STUDIES ON SOLAR PHYSICS IN SHAMAKHY ASTROPHYSICAL OBSERVATORY WITHIN THE PERIOD 1959-2019

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I. Physics of Solar Oscillations

The quasi-periodic motion of plasma is the most important class of dynamic phenomena observed in stars and in the Sun. Oscillations and waves are visible almost in the entire range of electromagnetic radiation in modern observations. These motions conventionally might be divided into local, atmospheric, and global eigen oscillations of the star. Experimental and theoretical researches of these phenomena are complementing each other, and allow using them mainly for the diagnosis of the solar plasma. The series of works in this direction were carried out jointly with colleges from Russia and Germany and significant scientific results are obtained.

Theory of the propagation and transformation of adiabatic and non-adiabatic magneto-acoustic-gravity (MAG) waves in a strongly inhomogeneous plasma, with consideration of gravity force and magnetic field, is developed. Obtined analytical solutions of magnetohydrodynamic (MHD) equations, expressed through generalized Meyer hypergeometric functions, allowed to be constructed the complete theory of transformation due to the inhomogeneity of plasma and magnetic field of some types of waves into other types. Respective energy coefficients of wave transformation and reflection are calculated. It is shown that resonance layers (cusp and Alfven) occur in regions with the almost horizontal magnetic field, in which part of the energy flux of waves falling on them, is captured. Applying to the solar conditions reflection and absorption of atmospheric waves during their propagation from deep layers of the photosphere, where waves are practically adiabatic, to upper layers, where they transform to isothermal waves had been analyzed. Formulas for the energy absorption coefficients of adiabatic waves in resonance layers are derived and their dependence on wave frequency and plasma parameters had been investigated. The interpretation of occurrence of propagating waves in the penumbra of sunspots is given [1, 2].

Wave interaction with radiation in the inhomogeneous medium is investigated in a series of works [3,4,1]. Small amplitude non-adiabatic hydrodynamic perturbations of arbitrary optical thickness in the inhomogeneous emitting compressible medium with stratified heat exchange is analyzed with consideration of radiation losses. The equation describing the oscillations of fluctuation of radiation intensity is derived. Analytical solution for the isothermal atmosphere in Milne-Eddington approximation for energy loss function was found for the first time. The general theory of propagation and radiative damping of non-adiabatic atmospheric (acoustic and gravitational) waves are developed based on obtained analytical solution. The developed model of non-adiabatic oscillations with taking into account the interaction of heat and acoustic modes and their transformation allowed us to explain the observed maximum in the distribution of fluctuations in integral solar emission flux at the frequency of $\nu = 3.3$ MHz (5-min oscillations). Relative values of the amplitude of the flux fluctuations on this frequency turned out about $\approx 10^{-5}$, which accords to observed data of different experiments. It is shown, that acoustic waves become strongly-non-adiabatic and occurs mixing of oscillation modes on the photosphere level, where the propagation velocities of heat and acoustic waves become comparable. As a result, it becomes possible to observe simultaneously acoustic and heat waves at the same frequency. Comparison of contributions of acoustic and heat waves as well as to fluctuations of integral radiation flux as to motion velocity is carried out.

It is found that oscillations observed in the continuous solar spectrum are predominantly heat waves, and acoustic-waves make greater contribution to motion velocity, as evidenced by Doppler measurements. The theoretical spectrum of phase shift between fluctuations of integral emission flux (brightness) and vertical velocity of motion (I-V spectrum) for radial solar oscillations is calculated. Comparison of the results with observational data shows good accordance in oscillation frequencies range ν=2.4-3.6 MHz. Because of the contribution of heat oscillations dominates in the fluctuations of integrated radiation flux, and the contribution of acoustic oscillations dominates in motion velocity, it is alleging that the obtained phase shift is the phase difference between heat and non-adiabatic acoustic waves.

With consideration of radiative losses, a complete theory of linear transformation, also the reflection and absorption of various types of non-adiabatic magneto-acoustic-gravitational (MAG) waves in the stratified atmosphere is developed. Impact of magnetic field oblique on wave damping is studied. It is found that with increasing of the field oblique, radiative absorption of MAG waves sharply increases. Amplitude ratio and phase shift between oscillation of motion velocity and fluctuation of temperature of plasma on the photosphere of sunspot are calculated. It was determined that near the edge of the spot, the phase shift increases sharply. It is shown that the most favorable region for observation of oscillations in Doppler shifts is umbra the spot, and in intensity of radiation is the penumbra. Furthermore, velocity and intensity are separating in phase for any given frequency of observed oscillations. Based on analysis it is shown that 3-min oscillations should be visible better in brightness oscillation in the penumbra of spots, where the magnetic field is strongly oblique [3,4,1].

The problem of the instability of small amplitude perturbations of magneto-hydrodynamic type, in optically thin ideally conducting plasma, with the cosmic abundance of elements is solved in the linear approximation. Electron heat conductivity along the magnetic field and proton heat conductivity across the field is taken into account. It is shown that entropy wave amplitude may exponentially increased, whereas magneto-sonic waves damp in a wide range of physical conditions, maximum approximated to conditions in the corona of stars and the Sun, with a relevant consideration of radiative losses. Slow magneto-sonic waves especially damp fastly. Calculated slow-wave damping coefficient for solar corona, accords well with the averaged damping coefficient in 11 quasiperiodic events observed from satellite "TRACE" in hard ultraviolet radiation [5].

In the series of works [6] to describe of nearly collisionless anisotropic plasmas of the solar corona and solar wind, the 16-moment anisotropic MHD transfer equations (integral relations of the Boltzmann–Vlasov kinetic equation) including the heat flux along the magnetic field, are applied. Waves and plasma instabilities with anisotropic pressure along and across the magnetic field are analyzed in the frame of this approximation, also is studied the effects related to heat flux. Along with classical incompressible firehose modes that do not change with consideration of heat flux, new additional compressible modes (heat waves), and analogs of fast and slow MHD waves, are found and studied. It is shown that the criterion of mirror instability coincides with the relevant condition of occurrence of mirror instability under kinetic consideration. It is established that in the presence of heat flux, the phase velocities of all detected modes are asymmetric relative to the direction of the external magnetic field, i.e. waves propagate with various velocities along and against the magnetic field. Modes coupling occurs under some values of plasma parameters. Strong coupling occurs between reverse modes (which propagating against the direction of the magnetic field). Instability occurs in the modes interaction region, where phase velocities of the waves coincide. Both types of instabilities are possible - aperiodic and oscillatory. Under conditions of occurrence of classical firehose instability, a new type of instability occurs under resonant interaction of three inverse modes (fast thermal, mirror-thermal and slow thermal).

