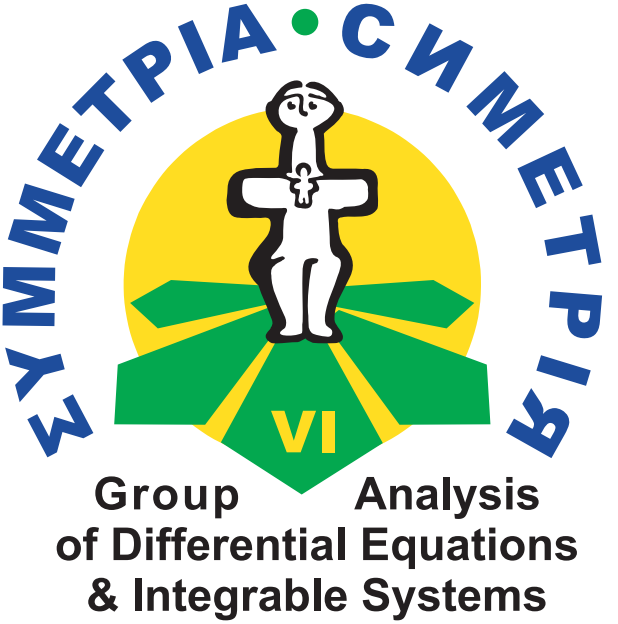
*The 6th International Workshop*




# Book of Abstracts

**Protaras, Cyprus**

**June 17–21, 2012**

# Preface

The Sixth International Workshop *Group Analysis of Differential Equations and Integrable Systems* GADEIS-VI will take place in Protaras, Cyprus, June 17–21, 2012 (http://www2.ucy.ac.cy/ symmetry/).

The aim of the meeting is to bring together leading scientists in group analysis, integrability and mathematical modelling. The main emphasis of the workshop will be on applications of group methods in investigating nonlinear wave and diffusion phenomena, integrability theory, the modern theory of Lie groups and Lie algebras as well as the classical heritage, historical aspects and new theoretical developments in group analysis.

The series of Workshops is organized by the Department of Mathematics and Statistics of the University of Cyprus and the Department of Applied Research of the Institute of Mathematics of the National Academy of Science of Ukraine. The theme of the series is concentrated on recent development in Lie theory of differential equations and integrability. It was initiated in 2005 as a meeting for discussion of results obtained due to intensive cooperation between the teams of Cyprian and Ukrainian scientists. The first three Workshops took place in the new Campus of the University of Cyprus near Nicosia October 27 (2005), September 25–28 (2006) and October 4–5 (2007). The forth and fifth Workshops took place in Protaras October 26–30 (2008) and June 6–10 (2010). The range of problems discussed on the Workshops is permanently extended.

Approximately 50 scientists from more than 20 different countries will participate in the Sixth Workshop. The proceedings of the workshop will be published.

*The Organizers*

## *Organizing Committee of the Series*

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# Workshop Programme

## Sunday, June 17

Arrival day

20.00–21.00 *Registration*

## Monday, June 18

8.30–9.00 *Registration*

**Chairperson Nikitin A.G.**

9.00–9.30 **Winternitz P.** Symmetries of difference equations and symmetry preserving discretization of differential equations

9.30–10.00 **Meleshko S.V.** On group classification of the spatially homogeneous and isotropic Boltzmann equation with sources

10.00–10.30 **Šnobl L.** Solvable Lie algebras with Borel nilradicals

10.30–11.00 **Novotny P.** Graded contractions of representations of Lie algebra $sl(3,\mathbb{C})$

11.00–11.30 *Coffee break*

**Chairperson Popovych R.**

11.30–12.00 **Pavlov M.** Finite component reductions of collisionless kinetic equations

12.00–12.30 **Kiselev A.V.** The deformation quantisation problem for multiplicative structures on noncommutative jet spaces

12.30–13.00 **Morozov O.** Recursion operators as Bäcklund autotransformations for tangent coverings and Cartan's method of equivalence

13.00–13.30 **Rosenhaus V.** On differential equations with infinite conservation laws

13.30–17.00 *Lunch break*

**Chairperson Tracinà R.**

17.00–17.20 **Popovych R.** Group classification of differential equations within the algebraic approach

17.20–17.40 **Vaneeva O.** Point transformations in classes of differential equations

17.40–18.00 **Andriopoulos K.** The Miller and Weller equation: complete group classification and conservation laws

18.00–18.20 **Stepanova I.V.** Group properties of equations of thermodiffusion convection in binary mixture

18.20–18.40 **Kallinikos N.** Symmetries of motion in electromagnetic fields

18.40–18.55 **Lyons T.** The inverse scattering transform applied to energy dependant spectral problems

18.55–19.10 **Popovych D.** Non-universality of IW-contractions

## Tuesday, June 19

**Chairperson Damianou P.**

9.00–9.30 **Dragović V.** Pseudo-integrable billiards: topological and arithmetic aspects

9.30–10.00 **Sabourin H.** Specific properties of the transverse Poisson structure to the minimal nilpotent orbit in a semi-simple Lie algebra

10.00–10.30 **Veselov A.** Universality in Lie algebras and Chern-Simons theory

10.30–11.00 **Hrivnak J.** Discretization of new Weyl group orbit functions

11.00–11.30 *Coffee break*

**Chairperson Veselov A.**

11.30–12.00 **Ivanov R.** Singular solutions of cross-coupled equations of Camassa–Holm type: waltzing peakons and compacton pairs

12.00–12.30 **Vladimirov V.** On the stability and dynamical features of localized traveling wave solutions to a hydrodynamic-type system of PDEs

12.30–13.00 **Meletlidou E.** Non integrability and continuation of periodic orbits in Hamiltonian systems under small perturbations

13.00–13.30 **Acatrinei C.** Nonlocal waves on a discrete space

13.30–17.00 *Lunch break*

**Chairperson Kiselev A.V.**

17.00–17.20 **Xenitidis P.** Linearization and potentiation of difference equations

17.20–17.40 **Boyko V.M.** Lie symmetries of systems of second-order linear ODEs with constant coefficients

17.40–18.00 **Sardón C.** Miura-reciprocal transformations for hierarchies in $2+1$ dimensions

18.00–18.20 **Kouloukas T.** Re-factorization problems related to Yang–Baxter maps

18.20–18.40 **Evripidou C.** Characteristic and Coxeter polynomials for affine Lie algebras

18.40–18.55 **Ringers S.** A comparison of definitions for the Schouten bracket on jet spaces

