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A joint scientific session of the Physical Sciences Division of the Russian Academy of Sciences (RAS) and the Joint Physical Society of the Russian Federation was held in the Conference Hall of the P N Lebedev Physics Institute, RAS, on 30 November 2005. The following reports were presented at the session:

(1) **Kuznetsov V D** (N V Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (IZMIRAN), RAS, Troitsk, Moscow region) "Heliophysics: from observations to models";

(2) **Zaitsev V V** (Institute of Applied Physics, RAS, Nizhnii Novgorod), **Stepanov A V** (Special Astronomical Observatory at Pulkovo (GAO), RAS, St.-Petersburg) "Problems of solar activity physics";

(3) **Churazov E M, Sunyaev R A, Sazonov S Yu, Revnivtsev M G** (Space Research Institute, RAS, Moscow), **Varshalovich D A** (A F Ioffe Physical-Technical Institute, RAS, St.-Petersburg) "Annihilation emission from the galactic center: the INTEGRAL observatory results";

(4) **Fabrika S N, Abolmasov P K, Karpov S V, Sholukhova O N** (Special Astrophysical Observatory (SAO), RAS, Nizhnii Arkhyz, Karachaevo-Cherkesiya Republic), **Ghosh K K** (Universities Space Research Association, NASA Marshall Space Flight Center, USA) "Ultraluminous X-ray sources in galaxies — microquasars or intermediate mass black holes".

An abridged version of the reports is given below.

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Heliophysics: from observations to models

V D Kuznetsov

1. Introduction

Modern heliophysics focuses on physical processes in the heliosphere, spanning from the solar interior to the boundary of the heliosphere at which the solar wind interacts with the interstellar medium forming the heliopause. Solar studies are important both for astrophysics and, as the Sun is the nearest star, for practical applications and for life itself on Earth. Modern solar and solar – terrestrial physics form virtually one science — heliophysics. As with many other branches of physics, heliophysical studies are based on a traditional scheme: from scientific equipment, through observations and experimental data gathering, to applications of theory and the construction of models of the phenomena observed.

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2. Observations — experimental data

Lately, new and very important heliophysical results have been obtained mainly by space missions. Now, several heliophysical space missions are operating and providing researchers with experimental evidence. These include the NASA spacecrafts ULYSSES (launched in 1990), TRACE (Transition Region and Coronal Explorer) (1998), and RHESSI (The Reuven Ramaty High-Energy Solar Spectroscopic Imager) (2002), the ESA mission SOHO (Solar and Heliospheric Observatory), and the Russian – Ukrainian satellite CORONAS-F (Complex Orbital Circumterrestrial Solar Activity Observations) (2001); the last satellite stopped operating on December 6, 2005 due to natural orbit degradation.

The CORONAS-F satellite gathered rich observational data [1 – 3]. Its scientific payload included 15 instruments that observed the Sun throughout the entire electromagnetic spectrum, from optical to gamma-rays, so the satellite comprised a real heliophysical observatory. The diverse data obtained by this observatory allow us to make a thorough analysis of heliophysical phenomena. Principal scientific results of heliophysical studies, obtained by CORONAS-F in its last few years, were reported at the session of the Presidium of the RAS in January 2005 and are published in Refs [1 – 4].

3. Helioseismology

The nature of the 11-year solar cycle and solar activity phenomena is rooted in the solar interior. Thermonuclear reactions in the central regions of the Sun liberate energy that is transferred outwards through the radiative area and then by means of convective energy transport which is more effective when approaching the solar surface. The convective zone formed thus determines the dynamics of a magnetic field in the solar cycle. Information about the internal layers of the Sun can be collected by registering solar neutrino flux in ground-based observations [5] and by means of helioseismology when making satellite-based observations of global oscillations of the Sun as a gravitating plasma sphere [6].

The multichannel DIFOS spectrophotometer onboard the CORONAS-F satellite registered global oscillations (p-modes with periods of about 5 min) of the Sun by measuring tiny variations (10^{-6}) in the solar radiation flux

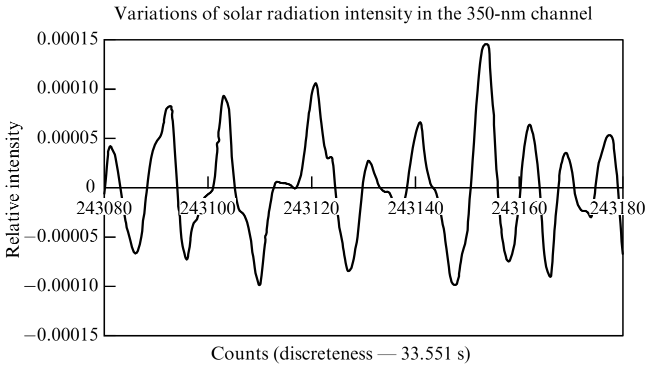

Figure 1. An example of the signal in the 350-nm channel of the DIFOS/CORONAS-F spectrophotometer, representing a set of harmonics with different periods, amplitudes, and phases, with a noise spectrum superimposed (the signal was cleaned from light reflected from the Earth's atmosphere).

