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Electromagnetic-Wave Mechanism of Formation and Propagation of Astrophysical Vortex Jets Generated in the Jumper of a Spiral Galaxy

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Abstract

An explanation of the mechanism of generation and acceleration of jets in outer space is given on the basis of experiments in the physics of electrical discharge. The presence of two arms in the spiral Galaxy gives grounds to assume that they have excess charges of the opposite sign. At the moment when the electric field strength between the tips of the arms becomes sufficient, an electrical breakdown occurs, which is accompanied by the movement of the current-plasma leader in the jumper between the tips of the arms. In the head part of the leader there is a flat electric domain of a strong field, which, during its inception, emits intense transverse electromagnetic waves in a direction perpendicular to the direction of the leader's motion and to the plane of the accretion disk. The electric domain periodically appears and collapses due to the entry of neutral particles. Transverse electromagnetic waves capture charged particles from the discharge region and accelerate them in the direction of wave propagation. The crossed fields of an electromagnetic wave perform the functions of a multistage accelerator. The acceleration of the particles of the plasma produced in the discharge to relativistic energy values in the region of narrow vortex jets occurs under the action of forces caused by the components of the electromagnetic wave fields and the pressure gradient. The charged particles of a vortex jet acquire a significant rotational moment under the action of the Lorentz force. Explanations of the generation of microwave, bremsstrahlung and optical radiation from the region of the jumper between the arms of the Galaxy in the absence of electrical breakdown are also given.

Keywords

Galaxy, Accretion Disc, Jumper, Jet, Electric Breakdown, Electric Domain

1. Introduction

In astrophysics, there are a number of theoretical models and unsolved problems that raise certain doubts. One of the urgent problems of physics is the problem of correct explanation of the mechanism of generation of objects that appear in electric discharges in the Earth's atmosphere and in outer space. R. Descartes many years ago suggested that all celestial bodies appear as a result of vortex motions [1]. One of the important problems is the problem of generation and acceleration of plasma jets. The Earth and its atmosphere are known to be elements of a global electrical circuit [2]. The fact that plasma jets appear as a result of electrical discharges in the upper layers of the atmosphere no longer raises any doubts. A number of articles are devoted to the problem of studying plasma jets formed during electrical breakdown in the upper layers of the atmosphere [3] [4] [5] [6] [7]. Studies of blue jets have shown that they are narrow cones that propagate vertically upward at a speed of 100 km/s [3]. This means that the surface of the planet is a reflector. It was assumed that blue jets are either giant negative streamers [4] or positive streamers [5]. A model of a blue jet in the form of a beam of runaway electrons was proposed in [6], and a model of a jet in the form of an ascending leader whose head part emits streamers in the direction of the leader was proposed in [7]. The progress achieved in the study of atmospheric plasma jets made it possible to study jets formed in outer space using laboratory astrophysics methods [8] [9] [10]. The fact that plasma jets appear as a result of electrical discharges no longer raises any doubts.

Plasma jets that emerge from the central region of the Galaxies are also observed in astrophysical research. It is known that the jumpers in the central part of the Galaxy are bright sources of electromagnetic radiation in the Universe [11]. Electromagnetic radiation has been observed in the radio, microwave, infrared, optical, ultraviolet, bremsstrahlung and gamma-ray wavelengths. Some accretion disks produce binary jets in the form of highly collimated fluxes of fast charged particles emerging in opposite directions from the central region of the Galaxy, *i.e.* from the area of the jumper between its arms. It is known that plasma jets are always directed perpendicular to the plane of the Galaxy.

The creation of theoretical models and the use of mathematical modeling provides a number of useful information. However, reliable information and a correct understanding of the processes occurring during the generation of plasma jets can only be obtained using laboratory experiments on electric discharges. The author of a significant number of results in the field of cosmology and astrophysics V.S. Netchitailo correctly noted in the review [12] that physics cannot exist without mathematics, but mathematics should not replace physics. It is very well known that the criterion for the reliability of any truth is the results of physical experiments. A correct understanding of the jet generation mechanism will make it possible to create an adequate model of star generation.

The mechanism of formation of plasma jets in astrophysics and their dynamics are currently not studied due to the very low resolution of the instruments used. The results of the influence of the jets are observed in the radio range. However, they are known to radiate in all wavelength ranges from radio to gamma. A number of results on laboratory modeling of astrophysical plasma jets were performed on high-power pulsed high-current laboratory facilities [8] [9] [10]. It should be noted that the use of coaxial electrodes in experimental setups for modeling plasma jets [9] [10] does not allow obtaining correct information about the occurring phenomena and giving an explanation why plasma jets move with a relativistic speed. The plasma-focus device, in addition to energy storage devices, consists of coaxial electrodes, between which, during the discharge, not one, but several current-plasma channels (CPC) are formed simultaneously. Current-plasma channels move between the electrodes. The CPC consists of a leader in the head part of which in the spark discharge there is a head according to the terminology [13], or an electric domain of a strong field in the initial stage of a high-current electric discharge, during breakdown [14]. It is difficult with the help of electron-optical cameras and electron-optical converters to register the structures formed in the initial stage of the discharge against the background of very intense plasma radiation.

In experiments performed at Caltech [8], solenoids were used to create poloidal and toroidal magnetic fields. In experiments on plasma jet simulation on a Z-pinch device carried out at Imperial College [10], a solenoid was also used to create a toroidal magnetic field. However, in the region of the plasma jumper between the tips of the arms of a spiral galaxy, there can only be an azimuthal magnetic field, which is due to the current flow in the arms. Since the motion of the plasma jet occurs at a relativistic speed, it is obvious that the use of the MHD approach for the theoretical description of the jet dynamics is not justified. The models proposed in articles [8] [9] [10] do not explain the mechanism of jet generation and the fact that blue jets always move perpendicular to the Earth's surface. It is obvious that the configuration of the electrode system in laboratory astrophysical experiments should be close to the configuration of the elements that perform the functions of electrodes in natural conditions. Otherwise, one can detect a number of instabilities that are characteristic of ordinary plasma [8] and which are absent in relativistic plasma jets. It should be noted that the author of the article, P. M. Belan, has performed a number of studies on the physics of jets, which are a significant contribution to science.

