LABORATORY OF MATHEMATICAL PROBLEMS IN NATURAL SCIENCES

DEPARTMENT OF DIFFERENTIAL EQUATIONS

FACULTY OF MATHEMATICS AND MECHANICS

MOSCOW STATE UNIVERSITY

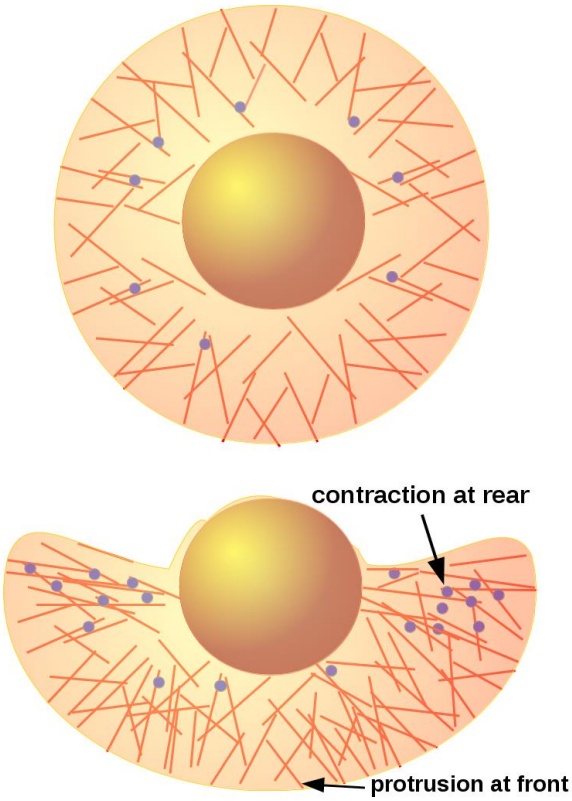
Laboratory of Mathematical Problems in Natural Sciences is a laboratory of industrial ("interdisciplinary") mathematics. It is a unit of Mechanics and Mathematics Faculty in Moscow State University.
Recently, a group of scientists from Differential Equations Department of Moscow State University, and Institute for Problems in Mechanics of Russian Academy of Sciences, took an active part in a number of applied research projects with Russian corporations “Uralchem” and “Uralkali”, University of Pennsylvania (USA), Scientific Technical Center “Kosmonit”, Public Corporation “Russian Space Systems”, as well as other industrial organizations. As a result of this collaboration, applied laboratory was created.

Mathematical biology

1. Chemotaxis

The ability of cells and cell ensembles in living organisms to move in a specific direction has long attracted attention of biologists, biochemists and biophysicists, as well as mathematicians, who create mathematical models of such motion. Examples are blood particles arriving to heal the wound in human skin, epithelial cells

moving collectively to regenerate damaged tissues, cells chasing intruders like enemy bacteria, etc. Somehow a cell or a group of cells decides where and when to move.
Cell motility is one of the most up-to-date and important problems of modern mathematical biology. Creating of appropriate mathematical models for this motion is actual problem in medicine and pharmacology.
Moreover, this field provides new and interesting problems in the theory of partial differential equations: existence of "traveling wave"-type solutions for parabolic equations and systems with nonlinear terms; well-posedness of boundary value problems for nonlinear parabolic and parabolic-elliptic systems with nonclassical boundary conditions: posed on an unknown boundary which moves in time, or nonlocal, linking boundary values at different points of the boundary.
Such problems are far from being studied yet, neither in regards of qualitative properties, nor in creating adequate numerical algorithms for solution and identifying parameters. We plan to continue our research from mathematical point of view.



2. Physics of Active Gels
Mathematical modeling of media with "active" elements is very interesting from both theoretical and practical points of view. For example, research of L.Berland proves that if a liquid contains bacteria able to react actively to situation, then the viscosity of this liquid changes dramatically (decreases several times!). First, this research was carried out by mathematical methods. Later, these works served as a basis for creation fluids with very low viscosity, using purely chemical methods (in the absence of any "living" elements). Now these liquids are used as ink for modern 3D printers. We consider this area to be extremely promising. Our group plans to continue this research, extending our interest to a wider range of media with active elements. These can be other continuous media (apart from classical liquids) with active elements others then bacteria.

Artificial Intelligence

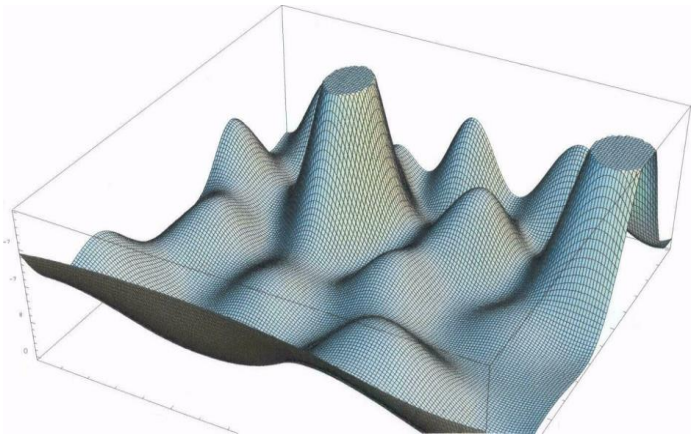
Mathematical models of different systems often contain parameters that cannot be obtained from “first principles”, they have “phenomenological” nature. However, these parameters can be determined by

configuring model parameters according to the results of experiments. This aim can be achieved using modern methods of artificial intelligence and electronic self-learning systems.
Various optimization methods play important role here, they help to find unknown parameters in our model. To do it, we must minimize the difference between certain sets of experimental and calculated data, which include the parameters to be identified.

Supercomputer "Lomonosov" installed in Moscow University in 2009

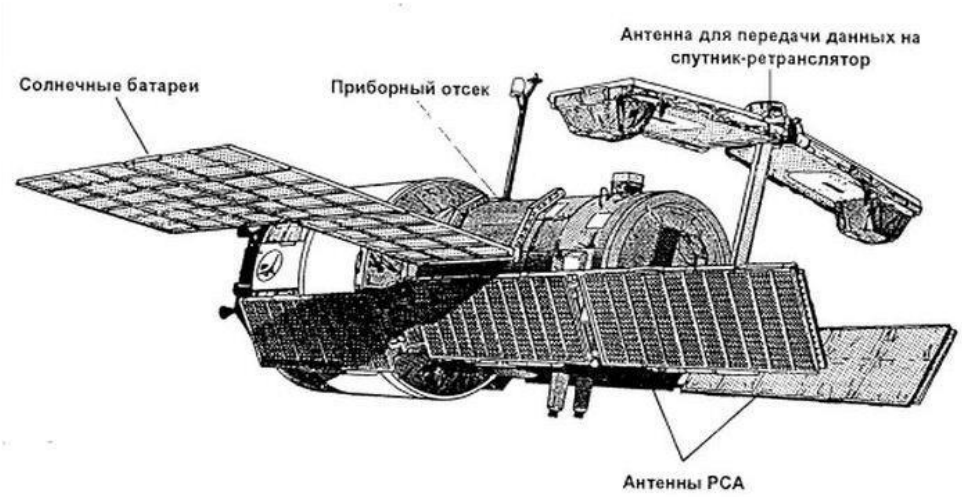
Inverse problems of electrodynamics

1. Holographic methods
Study of subwavelength capabilities of holographic methods. Reconstruction of the spatial structure of a molecule by holographic methods, comparing the interference picture of diverging electron beam on a molecule with a reference electron beam. Possible applications - synthesis of new medicaments.