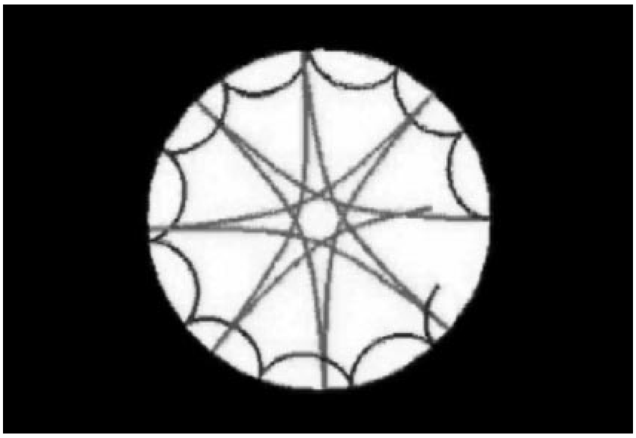

Figure 2. High and low spatial harmonics of global solar oscillations in the ray treatment. Shown is the propagation of a ray from the solar surface inward down to some critical radius where it is reflected back toward the surface, whence the ray is reflected inward again, thereby multiply propagating inside the Sun.

related to these oscillations over a wide wavelength range (350 – 1500 nm) [7]. Spectral analysis of optical signals received in eight spectral channels (Fig. 1) has been performed to find spectral harmonics with different periods, amplitudes, and phases. The device allows determination of low spatial harmonics of global oscillations (Fig. 2) (see also movie No. 1 in the electronic version of the paper on http://www.ufn.ru) (the number of nodes of an oscillation along the heliolongitude $l = 0, 1, 2$) that encompass all solar layers from the surface to the core. The resulting amplitude spectra of global oscillations (Fig. 3) show the presence of about 10 – 15 harmonics at each instant of time. Periods of individual harmonics as derived from these spectra allowed identification of the observed harmonics with the corresponding spatial ones of global solar oscillations (numbers l and n in Fig. 3). The coincidence of frequencies derived from observations with theoretically calculated ones allows verifying models of the internal structure of the Sun, for example, probing the convective zone depth. The frequencies coincide with high precision, allowing harmonics identification. An increasing measurement accuracy for periods of the harmonics and the refinement of their deviations from theoretically predicted

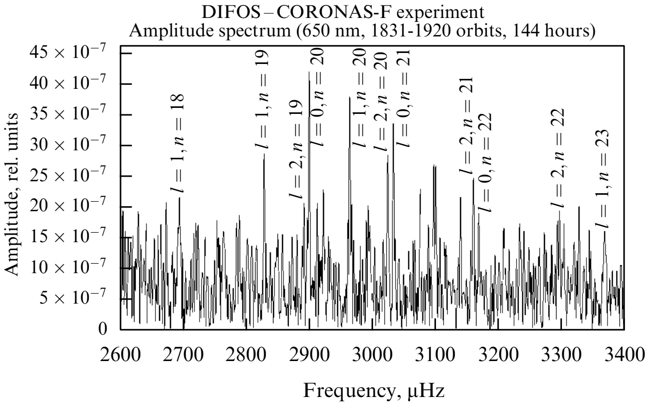

Figure 3. The amplitude spectrum of global solar oscillations reproduced from data obtained by the DIFOS/CORONAS-F instrument (IZMIRAN). Each peak corresponds to a global harmonic oscillation with a certain period (a harmonic). Numbers l and n characterize the number of nodes of the oscillation along the heliolongitude and the solar radius, respectively.

values enable us to correct the model of the solar inner layers, which is one of the most important goals of helioseismology [6].

At some instant of time, the observed harmonics are randomly excited, persist for several days or weeks, then disappear and new harmonics with other periods emerge. Such a behavior can be explained by treating global oscillations as stochastically excited damping oscillations

$$\ddot{x}(t) + \gamma \dot{x}(t) + \omega^2 x(t) = \varepsilon(t)$$

with the exciting 'external force' $\varepsilon(t)$ determined by the action of the convective shell with a broadband noise spectrum on global oscillations resonating inside the Sun.

