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Revisiting the nature of dark sunspots: not magnetic, but thermal activity of the Sun

Abstract

This article is a continuation of the works[1-4] of the author, devoted to elucidating the physical nature of dark sunspots. It has been proven that the scientific paradigm of dark cold sunspots prevailing in solar physics is erroneous, since it contradicts the second law of thermodynamics. It has been proven that dark sunspots in the solar photosphere can only be hotter than the photosphere, and their visual darkness is of a non-thermal nature. Sunspots are the hottest areas of the Sun's surface, the temperature of which is ~ $6{\cdot}10^6$ K, and they are the cause and sources of thermal energy of solar activity phenomena. The physical and empirical inconsistency of the concept of the magnetic activity of the Sun and the processes of magnetic reconnection in the solar atmosphere is proved. All unsolved problems of solar physics, including the heating of the corona, are due to the false paradigm of cold sunspots.

Keywords: sunspot physics, second law of thermodynamics, cold sunspots, hot sunspots, solar magnetic activity, solar thermal activity

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Soika Alexander Kuzmich
Department of Physics, Military Academy of the Republic of Belarus, Republic of Belarus

Correspondence: Soika Alexander Kuzmich, Department of Physics, Military Academy of the Republic of Belarus, Minsk, Republic of Belarus, Email soikaak@gmail.com

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Introduction

«At terrestrial temperatures matter has complex properties which are likely to prove most difficult to unravel; but it is reasonable to hope that in the not too distant future we shall be competent to understand so simple a thing as a star.»

Sir Arthur Stanley Eddington, The internal Constitution of Stars, Cambridge (1988), 393.

«Thousands of ways lead to error, to truth – only one.»

Jean Jacques Rousseau

No physical phenomenon has been studied for so long and so unsuccessfully as dark sunspots. Let us ask ourselves the question: "what do we know for certain today about sunspots, the scientific observations of which, starting from Galileo, have been going on for more than 400 years?". If, following Socrates, we answer sincerely, but without his irony, then we must say that we know nothing, except for four facts: 1) spots are dark in visible light; 2) they periodically appear and disappear; 3) they always have a magnetic field, about 1000 times stronger than in other parts of the photosphere; 4) the spots glow brightly in the ultraviolet and X-ray regions of the spectrum (although the official physics of the Sun denies this fact). As for the vast array of observational data on the appearance, evolution, and disappearance of sunspots on the surface of the Sun, as well as numerous models of their physical and magnetic structure, these extensive data hardly help to clarify the physical nature of sunspots. In this regard, a number of questions arise. Why did the great discovery by G. E. Hale of magnetic fields in sunspots (1908) not become a trigger for breakthrough scientific research and, by and large, after it, no fundamentally new knowledge about sunspots, recognized by the official physics of the Sun, was obtained? Why is the physics of the Sun still not giving answers to three simple questions: "why are the spots dark?", "why are they cold?" and "why do they appear on the Sun at all?". This article is devoted to a detailed discussion of all these and other similar issues.

The paradigm of cold sunspots and the crisis of modern solar physics

Since about the 60s of the twentieth century and up to the present, the official solar physics has been developing within the framework of the cold sunspot paradigm, according to which dark sunspots are areas of the solar photosphere cooled by the action of their own magnetic fields, as a result of which the temperature of matter in them is 1500–2000 K below the temperature of the substance of the photosphere. This controversial and unproven statement, taken in fact on faith, has become an unshakable postulate of solar physics (if not all of astrophysics), determining the subject and direction of all its research, all theories and all interpretations of observational data. This postulate is unconditionally followed by all textbooks, encyclopedias, reference books and Internet resources, where, without a shadow of doubt, the same thesis is given in different variations: "spots are dark because they are cold, and cold because their strong magnetic fields suppress convection". At the same time, solar physics has not yet provided intelligible answers to any of the triad of initial questions about sunspots: "why are they dark?", "why are they cold?" and "why do they appear on the Sun at all?". Moreover, for a long time no one has been trying to find reliable answers to these and other questions about sunspots, since, having become cold, they instantly lost their status as the primary (main) phenomenon of solar activity, which immediately passed to their magnetic fields - the only one after themselves spots to objects of the photosphere, which have significant energy.