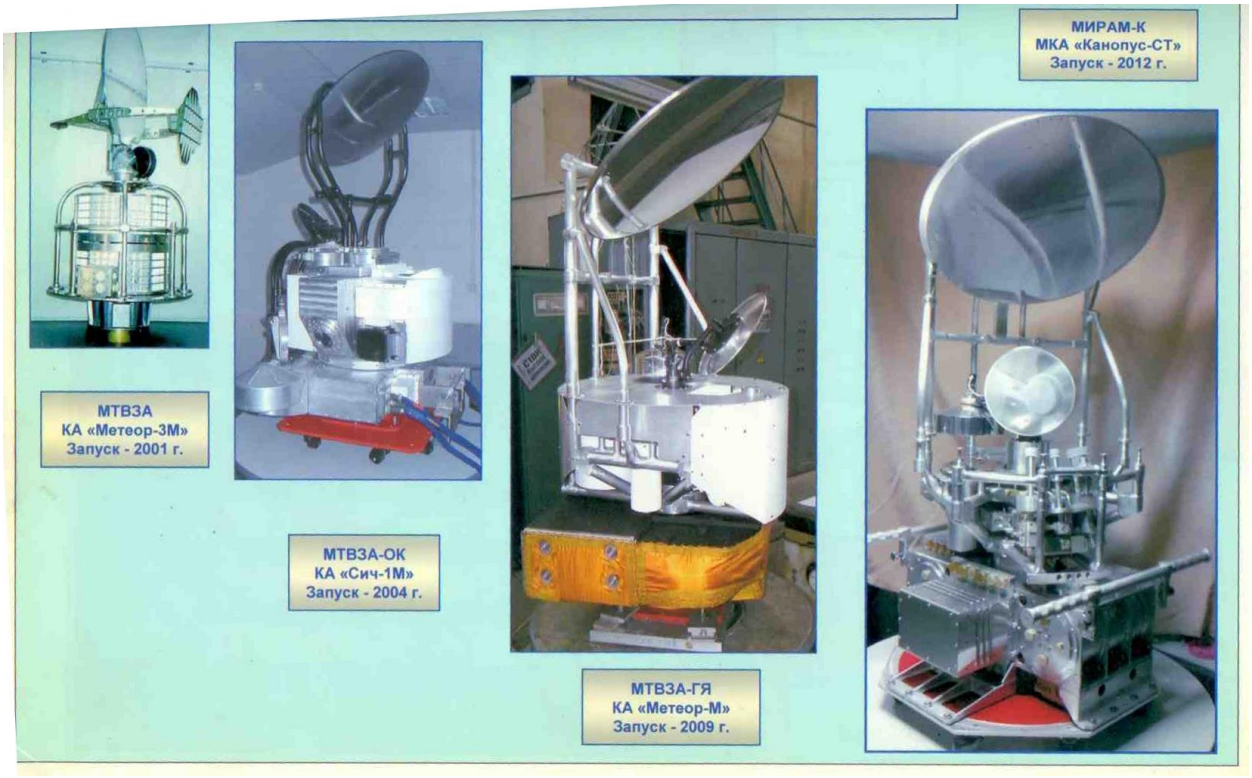


2. Radiometric and radiolocation studies of the World Ocean
Problems of radiometric and radar study of the world ocean, in collaboration with Scientific Technical Center “Kosmonit” and Public Corporation “Russian Space Systems”. The main challenge is reconstructing the parameters of sea waves using the ocean's own radio emission and reflected radio signals. Computer simulation for own and reflected radio emission of the sea surface is carried out.

Active and passive space radiolocation

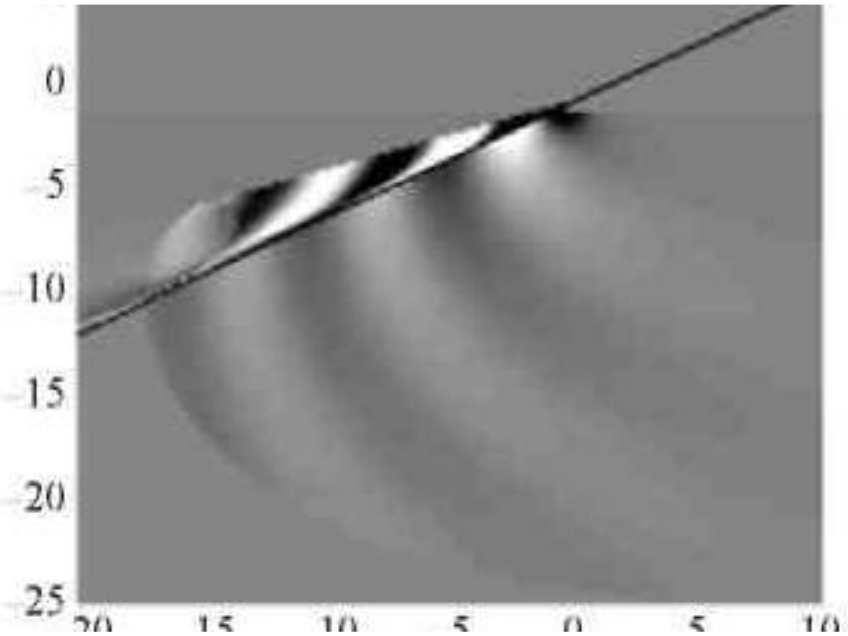


Almaz-1A

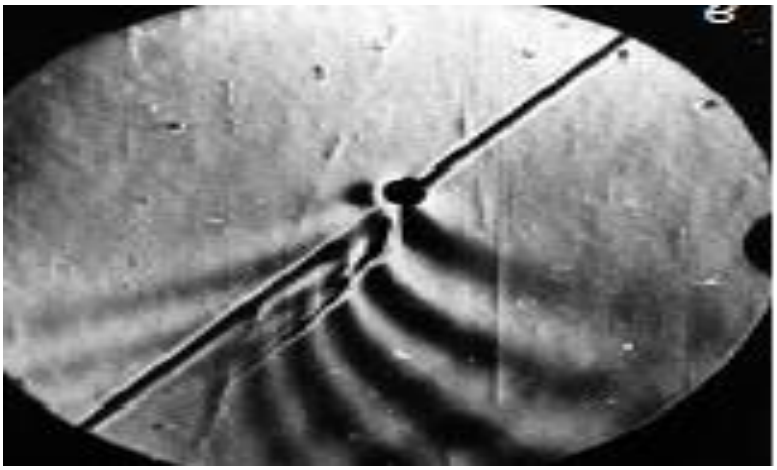


Radiometers

Internal waves in the ocean. Theory and experiment
The problem is to create an adequate model of waves caused by a moving object.