Laboratory experiments on the physics of electrical breakdown near the surface of a dielectric [14] [15] made it possible to obtain ball lightning in the laboratory [15] [16] and give an explanation of star formation in outer space in a first approximation [17]. Statements about the scaling of processes in physics [11] are not indisputable. Physical processes in Nature do not depend on the size of the object and have the same nature of implementation in both micro- and macro-objects. Qualitative results can be obtained not only on large, but also on small electrophysical devices.

The known mechanisms of electric breakdown in gas: the Taunsen mechanism and streamer mechanism, as well as the results published in monographs

[13] [18] [19], differ from the electric breakdown mechanism described in this paper, which is based on an electric domain with a strong field in the head part of the leader. There are also several other mechanisms of breakdown initiation in electric discharges: plasma [20] and break-down on runaway from collisions electrons [21].

2. Experiments on the Domain-Leader Transition during Electrical Breakdown

The experiments were carried out in air under normal conditions on a PP-10 setup consisting of a capacitive storage device, a charger, a starting device, diagnostic instruments, and a discharge cell with two pointed electrodes. The electrical circuit schema of the installation is given in **Figure 1** and the scheme of the experiment is given in **Figure 2**.

Using two pointed electrodes allowed not only increasing electric field strength due to geometric factor. Plexiglass was used as a dielectric in the discharge cell. The electrodes were made of ordinary steel. They protruded beyond the insulator

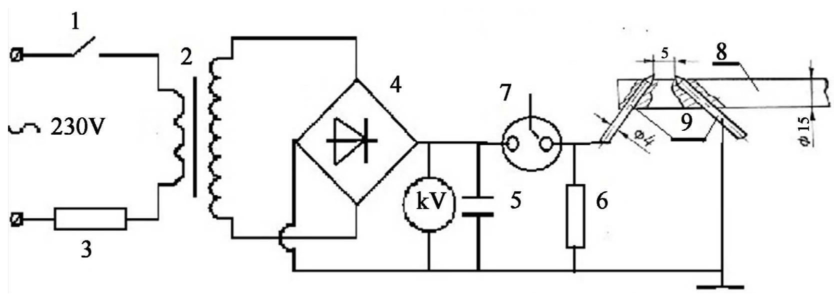

Figure 1. Electric schema of the installation for the study of electrical breakdown. Designations: 1: magnetic starter; 2: high-voltage transformer; 3: limiting resistor; 4: rectifier bridge; 5: capacitive energy storage; 6: high resistance resistor; 7: controlled spark gap; 8: discharge cell; 9: pointed electrodes.

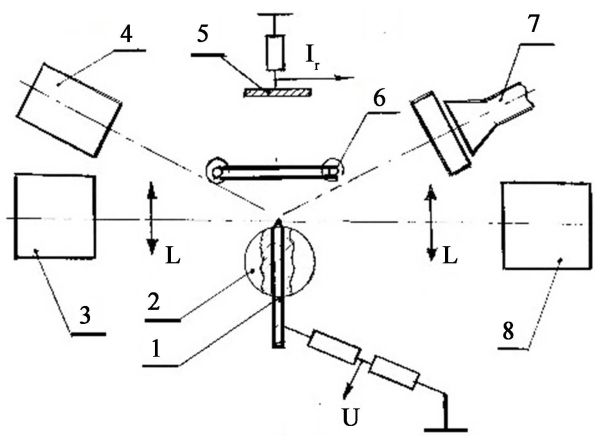

Figure 2. The scheme of experiments on research of electrical discharge near the dielectric surface. Designations: 1: electrode; 2: cell insulator; 3: FER-7 electron-optical camera; 4: detector of bremsstrahlung; 5: collector of high-energy particles; 6: Rogowski loop; 7: detector of microwave emission with phtoroplast absorber; 8: electron-optical convertor; L: lens.

plane at a distance of 0.1 cm. The angle between the electrodes was 90 degrees, the interelectrode gap was equal to 0.6 cm. The discharge cell used allowed for an accessible study of the processes occurring in a single current-plasma channel, and thus to draw conclusions about the processes that occur in coaxial device like plasma focus. Such device has a large number of CPCs in the initial stage of discharge. The discharge cell was removed from the controlled spark gap so that the processes occurring during the breakdown in the spark gap would not affect the processes occurring in the discharge cell.

The electrical circuit of the facility is similar to the circuits used in plasma guns. A high voltage pulse with a steep leading edge in such a circuit appears on the resistor (pos.6 in Figure 1), which connects the electrode with the initial zero potential to grounding after switching the circuit by a controlled arrester (pos.7). The pulse to start the arrester was formed with a unit based on a thyratron, which in turn was triggered using a GI-1 pulse generator. The amplitude value of the pulsed voltage applied to the electrodes of the discharge cell was 8.5 kV and was sufficient for breakdown between the pointed electrodes.

In the experiments there were recorded: applied voltage, current in the discharge by means of shunt installed in the circuit of capacitive energy accumulator, current of fast particles in near-electrode space by means of graphite collector with shunt, magnetic fields generated by microbeams of fast electrons through Rogowski loop as well as microwave and X-ray radiation. A resistive voltage divider was made of two low-inductance resistors of the TVO type and connected directly to the high-voltage electrode in order to reduce the inductive component. Typical waveforms of voltage and current in the discharge are given in Figure 3. The amplitude of the applied voltage was equal to 8.5 kV, and the discharge current was 130 A.

