Solar wind as a consequence of Coulomb mirror effect in astrophysics

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Abstract. The causes of the appearance of a solar wind consisting of protons, alpha particles and electrons arising as a result of ionization processes of atoms and molecules focusing to the Sun by gravitational forces are investigated. It is shown that a possible explanation of the occurrence of the solar wind is a slight violation of the neutrality of the Sun and the appearance of Coulomb mirrors for protons and alpha particles that reflect and accelerate light, positively charged particles. The parameters of the positively charged Sun are defined, allowing to estimate the reduced electric field in the photosphere, the chromosphere, the Sun's corona and to study the conditions necessary for reflection of positively charged particles from the positively charged Sun.

1. Introduction
Despite the huge amount of papers devoted to the problem of the origin and description of processes in the solar wind (SW) coming from the Sun to the Earth, at the present time there is no clear understanding of the causes responsible for the existence of the SW filling the heliosphere with the supersonic velocity which verified by numerous experimental observations.

Experimental research of SW began 58 years ago (on the Soviet rocket Luna-2 in 1959 and on American spacecraft Explorer 10 in 1961). The theoretical basis for understanding the dynamic processes of the formation of SW was laid by Parker in 1957 [1]. However, the mechanisms responsible for heating the base of the solar corona to temperatures of 1.5-2 million degrees and causing its expansion are still not entirely understood. Currently, the conventional models explain the heating of the solar corona and the existence of the SW by Alfvén waves [2,3,4]. It is believed that the mass composition of SW, as it moves, does not change in the interplanetary medium and therefore provides information on the chemical and ionic composition of the solar atmosphere. Heavy ions are formed in the lower corona, and when moving in the SW, their states do not change. Consequently, SW ions carry information about the conditions in the solar corona. Observations of SW are of practical importance, since the SW plasma is the main agent by which active processes on the Sun influence the state of near-Earth space and the Earth's magnetosphere, and, consequently, the weather and the well-being of the Earth's population.

Here, an entirely new mathematical model of SW is analytically studied, taking into account the weak violation of the neutrality (VN) of the mass of the entire Sun. In the opinion of the authors, the VN of the Sun is responsible (as in the ordinary single-pole discharge on a charged needle) for the escape and acceleration of positively charged ions and electrons from the Sun. The original results obtained on the basis of these calculations are given. It turns out that only knowledge of the types of
ions established in experiments can change the calculated parameters of the Sun and SW under different conditions and allow us to investigate new physical mechanisms responsible for the formation of SW, the dynamics of its large-scale perturbations, as well as the mechanisms governing the comparative behavior of various ionic components for various types of SW flows.

In this problem, an important fact, verified by experimental observations with the help of satellites and spacecraft, is the reverse direction of the SW movement from the Sun [5], and not to the Sun, which would be understandable, as a result of gravitational attraction between neutral plasma structures. The solution of this paradox is possible only if it is assumed that the Sun and SW are positively charged [6, 7]. It has been established that the main carriers of mass in SW are protons and alpha particles [5].

As shown in [8], in plasma cumulative-dissipative (CD) structures, such as lightning, bead lightning, cathode spots, positive columns, striations, etc. processes of formation and prolonged retention of the positive charge by the entire CD structure may occur. The term CD structure is introduced for dissipative structures, in which the forces of cumulation (focusing) of energy-momentum flows (EMMF) are significant [7]. The long-range Coulomb potential of any plasma structure is formed because of the greater mobility of electrons compared to ions or even protons. Therefore, a small part of the light-weight, in comparison with ions, high-energy electrons always leaves the plasma structure and thereby positive charges it. A positively charged structure tends to return the outgoing electrons. Some of the outgoing electrons with lower kinetic energy, indeed, return to the Coulomb potential well for the Fermi gas, but not all. Thus, turbulence (vortices) is formed in the region of charged plasma structures. Returning electrons, which receive additional kinetic energy from the electric potential, focus the entire positively charged structure in a single luminous whole by their pressure (Figures 1–4). These processes are responsible for the surface tension of plasma CD structures. Therefore, cylindrically focused lightning arises (Figure 4), stratified bead lightning (Figure 3), striations, 3D cathode spots, cylindrical and conical (Fig. 2) positive columns in experiments, etc. [9, 10]. The maximum electric field - E, - of a uniformly charged structure, as is clear from the solution of the Poisson equation, is achieved on its surface and is determined by the density of the charge in the structure that is not compensated by the electrons (they left the structure). Here, the reduced electric field or the parameter E/N is also maximal. Here N is the density of gas particles. Therefore, both the pressure and the average energy of the electrons compressing the positively charged structure are maximal there. Compression of the structure leads to heating of the entire electron gas in the structure, and the electron gas on the other hand counteracts its compression to the point. It is clear that to describe even weakly charged extended structures, such local parameters as the Debye radius are not very effective [11,12].