Result of mathematical modeling



Experiment Result

Mathematical Modeling of Mines

Joint projects with corporations "Uralchem" and "Uralkali" consider mathematical modeling of elastoplastic properties of salt formations, processes of creeping, plasticity and cracking in the salt mines of Perm region. Joint activities are related to the safety in potassium mines. Recently this topic became highly actual due to several accidents in salt mines near the town Bereznyaki. We plan to create mathematical model of potassium mines in Bereznyaki (Perm region) in order to predict the phenomena that may cause future accidents.
This project is named "virtual mine". We have already obtained analytical representations for effective characteristics of creeping processes in salt layers with clay inclusions.

Mine collapse in Solikamsk, September 2015

Layered salt formations (Bereznyaki)

Financial Mathematics

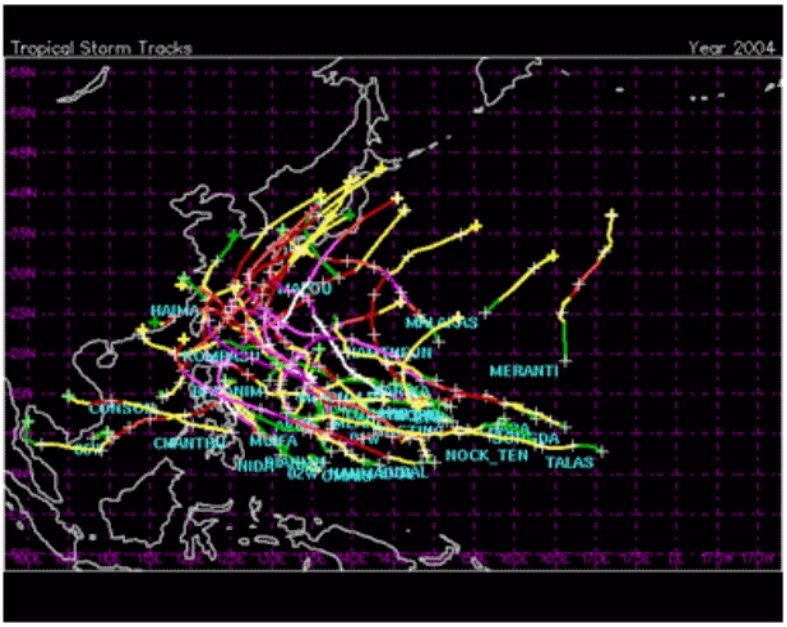
For almost twenty years seminar “Mathematical Models in Economics” is working at the Department of Differential Equations. This seminar is headed by professors O.S.Rozanova and A.S.Shamaev. Participants of this seminar include about 150 students of Mechanics and Mathematics Faculty, whose diploma works consider

mathematical models in economics. We are mostly interested in new and original boundary value problems for differential and integro-differential equations and systems that arise (and this is exactly the case!) in modern financial mathematics and economics.
For example, there are three Ph.D. theses of participants of our seminar - K.Khorev (Boundary value problems with unknown boundary related to the analysis of credit market), G.Kambarbaeva (Equations of Fokker-Plank type, arising in problem of managing an investment portfolio, whose actives are modeled by stochastic differential equations), A.Chechkin (Cauchy problems for parabolic equations with polynomial coefficients arising in actives management and hedging problems); also article of A.Asekov and A.Shamaev devoted to the construction of effective front in the actives management problem, where Fredholm theorems are applied for elliptic operators in unbounded domains. Interesting and new mathematical problems arise in creating actives models taking into account the psychology of market participants (O.S.Rozanova).
In our laboratory we plan to continue practical research in financial mathematics.

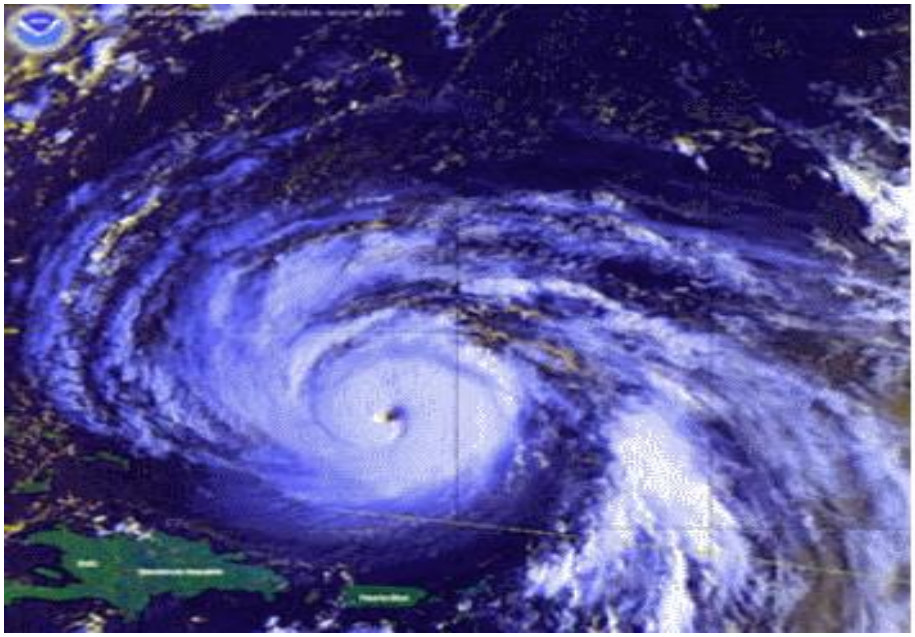
Atmosphere Dynamics

1. Study of large atmospheric vortices
Study of possible trajectories of long-lasting large-scale atmospheric vortices (typhoons or hurricanes), comparison with real trajectories. Study of their structure, conditions of their formation, stability in two-dimensional and three-dimensional models. Full model approximations. Study of topography influence on the trajectory of vortices. Collaboration with scientists from Taiwan, China, USA, France.

1. Rozanova, O.S., Turzynsky, M.K. (2018) Nonlinear stability of localized and non-localized vortices in rotating compressible media, Theory, Numerics and Applications of Hyperbolic Problems, Springer Proceedings in Mathematics & Statistics, v. 236, 567-580.
2. Rozanova, O.S., Turzynsky, M.K. (2018) On Systems of Nonlinear ODE Arising in Gas Dynamics: Application to Vortical Motion, Differential and Difference Equations with Applications. Springer Proceedings in Mathematics & Statistics, v. 230, 387-398.
3. Rozanova O.S. (2016) Frozen and almost frozen structures in the compressible rotating fluid Bulletin of the Brazilian Mathematical Society, 47, № 2, 715-726.
4. Rozanova Olga, Yu Jui-Ling, Hu Chin-Kun (2012) On the position of vortex in a two-dimensional model of atmosphere, Nonlinear Analysis: Real World Applications, 13, 1941-1954.
5. Rozanova Olga S., Yu Jui-Ling, Hu Chin-Kun (2010) Typhoon eye trajectory based on a mathematical model: comparing with observational data, Nonlinear Analysis: Real World Applications, 11, № 3, 1847-1861.



http://weather.unisys.com/hurricane/index.html



REFERENCES

«Bifurcation of traveling waves in a keller-segel type free boundary model of cell motility", Leonid Berlyand, Jan Fuhrmann, and Volodymyr Rybalko, Communications in Mathematical Sciences, V.16, No 3, pp. 735-762 (2018).

«Effective viscosity of bacterial suspensions: a three-dimensional PDE model with stochastic torque» Brian M. Haines, Igor S. Aranson, Leonid Berlyand, and Dmitry A. Karpeev, Comm. Pure Appl. Anal., v. 11(1), pp. 19-46 (2012).