Typical waveforms of the microwave emission signals from the discharge, current from the Rogowski loop, and signal from the collector are given in Figures 4-6, respectively. These measurements were made on a short sweep, 0.5 μs/div.

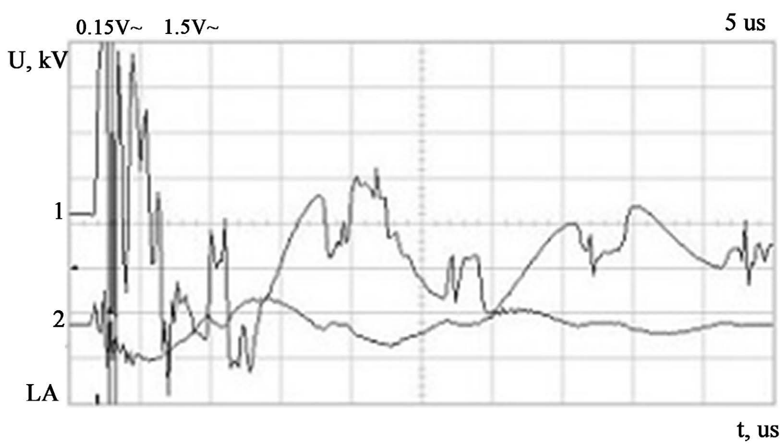

Figure 3. Typical waveforms: voltage (the upper trace-1) and current (the lower trace-2) in the discharge. The time scale, 5 μs/div. The voltage value amplitude, 8.5 kV and the current value amplitude, 130 A.

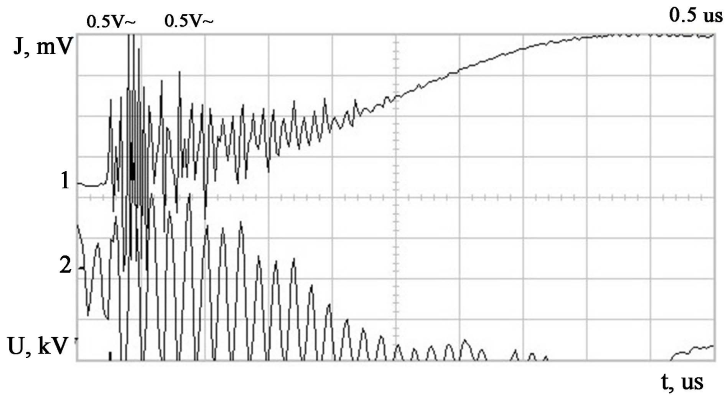

Figure 4. Typical waveforms: microwave emission (the upper trace-1) for $3 \le \lambda \le 6$ см and applied voltage (the lower trace-2) in the initial stage of discharge. The time scale, 0.5 μs/div.

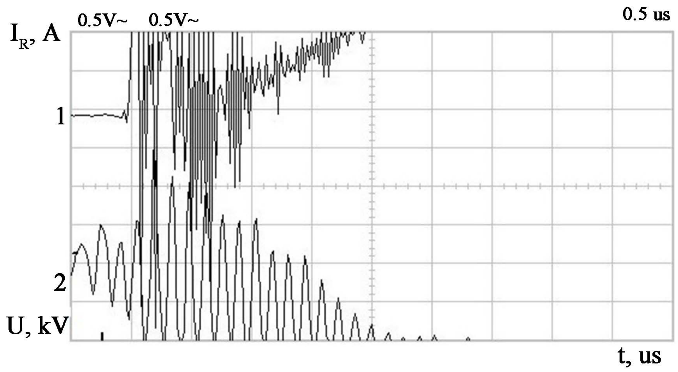

Figure 5. Typical waveforms: current from the Rogowski loop (the upper trace-1) and applied voltage (the lower trace-2) in the discharge. The time scale, 0.5 μs/div.

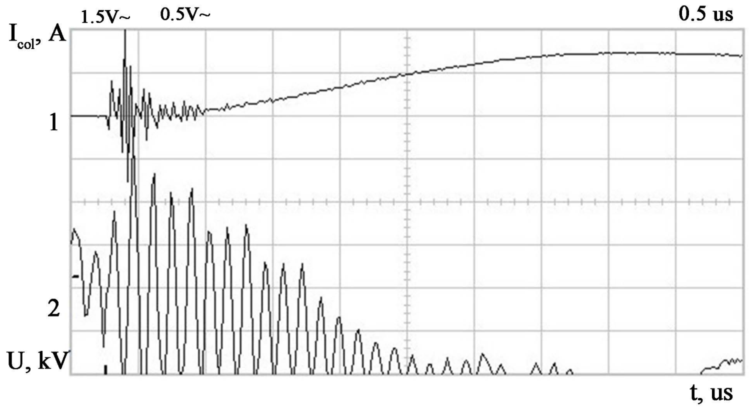

Figure 6. Typical waveforms: current from the collector (the upper trace-1) and applied voltage (the lower trace-2) in the initial stage of discharge. The time scale, 0.5 μs/div.

Microwave radiation in the discharge was registered in the wavelength range $3 \le \lambda \le 6$ cm by a detector, which was installed behind the fluoroplastic absorber. Optical registration of luminescence from the discharge area was performed by means of streak cameras FER-7 and electron-optical convertor EP-15, which allowed receiving single frames. The optical recorders were triggered using a six-channel pulse generator GI-1. The minimum exposure duration when obtaining an image with the EP-15 converter was equal to 5 ns. During the measurements, a two-beam oscilloscope was used. Therefore, the signal from the voltage divider was used as a reference.

