



**The 4th Gregynog Workshop on Computation and
Analytic Problems in Spectral Theory**

21st-26th July, 2002

University of Wales

Gregynog Hall

Newtown

Powys

The 4th Gregynog Workshop on Computation and Analytic Problems in Spectral Theory

Gregynog Hall, 21-26th July, 2002

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SPEAKERS

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TIMETABLE OF TALKS AND EVENTS

SUNDAY JULY 21ST, 2002

1900 Dinner

MONDAY JULY 22ND, 2002

0800 *Breakfast*

Chair M Marletta

0855 **Malcolm Brown** *Introductory remarks*

0900 **John Ball** *Compatibility condition for microstructures*

1000 **Christiane Tretter** *The spectrum of some quadratic operator pencils associated with damped dynamical systems*

1030 **Marianna A Shubov** *Asymptotic and spectral analysis of aircraft wing model in subsonic airflow*

1100 *Coffee*

Chair E B Davies

1130 **Michael S P Eastham** *The Hurwitz theorem for Bessel functions and its consequences for antibound states*

1200 **Michael Hitrik** *Eigenvalue asymptotics for non-selfadjoint semiclassical operators*

1230 **D Hinton** *On the location of the least point of the essential spectrum*

1300 *Lunch*

Chair P Binding

1400 **Karl Michael Schmidt** *Eigenvalues in gaps of perturbed periodic Dirac operators - numerical evidence*

1430 **Gunter Stoltz** *The spectral minimum for random displacement models*

1500 **Peter K Jimack** *Optimal preconditioning for the finite element solution of elliptic partial differential equations*

1530 **P Kurasov** *Self-adjoint point interaction model of p -scattering*

1600 *Tea*

Chair H Langer

1630 **Sergey Naboko** *Fredholm analytic theorem on the boundary of a domain and its application to perturbation theory*

Where there is more than one author the speaker is marked thus †.

1700-1730 **R Romanov** *Spectral analysis of the dissipative Boltzmann operator and spectral singularities*

1900 *Reception*

1930 *Dinner*

TUESDAY JULY 23RD, 2002

0800 *Breakfast*

Chair R Weikard

0900 **Ian Knowles** *Variational methods for inverse problems*

1000 **V S Samko** *Inverse spectral problem for the Sturm-Liouville equation, recovery of the potential from the spectral data*

1030 **Norbert Röhrl** *On a functional for solving inverse Sturm-Liouville problems*

1100 *Coffee*

Chair R T Lewis

1130 **A A Abramov[†], V I Ul'yanova, K Balla and L F Yukhno** *On a spectral problem for certain differential algebraic equations of index 1*

1200 **Rainer Hempel** *Weakly coupled systems and avoided eigenvalue crossings*

1230 **Leon Greenberg** *Monotonicity of eigenvalues*

1300 *Lunch*

Chair B M Brown

1400 **Christer Bennewitz** *Uniqueness theorems in inverse spectral theory*

1500 **R Weikard** *A local Borg-Marchenko theorem for complex potentials*

1530 **William Rundell** *Some new inverse eigenvalue problems*

1600 *Tea*

Chair M S P Eastham

1630 **Matthias Langer** *A Sturm-Liouville problem depending rationally on the eigenvalue parameter*

1700-1730 **Heinz Langer** *A Pontryagin space approach to singular perturbations of differential operators*

1900 *Dinner*

2030 **Impromptu musical event**

Wine reception

WEDNESDAY JULY 24TH, 2002

0800 *Breakfast*

Chair M Plum

0900 **Juan J Manfredi** *Viscosity solutions of p -Laplacian type equations, $1 < p \leq \infty$*

1000 **Wolfgang Reichel** *Eigenvalues and Fučik-spectrum of the radially symmetric p -Laplacian*

1030 **Jan Lang** *Precise behaviour of the approximation numbers of the Sobolev embedding in the one-dimension case*

1100 *Coffee*

Chair P K Jimack

1130 **H Behnke** *Bounds for eigenvalues of an eigenvalue problem arising in the design of integrated optical chips*

1200 **G Alefeld[†] and G Mayer** *Admissable sets for matrix eigenpairs*

1230 **Robin Williams** *Multiphase instabilities in astrophysics*

1300 *Lunch*

Afternoon Free

1900 *Dinner*

2030 **Piano Recital by Sybille Hempel-Abromeit**

Wine reception

THURSDAY JULY 25TH, 2002

0800 *Breakfast*

Chair W Reichel

0900 **B Kawohl** *Domain geometry and eigenvalues*

1000 **Guido Sweers** *Anti-maximum principles*

1030 **Catherine Bandle** *Rayleigh-Faber-Krahn inequalities and nonlinear boundary value problems*

1100 *Coffee*

Chair R Hempel

1130 **S Slavyanov** *Eigenfunctions generated by ODEs belonging to the Heun class and their applications in the Fourier analysis*

1200 **Paul Binding** *A hierarchy of Sturm-Liouville problems*

1230 **A B Mikhaylova and B S Pavlov[†]** *Scattering in networks and design of the resonance triadic quantum switch*

1300 *Lunch*

Chair A Zettl

1400 **Jiří Horák[†] and Wolfgang Reichel** *Fučík spectrum of the Laplacian on some subdomains of the plane*

1430 **B Breuer** *Existence and inclusion methods for nonlinear elliptic boundary value problems on unbounded domains*

1500 **R Pohler** *Enclosures and existence proofs of bifurcation points for nonlinear boundary value problems*

1530 **J Rohe** *Verified calculation of an error bound for a simplified elastoplasticity model*

1600 *Tea*

Chair D Hinton

1630 **A Watson** *Application of the Wittrick-Williams algorithm to the eigenvalues of the Sturm-Liouville problem on trees*

1700 **D J Gilbert** *An inverse spectral problem associated with the one-dimensional Schrödinger operator*

1730-1800 **A A Shkalikov** *Limit spectral curves for the Orr-Sommerfeld operator and quasiclassical eigenvalue distribution along these curves*