"Effective Viscosity of Dilute Bacterial Suspensions: A Two-Dimensional Model" B.Haines, I.Aronson, Leonid Berlyand and D.Karpeev, Physical Biology, 5:4, 046003 (9pp) (2008).

Bobyleva T.N., Shamaev A.S. An Efficient Algorithm for Calculating Rheological Parameters of Layered Soil Media Composed from Elastic-Creeping Materials // Soil Mechanics and Foundation Engineering. 2017. Vol. 54, № 4. P. 224–230.

Shamaev A. S.; Shumilova V. V. Asymptotic Behavior of the Spectrum of One-Dimensional Vibrations in a Layered Medium Consisting of Elastic and Kelvin-Voigt Viscoelastic Materials // Proceedings of the Steklov Institute of Mathematics. 2016. Vol. 295, № 1. P. 202-212.

Shamaev A. S.; Shumilova V. V. Homogenization of the Equations of State for a Heterogeneous Layered Medium Consisting of Two Creep Materials // Proceedings of the Steklov Institute of Mathematics. 2016. Vol. 295, № 1. P. 213-224.

Shamaev A. S.; Shumilova V. V. Passage of a plane acoustic wave through a layered composite with components of elastic and viscoelastic materials // Acoustical Physics. 2015. Vol. 61, № 1. P. 8-18.

Shamaev A. S.; Shumilova V. V. Reflection of a plane acoustic wave from the interface between an elastic material and a layered elastic-fluid medium // Fluid Dynamics. 2014. Vol. 49, № 6. P. 740-747.

Gavrikov A.A. Small oscillations of an emulsion of two weakly viscous compressible liquids // Journal of Applied Mathematics and Mechanics. 2013. V. 77. I. 5. P. 519-531.

Gavrikov A.A., Knyazkov D., Melnikov A.M., Shamaev A.S., Vedeneev V.V. On limits of applicability of the homogenization method to modeling of layered creep media // IFAC-PapersOnline, V. 51, № 2, P. 144-149.

Shamaev A., Knyazkov D. An Effective Method of Electromagnetic Field Calculation // Lecture Notes in Computer Science. 2013. V 8236, P. 487-494.

Knyazkov D. Web-interface for HPC computation of a plane wave diffraction on a periodic layer // Lobachevskii Journal of Mathematics. 2017. V. 38, № 5, P. 936-93.

Князьков Д.Ю. Обратная задача дифракции электромагнитной волны на плоском слое // Программные системы: теория и приложения. 2017. Т. 9, № 1, с. 21-36.

Князьков Д. Ю. Эффективные методы расчета электромагнитных полей // Выч. мет. программирование, 13:1 (2012), 263–270.

A. Gavrikov, D. Knyazkov, A. Romanova, V. Chernik, A. Shamaev Modeling of the effect of surface waves on the spectrum of the ocean own radiation
(in Russian :Моделирование влияния волнения поверхности на спектр собственного
излучения океана / А. А. Гавриков, Д. Ю. Князьков, А. В. Романова и др. //
Программные системы: теория и приложения. — 2016. — Т. 7, № 2. — С. 73–84.

Асташова И.В. О степенном асимптотическом поведении сингулярных решений слабо нелинейных дифференциальных уравнений типа Эмдена–Фаулера высокого порядка // Дифференциальные уравнения. 2017. Т. 53, № 11, с. 1575-1576.

Асташова И.В. О существовании исчезающих на бесконечности положительных решений дифференциальных уравнений второго порядка с гиперболической нелинейностью // Дифференциальные уравнения. 2016. Т. 52, № 6, с. 838-839.

Асташова И.В. Об асимптотическом поведении решений дифференциальных уравнений с сингулярной нелинейностью // Дифференциальные уравнения. 2014. Т. 50, № 11, с. 1551-1552.

Капустина Т.О. Асимптотические решения сингулярно возмущенной задачи Коши для параболического уравнения с разрывными коэффициентами // Дифференциальные уравнения, издательство Наука (М.), том 36, № 5, с. 662-666.

Kapustina T. On the boundary-value problem for a mixed-type equation: Asymptotic analysis and an effective numerical algorithm // Moscow University Computational Mathematics and Cybernetics. 2017. Т. 41, № 4, с. 157-164.

Rozanova, O.S., Turzynsky, M.K. Nonlinear stability of localized and non-localized vortices in rotating compressible media // Theory, Numerics and Applications of Hyperbolic Problems. Springer Proceedings in Mathematics & Statistics. 2018. V. 236, p. 567-580.

Rozanova O.S., Turzynski M.K. On Systems of Nonlinear ODE Arising in Gas Dynamics: Application to Vortical Motion // Differential and Difference Equations with Applications. ICDDEA 2017. Springer Proceedings in Mathematics & Statistics. 2018 V. 230, p. 387-398.

Rozanova O. Formation of singularities in solutions to ideal hydrodynamics of freely cooling inelastic gases // Nonlinearity. 2012. Т. 25, с. 1547-1558.

Nilsson B., Rozanova O.S., Shelkovich V.M. Mass, momentum and energy conservation laws in zero-pressure gas dynamics and δ-shocks: II // Applicable Analysis. 2011. Т. 90, № 5, с. 831-842.

Oleinik O.A., Yosifyan G.A., Shamaev A.S. Mathematical problems in elasticity and homogenization. Amsterdam: North-Holland, 1992. 412 p.

Chechkin G., Piatnitski A.L., Shamaev A.S. Homogenization: methods and applications. Providence: American Mathematical Society, 2007. 234 p.

Gavrikov A.A., Shamaev A.S. On the Modeling of Creep Layered Structures with Nonlinear Constitutive Relations // IFACPapersOnline, V. 51, № 2, P. 150-155.

Romanov I.V., Shamaev A.S. Exact bounded boundary controllability of vibrations of a two-dimensional membrane //Doklady Mathematics. 2016. V. 94, № 2, p. 607-610.

Shamaev A., Romanov I. Noncontrollability to Rest of the Two-dimensional Distributed System Governed by the Integrodifferential Equation // Journal of Optimization Theory and Appl. 2016, V. 170, № 3, p. 772-782.

Romanov I.V., Shamaev A.S. Exact Controllability of the Distributed System, Governed by String Equation with Memory // Journal of Dynamical and Control Systems. 2013.V. 19, № 4, p. 611-623.

Romanov I.V., Shamaev A.S. On the problem of precise control of the system obeying the delay string equation // Automation and Remote Control. 2013.V. 74, № 11, p. 1810-1819.