This instability has a maximum increment under oblique propagation and exceeds the maximum increment of classical firehose instability. Detected instability is due to compressible plasma perturbations in contrast to classical firehose instability. Density perturbations are calculated in detected modes. Obtained solutions of anisotropic MHD are in close fit with the low-frequency limit of kinetic description, which gives reason to count that the considered approximation of anisotropic MHD is correct for describe the large-scale dynamic of collisionless anisotropic plasma of heliosphere (solar corona and solar wind, ionospheric-magnetospheric plasma).

MHD instabilities of temperature-anisotropic coronal plasma are considered based on the developed theory. It is shown that under conditions of the solar corona for weak magnetic fields ($B < 1$ G) can develop aperiodic mirror instabilities of slow MHD waves, and for strong magnetic fields ($B > 10$ G) may arise oscillatory ion-acoustic instabilities. Increments of growth of instabilities are found, and time and spatial scales of development and decay of oscillatory instability estimated. It is shown that instabilities under consideration can play a notable role in the energy balance of corona and could be considered as a large-scale energy source of wave mechanism of coronal heating [6].

Supersonic flows of two semi-infinite anisotropic and homogeneous plasma layers with different physical parameters and velocities were considered. For the general case, i.e., when the interface between these two flows is a transition layer with a finite thickness, the general linear differential equation framework for determining the eigenmodes in the system is derived. Furthermore, thoroughly the limiting case of a zero thickness transition zone (contact discontinuity) is considered. It is shown that the shear flow excites the Kelvin-Helmholtz (KH) type of instability and “couples” the various branches of the free-plasma oscillations to each other. It is found that the region of mode interaction is determined by the resonance regions when the longitudinal phase velocities of the waves match. In the resonance flows with an average speed, the KH instability occurs. The growth rates of the KH instability are calculated as a function of the parameters, including the degree of plasma anisotropy. The obtained results are applied to the plasma conditions in the bimodal solar wind in the vicinity of the contact discontinuity between different flow patterns (fast and slow wind) [6].

Using the 16-moment equations that take into account heat fluxes in anisotropic collisionless bi-Maxwellian plasma, the properties of magnetohydrodynamic (MHD) instabilities are investigated. For all instabilities occurring in the MHD approach (the usual incompressible firehose instability, the second type of compressible almost longitudinal firehose instability, and the almost transverse mirror instability of slow magnetosonic modes, as well as thermal instability caused by the heat flux directed along the magnetic field), their kinetic analogs are considered. Also the general MHD dispersion equation taking into account two components of plasma (electrons and protons) and heat fluxes along the magnetic field is obtained. The thresholds and instability growth rates obtained in the MHD and kinetic approaches are found in good agreement. The results prove that, in contrast to the familiar CGL (Chew–Goldberger–Low) approximate model, the anisotropic MHD approach provides a correct description of the large-scale dynamics of collisionless anisotropic plasmas, such as solar corona, solar wind, and ionospheric and magnetospheric plasmas.

Model equations of solar wind are obtained in anisotropic plasma conditions.
These equations are describing stationary flows along the magnetic field in the radial direction from the Sun on the equatorial plane. These equations obtained on the base of the 16-moment MHD transport equation with consideration of plasma anisotropy and heat flow along the magnetic field. The obtained system of nonlinear equations is a generalization of the Parker model for isotropic solar wind in the case of anisotropic wind. The number of special analytical solutions of equations were found, also asymptotic solutions and solutions near the transition

point of flow from the subsonic regime to the supersonic regime are obtained, and boundary conditions for numerical solutions determined. The main goal is explaining of observational facts that could not be described by isotropic Parker model.

The theory of magnetic convection in stars and on the sun is developed. The standard model of the convective zone does not take into account the presence of a magnetic field. The convection model is building up with consideration of the magnetic field, rotation, and large-scale flow with gradient. Criteria of occurrence of shear instability, baroclinic instability, magneto-rotational, and other type of instabilities in tachocline with the strong magnetic field are investigated.

It is tasked in work [7] on finding the cause of rotation slowing-down of internal layers of the Sun. Accepting that angular momentum of rotation is carried out from central regions by waves, then what kind of these waves should be, and how should they manifest itself in other large-scale dynamic phenomena on the Sun? Qualitative analysis of the conservation equation of potential vortex in the rotating sphere is carried out. There is principled possibility of occurrence of a new type of resonant modes, which significantly differ from well-known inertial rotational modes in the theory of stars pulsation with consideration of differential rotation in latitudes. It is concluded that these new modes could be detected only in case, when they become unstable or when the impact of curvature might be neglected. It is shown that rotational modes can become unstable due to heat mechanisms of instability. For the beginning the low-frequency wave motions within the framework of planar geometry are considered, when the impact of curvature of the spherical surface is excluding by using "β-plane" approximation from geophysics. Possibility of the capturing of very low-frequency vortex waves in the near-nuclear space of the Sun is analysed. It is shown that retrograde waves with frequencies that significantly lower than the angular frequency of rotation might be captured in the radiative zone of the Sun. Eigenfunctions of compressible non-adiabatic vortex modes of Rossby type are found by using analytical methods for the case of small latitudinal gradients of the angular velocity of rotation. Nonadiabaticity of wave motions is providing by consideration of the energy input from nuclear burning and radiative transfer in diffuse regime (ε-mechanism). A complex integral dispersion equation, which is the solution of the boundary-value problem is obtained.

Determined resonant modes (named R-modes) fundamentally differ from r-modes, which are well known in the theory of pulsations of stars. Frequencies of R-modes, in contrast to r-modes, are functions of the internal structure, and their origin is not due to geometric effects. The instability of the R-modes relative to the ε mechanism is investigated.