![Figure 1](image1.png)

**Figure 1.** Dependence of the width of a cylindrical self-focusing discharge in nitrogen of special purity on current [13]: 1 = 0.6 (1); 0.8 (2); 1.1 (3); 1.65 (4); 2.2 (5, definition of the libration point); 2.9 (6); and 3.25 (7) mA; P = 5 Torr. a is a positive column (with a blue glow that diffuses towards the
anode, which is not photographed), b is Faraday space, c is a negative glow (or cathode spot, lower spot is a glare of the cathode spot on a mirror-polished electrode).

Figure 2. Structure of plasmoids in a discharge in a tube in nitrogen of special purity, depending on the discharge current at P = 15 Torr [14, 15]. The discharge is locally disturbed (the window size is 2 cm) in the center by a beam of high-energy electrons. (The gas was pumped at a velocity of 50 m/s from the cathode to the anode, along the arrow).

Figure 3. A bead lightning with internal points of libration between charged luminous structures on the background of a palm.
Figure 4. Discharge in air, with a persistent cross section. The glow indicates the radial focusing of the reduced electric field (E/N). This is an artificial lightning or plasma jet in which electron and ion fluxes are self-focused into a cumulative-dissipative structure.

Figure 5. Model of the Sun as a positively charged structure.

With the help of this approach, the reverse motion of the cathode spot discovered by Stark in 1903, the 3D processes in Faraday space between the striations, the cathode spot and the positive
(positively charged) column were explained and analytically calculated, libration points between positively charged structures were discovered [8, 9, 10, 16, 17]. These libration points (in Faraday spaces) between charged structures are analogs of Lagrangian points for gravitating structures, three of which were discovered by Euler 250 years ago in 1767.

On the basis of these representations, verified by a number of experiments, we will describe the "reverse" (against the gravitational forces) motion of SW, assuming that the Sun and SW, as plasma structures, have a positive charge. We shall characterize the energy of charged plasma particles in the chromosphere and solar corona by the parameter \( E/N \). \( E \) is the electric field in the region of the charged Sun, and \( N \) is the particle density in this region.

2. Comparison of Coulomb and gravitational interactions between elementary particles
Since 1928, Einstein, Schrödinger, Eddington, Dirac, and others have attempted to create a unified theory of electromagnetic and gravitational fields [18]. For example, for two identical particles with masses \( m \) and charges \( e \), the ratio of the electric potential \( K_e^2/r \) to the gravitational potential \( Gm^2/r \) is \( K_e^2/Gm^2 \), which for the electron gives a giant value of \( 4.17 \cdot 10^{32} \). In the 1930s, P. Dirac went further and noticed that the ratio of the electric force between the electron and the proton to the gravitational force between them is measured by a large number: \( K_e^2/Gm_p m_e \approx 2.27 \cdot 10^{39} \). Here \( m_p, m_e \) are the masses of the proton and electron, respectively.

3. Modification of the Eddington' and Dirac' methods
In [6,10], the forces of gravity and Coulomb forces in objects with real dimensions from \( 10^{26} \) to \( 10^{-16} \) m were compared. In this problem, the ultimate goal was the same - the creation of a unified theory of interference of gravitational and Coulomb fields, not for elementary particles, but for real massive objects of the Cosmos and their parts (the centers of galaxies, clusters of galaxies, pulsars, quasars, planets, their atmospheres, etc.). In gravitating bodies, the mass is determined not by the mass of electrons, but by the mass of nucleons (protons and neutrons) that are the foundation of the ordinary nuclear matter from which the atom, molecule, any planet, star, etc. is built. The masses of nucleons are larger than the mass of electrons 1836 times. Therefore, we can neglect the mass of electrons leaving the structure in the total mass of the structure. According to the Coulomb's and Newton's laws in the gravitating objects of the Cosmos, for example, with an arbitrarily distributed charge along the radius, when comparing the forces of gravity and electric repulsive forces, it is necessary to compare the values of the forces \( K \cdot (a_i \cdot N \cdot e) \cdot (n \cdot a_i^2 \cdot e) / R^2 \) and \( G \cdot (N \cdot m_p) \cdot (n \cdot m_p) / R^2 \). Here \( K = 1/4\pi \epsilon_0 \), \( \epsilon_0 \) is the electric constant, \( a_i \) is the degree of uncompensated volumetric charge of protons in the entire CD structure, for example, a star; \( N \) is the total number of nucleons in the sphere of the structure of radius \( R \), \( a_i^2 \) is the degree of uncompensated proton volume charge in the volume under investigation, for example, on the surface of the star at a distance \( R \) from its center; \( n \) is the number density of particles in this volume. The degree of uncompensated volumetric charge of the plasma structure - \( a_i \) is the ratio of the concentration of positively charged ions \( n \), which form the volumetric charge of the whole positively charged structure, to the density of the total number of nucleons \( N \), which determine the mass of the structure.