18.55–19.10 **Karásek D.** Lie algebras as symmetry algebras of a system of ODEs

19.10–20.20 Documentary film “Late Style” devoted to Yu.I. Manin

## Wednesday, June 20

**Chairperson Winternitz P.**

9.00–9.30 **Nikitin A.G.** Supersymmetric and superintegrable systems of coupled Schrödinger equations

9.30–10.00 **Leach P.G.L.** A novel Riccati sequence

10.00–10.30 **Chadzitaskos G.** Coherent states of down conversion process

10.30–11.00 **Maharaj S.** Stellar models with quadratic equation of state

11.00–11.30 *Coffee break*

**Chairperson Leach P.G.L.**

11.30–12.00 **Yehorchenko I.** Hidden symmetries for the wave equation with additional conditions

12.00–12.30 **Estévez P.G.** Construction of lumps with non-trivial interaction for a $2+1$ dimensional nonlinear Schrödinger equation

12.30–13.00 **Prada J.** On differential operators of infinite order in sequence spaces

13.00–13.30 **Abd-el-Malek M.B.** Group theoretic method and new exact solutions for problem of a heat mass transfer

13.30–15.00 *Lunch break*

15.00 *Excursion to Larnaca*

## Thursday, June 21

Departure

# List of Participants

1. **ABD-EL-MALEK Mina** (Alexandria University & American University in Cairo, Egypt)
   e-mail: minab@aucegypt.edu
2. **ACATRINEI Ciprian** (National Institute for Nuclear Physics and Engineering, Bucharest, Romania)
   e-mail: acatrine@theory.nipne.ro
3. **ANDRIOPOULOS Konstantinos** (The Moraitis School, Athens, Greece)
   e-mail: kand@aegean.gr
4. **BOYKO Vyacheslav** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
   e-mail: boyko@imath.kiev.ua
5. **CHADZITASKOS Goce** (Czech Technical University in Prague, Czech Republic)
   e-mail: goce.chadzitaskos@fjfi.cvut.cz
6. **CHARALAMBIDES Stelios** (University of Cyprus, Nicosia, Cyprus)
   e-mail: steliosc@ucy.ac.cy
7. **CHARALAMBOUS Kyriacos** (University of Cyprus, Nicosia, Cyprus)
   e-mail: kyriakosnj20@gmail.com
8. **CHRISTOU Marios** (University of Nicosia, Cyprus)
   e-mail: christou.ma@unic.ac.cy
9. **CICOGNA Giampaolo** (University of Pisa, Italy)
   e-mail: cicogna@df.unipi.it
10. **DAMIANOU Pantelis** (University of Cyprus, Nicosia, Cyprus)
    e-mail: damianou@ucy.ac.cy
11. **DRAGOVIĆ Vladimir** (Mathematical Institute SANU, Belgrade, Serbia & University of Lisbon, Portugal)
    e-mail: vladad@mi.sanu.ac.rs
12. **ESTÉVEZ Pilar G.** (University of Salamanca, Spain)
    e-mail: pilar@usal.es
13. **EVRIPIDOU Charalambos** (University of Cyprus, Nicosia, Cyprus)
    e-mail: cevrip02@ucy.ac.cy

14. **HRIVNAK Jiri** (Czech Technical University in Prague, Czech Republic)
    e-mail: jiri.hrivnak@fjfi.cvut.cz
15. **IVANOV Rossen** (School of Mathematical Sciences, Dublin Institute of Technology, Ireland)
    e-mail: rossen.ivanov@dit.ie
16. **IVANOVA Nataliya** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine & University of Cyprus, Nicosia, Cyprus)
    e-mail: ivanova.nataliya@gmail.com
17. **KALLINIKOS Nicos** (Aristotle University of Thessaloniki, Greece)
    e-mail: kallinikos@auth.gr
18. **KARÁSEK Dalibor** (Czech Technical University in Prague, Czech Republic)
    e-mail: dalibor.karasek@fjfi.cvut.cz
19. **KISELEV Arthemy** (Johann Bernoulli Institute, Royal University of Groningen, The Netherlands)
    e-mail: A.V.Kiselev@rug.nl
20. **KONTOGIORGHIS Stavros** (University of Cyprus, Nicosia, Cyprus)
    e-mail: kontogeorgis.stavros@ucy.ac.cy
21. **KOULOUKAS Theodoros** (University of Patras, Greece)
    e-mail: tkoulou@master.math.upatras.gr
22. **LEACH Peter** (University of KwaZulu-Natal, South Africa & University of Cyprus, Nicosia, Cyprus)
    e-mail: leach@ucy.ac.cy
23. **LYONS Tony** (School of Mathematical Sciences, Dublin Institute of Technology, Ireland)
    e-mail: d09120266@mydit.ie
24. **MAHARAJ Sunil** (University of KwaZulu-Natal, South Africa)
    e-mail: sun.maharaj@gmail.com
25. **MELESHKO Sergey** (Suranaree University of Technology, Nakhon Ratchasima, Thailand)
    e-mail: sergey@math.sut.ac.th
26. **MELETLIDOU Efthymia** (Aristotle University of Thessaloniki, Greece)
    e-mail: efthymia@auth.gr

27. **MOROZOV Oleg** (Institute of Mathematics and Statistics, University of Tromsø, Norway)
    e-mail: Oleg.Morozov@uit.no
28. **NESTERENKO Maryna** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
    e-mail: maryna@imath.kiev.ua
29. **NIKITIN Anatoly** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
    e-mail: nikitin@imath.kiev.ua
30. **NOVOTNY Petr** (Czech Technical University in Prague, Czech Republic)
    e-mail: petr.novotny@fjfi.cvut.cz
31. **PATERA Jiri** (CRM, University of Montreal, Canada)
    e-mail: patera@CRM.UMontreal.CA
32. **PAVLOV Maxim** (Moscow State University, Russia)
    e-mail: maxim@math.sinica.edu.tw
33. **POPOVYCH Dmytro** (Taras Shevchenko National University of Kyiv, Ukraine)
    e-mail: deviuss@gmail.com
34. **POPOVYCH Roman** (Wolfgang Pauli Institute, Vienna, Austria & Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
    e-mail: roman.popovych@gmail.com
35. **PRADA Julia** (University of Salamanca, Spain)
    e-mail: prada@usal.es
36. **RINGERS Sietse** (Johann Bernoulli Institute, Royal University of Groningen, The Netherlands)
    e-mail: S.Ringers@rug.nl
37. **ROSENHAUS Vladimir** (California State University, Chico, USA)
    e-mail: VRosenhaus@csuchico.edu
38. **SABOURIN Herve** (University of Poitiers, France)
    e-mail: herve.sabourin@math.univ-poitiers.fr
39. **SARDÓN Cristina** (University of Salamanca, Spain)
    e-mail: cristinasardon@usal.es
40. **ŠNOBL Libor** (Czech Technical University in Prague, Czech Republic)
    e-mail: Libor.Snobl@fjfi.cvut.cz