Most unstable are oscillations with periods of ≈ 1-3 years, 18–30 years, and 1500–20000 years. These three highlighted ranges of periods are well known from solar and geophysical experimental data. Characteristic times of amplitude increase of indicated most unstable modes correspond to ≈ 10^2, 10^3, and 10^5 years, respectively. The amplitude of the R-mode is increasing toward the center of the Sun. The possible role of detected low-frequency vortex modes in dynamics of magnetic fields, in the observed fluctuations of solar rotational velocity, also in long-period climate changes on Earth, is discussed. .

The impact of surface curvature on the properties of rotational oscillations is investigated. The general differential equation of second order in partial derivative describing the adiabatic nonradial long-period oscillations of the differential-rotational spherical star is obtained for pressure fluctuations. This equation includes high-order gravitational **g**-modes, all possible subclasses of rotational modes, also their interaction and instability. Such an equation derived for the first time and enables analyzing the special structures of the solution, which related to the spherical geometry of the problem and the presence of rotation. Widely used in geophysics, the "traditional" approximation, which assumes nearly horizontal motion, significantly simplifies the obtained equation and splits it into two ordinary second-order differential equations. More accurate condition of usability of “traditional” approximation under conditions of star pulsations, in the low-frequency range, is obtained. The possibility of the occurrence of critical latitudes is shown, around which, the resonant layer is formed. In these layers occurs resonant interaction of eigenmodes with inertial oscillations at frequency $\omega = 2\ \Omega \cos\theta$ (here Ω - the angular frequency of rotation of the star, θ - the latitudinal angle from pole). Transformation of global rotational modes into inertial ones, which are concentrating in narrow latitudinal zones, is considered as a new mechanism of resonant absorption of modes. This mechanism can play a significant role in the redistribution of angular momentum of rotation. The obtained equation is a generalized Laplace's equation in case of differential rotation. The condition of the occurrence of global instability is found from a qualitative analysis of this equation. This instability is related to the latitudinal gradient of rotation velocity of star and, in contrast to ordinary Kelvin-Helmholtz instability, is not smoothed by gravity. The appearance of global shear instability depends on the Rossby number (ratio of the rotational period to oscillation period), azimuthal wave number and rotation gradient. It is shown that the rotation gradient has a lower limit, below which the instability disappears. Primarily, those modes whose frequencies are close to inertial frequency should become unstable. The obtained results on shear instability are applied to real helioseismological data on the rotation profile of the Sun. It is shown that global $m = 1$ modes might become unstable almost at all latitudes. In the radial direction, the region of instability becomes the upper part of the tachocline (a region with a strong radial gradient of rotation velocity, which located on the base of the convective zone), the convective zone, and the photosphere of the Sun. The exact solution of the Laplace equation in case of low frequencies is expressing by Jacobi polynomials. Standard representation of eigenfunctions of modes in form of series on functions of spherical harmonics, which have significant difficulties with convergence on low frequencies, does not follow from the obtained accurate solutions. It is shown that interaction of low-frequency modes with rotation, is describing better by the Jacobi functions, which are higher-order polynomials than the Legendre functions.

It is established that in low-frequency limit (when Rossby number is small and the effects of shear instability might be neglected), only retrograde oscillations become eigenmodes. These modes are separating into two subclasses: fast and slow. In the azimuthal plane, the group velocity of fast modes is directed against rotation, and slow modes are transferred energy on the direction of rotation. It is shown that “active” narrow bands of latitudes in which is concentrating the basic wave energy occur on the spherical surface. These bands are located closer to the equator for slow modes, but closer to the pole for fast modes. Location and width of these bands of latitudes depend on permitted values of horizontal wavenumbers (l, m) (amount of nodal points in meridional and azimuthal planes). All possible pairs of (l, m) for both slow and fast modes, are found for 22-year solar oscillations. It is shown that for the scales of the oscillation modes similar to spatial scales of sunspots, active latitudes for 22-year slow modes occurs at latitudes of 30–40 degrees. Discussion took place on possible connections of detected modes in the generation of magnetic solar cyclicity [7, 1].

In the work [8] it is shown that if turbulent motions, which are ~~is~~ observed in coronal lines arise due to Alfven waves, then in contours of the majority of coronal lines in the center of the disk would be a central dip, which is not observed. This suggests that corona is unlikely heating by direct dissipation of Alfven oscillations. Basing on more accurate calculation of the resonant absorption of Alfven waves in structures of corona, it was shown that this mechanism could not be the major one in corona heating. The method is proposed for the determination of values of temperature and non-thermal velocities in coronal loops on the ratio of line intensities l5303 Å and l6374 Å. Calculation of contours of coronal spectral lines, with consideration of motions on torsional oscillations, is carried out. It is found that calculated contours are single-vertex and sufficiently approximated by Doppler profiles. Since observed coronal lines have a Doppler form, it is concluded that coronal lines were expanded by motions on torsion waves. Based on this, it concluded that in the heating of corona, the role of torsion waves is significant. Besides, it is concluded that the Moreton wave might propagate to photosphere heights based on the analysis of observed data in the Hα line.

II. Study of dynamic phenomena in the atmosphere of the Sun

Observations of solar dynamic phenomena in the ShAO were started since the installation of first solar telescopes (AFR-2, AFR-3). These observations were carried out within the frame of "Sun Service" programs, at first. Later, several interesting experiments were carried out and the next main scientific results were obtained.

New method for observing the region of the surface of the Sun (active region, spicule, etc) is developed and applied, which allowed to obtain the image in cuts with the preservation of the contour of the spectral line. The obtained data under this method of observation contains much more scientific information than under ordinary spectral and filter observations. Spectral "mask" for the Ha line, is developed and applied in observations, which is flattening intensity inside this line; observations by using this mask gives more accurate images than under ordinary spectral observations. A new camera is constructed and applied in observations, and a new method of observation of active regions of the Sun developed. The large eight-camera spectrograph is designed for the horizontal solar telescope of the ShAO.

This multichannel spectrograph differs from other existing multichannel spectrographs in that each camera of this spectrograph has an individual gate, which allow to obtain spectrograms of the standard density in all channels simultaneously, which is impossible under observations on conventional multichannel spectrographs [9, 10].