LABORATORY STAFF

Director of Laboratory
Professor, PhD
Alexey Stanislavovich Shamaev

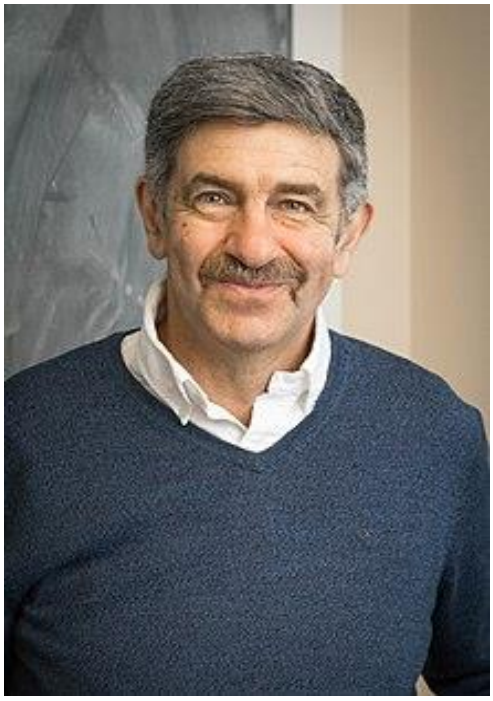
Foreign director and co-founder of the Laboratory
Honorary Professor of Moscow State University, Professor of Pennsylvania State University
Leonid Viktorovich Berlyand
Center for Mathematics of Living and Mimetic Matter and
Center for Interdisciplinary Mathematics

Laboratory members

- Bratus A.S.- professor
- Rozanova O.S.- professor
- Gavrikov A.A. - senior researcher
- Knyazkov D.Yu. - senior researcher
- Kapustina T.O. – associate professor
- Chernik V.V. - researcher
- Romanov M.S.- associate professor
- Turtsynsky M.K. – senior lecturer
- Drozhzhin S.V.- student
- Markin D.V.- postgraduate student

CONTACTS

Address and phone number of the Department of Differential Equations, Faculty of Mechanics and Mathematics, Moscow State University: MSU Main Building, 16-06, phone +7 (495) 939 16 31



Professor L.V.Berlyand
Foreign director and co-founder of the laboratory
http://www.personal.psu.edu/lvb2/

Professor A.S.Shamaev - Director of the laboratory

Professor A.S.Bratus

Professor O.S.Rozanova

Associate Professor T.O.Kapustina

Associate Professor M.S.Romanov

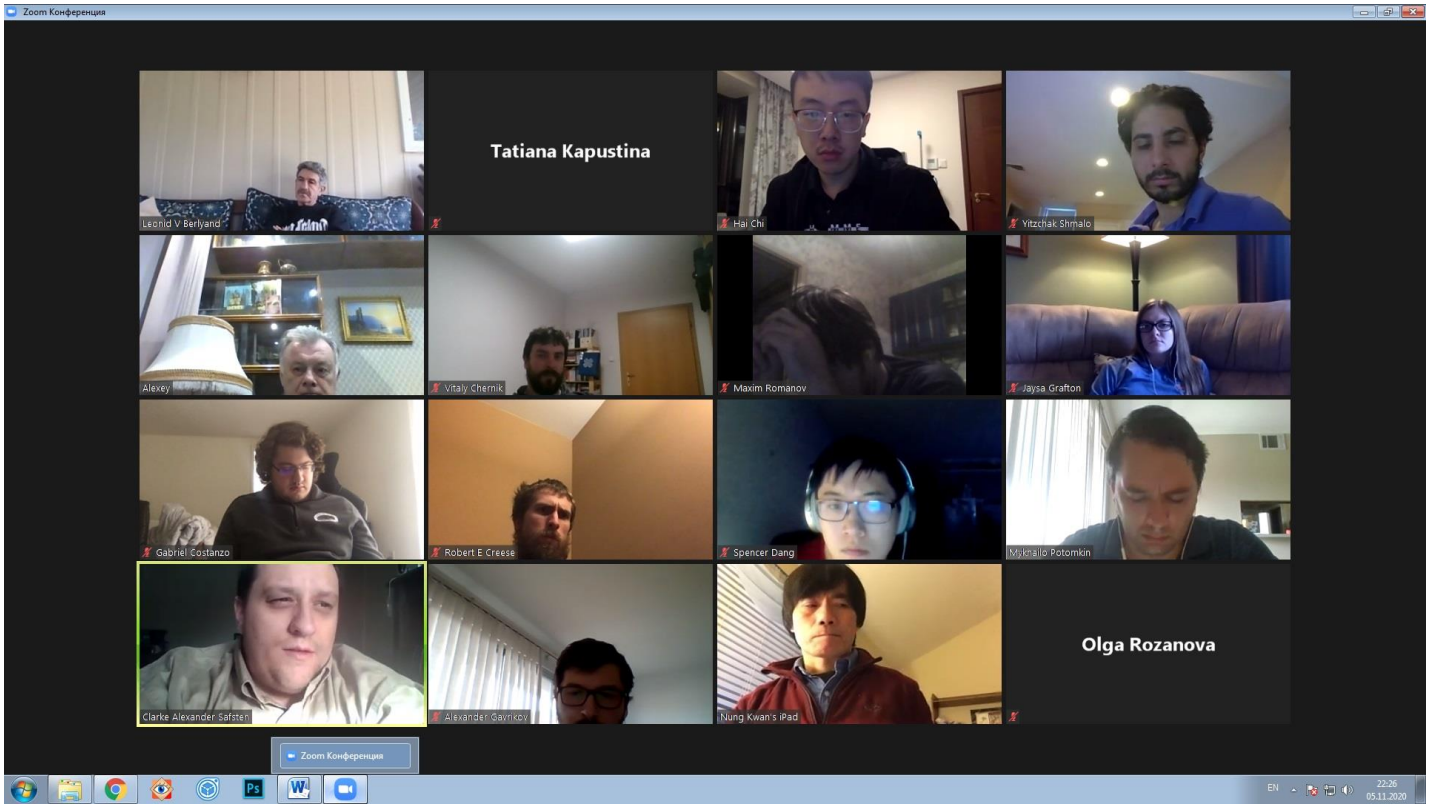
Senior Researcher A.A.Gavrikov
Currently Postdoc Researcher at Penn State University