1930 **Conference Dinner**

FRIDAY JULY 26TH, 2002

0800 *Breakfast*

Chair W D Evans

0900 **L N Trefethen** *Wave packet pseudomodes of twisted Toeplitz matrices*

1000 **D B Pearson** *Spectral theory for the Schrödinger equation with L^2 -sparse potentials*

1030 **Andreas M Hinz** *Delocalization for Schrödinger operators*

1100 *Coffee*

Chair A M Hinz

1130 **Jonatan Lenells** *The scattering approach for an integrable shallow water equation*

1200-1230 **A Zettl** *Left-definite Sturm-Liouville problems*

1300 *Lunch*

End of Workshop

ABSTRACTS OF PRESENTATIONS

ON A SPECTRAL PROBLEM FOR CERTAIN DIFFERENTIAL ALGEBRAIC EQUATIONS OF INDEX 1

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In this talk, several results described in [1] will be discussed. A self-adjoint linear homogeneous differential algebraic equation of index 1 is considered. One of the matrices occurring in the system depends on a spectral parameter (SP), in general, non-linearly. The self-adjoint homogeneous boundary conditions also may depend on the SP. We deal with the case when the dependence of problem data on the SP is of monotone type. A method is proposed and analyzed for computing the number of eigenvalues on a given interval of SP; this number takes the multiplicities into account. In the case when the boundary conditions are independent of the SP, an index, i.e. a serial number, is associated with each eigenvalue. A method for computing the eigenvalue with a prescribed index is given.

The results are closely related to ones considered in [2,3].

This work was supported by Russian Foundation for Basic Research (grants 02-01-00050, 02-01-00555) and Hungarian National Science Foundation (grant T029572).

REFERENCES

1. *Abramov A.A., Balla K., Ul'yanova V.I., Yukhno L.F.* On a nonlinear self-adjoint spectral problem for some differential algebraic equations of index 1. *Comp. Maths Math Phys.*, Vol. 42, N. 7, 2002 (to appear).
2. *Balla K., März R.* A unified approach to linear differential algebraic equations and their adjoint equations. Preprint N 2000-18, Berlin: Humboldt-Univ., 2000.

3. *Abramov A.A.* Calculation of eigenvalues in a nonlinear spectral problem for the Hamiltonian systems of ordinary differential equations. *Comp. Maths Math. Phys.*, Vol. 41, N 1, P. 27-36, 2001.

ADMISSABLE SETS FOR MATRIX EIGENPAIRS

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Let there be given a real (n, n) matrix A which is the center of an interval matrix $[A - \Delta A, A + \Delta A] = : [A]$. We consider the eigenpair sets

$$E = \{(x, \lambda) \in \mathbb{R}^{n+1} \mid Ax = \lambda x, A \in [A]\}$$

and

$$E_{\mathcal{P}} = \{(x, \lambda) \in \mathbb{R}^{n+1} \mid Ax = \lambda x, A \in [A], A \text{ has some property } \mathcal{P}\},$$

respectively. We discuss several equivalent conditions for a pair (x, λ) to belong to E or to $E_{\mathcal{P}}$, respectively.

COMPATIBILITY CONDITION FOR MICROSTRUCTURES

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The talk will cover two topics related to the study of microstructure arising from solid phase transformations. The first concerns work with C. Carstensen on generalizations of Hadamard's jump condition for Lipschitz mappings. This involves in particular defining limiting sets of gradients of a Lipschitz mapping or $W^{1,\infty}$ gradient Young measure from either side of a surface at an arbitrary point. The second is joint work with an electron microscopist D. Schryvers (Antwerp) and shows how an understanding of compatibility can be of use in constructing plausible scenarios for macrotwin formation in NiAl alloys.

RAYLEIGH-FABER-KRAHN INEQUALITIES AND NONLINEAR BOUNDARY VALUE PROBLEMS

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The classical Rayleigh-Faber-Krahn inequality states that among all domains of given volume the first eigenvalue of the membrane is smallest for the ball. This is expressed in terms of Sobolev constants as follows:

$$S_2(D) = \inf_{W_0^{1,2}(D)} \frac{\int_D |\nabla v|^2 dx}{\int_D v^2 dx} \geq S_2(B_1) \text{vol}(D)^{-\frac{N}{2}},$$

where B_1 is the unit ball in \mathbb{R}^N . This estimate is obtained by means of Schwarz symmetrization. In this talk we study more general Sobolev constants of the type

$$S_{p,q}(D, a, b) = \inf_{W_0^{1,p}(D)} \frac{\int_D a(x) |\nabla v|^p dx}{\left(\int_D b(x) |v|^q dx \right)^{\frac{p}{q}}},$$

where $a(x)$ and $b(x)$ are positive continuous functions. Without further assumptions on the weights no general Rayleigh-Faber-Krahn inequalities, that is estimates from below depending essentially on $\int_D b(x) dx$, are to be expected. We describe classes of functions

$a(x)$ and $b(x)$ for which such inequalities hold. They are then used to construct upper bounds for the solutions of nonlinear boundary value problems involving the p-Laplacian.

BOUNDS FOR EIGENVALUES OF AN EIGENVALUE PROBLEM ARISING IN THE DESIGN OF INTEGRATED OPTICAL CHIPS

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In the design of integrated optical chips the eigenvalue problem

$$-\Delta u(x, y) + \alpha(x, y) u(x, y) = \lambda u(x, y) \text{ in } \Omega \subset \mathbb{R}^2, \quad u(x, y) = 0 \text{ on } \partial\Omega,$$

arises. Here $\alpha : \Omega \rightarrow \mathbb{R}$ is a piecewise continuous function. Typical features of the technological problem are the possible occurrence of eigenvalue clusters and the necessity of quite stringent relative error tolerances for the eigenvalues.

For the computation of bounds we use finite elements based on the Rayleigh - Ritz and Temple - Lehmann - Goerisch methods for upper and lower eigenvalue bounds, respectively.

