24th cycle. We conclude that the maximum smoothed number of sunspots in the 25th cycle Wmax (25), most likely, should be equal to 185 ± 18 units in the new system, which corresponds to the average power of the solar cycle, with the fulfillment of the Gnievyshev-Olya rule. With such parameters of this cycle, there are signs of approaching the deep minimum of the age cycle in the middle of the 21st century. there is no This does not exclude the fact that this deep age minimum can occur suddenly and sharply immediately after the 25th day of the cycle, as it was, for example, in the Dalton minimum.

Key words: Sun, solar activity, number of sunspots, amplitude forecast of the 25th cycle, Gnievyshev-Olya rule, minimum of the age cycle.

LONG-TERM VARIATIONS OF MAGNETIC ACTIVITY OF THE SUN DURING THE HOLOCENE

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The main law of the evolution of the Earth's climate is the cyclical nature of global changes in the latter. One of the possible explanations for the cyclical nature of global climate changes is provided by the astrophysical model of fluctuations in the insolation of the Earth's surface by solar radiation. Modern climate change is mainly associated with variations in the magnetic activity of the Sun, one of the main proxies of which are sunspots. The decrease in the number of sunspots coincides with the epochs of cooling on the Earth, while during the maximum number of sunspots warming is observed. The paper reviews cosmogenic reconstructions of long-term variations in the Sun's magnetic activity (large minima and large maxima) during the Holocene (last 12,000 years). The accidental appearance of large minima and maxima can to some extent be reproduced by modern models of a turbulent dynamo with a stochastic drive.

An important key to studying the impact of solar activity variations on the Earth's climate is the Maunder minimum (late 17th century), during which extremely little sunspots were observed. Applying the method of analysis of rare events to these observations led researchers to conclude that the appearance of sunspots at the Maunder minimum was characterized by a weak amplitude of 22 years. The concept of continuity of magnetic cycles at this time is also confirmed by measurements of cosmogenic radionuclides in natural terrestrial archives. Therefore, today it is believed that during the Maunder minimum, the cyclic magnetic activity of the Sun did not stop, although the amplitude of the cycles was quite low.

In the $\alpha\Omega$-dynamo model, this may be due to the fact that the magnitude of the magnetic induction of the toroidal field excited by radial differential rotation in the SCZ at this time did not reach the threshold value required for lifting magnetic power tubes on the solar surface (nonlinear dynamo mode).

A scenario for explaining the north-south asymmetry of magnetic activity during the Maunder minimum is proposed. A key role in the proposed scenario is played by the special nature of the internal rotation of the Sun, revealed as a result of helioseismological experiments.

The modern grand maximum of solar activity, which began in the 1940s, has ceased after solar cycle 23, and activity of the Sun seems to be returning to its normal moderate level.

Key words: global climate changes of the Earth, sunspot cycles, magnetic fields of the Sun, cosmogenic proxies of solar activity, Maunder minimum, modern grand maximum, solar dynamo.

Science now has at its disposal reliable facts that the Earth's climate has repeatedly undergone radical global changes over different periods of time. The main regularity of the evolution of the Earth's climate is the cyclical nature of its global changes. The most important element of the climate that affects its other characteristics, primarily the temperature, is the radiant energy of the Sun. One of the possible explanations for the cyclicality of global climate changes is provided by an astrophysical model of fluctuations in the irradiation of the Earth's surface by solar radiation.

Modern climate changes are mainly associated with variations in the magnetic activity of the Sun, one of the main indices of which is sunspots. The decrease in the number of sunspots coincides with epochs of cooling on Earth, while during the maximum number of sunspots there is warming. This paper provides an overview of cosmogenic reconstructions of long-term changes in the Sun's magnetic activity (Grand minima and Grand maxima) during the Holocene (last 12,000 years).

Grand minima

Let's start by considering the Grand minima – periods of significant decrease in solar magnetic activity. An important key to studying the impact of variations in solar activity on the Earth's climate is the Maunder minimum (at the end of the 17th century) (Fig. 1), during which exceptionally few sunspots, carriers of a powerful global magnetic field, were observed.