More fine effects related to the dependence of the frequency of harmonics on the solar cycle phase require long-term observations. Such series of observations were acquired by the DIFOS/CORONAS-F experiment (IZMIRAN) over four and a half years of monitoring at the activity decay phase of the current 23rd solar cycle, from its maximum in 2001 to December 2005. To provide the required accuracy of the spectral analysis, these data have been processed and 'cleaned' from the noise light reflected by the terrestrial atmosphere. Changes in the frequency of the harmonics with the cycle phase can be related to changes in the parameters of the solar internal structure model in use [8].

Broadband (350 – 1500 nm) observations revealed the global oscillations amplitude increasing toward UV wavelengths [3, 7]. These observations were confirmed by theoretical predictions — solutions of radiative magnetic hydrodynamic (MHD) equations in the radiation formation layers inside the photosphere [9, 10]. Theoretical spectral functions of the relative intensity fluctuations related to global oscillations fit the observed spectrum well. The established amplitude growth makes the UV channel the most appropriate for observations of global solar oscillations, which should be taken into account in planning future helioseismological experiments. These experiments will be continued with the 'Sokol' instrument (IZMIRAN) on board the third satellite of the CORONAS series, the CORONAS-FOTON, which is scheduled for launch in 2007 – 2008.

Radiation at various wavelengths (six different spectral channels of the DIFOS instrument: 350, 500, 650, 850, 1000, and 1500 nm) is observed as coming from different depths of the solar atmosphere, which allows (by performing simultaneous observations at these wavelengths) determination of the phases of global oscillation waves and studies of their propagation. The first attempts at such an analysis of the DIFOS/CORONAS-F experimental data were reported in Ref. [11].

A fine frequency analysis of spectra obtained in long-series observations makes it possible to determine the frequency splitting of harmonics due to the rotation of the Sun. This in turn provides the principal possibility of evaluating the angular rotational velocity of the solar inner layers [12]. The depth dependences of the angular velocity derived at different latitudes from the measurement data of the MDI (Michelson Doppler Imager) experiment on board SOHO [13] established the location of the tachocline region at the convective zone bottom, i.e., the turbulent mixing region formed by shear displacements at the depths characterized by a sharp variation of angular velocity gradient, where a solar dynamo operates and the magnetic field is amplified [14].

4. Emergence of magnetic fields and their fragmentation into magnetic tubes

Magnetic fields are thought to be primarily responsible for active phenomena on the Sun. The magnetic field is generated under the photosphere and emerges to the surface due to the magnetic buoyancy effect [15, 16] (see movie No. 2 in the electronic version of the paper on http://www.ufn.ru). When coming to the surface, as evidenced by numerous observations, the magnetic field is fragmented into flux tubes which mainly determine the structure and dynamics of the outer solar atmosphere.

By modeling subphotospheric layers of the Sun in the gravitational field by an exponential isothermal atmosphere with constant Alfvén velocity and being left over in the framework of MHD equations with turbulent viscosity, it is possible to reproduce the process of magnetic field decomposition into flux tubes and to determine their lateral and longitudinal sizes in terms of the maximum scales of the linear instability increment of magnetic buoyancy [17, 18]. For conditions in the convective zone (typical values of the turbulent viscosity $\nu_t = 1/3 v l \approx 6 \times 10^{12}$ cm^2 s^{-1} as determined from the 'mixing length theory' and other parameters), the resultant magnetic tube sizes accord well with observed ones (lengthwise dimension 3×10^9 cm, lateral dimension 2×10^8 cm). In the solution obtained, the expression $\lambda_\perp \approx 2\pi(\nu_t u/g)^{1/2}$ (where u is the speed of sound, and g is the gravitational acceleration) for the lateral scale of the tubes is especially valuable, which has been obtained for the first time for a compressible medium using classical MHD approach. To an order of magnitude, this size is determined by the condition that the turbulent viscosity should have time to 'operate' over the characteristic time of magnetic buoyancy instability, which is determined in this case by the time of the sound propagation along the homogeneous atmosphere altitude (equal to u^2/g). The most suitable conditions for magnetic field fragmentation into tubes hold under the photosphere at depths of the hydrogen ionization zone (3×10^8 cm) where the adiabatic index of the gas, which determines its elasticity and resistance to the magnetic field line curvature, is minimal ($\gamma_{\min} = 1.09$).

The availability of magnetic flux buoyancy requires the finite superadaibaticity of convective zone, otherwise, by expanding according to the magnetic adiabatic law, magnetic clots can get cooler than the ambient medium and the magnetic buoyancy effect will be compensated. In the solar convective zone, the actual superadiabaticity is well above the calculated value of critical superadiabaticity:

$$\beta_\odot = \nabla T - \nabla_{\rm ad} T \approx 7 \times 10^{-9}\ \text{grad cm}^{-1} \gg \beta_{\rm crit} \approx 10^{-12}\ \text{grad cm}^{-1},$$

i.e., the conditions for the positive magnetic buoyancy in the Sun are well satisfied. But, in principle, for stars with very feeble convection the situation is possible when the magnetic field emergence does not occur and hence there is no surface magnetic activity.

