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MULTIVALUED WAVES AND THE RICHTMYER–MESHKOV INSTABILITY AS THE CAUSES OF THE FORMATION OF GALAXIES

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A few months ago, the Max Planck Institute (Dresden, Germany) organized an International Seminar for outstanding researchers of such a remarkable phenomenon as “extreme waves”. The seminar was led by such famous professors as Nail Akhdiev (Australian National University, Canberra, Australia) [1], Helmut Brand (University of Bayreuth, Germany) [2] and Amin Chabchub (Kyoto University, Japan) [3].

The phenomenon of "Extreme waves" is remarkable since widely spread in Nature, and at the same time it is used widely in technology. In particular it is used in modern optical communications (nonlinear optics). The results of the Workshop are widely discussed by experts. They preview promising new directions springing from group efforts.

This article is a review of my seminar presentation. At the same time, it includes some results of my book, which is being prepared for publication. The main outlines of this book are outlined by Marat Aksanovich Ilgamov in his article [5]. The book is devoted to multivalued waves existing in various scalar fields. An attempt is made to describe, on this basis, the entire variety of fundamental physical phenomena of the world around us, starting with quantum phenomena and ending with the emergence and initial development of the Universe.

It is known that Einstein tried to build a unified (interdisciplinary) field theory that would unite all interactions in nature into a single system. My report to Dresden made an attempt to use this idea, which was developed in the mentioned book and this article.

The first three parts of this article examine the stability of Richtmyer–Meshkov and Faraday waves. The last part discusses the theory of the origin of the Universe proposed in [4, 12]. The birth of galaxies in the first moments of the process of spherical expansion of our Universe is associated with the Richtmyer–Meshkov instability.

Key words: nonlinear Klein–Gordon equation, instability, Faraday waves, James Webb Space Telescope, origin of galaxies, revolution in cosmogony.

1. Theory. The nonlinear Klein–Gordon equation (NKGE).

This equation is usually presented in the following form

$$\Phi_{tt} - c_*^2\Phi_{xx} + \partial V / \partial\Phi = 0, \quad (1)$$

V is the scalar potential [4]. Let

$$V = -C\Phi - \tfrac{1}{2}m_1\Phi^2 - \tfrac{1}{3}m_2\Phi^3 + \tfrac{1}{4}\lambda\Phi^4. \quad (2)$$

Here C, c_*, m_1, m_2 and λ are constants. We substitute (2) in Eq. (1). As a result it gives

$$\Phi_{tt} - c_*^2\Phi_{xx} = C + m_1\Phi + m_2\Phi^2 - \lambda\Phi^3. \quad (3)$$

The main focus of the report was on multivalued waves (MWs) arising in resonators. Let us consider the corresponding solution method and boundary conditions.

Method of solution. New coordinates r and s are introduces

$$r = ct - x, \;\; s = ct + x, \quad (4)$$

Here c is a constant. In new variables Eq. (3) is transformed to form

$$c^2(\Phi_{rr} + 2\Phi_{rs} + \Phi_{ss}) - c_*^2(\Phi_{rr} - 2\Phi_{rs} + \Phi_{ss}) = \\ = C + m_1\Phi + m_2\Phi^2 - \lambda\Phi^3. \quad (5)$$

We assume that

$$c = c_* + \overline{c}, \quad (6)$$

where $\overline{c}$ is the perturbation of the speed c. In this case Eq. (5) yields that

$$4c_*^2\Phi_{rs} + (2\overline{c}c_* + \overline{c}^2)(\Phi_{rr} + 2\Phi_{rs} + \Phi_{ss}) = \\ = C + m_1\Phi + m_2\Phi^2 - \lambda\Phi^3. \quad (7)$$

The scalar field function Φ is represented as a sum:

$$\Phi = \Phi^{(1)} + \Phi^{(2)}, \quad (8)$$

where $\Phi^{(1)} >> \Phi^{(2)}$. Taking into account (8) and (6) we split (7) to two equations

$$2(c^2 + c_*^2)\Phi^{(1)}{}_{rs} = 0, \quad (9)$$

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$$2(c^2+c_*^2)\Phi^{(2)}{}_{rs}+(2c_*\bar{c}+\bar{c}^2)[(\Phi^{(1)}+\Phi^{(2)})_{rr}+$$
$$+(\Phi^{(1)}+\Phi^{(2)})_{ss}]-m_1(\Phi^{(1)}+\Phi^{(2)})- \qquad (10)$$
$$-m_2(\Phi^{(1)}+\Phi^{(2)})^2+\lambda(\Phi^{(1)}+\Phi^{(2)})^3=C.$$

Considering (9) we assume following expression

$$\Phi^{(1)}=J(r)+j(s), \qquad (11)$$

We emphasise that this simple expression takes place only if the resonance condition (6) occurs. Then Eq. (10) is considered. After the integration we found,

$$2(c^2+c_*^2)(\Phi^{(2)}{}_r+\Phi^{(2)}{}_s)=J_*(r)+j_*(s)-$$
$$-m^2(sJ+\int jds+\int Jdr+rj)-$$
$$-m_2\int (J+j)^2ds-m_2\int (J+j)^2dr$$
$$-(c^2-c_*^2)(sJ_{rr}+j_s+J_r+rj_{ss})+ \qquad (12)$$
$$+\lambda(sJ^3+3J^2\int jds+3J\int j^2ds+\int j^3ds+$$
$$+\int J^3dr+3j\int J^2dr+3j^2\int Jdr+rj^3)+C_1+C_2.$$

Here $J=J(r)$ and $j=j(s)$. Let $c^2\approx c_*^2$ and

$$J_*(r)-m^2\int Jdr-m_2\int J^2dr+\lambda\int J^3dr=J_2(r),$$
$$j_*(r)-m^2\int jds-m_2\int j^2ds+\lambda\int j^3ds=j_2(s). \qquad (13)$$

Then

$$4c_*^2(\Phi^{(2)}{}_r+\Phi^{(2)}{}_s)=J_2(r)+j_2(s)-m^2(sJ+rj)-$$
$$-m_2\int (J^2+2Jj)ds-m_2\int (2Jj+j^2)dr+$$
$$+\lambda(sJ^3+3J^2\int jds+3J\int j^2ds+ \qquad (14)$$
$$+3j\int J^2dr+3j^2\int Jdr+rj^3)+C_1+C_2.$$

We will not take into account the interaction of waves $J(r)$ and $j(s)$. The last expression can be represented in two versions with an appropriate choice of arbitrary functions $J_2(r)$ and $j_2(s)$

$$4c_*^2(\Phi^{(2)}{}_r\pm\Phi^{(2)}{}_s)=J_2^{\pm}(r)\pm j_2^{\pm}(s)-m^2(sJ\pm rj)-$$
$$-m_2sJ^2\mp m_2rj^2+\lambda(sJ^3\pm rj^3)+C_1\pm C_2. \qquad (15)$$

The choice of the option depends on the boundary conditions at the ends of the resonator. Let

$$\Phi_x=\Phi_s-\Phi_r=0 \text{ at } x=0 \text{ and } x=L. \qquad (16)$$

Thus, we will consider natural or parametrically excited resonant waves. We assume the functions $J_2^{\pm}(r)$ and $j_2^{\pm}(s)$ as seed ones. The boundary condition at $x = 0$ is satisfied automatically, if $j=J(s)$ and $J_2^{\pm}(t)=j_2^{\pm}(t)$.

The boundary condition at $x = L$ gives the equation

$$J_r-J_s+\tfrac{1}{2}Lc_*^{-2}[-m^2(J(r)+J(s))-$$
$$-m_2(J^2(r)+J^2(s))+ \qquad (17)$$
$$+\lambda(J^3(r)+J^3(s)]=l\cos^n\omega t+\tfrac{1}{2}C,$$

There is an appropriate choice of seed perturbations using $\Phi^{(2)}{}_r$ and $\Phi^{(2)}{}_s$.