Fig. 1. Variations in the activity of the Sun (mean annual Wolff numbers) during 1600–2000 according to observed sunspot data. A sharp weakening of solar activity in the periods 1645 –1715 and 1795 –1823 is commonly called the Maunder minimum and the Dalton minimum. The increase in activity in 1940–2000 is the modern high maximum [https://uk wikipedia.org/wiki/Solar activity]

The global magnetic field of the Sun determines the distribution of the interplanetary magnetic field in the heliosphere and affects the formation of the Earth's magnetic field. Together, they play the role of a protective shield against the penetration of galactic and solar cosmic rays into the Earth's atmosphere. The general movement of the plasma of the solar wind outwards from the Sun tries to "push" galactic cosmic rays (GCR) out of the solar system back into interstellar space, where they came from. As a result, there is an inverse correlation between the intensity of the GCR and the power of the solar corpuscular radiation (solar activity). The weaker the magnetic fields of the sunspots, the higher the intensity of cosmic radiation near the Earth. The main markers (proxies) indicating the intensity of galactic cosmic rays are cosmogenic radionuclides beryllium ^{10}Be and carbon ^{14}C. Both radionuclides are formed in a very similar way in the Earth's atmosphere as a result of nuclear reactions of galactic cosmic ray particles with atmospheric nitrogen and oxygen [Masarik J., Beer J. An updated simulation of particle fluxes and cosmogenic nuclide production in the Earth’s atmosphere// Journ. Geophys Res-Atmos. – 2009. – V.114. – D11103.]. The increase in cosmic radiation leads to an increase in the number of radionuclides ^{10}Be and ^{14}C in the Earth's atmosphere, since the rate of nuclear reactions of the formation of these radionuclides is directly related to the intensity of the GCR flow (which is modulated by magnetic fields in the heliosphere). In this regard, measurements of variations in the number of radionuclides provide a unique opportunity to reconstruct the history of cosmic radiation (galactic cosmic rays) over many millennia, which in turn reproduces variations in solar magnetic activity in the past. Therefore, measurements of radionuclides stored in terrestrial reservoirs (beryllium ^{10}Be in polar ice cores from Greenland and Antarctica, and carbon ^{14}C in the form of CO_2 in annual tree rings) (Fig. 2) provide a unique opportunity to reconstruct the history of cosmic radiation (galactic cosmic rays) over many millennia, which in turn reproduces variations in solar magnetic activity in the past [Steinhilber F. et al. 9,400 years of cosmic radiation and solar activity from ice cores and tree rings// Proceedings of the National Academy of Sciences. – 2012. – V.109, No 16. – P.5967-5971].

In other words, the reconstruction of variations in the concentration of cosmogenic radionuclides indirectly reflects the variations of the protective helio-geomagnetic shield, which regulates the penetration of GCR into the Earth's atmosphere. Changes in the intensity of global magnetism cause variations in solar radiation, on which the insolation (and temperature) of the Earth's surface depends. Within the framework of the astrophysical model, the latter causes climate changes.

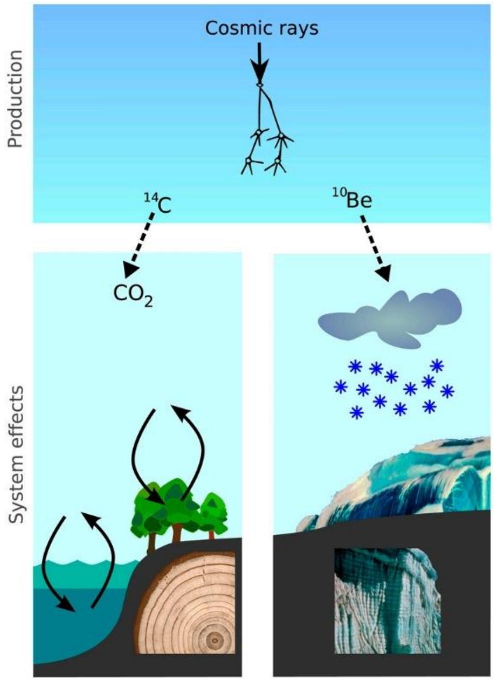

Fig. 2. Accumulation of radionuclides in terrestrial reservoirs: carbon ^{14}C in the form of CO_2 in annual tree rings and beryllium ^{10}Be in polar ice cores from Greenland and Antarctica

Measurements of variations in the content of cosmogenic radionuclides in the earth's archives led researchers to the conclusion that during the Maunder minimum, the cyclic magnetic activity of the Sun did not stop (Fig. 3), although the amplitude of the cycles was quite low.

