If one takes into account the sign of solar magnetic field and its changes with the period about 22 years the several spectral lines with $T \approx 22$ years will be present (see Table 2).

The results obtained show that the periods of spectral lines are almost in coincidence with the combinations of rotation periods of two or more planets (compare the first and second lines in Table 2). If the rotation periods of two planets differ slightly the beating will be observed, in the opposite case the side frequencies will be appear.

The oscillations with the periods of $T = 10.76$, 10.49, and 10.02 years given in Table 2 are the combinations of oscillations with $T = 11.06$ years, $T = 600$, 205, and 106 years: $T_{10.76} \approx (T_{600} \cdot T_{11.06}) / (T_{600} + T_{11.06}) = 10.86$ г., $T_{10.49} = (T_{205} \cdot T_{11.06}) / (T_{205} + T_{11.06}) = 10.49$ г., $T_{10.02} = (T_{106} \cdot T_{11.06}) / (T_{106} + T_{11.06}) = 10.02$ г. Spectral line with $T_{19.96} = 19.96$ yrs is the combination of the rotation periods of Jupiter (T_J = 11.86 yrs.) and Saturn (T_S = 29.46 yrs.): $T_{19.96} \approx (T_{11} \cdot T_{29}) / (T_{11} - T_{29}) = 19.86$ yrs. The line with $T = 22.15$ yrs. can be obtained from the expression $(1/T_{22}) = (1/T_{19}) - 1 / (T_{CM} + T_{19}/2)$, where $T_{CM} = 178.77$ yrs. is the Sun rotation period around the center mass of the solar system [11]. The line with $T = 11.06$ yrs. is the combination of the rotation periods of two planets Jupiter (T_J = 11.86 yrs.) and Neptune (T_N = 165.79 yrs.): $T_{11.06} \approx (T_{165} \cdot T_{11.9}) / (T_{165} + T_{11.9}) = 11.07$ yrs. These results reduce to the conclusion that planet motion influence solar activity.

Discussion

The results presented in Fig. 4 are difficult to explain by the occasional coincidence of the appearance of the grand solar activity minima with the position of the center mass of the solar system outside of the Sun. Also, it is difficult to understand the appearance of the spectral lines in the solar activity data and coincidence of these line periods with the combinations of rotation periods two (or more) planets (Table 2).

We suggest the following explanation of the results obtained. Sunspots arise after falling of large celestial bodies (such as comets, asteroids, and others) on the solar photosphere. After such falling the disturbances of the photosphere and photospheric magnetic field are aroused. These processes are triggers for the start of sunspot formation and active region. Further the development of sunspot and active region could be continued according to scenarios given in books on the Sun [see, for example, 14, 15].

In this scenario the 11-year solar cycle can be explained by the following way. The celestial bodies come to the solar system from the Oort cloud and Koiper belt. The gravitation fields of the solar system control the motion of these bodies. Under the influence of these fields the celestial bodies will be focused (or defocused) on the Sun at different heliolatitudes, giving “Maunder butterflies”. It allows to understand the appearance of spectral lines in the set of sunspot number and the coincidence of these lines periods with the combinations of rotation periods of several planets.

The dynamo mechanism is in operation inside of the Sun. It produces the poloidal magnetic field [4]. The differential rotation makes the toroidal field from the poloidal one. After the inversion of toroidal magnetic field the new poloidal field arises on the Sun again. We think that inversion process will take place independently on the presence or absence sunspots. The falling of celestial bodies on the solar photosphere disturbs photospheric plasma and magnetic field and trigger mechanism of sunspot, active regions and solar flare formation.

There are many papers devoted to the grand solar activity minima [16-18]. According to our point of view the appearance of such events occurs in the periods when center of mass of the solar system (Sun and external planets without Jupiter) is outside the Sun. We believe that during these periods the main part of celestial bodies in the solar system does not fall on the solar photosphere and grand minima take place. At present time we have the beginning of a new grand solar activity minimum. The next grand minimum will occur at the end of 22-nd century.

The cosmic ray fluxes observed at the Earth orbit are guided by solar activity. Thus, we can expect high cosmic ray fluxes in nearest future as solar activity is expected to be very low. In Fig. 6 the time dependences of cosmic ray fluxes in Pfotzer maximum in the atmosphere obtained at the polar and middle latitudes are presented. In 2009 we detected the highest flux of cosmic rays for ~ 50-years of observations. It was a consequence of very low solar activity observed in 2009. The strength of interplanetary magnetic field (IMF) was lowest for the past 40 years when there are data on IMF. During the next 10-20 years we expect ~11-year changes in cosmic ray flux but with the amplitude much less than it was during previous cycles from ~1950 till 2006.