We will further consider waves with a period equal to L. In this case, with exact resonance $J_r=J_s$. Let $n=1$. In this case the equation (17) yields

$$J^3(r)+r_*J^2(r)+RJ(r)+A\cos\omega c^{-1}r=\tfrac{1}{2}C. \qquad (18)$$

Here $r_*=-m_2\lambda^{-1}$, $R=-m^2\lambda^{-1}$, $A=-l\lambda^{-1}L^{-1}c_*^2$. The equation for $j(s)$ is written as (18). The method of its solution is discussed in detail in [4, 12]. Then we find the sum

$$\Phi=J(r)+j(s). \qquad (19)$$

Thus, we have obtained an expression defining the scalar field in the resonator. Both continuous and multivalued waves can occur there.

Continuous linear and nonlinear waves have been well studied. A huge scientific literature is devoted to them. But the same cannot be said for multivalued waves. There are only a few books, in one way or another, dedicated to them [4, 12]. When studying them, algebraic equations similar to (18) were used. The difficulty of studying multivalued waves is that they are usually unstable, and there are a few examples of their experimental study.

Below we will give several examples of experimentally recorded extreme multivalued waves. To describe them mathematically, three versions of the equation (18) will be used.

2. Waves with hair and the Richtmyer–Meshkov instability.

The most complex version of the wave profile occurs when it begins to transform (enclose) with vortices. This case is shown in Fig. 1.

Of course, this case is the most difficult, since it directly passes into the non-stationary part of the development of the wave profile associated with the appearance of vortices on it. This evolution is already entering the region of turbulence, and is beyond the scope of this paper. At the same time, this question has great interest and very close to the problem of MW, which is considered in this paper.

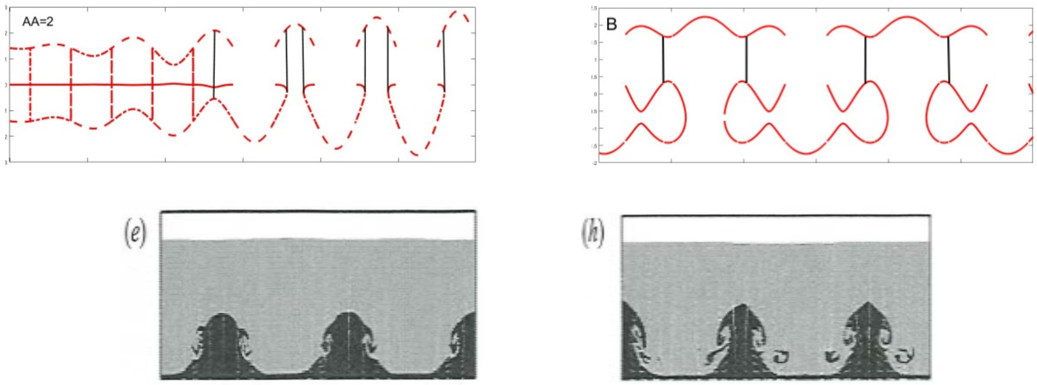

Fig. 1. Results of calculations (top) [4, 5] and experiments (bottom [6]

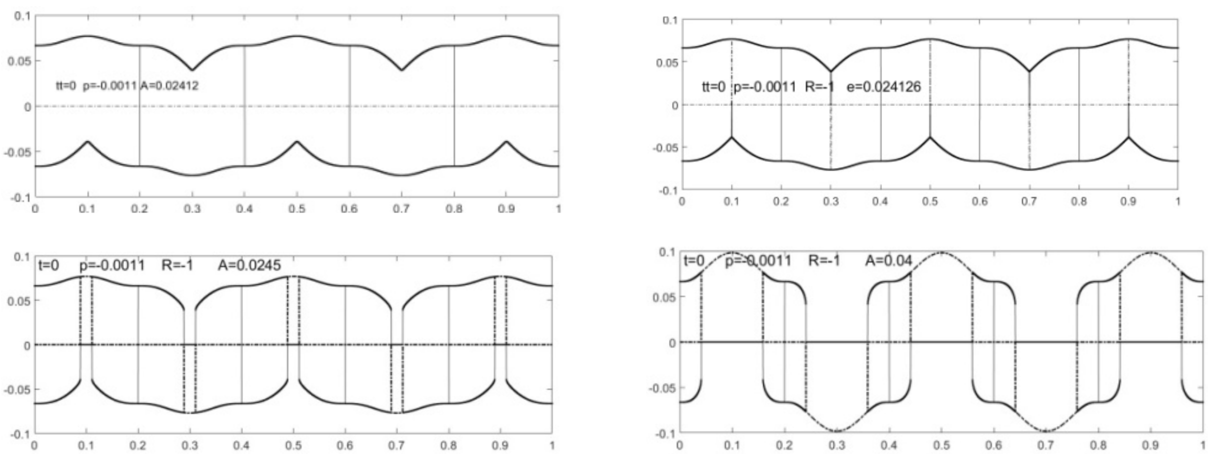

Fig. 2. Wave profiles calculated for four values of A

More than 10 years ago, the book were published [4], where the concept of catastrophic waves was introduced, that is, waves whose profile may contain folds and jumps. Here we must remember that the wave profile can have three values at each point according to (18). The jumps further increase and complicate the possible wave profiles.

Taking this into account we continue our study of the influence of the magnitude of the initial (seed) disturbance on $J(r)$. The following equations were used in the calculations:

$$J^3(r) - 0.0011J(r) + A\sin(5\pi r / L) = 0. \quad (20)$$

Here r changes from 0 to L. The results are presented in Fig. 2. When constructing the curves, we used either two solutions or one from the existing three solutions to clearly illustrate the possibility of jumps in the system.

There are two independent continuous wave profiles resembling cnoidal waves at A = 0.02412 . Local jumps appear connecting these solutions with a very small increase in amplitude to 0.024126. With a further increase in amplitude, these local jumps break up into two jumps. As a result, a very peculiar wave structure appears, which is clearly visible in the case of A = 0.04.

If we accept the possibility of the existence of waves with discontinuities, then the waves presented above can be interpreted as traveling waves carrying vortices or waves with hair (waves with wings). The similar waves are also presented in Fig. 3.

The profiles calculated for A=0.0245 (top) and A=0.04 (bottom) are shown. For both cases, two options for their interpretation are presented. In the first option, we illustrated the possibility of the simultaneous existence of two differently directed vortices concentrated near the wave centers, as well as jets (“hair” or “wings”) bordering the vortices (left). In the second option of the calculations (on the right), only jets (“hair” or “wings”) are shown. Similar options are presented for the case A =0.04. However, in this case, we assumed that the emergence of vortices excludes the simultaneous existence of jets (“hair” or “wings”) in the wave formations (bottom, left).