Applying the method of rare event analysis to the observations of the sunspots led the researchers to the conclusion that the appearance of sunspots during the Maunder minimum is inherent in a weak 22-year cycle in amplitude. In the $\alpha\Omega$ dynamo model, this may be due to the fact that the magnitude of the magnetic induction of the toroidal field, excited by the radial differential rotation in the solar convection zone (SCZ), at that time did not reach the threshold value necessary for the floating of magnetic power tubes to the solar surface (non-linear dynamo mode).

Using the data of ^{14}C measurements in the growth rings of tree trunks, the authors [Usoskin I.G. et al. Astron. Astrophys. 2007] carried out a quantitative reconstruction of solar magnetic activity over the past 11,000 years, based on which a list of 27 Grand minima was compiled. Grand minima of magnetic activity, a racy representative of which is the Maunder minimum, are typical solar phenomena. The average duration of these minima is 70 years, but the distribution in length is bimodal. As a rule, minima are either short (30–90 years) in duration, similar to the Maunder minimum, or quite long (> 100 years), similar to the Spörer minimum. The total duration of the grand minima is about 1900 years, indicating that the Sun at its current evolutionary stage spends ~17% of its time in a quiescent state corresponding to grand minima.

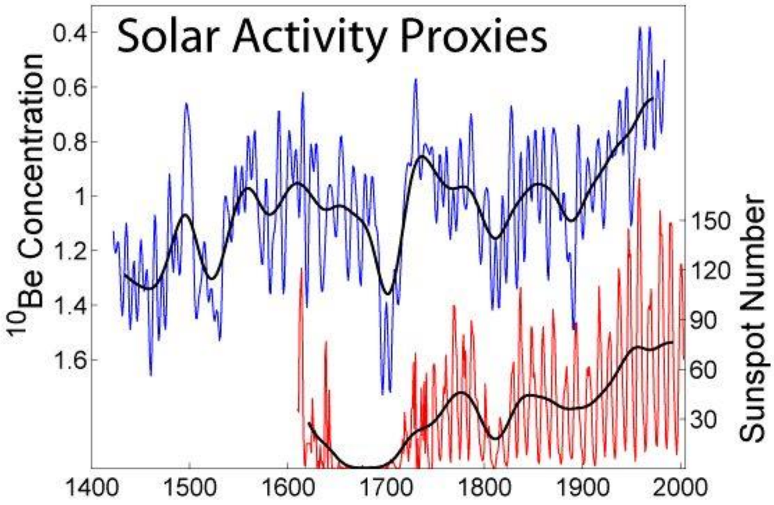

Fig. 3. Long-term variations of the Sun's magnetic activity during 1420–2000 based on data from observations of sunspots and isotopes of beryllium. The lower curve is the Wolf number (relative number of sunspots), which characterizes the intensity of spot formation. The upper curve is the concentration of the radionuclide beryllium ^{10}Be (relative units) in the polar ice cores, which serves as a marker of the intensity of the global magnetic field of the Sun. [F. Steinhilber, J.A. Abreu, J. Beer et al.// Proceed. of the National Academy of Sciences. – 2012. – V.109, No 16. – P.5967-5971]

