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Editorial

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At the present stage of development of science, the study of cosmic dynamic systems and the manifestations of their diverse physical properties is becoming increasingly important. It is based on the fundamental patterns of the formation of macromolecular structures from a homogeneous environment observed in the surrounding nature and space, the essence of which continuously expands the horizons of knowledge when being penetrated. A huge role in this process is played by the created mathematical models, primarily models of space objects that are usually inaccessible to direct research in order to understand their genesis and stages of evolution.

Each such model represents a certain schematization of the physical phenomenon being studied, taking into account not the entirety of the factors inherent in it, but only some of them, characterizing the phenomenon from one side or another. One of the general methods for schematizing the movement of liquids, gases and other deformable bodies is a method based on the construction of new continuum models of a medium with complicated physical and chemical properties. Schematization that replaces the real natural environment consisting of individual molecules by a continuous continuum turns out to be very convenient for using the powerful mathematical apparatus of continuous functions and, as practice has shown, it is quite effective in the vast majority of cases for studying a variety of observable natural phenomena and processes.

The study of the space environment using mathematical modeling methods is a new scientific direction in the section of fundamental sciences, the formation and development of which at the end of the last century became possible thanks to the enormous progress of astrophysics, planetary physics and cosmophysics, and widespread introduction of mechanical and computational experiment methods into this area. This made it possible to put on a more rigorous scientific basis the study of the processes of the origin and evolution of the Solar protoplanetary disk, when a key role is played by computer modeling based on rigorous mathematical models.

The achievements of recent decades have forced us to take a fresh look at still unresolved numerous problems of cosmogony. These problems are related to the most current directions in the study of the Solar system, including questions of the evolution of matter in protoplanetary accretion disks and the disks themselves, the birth of planet embryos—planetesimals, various dynamic processes, including the migration of small bodies. Modern stellar-planetary cosmogony has essentially united all these directions and therefore it serves as a fundamental discipline that integrates observational facts and created mathematical models, the range of which is narrowed due to the restrictions imposed by astronomical and cosmochemical data, while the complexity increases significantly. For this reason, most known models of accretion protoplanetary disks are based on numerous initial assumptions that significantly limit their reliability.

This issue of the journal presents seven articles devoted to the problems of constructing continuum models of developed turbulence in multicomponent mixtures of reacting gases, in electrically conductive and heterogeneous gas-dust media based on the methods of irreversible thermodynamics. Their goal is to model turbulence in a multicomponent medium with complex physicochemical characteristics, the description of which must take into account the compressibility of the medium, variability of thermophysical properties, the presence of heat and mass transfer processes, chemical reactions, phase transitions and radiation, as well as influence of gravitational and electromagnetic forces. Classical ideas about turbulent motions in an incompressible fluid are intertwined with other areas of mechanics, which combine fluid mechanics of mixtures, thermodynamics, kinetics of chemical reactions and electromagnetic field theory. In addition to fluctuations in velocity, a high significance is acquired by fluctuations in density, temperature, and concentrations of individual chemical components of the mixture. As a result, one has to face one of the most difficult problems in the mechanics of turbulent media, which consists in the need for semi-empirical modeling of interconnected hydrodynamic, physicochemical and radiation processes and phenomena in turbulent flow. It is for this reason that this issue of the journal systematically uses, along with the traditional theoretical-probabilistic averaging of pulsating thermohydrodynamic parameters, the weighted (weighted mean) Favre averaging, which makes it possible to significantly simplify the derivation and analysis of the averaged equations of motion of a compressible medium.