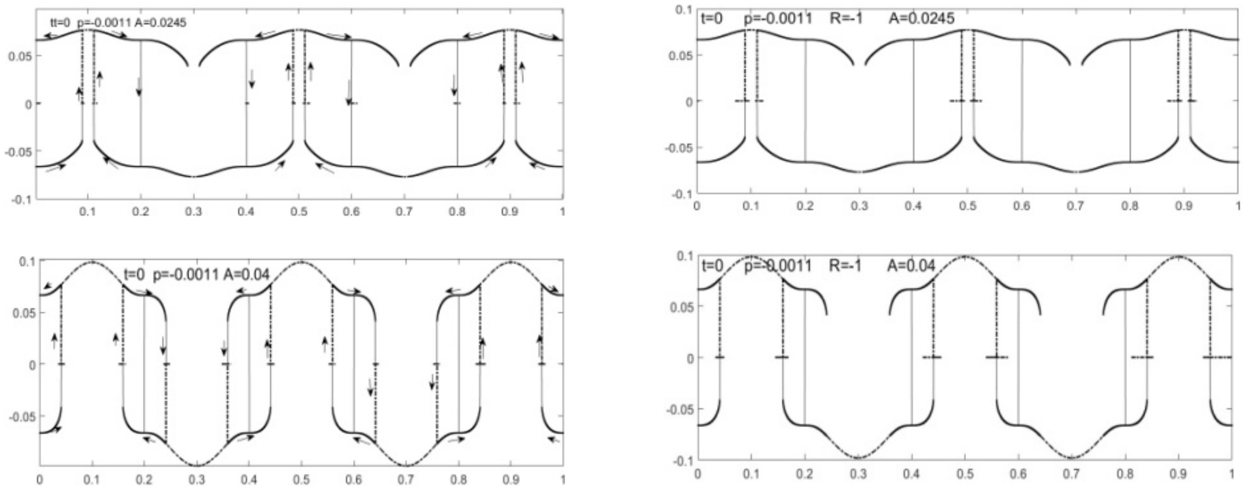

Fig. 3. Wave profiles illustrating the possibility of the emergence of vortices and jets (“hairs” or “wings”) as part of traveling waves. The arrows show the directions of movement of the field particles that create the vortices

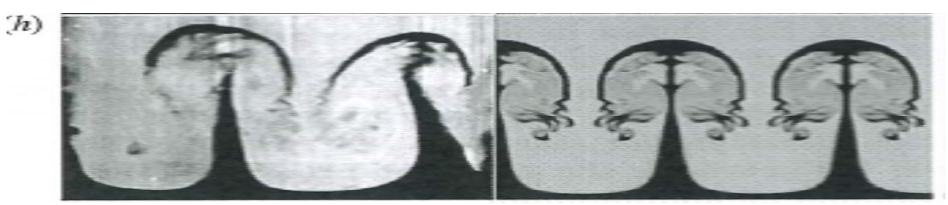

Fig. 4. Waves with hair (waves with wings) generating during the Richtmyer–Meshkov instability [7]

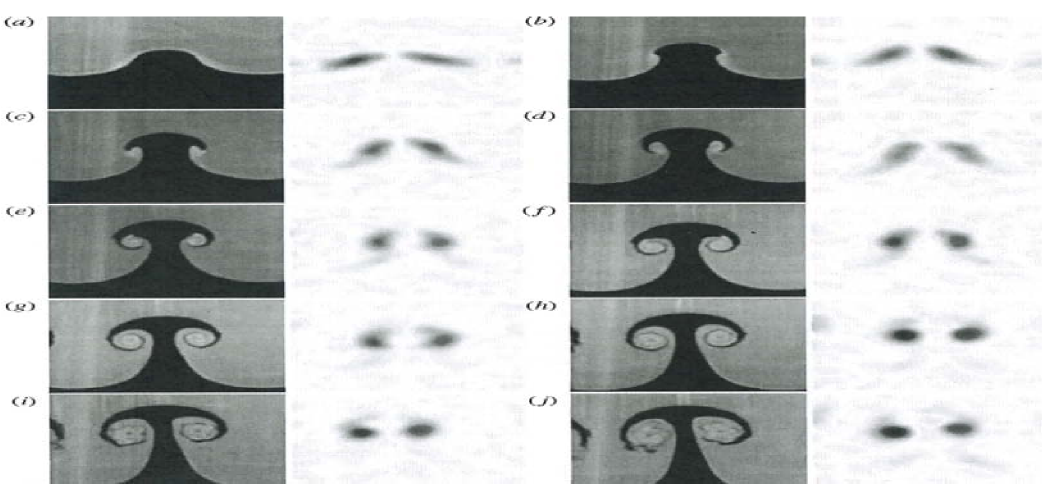

Fig. 5. Waves with hair (waves with wings) generating during the Richtmyer–Meshkov instability [7]

Figs. 4 and 5 show certain results from [7]. There shock tube experiments are used to study the very late-time development of the Richtmyer–Meshkov instability from a nearly sinusoidal, initial perturbation into a fully turbulent flow. The interface is generated by two opposing gas flows. The results from [7] are given as an illustration to Figs. 2 and 3.

In conclusion, we note that we have considered waves $J(r)$. In the case considered, their amplitude is several times greater than the amplitude of the initial perturbation A. Therefore, the initial perturbation will not change the presented results.

3. Counterintuitive Faraday waves on the free surface of a liquid.

Let us consider the case of two-frequency excitation. We used equation which has the form (18).

The transresonance evolution of waves is studied, when parameter R varies from negative values to positive values through zero. The excitatory function was specified by one of the following expressions: 0.05coskr or 0.05coskr-0.025cos2kr or 0.05coskr-0.05cos2kr. The calculation results are presented in Fig. 6.

It can be seen that the second harmonic can greatly change the nature of wave formation in the system.

The appearance and evolution of various multivalued surface waves is shown in Fig. 7. The appearance of these waves and the atomization of the surface is determined by the capillary effect, which in this case is much stronger than the effect of gravity. In general, the experimental data are consistent with the calculation (Fig. 6) and it is clear that the results of our theory presented above are in qualitative agreement with experiment.

We got an interesting result that can be interpreted in completely different ways. In particular, it can be associated with processes that arise during the surface cavitation.

In Fig. 8 results are shown of acoustic cavitation generated by ultrasonic vibrations. It is found that strong forcing leads to the excitation of nonlinear surface waves on gas–liquid interfaces. If the excitation is strong enough, then both the appearance of droplets and the generation of air bubbles occur simultaneously. Qualitatively, these processes correspond to the scheme described by the equation (18) and shown in Fig. 6.

4. Counterintuitive Faraday waves on the contact surface of two liquids.

A dynamic instability of an interface of two liquids is the well-studied phenomenon.

However, this is only true as long as the waves are very weak. We can expect the appearance of multivalued waves, when their amplitude increases.

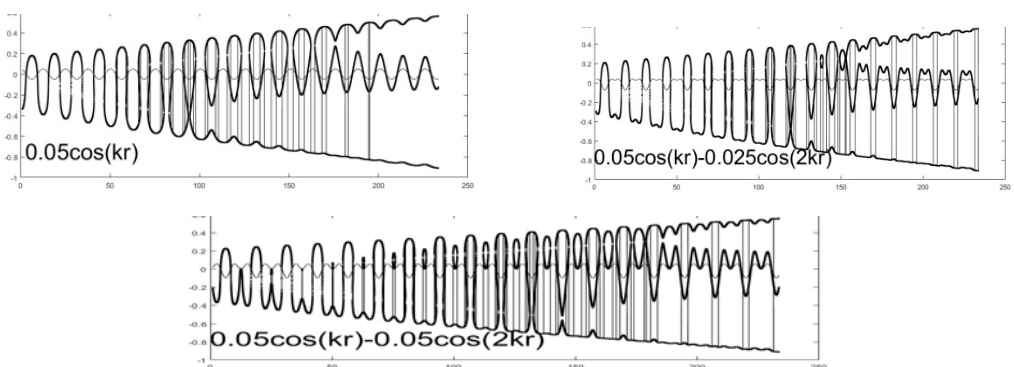

Fig. 6. Evolution of multivalued waves into particle – waves under three excitation options