The occurrence of Grand minima indicates that they do not appear periodically, but rather as a result of a chaotic process within clusters of magnetic activity manifestations separated by 2000–2500 years. Most researchers believe that the occurrence of Grand minima is a purely random process, for which the probability of Grand minimum occurring at any point in time is constant. Usoskin I. et al. in paper [Grand minima and maxima of solar activity: new observational constraints// Astron. Astrophys. – 2007. – V.471. – P.301–309] conducted a statistical analysis of the time of occurrence of Grand minima and concluded that their appearance is not the result of long-term cyclical changes, but is determined by stochastic processes. This means that an event can be random, but its probability is heterogeneous in time and depends on previous history. Such behavior can be interpreted as self-organized processes related to the accumulation and release of energy. The observed feature may be an artifact of small statistics (only 27 Grand minima), which makes this result only indicative, which requires further investigation in the future [Usoskin I.G. Living Reviews in Solar Physics. 2013; Moss D. at al. Solar Phys. 2008; Usoskin I.G. et al. Solar Phys. 2009].

North-south asymmetry of solar activity during the Maunder minimum

A very important feature of solar activity during the Maunder minimum was its strong north-south asymmetry, when sunspots were observed mainly only in the southern hemisphere of the Sun [Sokoloff D.D., E. Nesme-Ribes. Astron. Astrophys.1994]. We proposed a scenario to explain the north-south asymmetry of magnetic activity (the number of observed sunspots) during the Maunder minimum. A key role in the proposed scenario is played by the special nature of the internal rotation of the Sun, revealed as a result of helioseismological experiments. According to the data of helioseismology [Howe R. Solar interior rotation and its variation// Living Rev. Sol. Phys. – 2009. – V.6 (1). – P. 1-75], the SCZ is naturally divided into polar and equatorial domains with opposite signs of the radial gradient angular velocity parameter $\partial\Omega/\partial r$. In view of this, different regimes of differential rotation must obviously have a certain influence on the processes of magnetic excitation in the specified areas of the Sun. Fig. 4 shows the structure of the poloidal magnetic field excited within the framework of the $\alpha\Omega$ dynamo, which we built on the basis of physical characteristics taken from M. Stix's solar convection zone model [Stix M. The Sun: An Introduction – 2nd ed. – Berlin: Springer-Verlag. – 2002].

The north-south asymmetry of the distribution of the surface (background) magnetic field (left hemisphere) is clearly visible, caused by the exit of the lines of force of the deep poloidal field to the solar surface: in the northern hemisphere there are three latitudinal zones with interspersed signs of magnetic polarity, while in the southern hemisphere there are only two zones with opposite signs of polarity, since the directions of the lines of force of the dipole and quadrupole coincide here at mid-latitudes. Differential rotation, acting on the indicated harmonics of the poloidal field, excites dipole and quadrupole harmonics of the toroidal field, respectively.

The dominant harmonics of each type play a specific role in the magnetic cycle scenario. For a longer period of time, the cycles are usually ruled by the dipole, which is responsible for the north-south ratio of the signs of the magnetic poles of the global field, which is described by Hale's law [Hale G.E., Nicholson S.B. The low of Sun-spot polarity// Astrophys. Journ. – 1925. – V.62. – P.270-300].

