Analytic Theory of Differential and Difference Equations

Online conference dedicated to the memory of Andrey Bolibrukh

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Organizers

Steklov Mathematical Institute of Russian Academy of Sciences, Moscow

Steklov International Mathematical Center, Moscow

Institute for Information Transmission Problems
of the Russian Academy of Sciences (Kharkevich Institute), Moscow

National Research University — Higher School of Economics, Moscow

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Yu. Bibilo, *Application of Painlevé 3 equations to dynamical systems on 2-torus modeling Josephson junction*

V. Dragović, *Dynamics of extremal polynomials, isomonodromic and isoharmonic deformations*

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D. Guzzetti, *Isomonodromic Laplace transform with coalescing eigenvalues and confluence of Fuchsian singularities*

G. Helminck, *Darboux transformations of the dKP hierarchy and its strict version*

A. Khovanskii, *On solvability of linear differential equations by quadratures*

I. Kossovskiy, *Real-analytic coordinates for smooth strictly pseudoconvex CR structures*

A. Lastra, *On Gevrey asymptotics for linear singularly perturbed equations with linear fractional transforms*

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V. Roubtsov, *Quantum Painlevé monodromy manifolds and Sklyanin–Painlevé algebra, II*

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V. Shramchenko, *Algebro-geometric solutions to the* 2×2 *Schlesinger systems*

L. Stolovitch, *Geometry of hyperbolic Cauchy–Riemann singularities and KAM-like theory for holomorphic involutions*

Ts. Stoyanova, *Stokes matrices of a reducible equation with two irregular singularities of Poincaré rank 1 via monodromy matrices of a reducible Heun type equation*

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Ch. Zhang, *On the vanishing of coefficients of the powers of a theta function*

Abstracts

Sequences in the role of coefficients of difference operators

Sergei Abramov, Moulay Barkatou, Marko Petkovšek

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University of Limoges, France
University of Ljubljana, Slovenia

Some properties of linear difference operators whose coefficients have the form of infinite two-sided sequences over a field of characteristic zero are considered. In particular, it is found that such operators are deprived of some properties that are natural for differential operators over differential fields. In addition, we discuss questions of the decidability of certain problems arising in connection with the algorithmic representation of infinite sequences.

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Application of Painlevé 3 equations to dynamical systems on 2-torus modeling Josephson junction

Yulia Bibilo

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We consider a family of dynamical systems modeling overdamped Josephson junction in superconductivity. We focus on the family's rotation number as a function of parameters. Those level sets of the rotation number function that have non-empty interiors are called the *phase-lock areas*. It is known that each phase-lock area is an infinite garland of domains going to infinity in the vertical direction and separated by points. Those separation points that do not lie on the abscissa axis are called *constrictions*.

The model can be equivalently described via a family of linear systems (Josephson type systems) on the Riemann sphere. In the talk we will discuss isomonodromic deformations of the Josephson type systems – they are derived by Painlevé 3 equations. As an application of this approach, we present two new geometric results about the constrictions of the phase-lock areas solving two conjectures about them. We also present some open problems.

The talk is based on a joint work with A. A. Glutsyuk.

Dynamics of extremal polynomials, isomonodromic and iso-harmonic deformations

Vladimir Dragović

University of Texas at Dallas, Richardson, USA

We establish a synergy of integrable billiards, extremal polynomials, Riemann surfaces, combinatorics, potential theory, and isomonodromic deformations. The cross-fertilization between ideas coming from these distinct fields lead to new results in each of them. We introduce a new notion of iso-harmonic deformations. We study their isomonodromic properties in the first nontrivial examples and indicate the genesis of a new class of isomonodromic deformations. The talk is based on the current research with Vasilisa Shramchenko and:

[1] Dragović V., Radnović M., Periodic ellipsoidal billiard trajectories and extremal polynomials, *Comm. Math. Phys.* **372** (2019), 183–211.

[2] Dragović V., Shramchenko V., Algebro-geometric solutions of the Schlesinger systems and the Poncelet-type polygons in higher dimensions, *IMRN* **2018**:13, 4229–4259.