Since solar activity cannot be explained without knowing the sources of its energy, then, starting from the 1960s, the leitmotif of all research in solar physics was the search for all kinds of sources of non-thermal energy in the solar atmosphere, which was soon reduced mainly to the search for mechanisms for the conversion of magnetic energy sunspots into other forms of energy. To date, the results of these studies can be formulated as follows: 1) an extensive theory of magnetic reconnection has been created - a spontaneous transition (transformation) of the energy of magnetic fields into thermal energy (plasma heating), into kinetic energy (movement of plasma masses) and into non-thermal energy of directed and accelerated movements charged particles (solar wind, electromagnetic radiation from radio waves to gamma rays); 2) it is recognized that the magnetic fields of the Sun are not only a source of energy, but also the cause of all phenomena of solar activity; 3) it is recognized that the simultaneous release of thermal and non-thermal energy occurs in the processes of magnetic reconnection, which continuously occur in the solar atmosphere.

To date, solar activity has been renamed magnetic activity, which refers to all phenomena and processes associated with the formation, evolution and decay of solar magnetic fields. It is believed that magnetic activity is a manifestation of the topological properties of the dynamic magnetic fields of the Sun during their interaction with plasma, due to which their energy is spontaneously converted into heat, mass and charge flows that give rise to all phenomena of solar activity. Sunspots, on the other hand, are just indicators of the places of the highest concentration of solar magnetic fields, and today their regular observations are carried out mainly in order to determine the average monthly and average annual Wolf numbers - an index of the level of solar activity associated with the number of spots. Dark and cold sunspots themselves do not participate in active phenomena. They are also indifferently and silently present in numerous scientific articles, and, as a rule, under different synonymous names - magnetic formations, cores of magnetic complexes, etc., which once again emphasizes the dominant role of magnetic fields in the solar atmosphere, although there are no physical grounds not available for this.

On the contrary, there are sufficient grounds to assert that it is dark, but not cold, but hot sunspots that are the cause and sources of thermal energy of all active phenomena in the solar atmosphere. These grounds come from two immutable fundamental facts, which, by virtue of the second law of thermodynamics, take place in the photosphere of the Sun.[2-4] The first fact is that the appearance and existence of dark and cold sunspots in the solar photosphere is impossible, since any processes that would result in cooling of the photospheric gas in spots (with or without a magnetic field) contradict the second law of thermodynamics. The second fact is that dark spots that appear on the Sun can only be hotter than the photosphere surrounding them, which also necessarily follows from the second law of thermodynamics. And in general, without this law it is impossible to understand not only the nature of dark sunspots, but in general the entire physics of the Sun, which from a thermodynamic point of view is a heat engine that converts heat into solar radiation energy with all the ensuing consequences. The heater of this heat engine is the core of the Sun, the working body is photospheric gas, the cooler is dark and hot sunspots, and its work per unit time is equal to the total flux of solar radiation.[4] Since the laws governing the conversion of heat into work, i.e., into any non-thermal forms of energy, are determined by the second law of thermodynamics, all thermal processes occurring on the Sun cannot but obey this law.

Since the entropy of the core of the Sun is continuously decreasing (mainly due to the removal of heat, but also due to the occurrence of thermonuclear fusion reactions), then in some other part of the Sun, compensatory processes must necessarily occur in which the entropy increases as much as is required in order for the total change The Sun's entropy was only positive. These compensation processes take place precisely in sunspots - spontaneously arising deterministic dissipative structures of the photosphere, in which irreversible processes of absorption of a part of photons of solar study provide the required rate of entropy production, which is absolutely necessary to ensure the viability of the Sun as a star. Let's consider this question in a little more detail.