41. **SOPHOCLEOUS Christodoulos** (University of Cyprus, Nicosia, Cyprus)
e-mail: christod@ucy.ac.cy
42. **SPICHAK Stanislav** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
e-mail: spichak@imath.kiev.ua
43. **STEPANOVA Irina** (Institute of Computational Modeling of Siberian branch of RAS, Krasnoyarsk, Russia)
e-mail: stepiv@icm.krasn.ru
44. **TONGAS Anastasios** (University of Cyprus, Nicosia, Cyprus)
e-mail: tongas.anastasios@ucy.ac.cy
45. **TRACINÀ Rita** (University of Catania, Italy)
e-mail: tracina@dmi.unict.it
46. **TSAOUSI Christina** (University of Cyprus, Nicosia, Cyprus)
e-mail: christina.tsaousi@gmail.com
47. **VANEEVA Olena** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
e-mail: vaneeva@imath.kiev.ua
48. **VESELOV Alexander** (Loughborough University, UK)
e-mail: A.P.Veselov@lboro.ac.uk
49. **VLADIMIROV Vsevolod** (AGH University of Science and Technology, Krakow, Poland)
e-mail: vsevolod.vladimirov@gmail.com
50. **WINTERNITZ Pavel** (University of Montreal, Canada)
e-mail: wintern@CRM.UMontreal.CA
51. **XENITIDIS Pavlos** (University of Leeds, UK)
e-mail: P.Xenitidis@leeds.ac.uk
52. **YEHORCHENKO Irina** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
e-mail: iryna.ye@gmail.com
53. **ZHALIJ Alexander** (Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine)
e-mail: zhaliy@imath.kiev.ua

*Mina B. Abd-el-Malek*

Alexandria University and American University in Cairo, Egypt

## Group theoretic method and new exact solutions for problem of a heat mass transfer

In this paper, we have applied the group theoretic method to simulate the problem of heat and mass transfer in non-Newtonian power law, two-dimensional, laminar, boundary layer flow of a viscous incompressible fluid over an inclined plate. The governing non-linear partial differential equations describing the flow and heat transfer problem are transformed into a set of coupled non-linear ordinary differential equation. Homotopy perturbation method has been applied to find exact solutions for the obtained non-linear ordinary differential equations. We believe that the obtained exact solutions are new in that field. Dimensionless temperature and concentration profiles are presented graphically for different physical parameters and for the different power law exponents.

This is joint work with *Medhat M. Helal* (Zagazig University, Egypt) and *Mohamed El-Fakharany* (Tanta University, Egypt).

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2. R.S.R. Gorla, H.S. Takhar, I. Pop, M. Kumari and A. Slaouli, Free convection power-law near dimensional stagnation point, *Int. J. Heat and fluid flow* **16** (1995), 62–68.
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*Ciprian Acatrinei*

National Institute for Nuclear Physics and Engineering,
Bucharest, Romania

## Nonlocal waves on a discrete space

Noncommutative field theory leads naturally to a discretization of space, on which local and nonlocal excitations propagate. A complete solution of the equations of motion, including the nonlocal features, will be presented. No singularity appears, even at the location of the sources.

*Kostis Andriopoulos*

The Moraitis School, Athens, Greece

## The Miller and Weller equation: complete group classification and conservation laws

We consider a nonlinear equation which arises in Financial Mathematics, namely the equation introduced by Miller and Weller [*J. Econom. Dynam. Control* **19** (1995) 279–302]. The equation is studied in the context of the theory of modern group analysis. Specifically we perform a complete group classification and indicate the cases that can be mapped to the heat equation. For the purely nonlinear cases we provide the optimal set and some interesting similarity solutions. Finally we demonstrate the nonlinear self-adjointness of the equation. Hence we obtain a formal Lagrangian for the equation and with the use of its symmetries conservation laws are constructed.

This is joint work with *S. Dimas, Y. Bozhkov* and *P.G.L. Leach*.

*Vyacheslav M. Boyko*

Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine

## Lie symmetries of systems of second-order linear ordinary differential equations with constant coefficients

We exhaustively study Lie symmetries of systems of second-order linear ordinary differential equations with constant coefficients over both the complex and real fields. The explicit description of the maximal Lie invariance algebra of any system from the class is presented. We also give a simple and algorithmic tool in order for computing the dimensions of such algebras as well as estimates for possible values of these dimensions.

Talk is based on the joint work with *Roman O. Popovych* and *Nataliya M. Shapoval*, see arXiv:1203.0387.

*Goce Chadzitaskos*

Czech Technical University in Prague, Czech Republic

## Coherent states of down conversion process

We use the methods of construction SU(2) and deformed SU(2) coherent states for the construction of coherent states of down conversion processes. The down conversion process is understood as a quasi-exactly solvable model. We use the polynomial approach in order to calculate the eigenvalues of Hamiltonian. For low number of photons the eigenvalues are calculated and the approximation formula is expressed. The coherent states of the down conversion are eigenstates of the reduced annihilation operator as in deformed SU(2) case. The final result express the coherent states of incident coherent light on nonlinear medium for the down conversion process.

*Pantelis A. Damianou* and *Charalambos Evripidou*
University of Cyprus, Nicosia, Cyprus

## Characteristic and Coxeter polynomials for affine Lie algebras

We explore some interesting features of the characteristic polynomial of the Cartan matrix and the Coxeter adjacency matrix of a simple affine Lie algebra. We compute the spectrum of these matrices in an elementary fashion, using properties of the Chebyshev polynomials of first and second kind. In addition, we give explicit formulas for the characteristic polynomials, we compute the associated polynomials and use them to derive the Coxeter polynomial of the underlying graph. We determine the expression of the Coxeter and associated polynomials as a product of cyclotomic factors. The spectrum is explicitly determined in terms of the analogues of the exponents and the Coxeter number.