[3] Dragović V., Shramchenko V., Algebro-geometric approach to an Okamoto transformation, the Painlevé VI and Schlesinger equations, *Ann. Henri Poincare* **20**:4 (2019), 1121–1148.

[4] Dragović V., Radnović M., Caustics of Poncelet polygons and classical extremal polynomials, *Regul. Chaotic Dyn.* **24**:1 (2019), 1–35.

[5] Andrews G., Dragović V., Radnović M., Combinatorics of the periodic billiards within quadrics, *Ramanujan J.*, DOI: 10.1007/s11139-020-00346-y (arXiv:1908.01026).

New estimates of the potential in the Schrödinger equation

Aset Durmagambetov

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In this work, we show how the Poincaré–Riemann–Hilbert boundary value problem enables us to construct effective estimates of the potential in the Schrödinger equation. The apparatus of the three-dimensional inverse problem of quantum scattering theory is developed for this. It is shown that the unitary scattering operator can be studied as a solution of the Poincaré–Riemann–Hilbert boundary value problem. This allows us to go on to study the potential in the Schrödinger equation.

Convergence of generalized power series solutions of q-difference equations: the case without small divisors

RENAT GONTSOV

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Compared to formal solutions of algebraic equations, which are Puiseux power series at most, algebraic ordinary *differential* equations in general may have formal solutions in the form of power series with complex power exponents. Algebraic q-*difference* equations also may have such formal solutions, which are a newer object for studying though, compared with the differential case.

In this talk based on joint work with Irina Goryuchkina and Alberto Lastra, we study a question of the convergence of *generalized* formal power series solutions (those with complex power exponents) to an algebraic q-difference equation

$$F(z, u(z), u(qz), \ldots, u(q^n z)) = 0,$$

where F is a polynomial and $q \neq 0, 1$ is a fixed complex number. Even for formal Taylor series solutions, an additional phenomenon of small divisors that prevents convergence may arise for $|q| = 1$ (J.-P. Bézivin's, L. Di Vizio's works), in contrast to the differential case where one does not meet this phenomenon studying a question of convergence. For generalized power series solutions, the small divisors phenomenon may occur not only in the case of $|q| = 1$. Beginning the study of generalized formal power series solutions to algebraic q-difference equations, here we restrict ourselves to the case where small divisors do not arise and obtain a sufficient condition of the convergence of such formal solutions in this situation.

Isomonodromic Laplace transform with coalescing eigenvalues and confluence of Fuchsian singularities

Davide Guzzetti

SISSA, Trieste, Italy

This talk is based to the paper [4], which is submitted to a journal and will be put on arXiv soon. We consider a Pfaffian system expressing isomonodromy of an irregular system of Okubo type, depending on complex deformation parameters $u = (u_1, \ldots, u_n)$, which are eigenvalues of the leading matrix at the irregular singuilarity. At the same time, we consider a Pfaffian system of non-normalized Schlesinger type expressing isomonodromy of a Fuchsian system, whose poles are the deformation parameters $u_1, \ldots, u_n$. The parameters vary in a polydisc containing a coalescence locus for the eigenvalues of the leading matrix of the irregular system, corresponding to confluence of the Fuchsian singularities. We construct isomonodromic selected and singular vector solutions of the Fuchsian Pfaffian system together with their isomonodromic connection coefficients. This extends a result of [1] and [3] to the isomonodromic case, including confluence of singularities.

Then, we introduce an isomonodromic Laplace transform of the selected and singular vector solutions, allowing to obtain isomonodromic fundamental solutions for the irregular system, and their Stokes matrices expressed in terms of connection coefficients.

These facts, in addition to extending [1,3] to the isomonodromic case (with coalescences/confluences), allow to prove by means of Laplace transform the main result of [2], namely the analytic theory of non-generic isomonodromic deformations of the irregular system with coalescing eigenvalues.

[1] Balser W., Jurkat W.B., Lutz D.A., On the reduction of connection problems for differential equations with irregular singular points to ones with only regular singularities, I, *SIAM J. Math. Anal.* **12**:5 (1981), 691–721.