In this approach, the Eddington and Dirac numbers are modified into a number:

\[
K_e^2/Gm_e^2 = 4.17 \cdot 10^{42} \rightarrow K_e^2/Gm_pm_p = 2.27 \cdot 10^{39} \rightarrow K_{a_i^1 a_i^2 e^2/Gm_p^2} = 1. \tag{1}
\]

The condition of gravitational and Coulomb forces equality leads to instability of the star, galaxy, their system or visible universe, analogous to the rotational 2D instability. The instability arising for the CD-structures of the Cosmos due to VN in the general case, for the convenience of classification, will be called the 3D instability of the Vysikaylo, in accordance with the terminology in [10]. The condition (1) allows us to determine:

\[
((a_i^1 \cdot a_i^2)^{0.5})^* = a_i^* = 0.9 \cdot 10^{-18}. \tag{2}
\]
\(\alpha^i\) – the critical degree of the VN of the gravitating, charged body substance, when the body ceases to compress under the action of gravitational forces and, as in the case of rotational instability, parts of a charged quasineutral plasma in the form of a plasma, stellar, solar, etc. wind are emitted from its surface, as in the case of rotational instability [6, 10].

Vysikaylo' parameter of the dynamic order \(\alpha_i = (\alpha_{i1} \cdot \alpha_{i2})^{0.5}\) determines in the Cosmos the transition in CD structures from gravitational compression to Coulomb loosening or even sputtering and scattering of charged matter made of nucleons. The parameter \(\alpha_i\) is determined by two parameters: \(\alpha_{i1}\) is the parameter of the VN structure as a whole, and \(\alpha_{i2}\) is the VN parameter of the element to be studied for the Coulomb instability, which is chosen in the charged CD structure. An element can have the value \(\alpha_{i2} = 1, 1/2, 1/3\) or less. In the case of the proton \(\alpha_{i2} = 1\), the Vysikaylo instability begins for such a mass with the VN parameter for the entire star for \(\alpha_{i1} \geq 8.1 \cdot 10^{-37}\). At these values of \(\alpha_{i1}\) and \(\alpha_{i2}\), the value of \(\alpha_i\) will reach the Vysikaylo’ limit, see equation (2).

### 4. Classification of charged stellar wind

Vysikaylo instability first of all begins for protons, since the parameter \(\alpha_{i2}\) for them is the maximum and equal to 1. The values of \(\alpha_{i1}^2 = 2\) or 10 are impossible because of the impossibility of cumulating into the atomic nuclei of only protons. And for an atomic nucleus with 10 protons and 10 neutrons, the parameter \(\alpha_{i1}^2 = 1/2\). When the Vysikaylo parameter for the star \(\alpha_{i1} \approx 8.1 \cdot 10^{-37}\) is reached, a reflecting Coulomb "mirror" automatically appears for the protons, and the free path to the surface of the charged star or to its interior for the proton will be temporarily closed because of the star's charge and the dominance of the Coulomb repulsion forces over gravitational attraction of protons. Positive charge of stars and Vysikaylo instability for protons, as the author supposes in [6, 10], cause up to 90% of protons, experimentally observed in all energy-mass-momentum flows of the Cosmos. The possible range of the parameter \(\alpha_i^3\) values for cumulating on the attractor elements becomes clear and consists of \(1 \geq \alpha_{i2} \geq 0\). The change in the parameters of ordinary space gravitating stationary objects extends from \(\alpha_{i1} \cdot \alpha_{i2} \approx 0.81 \cdot 10^{-10}\) to 0.

### 5. Calculations of positively charged Sun and solar wind parameters

As an example, which can verify the calculation of the charged stars parameters, we determine the condition under which protons are reflected from the positively charged Sun. Knowing the mass of the Sun or the number of nucleons in the Sun is \(1.2 \cdot 10^{57}\) and the radius of the Sun is \(R_S = 6.96 \cdot 10^8\) m, the VN parameter for the appearance of the Coulomb mirror reflecting proton in the Sun is \(\alpha_{i1} \approx 0.81 \cdot 10^{-36}\). The solar charge in this case \(q_S = e \cdot \alpha_{i1} \cdot N_S = 154\) C and the electric field on its surface \(E_S = K e \cdot \alpha_{i1} \cdot N_S / R_S^2 = 2.86 \cdot 10^6\) V/m.