In the first article "*Fundamentals of the mechanics of a turbulent gas and dust medium for an accretion protoplanetary disk*," in relation to the problem of reconstructing the evolution of an accretion gas and dust disk using thermodynamic methods and approaches to describing multicomponent turbulence, an attempt was made to develop a model of a turbulent heterogeneous medium and to construct on this basis a new class of mathematical models of space environments that take into account the influence exerted on the nature and development of turbulence by the inertial properties of a polydisperse mixture of dust particles, processes of heat and mass transfer and coagulation, phase transitions, chemical reactions and radiation. Being widely used in this series of works, the Onsager formalism of classical nonequilibrium thermodynamics made it possible to obtain the most general structure of closing gradient relations both for the Reynolds stress tensor and for various turbulent flows, in particular, in the form of generalized Stefan–Maxwell relations for multicomponent multiphase turbulent diffusion. At the considered level of closure, these relations most fully describe turbulent heat and mass transfer in a multiphase turbulent medium. Unfortunately, any thermodynamic theory cannot provide any information about the coefficients of turbulent transfer, since they do not appear explicitly in the expression for entropy production and in the Gibbs identity. Therefore, to determine these coefficients, it is necessary to use both classical concepts dating back to Prandtl, Taylor and Karman, and more modern algebraic closure models to determine various second-order moments (for example, the *ASTM-l Algebraic Stress Model-scale* turbulence model), when the equations of the corresponding differential model do not take into account convective transport and diffusion of turbulence.

The second article *"Thermodynamic construction of the MHD model of turbulence of electroconductive fluid medium"* is devoted to the derivation (in the single-fluid magnetohydrodynamics approximation) of a closed system of mean motion scale magnetohydrodynamic equations intended for modeling shear and convective turbulent flows of electrically conductive media in the presence of a magnetic field. A model of an electrically conductive turbulent medium was developed systematically using, along with the traditional theoretical-probabilistic averaging of MHD equations, Favre weighted averaging, which makes it possible to significantly simplify the derivation of averaged equations of motion for a compressible electrically conductive fluid and the analysis of the mechanisms of macroscopic field amplification by turbulent flows. For the purpose of a visual physical interpretation of individual components of the energy plasma and field balance, various energy equations have been obtained that make it possible to trace possible energy transitions from one form to another, in particular, to understand the mechanisms of pumping gravitational and kinetic energy of mean motion into magnetic energy. Particular attention is paid here to the method of obtaining, within the framework of irreversible thermodynamics, closing relations for the complete (taking into account the magnetic field) kinetic tensor of turbulent stresses in an electrically conducting medium and turbulent electromotive force (or the so-called magnetic Reynolds tensor), which also allows one to analyze the restrictions imposed by the conditions of increase in entropy on the coefficients of turbulent transfer. A methodology is proposed for modeling turbulent transfer coefficients, in particular, the coefficient of kinematic turbulent viscosity, which allows taking into account the influence of the magnetic field and the reverse effect of heat transfer on the development of turbulence in an electrically conductive medium.

The third article *"On the modeling of a compressible MHD turbulence of an accretion protoplanetary disk"*, within the framework of the main problem of cosmogony associated with the reconstruction of the protoplanetary disk of the Sun at the earliest stages of its existence, based on the closed system of mean motion scale MHD equations obtained in the second article (intended for numerical solution of problems on mutually consistent modeling of the structure and evolution of the accretion protoplanetary disk and the associated corona), built a model of a thin (but optically thick) disk, taking into account the dissipation of turbulence due to kinematic and magnetic viscosity, environment opacity, the presence of accretion from the surrounding space, the effect of turbulent $\alpha\omega$-dynamo on the generation of a magnetic field, magnetic force and energy interaction between the disk and its corona, etc.