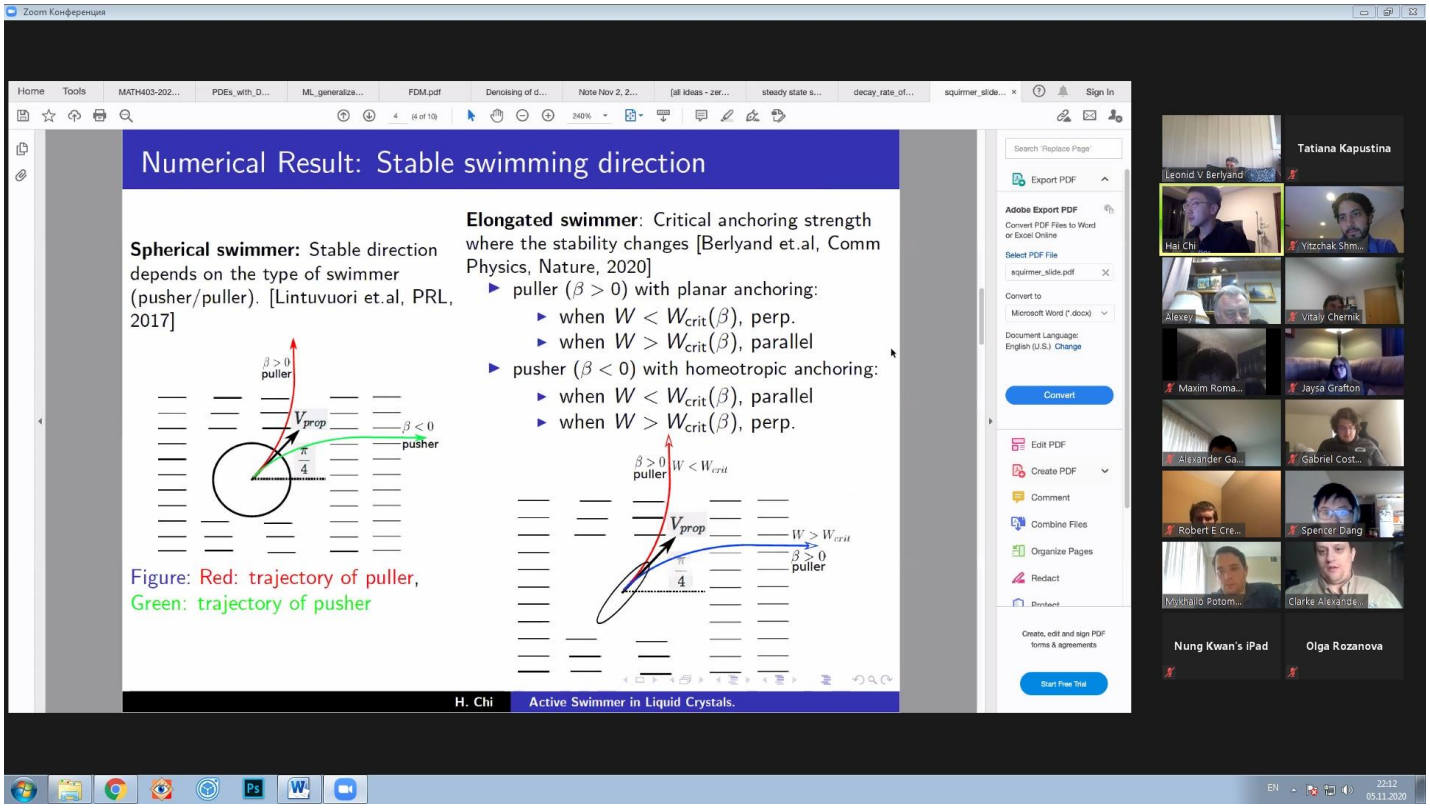
Researcher V.V.Chernik

Senior Researcher D.Yu.Knyazkov

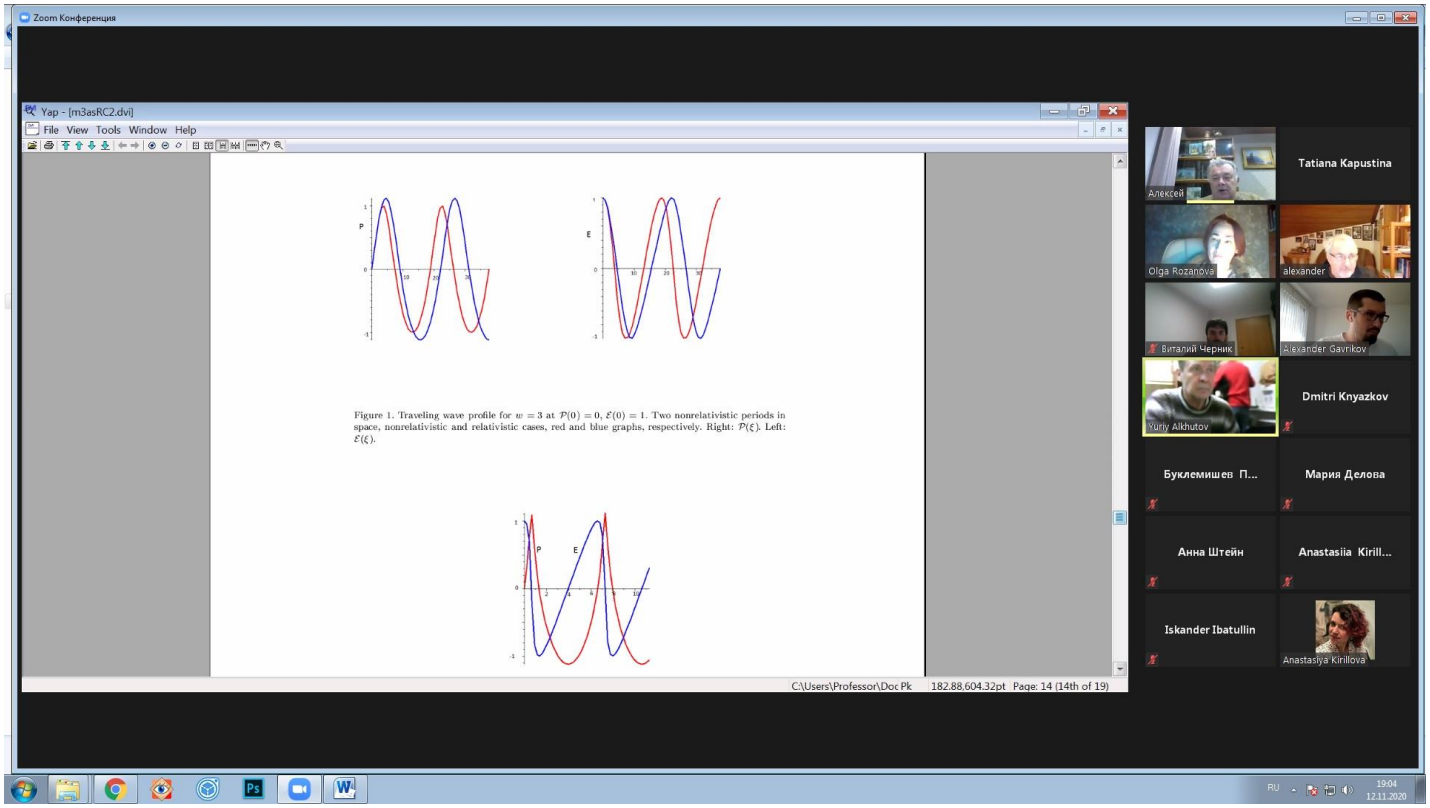
Senior Lecturer M.K.Turtsinsky

Laboratory Seminar





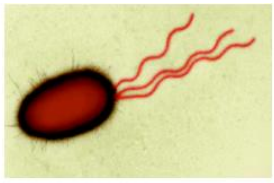
Discussion at joint Russian-American seminar concerning mathematical model of bacteria motion in viscous fluid with complex rheology, which simulates a mucous membrane. The problem is to create mathematical model explaining a number of experimentally observed phenomena in bacteria motion in viscous liquid with complex rheology: the choice of bacteria orientation during movement, mutual influence of bacteria, etc.



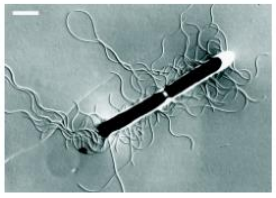
Second line - O.Rozanova and A.Bratus, third line - V.Chernik and A.Gavrikov.

Using appropriate mathematical model of bacteria motion, it would be possible to give recommendations about control of bacteria concentration for medical purposes.