UNIQUENESS THEOREMS IN INVERSE SPECTRAL THEORY

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The celebrated Borg-Marchenko uniqueness theorem says that given the spectral measure of a selfadjoint operator generated by a Sturm-Liouville operator $-u'' + qu = \lambda u$, then the potential q is determined. I will review this result and then discuss uniqueness theorems of the same nature, but for more general situations. I will discuss matrix-valued equations, higher order equations, the general Sturm-Liouville equation $-(pu')' + qu = \lambda wu$ and so called left-definite Sturm-Liouville equations. For some of these results method similar to those originally employed by Borg may be used, but some results depend on a new approach, using a generalized version of the classical Paley-Wiener theorem for the Fourier transform.

A HIERARCHY OF STURM-LIOUVILLE PROBLEMS

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Sturm-Liouville problems are studied subject to a class of eigenvalue dependent boundary conditions, involving rational functions obeying certain sign conditions. This class turns out to be stratified, with explicit transformations connecting problems subject to boundary conditions from adjacent strata. These transformations enable certain (e.g., asymptotic or inverse) questions to be answered via known results for the standard (constant boundary condition) case.

EXISTENCE AND INCLUSION METHODS FOR NONLINEAR ELLIPTIC BOUNDARY VALUE PROBLEMS ON UNBOUNDED DOMAINS

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Computer-assisted existence and inclusion methods for nonlinear elliptic boundary value problems of the type

$$-\Delta u(x) + f(x, u(x)) = 0 \quad \text{in } \Omega, \quad B[u](x) = s(x) \quad \text{on } \partial\Omega$$

with some given nonlinearity f yield good results when the spectrum of the linearisation of the left-hand side at some approximate solution is well bounded away from zero.

Here we will focus on unbounded domains where an additional difficulty consists in the possible presence of essential spectrum.

In the case of the Emden's equation, where $f(x, u) = -u^2$, we will present an existence and inclusion result when the domain is an infinite strip and discuss generalisations to more general domains.

THE HURWITZ THEOREM FOR BESSEL FUNCTIONS AND ITS CONSEQUENCES FOR ANTIBOUND STATES

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The Hurwitz theorem states (inter alia) that the Bessel function $J_{-v}(ix)$ has no zeros for real x and $2N < v < 2N + 1$ ($N = 0, 1, \dots$). We derive a number of consequences for the Dirichlet and Neumann antibound states concerning the Bessel and hypergeometric equations, in which the potential has only exponential decay $\sim \exp(-2x)$ at infinity. Little is known about the distribution of resonances and antibound states for this decay, and a number of conjectures are suggested, supported by computational considerations.

AN INVERSE SPECTRAL PROBLEM ASSOCIATED WITH THE ONE-DIMENSIONAL SCHRÖDINGER OPERATOR

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We consider the one-dimensional Schrödinger operator on the half-line with a real boundary condition at the origin. Our approach uses the Riccati equation to recover the potential from knowledge of related spectral derivatives at suitable values of the spectral parameter on the real axis.

The results are established for (i) the case where the absolutely continuous spectrum is non-empty, (ii) the case where the operator is bounded below, and explicit examples are given to illustrate the theory. This is joint work with B. J. Harris, Northern Illinois University.

MONOTONICITY OF EIGENVALUES

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For $0 < y \leq 1$, consider the family of Sturm-Liouville problems:

$$-(p(x)u')' + q(x)u = \lambda r(x)u, \quad 0 < x < y, \quad (1a)$$

$$\alpha_0 u(0) + \beta_0 p(0)u'(0) = 0, \quad (1b)$$

$$\alpha_1 u(y) + \beta_1 p(y)u'(y) = 0, \quad (1c)$$

where $p \in C^1[0, 1]$, $q, r \in C[0, 1]$, and $p, r > 0$. The Sturm-Liouville problem (1) has a sequence of eigenvalues: $\lambda_0(y) < \lambda_1(y) < \lambda_2(y) < \dots$. A well known Sturmian property states that if the second boundary condition (1c) is a Dirichlet condition (i.e. if $\beta_1 = 0$) then the eigenvalues $\lambda_n(y)$ are strictly decreasing functions of y . We ask the question: Does any vestige of this property remain true if $\beta_1 \neq 0$? The answer is yes.

Theorem 1. *There exists an integer $n_0 \geq 0$ such that for $n \geq n_0$, the eigenvalues $\lambda_n(y)$ are strictly decreasing functions of y .*

Theorem 2. *For given functions p, r and a given integer $n_0 \geq 0$, there exists a continuous function q such that the eigenvalues $\lambda_n(y)$, $0 \leq n \leq n_0$, are not decreasing. In fact, for any given $y_0 \in (0, 1)$, q can be found so that $\lambda_n(y)$ is increasing in a neighborhood of y_0 , $0 \leq n \leq n_0$.*

WEAKLY COUPLED SYSTEMS AND AVOIDED EIGENVALUE CROSSINGS

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We discuss typical situations where a family $S(\lambda)$ of self-adjoint operators in a Hilbert space \mathcal{H} exhibits the phenomenon of *avoided eigenvalue crossings*, i.e., at certain points eigenvalues come extremely close to one another but do not cross (while, at the same time, the eigenprojections do cross). All our examples come with a comparison family

$T(\lambda)$ that is close to $S(\lambda)$ and which decouples in a suitable sense. We are thus led to conjecture that avoided crossings are related to weak coupling or symmetry breaking. We also discuss the shift of eigenvalues under weak coupling and some implications for the numerical computation of eigenvalues.

ON THE LOCATION OF THE LEAST POINT OF THE ESSENTIAL SPECTRUM

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A new criterion for the least point of the essential spectrum is given for a one term second order differential operator. This criterion is sharper than the Friedrich's criterion. Application is given to the singular eigenvalue problem associated with the buckling of a column under self-weight subjected to the constraint of fixed volume. Examples are given which illustrate the sharpness of the bounds for the least point of the essential spectrum.

DELOCALIZATION FOR SCHRÖDINGER OPERATORS

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The phenomenon of localization, i.e. the appearance of intervals of dense point spectrum associated with exponentially decaying eigenfunctions, has become a popular topic in the spectral theory of Schrödinger operators. The antithetical event, namely isolated eigenvalues with long range eigenfunctions, is not so well-known. There are examples for the one-dimensional case which provide insight into the limitations of some theorems relating the behavior of eigensolutions at infinity to the spectrum. Such ideas have also been employed to show that Dirac operators with potentials tending to infinity may have holes in the essential spectrum. We will summarize these results and indicate possible approaches for higher dimensions.