Various determination methods of optical thickness of flares and other solar formations at frequencies of considered spectral lines, with consideration of absorption of photospheric emission in layers of chromospheric flare, are developed. The proposed simple method determines the maximum possible value of the optical thickness of flares in the lines of the Balmer series of hydrogen. A new determination method of optical thickness in the H and K CaII lines on the ratio of their equivalent widths and a multilayer flare is proposed.

It is shown that calculational contours of lines in the flares spectrum by using the found values according to proposed methods, consistent well with the observed ones. It is found that contrary to previous determinations of other authors, the optical thickness of flares in the Hb line is $\tau_{H\beta} < 1$ [9]. Equations of stationarity for hydrogen and calcium are drawn up, and results of solutions depending on values of various physical parameters, are tabulated. These tables allow us to determine both values of physical quantities (by using observed values of atomic populations), and effective geometric thicknesses of active formations. It is determined, that effective geometric thickness of flares is 10-100 times less than visible geometric thickness. It was obtained that due to emission of Lb quanta via distant wings, survival coefficient of H_α-quanta becomes less than the unit, and this significantly affects theoretical calculational contour. A close relation of brightness variations of neighboring calcic flocculi with flares is found.

It is shown that the filamentary structure of solar active formations decreases optical thickness compared to the uniform distribution of emitting plasma. It is managed for the first time to observe wave-like motions on the unperturbed surface of the Sun with lifetime from two to several tens of minutes and wave motion velocities up to 30 km/s, by using the spectral mask for the H_α, line.

Several studies on the physics of solar spicules are carried out [9]. Radial velocities of the spicules on the entire height and their variation, with the time, are measured.

The constructed radial velocity curves show that these velocities are due to spicules motion as the whole, and not by plasma motion in the magnetic tube of the spicule, as is generally accepted. Histogram of spicules distribution on radial velocities is built up, which showed the existence of their grouping at velocities up to ± 30 km/s. Corona mass balance is calculated by using obtained observational data, which showed that if the observed radial velocities are due to plasma motion in the magnetic tube, corona mass balance would be disturbed within one hour. This is a serious argument in favor of the condensational theory of the occurrence of spicules. Sudden changes in length, a cross-section of spicules and half- widths of the H_α, line profile, and sudden emergence of some spicules over whole height, are detected from observations. All these facts evidenced in favor of the condensation theory of spicules occurrence. Spatial groupings of spicules on radial velocities are detected. For the first time, both radial and tangential velocities of spicules over whole height are measured simultaneously. Therefore, it is concluded that tangential and radial velocities are components of spicules motion. Theoretical calculation of the process of condensation of coronal gas is carried out, as a result are occurring chromospheric spicules. The presence of the MHD wave in spicules is determined. The idea of corona heating caused by spicules motion is put forward, the presence of such motions proved and their velocities measured. The motion of spicules along the limb is studied, and their tangential velocities are determined [11]. The contour of the H_α line in the spectrum of coronal prominences is obtained by using the developed new observation methodology. Coronal prominences were observed on the disk of Sun. Managed to observe the K CaII line in the spectrum of coronal prominences, which was turned to be in emission [10, 12].

Dynamics of loop-type prominences, also ejections are investigated by filter observations. Average velocities method is developed, which allows the accurate determination of the laws of motion of nodes. Estimates of temperature at trajectories of nodes are given. Estimation of the relation of densities in nodes, and surrounding their medium is made. It is determined that the formation of loop-type prominences and surges are interrelated. Structure of the magnetic field of active region accords to the model of the “magnetic tree” of Piddington. Oscillations in loop-type prominences with a period - 5 min are detected. Rotational motions are detected in surges [13].

It is shown that calcium floccules are not always a direct continuation of photospheric faculae into the chromosphere, although in most cases, they repeat each other in two layers of the solar atmosphere. Based on the analysis of numerous spectrophotometric observed data, also photographic photometry, it is obtained, that the law of changes of the curve of faculae depending on the heliocentric distance, could not be considered as credible without consideration of the selection of observed faculae. It is necessary to divide considered faculae into “strong” and “weak” when constructing a curve of a contrast of the “average” facula. For temperature difference between the groups of “strong” and “weak” torches, are obtained ~ 94° K. The decrease of the difference of turbulent velocities of the “torch-photosphere” in the upper atmosphere, is determined. The value of 88 degrees, is obtained for the slope angle of the torch to normal of the surface of the Sun. The maximum values of the heights of calcium floccules equal to approximately 700-1000 km are determined. The λ4077.71 Sr II line in the spectra of torches, floccules, and flares, is investigated. It is determined, that compared to the contour of the line of the unperturbed photosphere, a small emission (~2%) is observed in the center of the line of the spectra of torches, and its wings are expanded and lowed. Wings of the line are expanded and lowered, in the band of torch emission without calcium flocculus. The contour of the line does not differ from the contour of the unperturbed photosphere in the floccule region, without torch emission. In the center of the line of the flare spectrum, noticeable emission (~10%) is observed, and wings of the line are expanded and lowered, moreover this effect is more significant than in the torch. Various structural peculiarities in torch fields were detected. Torches show a cellular structure like a supergranulation cell. The radius of torch rings, on average ~ 20,000 km. Large scale structures are observed. Deformations of sides of torch cells indicate the existence of dynamic cell interaction [14].

Theoretical researches of dynamic processes occurring in flares and coronal condensations are carried out in a series of works [15]. The applied model of the initial phase of chromospheric flare within the theory of powerful gas-dynamic explosion with consideration of basic processes and volume emitting has led to interesting results, confirmed in observations. It is shown that the development of initial - up to the optical phase of chromospheric flare is accompanied by the emerging and enhancement of heat instability behind the shock front. This instability generates turbulence and causes plasma bifurcation, which in turn leads to the fibrous structure of flares. Mechanism of expansion of emission lines in the spectrum of solar flares with consideration of the existence of a magnetic field, which controls the direction of motion of plasma jets are investigated. Determination method of physical parameters of the flare, their peculiarities of variation, both with time and with depth are improved. Calculations of all possible elementary processes in solar flares, with consideration of complete deviation from local thermodynamic equilibrium and non-stationarity of processes, are carried out. Physical causes of overexcitation of upper energy levels of hydrogen atoms are investigated. Reasons for asymmetry of contours of emission lines, which are observed in the spectrum of flares, both on the disk and limb are found out. Distribution of flares on height in the solar atmosphere, which allowed to explain the observable differences of flares of chromospheric and coronal origin are studied. Calculations on ascertainment of the role of accelerated electron flows, in the mechanisms of flare glow are carried out. Causes of long-term energy-release during flare are studied in the optical region and low-energy protons, and in roentgen. It is shown that the generation of flares and loop-like prominences could be considered as the effect of the shock waves [15, 16].