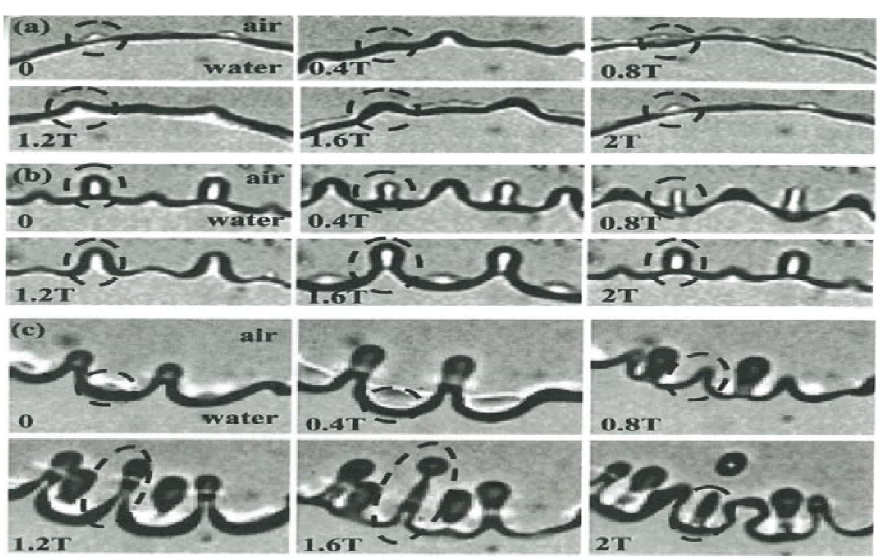

Fig. 7. Surface instabilities resembling Faraday waves [8]

This was clearly shown in a wonderful article [6]. There a tank containing a two-layer liquid with a free surface was considered. During vertical excitations, the layer interface and the free surface can be excited separately or simultaneously. Of particular interest to us are resonant waves at the interface between layers. Analysis of these waves showed that their surprising multivalued may be associated with the contribution of the combined effects of vertical acceleration of the fluid and external excitation. This contribution comes down to the fact that the upper layer of liquid in some cases becomes significantly "heavier" than the lower layer.

The experiments used a container 1 m long, 0.15 m wide and 0.3 m high. The thickness of the lower, heavier layer of liquid was 0.05 m. The thickness of the upper layer of liquid was 0.2 m. The layer was excited according to the harmonic law and lasted approximately 15 seconds. The acceleration amplitude of vertical external excitation is approximately 0.85 g. The snapshots of the free surface and interface at the mid-plane of the tank width at different moments of time are shown in Fig. 9.

We will not discuss the results of the experiment here. The reader can find a discussion in the article [6]. Let us note only the most important for us. It can be seen that from the beginning of parametric excitation there is a very strong change in the profile of Faraday waves from almost harmonic to multivalued. They reminiscent of waves with hair or the breakdown of a standing wave into two traveling waves. It is important for us that, albeit very roughly, the wave evolution retains some semblance of periodicity over several cycles of excitation. Afterwards, the flow cecomes chaotic as can be seen from Figs. 9 (i–l).

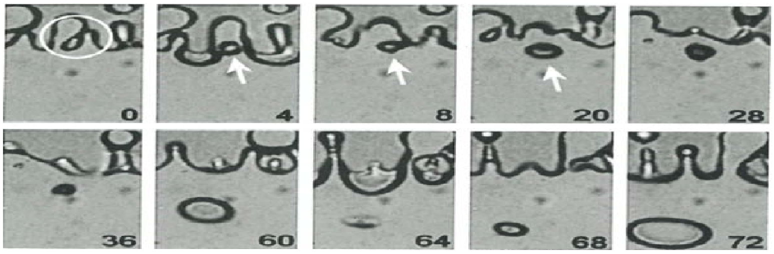

Fig. 8. Selected frames showing the entrapment of gas bubbles and separation of drops during surface cavitation

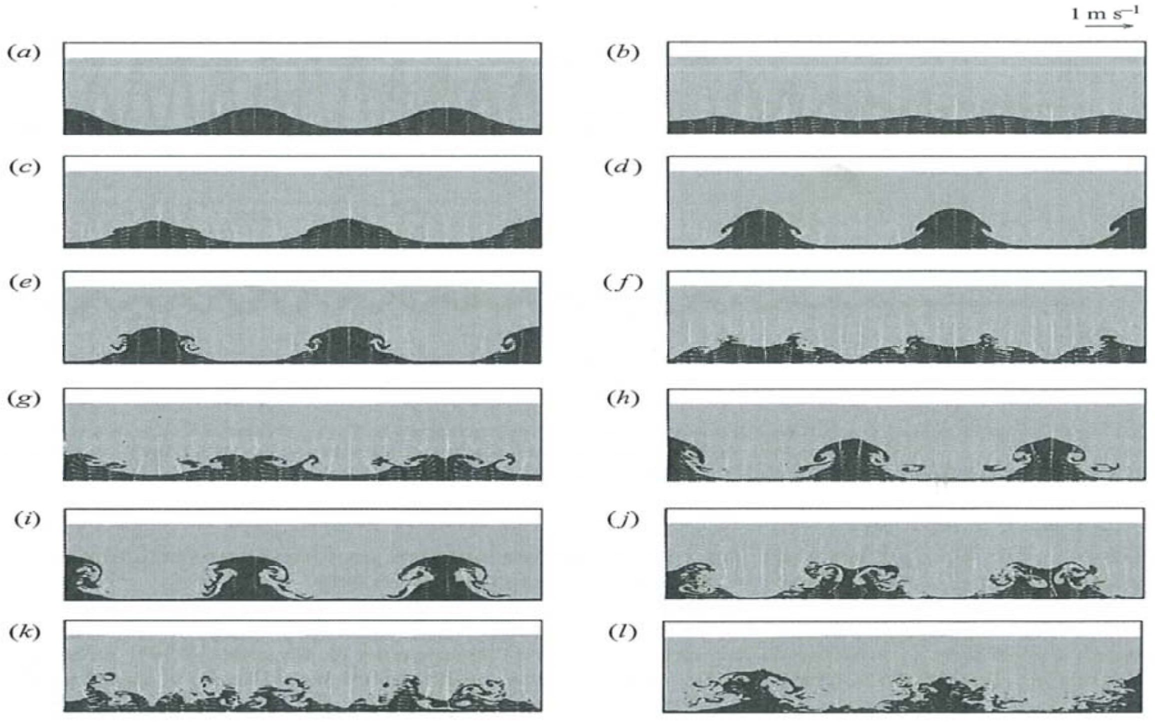

Fig. 9. Snapshots of Faraday waves on the free surface and the interface [6]

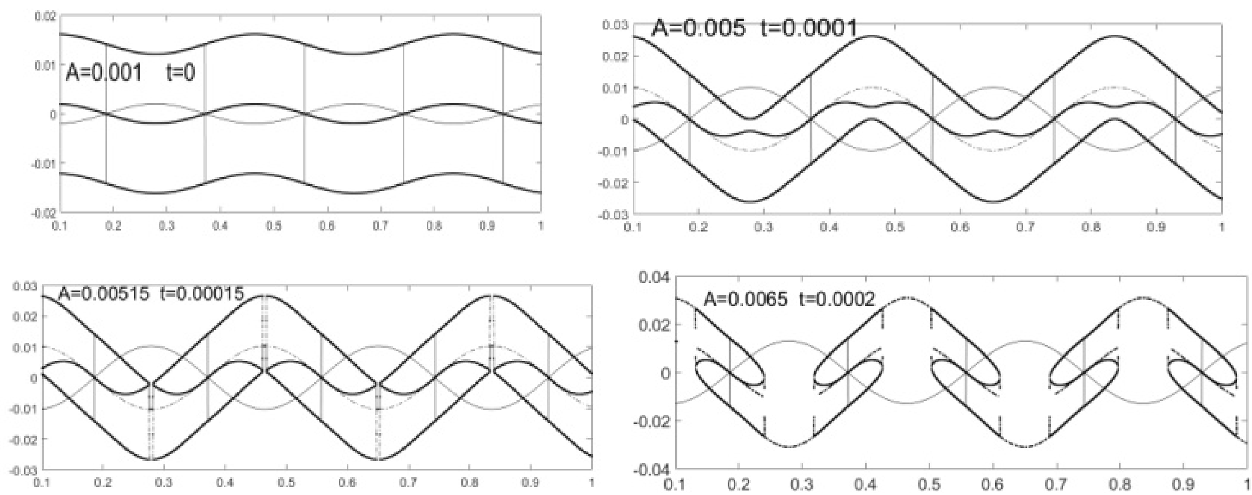

Fig. 10. The beginning of the formation of waves with hair

To model this wave process we used the following equation

$$J_r^3 - 0.005 J_r + 0.0001 \cos \pi N L^{-1} r - \\ -0.00004 \cos 3\pi N L^{-1} r = 0. \quad (21)$$

The equation for j_s has a similar form.