Many observations [19] allowed establishing the key role of buoyant magnetic fluxes in initiating flares and mass ejections. Here, one of the important parameters that determines the character of flaring and eruptive processes is the velocity of the flux rise to the corona; this velocity determines regimes of the magnetic reconnection and energy release in the current sheets, as well as the onset of the eruptive mass ejection instability (see Section 6).

The velocity of magnetic flux rise was estimated for average parameters from equating the magnetic buoyancy force (the analog of the Archimedes force) to the decelerating force on the assumption of mass and magnetic flux conservation for a clot, as well as its adiabatic (according to the magnetic adiabatic law) expansion [16]. In the convective zone, the decelerating force is due to the Stokes viscous force with the same value of the turbulent viscosity as we used when estimating magnetic tube scales (see above). When a clot comes from beneath the photosphere to the corona, where there is no more turbulence, the only force restricting the clot motion is the aerodynamic drag force. Thus, it becomes possible to justify the characteristic time of the magnetic field transport through the convective zone in the solar cycle, on the one hand, and to obtain the observed velocities of magnetic fluxes rising to the corona (not more than 1 km s^{-1}), as well as the observed direct dependence of the velocities on the strength of characteristic magnetic fields, on the other hand. So, good consistency of the model with observations may be achieved.

5. Current sheets and solar flares

Plasma conductivity in the solar corona is very high and as a consequence the magnetic field is 'frozen' into plasma. By interacting with coronal magnetic fields, new magnetic fluxes rising from beneath the photosphere (in the form of magnetic tubes and loops) form current sheets. The energy dissipation in these sheets leads to flares [20, 21] (see movie No. 3 in the electronic version of the paper on http://www.ufn.ru). The analysis of extensive observational data with high spatial resolution, obtained over the last few years by the TRACE and SOHO satellites [19], gives compelling evidence that solar flares preferentially occur exactly in regions of a new buoyant magnetic field. This fact strongly confirms once again the concept developed by S I Syrovatskii and his disciples that current sheets and magnetic reconnection are the principal physical factors responsible for flaring energy release (see, for example, Refs [20, 22, 23]). It also serves as the physical basis for developing the methods of solar flare prognosis now providing a 90% accuracy from observations of magnetic fields and their associated currents [24]. The build-up of currents that emerge from the interaction of buoyant magnetic fields and lead to flares starts at around 10–30 hours before a flare and depends on the velocity of the rising flux tube and the magnetic field strength [25, 26].

Current sheets are formed on zero (in general, separatrix) magnetic field lines that can be localized from the magnetic field distribution at the photospheric level where measured data are available for the magnetic fields [27]. Even the greatly simplified but typical flare activity model in which a fresh magnetic flux rising into an already existing active region with a weak background magnetic field (which is always present) gives birth to many zero points. The localization of these points topologically changes depending on the field strength. They fall either on open or closed field lines, which largely determines the dynamics of particles accelerated in flares and their escape to the interplanetary space [28]. The three-dimensional magnetic field of an active region represents a continuous magnetic carpet [29] (see movie No. 4 in the electronic version of the paper on http://www.ufn.ru) and comprises many zero points and lines, separatrix and singular surfaces on which current sheets are produced and the magnetic reconnection occurs. The latter provides a redistribution of magnetic fields between interacting magnetic fluxes.

Rather many mechanisms have been proposed for describing instabilities and the destruction of current sheets that cause rapid release of stored magnetic energy [21]. The energy accumulation in a sheet occurs with an increase of current that heats up plasma and leads to the production of nonthermal particles. Using equations of anisotropic (collisionless) MHD [30] made it possible to establish that a fairly small admixture of hot ions with positive temperature anisotropy ($A = T_{\perp,\mathrm{h}}/T_{\parallel,\mathrm{h}} - 1 \approx 0.5$), corresponding to real conditions in a current sheet, is capable of initiating the passage to the fast reconnection regime (the increment $\gamma L/V_{A,\mathrm{i}} \geqslant 0.1$). When the number density of these particles (ions) reaches some threshold value (for typical conditions in the corona it is about 0.02 of the background particle number density), an anisotropic instability develops in the sheet (the analog to the Weibel instability for Alfvén type perturbations), initiating the fast reconnection regime with the characteristic Alfvén velocities. Therefore, due to this instability current sheets are 'doomed' to be destroyed when the current increases and critical conditions are reached.