[2] Cotti G., Dubrovin B., Guzzetti D., Isomonodromy deformations at an irregular singularity with coalescing eigenvalues, *Duke Math. J.* **168**:6 (2019), 967–1108.

[3] Guzzetti D., On Stokes matrices in terms of connection coefficients, *Funkcial. Ekvac.* **59**:3 (2016), 383–433.

[4] Guzzetti D., Isomonodromic Laplace transform with coalescing eigenvalues and confluence of Fuchsian singularities, submitted (2020).

Darboux transformations of the dKP hierarchy and its strict version

Gerardus Helminck

KdV Institute, University of Amsterdam, The Netherlands

We introduce for the discrete KP hierarchy and its strict version the analogue of the notion of Darboux transformation from the differential setting and we describe in the geometric picture which solutions are linked by such a transformation.

On solvability of linear differential equations by quadratures

Askold Khovanskii

University of Toronto, Canada

In 1839 Liouville published his ingenious pioneering work containing an elementary criterium for solvability of second order linear differential equations by quadratures. Surprisingly beatific Liouville's theory did not get an appropriate credit. About 70 years later Picard and Vessiot found a criterium for solvability of a linear differential equation of arbitrary order n in terms of its Galois group. This result is based on their differential Galois theory which is rather involved.

In 1948 J. F. Ritt clarified the original Liouville's proof [1], [3]. In 2018 I understood that the elementary Liouville–Ritt method based on developing solutions in Puiseux series as functions of a parameter works smoothly for an arbitrary n and proved a similar criterium [2], [3]. In the talk I will discuss this criterium and ideas of its proof.

[1] Ritt J. F., Integration in Finite Terms. Liouville's Theory of Elementary Methods. Columbia University Press, New York, 1948.

[2] Khovanskii A. G., Solvability of equations by quadratures and Newton's theorem, *Arnold Math. J.* **4**:2 (2018), 193–211.

[3] Khovanskii A. G., Comments on J. F. Ritt's book "Integration in Finite Terms", arXiv:1908.02048 [math.AG] (Aug 2019).

Real-analytic coordinates for smooth strictly pseudoconvex CR structures

Ilya Kossovskiy

Masaryk University, Brno, Czech Republic

Let M be a smooth manifold, E the complexified tangent bundle, $X_1, \dots, X_k$ local sections of E satisfying the integrability condition. Under which condition there exists a (local) smooth diffeomorphism transforming the vector fields $X_1, \dots, X_k$ into real-analytic ones? We resolve this question for the case when the vector fields generate a hypersurface type strongly pseudoconvex CR structure.

On Gevrey asymptotics for linear singularly perturbed equations with linear fractional transforms

Alberto Lastra

University of Alcalá, Madrid, Spain

A family of linear singularly perturbed Cauchy problems is studied. The equations defining the problem combine partial differential operators together with the action of linear fractional transforms. The exotic geometry of the problem in the Borel plane, involving both sectorial regions and strip-like sets, gives rise to asymptotic results relating the analytic solution and the formal one through Gevrey asymptotic expansions. The main results lean on the appearance of domains in the complex plane which remain intimately related to Lambert W function, which turns out to be crucial in the construction of the analytic solutions.

This is a joint work with Stéphane Malek.

Projective structures and neighborhoods of rational curves

Frank Loray

Institut de Recherhe Mathématique de Rennes, France

We survey on a construction going back to Cartan, and leading, in a paper of Hitchin, to a non linear generalization of the duality between lines and points in the projective plane. Projective structures are defined by second order differential equations, like Painleve equations, while neighborhoods of rational curves have been classified by Grauert and Mishustin. We will explain this duality in details and discuss the existence of meromorphic functions on the neighborhoods. We end by some results recently obtained in collaboration with Maycol Falla Luza.