Analysis of typical current and voltage waveforms allows us to distinguish three characteristic stages during a discharge: initial, main, and final. The initial stage of discharge is associated with the emergence and development of primary breakdown in the interelectrode gap, which is accompanied by the appearance of a conductive medium. The main stage is related to the oscillatory process in the electric circuit. With the available parameters of the RLC-circuit and the load, the shape of the voltage and current pulses in the main stage has a damped harmonic character with peculiarities. The duration of the initial stage was 2.5 μs, the main stage was 50 μs, and the final stage was about 20 μs. At the final stage of the discharge we observed low reproducibility of the registered values of current and voltage from start to start, which manifested itself after about 55 μs from the beginning of the pulse. In the final stage there was no reproducibility of current and voltage signals from start to start and there were current and voltage spikes that were sporadic in nature.

Typical waveforms (see **Figure 3**) indicate that in the main stage there are voltage spikes, which correlate with the shelves on the current oscillogram. The appearance of shelves and the decrease in current can only be explained by the transition of some of the electrons from the conducting state in plasma to a bound state, layers of excess negative charge of electric domains. This leads to a decrease in plasma conductivity, and therefore the differential conductivity of the plasma becomes negative. It should be noted that electric domains were first discovered in semiconductor plasma by Nobel laureate J.B. Gunn [22]. Electrical domains consist of two regions (layers) with excess charges with opposite sign. The distance between the charged regions exceeds Debye shielding length. The voltage spike in the domain region is explained by the fact that even at a small potential difference between the domain regions (layers), a very strong electric field is established due to the small distance between them [23]. Electric domains that are responsible for the anomalous transport of plasma across the longitudinal magnetic field have been found in magnetically isolated plasma [24] as well as in glow discharge plasma [25].

Using electro-optical convertor the generation of anomalous formations in the initial stage of the discharge was experimentally detected. The exposure during filming was controlled by the length of the RK-75 RF cables, which were used to supply a voltage pulse to the image intensifier tube. **Figure 7** shows a series of sequentially recorded images of the glow in the interelectrode gap. At the initial moment of time, in the near-electrode zone bordering one of the electrodes, due to the inequality of directed drift fluxes, charges are separated and a flat domain appears (see **Figure 7(a)**). Its birth is accompanied by the generation of a transverse electromagnetic wave, which is used to capture and accelerate charged particles in a direction perpendicular to the axis of the discharge cell. Generation of

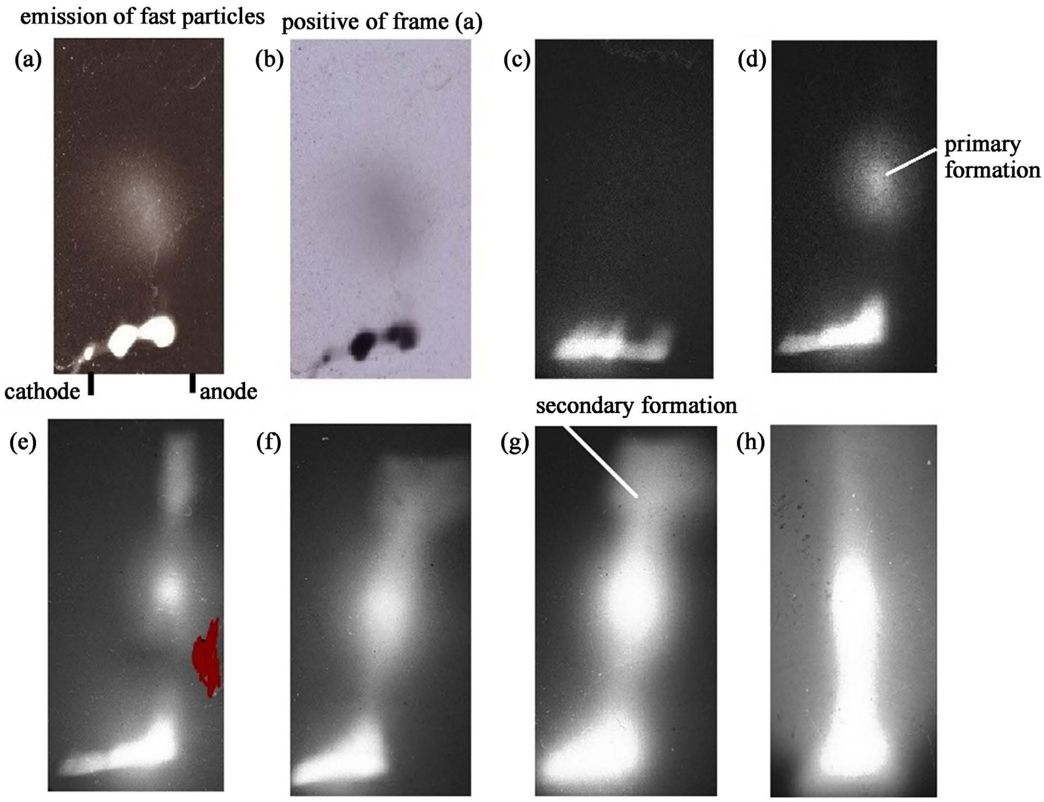

Figure 7. A series of sequentially recorded images of the plasma glow (frames a-h) during electrical breakdown near the surface of the dielectric obtained using an electron-optical converter in the time range from 0 to 665 ns. Shooting time t (a) = 0 - 5 ns; image (b) is the positive of image (a); shooting time: t (c) = 5 - 10 ns; t (d) = 45 - 65 ns; t (e) = 110 - 130 ns; t (f) = 140 - 160 ns; t (h) = 500 - 520 ns.

microwave radiation in the initial stage of the discharge is confirmed experimentally using a detector, see Figure 4. In Figure 7(a) & Figure 7(b) one of the electrodes is also observed at the bottom left.