Superimposing hard X-ray and hard UV images simultaneously obtained by the TRACE and RHESSI space missions allowed localization of the flaring energy release and proved that it is related to the current sheet and magnetic reconnections inside it [31] (see movie No. 5 in the electronic version of the paper on http://www.ufn.ru).

6. Mass ejections

Emerging twisted magnetic loops are injected from the corona into the interplanetary space in the form of so-called coronal mass ejections [32, 33]. These are the largest-scale and most powerful solar activity phenomena (Fig. 4) (see also movie No. 6 in the electronic version of the paper on http://www.ufn.ru). Many observations show [32] that the slow evolution of magnetic configurations (loops, arches) in the Sun is followed by the loss of equilibrium and in most cases mass ejections represent twisted magnetic loops. Twisting of

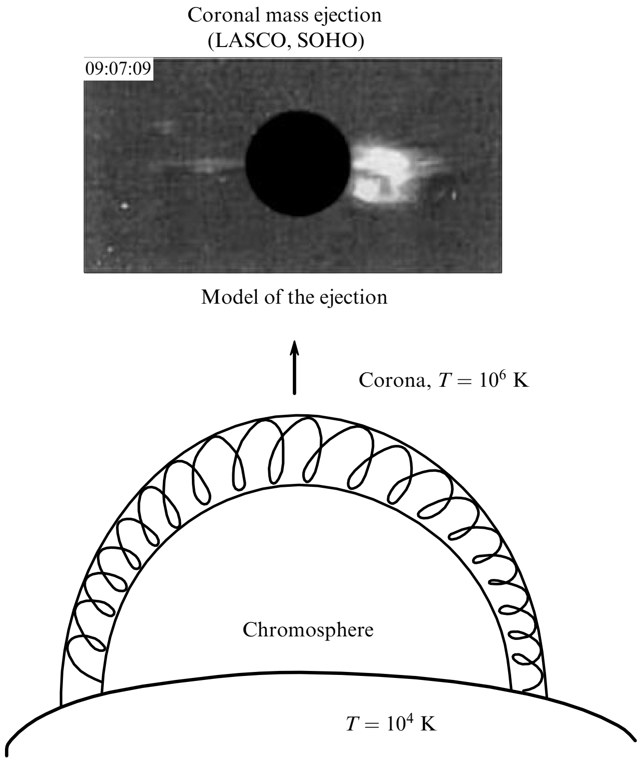

Figure 4. A coronal mass ejection in the form of a twisted loop.

the loops is observed both in the Sun during the eruption itself in the corona, as evidenced by observations made with the Yohkoh and TRACE spacecrafts [34] (see movie No. 7 in the electronic version of the paper on http://www.ufn.ru), and in the interplanetary space, as measured by other space missions. The loop strongly expands by preserving its connection to the Sun [35].

The eruptive instability of emerging twisted magnetic loops can be understood in terms of quasistationary MHD evolution [36] which proceeds in its development through a sequence of equilibrium states of an emerging twisted magnetic tube in the solar atmosphere. On the other hand, the disturbance of equilibrium and setting in of the dynamical phase (i.e., the necessity of taking into account the velocity terms in MHD equations) is related to the absence of (quasistationary) solutions for some conditions (at some critical altitude in the solar atmosphere in this case).

Using the Gold and Hoyle type twisted magnetic field for the model [37] and modifying it by the gas pressure inside the tube, and also assuming tube equilibrium with the ambient plasma (the equality of total pressures at the boundary), as well as the conservation of mass and longitudinal magnetic flux in the tube, it is possible to establish [37, 38] that the growth of twistedness of a magnetic field in the tube, as it slowly rises and expands (in the solar atmosphere with pressure decreasing with height), at a certain altitude reaches some critical value corresponding to the onset of developing kink instability. This instability leads to energy dissipation from the twisted magnetic field component and the heating of plasma in the tube. In the framework of quasistationary approximation, the phenomenological account for such heating in the flux tube equation, which represents a unique and monotonic dependence of the tube's equilibrium radius on the altitude in the solar atmosphere, reduces to introducing a temperature dependence in the rising flux tube on its