Quantum Painlevé monodromy manifolds and Sklyanin–Painlevé algebra, I

Marta Mazzocco

University of Birmingham, United Kingdom

In this talk, I will discuss the Painlevé monodromy manifolds as a special class of del Pezzo surfaces. I will discuss the natural Poisson structure on these manifolds and the Riemann–Hilbert correspondence in terms of a map between Okamoto and Looijenga pairs. Finally, I will related introduce the generalised Sklyanin–Painlevé algebra.

On commuting difference operators

Andrey Mironov

Sobolev Institute of Mathematics RAS, Novosibirsk, Russia

We consider one-point commuting difference operators of rank one. The coefficients of these operators depend on a functional parameter, shift operators being included only with positive degrees. We study these operators in the case of hyperelliptic spectral curves when the marked point coincides with the branch point. We construct examples of operators with polynomial and trigonometric coefficients. Moreover, difference operators with polynomial coefficients can be embedded in the differential ones with polynomial coefficients. This construction provides a way of constructing commutative subalgebras in the first Weyl algebra.

Nilpotent singularities of foliations of generalized Poincaré–Dulac type

JORGE MOZO

University of Valladolid, Spain

We will review several results concerning nilpotent singularities of holomorphic foliations in dimension two, and we shall focus in some recent work being done in the case when, in the reduction of singularities of such a foliation, a singularity of Poincaré–Dulac type appears. It is a case that apparently has not been treated yet by the different authors who have studied these singularities.

It is work in progress, in collaboration with Percy Fernández (PUCP, Peru).

q-Stokes phenomenon of basic hypergeometric equations and the Painlevé equations

YOUSUKE OHYAMA

Tokushima University, Japan

We study q-connection problems and q-Stokes phenomenon on basic hypergeometric equations. We apply the connection formula to global analysis on q-Painlevé equations. Some parts are joint works with Changgui Zhang (Lille).

Quantum Painlevé monodromy manifolds and Sklyanin–Painlevé algebra, II

Vladimir Roubtsov

University of Angers, France

In this talk, I will study the generalised Sklyanin–Painlevé algebra and characterise its PBW/PHS/Koszul properties. This algebra contains as limiting cases the generalised Sklyanin algebra, Etingof–Ginzburg and Etingof–Oblomkov–Rains quantum del Pezzo as well as the quantum monodromy manifolds of the Painlevé equations.

Isomonodromic degenerations of irregular singularities

Claude Sabbah

Ecole Polytechnique, Palaiseau, France

Part of the work of Andrey Bolibrukh has been concerned with isomonodromic confluence of regular singularities of differential equations. In this talk, I will consider cases with irregular singularities, inspired by the work of Cotti, Dubrovin and Guzzetti. I will emphasize the use of asymptotic normal forms for irregular singularities in higher dimensions.

Right inverses for the asymptotic Borel map in ultraholomorphic classes on sectors

JAVIER SANZ

University of Valladolid, Spain

We present results about the existence of local and global right inverses for the asymptotic Borel map in Carleman–Roumieu ultraholomorphic classes in sectors. By local right inverses we understand those which interpolate for asymptotic power series of a fixed type, while the global ones are defined in the corresponding whole space of Carleman–Roumieu formal power series. We extend previous results by J. Schmets and M. Valdivia and by V. Thilliez, and show the prominent role played by the index $\gamma(\mathbb{M})$ of Thilliez and the condition (β_2) of H.-J. Petzsche. The techniques involve different facts from the general theory of regular variation.

This is joint work with J. Jiménez-Garrido (University of Cantabria, Spain) and G. Schindl (University of Vienna, Austria).

Uniformization of holomorphic foliations with hyperbolic leaves

Arsenii Shcherbakov

Independent Moscow University, Russia

We consider foliations of compact complex manifolds by analytic curves. We suppose that the line bundle tangent to the foliation is negative. We show that in a generic case the manifold of universal coverings with the base B is diffeomorphic to $B \times D$ (D is the unit disk) with some almost complex structure quasiconformic on the fibers. Also there exists a finitely smooth homeomophism, holomorphic on the fibers and mapping fiberwise the manifold of universal coverings onto some domain in $B \times \mathbb{C}$ with continuous boundary. The problem can be reduced to a study of the Beltrami equation with parameters on the unit disk in the case, when derivatives of the corresponding Beltrami coefficient grow no faster than some negative power of the distance to the boundary of the disk.