The Spatio-temporal dependency of the polarity sign of the large-scale solar magnetic field is analyzed. The existence of two activity waves with periods of 17-23 years and 3-5 years is confirmed. It is shown that drift begins from the equatorial zone to the poles. Statistical analysis of a large-scale magnetic field allowed determining the sector structure of the interplanetary magnetic field for the period 1915-1982 [17].

The new version of the polynomial approximation method is developed and applied for processing the brightness field of the unperturbed photosphere, for magnetograms of the active region, also velocity fields in a flare, and for maps of solar radio-sources, to detect the nature of large-scale and small-scale solar fields. It is obtained that on the limb of the solar disk elements in size 3"5 are 1.4 times larger than in the center. It is impossible to talk on the predominant elongation of the granules in any direction. The probability of contrast distribution for bright and dark elements relative to mean, is almost symmetrical, which speaks in favor of the absence of expressed light-dark asymmetry of the brightness field. The topology of the radiation field does not differ from the topology of the cooling field. Contours of small elements are inside large scales contours. Regular change of ridges and troughs of the intensity gradient indicates the existence of wave motions. Flare activity of the vector field of velocities is restoring with a period of about six minutes. Energy releasing in flare occurs as a pulsed mechanism of the surge. It is found that before flare activity, the value of the modulus of the gradient of solar radio-emission intensity has an oscillatory character with 2-day period under displacement of the local source from the east to the west edge. Maximum of the intensity gradient accords to the day of flares then damps monotonously [18].

In work [19], investigations of the fine structure of photospheric absorption lines are carried out. For this purpose number of new methods were proposed: 1) method for determining the local continuous background of the spectrum by Voigt analysis of the profiles of weak Fraunhofer lines. 2) Method for determining the mechanism of broadening of strong Fraunhofer lines in the photosphere of the Sun and stars; 3) quantitative method for measuring and analyzing the fine structure of the profiles of weak Fraunhofer lines. Based on these methods, the most accurate profiles of strong resonant and subordinate ones, i.e. almost resonant Fraunhofer lines H and K CaII; D_1 и D_2 NaI; b_1, b_2 и b_4 of the MgI triplet and the first four lines of the Balmer hydrogen series H_α, H_β, H_γ and H_δ in the resolved and unresolved solar spectrum are obtained. Basic parameters characterizing the line profiles (equivalent widths W, half-widths, quarter-widths, and central residual intensities) are determined with high accuracy. Positions of violet and red emission components of the H and K CaII lines and the distances between them in the resolved and unresolved solar spectrum were clarified. It could be useful in clarifying the empirical formula of the Wilson-Bappu effect.

New method was developed that allows to determine the level of the local continuous background of the solar spectrum on the Voigt analysis of the profiles of weak Fraunhofer lines. The advantage of this method, compared with the method based on the profiles of strong Fraunhofer lines, is that weak lines are in all spectral regions. A new quantitative and physically substantiated method was developed for measuring and analyzing the asymmetry of the profiles of weak and moderate Fraunhofer lines in the spectrum of the Sun and stars. New physical quantities (differential, integral, residual, and relative asymmetries) were introduced, which enables a more detailed investigation of the asymmetry of the profiles of weak and moderate Fraunhofer lines and their dependence on microscopic (atomic) and macroscopic (photospheric) quantities. It is found that the asymmetry of the profiles of weak and average Fraunhofer lines is complex, and within the same line can repeatedly change by magnitude and sign. Growth curves for the resolved and unresolved solar spectrum are built up based on the newest digital spectral materials and the most accurate forces of oscillators of lines in the absolute scale. It is shown that the physical characteristics of the photosphere by the lines of even-odd and odd-even transitions differ significantly. In this sense, the excitation temperature is especially sensitive, which turned out to be significantly higher for odd-even transitions [19].

Objective method for the determination of continuum level in the spectra of stars (Sun) with hydrogen lines is proposed, which consists of the theoretical drawing of the form of the Stark wing of hydrogen lines [20]. It is shown that atmospheric absorption lines that consider "ideal" reference turns out to be not "ideal" but change their position depending on the zenith distance of the observation of the Sun, which should be taken into account when studying line shifts in the spectrum of Sun by introducing respective corrections. The method of observing the spectrum of Sun by using the fact of the imposition of various orders of the spectrum was proposed. The method allows us to expand significantly the wavelength range under the investigations of the Fraunhofer line shifts. Rational scheme for fast calculating of corrections to measured radial velocities due to diurnal and annual rotation of the Earth at the moment of observation was proposed. It was determined more accurate value (± 0.100 km / s) of the dispersion of fluctuations of the horizontal component of the velocity field on the surface of the Sun. Quasi-periodic wave motions in the atmosphere of the Sun, changing from 5.8 min for τ = 1.0 to 6.5 min for τ = 0.005 were investigated by direct spectrometric measurements. The assumption is put forward on quasi-periodicity or cyclicality of the observed phenomena. More accurate curve for the "Edge effect" of Fraunhofer lines in the spectrum of the Sun was obtained. It is found that it is not physical processes are lead to the "edge effect" of Fraunhofer lines, but the erroneous system of wavelengths of the Fraunhofer spectrum, both in the center and at the Solar limb. Redundant wavelengths of lines at the limb are the result of "deficit" of lengths at the center of the solar disk due to the entrance of incorrect "deficit" corrections in the wavelength system in SRRT [20]. It is shown that there is a significant correlation between the “edge effect” and the intensity of torch areas on the solar disk. East-west "asymmetry" of the solar disk both in the shifts and in the central residual intensities of Fraunhofer lines was detected, which should be taken into account when calculating atmospheric models. Based on theoretical calculations of the absorption line contours by small parameter method - gradient of rotation velocity, it is concluded that the east-west asymmetry of Fraunhofer lines is caused by differential rotation of the solar photosphere [16].