The electrical domain located at the head of the leader periodically appears and collapses during movement between the electrodes, see Figure 7(c). The destruction of a domain can be explained by the entry of neutral particles into its region. The emission of fast particles with the help of a transverse electromagnetic wave leads to the appearance of an anomalous formation, see Figure 7(d). Then a secondary luminous formation appears (Figure 4(e)). The probable reason for the appearance of a secondary formation is the presence of a strong field between the core and the outer shell in the primary formation. The secondary formation appears as a result of an electrical breakdown between the elements of the primary, the initiation of which is due to a strong field or particles that come from the discharge region. The intensity of the plasma glow in the area of the primary anomalous formation is increasing, see Figure 7(g). Inside this formation, the core and shell are clearly observed. In the final stage of the discharge, the plasma has an approximately cylindrical shape. The presence of a signal from the Rogowski coil indicates the presence of a magnetic field, and the presence of a current from the collector indicates a flux of fast particles from the discharge region. In these experiments, the collector actually played the role of a reflector of electromagnetic waves.

In some launches, the process of generating a secondary formation had a branching (V-shaped) character, see Figure 8(a). However, this was very rare. Anomalous formations were destroyed during the transition of the discharge to the main stage, when a harmonic component with features in the form of dips appeared on the voltage oscillogram. It is likely that during the main stage of the discharge, charged particles from the discharge region entered the region of the anomalous formation, which could not compensate for the space charge in the anomalous formation. The presence of the electric domain during breakdown in the initial stage of the discharge was directly recorded in the experiments near the dielectric surface (Figure 7(a) & Figure 7(c) and Figure 8(c)). This domain moves from the cathode to the anode and is periodically destroyed due to neutral air particles hitting it.

Plasma production in the near-electrode space occurs when an electric domain with a strong field passes between the electrodes. Such a region injects fast particles in the direction approximately perpendicular to the discharge cell axis (Figure 8(b) & Figure 8(e)). Fast electrons with an energy of 80 keV were registered in the region under the collector. The injection of fast electrons into the near-electrode space correlates with the moments of glow amplification in the passing region. When putting a plastic scintillator POPOP inside copper cup with thickness of 0.15 cm instead of collector (pos. 5 in Figure 2), a glow conditioned by braking radiation with energy of 80 keV was registered. Similar estimates can be obtained from the length of the path of electrons in air from the

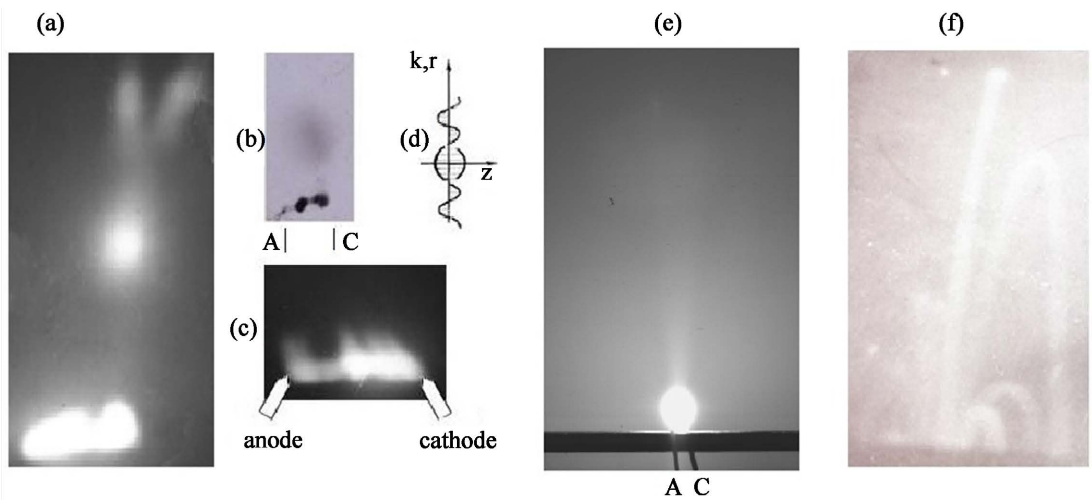

Figure 8. Optical image of the discharge glow in the near-electrode region with a branching secondary formation 110 ns after the beginning of the voltage increase (a); image of the glow from the near-electrode region during the passage of the electric domain in the head part of the current-plasma channel from the cathode to the anode (c); emission of fast particles from the region of the electric domain at the initial moment of time (b); orientation of the electric component of the wave relative to the domain regions (d); emission of fast particles in another discharge near the dielectric surface (e); current-plasma channels at the "Prometheus" facility (f). Designations: A-anode, C-cathode, $\boldsymbol{k}$ -wave vector.

place of their generation to the center of the region of their deceleration. Thus, the energy of fast electrons is about 10 times greater than the energy corresponding to the voltage applied to the electrodes. Their existence is due to the process of energy increase under the action of transverse electromagnetic waves, which are formed by the separation of charges and the generation of electric domains. The typical waveform from the detector measuring microwave emission in the discharge is given in **Figure 4**. The crossed fields of an electromagnetic wave perform the functions of a multistage accelerator of charged particles in a plasma. In the experiments, the registration of fast ions and electrons was also performed. For this purpose, the cell electrodes were shifted equi-distantly upward relative to the dielectric plane at a distance of 12 mm. Under the high-voltage electrode, a narrow strip of 5 μm thick aluminum foil was attached to the dielectric. After the start-up, through holes of very small diameter were observed in the foil, which are due to the impact of the microbeams of fast electrons, as well as depressions on the surface of the foil. The presence of depressions can only be explained by the bombardment of the foil surface by the microbeams of fast ions.