*Vladimir Dragović*

Mathematical Institute SANU, Belgrade, Serbia &
Mathematical Physics Group, University of Lisbon, Portugal

## Pseudo-integrable billiards: topological and arithmetic aspects

We introduce a class of nonconvex billiards with a boundary composed of arcs of confocal conics which contain reflex angles. We present their basic topological and arithmetic properties. We study their periodic orbits and establish a local Poncelet porism.

This research is done jointly with *M. Radnović*.

*Pilar G. Estévez*

Department of Fundamental Physics, University of Salamanca, Spain

## Construction of lumps with non-trivial interaction for a $2+1$ dimensional nonlinear Schrödinger equation

The Singular Manifold Method is used to generate lump solutions of a generalized integrable nonlinear Schrödinger equation in $2+1$ dimensions. We present several essentially different types of lump solutions. The connection between this method and the Ablowitz–Villarroel scheme is also analyzed.

*Pilar G. Estévez* and *Cristina Sardón*

Department of Fundamental Physics, University of Salamanca, Spain

## Miura-reciprocal transformations for hierarchies in $2+1$ dimensions

We present two hierarchies of partial differential equations in $2+1$ dimensions. We use reciprocal transformations that connect these hierarchies to the Calogero–Bogoyanlevski–Schiff equation and its modified version respectively, to prove that one of the hierarchies can be considered as a modified version of the other. The relation between them is described by means of a combination of reciprocal and Miura transformations.

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2. J. Cerveró and P.G. Estévez, *J. Math. Phys.* **39** (1998), 2800.
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*Jiri Hrivnak*[1] and *Jiri Patera*[2]

[1] Czech Technical University in Prague, Czech Republic
[2] CRM, University of Montreal, Canada

## Discretization of new Weyl group orbit functions

We discuss the orthogonality of recently discovered special functions related to the Weyl groups. These functions, called $S^s$- and $S^l$-functions, are together with $C$- and $S$-functions a generalization of the common cosine and sine functions. The $S^s$- and $S^l$-functions are 'half invariant and half skew-invariant' under the action of the Weyl group. We sample these functions on finite fragments $F^s_M$ and $F^l_M$ of a lattice in any dimension and of any density controlled by $M$. The symmetry of the lattice is inherited from a compact simple Lie group with two different lengths of roots. An explicit description of their pairwise discrete orthogonality and application to interpolation is given.

This is joint work with *Lenka Motlochova*.

*Rossen Ivanov*

Dublin Institute of Technology, Ireland

## Singular solutions of cross-coupled equations of Camassa-Holm type: waltzing peakons and compacton pairs

We consider singular solutions of a system of two cross-coupled Camassa–Holm (CCCH) equations [1]:

$$\partial_t m + (vm)_x + mv_x = 0 \quad \text{with} \quad m := m = u - u_{xx},$$
$$\partial_t n + (un)_x + nu_x = 0 \quad \text{with} \quad n := v - v_{xx}.$$

This CCCH system admits peakon solutions, but it is (most likely) not integrable. The system is a pair of coupled Hamiltonian partial differential equations for two types of solutions on the real line, each of which separately possesses $\exp(-|x|)$ peakon solutions. However, there are no self-interactions, so each of the two types of peakon solutions moves only under the induced velocity of the other type. We analyse the 'waltzing' solution behaviour of the cases with a single bound peakon pair (a peakon couple), as well as the over-taking collisions of peakon couples and the antisymmetric case of the head-on collision of a peakon couple and a peakon anti-couple. We discuss compacton couple solutions of the cross-coupled Euler–Poincaré (CCEP) equations and illustrate the same types of collisions as for peakon couples, with triangular and parabolic compacton couples.

Still an **open question** is the integrability of the system [2]. The only known conservation laws are the Hamiltonian $H(u, v)$ and the momentum $M(u, v)$,

$$H(u,v) = \int_{\mathbb{R}} (uv + u_x v_x)\,\mathrm{d}x, \quad M(u,v) = \int_{\mathbb{R}} (u+v)\,\mathrm{d}x.$$

The cross-coupled generalization of the CCEP equation also possesses solutions in the form of waltzing concentric peakons whose interaction involves also rotation around their center.

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2. J. Escher, R. Ivanov and B. Kolev, Euler equations on a semi-direct product of the diffeomorphisms group by itself, *J. Geom. Mechanics* **3** (2011) 313–322.

*Nikos Kallinikos*

Aristotle University of Thessaloniki, Greece

## Symmetries of motion in electromagnetic fields

A symmetry analysis is presented for the non-relativistic motion of charged particles in arbitrary stationary electromagnetic fields. We find the Lie point symmetries and the general form of the fields that respect them, considering non-trivial cases of physical interest. All of them, but one, are of Noether type, yielding a second integral of motion, besides the Hamiltonian. The time-independent symmetries are also preserved by the electric and magnetic field lines, and the corresponding integral is derived from the previous one.

This is joint work with *Efi Meletlidou* (Aristotle University of Thessaloniki, Greece).

*Dalibor Karásek*

Czech Technical University in Prague, Czech Republic

## Lie algebras as symmetry algebras of a system of ODEs

For the purpose of classification of Lie algebras, solvable extensions of certain nilpotent Lie algebras were constructed and classified. Several classes of solvable algebras are known for arbitrarily large dimension $n$. For several of these series of solvable algebras we are searching for all ODEs or systems of ODEs, which have the chosen solvable algebra as its algebra of infinitesimal symmetries. This procedure involves construction of all realizations of the given algebra in terms of vector fields and computation of their differential invariants. Similar procedure can be used to find difference equations with same algebra of symmetries. We can exploit these difference equation and create difference schemes that not only approximate given ODE but also preserve symmetries. We shall present several such systems of ODEs for the case with two dependent variables.

*Arthemy V. Kiselev*

Johann Bernoulli Institute for Mathematics and Computer Science, University of Groningen, The Netherlands

## The deformation quantisation problem for multiplicative structures on noncommutative jet spaces

We outline the basic notions and concepts from the differential calculus –up to the construction of the variational Schouten bracket– on a class of noncommutative jet spaces and we pose the deformation quantisation problems for the non-associative but commutative multiplications in the two spaces of differential functions (i.e., the noncommutative fields) and integral functionals (i.e., the Hamiltonians), aiming to restore the associative but not commutative star-products. During the entire talk, the constructions and reasonings will appeal to the profound properties of a pair of pants borrowed from the topological closed string theory.