EIGENVALUE ASYMPTOTICS FOR NON-SELFADJOINT SEMICLASSICAL OPERATORS

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We study small non-selfadjoint perturbations of semiclassical selfadjoint operators with periodic Hamilton flows. In dimension 2, we give a precise description of the entire spectrum in a domain in the complex plane, directly related to the size of the perturbation. Applications include spectral asymptotics for damped wave equations on Zoll manifolds and barrier top resonances for Schrödinger operators. This is a joint work with Johannes Sjöstrand.

FUČÍK SPECTRUM OF THE LAPLACIAN ON SOME SUBDOMAINS OF THE PLANE

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The problem $\Delta u + \mu u^+ - \nu u^- = 0$ in $\Omega \subset \mathbb{R}^2$ with $u = 0$ on $\partial\Omega$ is studied, where $u^\pm = \max(0, \pm u)$, $\mu, \nu \in \mathbb{R}$. A pair (μ, ν) is called a Fučík eigenvalue if there exists a function $u_{\mu, \nu} \neq 0$ that solves the problem. Local existence results are obtained and a numerical method is used to approximate some of the Fučík eigenvalues on various domains in \mathbb{R}^2 . Based on a variational formulation in $W_0^{1,2}(\Omega)$, critical points of the functional $F(u) = \int_\Omega |\nabla u|^2 dx$ subject to constraints $\int_\Omega (u^+)^2 dx = t$ and $\int_\Omega (u^-)^2 dx = 1 - t$ with $t \in (0, 1)$ are sought. The information obtained numerically is compared to the known analytical results.

OPTIMAL PRECONDITIONING FOR THE FINITE ELEMENT SOLUTION OF ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS

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Preconditioning plays an important role in the iterative solution of algebraic problems arising from the numerical discretization of differential operators. It is well known that for many common differential operators the application of standard finite element or finite difference schemes leads to linear systems whose condition number behaves like $O(h^{-2})$ as $h \rightarrow 0$, where h is a typical edge length in the finite element/difference grid. As the grid becomes very fine therefore the importance of preconditioning grows significantly.

A popular class of preconditioning is based upon a geometric decomposition of the grid using additive or multiplicative Schwarz methods. This is because such an approach is naturally amenable to implementation on a parallel computing platform due to the inherent decomposition of the problem. This talk will describe work with three different collaborators, R. Bank, S. Nadeem and S. Nepomnyaschikh, on the development and application of a new variant of a two level additive Schwarz preconditioner that has many of the properties of more complex multilevel preconditioners of the same family. In particular it can be shown that this preconditioner yields a condition number that is independent of the mesh spacing h . Examples of the application of this approach will be provided for problems arising from the discretization of a number of three-dimensional PDEs using linear tetrahedral finite elements.

DOMAIN GEOMETRY AND EIGENVALUES

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In my lecture I will first present a solution to a question of McKenna and Walter, concerning the positive deformation of hinged plates in a spring bed under positive load. If the spring constant b is small, the corresponding differential operator is positivity preserving, but if it gets larger than a critical constant $b_c(\Omega)$, it is no longer positivity preserving.

G.Sweers and I were able to prove that the canonical conjecture $b_c(\Omega) \leq b_c(\Omega^*)$ is false. Here Ω^* is a disc of same area as $\Omega \subset \mathbb{R}^2$.

In the second part of my lecture I will address the pseudo-Laplace eigenvalue problem, which comes from minimizing $\sum_{j=1}^p \int_{\Omega} |\partial v / \partial x_j|^p dx$ on $K := \{v \in W_0^{1,p}(\Omega) \mid \|v\|_{L^p(\Omega)} = 1\}$. The Euler-Lagrange equation reads

$$\sum_{j=1}^n \frac{\partial}{\partial x_j} \left(\left| \frac{\partial v}{\partial x_j} \right|^{p-2} \frac{\partial v}{\partial x_j} \right) + \lambda |u|^{p-2} u = 0,$$

and is more degenerate than $\Delta_p u + \lambda |u|^{p-2} u = 0$. If Ω is a ball, the minimizer is not radially symmetric, but one can still say something about symmetry of the level sets. If Ω is convex, the level sets are convex. These results were obtained jointly with M.Belloni.

If there is time left, I will present results on the symmetry of eigenfunctions in situations where some standard tricks seem to fail.

VARIATIONAL METHODS FOR INVERSE PROBLEMS

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Inverse problems involving the recovery of coefficient functions in partial differential equations from measurements involving the solutions, are in general computationally difficult, verging on intractable. We consider recovery methods based upon the minimization of certain functionals with unique global minima and unique stationary points. Applications include the electrical tomography problem, i.e. the recovery of electrical conductivity from Dirichlet-Neumann map data, and the full groundwater modelling problem. The use of critical point theory in establishing uniqueness will also be discussed.

SELF-ADJOINT POINT INTERACTION MODEL OF p -SCATTERING

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We are going to present an exactly solvable model of point interaction leading to non-trivial scattering amplitude in p -channel. This model is a generalization of the celebrated Berezin-Faddeev model which is used to describe the s -scattering. The operator under investigation is given by the formal expression

$$-\Delta + \alpha_x \partial_x \delta + \alpha_y \partial_y \delta + \alpha_z \partial_z \delta,$$

where $\alpha_{x,y,z}$ are arbitrary real constants and δ is Dirac's delta function. To determine this operator rigorously the theory of finite rank singular perturbations of self-adjoint operators is used. It is proven that this operator can be determined in a certain finite-dimensional extension of the Hilbert space $W_2^1(\mathbf{R}^3)$. Spectral and scattering properties of the described model are investigated. In the case $\alpha_x = \alpha_y = \alpha_z$ one gets a spherically symmetric model (the operator commutes with the rotations) with nontrivial p -component of the scattering amplitude. Possible generalizations to include higher order interactions are discussed.