We believe that the sum $J_r + j_s$ (19) qualitatively describes the dynamics of parametrically excited waves on the contact surface of two different layers of liquid.

On Figs. 10 and 11 the results are given of a comparison of remarkable experiments [6] and the results of the theory.

Of course, based on the experimental data (*a*) – (*d*) presented in Fig. 9, it is difficult to imagine how a wave with hair arises from the initial harmonics. Calculations come to the rescue. There are three different harmonics according to them. They begin to converge and interact as they approach resonance. It is shown in Fig. 10.

In particular, these three harmonics can form (*d*) wave. Further development of this wave is shown in Fig. 11. In this case, it is assumed that we are at some fixed point of the resonant band

There is a qualitative consent of the calculated profiles and the wave profiles in Figs. 9–11. In particular, Fig. 11 describes the experimental data almost on all length of the container. In the certain cases the discrepancies are only near the boundaries.

5. The birth of multivalued waves as a stage in the formation of galaxies.

Modern cosmology believes that the Universe arose from a certain singularity, very small in size and shaped like an ideal sphere. At some point in time, for unknown reasons, the sphere began to rapidly expand, and a certain substance appeared in it. When the expansion slowed down somewhat, gravity emerged. Thanks to it, the substance began to slowly gather around the disturbances in the density that arose at the beginning of the expansion of the sphere. The emergence of stars and galaxies is associated with the existence of quantum disturbances that arose in the initial period (inflation) and the subsequent grouping of matter around these disturbances due to gravity. The emergence of stars took hundreds of millions of years. Then the formation the galaxies from the stars also took at least a billion years.

The above applies to the generally accepted (standard) model of the development of the Universe. Along with this model, other models well known to specialists have been developed. In recent years, models have appeared related to the possibility of an "eruption" of our Universe from the pre-universe. One of them is developed by Galiev and Galiyev [4, 12].

The main assumptions and stages of the evolution of the Universe from the pre-universe are, according to the latest model: 1. The pre-universe exists in multidimensional space-time. This pre-universe is described by a scalar field that has its own structure. The field is roiled by the quantum fluctuations; 2. At any moment the pre-universe gives birth to billions of 'seeds' of rapidly evolving universes, one of which accidentally evolved into our Universe; 3. The Universe sprang into existence due to quantum fluctuations that fragment some multidimensional scalar 'seed' into vibrating elements having very high energy. 4. The elements are modelled as one-dimensional strings;

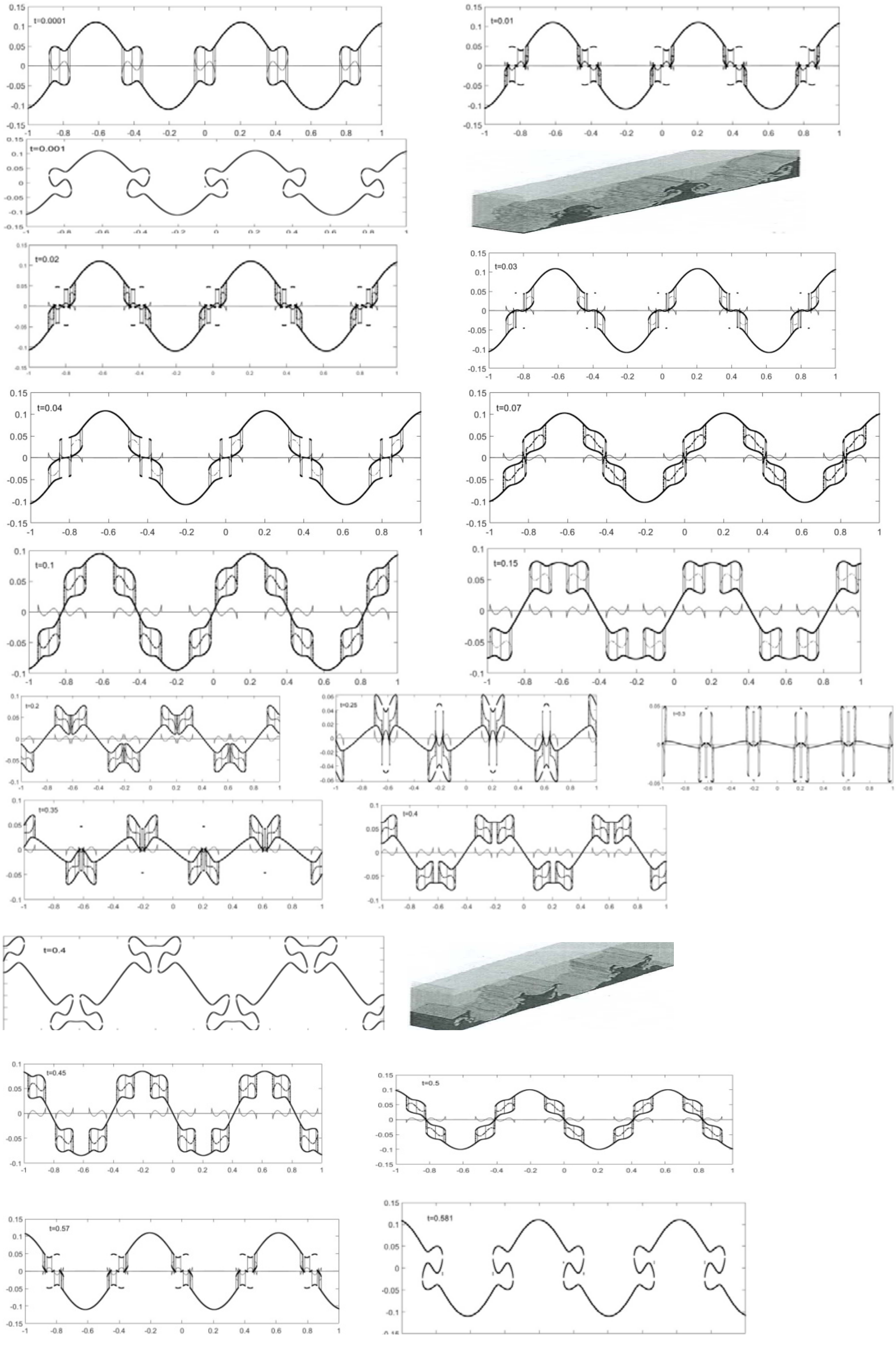

Fig. 11. Comparison of theoretical results and experimental data [6]. The thin line defines a seed disturbance whose amplitude is increased by 100 times

5. Highly nonlinear oscillations (waves) of those elements emitted very heavy particles of mass and energy which formed the four-dimensional spacetime. Our Universe appeared with huge energy, mass and the finite size; 6. The spacetime began to spread very rapidly as more and more particles appeared and the heavy particles began breaking up into lighter particles and the energy continued to transform into mass. It was the Universe's rapid growth spurt [4, 12].