Entropy factor, i.e. the trend (necessity) of a steady increase in the entropy of the Sun should be considered as a driving force that organizes and sets in motion the processes of transferring a certain part of the heat of the heater to the cooler of the heat engine, as required by the second law of thermodynamics. This means that in the photosphere, which transforms the heat of the core of the Sun supplied to it into solar radiation, only stable local (radiant and thermal) equilibrium cannot prevail everywhere, but non-equilibrium and unstable regions or structures must also be present. In a locally equilibrium photosphere, particles of matter and particles of electromagnetic energy (photons) are equal carriers of thermal energy, which they exchange with each other in equiprobable reversible processes of absorption and emission of photons. Some of these photons emitted per unit time outside the Sun by the uppermost nonequilibrium layer of the photosphere create a flux of solar radiation, the energy of which, however, is no longer thermal, and its transfer (leaving) into outer space does not affect the entropy of the Sun. Therefore, a compensatory increase in the entropy of the Sun can be obtained only due to irreversible processes of absorption (for the same unit of time) of the rest of the photospheric photons. It is this circumstance that necessitates the emergence of dissipative structures in the photosphere, in which the thermal energy of equilibrium photons of solar radiation is irreversibly converted into the energy of matter particles. If the temperature of this substance is much lower than the temperature of the heater, then the total entropy of the Sun will increase, even if the energy of the absorbed photons is much less than the thermal energy supplied to the photosphere. Dark sunspots are the dissipative structures of the photosphere, which play the role of a cooler of the solar heat engine, in which the processes of absorption of photons of solar radiation dominate over the processes of their emission, as a result of which the spots become dark and hot.

The physical mechanism that provides darkness and heating of photospheric gas in sunspots, at least to temperatures of $\sim 10^5$ K, upon reaching which other mechanisms also arise, is of a quantum mechanical nature, and the magnetic fields of spots play a key role in it.[1-3] It is known that the processes of recombination (formation) of negative hydrogen ions occurring in it are responsible for almost all the visible radiation of the photosphere of the Sun, and the processes of photoionization (decay) of negative hydrogen ions are responsible for the absorption of the same photons. In an equilibrium photospheric gas (outside spots), these processes are reversible and equally probable, i.e., the principle of detailed equilibrium is satisfied for them. However, this principle is sharply violated in sunspots, where the photospheric gas is subject to the action of their magnetic fields, as a result of which the processes of recombination of negative hydrogen ions are completely suppressed, while the intensity of the processes of photoionization of negative hydrogen ions does not depend on the magnetic fields of spots. The magnetic field suppression of the processes of recombination of negative hydrogen ions, as a result of which the photospheric gas in spots becomes an absorbing medium for photons of visible sunlight, can be explained as follows. Neutral hydrogen atoms and free electrons are paramagnetic particles (their spin numbers are $S = ½$), and negative hydrogen ions H^-, which have two paired electrons each, are diamagnetic particles (their spin numbers are $S = 0$). This means that the recombination of a negative hydrogen ion is possible only when the quantum system hydrogen atom + electron, which arises when these two particles approach each other, is in the singlet state, i.e., its spin number $S = 0$, for which it is necessary that the spin moments the hydrogen atom and the electron were antiparallel. Only in this case, attractive forces arise between these particles, due to which the radiative recombination of negative hydrogen ions becomes possible. But in a sufficiently strong magnetic field of sunspots, the spin magnetic moments of hydrogen atoms and free electrons are oriented in the same direction, along the field, which leads to the suppression of the processes of recombination of negative hydrogen ions in the photospheric gas of spots.

An estimate of the temperature of the sunspot matter, made on the basis of an analysis of the operation of a solar thermal engine in the Carnot approximation,[4] gives a value of $T \sim 6 \cdot 10^6$ K, which is

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three orders of magnitude higher than the temperature of the Sun's surface. This means that dark sunspots should shine brightly against the background of the photosphere in ultraviolet and X-rays, the wavelengths of which are three orders of magnitude shorter than the wavelengths of solar radiation. It is this fact that for almost half a century, starting from the images of the Skylab orbital station (1973), has been demonstrated and convincingly proved by many thousands of satellite photographs of the Sun, especially those in which sunspots are located near the limb of the Sun. However, in solar physics, it has long been generally accepted that the hard ultraviolet and X-ray radiation of the Sun ($\lambda < 20$ nm) is generated exclusively within the upper chromosphere and the solar corona. And today, solar physics denies the short-wavelength glow of sunspots, attributing it to some magnetic structures located in the corona above the spots, which is also allegedly confirmed by blurry images of these luminous coronal structures on satellite images projected onto the solar disk (see, for example, the Skylab image taken September 18, 1973). However, what is the physical nature of these coronal structures with unusual shapes and details, and how the extremely rarefied gas of the corona can form them, remains a mystery. (It can be argued that, within the framework of the cold sunspot paradigm, this riddle will remain unsolved.)