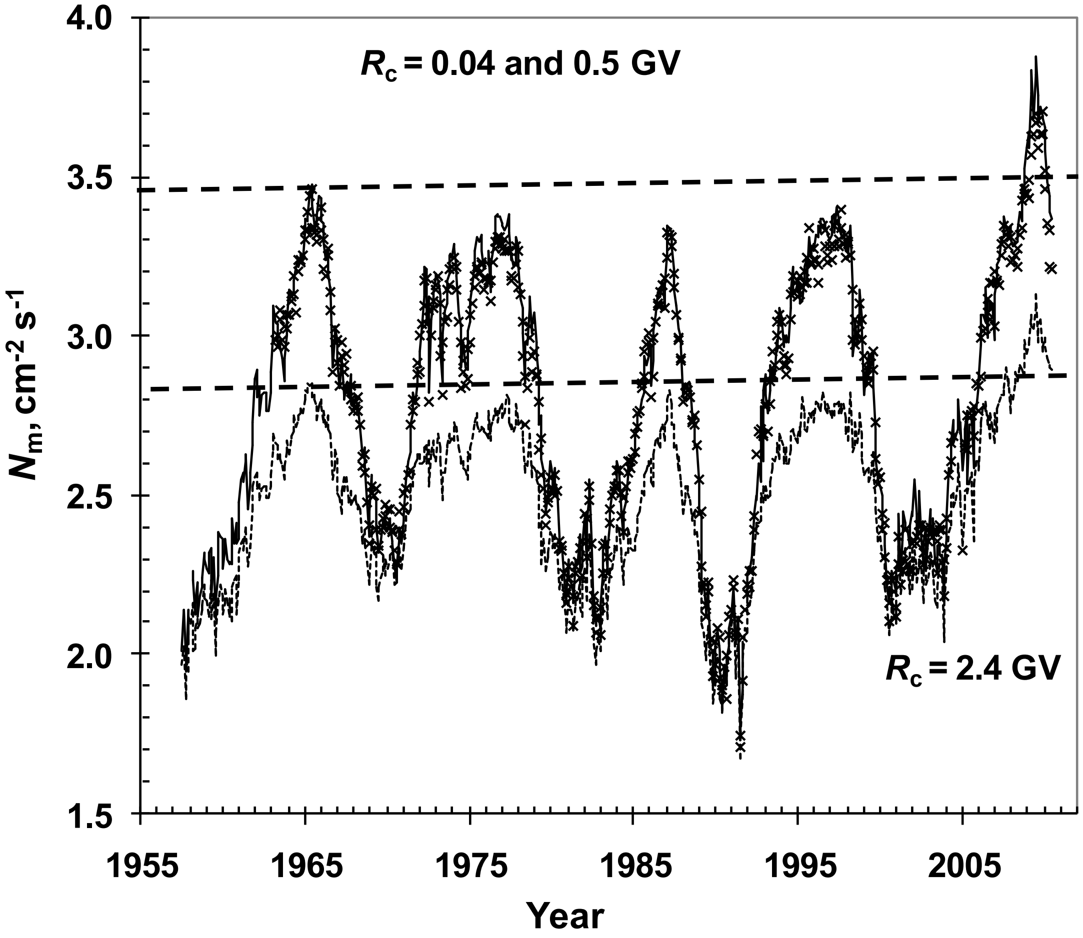

Fig. 6. Time dependences of cosmic ray fluxes measured at Pfotzer maximum in the atmosphere N_m at northern polar latitude (upper thin curve), southern polar latitude (crosses) and at the middle northern latitude (bottom dotted curve). Monthly averages of N_m are presented. The geomagnetic cutoff rigidities R_c are shown near the curves. The horizontal dashed lines show the highest cosmic ray fluxes observed in the 1965.

Conclusion

It is shown that the long-term solar activity minima occurred in the past had been taken place in the periods when center of mass of the solar system (the Sun and external planets without Jupiter) was outside of the Sun. The spectral analysis of the long set of data on solar activity (sunspot number R_Z) shows the presence of spectral lines with the periods close to the combinations of rotation periods of two (or several) planets around the Sun. The conclusion was made that the planets influence the process of sunspot formation.

The trigger for the start of sunspot formation is the falling of celestial bodies (comets, asteroids and others) on the solar photosphere. The gravitation fields of the Sun and planets govern the motions of these bodies. These field direct (or deflect) these celestial bodies to the solar photosphere. When center mass of the solar system is outside of the Sun the most of celestial bodies does not fall on the Sun and we have long-term solar activity minimum. Now we are at the beginning of a new grand solar activity minimum. The prognosis of solar activity for the period of present time – 2020 is given. The maximum value of R_Z will not exceed 50 (according to the Brussels scale of sunspots).

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