E. coli

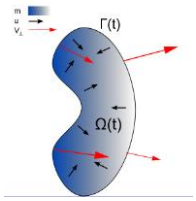


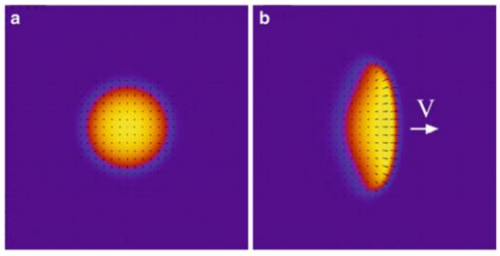
E. coli



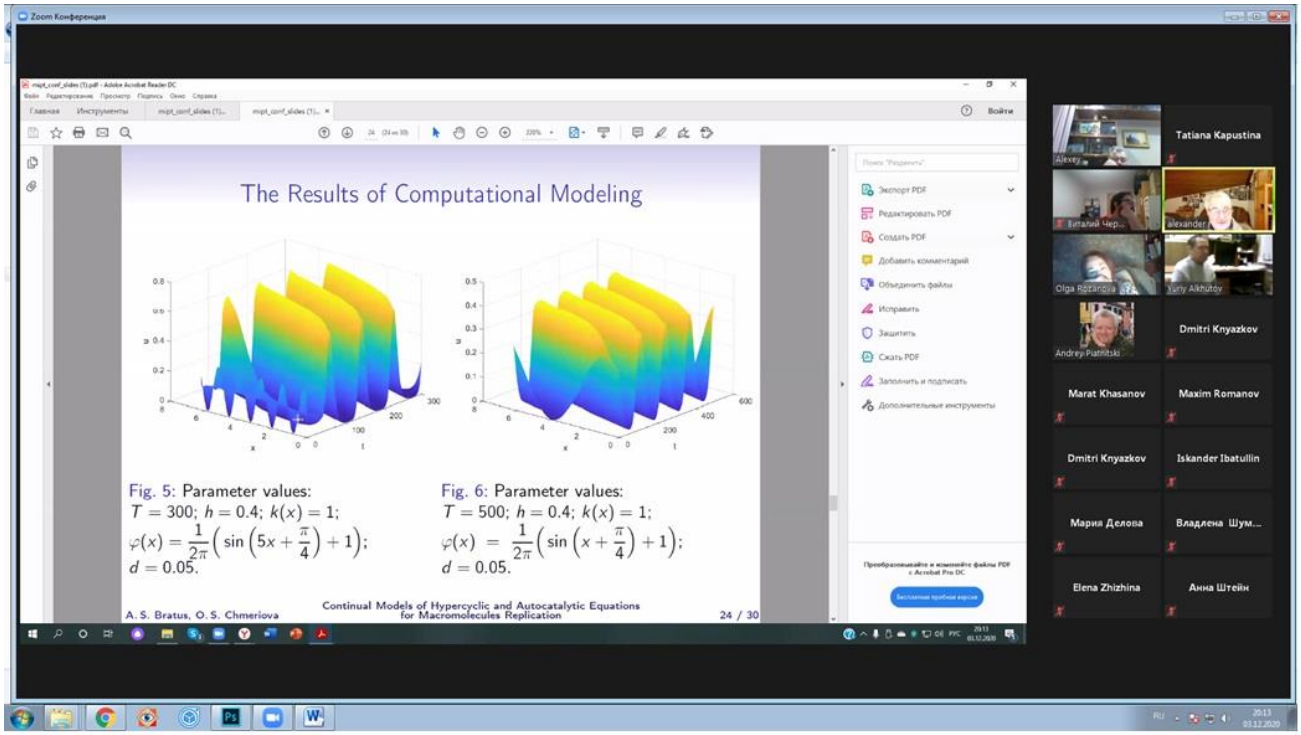
Bacillus subtilis

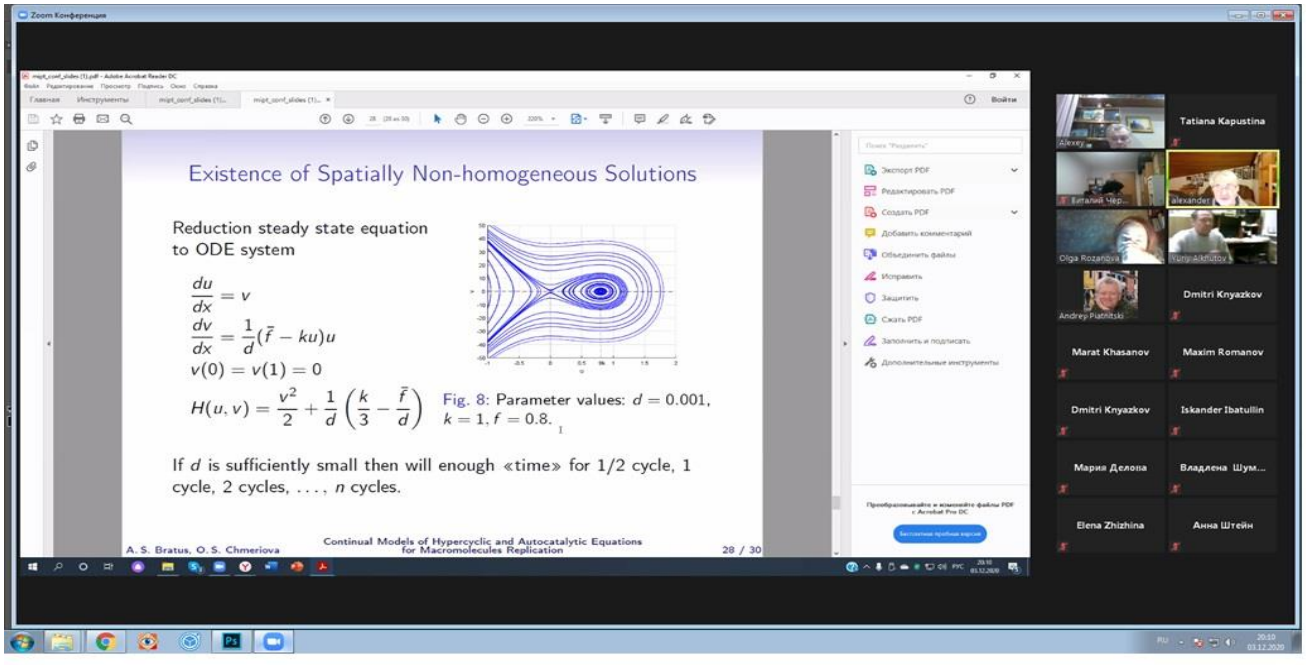
Various types of bacteria. Active elements are visible, which bacteria use to move in liquid medium. Mathematical model should consider bacteria structure.