*Theodoros Kouloukas*

University of Patras, Greece

## Re-factorization problems related to Yang–Baxter maps

We study re-factorization problems of polynomial matrices which lead to Lax representations of quadrirational Yang–Baxter maps. First degree polynomial Lax matrices are considered as building blogs of higher dimensional Yang–Baxter maps. These maps are Poisson with respect to the Sklyanin bracket and can be reduced to symplectic maps which preserve the spectrum of the corresponding monodromy matrix.

This is joint work with *Vassilios G. Papageorgiou* (University of Patras, Greece).

*Peter G.L. Leach*

University of Cyprus, Nicosia, Cyprus & School of Mathematical Sciences, University of KwaZulu-Natal, Republic of South Africa

## A novel Riccati sequence

Hierarchies of evolution partial differential equations have become well established in the literature over the last thirty years. More recently sequences of ordinary differential equations have been introduced. Of these perhaps the most notable is the Riccati Sequence which has beautiful singularity, symmetry and integrability properties. We examine a variation of this sequence and find that there are some remarkable changes in properties consequent upon this variation.

*Tony Lyons*

Dublin Institute of Technology, Ireland

## The inverse scattering transform applied to energy dependant spectral problems

We study the inverse problem for spectral problems with "energy dependant potentials". In particular we study spectral operators with quadratic dependance on the spectral parameter. The corresponding hierarchy of integrable equations includes the Kaup–Boussinesq equation.

The talk will briefly review the Riemann–Hilbert problem formulation for this inverse problem. We will then present the explicit construction of the one-soliton solution. We also discuss briefly the construction of the multi-soliton solutions.

The talk is based on work with *Rossen Ivanov*.

*Sunil Maharaj*
University of KwaZulu-Natal, South Africa

## Stellar models with quadratic equation of state

We study exact solutions to the nonlinear Einstein–Maxwell system of equations which are physically reasonable. The spacetime is static and spherically symmetric with a charged anisotropic matter distribution. We utilise an equation of state which is quadratic relating the radial pressure to the energy density. Earlier models, with linear and quadratic equations of state, are shown to be contained in our general class of solutions. The new solutions to the Einstein–Maxwell system can be expressed in terms of elementary functions. A physical analysis of the matter and electromagnetic variables indicates that the model is well behaved and regular.

*Sergey V. Meleshko*

Suranaree University of Technology, Nakhon Ratchasima, Thailand

## On group classification of the spatially homogeneous and isotropic Boltzmann equation with sources

In [1] an admitted Lie group of transformations was studied for the spatially homogeneous and isotropic Boltzmann equation with sources. In fact the author of [1] considered the equation for a generating function of the power moments of the Boltzmann equation solution. This equation is still a nonlocal partial differential equation. However, this property was not taken into account there. In the present paper the admitted Lie group of this equation by using our original method developed for group analysis of equations with nonlocal operators [2–4] is studied. The Lie groups obtained are compared. The lack of [1] is corrected.

This is joint work with *Yurii N. Grigoriev* (Institute of Computational Technology, Novosibirsk, Russia).

The research was partially supported by the Office of the Higher Education Commission under NRU project (SUT).

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3. S.V. Meleshko, *Methods for Constructing Exact Solutions of Partial Differential Equations*. Mathematical and Analytical Techniques with Applications to Engineering, Springer, New York, 2005.
4. Yu.N. Grigoriev, N.H. Ibragimov, V.F. Kovalev and S.V. Meleshko, *Symmetries of integro-differential equations and their applications in mechanics and plasma physics*, Lecture Notes in Physics, Vol. 806, Springer, Berlin / Heidelberg, 2010.

*Efthymia Meletlidou*

Aristotle University of Thessaloniki, Greece

## Non integrability and continuation of periodic orbits in Hamiltonian systems under small perturbations

When we add small perturbations to an integrable Hamiltonian system, it is generically nonintegrable and chaotic and the K.A.M. theorem and Poincare's theorems on non integrability and continuation of periodic orbits (or alternatively Poincare–Birkoff theorem) apply. We present our results on the non integragrability of such systems if certain conditions are satisfied as a different proof of Poincare's nonintegrability theorem and as an extension to it to the maximal allowed integrals of motion in an $n$-degrees of freedom Hamiltonian system. We relate it to the Poincare's on the continuation of periodic orbits (Poincare–Melnikov–Arnold theorem). We extent the above theorem for some cases that it cannot predict, i.e. when the average value of the Hamiltonian is constant on a specific torus and when the perturbed Hamiltonian contains more degrees of freedom than the integrable one.

*Oleg Morozov*

Institute of Mathematics and Statistics, University of Tromsø, Norway

## Recursion operators as Bäcklund autotransformations for tangent coverings and Cartan's method of equivalence

I will talk about applications of Cartan's method of equivalence to the problem of finding Bäcklund autotransformations for tangent coverings of nonlinear partial differential equations. These transformations yield recursion operators for symmetries of the equations under the study. Examples will include the recursion operators for the universal hierarchy equation and the integrable case of the generalized mdKP equation.

*Anatoly G. Nikitin*

Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine

## Supersymmetric and superintegrable systems of coupled Schrödinger equations

Supersymmetric and (super)integrable Schrödinger–Pauli equations are classified, which describe neutral fermions with non-trivial dipole moments.

1. A.G. Nikitin and Yu. Karadzhov, *J. Phys. A: Math. Theor.* **44** (2011), 305204.
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3. A.G. Nikitin and Yu. Karadzhov, *J. Phys. A: Math. Theor.* **44** (2011), 445202.
4. A.G. Nikitin, arXiv:1201.4935, 2012.
5. A.G. Nikitin, arXiv:1204.5902v2, 2012.

*Petr Novotny*

Czech Technical University in Prague, Czech Republic

## Graded contractions of representations of Lie algebra $sl(3,\mathbb{C})$

The classification of all representations of a given solvable Lie algebra presents an open problem even in the case of three dimensional Euclidean Lie algebra $e(2)$. We present the concept of graded contractions for representations of Lie algebras, which allows one to construct representations of some solvable Lie algebras from known irreducible representations of simple Lie algebras. We focus on the construction of faithful indecomposable representations and mutually nonequivalent representations. As an example we contract one class of irreducible representations of simple Lie algebra $sl(3,\mathbb{C})$ to the representations of seven dimensional solvable Lie algebra.

*Maxim Pavlov*

Moscow State University, Russia

## Finite component reductions of collisionless kinetic equations

We consider two approaches for extraction of finite component systems from collisionless kinetic equations. The first method is based on the theory of generalized functions, which in simplest case is nothing but the so called multi flow hydrodynamics well known in plasma physics. An alternative is the so called the moment decomposition method successfully utilized for hydrodynamic chains. We prove that both approaches lead to the same finite component systems.