The reduced electric field \(E/N\) (Townsend) for plasma particles (hydrogen atoms) significantly depends on the plasma particles density and rapidly grows from the photosphere to the chromosphere. We take the relation of \(N\) with the height from [19]. We calculate the relation \(E/N\) with the height.

It can be seen from Table 1 that in the photosphere region, where the concentration of plasma particles is large, the parameter \(E/N\) is small, but in the chromosphere this parameter grows rapidly with height and reaches significant values, which apparently leads to a substantial heating of the electrons already in this region of positively charged Sun. According to the above model, in the upper chromosphere and the corona, a non-equilibrium plasma is formed in the external electric field of the positively charged structure – the Sun with \(E/N\) values much larger than the breakdown fields in the completely ionized hydrogen plasma. This, as we suppose, generates SW in outer space and the removal of plasma, as in an ordinary plasmatron. Helium ions are observed in the SW. This means that all Sun's parameters are two or four times (see table 1 - \(E/N^*\)) more. If we take into account the presence of the seven times ionized iron of Fe observed in the SW [20], this leads to an 9-fold increase in these parameters (\(E/N^{**}\)), and the presence of xenon ions indicates the possibility of increase of these parameters up to 130 times, but this data already questionable.
Table 1. The values of $N_{hi}$, cm$^{-3}$ and $E/N$, Td as a function of height above the surface of the Sun

| $h$, km / $r$, Rs | $N_{hi}$, cm$^{-3}$ | $E/N$, Td | $E/N^{x2}$, Td | $E/N^{x9}$, Td |
|-------------------|---------------------|----------|----------------|----------------|
| 0/1               | 3.98x10$^{15}$      | 7.19x10$^{-7}$ |                |                |
| 1 000             | 3.16x10$^{13}$      | 9.05x10$^{-5}$ |                |                |
| 2 000             | 6.31x10$^{12}$      | 4.53x10$^{-4}$ |                |                |
| 3 000             | 1.99x10$^{12}$      | 1.44x10$^{-3}$ |                |                |
| 4 000             | 7.94x10$^{11}$      | 3.6x10$^{-3}$  |                |                |
| 6 000             | 2.51x10$^{9}$       | 1.14      |                |                |
| 8 000             | 1.0x10$^{9}$        | 2.86      |                |                |
| 10 000            | 6.31x10$^{8}$       | 4.53      |                |                |
| 15 000            | 1.99x10$^{8}$       | 13.78     |                |                |
| 70 000            | 7.94x10$^{7}$       | 29.75     |                |                |
| 280 000           | 1.26x10$^{7}$       | 115.79    |                |                |
| 420 000           | 5.01x10$^{6}$       | 223.31    |                |                |
| 700 000/2         | 1.58x10$^{6}$       | 452.28    |                |                |
| 1 400 000/3       | 3.98x10$^{5}$       | 798       |                |                |
| 2 800 000/5       | 6.31x10$^{4}$       | 1812      |                |                |
| 6 200 000/10      | 1.0x10$^{4}$        | 2942      |                |                |
| 13 000 000/20     | 2.51x10$^{3}$       | 2973      | 26757          |                |
| 44 000 000/65     | 1.0x10$^{3}$        | 701       |                |                |
| 150 000 000/215   | 6.31x10$^{2}$       | 97.7      |                |                |

6. Calculation of protons and alpha particles energy in the Earth’s region

The Coulomb potential energy of a proton born at a distance $r$ from the Sun will be:

$$W = K q_S e / r.$$  \hspace{1cm} (3)

This potential energy can be completely changed to the kinetic energy of a charged particle far from the Sun if the particle does not experience inelastic collisions that substantially change its kinetic energy. For protons born in the Earth’s orbit, $W = 1.5 \cdot 10^{-18}$ J (9.2 eV), where $r$ is the astronomical unit (the distance from the positively charged Sun to the Earth) if the solar charge is 154 K.