Algebro-geometric solutions to the 2×2 Schlesinger systems

Vasilisa Shramchenko

University of Sherbrooke, Canada

A 2×2 Schlesinger system is naturally associated with a family of hyperelliptic curves. In some cases, one can solve the Schlesinger system in terms of various quantities defined on these curves. We'll discuss and compare two such solutions and their tau-functions.

Geometry of hyperbolic Cauchy–Riemann singularities and KAM-like theory for holomorphic involutions

Laurent Stolovitch

University of Nice, France

This joint work with Z. Zhao (Nice) is concerned with the geometry of germs of real analytic surfaces in $(\mathbb{C}^2, 0)$ having an isolated Cauchy–Riemann (CR) singularity at the origin. These are perturbations of *Bishop quadrics*. There are two kinds of CR singularities stable under perturbation : *elliptic* and *hyperbolic*. Elliptic case was studied by Moser–Webster who showed that such a surface is locally, near the CR singularity, holomorphically equivalent to *normal form* from which lots of geometric features can be read off.

In this talk we focus on perturbations of *hyperbolic* quadrics. As was shown by Moser–Webster, such a surface can be transformed to a formal *normal form* by a formal change of coordinates that may not be holomorphic in any neighborhood of the origin.

Given a *non-degenerate* real analytic surface M in $(\mathbb{C}^2, 0)$ having a *hyperbolic* CR singularity at the origin, we prove the existence of Whitney smooth family of holomorphic curves intersecting M along holomorphic hyperbolas. This is the very first result concerning hyperbolic CR singularity not equivalent to quadrics.

This is a consequence of a non-standard KAM-like theorem for pair of germs of holomorphic involutions $\{\tau_1, \tau_2\}$ at the origin, a common fixed point. We show that such a pair has large amount of invariant analytic sets biholomorphic to $\{z_1 z_2 = const\}$ (which is not a torus) in a neighborhood of the origin, and that they are conjugate to restrictions of linear maps on such invariant sets.

Stokes matrices of a reducible equation with two irregular singularities of Poincaré rank 1 via monodromy matrices of a reducible Heun type equation

Tsvetana Stoyanova

Sofia University "St. Kliment Ohridski", Bulgaria

In this talk we consider a second order reducible equation that has non-resonant singularities at $x = 0$ and $x = \infty$. Both of them are of Poincaré rank 1. By introducing a small complex parameter ε we split together $x = 0$ and $x = \infty$ into four different Fuchsian singularities $x_L = -\sqrt{\varepsilon}$, $x_R = \sqrt{\varepsilon}$ and $x_{LL} = -1/\sqrt{\varepsilon}$, $x_{RR} = 1/\sqrt{\varepsilon}$. The perturbed equation is a second order reducible Fuchsian equation with four different singularities, *i.e.*, a Heun type equation. We prove that when the perturbed equation has exactly two resonant singular points of different type, all the Stokes matrices of the initial equation are realized as a limit of the parts of the monodromy matrices of the perturbed equation when $\varepsilon \to 0$. To establish this result we combine a direct computation with a theoretical approach.

This talk is partially supported by Grant DN 02-5/2016 of Bulgarian Fond "Scientific Research".

Darboux transformations for orthogonal differential systems and differential Galois theory

Jacques-Arthur Weil

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On the vanishing of coefficients of the powers of a theta function

Changgui Zhang

University of Lille, France

A result on the Galois theory of q-difference equations leads to the following question: if $0 < |q| < 1$ and if one sets

$$\theta_q(z) := \sum_{m \in \mathbb{Z}} q^{m(m-1)/2} z^m,$$

can some coefficients of the Laurent series expansion of $\theta_q^n(z)$, $n \in \mathbb{N}^*$, vanish? We give a partial answer. This is a joint work with Jacques Sauloy (see arXiv:2007.16092[math.DS]).

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