Graduate Studies in Mathematics

2008-09

University of Toronto
Department of Mathematics
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416-978-7894

2008-2009 GRADUATE STUDIES IN MATHEMATICS HANDBOOK

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1. INTRODUCTION

The purpose of this handbook is to provide information about the graduate program of the Department of Mathematics, University of Toronto. It includes detailed information about the department, its faculty members and students, a listing of core courses offered in 2008-2009, a summary of research activities, admissions requirements, application procedures, fees and financial assistance, and information about similar matters of concern to graduate students and prospective graduate students in mathematics.

This handbook is intended to complement the calendar of the university's School of Graduate Studies, where full details on fees and general graduate studies regulations may be found.

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2. DEPARTMENT OF MATHEMATICS

Mathematics has been taught at the University of Toronto since 1827. Since the first Canadian Ph.D. degree in mathematics was conferred to Samuel Beatty (under the supervision of John Charles Fields) in 1915, more than 350 Ph.D. degrees and 900 Master's degrees have been awarded in this University. Many of our recent graduates are engaged in university teaching, and a significant number hold administrative positions in universities or in the professional communities. Others are pursuing careers in industry (technological or financial), or in government.

The Department of Mathematics, University of Toronto is a distinguished faculty of more than sixty mathematicians. We have a large selection of graduate courses and seminars, and a diverse student body of domestic and international students, yet classes are small and the ratio of graduate students to faculty is low. We are in a unique position to take maximum advantage of the presence of the Fields Institute, which features special programs in pure and applied mathematics. Currently the department has 116 graduate students, of whom 32 are enrolled in the Master's program, and 84 in the Ph.D. program.

Opportunities for graduate study and research are available in most of the main fields of pure and applied mathematics. These fields include real and complex analysis, ordinary and partial differential equations, harmonic analysis, nonlinear analysis, several complex variables, functional analysis, operator theory, C*-algebras, ergodic theory, group theory, analytic and algebraic number theory, Lie groups and Lie algebras, automorphic forms, commutative algebra, algebraic geometry, singularity theory, differential geometry, symplectic geometry, classical synthetic geometry, algebraic topology, set theory, set theoretic topology, mathematical physics, fluid mechanics, probability (in cooperation with the Department of Statistics), combinatorics, optimization, control theory, dynamical systems, computer algebra, cryptography, and mathematical finance.

We offer a research-oriented Ph.D., and Master's program. Very strong students may be admitted directly to the Ph.D. program with a Bachelor's degree; otherwise; it is normal to do a 1-year Master's degree first. (Provisional admission to the Ph.D. program may be granted at the time of admission to the Master's program.) The Master's program may be extended to 16 months or 24 months for students who do not have a complete undergraduate preparation, or for industrial students engaged in a project.

There is a separate Master's of Mathematical Finance Program not directly under the Department's jurisdiction, but with which some of our faculty members are associated.

During their studies here, graduate students are encouraged to participate in the life of the close community of U of T mathematics. Almost all of them do some work in connection with undergraduate teaching, either as tutorial leaders, markers, or, especially in later years of their program, instructors. There is a Mathematics Graduate Student Association which organizes social and academic events and makes students feel welcome.

GRADUATE FACULTY MEMBERS

AKCOGLU, M.A. (Professor Emeritus) Ph.D. 1963 (Brown)
- Ergodic theory, functional analysis, harmonic analysis

ANGEL, O. (Assistant Professor) Ph.D. 2003 (Weizmann Institute of Science)
- Probability theory

ARKHIPOV, S. (Assistant Professor) Ph.D. 1998 (Moscow State)
- Geometric representation theory

ARTHUR, J. (University Professor) B.Sc. 1966 (Toronto), M.Sc. 1967 (Toronto), Ph.D. 1970 (Yale)
- Representations of Lie groups, automorphic forms

BARBEAU, E. (Professor Emeritus) B.Sc. 1960 (Toronto), M.A. 1961 (Toronto), Ph.D. 1964 (Newcastle)
- Functional analysis, optimization under constraint, history of analysis, number theory

BAR-NATAN, D. (Professor) Ph.D. 1991 (Princeton)
- Theory of quantum invariants of knots, links and three manifolds

BIERSTONE, E. (Professor) B.Sc. 1969 (Toronto), Ph.D. 1973 (Brandeis)
- Singularity theory, analytic geometry, differential analysis

BINDER, I. (Assistant Professor) Ph.D. 1997 (Caltech)
- Harmonic and complex analysis, conformal dynamics