However, the "cases" of dark hot sunspots do not end there. According to Carnot's principle, wherever there are temperature differences, driving forces arise, the magnitude of which depends only on the temperature difference of the bodies between which heat is transferred. The huge difference between the temperatures of the gas in the spots and the gas of the photosphere cannot but give rise to large driving forces. This means that in addition to the stellar heat engine that produces the flux of solar radiation, there are many photospheric heat engines operating on the Sun that produce all the movements and phenomena called solar activity. The heaters of these heat engines are sunspots, the working body is the photospheric gas, and the cooler is the chromosphere and the corona of the Sun.

Thus, solar activity can hardly be a manifestation of the mysterious processes of magnetic reconnection, although it does not occur, as shown above, without the magnetic fields of sunspots. Nature solves its problems only by simple methods and means, and only their combination sometimes significantly complicates the understanding of some phenomena, turning them into scientific riddles, as happened, for example, with dark sunspots. Initially, a misunderstanding of their physical nature, which continues to this day, led to the creation of an incorrect theory of the magnetic activity of the Sun. The phenomena of solar activity are just a certain part of the work of the driving forces of the same thermal energy of the core of the Sun, which, along with gravitational energy, determines both small and grandiose processes occurring inside and outside the Sun. Against this background, the purely magnetic energy of the phenomena of solar activity is nothing but a scientific phantasmagoria.

Let us consider the main stages of the implementation of the magnetic energy of active phenomena of the Sun. The solar dynamo converts part of the thermal, kinetic and electrical energy of the deep layers of the solar plasma into the energy of magnetic fields, concentrated in huge annular magnetic flux tubes. These tubes, filled with hot plasma, stretch out, expand and go outside the Sun, forming dark cold spots at the intersections of its surface. This means that in the photosphere the magnetic tubes are no longer filled with hot plasma, but with significantly cooled photospheric gas. Then or at the same time, which is not known exactly, by means of magnetic reconnection, the energy of these magnetic tubes is converted again into thermal, kinetic and electrical forms of energy, already associated with particles of photospheric gas, which supposedly give rise to the corresponding phenomena of solar activity. It is extremely difficult to understand the causes and purpose of this entire gigantic energy metamorphosis, especially the role of dark and cold sunspots in it. Nature is not characterized by excessive structures, processes and movements that do not fit into the cycle of events or have no purpose. If we consider that in the photosphere the matter in magnetic tubes really cools, then at least three problematic questions arise, which still have no answers: 1) where does that enormous heat go, the escape of which from the spots makes them cold?; 2) what happens to those heat fluxes (~ 60 MW/m^2) coming from the depths of the Sun to its photosphere, the blocking of which by the magnetic fields of sunspots darkens huge areas of the Sun's surface?; 3) with what plasma does the magnetic field of sunspots interact in the processes of magnetic reconnection?

The answers to the first two questions are given in the second part of this article. Here the third question is of greatest interest. According to the theory, magnetic reconnection occurs when magnetic tubes filled with sufficiently hot plasma, whose fields are directed oppositely to each other, come close together. However, the gas in cold spots can hardly be called a plasma, as well as the hotter photospheric gas, the average degree of ionization of which is less than 0.1%, and its conductivity (~ 1 $\Omega^{-1}\cdot m^{-1}$) corresponds to the conductivity of sea water (recall that copper conductivity ~ $5\cdot 10^7$ $\Omega^{-1}\cdot m^{-1}$). In this regard, the question arises, where do continuous (or even discrete) processes of magnetic reconnection occur in the solar atmosphere? It is obvious that magnetic tubes with sufficiently strong magnetic fields, which exist only in cold spots, where, however, there is no plasma as such, should approach each other. Hot plasma, although extremely rarefied - approximately to the degree of the highest technical vacuum on Earth - exists in the upper chromosphere and corona, where, however, the magnetic fields are very weak, since the relatively strong magnetic fields of sunspots decrease very quickly with distance from the surface of the Sun. (It is appropriate to note here that there are no satisfactory methods for measuring the solar atmospheric magnetic fields, with the exception of sunspot umbra.) The only possible answer to the question formulated above suggests itself: nowhere in the solar atmosphere can any high-energy magnetic reconnection processes occur in principle.