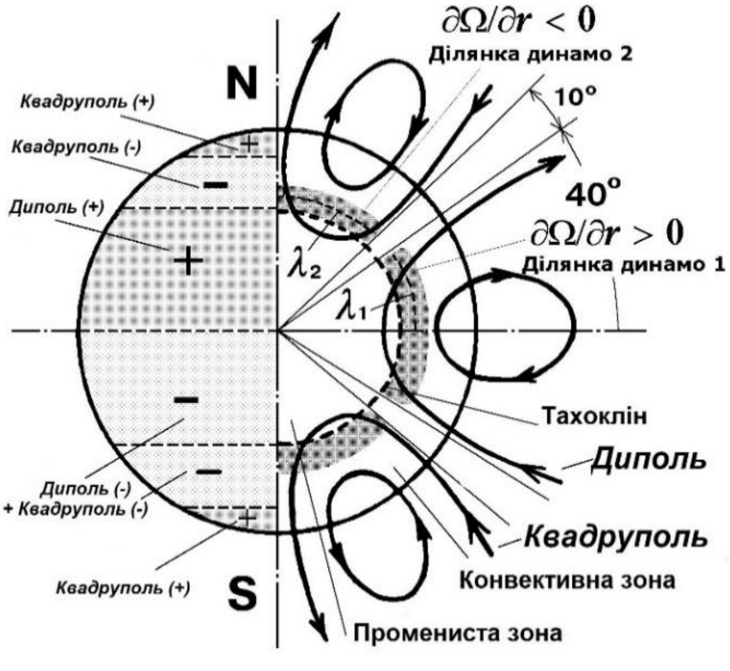

Fig. 4. The structure of the global poloidal field (dipole and quadrupole modes) excited by the $\alpha\Omega$-dynamo mechanism in the SCZ in the vicinity of the tachocline section near the epoch of the maximum activity of the 23rd cycle. Right hemisphere: magnetic field lines of dipole ($\theta^* < 40^{\circ}$, $\partial\Omega/\partial r > 0$, dynamo section 1) and quadrupole ($\theta^* > 50^{\circ}$, $\partial\Omega/\partial r < 0$, dynamo section 2), λ_1, λ_2 – meridional extent of generation areas. Left hemisphere: latitudinal zones with positive (+) and negative (–) magnetic polarity of the surface (background) field, which correspond to deep magnetic structures

However, when approaching the moment of sign change (reversal) of polar magnetism, favorable conditions are created for the excitation of a quadrupole against the background of a fading dipole. The quadrupole dynamo-harmonic of the toroidal field gives rise to a small number of bipolar groups of spots with the "wrong polarity" of spots. We believe that during the Maunder minimum, the quadrupole dynamo-harmonic of the toroidal field prevailed, which led to an increase in the number of sunspots in the southern hemisphere of the Sun.

Grand maxima

Let's move on to the consideration of Grand maxima. The last decades have been a period of very active Sun, with an unprecedentedly high level of solar activity in the last few centuries covered by direct solar observations. The number of sunspots increased rapidly between 1900 and 1940, with the average number of sunspots more than doubling, and remained at this high level until recently [Usoskin I.G. A history of solar activity over Millennia// Living Reviews in Solar Physics. – 2013. – V.10. – P.1-94]. The average number of sunspot groups for 1750–1900 was 35 ± 9, while in 1950–2000 it was at a high of 75 ± 3. Therefore, the current episode of the active Sun, which began in the 1940s, can be considered as a Grand maximum of SA (Fig. 5).

However, after a very weak solar minimum in 2008–2009, we can confidently say that solar activity is returning to its normal moderate level or perhaps even to a low activity stage [Usoskin I.G. Living Reviews in Solar Physics. 2013]. And thus, the episode of high solar activity known as the modern Grand maximum ***appears to have ended***. Although researchers generally perceive the current episode of active Sun as a special phenomenon, and the question of whether such a high solar activity is typical or something extraordinary is a matter of debate.