All of the above provisions of the described theory are, of course, speculative. This makes them not much worse than all other theories of the origin of the Universe. In this article, the Galiev-Galiyev model (MGG) is supplemented with results that can be called verifiable, and even qualitatively consistent with observations. The fact is that in 2022 the James Webb Space Telescope (JWST) was launched into space [13, 14]. In the last year, he began sending information that contradicted the standard model. According to it, well-developed and large galaxies already existed 300 million years ago. Therefore, the existing theory has come into conflict with observations and another theory is needed.

The MGG [4, 12], which is extended to the case of galaxy formation, is proposed here. It is assumed that at the moment the expansion begins, the Universe is filled with a scalar field described by the nonlinear Klein–Gordon equation. The field is very viscous and very dense. During the expansion process, viscosity and density rapidly decrease. Conditions are created for the growth of initial disturbances and the emergence of turbulence. In particular, at the front of the expanding sphere, due to the Richtmyer–Meshkov instability, multivalued waves and vortices arise. Qualitatively, this process could correspond to that presented in Figs. 5, 7, 9 and 12.

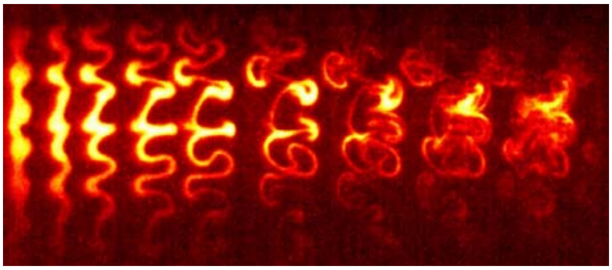

Fig. 12. This image was originally captioned "Coexistence of three patterns" and was additionally noted: "This poster was created for the 1996 APS-DFD Gallery of Fluid Motion by Paul Rightley, Robert Benjamin and Peter Vorobieff. It won the Gallery of Fluid Motion Award". This image was obtained from http://cnls.lanl.gov/~azathoth/cover.html

From presented above calculations and Figs. 5, 7, 9, 12 [7, 10, 11] it follows that the waves and vortices arising from the Richtmyer–Meshkov instability can be quite large, incomparably larger than those that can arise due to quantum perturbations , which are appearing in the standard model of cosmology. Multivalued waves arising in spherical resonators can be no less complex. Examples of such waves are given in Fig. 13.

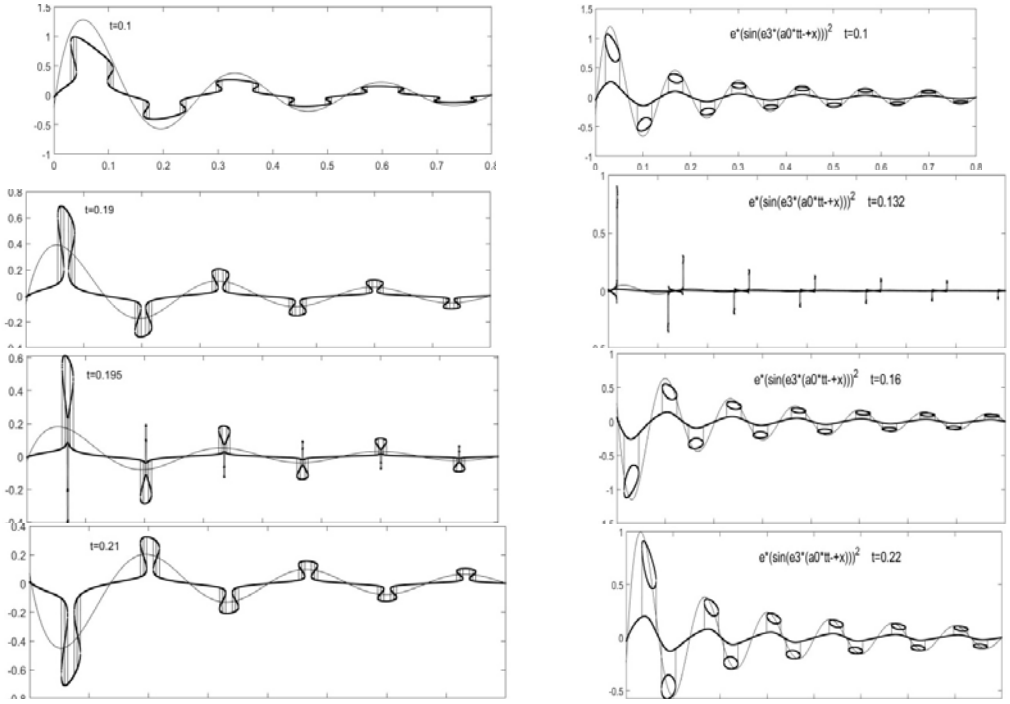

Fig. 13. Calculations for the case of purely harmonic excitation sin (ωt) of a sphere boundary (left). Calculations for the case of excitation of the sphere boundary by a disturbance $\sin^2(\omega t)$ (left)

Curves of Fig. 13 were obtained on the basis of an approximate solution of equation (3) written for spherical waves. The solution technique is similar to that presented in section 1 of this article. The functions defining the traveling waves were found from equations similar to equation (18).

It can be seen that waves reminiscent of Euler's figures [4, 12, 15] (left) can appear inside the sphere. On the other hand (right), resonant particle-waves may appear inside there.

The calculation is given for 4 points in dimensionless time (0.1, 0.19, 0.195 and 0.21). A comparison of linear (thin lines) and nonlinear (thick lines) calculations of standing spherical waves is given. The amplitude of linear waves is increased by 1000 times. In general, the results of the linear calculation corresponded to the spherical Bessel functions.

As a result of this calculation, we can assert that the solutions of the equation describe, qualitatively, a strongly nonlinear version of the spherical Bessel functions. The above, in our opinion, explains the success of using spherical Bessel functions in analyzing the results of highly nonlinear processes. We are referring to the first moments of the existence of the Universe, when it increased from Planck dimensions to the size of elementary particles. At the pressure and temperature that existed at that time, all wave processes were extremely nonlinear. However, when analyzing the cosmic microwave background radiation, a linear version of the spherical Bessel functions is used, and apparently successfully. The success of the analysis is apparently due to the fact that linear theory usually predicts frequencies and wavelengths quite accurately. It can make a huge mistake in the amplitudes of the waves, as well as with all sorts of phase transitions in the original scalar field. The transitions can be determined by jumps, and multivalued zones, in the profiles of nonlinear waves, similar to those shown in Fig.13.

The amplitude of the wave increases greatly, when approaching the center of the sphere. At the same time, the nature of the wave change resembles the results obtained for one-dimensional, plane waves (Figs. 1, 2, 3, 10, 11). If we do not consider that we are dealing with multivalued waves, then in general the change in multi-valued waves resembles the change in a linear spherical wave, in particular spherical Bessel functions.

On Fig. 14 shows examples of calculating the process of decay of the surface of an expanding sphere of a scalar field. It is taken into account that during the expansion process the field viscosity rapidly decreases. The calculation parameters were taken completely arbitrarily. The traveling wave parameter is plotted along the coordinate. The influence of the initial energy of the scalar field C (see (2)) on Φ is studied .

On Fig. 14 curves are plotted corresponding to approximate solutions of the nonlinear Klein-Gordon equation written taking into account the influence of vacuum viscosity and stationary energy of the scalar field. The seed perturbation was specified as a solution to the linearized equation. The value of vacuum viscosity changed with decreasing curvature of the sphere surface. From Fig. 14 one can see how, as the wave formation propagates , the waves of the front deviates more and more from the linear, harmonic description.