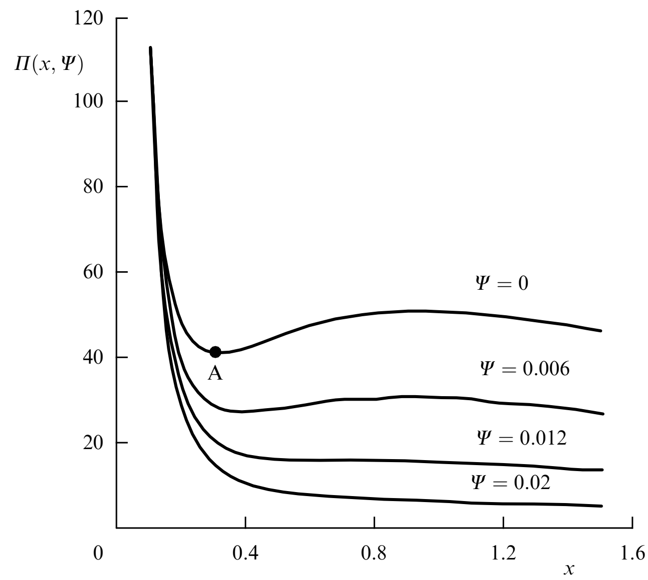

Figure 5. The total pressure $\Pi(x)$ in the flux tube as a function of the dimensionless radius [or the altitude h in the solar atmosphere, $x = x(h)$] for different values of the dimensional parameter Ψ characterizing the ratio of the mass outflow velocity to the flux tube rise speed. The point A corresponds to loss in tube equilibrium.

radius (or the altitude in the solar atmosphere, which is equivalent). This changes the tube equation itself and leads to the appearance of a point A in the 'tube radius – altitude' dependence (Fig. 5), at which the monotonic (quasistationary) solution disappears, and, hence, small changes in the tube altitude in the solar atmosphere should correspond to finite changes in its radius, which is only possible for finite velocities, i.e., the solution is no longer quasistationary. This signals the occurrence of the dynamical phase — rapid flux tube expansion. The density in the tube also rapidly decreases, and due to the emerging impulse buoyancy force the tube is abruptly pushed upwards into more rarefied layers of the corona. The tube occupies there a new quasistationary equilibrium state and is perceived as a mass excess, which is the actual mass ejection observed.

The physical meaning of the appearance of point A in the curve shown in Fig. 5 is related to the increase in magnetic tube twistedness and the associated energy dissipation, heating, and pressure in the tube as it rises and expands sideways, while the pressure in the solar atmosphere decreases with altitude, which leads (in the framework of quasistationary MHD evolution) to the 'nonequilibrium point', analogous to the theory of catastrophes.

In the place of an ejected loop, a rarefaction emerges, which appears as a darkening because the plasma mass and emission measure decrease. These darkenings have been observed many times by the solar X-ray telescope on board the CORONAS-F satellite, for example, during a period of very powerful events in October 2003 [1, 3] (see movie No. 8 in the electronic version of the paper on http://www.ufn.ru).

If a loop rises slowly, the mass outflow through its ends should be taken into account. This results in the total pressure decreasing in the tube, which can suppress the eruptive instability under certain conditions.

The mass loss with constant outflow velocity is proportional to the mass itself, so an exponential term appears in the equation for the pressure in the tube. Numerical solutions of the transcendental equation for different values of the dimensionless parameter Ψ involved that characterizes the ratio of the mass outflow velocity to the tube rise velocity are shown in Fig. 5. When the dimensionless parameter Ψ exceeds some critical value (0.012 in this case), the nonequilibrium point A disappears. The inflexion point of the curve is critical, where both the first and second derivatives vanish. At this point, the radius of the tube increases 2.6 times with respect to its value at the beginning of outflow, the tube loses most of its mass, and the minimal ejection mass is 0.28 times the initial mass of the tube. The model-based injection altitudes of the flux tube and all its parameters at the moment of injection (the total mass, the magnetic flux) correspond well to observed values.

Thus, in this model the mass ejection and the setting in of eruption instability are related to each other: flux tubes losing a lot of mass (during a slow rise) are stable against the eruptive instability, while those losing little mass (during a rapid rise), in contrast, are subject to the eruptive instability that effects the mass ejection. As noted in Section 4, the elevating velocity of buoyant magnetic fluxes is directly proportional to the magnetic field strength that ultimately determines the development of events.

7. Heliopause

The solar wind, disturbances, and mass ejections extend over the heliosphere, interact with planetary magnetospheres, and ultimately reach the heliospheric boundary — the heliopause that results from the interaction of the solar wind with the interstellar medium at around 100 AU from the Sun. Two shock waves are generated on each side of the heliopause. One of them retards the incoming flow of supersonic interstellar gas, the other retards the solar wind supersonic flow. After crossing these shocks, the colliding media form the heliopause separating the solar wind and the interstellar medium.