GROMOV COMPACTNESS OF MANIFOLDS WITH BOUNDARY AND STABILITY IN INVERSE BOUNDARY SPECTRAL PROBLEMS

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In this talk (joint with A Katsuda, M Lassas and M Taylor) we formulate geometric conditions on Riemannian manifolds with boundary which guarantee their (pre)compactness in the Gromov-Hausdorff topology. We study the metric properties of the closure of this set. We show that the Gel'fand inverse boundary spectral problem is uniquely solvable in this class and prove a corresponding result on relative stability.

PRECISE BEHAVIOUR OF THE APPROXIMATION NUMBERS OF THE SOBOLEV EMBEDDING IN THE ONE-DIMENSION CASE

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We consider the Sobolev embedding $I : W^{1,p}(a, b) \rightarrow L^p(a, b)$, $-\infty < a < b < \infty$ and $1 < p < \infty$. We show that for all n in \mathbb{N} the n -th approximation number $a_n(I)$ of I is given by

$$a_n(I) = \frac{c_p}{n}$$

where c_p is a constant dependent only on p . We also find the best n dimensional linear approximation of I and we will discuss the shape of unit ball in $W^{1,p}$.

A PONTRYAGIN SPACE APPROACH TO SINGULAR PERTURBATIONS OF DIFFERENTIAL OPERATORS

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In the study of singularly perturbed differential expressions operators of the form $A + \langle \cdot, \chi \rangle \chi$ arise, where A is a self-adjoint operator in some Hilbert space \mathcal{H} and χ is some element of a space with negative norm ($\chi \in \mathcal{H}_{-k-1} \setminus \mathcal{H}_{-k}$) associated with A . Recently, by Yu. Shondin and J.F. van Diejen/A.Tip a method was developed which associates with the problem a family of operators in some Pontryagin space with negative index k which are extensions of a symmetric operator in the given Hilbert space. In the lecture an analytic approach to these extensions using the Q -function or Titchmarsh-Weyl function will be explained. The method applies also e.g. to the Bessel operator $-\frac{d^2}{dx^2} + \frac{\nu^2 - \frac{1}{4}}{x^2}$ in the self-adjoint case $\nu > 1$, if the Q -function from the non-self-adjoint case $0 < \nu < 1$ is considered for such values $\nu > 1$. Joint work with Y. Shondin and A. Dijkma.

A STURM-LIOUVILLE PROBLEM DEPENDING RATIONALLY ON THE EIGENVALUE PARAMETER

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We consider eigenvalues of the following Sturm–Liouville problem

$$-y'' + \left(q - \lambda - \frac{w}{u - \lambda}\right)y = 0$$

on the interval $[0, 1]$ with Dirichlet boundary conditions, where q , u , and w are real functions. If u is piece-wise continuous, then in every gap of the range of u the eigenvalues can be characterised by a variational principle with an index shift. The behaviour at the end-points of the gaps and the number of eigenvalues are investigated.

THE SCATTERING APPROACH FOR AN INTEGRABLE SHALLOW WATER EQUATION

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The isospectral problem for the Camassa-Holm shallow water equation is a weighted Sturm-Liouville problem. The spectral data consists of a continuous spectrum and a finite or infinite number of eigenvalues. We present an approach for determining the evolution of the scattering data, applicable independently of the number of eigenvalues. In the case of finitely many eigenvalues the initial value problem can be solved by the inverse scattering method.

VISCOSITY SOLUTIONS OF p -LAPLACIAN TYPE EQUATIONS, $1 < p \leq \infty$

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In the first part of the talk we will compare three different notions of weak solutions of the p -Laplace equation: Sobolev weak solutions based on distributional derivatives, semi-continuous weak solutions based on the comparison principle, and viscosity solutions based on generalized point-wise derivatives or jets. For $1 < p < \infty$ it is easy to show that Sobolev weak solutions are semi-continuous weak solutions and that these are viscosity solutions. In fact, viscosity solutions are semi-continuous weak solutions. A sketch of the proof, ultimately based on Jensen's comparison principle will be presented.

In the second part, we concentrate on the case $p = \infty$, where we are forced to use viscosity solutions. We will present applications to ∞ -harmonic functions, and discuss the ∞ -eigenvalue problem.

FREDHOLM ANALYTIC THEOREM ON THE BOUNDARY OF A DOMAIN AND ITS APPLICATION TO PERTURBATION THEORY

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The Fredholm Analytic Theorem is a standard instrument of the spectral analysis having numerous applications. Its main field is the perturbation of the discrete spectra. For the purposes of the continuous spectra perturbation (say in scattering theory) one needs to apply a version of the Fredholm Analytic Theorem where the invertibility is investigated

on the boundary of a domain (for example on the real axis in case of the upper half-plane). We present some “boundary” version of the theorem. Applications to the scattering theory are considered.

SCATTERING IN NETWORKS AND DESIGN OF THE RESONANCE TRIADIC QUANTUM SWITCH

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Based on connection between the Dirichlet-to-Neumann Map and the scattering matrix for scattering problem on the networks the resonance transmission through the splitting is considered.

The mathematical design of a realistic three-position quantum switch controlled by the constant electric field is suggested in form of a circular quantum well - a unit disc on a plane- with four straight channels attached to it. The magnitude of the constant electric field directed parallel to the disc may be defined such that rotation of this field in the plane of the device permits manipulation of the electron current through the triple splitting. Explicit expression for transmission coefficient from one channel to another is obtained via reduction of the analysis of the corresponding infinitely-dimensional spectral problem to the analysis of a relevant finite-dimensional analytic matrix function. Our techniques is based on methods developed in [7, 6, 8] and the results are published in other papers quoted below.

Our main practical result is the calculation of the working point of the switch in the multi-dimensional space of the numerical parameters of the switch , to enable the resonance manipulation of the current across the quantum well from one wire to another.

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SPECTRAL THEORY FOR THE SCHRÖDINGER EQUATION WITH L^2 -SPARSE POTENTIALS

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A potential V defined on the positive half line is said to be L^2 -sparse if there exist arbitrarily long intervals on which the L^2 norm of V is arbitrarily small. Equivalently, V is the sum of a sparse potential (ie a potential vanishing on long intervals) and an L^2 potential.