From the experimental studies of the SW in the region of the Earth, it is known that the velocity of protons and ions in it reaches from $V = 400$ km/s to 1000 km/s [1]. Consequently, these protons came from a region close to the Sun. Knowing from the experiments the average speed of the solar wind near the Earth - $V$, we can estimate the kinetic energy of the protons in the solar wind:

$$W = m \cdot V^2 / 2 = 1.34 \cdot 10^{-16} + 8.36 \cdot 10^{-16} J (835 \div 5 \cdot 200 eV).$$  \hspace{1cm} (4)

Such energy can be obtained by protons born in the corona of the positively charged Sun and accelerated by its charge to such velocities in the region of the Earth. In this case, the mean free path, in which protons flying to the Earth, do not experience collisions with other nucleons, can be estimated from the formula:

$$L = 1 / (\sigma N).$$  \hspace{1cm} (5)

$\sigma$ is the effective collision cross section of protons, which for energies of the order of 1 keV is equal to $2 \cdot 10^{-17}$ cm$^2$. In this case, protons born at distances of the order of 2 800 000 km to 6 000 000 km (5 ÷ 10 solar radii) will arrive to the Earth with a small number of collisions. At these distances,
their potential energy at birth is about 3 keV, if the solar charge is of the order of 1000 K, i.e. protons, alpha particles and even six times ionized iron ions are reflected from the Sun (Figure 1).

If we consider that the Sun reflects alpha particles, iron ions, then we get an increase in the energy of positively charged particles in the region of the Earth also by two, four and nine times, respectively. Thus, experimental observations in the interplanetary space of the mass and charge compositions of the SW ions already provide valuable information not only about the solar atmosphere, but also about the average parameters of the Sun, such as its total charge, the electric field magnitude in the corona, and make a significant contribution to the verification of mathematical models of processes on the Sun.

Conclusion

The paper first proposed a specific mechanism for heating the solar wind plasma in its corona in the constant Coulomb field of the entire Sun, as a positively charged cumulative-dissipative structure. Cumulative processes on the Sun are caused by gravitational forces, and dissipative processes are determined mainly by the scattering of electromagnetic radiation and to a lesser extent by “corpuscular rays” - the solar wind. As shown in [21], the cumulative processes occurring in the gravitational or Coulomb potentials with the $U(r) \sim 1/r$ law can only convert half of the potential energy to the kinetic energy of the particles remaining in the CD structure. The second half of the potential energy must be scattered into the space surrounding the cumulative structure. This follows from the virial theorem [22] or Newton’s third law [21]. In excited Coulomb structures such as atoms, molecules, the take-off of ½ potential energy is carried out by light quanta – electromagnetic waves. In more complex structures, for the fulfillment of this law of cumulation, streams of particles with non-zero mass, for example, electrons, can be used, and after charging the CD structure with positive charge, protons and other ions. According to Parker [1], the first clear statement that something but light comes to the Earth from the Sun was expressed in 1896 by Norwegian physicist Kristian Birkeland. He came to this conclusion on the basis of the fact that the auroras are very similar to the electric discharge in the newly invented tubes, which generate charged particle fluxes (“cathode rays”). Thus, the energy for the outflow of the solar wind is due to gravitational compression of the Sun in its own gravitational field. This is accompanied by thermonuclear reactions of the neutronization of hydrogen atoms to helium atoms, the release of a small fraction of electrons from the Sun, as the most mobile gas, the charging of the entire Sun to several hundred Coulombs, the formation of Coulomb mirrors reflecting positive ions and the formation of solar wind from the Sun. We can say that the authors of this work are followers of the ideas of K. Birkeland and R. Clausius, who introduced the concept of the virial in 1870.

Our analysis using mathematical methods of the causes of the solar wind shows that an indirect sign of cumulative processes in CD structures such as the Sun and the Solar System can be not only rotation, but also a violation of neutrality and the formation of oppositely directed bicyclic rotating flows that cumulate the entire mass of the Sun to its center and defocusing mass of the solar wind leaving the solar system, see [7].

As proved by analytical calculations, having determined in the experiments the ion composition of the solar wind and finding the minimum value of the ratio $Z/m$, according to the method proposed in this paper, it is possible to calculate the minimum electrical parameters of the Sun itself, its corona and analytically calculate the energy parameters of the solar wind in the region of the Earth. This requires detailed experimental studies of the parameters of the solar corona (the particle density profile), and reliable data on the ion composition of the solar wind arising from Coulomb mirrors reflecting these positively charged ions from the Sun.

The smaller the $Z/m$ ratio, the greater the positive charge of the Sun for the equality of Coulomb repulsive forces and gravitational attraction forces for a given ion. The ion velocity in the solar wind is also essentially dependent on this parameter and on the place where the ion was born. This determines the variance of the solar wind velocity from the ratio $Z/m$. 
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