The problem of planet formation in the system of a solar-like disk is directly related to the early stage of its formation and evolution. According to modern concepts, planets arise after the loss of gravitational stability by a subdisk formed as a result of differential rotation of the gas and dust matter of a protoplanetary cloud in orbit around a star and accretion processes when its dust component settles to the equatorial plane that is perpendicular to the disk rotation axis. With a strong flattening of the dust component of the formed subdisk, when the density of matter in the layer reaches a certain critical value, the subdisk becomes gravitationally unstable and breaks up into numerous dust ones. In areas with a high density of these concentrations, subsequent evolution leads to the emergence of local discrete centers of compaction, i.e. to the formation of a swarm of primary solitary gas and dust agglomerates, which serve as the basis for the embryos of initially loose proto-planetesimals that give rise to the formation of solid planetesimals with a large initial mass, and then, at the final stage of the process of evolution of the disk matter, the formation of planets by combination of planetesimals. Unfortunately, despite the enormous progress in studying extraterrestrial matter, obtaining observational data of circumstellar accretion disks, discovering exoplanets, and improving mathematical modeling methods, astrophysicists are still far from solving many of the key problems of the above scenario. Apparently, progress in explaining the well-known sophistication of the actual implementation of this scenario can be achieved by expanding the arsenal of theoretical approaches to modeling various problems of cosmogony, in particular, the evolution of astrophysical disks. The fourth article *“Modeling of the processes of formation of dust fractal clusters in a protoplanetary cloud”* proposes a correction of models of the early evolution of a protoplanetary disk, which is associated with a more in-depth understanding of those real processes that accompany the unification of submicron- and micron-sized particles during mutual collisions into solid-state aggregates. In this regard, it is important to note that, until recently, most well-developed cosmogonic models of the protoplanetary disk initially assumed the compact structure of growing dust clusters. However, as it has now become clear, such dust formations can have a very fluffy structure and extremely low bulk density. Such fluffy aggregates, which have relatively large geometric cross sections compared to dense dust particles, undergo changes in the entire path of evolution in the original gas-dust environment, i.e. the path from dust particles through fluffy aggregates to compact planetesimals. It is quite obvious that in order to adequately describe the evolution of such astrophysical protoplanetary disks and, ultimately, the mechanism of formation of protoplanetesimals in them, it is necessary, in the general case, to take into account the fractal properties of disk media. With this approach, hydrodynamic modeling of a fractal disk medium that has a non-integer fractal (mass) dimension must be carried out within the framework of generalized hydrodynamic equations, which are in the general case a consequence of the model in fractional-integral form.

In relation to the problem of the formation of planetesimals in the solar protoplanetary cloud, taking into account fractal ideas about the properties of dust clusters, this article formulated an evolutionary hydrodynamic model of the formation and growth of loose dust aggregates in the aerodisperse environment of a laminar disk, which initially consisted of gas and solid particles of (sub)micron size. It is shown how they are partially merged in the process of cluster-cluster coagulation with the formation of large fractal aggregates, which are the main structure-forming element of loose protoplanetesimals resulting from the physicochemical and hydrodynamic processes that are similar to the growth processes of fractal clusters.

The recent period has brought about very intensive studies of various coherent (dissipative) structures in turbulent incompressible fluids, which have a strong influence on various dynamic characteristics of the flow. From an actual point of view, the richest in such structures is the developed turbulence in a thermodynamically open system, when various symmetries (spatial transfers, time shifts, rotations, Galilean and scale transformations, etc.) allowed by Navier–Stokes equations and boundary conditions are violated at very high Reynolds numbers. In this case, various spatiotemporal coherent formations self-organize in a turbulent flow, such as vortex filaments, spirals and tangles, turbulent spots, burstings, etc. However, in cases where the flow is free from external compulsion (associated, for example, with a large-scale velocity shift during the rotation of a space object), developed turbulence in the limit of infinitely large Reynolds numbers is known to have a tendency to restore (in a statistical sense) broken symmetries far from the boundaries of the flow.

Meanwhile, there is turbulence, which does not restore the broken reflection symmetry (parity law) of the pulsation velocity field in the case of transformation of $x \to -x$ coordinates even at very high Reynolds numbers. An example of such turbulence is a pulsating velocity field in the convective zone of an astrophysical accretion disk: the average properties of this field do not remain invariant when mirrored in its equatorial plane. Such turbulence is known to be called spiral (or gyrotropic) and arises under the influence of mass forces with pseudo-vector properties (for example, the Coriolis force, magnetic field, etc.). In particular, real turbulence in a rotating solar protoplanetary disk has a spiral character. Spiral turbulence has an additional channel for the release of pulsational energy, which turns out to be the mechanism of generation of large- and mesoscale vortex structures (the opposite of what usually occurs in “ordinary” turbulence) that leads to the transfer of part of the energy of small-scale turbulence to the region of large scales. Thus, spiral turbulence in an astrophysical non-magnetic disk can often act as a generator of a large- and mesoscale vortex field, strengthening and enlarging the vortices and thereby generating a variety of coherent vortex formations. The fifth article *“On the theory of an inverse energy cascade in helical turbulence of a nonmagnetic astrophysical disk”* of the thematic issue considers this problem taking into account the results of numerical experiments that prove the real existence of an inverse energy cascade in three-dimensional spiral turbulence. The inclusion of the vortex dynamo mechanism in the evolutionary model of the disk leads to a modification of the constitutive relations for the turbulent heat flux and the turbulent stress tensor, as well as to the need to consider additional transport equations for the averaged vorticity and averaged vortex helicity.