There are many other unanswered questions. Let's name some of them. Why does the energy of magnetic reconnection in flares transform predominantly into electromagnetic radiation, while in prominences, solar wind and so-called coronal mass ejections – into kinetic energy? How does magnetic reconnection occur in general - at individual points, along lines, surfaces, or in bulk structures? Does the rate of magnetic reconnection depend on the geometry and size of the region where it occurs? Since no magnetic charges have been found in nature, why does the theory of magnetic reconnection violate Maxwell's equation divB = 0, which forbids the breaking of magnetic field lines? Why are there many types of magnetic reconnections - slow, fast, spontaneous, forced, stationary, non-stationary, impulse, etc., and in each type - many different types, models and configurations? Why do current sheets, the key elements of many models of magnetic reconnection, carry electric currents that, as is well known, can only flow in closed electrical circuits?

You can comment on the above unanswered questions as follows. In principle, it is not a big problem that there is no physical understanding of magnetic reconnection, since, generally speaking, it is not required. For example, we do not have a physical understanding of the action of gravitational forces, but we have a theoretical law that allows us to calculate these forces between any bodies. Using this law, we can predict phenomena that can be experimentally (empirically) verified, and if the results of this verification confirm the correctness of the law, then the theory of gravitational forces is scientific and correct. In other words, in order to recognize the theory of a given phenomenon as scientific and correct, it is necessary and sufficient that the results of this theory provide an opportunity for their empirical verification, although the physical essence of the phenomenon will remain hidden. However, the theory of magnetic reconnection, as well as the theory of the magnetic activity of the Sun, does not provide a single opportunity for empirical verification of any statements, formulas or laws, which is confirmed by the questions formulated above, both in the context of their formulation and outside it. There is only one way to recognize these theories as scientific - to postulate their correctness, which - by analogy with the hypothesis of dark and cold sunspots - was done in solar physics.

It is impossible not to note three characteristic features of scientific publications on the magnetic activity of the Sun: 1) ambiguous and confusing terminology, where one unclear concept is defined through another, also unclear; 2) references to other works confirming the initial facts and provisions used, in fact, turn out to be references only to assumptions and hypotheses made by other authors; 3) unconditional transfer of all phenomena of solar activity to the chromosphere and corona, even if observations (images) of these phenomena on the limb of the solar disk clearly indicate that they occur on the surface of the Sun.

So, solar flares and prominences occur in the chromosphere and corona, the solar wind is the result of continuous dynamic expansion of the corona, and the stable term "coronal mass ejections" ("CME"), by analogy with "volcanic ash ejections", indicates that the source of ejected masses - all the same corona, where the density of particles is ~ 10^8 cm^{-3}. Meanwhile, the spectrum of flares is surprisingly similar to the spectrum of high-temperature hydrogen plasma, and the composition of the matter of the chromosphere, corona, prominences, and ejected masses is almost identical to the composition of the photosphere, except that in the paradigm of cold sunspots in the photosphere there is no hydrogen plasma and multiply ionized heavy atoms. Again, unanswered questions arise.

If active phenomena do not occur in the photosphere with its cold spots, then why does its substance, despite gravity, and even in the form of hydrogen plasma and multiply ionized atoms, end up in the chromosphere and corona? How does a corona with a matter density of ~ 10^{-12} kg/m^3 create a stationary flow of particles with velocities up to ~ 2000 km/s, carrying away up to ~ 10^{10} kg of matter every second? Who or what supplies this mass of matter to the corona? If the heating powers of the corona and the solar wind are approximately the same and are estimated at ~ (10^{20}–10^{22}) W, then in what areas of the solar atmosphere filled with its plasma and permeated by its magnetic fields do magnetic reconnection processes provide such continuous thermal and kinetic powers?