One can even say that there is some correspondence between figures 14 and 12, 7, 5, 4. Indeed, at the beginning of the process, as follows from Figs. 14 and 12, wave formation on the surface of an expanding sphere is described by a harmonic law. Further, the influence of nonlinearities, instability and viscosity quickly increases, while the amplitude of waves Φ decreases. Folds appear on the front waves, well corresponding to the Euler figures [4, 12, 15].

Under certain circumstances, these folds can evolve into loops and closed structures (see Figs. 1, 4, 7, 8). Based on my earlier publications [4, 12], these closed structures can be interpreted as vortices (Figs. 4, 5). But in any case, the results Fig. 14 are qualitatively consistent with the experimental data presented in Fig. 12.

Thus, from the presented results, as well as experiments, it follows that the occurrence of seed disturbances, which subsequently led to the formation of galaxies, can be associated with the Richtmyer–Meshkov instability. This instability could have manifested itself already at the very early stages of the development of the Universe and led to the emergence of multivalued waves and vortices in the matter of the very early Universe. Apparently, the formation of galaxies began from this time. After their formation, the birth of stars inside galaxies began. Perhaps, over time, JWST or other telescopes will discern faintly luminous galaxies in space with a huge mass of matter and very few formed stars.

Thus, the waves and vortices that arise during the Richtmyer–Meshkov instability can be quite large, incomparably larger than those that can arise due to quantum perturbations appearing in the standard cosmology model. Therefore, the time required for the formation of galaxies can be significantly reduced. This explains the mysterious result of observations of the Universe [13, 14] and bring the observations into agreement with the Big Bang theory.

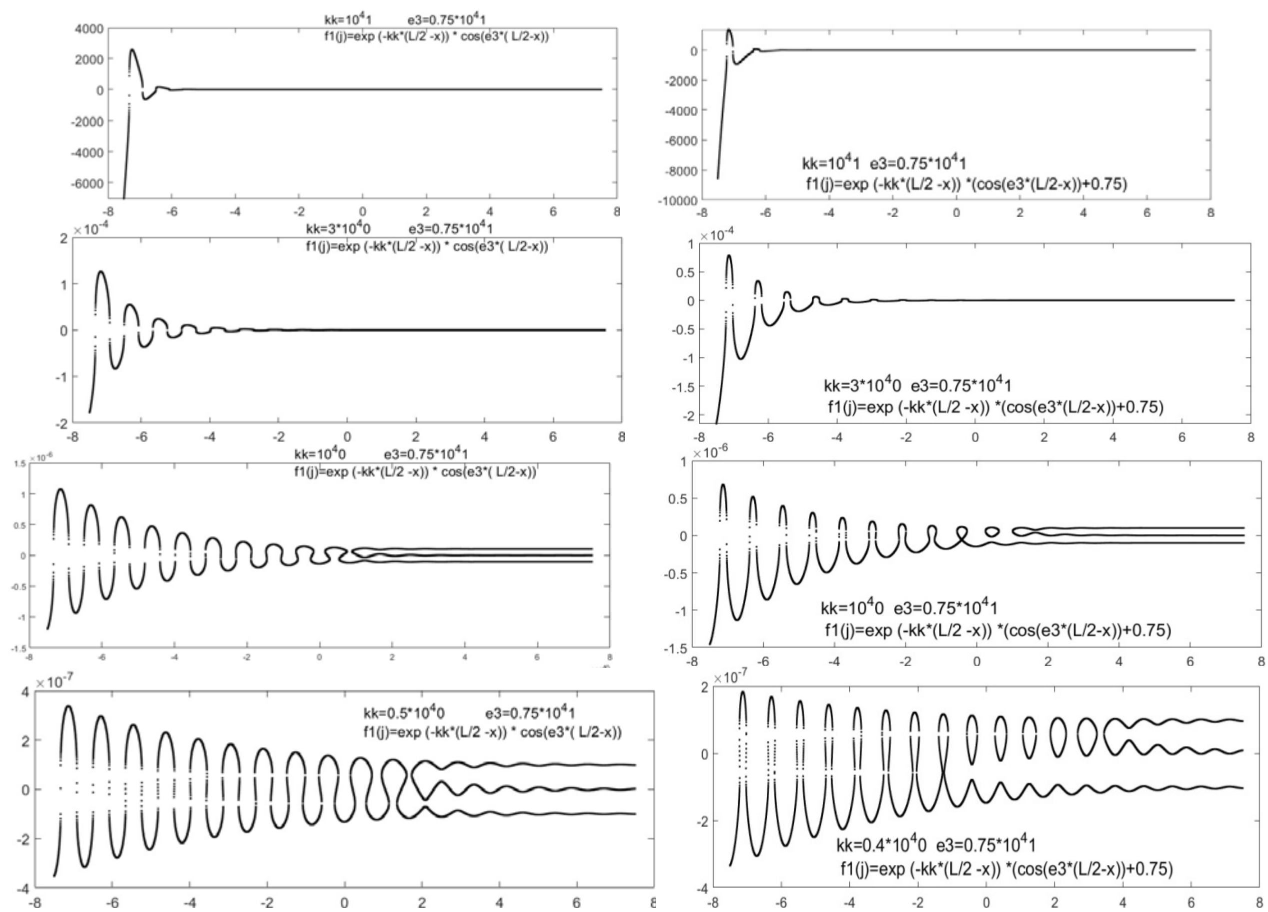

Fig. 14. Solutions describing the propagation of a wave from the center of the sphere. On the left are calculations without taking into account the influence of the stationary energy of the scalar field. On the right, this influence is taken into account

In conclusion of this part of the article, we note that the Richtmyer–Meshkov instability is well known to many specialists. It arises during the creation and debugging of nuclear weapons and the propagation of the spherical shock wave during testing of nuclear weapons.

Final remarks. After all the calculations presented above, the author very surprise that the developed theory based on several strong assumptions, to a certain extent describes the experimental data, which were observed during the Richtmyer–Meshkov instability and the experiments with nonlinear Faraday waves and, also, multivalued Rayleigh-Bénard convection (see Fig. 15).

The experimental study of multivalued waves is a difficult problem. This may be why we did not find many articles devoted to the experimental study of multivalued waves. All the more interesting are these articles and the experimental and theoretical data presented in [6–11].

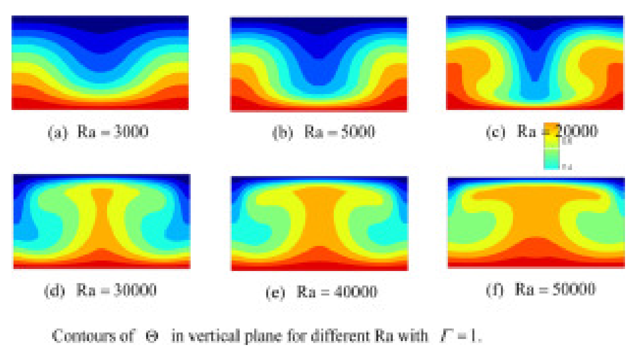

Fig. 15. Counterintuitive waves that arise during Rayleigh–Bénard convection in a cylinder with incompressible fluid [9]

We reviewed here the theoretically very interesting experimental results presented in [6–11]. The results were then used to explain some of the James Webb Space Telescope observations [13, 14] associated with the appearance of galaxies in the very early Universe.

References

1. Akhmediev N.N., Ankiewicz A. Solitons. Chapman & Hall (1997); Akhmediev N.N. Nonlinear physics – Deja vu in optics// Nature. 413: 267–268 (2001); Akhmediev N., Ankiewicz A., Taki M. Waves that appear from nowhere and disappear without a trace // Phys. Lett. A 373: 675-678 (2009); Kibler B., Fatome J., Finot C., Millot G., Dias F., Genty G., Akhmediev N., Dudley M. The Peregrine soliton in nonlinear fibre optics // Nature Physics (2010). doi:10.1038/nphys1740.