The Voyager-1 and Voyager-2 spacecrafts, which were launched in 1977 and are now investigating the outer heliosphere, have already approached its putative boundary. The first measurement data obtained from Voyager-1 that crossed the internal shock showed the presence of a spatial anisotropy of particles, a jump in the magnetic field strength and other features in the medium parameters [39]. Additional information is expected to come soon when Voyager-2 will cross the heliospheric boundary.

The state of the heliopause as a tangential MHD discontinuity is determined by its stability or instability with respect to disturbances in the medium that forms it. The exchange between the heliosphere and the bounding interstellar medium, in particular, the penetration of interstellar hydrogen into the heliosphere and the formation of chemical composition of the heliosphere, also depends on this state. This problem is actively discussed in the literature [41].

We studied the dependence of the heliopause stability on the characteristics of the forming medium by modeling the heliopause as a plane tangential discontinuity separating the magnetized interstellar plasma and nonmagnetized solar wind plasma in the anisotropic MHD approximation [42]. Figure 6 depicts the model-produced dependence of the threshold Mach number at which the modified (by 'hose' anisotropic instability) Kelvin – Helmholtz instability of the heliopause occurs as a function of the plasma temperature anisotropy $D = 1 - T_{\parallel}/T_{\perp}$. Such an anisotropy can be tied up with nearby shocks. The critical Mach number in the

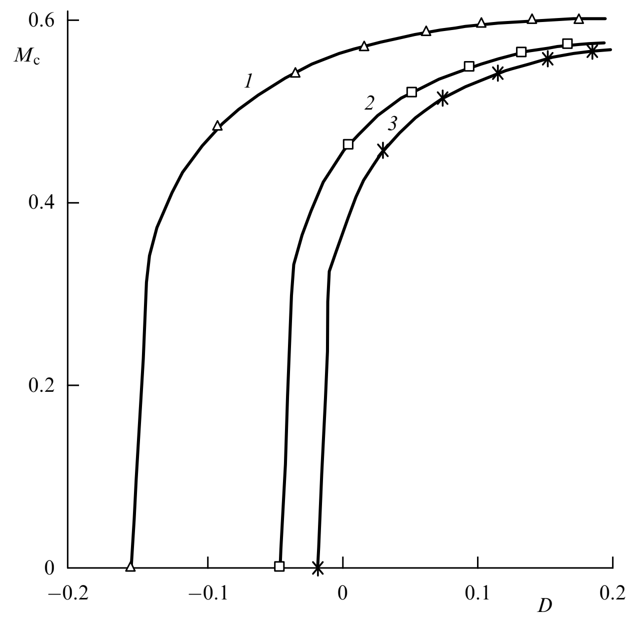

Figure 6. The critical Mach number (M_c) corresponding to the Kelvin – Helmholtz instability threshold as a function of the temperature anisotropy degree D. Curve *1* corresponds to $\beta = 0.05$, *2* — 0.03, and *3* — 0.02; β is the kinetic-to-magnetic pressure ratio. Regions above the curves are unstable.

isotropic case is $M = 0.45$. It is seen that in the anisotropic case the instability is possible at smaller Mach numbers, and the dependence itself of the threshold Mach number on the degree of anisotropy is very sharp in character. The zero critical Mach numbers correspond to purely anisotropic 'hose' instability that sets in at small anisotropies (5 – 15%). Thus, the heliopause is characterized by a high instability with respect to parameters of the medium that forms it and so can reside in a diffusive turbulent state. This should be born in mind when interpreting measurements to be carried out by the Voyager-1 and Voyager-2 spacecrafts.

8. Future heliophysical space projects

Getting new heliophysical data capable of stimulating the development of new models and providing better understanding of physical processes occurring in the Sun and in the heliosphere is related to future space missions that are being developed and prepared by space agencies in different countries.

Modern heliophysical space studies focus on obtaining images with high spatial resolution [as in the NASA projects TRACE, SDO (Solar Dynamic Observatory)], performing local measurements in several spatially separated points (the NASA project SENTILIES) and near the Sun (the NASA project 'Solar Probe', the RAS and Roskosmos project 'Interheliozond'), and carrying out stereo observations of the Sun [the NASA project STEREO (Solar Terrestrial Relations Observatory)]. Numerical simulation of the heliophysical processes using data obtained from space observatories should also play a significant role.

Within the framework of the Federal Space Program, IZMIRAN together with the Space Research Institute (IKI), RAS are working on the heliophysical project 'Interheliozond' [43, 44], which envisages performing new original observations that become possible due to the proposed heliocentric orbit of the spacecraft. The spacecraft will start from the Earth and after a large series of gravitational maneuvers near Venus will approach the Sun by a distance of up to 30 solar radii. The gravitational maneuvering near Venus also makes it possible to incline the spacecraft orbit to the ecliptical plane.