This talk will examine the spectral theory of L^2 -sparse potentials, using the theory of the Weyl m -function, and in particular using hyperbolic space estimates to derive bounds for m .

Particular consequences will be the absence of negative absolutely continuous spectrum, an estimate for the large distance asymptotics of the logarithmic derivative of solutions of the Schrödinger equation at real spectral parameter, and an analysis of the spectrum for some interesting perturbations of L^2 -sparse potentials.

The results described are the outcome of joint work with S. Breimesser and J. Grant.

ENCLOSURES AND EXISTENCE PROOFS OF BIFURCATION POINTS FOR NONLINEAR BOUNDARY VALUE PROBLEMS

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For parameter dependent nonlinear elliptic boundary value problems a computer-assisted method enclosing solution branches and bifurcation points is presented. Starting from finitely many approximate solutions giving rise to the conjecture that there might be a bifurcation, the method encloses continuous solution branches, at the same time proving that bifurcation does indeed take place. It is based on bounds for the defects of the approximate solutions and on eigenvalue bounds for the linearization at these approximate solutions.

EIGENVALUES AND FUČIK-SPECTRUM OF THE RADIALY SYMMETRIC p -LAPLACIAN

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For $p > 1$ we consider the p -Laplacian boundary value problem

$$(1) \quad \operatorname{div}(|\nabla u|^{p-2}\nabla u) + (-q + \lambda w)|u|^{p-2}u = 0 \text{ on the ball } B_1(0) \subset \mathbb{R}^n$$

with homogeneous boundary conditions on $\partial B_1(0)$. Radially symmetric solutions satisfy an ordinary differential equation. We will discuss analytical and numerical tools to find all radial eigenvalues of the problem. In generalization to (1) we also discuss the boundary value problem

$$(2) \quad \operatorname{div}(|\nabla u|^{p-2}\nabla u) - q|u|^{p-2}u + w\left(\mu(u^+)^{p-1} - \nu(u^-)^{p-1}\right) = 0 \text{ in } B_1(0)$$

with homogeneous boundary conditions, where $u^+(x) = \max\{u(x), 0\}$ and $u(x) = u^+(x) - u^-(x)$. A pair of constants $(\mu, \nu) \in \mathbb{R}^2$ for which a non-trivial solution u exists is called a Fučik-eigenvalue; the collection of all Fučik-eigenvalues is called the Fučik-spectrum. We describe the entire radial Fučik-spectrum analytically, and we give an algorithm for its computation. Numerical result will be presented.

ON A FUNCTIONAL FOR SOLVING INVERSE STURM-LIOUVILLE PROBLEMS

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We discuss a functional whose unique global minimum solves the inverse Sturm-Liouville problem on a bounded interval. It is based on a functional of Brown, Knowles, and Samko, using boundary value solutions instead of initial value solutions. Its advantage is the simpler structure of its derivative, which makes it more suitable for proving important properties.

Since for solving actual inverse problems, the functional has to be minimized with a numerical algorithm, we would like to prove that there is no stationary point except for the global minimum. This is not known for most functionals used for this type of computations. We will present some first results in this direction.

VERIFIED CALCULATION OF AN ERROR BOUND FOR A SIMPLIFIED ELASTOPLASTICITY MODEL

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We consider a simplified model for nonlinear plasticity. Let $f \in L^2(\Omega)$,

$$S_f = \{\sigma \in (L_2(\Omega))^2 \mid -\operatorname{div} \sigma = f\}$$

the equilibrium set, and

$$K_f = \{\sigma \in S_f \mid \|\sigma\|_\infty \leq k\}, \quad k > 0.$$

Then, the convex minimisation problem to be considered is

$$\min_{\sigma \in K_f} \|\sigma\|_{(L_2(\Omega))^2}^2$$

We will propose a method for enclosing the solution σ when Ω is a bounded, simply connected, polygonal domain in \mathbf{R}^2 . If $K_f \neq \emptyset$, there exists a unique solution. If an approximation for it in K_f is known, an error bound can be given in the L^2 norm using duality methods. The main difficulty is the construction of an initial element in K_f .

SPECTRAL ANALYSIS OF THE DISSIPATIVE BOLTZMANN OPERATOR AND SPECTRAL SINGULARITIES

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We present some results on the spectral analysis of the dissipative one-speed Boltzmann operator [1]. It is shown that the essential spectrum of the operator is absolutely continuous with one possible spectral singularity at the point 0. The spectral singularity appears for a discrete set of values of a physical parameter involved in the problem. The absolutely continuous component of the operator is shown to be similar to a direct sum of a selfadjoint operator and an operator with spectrum of finite multiplicity. We also study the geometry of invariant subspaces of the operator in the presence of the spectral singularity. The consideration is based on the abstract setup of the functional model of Sz-Nagy and Foias.

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SOME NEW INVERSE EIGENVALUE PROBLEMS

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We will look at two quite different problems to recover the potential in a second order differential operator from information on its spectrum. The first concerns the classical equation $-u'' + qu = \lambda u$ with (say) the boundary condition $u(0) = 0$. At the other end point, $x = 1$ $u'(1) = \sqrt{\lambda}u(1)$. This problem has complex eigenvalues and we will show that a single such spectrum suffices to determine q .

In the second problem we have the equation $-u'' + \ell(\ell + 1)/x^2 + qu = \lambda u$ with fixed conditions at $x = 1$ and boundedness at $x = 0$. We examine the conjecture that two complete spectra $\{\lambda_{n,\ell}\}$ for $n = 1, 2, \dots$ and for ℓ equals two distinct values ℓ_1, ℓ_2 is sufficient to determine q .

INVERSE SPECTRAL PROBLEM FOR THE STURM-LIOUVILLE EQUATION, RECOVERY OF THE POTENTIAL FROM THE SPECTRAL DATA

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A method is introduced for the reconstruction of the potential of a Sturm-Liouville operator L generated by $l(y) = -y''(x) + q(x)y(x)$ and separated boundary conditions in $L^1[0, b]$, $0 < b < \infty$ from a spectrum and a set of normalizing constants. These constants can be calculated from the second spectrum with the same boundary conditions at zero.