The sweeps of plasma luminosity from the areas cut by the slit, obtained with the electron-optical camera FER-7, are shown in **Figure 9**. The velocity of the head part of the CPC at the beginning of the main part of the pulse duration exceeded 10^7 cm/s. Such velocities are realized only at the presence of a strong own electric field. The maximum velocity of the electric domain in pulsed electric discharges was equal to 1.5×10^8 cm/s [26]. The absence of a preamplifier in the FER-7 electron-optical camera and problems with the orientation of the camera slit to distinguish the direction of the fast particle flux in the gap did not allow to obtain more information about the initial breakdown stage. The current-plasma channel in the main part of the discharge duration moves along an arc between the electrodes (**Figure 9(b)**), which shifts with time in the vertical direction.

Analysis of typical wave fronts of voltage and current shows that in the main part of the pulse duration (2.5 - 50 μs) the polarity of the applied voltage on the electrodes changed every half-period, see **Figure 3**. The current-plasma channel appears at one electrode each time, makes a passage through the space and destroys at the other electrode (see also **Figure 9(a)**). During the time between reaching the maximum and minimum values of voltage the current passes through the gap, at first the current increases and then it decreases to zero. In

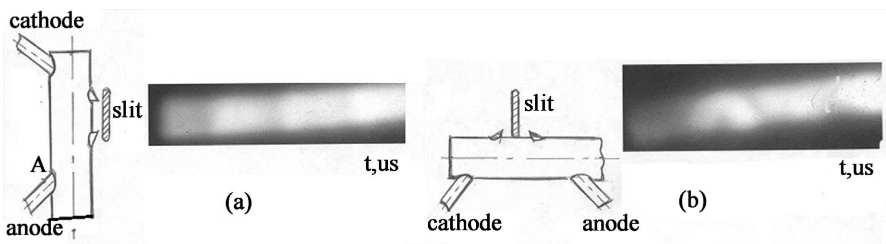

Figure 9. Scans of the plasma glow from the near-electrode region obtained using an FER-7 electron-optical camera for two positions of the slit.

the main stage of the pulse duration there are peculiarities in the form of dips of finite depth and duration at any polarity in the voltage oscillogram when approaching the extreme value. Their duration increases closer to the end of the main stage of the pulse, and their depth decreases. The steepness of the leading and trailing fronts also changes. In addition to the above data, the experiments also obtained oscillograms of the current of fast particles to the collector (**Figure 6**), the current from the Rogowski loop (**Figure 5**) and the signal from the semiconductor detector measuring the bramstrahlung from the region of anomalous formation generation. As a result of measurements it turned out that injection of beams of fast particles into the near-electrode space correlates with the appearing magnetic fields and the bramstrahlung generated during braking of fast electrons in air. Note the fact that the use of a current collector led to a sharp decrease in the generation of anomalous formations. The absence of a current collector makes it possible to significantly increase the path length of charged particles captured by an electromagnetic wave.

3. Theoretical Justification of the Experimental Results and Model of Vortex Relativistic Jets Generation

It is known that the average value of electric field strength between two electrodes in air under normal atmospheric conditions depends on their geometry and is 2 - 3 kV/mm. If you slowly increase the potential difference between the electrodes, then with the help of an electron-optical converter operating in a static mode, you can detect the appearance of small brightly luminous areas in the region of the active electrode. The presence of glow on the active electrode (cathode or anode) at the stage preceding the electrical breakdown indicates that the electric field strength in the near-electrode region significantly exceeds the average value of the strength in the gap. Electric breakdown is the initial stage of pulsed electric discharge and is accompanied by appearance of conductive medium in the interelectrode gap. In laboratory devices, electrical breakdown appears when a high voltage pulse is applied to the electrodes. At some point in time the electric field strength becomes sufficient to initiate the electrical breakdown. The difference in mobility of charge carriers results in charge separation, which is accompanied by displacement of a group of particles of one type from a group of particles of another type by an amount greater than the Debue screening length. There appears a flat (semi-elliptical domain) that is located in the head part of the current-plasma channel (leader) moving between the electrodes. In the spark discharge there is a head in the head part [13]. However, there is a significant difference in energy between spark discharge and high-current discharge. Flat electric domain consists of a layer with excess positive charge and a layer with excess negative charge. The distance between the layers exceeds the Debye screening length. It was previously noted that high values of the electric field strength in the region of the emerging electric domain exist even at a small potential difference between the layers of the domain due to the very small distance between its layers [23].

The process of formation of an electric domain in a plasma is equivalent to the process of transformation of an element with the ohmic component of impedance dominating at the beginning of the process into an element with a capacitive component dominating at the end of the process in some "plasma tube with current" [27]. The displacement of a group of charged particles of one type relative to a group of charged particles of another type in a very short time leads to the appearance of an induced electric field $\mathrm{d}E_{ind}/\mathrm{d}t$ and generates a transverse electromagnetic wave. This expression is displacement current to within a factor of $1/c$. As is known, the relationship between the current density, the displacement current and the magnetic field of the induction rotor is given by the classical Maxwell equation

$$\nabla \times \boldsymbol{B} = \frac{4\pi \boldsymbol{J}}{c} + \frac{1}{c}\frac{\partial \boldsymbol{E}}{\partial t}. \tag{1}$$

During domain generation, the conduction current drops to zero in the charge separation zone and the bias current increases. The second term in Equation (1) in the first approximation is equal to the difference of directional drift fluxes of ions and electrons [27]

$$\frac{\partial \boldsymbol{E}_{ind}}{\partial t} = \frac{4\pi e}{\varepsilon}\left(n_e \mu_e\left(\boldsymbol{E}\right) - n_i \mu_i\left(\boldsymbol{E}\right)\right)\boldsymbol{E}. \tag{2}$$

In Equation (2) n and μ are the density and mobility of the infected particles, respectively. It is generally accepted that the generation time of a flat electric domain is equal to the triple time of the Maxwellian relaxation of the space charge, *i.e.* $t_f = 3\tau_M$.

