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Passive longitudes of solar cosmic ray sources

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Abstract. Solar proton events during a period from 1956 to 2012 are considered. Fluences of protons of various energies in these events have been computed. On the basis of these extensive data the inhomogeneity of the distribution of their sources on the Sun along the Carrington longitude has been confirmed, which had been earlier revealed in our studies. Special attention is paid to the discovered interval of “passive longitudes”, extensive over the longitude (≈90–170°) and the life time (the whole period of observations). The summarized proton fluence of the events, which sources belong to this interval of Carrington longitudes, is considerably lower, than the summarized proton fluences of the events in the other heliolongitude intervals. From the 60 most powerful solar proton events during the whole period of observations not more than 1 event has been originated from this interval of “passive longitudes”.

1. Introduction
From the beginning of solar cosmic ray measurements the subjects of analysis were the sort of particles, their distribution over the energy and the direction (anisotropy). While receiving the new data various authors performed the statistical analysis of solar proton events (SPE). Originally this analysis did not take into account that the power of different SPEs varied significantly. In order to eliminate this drawback it was suggested in the study [1] to perform statistical analysis of the proton fluences in each event. First it was made using the data for the 19th solar cycle, and then for the next solar cycles by the scientists in our country and abroad.

One of the directions of such analysis is the investigation of heliolongitude distribution of the sources of SPEs. In our works [2–4] we have performed such analysis using the data on ≈380 SPEs during a period from 1956 till 2007 year. It was discovered, that the distribution of the activity of solar cosmic ray injection regions by the proton fluence value in SPEs along the Carrington longitude is considerably inhomogeneous.

A special attention deserves the discovered interval of “passive” longitudes, extensive over the longitude (≈90–170°) and the life time (the whole period of observations). In the current study existence of this interval is shown using more extensive experimental data set, including the data on the first half of the new 24th solar cycle.

2. Data
The initial data contain the information about SPEs in the 19th and the following solar cycles, picked from different sources, and experimental data on measurements of the fluxes of energetic cosmic ray protons in Earth’s orbit outside its magnetosphere.
The data for the 19th cycle were obtained using various kinds of measurements (ground-based equipment, stratospheric balloons, geophysical rockets, first spacecraft), which at that time had not been performed systematically. Many solar cosmic ray parameters were determined by indirect methods using the results of riometric measurements and registration of geomagnetic perturbations and peaks in solar radio emission [5]. For the 20th solar cycle the more reliable data on SPEs and proton fluences during them from various sources based on the spacecraft measurements [6–8] were used.

For the period from 1970s till 2001 year we used almost uninterrupted data set with the length of ≈30 years containing measurements of interplanetary proton fluxes by identical set of detectors onboard IMP series spacecraft in the near-Earth’s orbit with the altitude of ≈35 Earth’s radii, i.e. outside its magnetosphere [9]. Finally, for the period from October 2001 till April 2012 we used the data on hourly-averaged fluxes of protons with energies >10 and >30 MeV, measured by ACE spacecraft, located in the Sun-Earth libration point L1 at a distance of ≈1.5 million km from Earth [10].

On the basis of these sources we created a data base on ≈400 SPEs from 1956 till 2012 year. It contains the data about the time when SPE occurred, fluence of solar protons with energies >30 MeV during this SPE and the Carrington longitude of its source on the Sun. For the 19th and 20th solar cycles these data were taken from the sources described above. For the period from 1970 till 2012 we have computed proton fluences in SPEs using IMP and ACE spacecraft measurements. Beforehand the time series of the background fluxes of galactic cosmic ray protons were computed for this period of time, using our method described in [11]. The background flux values were subtracted when calculating the fluxes. The heliocoordinates of the particle injection sources for the period starting from 1976 were taken from NOAA data [12].

3. Results of analysis

The analysis, performed using this more extensive data set, has confirmed the considerable inhomogeneity of the distribution of solar proton event sources along the Carrington longitude, which we had discovered earlier. A special attention deserves extensive over the longitude (≈90–170°) and the life time (the whole period of observations) interval of “passive” longitudes.

In Fig. 1a the power and heliolongitudes of all SPEs during 19–24 solar cycles are shown, for which fluences of protons with energies >30 MeV were higher than 10⁷ cm⁻². As one could see from the plot, during the whole period of observations a total of 60 very powerful SPEs had occurred with fluence ≥10⁸ cm⁻². And among them just only one SPE has the Carrington longitude of its source inside the interval of 100–170°.

It is the event of November 4, 2001 with the fluence equal to 2·10⁹ cm⁻²; the Carrington longitude of the active region 9684, which was according to NOAA data the source of proton injection for this event, is equal to 135°. We have checked the correctness of determining the source region for this event according to NOAA data. In Fig. 2 the configuration of active regions on the Sun for November 4, 2001 is shown. Beside the mentioned region at the same time active regions 9682 and 9687 existed, which during that day had produced multiple C-class flares. Both of them were located outside the passive longitude region. But only the region 9864 at that day at 16:03 produced the strong X1-class solar flare, and one hour after its start the detectors onboard ACE spacecraft measured the increase of the fluxes of protons with energies >30 MeV by 3 orders of magnitude.

Thus apparently the strong event of November 4, 2001 does appear to be the only exception from the rule. The sources of other 59 powerful SPEs in solar cycles 19–24 with fluences ≥10⁷ cm⁻² lay outside the interval of 100–170°. From another 70 “medium” events in cycles 19–24 with fluences varying from 10⁷ to 10⁸ cm⁻² sources of only 10 SPEs are located in the interval of 100–170°.
Figure 1. a) Fluences of protons with energies >30 MeV in solar proton events of 19–24 solar cycles with values ≥10^7 cm\(^{-2}\); b) distribution of fluences of protons with energies >30 MeV in SPEs of 19–24 cycles along the Carrington longitude. Interval of “passive” longitudes 90–170° is emphasized. The only “anomalous” strong SPE during 57 years, which source lay in the interval of passive longitudes, is marked by the dash line.

Figure 2. Configuration of active regions on the Sun during “anomalous” SPE on November 4, 2001. Location of passive longitude region is also shown.
In Fig. 1b for each 10-degree interval of Carrington longitudes a portion of protons with energies >30 MeV injected from this interval is calculated relative to the total fluence over all longitudes for the whole investigated period of time. From the plot follows that the values of total fluences for 10-degree intervals inside the “passive” longitude range ≈90–170°, without taking into account “anomalous” SPE of November 4, 2001, do not exceed 5.5% from the mean fluence value for all longitudes. The summarized fluence for the passive longitude interval amounts to just only 1.2% (and even taking into account the event of November 4, 2001 – only 5%) from the total fluence for all the considered SPEs.

Thus from the data in this section it follows, that in the discovered region of “passive” Carrington longitudes ≈90–170° during the whole investigated period very few strong SPEs took place; the total proton fluence in the events which sources belong to that interval is considerably lower than total fluences of protons in other heliolongitude intervals.

4. Discussion

The existence of the interval of “passive” Carrington longitudes, extensive over the longitude and the life time, is the remarkable phenomena in solar physics.

In order to find out its possible explanations it seems reasonable to study the heliolongitude distribution of other indices of solar activity and the time dependence of the magnetic field structures on the Sun.

Another result of this research is the confirmation of physical relevance of the mean synodic period of Sun’s rotation, which was determined by R. C. Carrington as equal to 27.2753 days.

References