This method is based on the approach of I. W. Knowles for the recovery of coefficients in a PDE from boundary data and modified for use in this inverse spectral context. We define a functional which is zero at the true potential and calculate its Gateaux derivative in the form $G'(q)[h] = \int_0^1 h(x)H(x)dx$. Then, by the Riesz representation theorem the L^2 gradient is $H(x)$ and we use the gradient descent algorithm to recover the potential in the iterative process.

Since this problem is ill-posed a regularization method is developed to select the best recovered potential. We also discuss results obtained using different types of gradients, behaviour of the method in the presence of noise in the initial data and the implementation details.

EIGENVALUES IN GAPS OF PERTURBED PERIODIC DIRAC OPERATORS - NUMERICAL EVIDENCE

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This talk presents a method for the numerical investigation of the distribution of the eigenvalues introduced into a spectral gap of a periodic Dirac system by a perturbation of the type of the angular momentum term. A number of examples illustrate the effectiveness of the method and demonstrate the remarkable accuracy of the strong coupling asymptotic formula even for small values of the perturbation coupling constant. These results also shed some light on the spectrum in the exceptional gap of radially periodic three-dimensional Dirac operators.

LIMIT SPECTRAL CURVES FOR THE ORR-SOMMERFELD OPERATOR AND QUASICLASSICAL EIGENVALUE DISTRIBUTION ALONG THESE CURVES

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We study the well-known in hydrodynamics Orr-Sommerfeld problem on the finite interval $[-1, 1]$. We are interested in the question: how do the λ -eigenvalues of this problem behave as the Reynolds number $R \rightarrow \infty$? To answer this question we consider an auxiliary model problem

$$\begin{aligned} i\varepsilon^2 y'' + q(x)y &= \lambda y, \\ y(-1) = y(1) &= 0, \end{aligned}$$

where $\varepsilon = (\alpha R)^{-1/2}$. The limit behaviour of the eigenvalues of this problem as $\varepsilon \rightarrow 0$ depends on analytic properties of $q(z)$, namely, on the topology the Stokes lines, which

are defined in the complex plane by the equation

$$\operatorname{Re} S(z) = 0, \quad S(z) = \int_{\xi_\lambda}^1 \sqrt{i(q(\xi) - \lambda)} d\xi,$$

where ξ_λ is the root of $q(\xi) - \lambda = 0$.

We investigate the model problem in two cases: 1) an analytic monotone profile $q(z)$, 2) the so-called Couette–Poiseuille profile $q(z) = az^2 + bz + c$, $a, b, c \in \mathbb{R}$. We prove that the spectrum of the model problem is concentrated along some critical curves in the complex plane, defined by the Stokes lines, which for a monotone profile form a “spectral tie”. We find the formulas for the eigenvalue distribution along the limit curves which are uniform with respect to ε . Then we prove that the limit spectral curves for the original Orr-Sommerfeld problem coincide with those for the model problem, as well as the main terms in the formulas for the eigenvalue distribution along the curves.

ASYMPTOTIC AND SPECTRAL ANALYSIS OF AIRCRAFT WING MODEL IN SUBSONIC AIRFLOW

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The aircraft wing model, which will be discussed in this talk, has been developed in the Flight Systems Research Center of UCLA in collaboration with NASA Dryden Flight Systems Center. The mathematical formulation of this model has been originally presented in the works by A.V. Balakrishnan. The model has been recently tested in a series of flight experiments at Edwards Airforce Base. The experimental results have shown very good agreement with the theoretical predictions of the model for at least several lowest aeroelastic modes. The objective of the entire wing modeling project is to treat the flutter phenomenon in aircraft wing.

In this talk, I will present the results of my four recent works and of a joint paper with A.V. Balakrishnan devoted to the mathematical analysis of the model. The model is governed by a system of two coupled linear integro-differential equations and a two-parameter family of boundary conditions modeling the action of self-straining actuators. The differential parts of the equations of motion form a coupled linear hyperbolic system; the integral parts are of the convolution type. The aforementioned system is equivalent to a single operator evolution-convolution equation in the state space equipped with the energy metric. The Laplace transform of the solution of this equation can be represented in terms of the so-called generalized resolvent operator, which is an operator-valued function of the spectral parameter. This generalized resolvent operator is a finite-meromorphic function on the complex plane having a branch-cut along the negative real

semi-axis. Its poles are precisely the aeroelastic modes and the residues at these poles are the generalized projectors on the corresponding eigenspaces.

I will describe the following results:

- Asymptotics of the eigenvalues and eigenvectors of the nonselfadjoint operator, which is a dynamics generator of the differential part of the model.
- Riesz basis property of the generalized eigenvectors of the above operator in the state space.
- Asymptotics of aeroelastic modes and mode shapes for the entire model.
- Riesz basis property of the mode shapes.
- Application of the results of asymptotic and spectral analysis to the representation of the solution to the main initial-boundary value problem in the space-time domain.
- The problem of flutter control will be discussed.

EIGENFUNCTIONS GENERATED BY ODES BELONGING TO THE HEUN CLASS AND THEIR APPLICATIONS IN THE FOURIER ANALYSIS

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The measure distributions are often studied as the basic set of functions in the theory of the Fourier transform. The hypergeometric class of special functions gives a very poor amount of corresponding modelling distributions. A much broader variety of models can be found in the Heun class. The fact that the prolate spheroidal functions are eigenfunctions of the finite Fourier transform is well known and largely exploited. However modified spheroidal functions and double-confluent Heun functions give more sophisticated examples for needs of the Fourier transform.

The asymptotic study of ground eigenfunctions of particular cases of equations belonging to Heun class is given along with the treatise of the corresponding Fourier transform. The advantages and disadvantages of the studied functions comparatively to other functions are discussed.

The physical problem of reconstruction of the structure of thin films is formulated and some examples of its solution in terms of the discussed functions is shown. This inverse ill-posed problem shows robust solution in particular physically adjusted cases.