The new universal formula was derived for determining the optical depths of formation of Fraunhofer lines in the solar atmosphere (equitable for any formation mechanisms), both by calculation and on the basis of accurate observations (with high spatial resolution) of the line contours at different angular distances from the center of the disk. Formulas for determining the optical depth of formation of the radiant flux from the star (Sun), for approximate estimates of τ are also derived. The elementary method - function approximation method for the numerical solution of the integral equation for the source function, was proposed. Several new recurrence relations, widely used in radiative transfer theory in the atmospheres of stars and planets, were obtained. Catalog of optical depths and the corresponding geometric altitudes of formation of Fe I lines (2600 lines) and TiI, TiII, CrI, MnI lines (150 lines) in the solar atmosphere for the center (μ=1) and for the limb of the disk (μ= 0.05), in the range $\lambda\lambda$3000 — 8000 ÅÅ was compiled [20].

Red shift and asymmetry of Fraunhofer lines in the solar spectrum were investigated in detail. It is shown that Freundlich hypothesis on the red shift of lines in the solar spectrum does not contradict the general relativity theory (GR), but it is a development of general relativity theory with consideration of the current level of development of the quantum nature of light. Based on theoretical calculations it is alleged that Druzhkin's "new hypothesis" on the solar redshift has no real ground. New ratio connecting Newton's gravity constant G with other fundamental constants of physics is obtained. It is shown that the low accuracy of the magnitude of the constant of gravitation, which is found in experimental measurements, is related to the seasonal change of G. It is shown that variations of rotation velocity of the Sun with depth in the photosphere are significantly lower than that previously obtained by other authors. The system of energy levels and wavelengths of 26757 lines of neutral iron at the range $\lambda\lambda$1622 ÷ 9948 ÅÅ was calculated again. Large group of spectral lines were identified and classified both in the laboratory and in the solar spectrum [21].

Methods of scientific photography, filming, and television were used to investigate the fine structure of the solar surface, as well as processes in the terrestrial atmosphere. It is shown that "switching" waves of Landau are possible in the photosphere. Jet flows in the atmosphere of the Sun and the Earth are investigated. The existence of these flows and their stability is caused by the feeding of large "gravitational" and small-scale waves under non-linear resonant interactions. It is shown that feeding of both small waves by large ones and conversely, lead to the stability of large vortexes (waves). Besides, for observation of bright photospheric "tracks", new television system with a high spatial resolution (~ 0."4), as well as its appearance mechanism, was proposed. It is assumed that "tracks" are arised because of the rupture of the lines of force of the magnetic field, and the particles propagate moving with acceleration of ~ ~ 10^6 km/sec^2, which leads to energy release – 10^4 erg [22].

III. Participation of ShAO in international programs on solar physics.

Shamakhy Astrophysical Observatory, while still the Sector of Astrophysics within the Academy of Sciences of the Azerbaijan SSR, year after its establishment, actively participated in the international programs "Sun Service." In parallel with other astronomical institutions of the USSR, ShAO was equipped with a photospheric-chromospheric solar telescope to participate in the IGY program (International Geophysical Year, 1957-1959). The employee of the Main Astronomical Observatory of NAS of the Ukrainian SSR, Professor E.A.Gurtavenko, was invited to ShAO to prepare the telescope for observations. With his participation, the telescope was prepared for observations by the staff of the Department of Solar Physics. Observations within the IGY program began in 1957. The photosphere tube was used for regular photography of the Solar photosphere. Coordinates and areas of the observed spots were determined by the obtained photo-heliograms; the quality of the obtained heliograms was estimated on a 5-point scale. The data obtained by this way was sent to the coordination centers: the KrAO of the Academy of Sciences of the USSR and the bulletin "Solar data" of the PAO AS USSR.

An image of the solar chromosphere was obtained in the chromospheric tube by using interference-polarized Hα filters (IPF). During the time intervals allotted for observations, filming was carried out. The latitudinal and longitudinal coordinates of both ends of the hydrogen fibers were determined by using obtained photographic tapes, as well as the lifetime, coordinates, and brightness (by points) of the observed chromospheric flares. The results were sent to three coordination centers: KrAO AS USSR, GAO AS USSR (bulletin "Solar data"), and to the Kislovodsk Mountain Astronomical Station GAO AS USSR. The first scientific article, based on the materials obtained within the IGY program, was written at ShAO in 1959 [23]. The article is devoted to the microphotometric research of the chromospheric flare. MF-2 microphotometer of the Institute of Physics of the Academy of Sciences of the Azerbaijan SSR was used to carry out this work.

In 1963, the ATsU -5 horizontal solar telescope (HST) was installed on the territory of the Observatory. After putting into operation the HST-ATsU5, special equipment for mounting on this telescope was manufactured in KrAO to carry out visual measurements of the magnetic fields of sunspots. It was installed in ShAO in front of the spectrograph ASP-20.

Further, after the installation of GST-ACU5, employees of the Department of Solar Physics took part in two international programs for observing the magnetic fields of sunspots: a) measuring the maximum intensity of magnetic fields of sunspots; b) rapid changes in the magnetic fields of the Sun. The last program was a composite part of the common international program of the Commonwealth of the Academy of Sciences of the Socialist Countries (the KAPG program). Observations within this program were carried out at four observatories: the Potsdam Observatory of the GDR, the Ondřejov Observatory of Czechoslovakia, Pulkovo Observatory of the USSR, and the Shamakhy Astrophysical Observatory of the Academy of Sciences of the Azerbaijan SSR. Data on magnetic fields on the first program were sent on the same day via a coded telegrams. The next day, prints were sent with photoheliograms and copies of cards for each group of spots with a drawing of all the spots and pores with the drawing of magnetic fields. Materials were sent to the KRAO of the USSR Academy of Sciences.

According to the second program, unlike the first (the coordination center was located in Tashkent), observations were carried out by specified coordinates and numbers of groups of spots, and the start and end times of spot observations were recorded. According to this program, the magnetic fields of selected spots were measured during the day, and graphs of the magnetic field dependence from the time were constructed based on the obtained materials. Determined reports about the results of the observations were sent to the center located in Pulkovo. After several series of such observations, final results were presented in regular conferences held in Pulkovo.