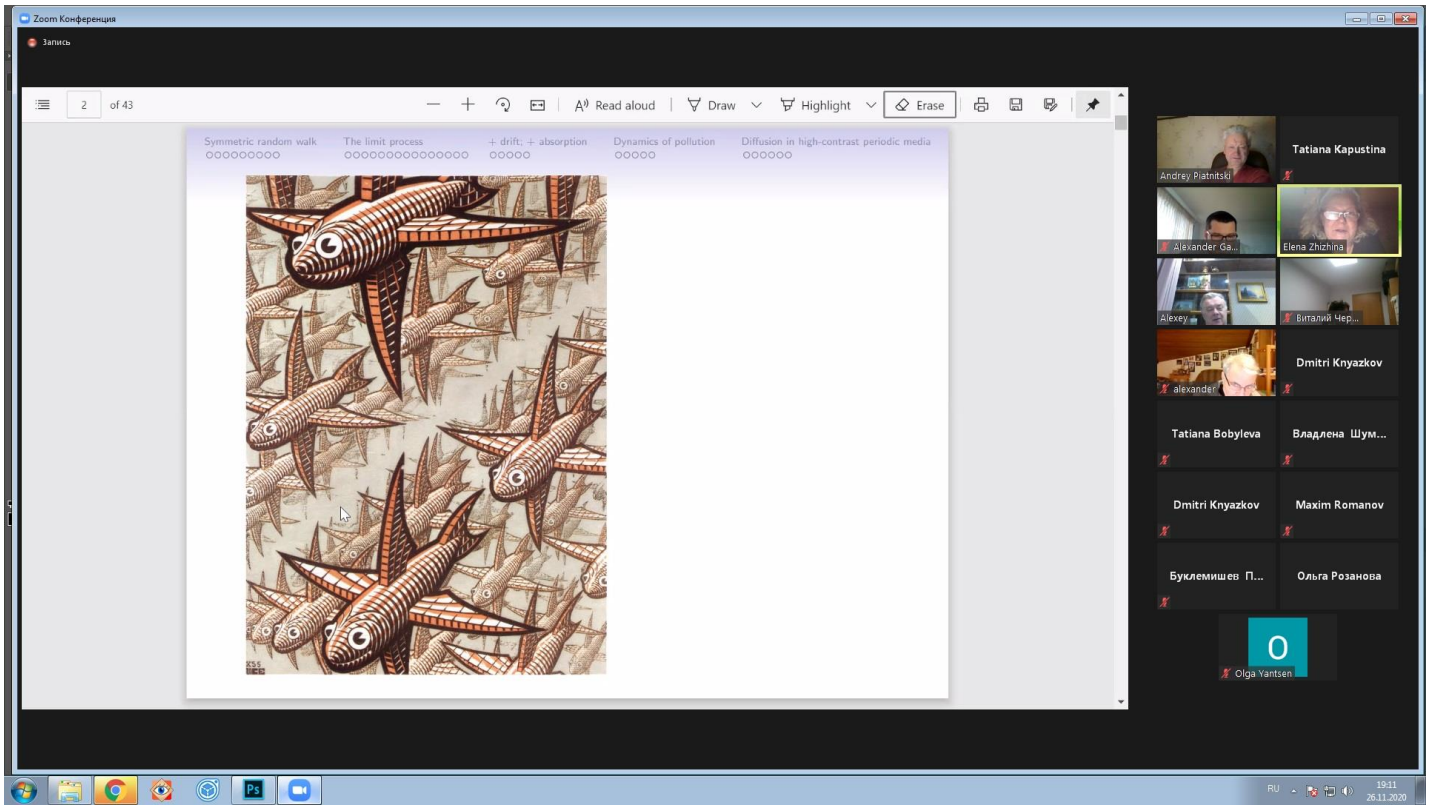


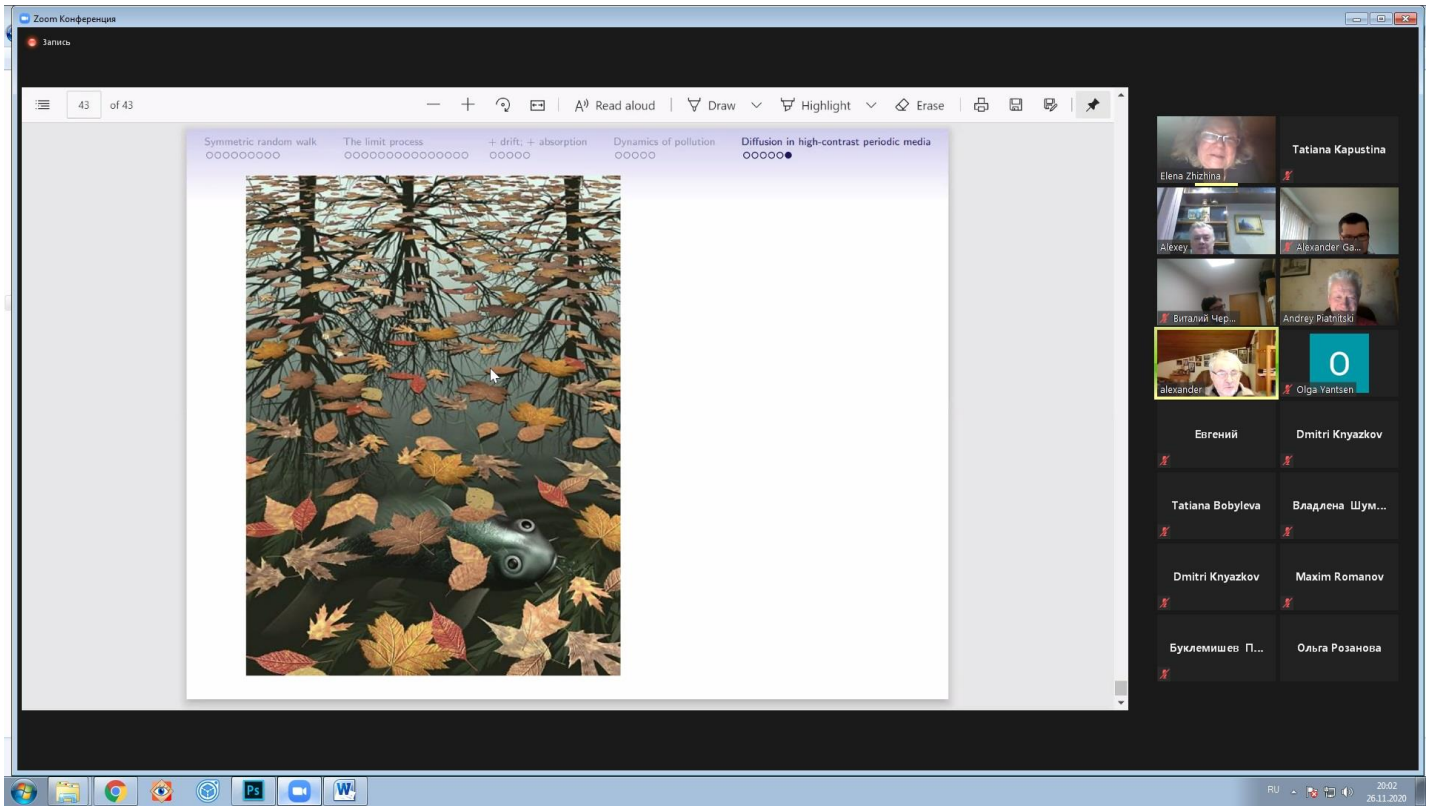
Mathematical modeling of cell motion (phenomenon of "chemotaxis"). When the cell shape or chemical environment is disturbed, the cell begins to move – how to explain it? We are searching for adequate mathematical model.





Discussion at a joint Russian-American seminar: problems concerning stability of hypercyclic replication. This mathematical model is used to simulate the processes of "prebiological" evolution.





Discussion of questions related to biological technologies for water purification. Active films inside the filter contain bacteria which absorb contaminants and hence purify water.