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THE SPECTRAL MINIMUM FOR RANDOM DISPLACEMENT MODELS

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Consider a one-dimensional Schrödinger operator with potential V given as follows: Fix a *single site potential* f which is supported in an interval of length less than 1. Construct V by placing a translate of f into each unit interval $[n, n + 1]$ for integer n , where otherwise the positions of each translate are arbitrary. Which configuration of single sites minimizes the spectral minimum of the Schrödinger operator with potential V ? This question is equivalent to finding the spectral minimum of the random displacement model. We conjecture that the minimum is realized through *pair formation* of the single sites. We provide a partial proof of this conjecture and additional numerical evidence for its correctness. This is joint work with Jason Lott.

ANTI-MAXIMUM PRINCIPLES

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For second order elliptic boundary value problems such as $-\Delta u = \lambda u + f$ in Ω and $u = 0$ on $\partial\Omega$ it is well known that for any reasonable bounded domain in \mathbb{R}^n a first eigenvalue λ_1 exists and moreover, for any $\lambda < \lambda_1$ a positive source term f implies that the solution u is positive. Clément and Peletier showed that for λ in a right neighbourhood of λ_1 opposite behaviour occurs, an phenomenon which they named the *anti-maximum principle*: certain

$f > 0$ imply $u < 0$. Such behaviour is roughly explained by the pole of the resolvent at λ_1 and the positive sign of the corresponding eigenfunction φ_1 :

$$u = \frac{1}{\lambda_1 - \lambda} \langle \varphi_1, f \rangle \varphi_1 + R_\lambda f.$$

with $R_\lambda f$ the remaining regular part. A more precise statement reads as: if $0 < f \in L^p(\Omega)$ with $p > n$, then there is $\delta_f > 0$ such that for $\lambda \in (\lambda_1, \lambda_1 + \delta_f)$ the solution satisfies $u < 0$. For higher order elliptic boundary value problems with appropriate boundary conditions sometimes a stronger *uniform anti-maximum principle* holds, that is, for $Lu = \lambda u + f$ in Ω with $Bu = 0$ on $\partial\Omega$ there exists $\delta > 0$ such that for all $\lambda \in (\lambda_1, \lambda_1 + \delta)$ and $f > 0$ one obtains $u < 0$.

The anti-maximum principle for higher order elliptic boundary value problems is joint work with Ph. Clément. Sharp conditions for the uniform anti-maximum principle will appear in a joint work with H.-Ch. Grunau.

WAVE PACKET PSEUDOMODES OF TWISTED TOEPLITZ MATRICES

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The spectra and pseudospectra of nonsymmetric Toeplitz or circulant matrices with slowly varying coefficients are considered. Such matrices are characterized by a symbol that depends on both space and wave number. It is shown that when a certain twist condition is satisfied, analogous to Hormander's commutator condition for partial differential equations, epsilon-pseudoeigenvectors of such matrices for exponentially small values of epsilon exist in the form of localized wave packets. These results are a discrete analogue of similar results for differential operators discussed recently by E. B. Davies and M. Zworski.

THE SPECTRUM OF SOME QUADRATIC OPERATOR PENCILS ASSOCIATED WITH DAMPED DYNAMICAL SYSTEMS

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We investigate the spectrum of a damped quadratic operator pencil with 2×2 block operator matrix coefficients. Our main result is that the spectrum splits asymptotically into four branches of eigenvalues and we determine their asymptotic behaviour. An application to the vibrations of two interacting connected strings and beams is given where one of them is damped.

(joint work V. Pivovarchik, Odessa)

APPLICATION OF THE WITTRICK-WILLIAMS ALGORITHM TO THE EIGENVALUES OF THE STURM-LIOUVILLE PROBLEM ON TREES

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A new method is presented for computing the eigenvalues of the Sturm-Liouville problem on trees. This is used to confirm some recent results of Sobolev and Solomyak.

A LOCAL BORG-MARCHENKO THEOREM FOR COMPLEX POTENTIALS

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Consider the Sturm-Liouville problem given by the equation $-y'' + qy = \lambda y$ on $[0, \infty)$ and the boundary condition $y(0) = 0$. The famous Borg-Marchenko theorem states that the associated Weyl-Titchmarsh m -function determines uniquely the potential q when q is real. The local version states that q is determined on $[0, a]$ if the m -function is known up to errors of the order of $\exp(-2a\Re(\sqrt{-\lambda}))$ (where $\Re(\sqrt{-\lambda})$ is positive) as λ tends to infinity along some non-real ray.

We show that under certain very general restrictions on q an analogous result holds also for complex-valued potentials.

This is joint work with B. M. Brown and R. A. Peacock.

MULTIPHASE INSTABILITIES IN ASTROPHYSICS

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Many astronomical structures are, in essence, multiphase flows. I will describe analytic and numerical work on the stability of some examples: ionization fronts (as seen in the well-known Orion nebula) and dust-driven winds. These specific examples lead on to a more general discussion of the Whitham theory of flow stability in damped hyperbolic systems, and of the nature of characteristic information.

LEFT-DEFINITE STURM-LIOUVILLE PROBLEMS

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Left-Definite, regular or singular, self-adjoint Sturm-Liouville problems with separated or coupled boundary conditions are discussed. Inequalities among the eigenvalues for different boundary conditions are established: these yield an elementary (without operator theory) proof of the existence of eigenvalues for coupled boundary conditions, an algorithm for their numerical computation as well as an asymptotic formula for them.

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PIANO RECITAL

There will be a piano recital by **Sybille Hempel-Abromeit** on Wednesday July 24th from 2030hrs.

Sybille Hempel-Abromeit studied piano at Freiburg and München. She has taught at several music schools and these days concentrates on chamber music and on accompanying soloists.

The recital will consist of:

- Bach** Prelude and Fugue, BWV 877 WT 2
- Mozart** Sonata, KV 311
- Chopin** Nocturne, Op. 27/2
- Debussy** 3 Preludes
- Brahms** Intermezzi 1 and 2 from Op. 119