Such a heliocentric orbit, where the spacecraft having approached the Sun will go out of the ecliptical plane and take different positions relative to the Sun – Earth line, allows:

• observing small scales in the Sun, which is a prerequisite to studying the fine structure and dynamics of the solar atmosphere — the magnetic network, magnetic elements, turbulence — as well as to investigating supergranulation and magnetic loops in microflares and reconnection;

• carrying out observations of the Sun and local measurements in the regime of spacecraft corotation with solar rotation, which is important when studying spatial and temporal links between local characteristics of the solar wind, energetic particles and magnetic fields in the heliosphere and their sources in the Sun and coronal structures;

• performing local measurements near the Sun, which are necessary for investigating mechanisms of the solar corona heating and solar wind acceleration, the nature of turbulence and particle acceleration;

• executing out-of-ecliptical observations of the Sun and its poles, the ecliptical corona and the coronal streamer belt, and the heliolongitudinal extent of mass ejections;

• realizing stereoscopic observations of the Sun in cooperation with ground-based and circumterrestrial observations.

9. Conclusion

Modern heliophysics is a very broad and deep science with many researchers involved in its advancement. The present communication reports on the results obtained by the author in this field and does not pretend to be a comprehensive review of modern heliophysics. Recently, a lot of interest in heliophysics has been related to its applications, so-called space weather — effects of solar activity on the Earth and various aspects of human activities on the Earth and in space. It is important that the results of fundamental research ultimately underlay space weather forecasting, and the task of heliophysicists is to extend this knowledge on the basis of observations, theory, and modeling.

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Problems of solar activity physics

V V Zaitsev, A V Stepanov

1. Introduction

The energy emitted by the Sun ('the solar luminosity', 3.86×10^{26} W) determines almost all processes on the Earth. Although the solar bolometric luminosity is 3 – 4 orders of magnitude higher than the power of flares and solar ejections of matter, it is these phenomena that have a significant impact on the situation in the circumterrestrial space, ionosphere, and the terrestrial atmosphere. Solar flares are accompanied by plasma heating, charged particle acceleration, eruptive phenomena and electromagnetic energy generation in a wide wavelength range from the gamma-rays to radio band, and most completely reflect the concept of a solar activity.

In 2007, under the auspices of the United Nations Organization, the scientific program International Heliophysical Year (IHY) will begin. This program, like the program International Geophysical Year executed 50 years ago, should join efforts of solar researchers and geophysicists from around the world to formulate and solve important problems concerning the origin of solar activity, the prognosis of active solar phenomena, and their impact on the Earth.

In this report we discuss actual problems of the physics of solar flares, which include mechanisms of flaring energy release; mechanisms of charged particle acceleration and features of their propagation, and the problem of flaring plasma diagnostics. Prospects for solving these problems are illustrated by the example of coronal magnetic arches — fundamental structures in the solar atmosphere and in flare stars.

2. The origin of a flare. Equivalent electric circuit

Most likely, there is no universal mechanism for describing different features of solar flares (C de Jager: "*Flares are different*"). More than ten models and their modifications are being discussed in the current literature. A developed solar flare possesses a complex magnetic configuration consisting of a set of arches (loops) with a characteristic size of $10^9 - 10^{10}$ cm. Such a structure is also observed in late-type stars. The most popular current models comprise the model of interacting magnetic loops [1, 2]; flares in the coronal streamer [3]; the model with outgoing magnetic flux [4]; 'statistical' flares [5], and models of single flare loops [6, 7]. These models, as a rule, invoke the mechanism of 'reconnection' of magnetic field lines, studied by Syrovatskii [8] and Somov [9].

The 'electric circuit' model proposed by Alfvén and Carlqvist [10] is based on measurements made by Severnyi (see Ref. [11]), who discovered electric currents $I \geqslant 10^{11}$ A in the vicinity of solar spots, and on the analogy to a circuit with mercury rectifier capable of producing a sharp transition from a high-conductivity state to that with a great resistance. At the instant of breaking the current in the circuit, an explosive energy release occurs. It is crucial to understand the mechanisms of the current 'breaking'. By developing the model [10], we accounted for the following: (1) a flare is principally a nonstationary process, so that the stationary Ohm law $\mathbf{j} = \sigma \mathbf{E}$ is inapplicable for describing the flare, and (2) the neutral plasma component plays a decisive role in the electric current energy dissipation.

2.1 The model of a single loop flare with current

Data from optical, X-ray (SMM, Yohkoh, TRACE, RHESSI, CORONAS-F) and radio observations (VLA, NoRH, SSRT) indicate that quite frequently solar flares are registered as occurring in isolated arches (single loop flares)