Passive Carrington Longitudes of Solar Cosmic Ray Sources in Solar Cycles 19–24

To cite this article: M V Podzolko 2019 J. Phys.: Conf. Ser. 1181 012016

View the article online for updates and enhancements.
Passive Carrington Longitudes of Solar Cosmic Ray Sources in Solar Cycles 19–24

M V Podzolko
D. V. Skobeltsyn Institute of Nuclear Physics of M. V. Lomonosov Moscow State University (SINP MSU), Leninskie Gory, Moscow, 119991, Russian Federation
E-mail: spacerad@mail.ru

Abstract. Distribution of the fluences of solar proton events in solar cycles 19–24 over the Carrington longitude of their sources on the Sun has been considered. An interval of “passive” Carrington longitudes, extensive over the longitude (≈100–170°) and the lifetime (the whole period of observations) has been discovered, which very rarely produced the powerful solar proton events. It was earlier found in cycles 19–23 and now confirmed for the complete cycle 24 as well.

1.  Introduction
In this study a distribution of the fluences of energetic protons of solar cosmic rays over the Carrington longitude of their sources on the Sun is considered.

A concept of the fluence (cumulative flux) of protons during the solar proton event (SPE) is standardly used in statistical models of solar cosmic rays. However, for the study of the longitudinal distribution of the solar activity typically the number of solar flares or number of sunspots or active regions are taken, which for the long time intervals demonstrate weak longitudinal dependency (see, for example, [1]).

We have carried out the analysis of the distribution of the fluences of energetic protons in SPEs over the Carrington longitude of their sources. A considerable inhomogeneity of this distribution has been found. In particular, an interval of “passive” Carrington longitudes, extensive over the longitude (≈100–170°) and the lifetime (the whole period of observations) was discovered, which very rarely produced the powerful solar proton events. It was earlier found in cycles 19–23 in the studies by I. V. Getselev et al. [2, 3], and now confirmed for cycle 24 as well.

2.  Data
For this study a database on ≈450 solar proton events was used, which had been compiled from different sources and contained the information about the fluences of protons with energies >30 MeV during the SPEs and the heliolongitudes of the solar flares, during which these particles had been injected.

The data for solar cycles 19 and 20 were taken from different published catalogues [4–7]. For the 19th cycle the measurements were obtained using various methods (ground-based equipment, stratospheric balloons, geophysical rockets, first spacecraft); proton fluences were partially determined by indirect methods using the results of riometric measurements and registration of geomagnetic perturbations and peaks in solar radio emission. For the 20th cycle the data on proton fluences were obtained using the measurements onboard spacecraft.
For the period from 1970s till the current time we used the continuous sets of measurements of the interplanetary protons fluxes onboard IMP series spacecraft in the high-altitude near-Earth orbits and ACE spacecraft in the L1 libration point of the Sun-Earth system at a distance of \( \approx 1.5 \) million km from the Earth, which are publically available [8]. Using these data the fluences of protons with energies \( >30 \) MeV in the SPEs were computed. During these computations the background fluxes of galactic cosmic ray protons were subtracted using the developed formalized method [9]. The links to the sources of particle injection on the Sun starting from 1976 were taken from the NOAA data base [10].

Using the data on the observed heliolongitudes of the solar proton event sources, the Carrington longitudes were computed for all SPEs in the data base using the constant Carrington rotation period.

3. Results of analysis

The results of the analysis of the distribution of the fluences of protons in SPEs over the Carrington longitude of their sources on the Sun are presented in Fig. 1.

In Fig. 1a the fluences of protons with energies \( >30 \) MeV for all considered SPEs during 19–24 solar cycles with the fluence higher than \( 10^7 \) cm\(^{-2} \) are shown related to the Carrington longitudes of their sources. In our study [3] it was shown, that during the period from 1956 till 2012 from a total of 60 most powerful SPEs with fluences of protons \( \geq 10^8 \) cm\(^{-2} \) only one SPE of November 4, 2001, generated by active region 9684, had the Carrington longitude of its source inside the interval of 100–170°. Taking into account the complete data on 24th solar cycle it appears that the last solar proton event of the cycle of September 10, 2017, generated by active region 12673, with the fluence value \( 8 \cdot 10^8 \) cm\(^{-2} \) also had the Carrington longitude of its source inside the interval of 100–170°. Thus during the whole period of observation from 65 most powerful SPEs with fluences of protons with energies \( >30 \) MeV \( \geq 10^8 \) cm\(^{-2} \) only two SPEs had their sources inside the “passive” longitude interval. From another 85 “medium” SPEs with fluences \( 10^7–10^8 \) cm\(^{-2} \) in cycles 19–24 sources of only \( \approx 12 \) SPEs were located in the passive longitude interval.

In Fig. 1b for each 10-degree interval of Carrington longitude a fraction of the fluences of protons with energies \( >30 \) MeV injected from this interval is computed, relative to the total fluence over all longitudes for all considered SPEs. From the plot it follows that the summarized fluence for the passive longitude interval amounts to only 6% from the total fluence for all the considered SPEs during the whole investigated period of observations.

It should be mentioned, that the computations of the same distributions for each solar cycle separately showed, that the active Carrington longitudes, from which the major fraction of the proton fluences was injected, changed from one cycle to another. Whereas the discovered passive longitude interval can be determined for the whole 6 solar cycles.