The method of hydrodynamic reductions successfully utilized in the theory of integrable hydrodynamic chains is applied to the local and nonlocal kinetic equations.

$N$ component reductions parameterized by $N-1$ arbitrary constants for non-hydrodynamic chain arising in the theory of high frequency nonlinear waves in electron plasma are found. These evolution dispersive systems equipped by a local Hamiltonian structure possess periodic solutions.

*Dmytro Popovych*

Taras Shevchenko National University of Kyiv, Ukraine

## Non-universality of IW-contractions

Limiting processes (contractions) of Lie algebras appear in different areas of physics and mathematics, e.g., in the study of representations, invariants and special functions. Contractions of Lie algebras relevant to physics are usually realized as simple or generalized *Inönü–Wigner contractions*. At the same time, we show that even in the dimension four generalized IW-contractions are not sufficient for realizing all possible contractions, and this is the lowest dimension in which generalized IW-contractions are not universal. We prove that there exists just one pair of complex four-dimensional Lie algebras such that a well-defined contraction among them is not equivalent to a generalized IW-contraction (or to a one-parametric subgroup degeneration in conventional algebraic terms). Over the field of real numbers, the above pair of algebras is split into two pairs with the same contracted algebra. This is the first example of nonexistence of generalized IW-contraction for the case when the contracted algebra is not characteristically nilpotent and, therefore, admits nontrivial diagonal derivations. The lower bound (equal to three) of nonnegative integer parameter exponents which are sufficient to realize all generalized IW-contractions of four-dimensional Lie algebras is also found.

*Roman Popovych*

Wolfgang Pauli Institute, Austria &
Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine

## Group classification of differential equations within the algebraic approach

Direct group classification is a tool for selection of modeling differential equations from classes of such equations parameterized by arbitrary constants or functions. The criterion for the selection is that models have to admit the most extensive symmetry groups from the possible ones. The study of group classification problems is interesting from the purely mathematical point of view and important for physical applications. The complexity of these problems led to the development of a great variety of specialized techniques for their solution, which are conventionally partitioned into two approaches. The first approach is based on the compatibility analysis and integration of the corresponding determining equations up to a relevant equivalence relation. We discuss the other approach, which is of algebraic nature. Any of its versions involves, in some way, the classification of algebras of vector fields up to certain equivalence induced by point transformations. The key question is what set of vector fields should be classified and what kind of equivalence should be used. Depending on this and completeness of solution, one can talk about partial preliminary, complete preliminary and simply complete group classifications [1,2].

Within the framework of group classification, an important role is played by the notion of normalized classes of differential equations [1,3]. Thus, for a weakly normalized class, complete preliminary group classification and complete group classification coincide. If the class is semi-normalized, the group classification up to equivalence generated by the associated equivalence group coincides with that up to general point equivalence. As normalized classes are both semi-normalized and weakly normalized, they are especially convenient for classifying by the algebraic method. This is why the normalization property can be used as a criterion for selecting classes of differential equations to be classified or for splitting of such classes into subclasses which are appropriate for group classification.

As an illustration, we present the complete solution of the group classification problem for nonlinear wave equations of the form

$$u_{tt} = f(x, u_x)u_{xx} + g(x, u_x).$$

The symmetry analysis of such equations was initiated in [2] twenty years ago, where partial preliminary group classification of them was carried out. We also discuss group classification of generalized Burgers equations and nonlinear Schrödinger equations with potentials.

1. A. Bihlo, E. Dos Santos Cardoso-Bihlo and R.O. Popovych, Complete group classification of a class of nonlinear wave equations, arXiv:1106.4801, 39 pp.
2. N.H. Ibragimov, M. Torrisi, A. Valenti, Preliminary group classification of equations $v_{tt} = f(x, v_x)v_{xx} + g(x, v_x)$, *J. Math. Phys.* **32** (1991), 2988–2995.
3. R.O. Popovych, M. Kunzinger and H. Eshraghi, Admissible transformations and normalized classes of nonlinear Schrödinger equations, *Acta Appl. Math.* **109** (2010), 315–359.

*Julia Prada*

University of Salamanca, Spain

## On differential operators of infinite order in sequence spaces

Given two differential operators $T$ and $S$ in a space $H$, an operator $X$ is an "operateur de transmutation" from $T$ to $S$ if $X$ is an isomorphism from $H$ onto $H$ such that $SX = XT$. It was introduced in 1938 by J. Delsarte, $T$ and $S$ being differential operators of second order and $H$ a space of functions of one variable defined for $x \geq 0$ [1].

If $T$ and $S$ are differential operators of order $m > 2$ with infinitely differentiable coefficients and $H$ is a space of infinitely differentiable functions on $R$, then does not exist, in general, "operateurs de transformation". M.K. Fage, in 1957 presented a theorem of transmutation for certain classes of functions of real variables [3].

The situation is, on the contrary, very simple taking $T$ and $S$ differential operators without singularities in the complex domain $C$ and $H$ the space of entire functions of one variable. J. Delsarte and J.L. Lions proved in 1957 that in this case, provided the operators are of the same order, there is, always, an "operateur de transmutation" [2].

In the beginning of the sixties the term equivalence of operators appeared (two operators $T$ and $S$ are said to be equivalent when there is an "operateur of transmutation" between them). The subject was the object of intensive studies, mainly from USSR mathematicians. Some of the relevant works are [4–10,14].

A few years ago we started to consider the problem of the equivalence of differential operators taking the space $H$ to be a sequence space and substituting the usual derivative by the general Gelfand-Leontev derivative [11,12].

Nowadays we are interested in differential operators of infinite order. Nagnibida and Oliinyk studied the equivalence of differential operators of infinite order in the spaces of analytic functions (on a disk and on the whole complex plane) giving a very neat result [13]. We deal with the same problem in the more general setting of sequence spaces.

In this talk we will present a complete characterization of differentials operators of infinite order that are equivalent to the derivative operator $D$ in the space $s$ of rapidly decreasing sequences.

This is joint work with *M. Maldonado* and *M.J. Senosiain* (University of Salamanca, Spain).