The Maxwellian relaxation time of the spatial charge is given by the expression

$$\tau_M = \frac{\varepsilon}{4\pi e n_e \mu_e}, \tag{3}$$

in which ε is the permittivity of the medium.

However, fluxes of fast particles, which are directed perpendicularly to the line connecting the electrodes, are observed in experiments. These fluxes cannot be obtained using the vortex magnetic field included in Equation (1). Experimental registration of microwave emission gives grounds to believe that transverse electromagnetic waves generated during nucleation of electric domains are the reason for the existence of particle fluxes. Domain generation is accompanied by space charge waves. The expression for the frequency of space charge waves was obtained as a result of the linearization of the system of equations consisting of the equations of continuity, motion for electrons and ions, and the Poisson equation in [15]

$$\omega_{wsc} = \omega_{pe} - \frac{\omega_{pe}^2}{12\pi\sigma_d} i \tag{4}$$

In this expression: ω_{pe}, Lengmuir frequency; σ_d, differential conductivity of plasma, $\sigma_d = en\mu_d$, Expression (4) determines the increments for instability due to electric domains in the plasma. Linearization of the equations of motion, continuity and Maxwell's Equation (1) made it possible to obtain the dispersion equation for transverse electromagnetic waves

$$\omega_{mw}^2 = k^2c^2 + \left(\omega_{pe} - \frac{\omega_{pe}^2}{12\pi\sigma_d}i\right)^2 \quad (5)$$

which appear at the separation of charges in plasma and pass into light waves in the absence of plasma for which $\omega = kc$. The difference between expression (5) obtained in [15] and the expression given in [27] is in taking into account the conductivity of the plasma, which characterizes the continuity of the medium. Note that the original system of equations in [15] took into account the separation of charges under the action of electric and magnetic fields, while in [28] only the effect of the plasma density gradient was taken into account.

Jets are formed during an electrical breakdown between the electrodes or the tips of the galaxy's arms. Breakdown is the initial stage of an electric discharge, in which a highly conductive plasma medium is formed in the jumper between the arms or in the interelectrode space. Electromagnetic waves generated during the formation of electrical domains capture and accelerate charged plasma particles in the form of jets in directions perpendicular to the dielectric plane or the Earth's surface, which reflect electromagnetic radiation. The absence of reflective surfaces during electrical breakdown in the region of the galactic jumper leads to the generation of two oppositely directed jets. In the jet model, called by its author D. Lynden-Bell "a magnetic tower" and consisting of a force-free plasma, whose magnetic pressure at the interface with the medium is balanced by the gas-dynamic pressure of the medium [29]. However, the environment in outer space is rarefied. However, the external environment is not capable of exerting sufficient pressure on the plasma jet.

Experiments in high-current electric discharges on the generation of ball lightning showed that the potential of ball lightning in the zone of its generation is 15 - 20 MeV. Therefore, as a result of the nuclear photoelectric effect, ions decay and protons are released [30]. Obviously, under the action of a transverse electromagnetic wave in the discharge region, charge separation occurs: protons (ions) are displaced to the periphery of the electromagnetic wave, while electrons remain in its axial part. If we assume that charge separation occurs in the jet, then it consists of a core with an excess negative charge and a shell with an excess positive charge, see **Figure 10(a)**. Thus, the jet is an electrical region of a conical shape. It consists of an excessively negatively charged core and an excessively positively charged outer shell. Under the action of the Lorentz force, the shell of the jet receives a significant rotational moment. The condition for the equilibrium of the jet is that the force of electrical attraction between the external shell and the core is balanced by the force due to centripetal acceleration in each section of the jet. It is difficult to give an unambiguous answer about the presence of an azimuthal magnetic field in the jet, since it consists of structural

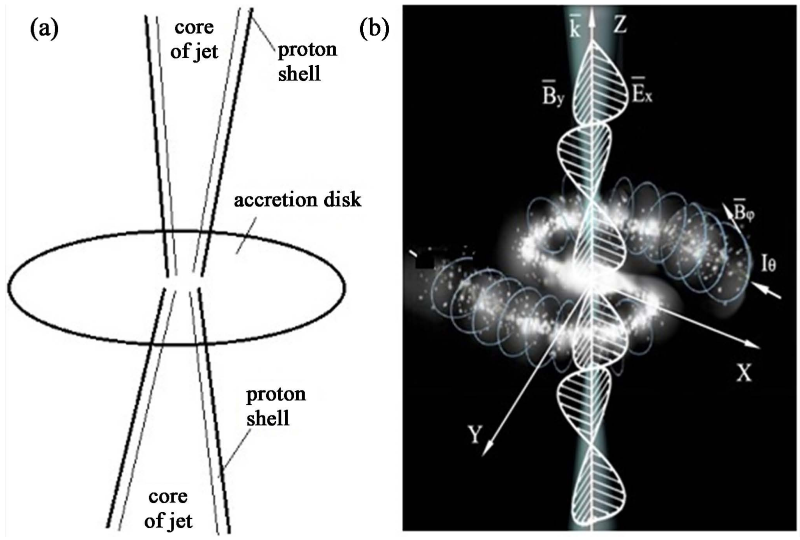

Figure 10. (a) A structure of binary jet. (b) A schema of the jets generation during at electrical breakdown between the tips of the arms of a spiral galaxy. Designations: $\boldsymbol{B}_\varphi$, induction of azimuthal magnetic field, I_o, electric current in the discharge, $\boldsymbol{B}_y$ and $\boldsymbol{E}_x$, components of fields electromagnetic wave. $k = 2\pi/\lambda$, wave vector.