The sixth article *“Synergetic approach to constructing a structured turbulence model”* examines the extremely pressing problem of self-organization in developed turbulent flows, which is a reflection of the most general concept of the relationship between order and chaos in natural processes. In this regard, it should be noted that, contrary to the traditional point of view of mechanics on turbulence, a large number of various vortex coherent structures (CS) have been discovered in the last decade thanks to the progressive development of methods for visual observation of turbulent fluid flows, and their topological characteristics have been reliably established. Examples include “Taylor vortices”, “turbulent spots”, “vortex rings”, “vortex spirals”, “Brown-Thomas structures”, etc. The frequency of appearance of a particular structure depends on the type of flow (boundary layer, mixing layer, jet, etc.), geometry and mode of fluid movement. It was important to describe how coherent structures of this kind could arise. The answer to this question can be partially obtained within the framework of stochastic nonequilibrium thermodynamics, the principles of which are widely used in the monograph when constructing a semi-empirical model of structured turbulence. The stochastic-thermodynamic approach to modeling structured turbulence that is used in the book is based on introducing into the model a set of internal random parameters—pulsating internal coordinates (such as the rate of dissipation of turbulent energy) that characterize the structure and time evolution of the pulsating field of hydrodynamic flow parameters. This makes it possible to use thermodynamic methods to derive the kinetic Fokker–Planck–Kolmogorov (FPK) equations intended to describe the evolution of the probability distribution function of internal small-scale characteristics of turbulence. These equations serve, in particular, as the basis for the analysis of Markov diffusion processes of transition in the space of internal coordinates from one stationary nonequilibrium state to another as a result of a sequential loss of stability (increasing supercriticality) by a subsystem of turbulent chaos, which is far from the complete chaos of thermodynamic equilibrium.

Finally, in relation to the problem of reconstructing the evolution of a preplanetary gas and dust cloud, the last seventh article *“Modification of gravitational instability criteria for astrophysical disks within nonadditive thermodynamics”* considers one of the possible approaches associated with adequate modeling of the strong gravitational interaction between individual parts of the disk medium, which manifests itself in a specific way as a result of a long process of evolution. As it has now become clear, astrophysical disks generally belong to the group of so-called anomalous systems, a distinctive feature of which is the irreducibility of the entire system to a simple sum of its parts. It is the strong gravitational interaction that is the reason for the thermodynamic non-additivity of the disk medium when, for example, its entropy is not an additive quantity. For this reason, modeling the evolution of disk matter based on classical kinetics and Gibbs-Boltzmann statistics is in the general case not completely adequate. In other words, the disk system is one of the complex systems that are characterized by weak chaotization of the phase space, when exponentially fast mixing takes on a different (power-law) character. Such a theory is the recently intensively developed non-extensive (non-additive) Tsallis statistics (thermodynamics), which is intended to describe the behavior of anomalous systems with strong force interaction, the fractal nature of the phase space and strong correlations between its individual parts.

In connection with the foregoing, this article earlier considered the matter of the disk as a special type of continuous medium—a fractal medium, in the phase space of which there are points and areas that are not filled with its components. Within the framework of the Tsallis deformed statistics formalism, generalized hydrodynamic Navier–Stokes equations for a fractal medium (the so-called q hydrodynamics equations) are derived here. These equations were used as a basis to obtain linearized equations of oscillations of a solid-rotating disk, taking into account dissipative effects, and to derive the dispersion equation in the WKB approximation. Axisymmetric oscillations of an astrophysical differentially rotating gas-dust disk were analyzed, and modified Jeans and Toomre criteria for gravitational instability for rotating astrophysical space objects were obtained.

The author is well aware that he was not able to cover all the questions in the broad range of problems that this issue of the journal is devoted to with the same degree of completeness. This is, first of all, due to the fact that, despite certain successes achieved in recent years in the study of such a complex area as turbulence and, especially, the turbulence of inhomogeneous compressible media and structured turbulence, much is still remains unclear, and the emerging mathematical difficulties often seem insurmountable. In this regard, it is necessary to develop new original approaches that make it possible to effectively simulate such environments.

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