1. J. Delsarte, Sur certaines transformations fonctionnelles relatives aux equations lineaires aux derivees partielles du second ordre, *C. R. Acad. Sci. Paris* **206** (1938), 1780.
2. J. Delsarte and J.L. Lions, Transmutations d'opérateurs différentiels dans le domaine complexe, *Comment. Math. Helv.* **32** (1957–1958), 113–128.
3. M.K. Fage, Operator-analytical functions of one independent variable, *Dokl. Akad. Nauk SSSR*, **112** (1957), 1008–1011 (in Russian).
4. M.K. Fage, On the equivalence of two linear differential operators with analytic coefficients, *Studies on contemporary problems in the theory of functions of a complex variable*, Fizmatgiz, Moscow, 1961, pp. 468–476.
5. K.M. Fišman, Equivalence of certain linear operators in an analytic space, *Mat. Sb.* **68 (110)** (1965), 63–74.
6. K.M. Fišman, The reduction to diagonal form of certain classes of row-finite matrices in analytic spaces on the disc, *Teor. Funkciĭ Funkcional. Anal. i Prilożen.* No. 7 (1968), 27–36.
7. K.M. Fišman, The similarity of certain classes of row-finite matrices in analytic spaces on the disc, *Teor. Funkciĭ Funkcional. Anal. i Prilożen.* No. 13 (1971), 112–140.
8. K.M. Fišman, The equivalence of differential operators with a regular singular point, *Funct. Anal. Appl.* **8** (1974), 169–171.
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11. M. Maldonado, J. Prada and M.J. Senosiain, On differential operators on sequence spaces, *J. Nonlinear Math. Phys.* **15** (2008), suppl. 3, 345–352.
12. M. Maldonado, J. Prada and M.J. Senosiain, An application of Hermite functions, *Proc. 4th Workshop "Group Analysis of Differential equations & Integrable Systems"*, 2009, pp. 146–154.
13. N.I. Nagnibida and N.P. Oliinyk, On the equivalence of differential operators of infinite order in analytic spaces, *Math. Notes* **21** (1977), 19–21.
14. I.J. Viner, Transformation of differential operators in the space of holomorphic functions, *Uspehi Mat. Nauk.* **20** (1965), 185–188.

*Sietse Ringers*

Johann Bernoulli Institute for Mathematics and Computer Science, University of Groningen, The Netherlands

## A comparison of definitions for the Schouten bracket on jet spaces

The Schouten bracket (or antibracket) plays a central role in the Poisson formalism and the Batalin–Vilkovisky quantization of gauge systems. There are several (in)equivalent ways to realize this concept on jet spaces. In this talk, we compare the definitions, examining in what ways they agree or disagree and how they relate to the case of usual manifolds.

*Vladimir Rosenhaus*

California State University, Chico, USA

## On differential equations with infinite conservation laws

We consider partial differential equations admitting infinite symmetry algebras parameterized by arbitrary functions of dependent variables and their derivatives. It was shown earlier that unlike infinite symmetries with arbitrary functions of independent variables, these symmetries lead to an infinite number of (essential) conservation laws, [V. Rosenhaus, *Theor. Math. Phys.* **160** (2009) 1042–1049, ibid. **151** (2007) 869–878]. We will discuss the solution of the problem of finding all Lagrangian PDE of the second order possessing an infinite set of conservation laws with an arbitrary function of the dependent variable and its first and second derivatives. We will show that the problem leads to three classes of PDE. We will analyze equations of each class, and discuss their meaning.

*Herve Sabourin*

University of Poitiers, France

## Specific properties of the transverse Poisson structure to the minimal nilpotent orbit in a semi-simple Lie algebra

The dual of any Lie algebra can be equipped with its standard Lie-Poisson structure and we know that the symplectic leaves are the co-adjoint orbits. In that case, we can introduce a natural transverse slice to each orbit and define its transverse Poisson structure. When the Lie algebra is semi-simple, it turns out that the study of that transverse Poisson structure can be reduced to the case of nilpotent orbits. In this talk we will consider the unique nilpotent orbit of minimal dimension which is generated by a highest root vector and we will present some specific and nice properties of its transverse Poisson structure, especially in terms of its polynomial structure.

*Libor Šnobl*

Czech Technical University in Prague, Czech Republic

## Solvable Lie algebras with Borel nilradicals

We shall review our research program the aim of which is to find all indecomposable solvable extensions of a given class of nilpotent Lie algebras. Specifically in this talk we consider a nilpotent Lie algebra $\mathfrak{n}$ that is isomorphic to the nilradical of the Borel subalgebra of a complex simple Lie algebra, or of its split real form. We treat all classical and exceptional simple Lie algebras in a uniform manner. We identify the nilpotent Lie algebra $\mathfrak{n}$ as the one consisting of all positive root spaces. We present general structural properties of all solvable extensions of $\mathfrak{n}$. In particular, we study the extension by one nonnilpotent element and by the maximal number of such elements. We show that the extension of maximal dimension is always unique and isomorphic to the Borel subalgebra of the corresponding simple Lie algebra.

In collaboration with *Pavel Winternitz*, see *J. Phys. A: Math. Theor.* **45** (2012), 095202.

*Irina V. Stepanova*

Institute of Computational Modelling SB RAS, Krasnoyarsk, Russia

## Group properties of equations of thermodiffusion convection in binary mixture

The work is devoted to investigation of group properties of equations which describe thermodiffusion convective flows in binary mixtures. Thermodiffusion convection refers to specific flows which appear in a fluid with density inhomogeneity. The variations of density can be caused by the thermal or compositional gradient. This mathematical model is characterized by accounting of dependency of coefficients of viscosity, thermal diffusivity, diffusion and thermodiffusion on temperature and concentration. Reasonableness of these assumptions is confirmed by experimental data for many real liquids [1,2].

So the considered model is much more complex than classical Navier–Stokes and heat/mass transfer equations. It should be noted that symmetry classification problem was solved when all physical parameters are constants [3]. Also group properties of thermodiffusion equations were investigated if the buoyancy force depends on temperature and concentration nonlinearly [4]. Symmetry properties of the equations of thermal convection in case the temperature dependency of transport coefficients were performed in [5].

We have performed symmetry classification of this model with respect to the parameters (viscosity coefficient, thermal diffusivity, and diffusion and thermal diffusion coefficients). All of them are functions which depend on temperature and concentration. We consider two cases: when liquid is under buoyancy force influence and when the binary mixture is in weightlessness and buoyancy force leaves out of account. It was observed that if the diffusion and the thermal diffusivity coefficients are equal then thermodiffusion coefficient is equal to zero. Such case is not typical for liquids and it was considered apart from other.

This work is supported by the Grant of Russian Foundation for Basic Research (11-01-00283) and the Integrational project of Siberian Branch of Russian Academy of Sciences (44).