elements with charges opposite in sign. It is likely that a structural element with a large moment will drive an element with a smaller moment due to ambipolar acceleration. The azimuthal magnetic field of the jet can be neglected. Let us write the equations of motion for charged particles moving in the field of an electromagnetic wave in the form [31]:

$$\frac{\mathrm{d}\left(m_{i,p}\boldsymbol{u}_{i,p}\right)}{\mathrm{d}t} = q_{i,p}\left(\boldsymbol{E}_x + \frac{\boldsymbol{u}_{i,p}\times\boldsymbol{B}_y}{c}\right), \tag{6}$$

$$\frac{\mathrm{d}\left(m_e\boldsymbol{u}_e\right)}{\mathrm{d}t} = q_e\left(\boldsymbol{E}_x + \frac{\boldsymbol{u}_e\times\boldsymbol{B}_y}{c}\right). \tag{7}$$

in which the electric and magnetic components of the electromagnetic wave are determined accordingly by the expressions: $\boldsymbol{E}_x = E_0\mathrm{e}^{i(\omega+kx)}$; $\boldsymbol{B}_y = B_0\mathrm{e}^{i(\omega+ky)}$ The proposed structure of the jets and the scheme of the fields of an electromagnetic wave formed during an electrical breakdown between the tips of the arms of a spiral galaxy are shown in Figure 10.

The presence of a wide spectrum of radiation in outer space can only be explained by the fact that, due to the leakage current between the arms in the region of the galactic jumper, there is a glowing mode of electric discharge. An analysis of the images of spiral galaxies shows that there is always plasma in the region of the jumpers, due to which, and due to the potential difference, there is a leakage current between the arms. This current leads to the interaction of fast electrons of this current with the medium. Fast electrons create regions in which the field strength is insufficient for breakdown to develop. In the jumper region, electric domains of a weak field appear, which, when they arise, also create a wide spectrum of electromagnetic radiation. A similar phenomenon occurs if a potential difference is applied to two electrodes in the laboratory, the value of which is slightly less than the value corresponding to the electric field strength required for breakdown. This process is also accompanied by the passage of electrical regions between the electrodes and generates a wide spectrum of radiation, including optical, microwave, and bremsstrahlung. Bursts of optical radiation and the passage of regions with a weak field can be visually observed on the screen of a good electron-optical camera operating in a static mode, and microwave emission and bremsstrahlung can be recorded using detectors. It is known that in the Universe there is a cosmic microwave background, registered by the Nobel Prize winners A. A. Penzias and R. W. Wilson [32]. However, the interpretation of the reason for its existence is not indisputable. A.A. Penzias and R. W. Wilson concluded that our Galaxy cannot be the source of this background. The Milky Way is in a fragmented state after much work was done in the creation of the Sun and the Solar system. It should be noted that the planets of the Solar system many millions of years ago were stars. The absence of a jumper and arms in the Milky Way does not allow our Galaxy to be a source of microwave emission. However, the galactic microwave emission registered on Earth comes from other galaxies. The source of radio emission can be electric domains of a weak field, which continuously pass inside the jumper between the tips of the arms. The reason for the existence of such domains is the leakage current between the arms. According to the author of the article, the registered cosmic microwave background is a consequence of the processes occurring in the jumpers in the absence of electrical breakdown.

It should be noted that the generation of stars occurs in jets as a result of charge separation. Stars get a significant rotational moment in vortex jets, which they cannot get in any way in inflationary and chemical models of their origin.

4. Conclusions

Experimental results on the physics of electrical breakdown made it possible to establish that in the head part of the moving leader there is an electric domain of a strong field, which periodically arises and collapses. The nucleation of the domain is accompanied by the generation of a transverse electromagnetic wave in a direction that is perpendicular to the line connecting the electrodes. An electromagnetic wave captures and accelerates charged particles. The fact that the wave repeatedly passes in the region of accelerated particles gives grounds to believe that it performs the functions of a multistage accelerator. The experimental results made it possible to explain the mechanism of formation and propagation of astrophysical vortex jets generated during electrical breakdown in the jumper between the arms of a spiral galaxy, as well as to create a model of a relativistic vortex jet in the form of a conical electrical domain. The energy of accelerated particles in this case can be hundreds of MeV.

The main difference between the most advanced streamer-leader model of breakdown proposed in [7] and the leader-domain model of the author of this article is in the direction of the flow of particles emitted by the head of the leader. In model [7], the leader's head emits streamers in the direction of the leader's movement. In the experimentally confirmed leader-domain model of electrical breakdown, there is an electric domain of a strong field in the head of the leader, which emits flows of charged particles in a direction that is perpendicular to the direction of movement of the leader under the action of the generated microwave radiation. It should be noted that none of the publications on atmospheric jets explains why the jet moves vertically upwards. It is likely that the vertical movement of the blue jet is due to the fact that electrical breakdown occurs between horizontal clouds, and the Earth's surface is a reflector of microwave radiation.

A new hypothesis about the cause of the cosmic microwave background is presented, which differs significantly from the hypothesis proposed in [32]. The fact that ball lightning is a microanalogue of a star was noted in [33]. The existing experience in the generation of high-energy ball lightnings [30] [34] [35] makes it possible to use it for laboratory modeling of ministars and a possible solution to the problem of nuclear fusion under normal conditions. The generation of stars, like the generation of ball lightning, occurs with the help of jets.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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