Several scientific articles were published based on these materials jointly with the observatory staff who participated in this program. In 1980, in the year of the Solar Maximum, a new task was received - to observe Hα-flare in the line. The coordinates of the flare region were informed by telegram. This work was carried out at a high level, and obtained materials were thoroughly processed and sent to the coordination center.

During the development of space flights, especially when there was a man on board of spacecraft, interest in active formations on the surface of the Sun increased greatly. At this time, a new program was developed in the Soviet Union, the so-called "Nothern - Sinop" program.

The employees of the Department of Solar Physics of the ShAO took an active part in this program. Special attention was paid to tracing possible changes in flare regions at the center of the Hα lines. According to the objectives of this program, the magnetic fields of the spots were systematically measured, and their coordinates were determined. All data on active formations observed on the solar disk were sent to the coordination center.

In the 1970s, a second photospheric-chromospheric telescope on the north tower of the main building was put into operation at the observatory. Preparation for work and adjustment procedures were carried out by M. Musaev, an employee of the Department of Solar Physics.

Observations on this telescope were carried out within the "Sun Service" program and the obtained heliograms were systematically sent to the Mountain Astronomical Station of the Main Astronomical Observatory of Academy of Sciences of USSR in Kislovodsk. This work continued until the dissolution of the Soviet Union. Several studies on the structure of torch areas were carried out using the heliograms obtained on this telescope. High-quality heliograms allowed to reveal the torch fields of a ring-shaped cellular structure. The measured sizes of these cells corresponded to the sizes of supergranulation cells. A very interesting structure was found - hexagonal dark cell, on which pores (small spots) localized. The sizes of this cell are slightly smaller than the bright cells. Active formations of spots, pores, dark paths, flares arising in torch areas of the cellular structure were traced.

It was concluded that these areas are especially flare-active. Viewing heliograms accumulated over many years and visual observations on the GST made it possible to conclude that, depending on the value of the intensity of the magnetic field that accumulates at the boundary of super-granules, can appear in the form of both bright and dark cells [23].

It should be noted that the results of observations within the "Sun Service" program and their interpretation [15] were included in the catalog of eruptive protuberance published in Czechoslovakia (J. Klechek. Bull. Of the Astr. Inst. Of Chech. 1964. V.15. 2), and were used in calculating the time of reaching the earth's surface of cosmic and proton-emission of the Sun.

REFERENCES

1. Джалилов Н.С., Штауде Ю.//Глобальные колебания Солнца (монография), 2005, Б.: «Элм», IBN 5-8066-1720-3, С. 312.
2. Джалилов Н.С. и др. //В кн.: Проблемы космической электродинамики. М., 1981, 6-11 //Изв. АН Азерб. ССР 1983, №1, 90-98 / Астрон. ж. 1986, т. 63, вып.4, 754-761; 1990, т.67, 561-571/ДАН Азерб.ССР 1987, 43, №8, 44-49 / Циркуляр ШАО АН Азерб.ССР 1988, № 81, 24-30 ; 1991, № 89, 3-13.
3. Джалилов Н.С., Бабаев Э.С. и др. // Препринт ИЗМИРАН 1991, № 14(961), 30 с; 1991, №15(962), 24 с / В: Исслед. по геом., аэрономии и физике Солнца, 1992, вып. 99, 26-48 / Письма в Астрон. ж. 1995, т.21, №1, 59-65 / Изв. РАН, сер. Физическая 1996, т. 60, №8, 171-178 / Труды межд. конф. «Исследования солнечной системы», 14-17 июня 2004 г. ШАО АН Азерб., ISBN: 5 8066 1700 9, 2005, С. 7-13.
4. Бабаев Э.С., Джалилов Н.С. и др. // Turkish Journal of Physics 1994, v.18, №11, 1181 – 1186/ Астрон. Ж.1995, 72, №2, с.230-239; 1995, 72. №2. с.240-249 / Письма в Астрон.Ж.1996, 22, № 5, 392-400.
5. Джалилов Н.С. и др. // Astron. Letters 2007, 33, №5, 309-318 / Cosmic Research 2008, V.46, №5, p. 392-395.
6. Джалилов Н.С. и др. // Sun and Geosphere 2007, № 2(2), 65-77 / Astron. Astrophys. 2008, 489, 769-773 / Astro-ph arXiv: 0805.2405 v2, 2008, 12 pgs / Физика плазмы 2009, т.35, №11, 1040-1054; 2010, т.36, № 9, 843-848; 2013, т.39, №12, 1122-1130 / Contrib. Plasma Phys.2011, v.51, № 7, 621- 638 (DOI 10.1002/ctpp.201000089) / Письма в Астрон.ж.

2011, 37, №9, 706-712 / Geomagnetism and Aeronomy 2014, 54, 886-891 /Аз. Астрон.ж. 2009, №1-2, 20-24; 2011, т. 5, №4, с. 12; 2015,10,№3,5-24; 2016,11,№1,4-22; 2016,11,№1,23-38; 2016,11,№2,15-19; 2016,11,№2,27-36; 2017,12,№2,4-20/ Proc. IAM 2014, 3, №1, 3-14 / Physics of Plasmas 2018, 25(6), 062903, 1-10 / Plasma Physics Reports, 2019, Vol. 45, No. 7, pp. 685–698 / In book: Variability of the Sun and Sun-Like Stars: From Asteroseismology to Space Weather, Ed. (J.-P.Rozelot, et al.), İSBN: 978-2-7598-2195-2, EDP Sciences Proceedings, France, Springer, 2018, 119-124.