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5. O.N. Goncharova, Group classification of the free convection equations, *Dinamika Sploshn. Sredy* No. 79 (1987), 22–35 (in Russian).

*Olena Vaneeva*

Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine

## Point transformations in classes of differential equations

After recalling the classical statement of group classification problems [1], we discuss the role of point transformations in successful solution of such problems and their possible extensions. Illustrative examples of group classifications for reaction-diffusion and KdV-like equations [2–4] are also presented.

The talk is based on joint works with *R. Popovych* and *C. Sophocleous*.

1. L.V. Ovsiannikov, *Group analysis of differential equations*, Academic Press, 1982.
2. O.O. Vaneeva, R.O. Popovych and C. Sophocleous, Extended group analysis of variable coefficient reaction-diffusion equations with exponential nonlinearities, *J. Math. Anal. Appl.*, doi:10.1016/j.jmaa.2012.05.084.
3. R.O. Popovych and O.O. Vaneeva, More common errors in finding exact solutions of nonlinear differential equations. I, *Commun. Nonlinear Sci. Numer. Simul.* **15** (2010), 3887–3899.
4. O.O. Vaneeva, R.O. Popovych and C. Sophocleous, Enhanced group analysis and exact solutions of variable coefficient semilinear diffusion equations with a power source, *Acta Appl. Math.* **106** (2009), 1–46.

*Alexander Veselov*

Loughborough University, UK

## Universality in Lie algebras and Chern–Simons theory

I will show that the eigenvalues of certain natural Casimir operators in the adjoint representation of simple Lie algebras can be expressed rationally in the universal Vogel's parameters and give explicit formulae for the corresponding generating functions. Similar universal formulae can be given for some quantities in Chern–Simons theory on a 3D sphere.

The talk is based on joint results with *Mkrtchyan* and *Sergeev*.

*Vsevolod Vladimirov*

AGH University of Science and Technology, Krakow, Poland

## On the stability and dynamical features of localized traveling wave solutions to a hydrodynamic-type system of PDEs

We consider the hydrodynamic system of balance equations for mass and momentum. The system is closed by a dynamic equation of state, taking into account the effects of spatial non-locality. For this system the symmetry and the local conservation laws are studied, up to the 7-th order. Next it is show that the system supports a one-parameter family of soliton-like traveling wave (TW) solutions. Depending on the sign of a certain parameter, the above-mentioned family describes localized waves of either compression or rarefication. Stability of the TW solutions is studied by means of the Evans functions technique. The qualitative study is backed by the direct numerical simulation, showing that the solitary wave solutions evolve in a self-similar mode, and maintain their shape after the mutual collisions.

*Pavel Winternitz*

University of Montreal, Canada

## Symmetries of difference equations and symmetry preserving discretization of differential equations

We show how one can approximate an Ordinary Differential Equation by a Difference System that has the same Lie point symmetry group as the original ODE. Such a discretization has many advantages over standard discretizations. In particular it provides numerical solutions that are qualitatively better, specially in the neighborhood of singularities.

*Pavlos Xenitidis*

University of Leeds, UK

## Linearization and potentiation of difference equations

The class of admissible transformations relating two quadrilateral difference equations, as well as their hierarchies of symmetries and canonical conservation laws, is discussed. More precisely, we present the necessary and sufficient conditions under which a given quad equation is linearizable by a point transformation. Moreover, Miura and Bäcklund transformations and their relation to conservation laws are discussed. In particular, the necessary conditions under which conservation laws can be used in the derivation and construction of Miura and Bäcklund transformations are presented.

*Irina Yehorchenko*

Institute of Mathematics of NAS of Ukraine, Kyiv, Ukraine

## Hidden symmetries for the wave equation with additional conditions

We investigate hidden symmetries of the wave equation with linear and non-linear additional conditions and classes of equations having symmetries of such types. In particular, we consider additional conditions of the type $x_\mu u_\mu = F(x,u)$ and $u_\mu u_\mu = F(x,u)$ and apply them to various Poincaré-invariant wave equations.

1. Yehorchenko I.A., Reduction of non-linear d'Alembert equations to two-dimensional equations, in Proc. of the 4th Workshop "Group Analysis of Differential Equations and Integrable Systems", 2009, 243–253.
2. Abraham-Shrauner B., Hidden symmetries and nonlocal group generators for ordinary differential equations, *IMA J.Appl.Math.*, 1996, V.56, 235–252.
3. Abraham-Shrauner B., Hidden symmetries, first integrals and reduction of order of nonlinear ordinary differential equations, *J. Nonlin. Math. Phys.*, 2002, V.9, Suppl. 2, 1–9.

# Instructions for Paper Submission

All papers should be written in good English and should be no longer than 20 pages. The files of the papers shall be prepared in the LaTeX2$\epsilon$ format using the style file that can be found in the web page of the workshop. Amendments of the style file are not allowed. Abbreviations for standard LaTeX commands are not allowed in the paper!

Please adhere to the following order of presentation:Article title, Author(s), Affiliation(s), E-mail(s), Abstract, Main text, Acknowledgements, Appendices, References.

References to other work should be consecutively numbered in the text using square brackets and listed by number in the Reference list. References to books should include the author's name; year of publication; title; page numbers where appropriate; publisher; place of publication, in the order given in the example below.

Olver P., *Applications of Lie groups to differential equations*, Springer-Verlag, New York, 1986.

References to articles in conference proceedings should include the author's name; year of publication; article title; editor's name (if any); title of proceedings; first and last page numbers, in the order given in the example below.

Ivanova N.M., Popovych R.O. and Sophocleous C., Conservation laws of variable coefficient diffusion–convection equations, 2005, *Proceedings of Tenth International Conference in Modern Group Analysis (Larnaca, Cyprus, 2004)*, 107–113.

References to articles in periodicals should include the author's name; year of publication; article title; full title of periodical; volume number; first and last page numbers, in the order given in the example below.

Nikitin A.G., Group classification of systems of non-linear reaction-diffusion equations with general diffusion matrix. I. Generalized Ginzburg-Landau equations *J. Math. Anal. Appl.*, 2006, V.324, 615–628.

We will provide you with a sample paper that can be found on the web page of the Workshop http://www2.ucy.ac.cy/ symmetry/.

The deadline for submission of papers is **August 31, 2012**.

# Contents

**Group Analysis of Differential Equations and Integrable Systems.** Book of abstracts of the 6th International Workshop held in Protaras, Cyprus, June 17–21, 2012.

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