From what has been said above, two main conclusions clearly follow. First, the stubborn fact that sunspots are the hottest regions of the photosphere, figuratively speaking, puts an end to both the concept of the solar magnetic activity and the theory of magnetic reconnection. The physical dissimilarity between hot and cold sunspots is of a fundamental nature, although formally it is reduced only to the difference between heating and cooling of the gas in the spots. But it is precisely this difference that overturns the pyramid of physical entities and arguments regarding the phenomena of solar activity, as a result of which they become natural and expected in the case of hot spots (thermal activity of the Sun), but remain mysterious and even improbable in the case of cold spots (magnetic activity of the Sun).

Second, the cold sunspot paradigm was wrong from the start. This circumstance could not but give rise to contradictions, the resolution of which, in turn, could not but direct the physics of the Sun along a false path of development, from which it is hardly possible to turn back to the correct path in an evolutionary way. We are talking about natural contradictions between the paradigm of cold sunspots and alternative interpretations of observational data on the Sun. These contradictions, as colorfully described in,[5] where the theory of the Sun's magnetic activity is called a "triumph of macrophysics", have always been resolved by unconditional victories of the paradigm over alternative interpretations. And today, solar physics continues to consider all unsolved problems from the same unchanging point of view, which is determined by the same false implication - "spots are dark because they are cold", although data from space observations of the Sun have long suggested a true implication - "spots are dark because they are hot."

Despite tens of thousands of scientific articles published on the magnetic activity of the Sun, the physical understanding of the causes and mechanisms of solar activity phenomena remains at the level of the 40s of the XX century, when the hypothesis of cold sunspots was proposed (L. Biermann, 1941). Such an impressive discrepancy between the efforts expended and the results obtained cannot be called otherwise than as a crisis in solar physics, which is caused by the false paradigm of cold sunspots. As long as dark sunspots remain cool, the physics of the Sun will tread water, despite the efforts of researchers, an abundance of observational data, and a riot of theories and simulations.

In the works,[1-4] the author proposed and substantiated the paradigm of hot sunspots, within which the causes, mechanisms and energetics of all solar activity phenomena find their natural physical explanation. However, these works were not noticed by solar physicists, just as the author's attempts to publish them in the so-called "prestigious" journals were not successful. In this regard, the author argues a posteriori that today, unfortunately, prestigious journals publish only those works in which new ideas do not negate old ones. Even if the old ideas are wrong, for some reason they still remain necessary and useful to many researchers. Neglect of alternative ideas, as well as observational data that deny the paradigm of cold sunspots, once again indicates a dead end in the development of modern official solar physics.

Why dark sunspots can only be hot

For more than 60 years, the official physics of the Sun has "not noticed" the obvious contradiction between the paradigm of cold sunspots and the second law of thermodynamics. Since the question of which dark sunspots are actually colder or hotter than the photosphere is a fundamental question of solar and stellar physics, there is an urgent need to obtain a reliable answer to this question. And the problem here is not only that there are no and cannot be methods for directly measuring the temperature of sunspots, and photometric measurements cannot be considered reliable, since the laws of thermal radiation in spots can be strongly violated. The physical situation with the temperature of the substance of dark sunspots is not as simple and unambiguous as it might seem at first glance.

In nature, there are a large number of cold (T ~ 300 K and below) objects, bodies and living beings that glow brightly with all the colors of the rainbow (polar lights, rotting wood, fireflies, many marine organisms, plants, etc.), which, except for dimensions can be considered as inverse analogues of dark sunspots (T ~ 4000 K according to the data of official solar physics). Since it is known that the glow of all these objects, called luminescence, is not thermal

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radiation, no one has tried to measure their temperature by optical methods, which are used to measure the temperature of heated bodies by their thermal radiation, including the temperature of the photosphere and its dark spots.

The visual darkness of sunspots against the background of the photosphere, as well as the glow of bodies, can be both thermal (change only in the temperature of the gas in the spots) and non-thermal (change in the physical properties of the gas in the spots + change in its temperature). In the first case, the spots, like the photosphere, remain black bodies, and can be either colder than the photosphere (the radiation maximum is shifted to the long-wavelength region) or hotter than it (the radiation maximum is shifted to the short-wavelength region). However, if the darkness of the spots is of a non-thermal nature, i.e., the spots lose the properties of black bodies, then they can only be hotter than the photosphere (they emit less visible light than they absorb it), since otherwise the spots should be brighter than the photosphere. (Note that in these considerations we are not interested in the causes of changes in the temperature of sunspots.) Consequently, if the nature of the darkness of sunspots is unknown, then measurements of their temperature by optical methods do not answer the question of whether the sunspots are colder or hotter than the photosphere. If, however, it is known that the darkness of the spots is of a non-thermal nature, then one can immediately say that the spots are hotter than the photosphere.