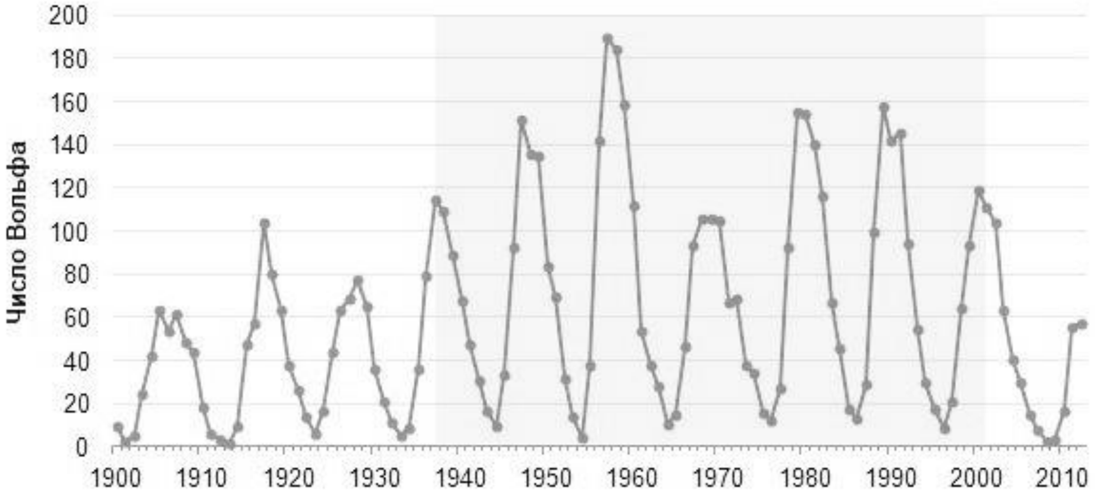

Fig. 5. Temporal cyclic variations of solar activity (smoothed annual average Wolff numbers) for 1900–2012. The increase in solar activity from 1940 to 2000 (shaded part of the figure) is commonly called the modern Grand maximum [https://uk wikipedia.org/wiki/Solar cyclicity]

The question of how often episodes of high maxima occur and how strong they are cannot be studied with a 400-year series of direct observations. Therefore, quantitative analysis is only possible using long-term cosmogenic radioisotope records. As a result of the analysis of the solar activity series reconstructed from the data of ^{10}Be and ^{14}C [S.K.Solanki et al. Nature. 2004] measurements, it was established that the previous similar burst of activity occurred approximately ***8 millennia ago.*** Based on this, it was concluded that the current burst of activity is a very rare event [Usoskin I.G. A history of solar activity over Millennia// Living Reviews in Solar Physics. – 2013. – V.10. – P.1-94]. In connection with this, the search for slightly smaller amplitude bursts of activity becomes relevant. In paper [Usoskin I.G. Living Reviews in Solar Physics. 2013] a list of bursts of activity determined using the data of cosmogenic measurements of ^{14}C for the last 11,400 years, when the number of sunspot groups in 50 years consistently exceeded 50, was considered. A total of 19 such Grand maxima were identified with a total duration of about 1030 years, which indicates about the Sun being in a heightened active state for about 10% of the time.

Statistical analysis of the time of occurrence of Grand maxima shows that they do not follow long-term cyclical variations, but, like Grand minima, are determined by stochastic processes. Most of the reconstructed major maxima (about 75%) were not longer than 50 years, and only four major maxima (including the present one) were longer than 70 years [Barnard L. et al. Predicting space climate change// Geophys. Res. Lett. – 2011. – V.38. – L16103.– 6 p.]. This indicates that the probability of the continuation of the current episode of the active Sun is low [S.K.Solanki et al. Nature. 2004; J.A.Abreu et al. Geophys. Res. Lett. 2008]. Although, as noted in paper [Usoskin I.G. Living Reviews in Solar Physics. 2013] this is not a forecast of future solar activity, but only a statistical estimate.

Fig. 6 shows the long-term cyclic variations of the Sun's magnetic activity during the last millennium, determined by measurements of the ^{14}C radionuclide concentration in the annual growth rings of tree trunks.

Fig. 6. Long-term cyclical variations of the δ-concentration of the radionuclide ^{14}C (in relative units per mille based on measurements in annual tree rings), which serves as a marker of the intensity of the global magnetic field of the Sun during the period 900–2000 [https://uk wikipedia.org/wiki/Solar cyclicity]

Conclusions

Thus, studies of several decades proved that during the last post-glacial period in the Earth's history (the Holocene lasting ≈ 11.7 thousand years), the Sun spent about 70% of its time in a normal state characterized by average solar activity.

However, about 15–20% of the time the Sun experiences a Grand minimum, while ~10% of the time is occupied by periods of Grand maxima.

Features of the long-term observed unusual changes in the time of the magnetic activity of the Sun serve as a challenge for the developers of theoretical models of the solar dynamo.

The random appearance of Grand minima and Grand maxima can to some extent be reproduced by modern models of turbulent dynamo with stochastic drive, but some problems still remain and await their solution in the future.