2. Descalzi O., Cisternas J., Brand H.R. Mechanism of dissipative soliton stabilization by nonlinear gradient terms // Phys. Rev. E 100, 052218 (2019); Descalzi O., Cartes C., Brand H.R. Multiplicative noise can induce a velocity change of propagating dissipative solitons // Phys. Rev. E 103, L050201 (2021); Descalzi O., Cartes C., Brand H.R. Oscillatory dissipative solitons stabilized by nonlinear gradient terms: The transition to localized spatiotemporal disorder // Phys. Rev. E 105, L062201 (2022).

3. He Y., Witt A., Trillo S., Chabchoub A., Hoffmann N. (2022). Extreme wave excitation from localized phase-shift perturbations // Physical Review E. 106(4); Kibler B., Chabchoub A., Gelash A., Akhmediev N., Zakharov V. (2017). Ubiquitous nature of modulation instability: from periodic to localized perturbations // In Stefan Wabnitz (Eds.), Nonlinear Guided Wave Optics: A testbed for extreme waves (pp. 7-1-7-22). Bristol: IOP Publishing; Chabchoub A., Onorato M., Akhmediev N. (2016). Hydrodynamic Envelope Solitons and Breathers // In Miguel Onorato, Stefania Residori, Fabio Baronio (Eds.), Rogue and Shock Waves in Nonlinear Dispersive Media (pp. 55-87). Cham: Springer.

4. Galiev Sh.U. Charles Darwin's Geophysical Reports as Models of the Theory of Catastrophic Waves. Moscow. ISBN 978-5-904403-06-5 (in Russian) (2011); Galiev Sh.U., Galiyev T.Sh. Nonlinear scalar field as a model describing the birth of the Universe // Herald of Ufa Scientific Center, Russian Academy of Sciences. 2: 7 (2014); http://journal.ufaras.ru/wp-content/uploads/2022/02/izvestiya_2_2014.pdf; Galiev Sh.U., Galiyev T.Sh. Simple model of the origin of the Universe // Herald of Ufa Scientific Center, Russian Academy of Sciences. 4: 27 (2016); Galiev Sh.U. Evolution of Extreme Waves and Resonances. CRC Press (2020).

5. Ilgamov M.A. On Charles Darwin's centennial and bicentennial // Herald ASRB. 2012. 17(2):66–69 (in Russian); Ilgamov M.A. Modeling of natural phenomena using nonlinear dynamics methods // Herald of Ufa Scientific Center, Russian Academy of Sciences. 2012. № 1. С. 69–72 (in Russian); Ilgamov M.A. Darwin, Geodynamics and Extreme Waves. Galiev Sh.U. Springer (2015). 362 pp. // Herald of Ufa Scientific Center, Russian Academy of Sciences. 2020. № 4. С. 110–113 (in Russian); Ilgamov M.A. Simulation of Extreme Waves in Technology and Nature. CRC Press. Galiev Sh.U. (2020). 822 p. Vol. 1. The Evolution of Extreme Waves and Resonances // Herald of Ufa Scientific Center, Russian Academy of Sciences. № 1. С. 116–123 (in Russian) DOI 10.31040/2222-8349-2020-0-1-116-123; Ilgamov M.A. Simulation of Extreme Waves in Technology and Nature. CRC Press. Galiev Sh.U. (2020). 822 p. Vol. 2. Extreme Waves and Shock-Excited Processes in Structures and Space Objects // Herald of Ufa Scientific Center, Russian Academy of Sciences. 2021. № 2. С. 115–120 (in Russian); Ilgamov M.A., Galiev Sh.U., Mace B.R., GaliyevT.Sh. Modelling of resonant and transresonant waves in natural resonators: from gravity waves to the origin of the Universe // Herald of Ufa Scientific Center, Russian Academy of Sciences. 4: 26–37 (2015); http://journal.ufaras.ru/wp-content/uploads/2021/12/izvestiya_4_2015_1-126.pdf; Ilgamov M.A. Annotation book Galiev S.U. «Extreme Multivalued Waves in Scalar Fields» planned by Springer for publication in early 2024 // Herald of Ufa Scientific Center, Russian Academy of Sciences. 2023. № 3. С. 115–120. DOI 10.31040/2222-8349-2021-0-2-115-120

6. Liu D., Lin P. (2022) Two-layer liquids Interface instabilities in Faraday waves of two-layer liquids with free surface // Journal of Fluid Mechanics. 941:A33. DOI:10.1017/jfm.2022.259

7. Morgan R.V. et al. On the late-time of the two-dimensional Richtmyer-Meshkov instability in shock tube experiments // JFM. 712: 354-383 (2012).

8. Tandiono et al. Creation of cavitation activity in a microfluidic device through acoustically driven capillary waves // Lab Chip. 2010. 10. 1848-1855.

9. Pan-Xin Li et al. 3D DNS of laminar Rayleigh-Bénard convection in a cylinder for incompressible fluid flow // Chinese Journal of Physics. V. 79. October 2022. P. 374-394.

10. Rightley P.M, Vorobieff P., Martin R., Benjamin R.F. Experimental observations of the mixing transition in a shock-accelerated gas curtain // Physics of Fluids. 11: 186-200 (1999). DOI: 10.1063/1.869911.

11. James D. Sadler et al. Simulations of three-layer Richtmyer–Meshkov mixing in a shock tube // Physics of Fluids. 36, 014120 (2024) https://doi.org/10.1063/5.0177419

МНОГОЗНАЧНЫЕ ВОЛНЫ И НЕУСТОЙЧИВОСТЬ РИХТМАЙЕРА–МЕШКОВА КАК ПРИЧИНЫ ВОЗНИКНОВЕНИЯ ГАЛАКТИК

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Несколько месяцев назад Институт Макса Планка (Германия, Дрезден) организовал Международный семинар для выдающихся исследователей такого замечательного явления, как «экстремальные волны». Семинар вели известные профессора Наиль Ахмедиев (Австралийский национальный университет, Канберра, Австралия) [1], Хельмут Бранд (Университет Байройта, Германия) [2] и Амин Чабчуб (Киотский университет, Япония) [3].

Явление «экстремальных волн» примечательно тем, что широко распространено в природе и в то же время все шире используется в технике, в частности, в современной оптической связи (нелинейной оптике). Результаты семинара широко обсуждаются экспертами. Они рассматривают новые многообещающие направления, возникающие в результате групповых усилий.

Эта статья является обзором моего доклада на семинаре. Вместе с тем в него включены некоторые результаты моей книги, которая готовится к печати. Основные контуры этой книги обозначены Ильгамовым Маратом Аксановичем в его статье [5]. Книга посвящена многозначным волнам, существующим в различных скалярных полях. Делается попытка описания на этой основе всего разнообразия фундаментальных физических явлений окружающего нас мира, начиная с квантовых явлений и заканчивая возникновением и начальным развитием Вселенной.

Известно, что Эйнштейн пытался построить единую (междисциплинарную) теорию поля, которая объединила бы все взаимодействия в природе в единую систему. В моем докладе в Дрездене сделана попытка использования этой идеи, что получило развитие в упомянутой книге и настоящей статье.

В первых трех частях этой статьи исследуется устойчивость Рихтмайера–Мешкова и волны Фарадея. В последней части рассматривается теория возникновения Вселенной, предложенная в [4, 12]. Зарождение галактик в первые моменты процесса сферического расширения нашей Вселенной связывается с неустойчивостью Рихтмайера–Мешкова.

Ключевые слова: нелинейное уравнение Клейна–Гордона, неустойчивость, волны Фарадея, космический телескоп «Джеймс Уэ́бб», зарождение галактик, революция в космогонии.