The question arises, what temperature of the substance of dark sunspots was measured by solar physicists? Since they used optical methods of measurement, obviously, only the thermal nature of the darkness of the spots was taken into account and only one possibility was allowed, predetermined by the notorious implication - if the spots are dark, then they are cold. However, as shown above, in this case, dark spots can just as well have a temperature higher than that of the photosphere. Surprisingly, it is in this case that the results of spot temperature measurements (within the limits of experimental errors) could be reliable, although the measurement procedure would be much more complicated. It is not possible to recognize as reliable the results of measurements of the temperature of sunspots obtained by solar physicists for the simple reason that such spots - dark and cold - do not exist on the Sun or on the stars, just as there are no natural phenomena in nature that violate the second the law of thermodynamics. In other words, only dark and hot sunspots can appear and exist in the photosphere of the Sun, the temperature of the substance of which exceeds the temperature of the substance of the photosphere.

This statement can be proved in different ways, using the well-known formulations of the second law of thermodynamics. Since we are talking about heating and cooling bodies - in this case, photospheric gas in sunspots, it is easiest to use a simple, although far from obvious, consequence of the second law of thermodynamics. It lies in the fact that the heating and cooling of bodies - respectively above and below the ambient temperature - are fundamentally unequal and asymmetric processes. Without affecting the entropy nature of this consequence, we note only its specific manifestations in real thermal processes. Any body can be heated in two different ways - through heat transfer, for example, by burning fuel, or by doing work on it. Note that both of these methods of heating bodies were mastered and widely used by ancient people, warming themselves by the fire and making fire by friction. Any body can be cooled in one and only way - by removing heat from it to another colder body, which, in turn, can (and should) be cooled only by doing work on it by an external force. This body - gas or liquid - is called the working body of the refrigeration machine. Note that the problem of cooling any body below the temperature of the surrounding bodies (environment) was solved (in principle) only in the second half of the 19th century, when the first prototypes of modern refrigeration machines were created.

So, the cooling of bodies requires the implementation of two mandatory processes: 1) removal of heat from the cooled body; 2) performing work on other bodies. (Note that work in physics refers to any non-thermal interaction of bodies with each other or with the environment.) Natural (spontaneous) cooling of bodies is carried out due to heat transfer, which always goes in one direction - from hotter bodies to less hot bodies. Artificial (forced) cooling of bodies below the temperature of other bodies (environment) is possible only with the help of a refrigeration heat engine.

Now, taking into account what has been said, it is not difficult to prove the impossibility of the appearance and existence of dark and cold sunspots in the photosphere. To do this, it is enough to compare the conditions and requirements necessary for cooling bodies, which are dictated by the second law of thermodynamics, with the physical conditions and indisputable facts that take place in the solar photosphere.

First, the removal of heat from them to other colder bodies by means of convection and (or) heat conduction, which is necessary for cooling spots, is not feasible, since there are no other bodies in the solar photosphere, except for photospheric gas, and cannot exist at all. The magnetic fields of sunspots are not bodies and cannot receive, store or transmit thermal energy, and their possible influence on convection and thermal conductivity of photospheric gas in no way changes the essence of the matter.

Secondly, even if the magnetic field of the sunspot is capable of performing work on the photospheric gas, which, we note, is fully allowed by the theory of magnetic reconnection, then it will still not be possible to implement a "magnetic refrigerating machine" in the sunspot, since work must be done on the gas located outside the spot, where its magnetic field no longer exists.