ДОВГОТРИВАЛІ ВАРІАЦІЇ МАГНІТНОЇ АКТИВНОСТІ СОНЦЯ ВПРОДОВЖ ГОЛОЦЕНУ

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Основною закономірністю еволюції клімату Землі є циклічність глобальних змін останнього. Одне із можливих пояснень циклічності глобальних змін клімату надає астрофізична модель коливань опромінення поверхні Землі сонячною радіацією. Сучасні зміни клімату пов’язані

переважно з варіаціями магнітної активності Сонця, одним з основних індексів якої є сонячні плями. Зменшення кількості сонячних плям збігається з епохами похолодання на Землі, тоді як під час максимальної кількості плям спостерігається потепління. У статті зроблено огляд космогенних реконструкцій довготривалих змін магнітної активності Сонця (великі мінімуми та великі максимуми) протягом голоцену (останні 12 000 років). Випадкова поява великих мінімумів і максимумів певною мірою може бути відтворена сучасними моделями турбулентного динамо зі стохастичним приводом.

Важливим ключем до вивчення впливу варіацій сонячної активності на клімат Землі є мінімум Маундера (наприкінці XVII ст.), під час якого спостерігалося винятково мало сонячних плям. Застосування методу аналізу рідкісних подій до цих спостережень привело дослідників до висновку, що появі сонячних плям під час мінімуму Маундера притаманний слабкий за амплітудою 22-річний цикл. Концепція безперервності магнітних циклів у цей час підтверджується також вимірюваннями космогенних радіонуклідів у природних земних архівах. Тому нині прийнято вважати, що під час мінімуму Маундера циклічна магнітна активність Сонця не припинялася, хоча амплітуда циклів була досить низькою.

У моделі $\alpha\Omega$*-динамо це може бути пов'язано з тим, що магнітна індукція тороїдального поля, збудженого радіальним диференційним обертанням у СКЗ, у цей час не досягала порогового значення, необхідного для спливання магнітних силових трубок на сонячну поверхню (нелінійний режим динамо).*

Запропоновано сценарій пояснення північно-південної асиметрії магнітної активності під час мінімуму Маундера. Ключову роль у запропонованому сценарії відіграє особливий режим внутрішнього обертання Сонця, виявлений у результаті геліосейсмологічних експериментів.

Сучасний великий максимум активності Сонця, який почався в 1940-х рр., припинився після 23-го сонячного циклу, і активність Сонця, здається, повертається до свого нормального помірного рівня.

Ключові слова: глобальні зміни клімату Землі, цикли сонячних плям, магнітні поля Сонця, космогенні маркери сонячної активності, мінімум Маундера, сучасний високий максимум, сонячне динамо.

РЕЗУЛЬТАТИ ОПТИЧНОГО МОНІТОРИНГУ АКТИВНОГО ЯДРА ГАЛАКТИКИ MARKARIAN 501

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У статті представлено результати спостережень і досліджень АЯГ типу BL Lacertae – Markarian 501. Спостереження були виконані за допомогою телескопа-рефлектора АЗТ-8 (D = 0.70 м, F = 2.8 м) спостережної станції у с. Лісники Астрономічної обсерваторії Київського національного університету імені Тараса Шевченка протягом 2018-2020 років. Телескоп АЗТ-8 був обладнаний ПЗЗ-камерою PL4710-1-BB-E2V та широкосмуговими фільтрами UBVRI системи Джонсона-Бесселя.

Над файлами були виконані всі базові редукції. Потоки енергії від Markarian 501 були перетворені у видимі зоряні величини за допомогою фотометричних зір-стандартів. Криві зміни блиску за період спостережень були побудовані, коливання блиску були виявлені у фільтрах BVRI. На їх основі було досліджено показники кольору.

Ключові слова: активне ядро галактики, фотометрія, оптичні спостереження, зміни блиску, UBVR-фільтри.

Вступ. Блазари є одним з імовірних джерел космічних променів гранично високих енергій (КПГВЕ). Розрізняють два типи блазарів: об'єкти BL Lacertae (BL Lac), що характеризуються наявністю беземісійних оптичних спектрів та об'єкти з окремими