Returning to Fig. 1a, one could see that the last powerful SPE on September 10, 2017 had its source near the border of the passive longitude interval. This led us to check the influence of the accuracy of the definition of Carrington period to the longitudinal distribution of the SPE fluences. The value of the sidereal period of Sun’s rotation was determined by R. C. Carrington from the observations of low-latitude sunspots with the accuracy of 2 decimals equal to 25.38 days (corresponding synodic period 27.2753 days). We took the value of the sidereal period changed in the third digit to 25.379 days (corresponding synodic period 27.2742 days) and computed the distribution of the SPE fluences over the modified Carrington longitude values. To make the comparison of the initial and modified distributions more accessible in both cases for the time of the initial Sun’s rotation the time of 1369s Carrington rotation 1956-01-07 13:00 UT was taken, which corresponds to the beginning of 19th solar cycle. The modified distribution of the SPE fluences over the Carrington longitude is shown in Fig. 2. As one could see from this figure, with the value of sidereal Carrington period \( T = 25.379 \) days only one “anomalous” powerful SPE of November 4, 2001 remained in the passive longitude interval; and the summarized value of the fluence of SPEs in the passive longitude interval decreased to only 4.5% from the total fluence for all the considered SPEs.

The changing of the Carrington period by notably larger value leads to disappearing of the inhomogeneity of SPE fluence distribution over the Carrington longitude.
Figure 1. Distribution of the fluences of protons with energies >30 MeV in solar proton events in the solar cycles 19–24 over the Carrington longitude of their sources a) for the individual SPEs, b) summed over 10-degree intervals. Interval of “passive” longitudes 100–170° is emphasized. The two only “anomalous” strong SPEs during 62 years, which sources lay in the interval of passive longitudes, are marked by dash lines.

Figure 2. Distribution of the fluences of protons with energies >30 MeV in solar proton events in the solar cycles 19–24 over the Carrington longitude of their sources for the value of sidereal Carrington period \( T = 25.379 \) days instead of 25.38. Only one “anomalous” SPE of November 4, 2001 remained in the passive longitude interval.
4. Conclusions and discussion

On the basis of the study of the solar proton event fluence distribution over the longitude of their sources on the Sun the interval of “passive” Carrington longitudes, extensive over the longitude (≈100–170°) and the lifetime (6 solar cycles) has been discovered. From 65 most powerful SPEs during the whole period of observations with fluences of protons with energies >30 MeV ≥10^8 cm^{-2} only 1–2 SPEs had their sources inside the passive longitude interval. The summarized value of the fluence of SPEs in the passive longitude interval amounts to only 4.5–6% from the total fluence for all the considered SPEs.

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

Author does not have the physical explanation of this phenomenon. Very speculatively, it may be the asymmetry of the solar magnetic dynamo.

It should be also noted, that such inhomogeneous longitudinal distribution of the sources of energetic proton fluences was received using the constant Carrington period of Sun’s rotation, despite the fact that solar photosphere experiences the differential rotation. This fact may serve as a certain confirmation of the physical relevance of the Carrington period; and lead one to conjecture that the nature of the magnetic fields in the active regions, accelerating the particles during the most powerful solar flares is connected with the deeper layers of the Sun.

For the further research on the problem we intend to and investigate the longitudinal and temporal dependencies of the fluences of higher energy protons and the other indices of solar activity and the magnetic field structures on the Sun.

Proof of the existence of the passive interval of Carrington longitudes may have applications for the mid-term forecasting of the space radiation risks, for instance for determining the time window for sending the manned spacecraft to the Moon.

Acknowledgements
The research was supported by the grant No. 17-29-01022 of the Russian Science Foundation.

References
[1] Vernova E S, Mursula K, Tyasto M I and Baranov D G 2004 Long-term longitudinal asymmetries in sunspot activity: difference between the ascending and descending phase of the solar cycle Solar Physics 221 151–65
[2] Getselev I V, Okhlopkov V P and Chuchkov E A 2003 Active longitudes in injection regions of solar cosmic rays Bulletin of Russian Academy of Sciences: Physics 67(4) 532–4
[3] Getselev I V, Podzolko M V and Okhlopkov V P 2013 Passive longitudes of solar cosmic ray sources J. Phys. Conf. Ser. 409 012203.
[4] Dolginova Yu N 1972 Catalogue of chromospheric flares and corresponding phenomena over the period from 1957 till 1965 Sun-Earth Physics vol. 2 (Moscow: IZMIRAN) (in Russian)
[5] Akinyan S T, Basilevskaya G A, Ishkov V N et al. 1982 Catalogue of solar proton events 1970–1979 ed. Logachev Yu I (Moscow: IZMIRAN) (in Russian)
[6] King J H 1974 Solar proton fluences for 1977–1983 space missions J. Spacecraft Rockets 11 401–8
[7] Feynman J, Armstrong T P, Dao-Gibner L and Silverman S 1990 A new interplanetary proton fluence model J. Spacecraft Rockets 27(4) 403–10
[8] http://spdf.gsfc.nasa.gov/
[9] Getselev I V, Podzolko M V and Veselovsky I S 2009 Optimization of the interplanetary energetic proton flux database and its application in modeling radiation conditions Sol. Syst. Res. 43(2) 136–42
[10] http://umbra.nascom.nasa.gov/SEP/