Finally, thirdly, consider the main argument cited in the scientific literature (without any substantiation) usually to state or confirm a decrease in the temperature of sunspots, according to which sunspots cool and darken due to the emission of their gas. Of course, cooling of bodies due to radiant heat transfer is possible, but only if the radiation flux leaving the cooled body exceeds the radiation flux entering it. In the absence of an incoming radiation flux, cooling of a body by luminescence occurs only when photons are born due to the internal energy of this body and, without being absorbed in it, go outside. It is easy to see that the source of the radiation flux entering any sunspot is the thermally stationary photospheric gas surrounding it, as a result of which the radiation flux entering this spot is almost unchanged in power and spectral composition. Since the magnetic field of the spot by default does not affect the motion of photons and the density of the photon gas, the cooling of the spot would mean that the radiation flux leaving it exceeds the incoming flux, but then the spot should be brighter than the photosphere. However, all spots stubbornly and convincingly demonstrate their darkness. Moreover, the visible light of the incoming stream, penetrating each spot from all sides in all directions, is not detected or manifested anywhere else, even at the exit from the spots to the outside of the Sun, where it should be observed, especially in large spots. On the contrary, large spots are known to have the darkest umber. There is only one explanation for this fact: all photons of visible light that penetrate the spots are completely absorbed in them. This means not just a violation, but a negation of the Kirchhoff law, which entails a sharp change in the physical (optical) properties of the photospheric gas in spots, i.e., its transformation into a dissipative medium that absorbs visible radiation, which makes the spots hot.

So, the only possible solution to the puzzle called dark sunspots is that they can only be hotter than the photosphere, and their darkness in visible light is non-thermal in nature and cannot be explained by the laws of thermal radiation. Note that hot sunspots immediately resolve one of the unsolved problems of solar and stellar physics, the so-called problem of radiant energy deficiency, caused by dark spots on the surface of the Sun. Various solutions to this problem are discussed, but all of them are incorrect, since sunspots do not cool, but heat up, and the flux of radiant energy that would be radiated from the surface of the Sun covered with spots is completely absorbed by the substance of the spots.

Since the Sun is the main body and the main phenomenon of the world around us, then, in the author's opinion, the extremely laconic formulation of the statement proved above - dark sunspots can only be hotter than the Sun's photosphere - should be considered one of the possible formulations of the second law of thermodynamics.

In conclusion, to all those who believe that sunspots are cold, the author proposes a simple experiment. Using any magnetic fields, try to form at least a tiny piece of ice in sea water (by any means). Even in the most favorable conditions, when ice floes will float in a vessel with water ($t \approx 0$ °C), no one will be able to add another ice floe to them and never. However, it will not be difficult to melt all the pieces of ice, since the second law of thermodynamics does not prohibit heating a substance with a magnetic field.

Conclusion

The paradigm of cold sunspots, currently dominant in solar physics, has been erroneous since its inception, since it contradicts the second law of thermodynamics. Consequently, the concept of the magnetic activity of the Sun, the main motivating factor for the occurrence of which were cold spots, is physically completely untenable. This means that there is no need to criticize her theories, including the theory of magnetic reconnection, since they were also flawed from the very beginning. Almost all unsolved old and new problems of solar physics are due, one way or another, to the false paradigm of cold sunspots. Moreover, the more efforts within this paradigm are made to solve specific problems, the more new problems arise, often false ones, such as, for example, the problem of radiation deficiency discussed above. It is known that the efforts of those who follow the wrong path do not help to achieve the goal, but multiply delusions.

Hot sunspots in the solar photosphere create a fundamentally different physical situation in the solar atmosphere, which should objectively not only refute the "magnetic" interpretation of solar activity phenomena, but also radically change the attitude towards the observational data on the Sun that have long been known. It would seem that the physical picture of phenomena in the solar atmosphere, which arises on the basis of observations of the Sun and is constantly corrected with the progress of observation tools, in principle does not depend on the settings and positions of the scientific paradigm, however, as the history of the development of solar physics shows,[5] this is far from so. In any picture, a person, like a researcher in the physical picture of a natural phenomenon, sees, first of all, what he expects and wants to see, such is our nature. This property is even more extreme in the methods and approaches used by observers to interpret and evaluate what they see. Contradictions between the paradigm of cold sunspots and observational data almost always existed, but for some reason they were not noticed. For example, the X-ray images of the Sun obtained by the Skylab orbital station (1973), not to mention the many modern images supplied daily by the fleet of spacecraft. Be that as it may, but modern solar physics can fruitfully develop only within the framework of a correct scientific paradigm.

Conflict of interest

Author declares that there is no conflict of interest.

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