7. Джалилов Н.С. и др. // Известия РАН, Серия Физическая 2000, Т.64, №9, 1793-1798; 2006, т.70, №10, с.1430-1433 / Astron. Astrophys.2002, v.384, 282-298; 2004, v.421, 305-322 / Proc. SOLSPA: The Sec. Solar Cycle and Space Weather Euroconference, (Vico Equence, Italy, 24-29 Sept. 2001), ESA SP-477. - 2002. - P. 167-170 / Proc. International Symp.: Cyclicity and cosmological problems, Baku, Azerbaijan, 2-4 May 2003, P. 115-122 / Труды межд. конф. «Исследования солнечной системы» 14-17 июня 2004 г., ШАО, ISBN: 5 8066 1700 9, 2005, С. 14-19.
8. Мамедов С.Г. и др. //ААЖ 2008, №5-6, с. 9-18; 2009, №3-4, с.12-17; 2011, №4. с.10-22.
9. Мамедов С. Г. и др. // Солн. Данные 1962, №1, с. 57-61; 1962, №8, с. 54-63; 1970, №6, с.106-111; 1970, №12, с. 111-113 / Астрон. ж. 1978, 55, 786-794; 1983, 60, 1192-1198 / Циркуляр ШАО 2000 №98, 3-6.
10. Мамедов С. Г. И др. // Солн. Данные 1968, №7, с.95-100 / Циркуляр ШАО 1970, №12, с. 8-13 / SolarPhys. 1998, v. 178, p. 178-181.
11. Гаджиев Т.Г., Газиев Г.А.// Солн. данные. 1982. № 10.
12. Караев А.А. //Астрон. цирк. 1969. № 548 / Солн. данные. 1970. № 12; 1973. № 4
13. Махмудов М.М. и др./ / Солн. данные. 1977. № 12; 1979. № 5, № 6; 1979. № 7; 1983. №11,12; 1984. № 3 / Изв. АН Аз.ССР. сер. физ.-тех. мат. наук. 1984. № 6. С.82; 1985. № 1. С. 83 / Препр. ИЗМИРАН.1979. № 9 / SolarPhys. 1980. V.66. P.89. / Астрон. вестник. 1979. № 9.
14. Мусаев М.М.//Солн. данные. 1968. № 12; 1982. № 9 / Докл. АН Аз.ССР. 1983. № 2. Т. 39 / Цирк. ШАО. 1971. № 8;. 1989. № 84, 86; 1999. № 96, 10.
15. Гусейнов Р.Э. и др. // Динамические процессы в солнечных вспышках, 1975, Баку - «Элм», 199 с; / Солнечные данные 1959 № 1; 1960 №4, № 7, 10, №9, №10; 1961 № 5, 12; 1965 № 3, 5; 1966 № 5, 6 / Астрон. ж. 1961, 38, 863; 1963, 40, вып.3; 1966. Т. 43. вып. 5; 1971, 48, 1217; 1977, 54, 123 / Solar Phys. 1973: 28, №2, 31 / Изв. АН Азерб. ССР. серия физ-тех. мат.наук. 1966. № 2, 3, 4 / Изв. ГАО. 1967. № 182 / Усп. физ. наук. 1969. Т. 99. вып. 3
16. Рустамов А.А. // Солн. данные 1979, № 2, 12 / Цирк. ШАО 1983. № 70
17. Газиев Г.А. и др. //Астрон. цирк. 1989. № 1536 / «The solar cyc1e». ASP. Conf. ser. 1992, V.27, 410.
18. Магеррамов В.А // Автореф. канд. дисс. Ленинград. 1985
19. Кулизаде Д.М. и др. //Астрон.ж. 1968, 45, №1, 69-73; 45, №2, 321-324; 1976, 53, №3, 577-587; 1976, 53, №4, 836-840; 2001, 45, №1, 75-78 / Кинематика и физика небесных тел 1989, 5, №3, 32-37; 1995, №2, 51-56; 2008, 24, №6,1-6 / Фраунгоферов спектр Солнца, Баку, 2006 / Физика Солнца, 2011, Баку
20. Салман-заде Р.Х. и др.// Солн. данные 1963, № 7; 1976, № 6 / Труды ШАО 1964, 3, 63 /Труды АО ЛГУ 1964, 21, 27; 1970, 27, 18; / Докл. АН СССР 1972, 205, № 5, 1054 / Сб. «Динам. и эвол. зв. сист.» 1975, вып. 4, 20 / Астрон. цирк. 1976, № 910 / Астрон. ж. 1969, № 3, 46, 589; 1976, 53, 827 / Вестник ЛГУ 1966, № 1, 166; № 19, 129; 1972, № 1, 145 / Fizika. Изд. ИФ АН Азерб. 1997, 3, №4, 3; 1997, 3, №4, 9; 1998, 4, № 1, 47 / Об оптич. глуб. Фраунгоф. линий в зв. атм. Баку. «Элм». 1998. 200 С. / ŞAR Sirkulyarı 1998, № 93, 94 / Препр. ИЗМИРАН 1999, № 2 (1118), № 3 (1119).
21. Гасанализаде А.Г.// Солн. данные 1963, № 4; 1964, № 8, № 9; 1965, № 7; 1966, № 5, 12; 1967, №10; 1971 № 12; 1976. № 2; 1979. № 7: 1986. № 10, № 11; 1987. № 10.11; 1992. № 9 / SolarPhys. 1967. V.1. № 3-4; 1970: V. 11. №3; 1971. V.20. № 2 / Докл. АН. Азерб.ССР. 1979. № 7 / Астрон. журн. 1977. Т.54. № 4 / Изв. ГАО АН СССР. 1979. №

197. / Astrophys.Space.Sci 1992. V.189. P.155; 1992. V.195. P.463; 1994. V.211. P.233; 1995. V.226. P.337. / Деп. ВИНИТИ. 1987. № 5794 - 5796. В 87.
22. Керимбеков М.Б.// Солн. данные 1960. № 9; 1964. № 1 / Fizika. Изд. ИФ АН Азерб. 1999. № 2 / Докл. АН Азерб. Респ. 2000. № 1-2 / Солн. данные 1968. № 11; 1976. № 2 / Цирк. ШАО 1973. № 30, 31 / Докл. АН Азерб., 1990. № 1-2.
23. Мусаев М.М. и др. // Солнечные данные 1959, №1, 79; 1967, № 3, 90; 1977, № 4, 67-78/Известие АН Аз ССР серии по физике, технике и математике 1969, № 5, 81-85/ Доклады НАН Азерб. 2005, LXI, № 1, 81-85 / В VIII Консультативном совещании АН Соц. стран по физике Солнца , с. 76-87, Наука 1976 / Циркуляр ШАО 1989, № 84, 29-35; № 86, 13-17.