BLAND, J. (Professor) Ph.D. 1982 (UCLA)
- Several complex variables, differential geometry

BLOMER, V. (Assistant Professor) Ph.D. 2002 (Stuttgart)
- Analytic number theory

BLOOM, T. (Professor) Ph.D. 1965 (Princeton)
- Several complex variables

BUCHWEITZ, R.-O. (Professor) Ph.D. (Dr.rer.nat.) 1976 (Hannover), Doctorat d'Etat 1981 (Paris VII)
- Commutative algebra, algebraic geometry, singularities

BURCHARD, A. (Professor) Ph.D. (Georgia Tech) 1994
- Functional analysis

BUTSCHER, A. (Assistant Professor) 2000 (Stanford)
- Geometric analysis

CHOI, M.-D. (Professor) M.Sc. 1970 (Toronto), Ph.D. 1973 (Toronto)
- Operator theory, operator algebras, matrix theory

COLLIANDER, James (Professor) Ph.D. 1997 (Illinois, Urbana-Champaign)
- Partial differential equations, harmonic analysis

DAVIS, C. (Professor Emeritus) Ph.D. 1950 (Harvard)
- Operators on Hilbert spaces, matrix theory and applications (including numerical analysis)

DEL JUNCO, A. (Professor) B.Sc. 1970 (Toronto), M.Sc. 1971 (Toronto), Ph.D. 1974 (Toronto)
- Ergodic theory, functional analysis

DERZKO, N. (Associate Professor) B.Sc. 1970 (Toronto), Ph.D. 1965 (Caltech)
- Functional analysis, structure of differential operators, optimization and control theory with applications to economics

ELLERS, E. (Professor Emeritus) Dr.rer.nat. 1959 (Hamburg)
- Classical groups

ELLIOTT, G. A. (Canada Research Chair and Professor) Ph.D. 1969 (Toronto)
- Operator algebras, K-theory, non-commutative geometry and topology

FRIEDLANDER, J. (University Professor) B.Sc. 1965 (Toronto), Ph.D. 1972 (Penn State)
- Analytic number theory

GOLDSTEIN, M. (Professor**)** Ph.D. 1977 (Tashkent), Doctorat d'Etat 1987 (Vilnius)
- Spectral theory of Schroedinger operators and localization

GRAHAM, I. (Professor) B.Sc. 1970 (Toronto), Ph.D. 1973 (Princeton)
- Several complex variables, one complex variable

GREINER, P.C. (Professor Emeritus) Ph.D. 1964 (Yale)
- Partial differential equations

GUALTIERI, M. (Assistant Professor) Ph.D. 2003 (Oxford)
- Differential geometry and mathematical physics

GUTH, Lawrence (Assistant Professor) Ph.D. 2005 (MIT)
- Geometry and Functional analysis

HALPERIN, S. (Professor Emeritus) B.Sc. 1965 (Toronto), M.Sc. 1966 (Toronto), Ph.D. 1970 (Cornell)
- Homotopy theory and loop space homology

HORI, K. (Assistant Professor) Ph.D. 1994 (Tokyo)
- Gauge field theory, string theory

IVRII, V. (Professor) Ph.D. 1973 (Novosibirsk)
- Partial differential equations

JEFFREY, L. (Professor) Ph.D. 1992 (Oxford)
- Symplectic geometry, geometric applications of quantum field theory

JERRARD, Robert (Professor) Ph.D. 1994 (Berkeley)
- Nonlinear partial differential equations, Ginzburg-Landau theory

JURDJEVIC, V. (Professor Emeritus) Ph.D. 1969 (Case Western)
- Systems of ordinary differential equations, control theory, global analysis

KAMNITZER, Joel (Assistant Professor) Ph.D. 2005 (Berkeley)
- Geometric and combinatorial representation theory

KAPOVITCH, V. (Associate Professor) Ph.D. 1997 (University of Maryland)
- Global riemannian geometry

KARSHON, Y. (Professor) Ph.D. 1993 (Harvard)
- Equivariant symplectic geometry

KAVEH, K. (Assistant Professor) Ph.D. 2002 (University of Toronto)
- Algebraic group

KEYFITZ, B. (Adjunct Full Professor) Ph.D. 1970 (New York University)
- Nonlinear partial differential equations

KHANIN, K. (Professor) Ph.D. 1983 (Landau Institute, Moscow)
- Dynamical systems and statistical mechanics

KHESIN, B. (Professor) Ph.D. 1989 (Moscow State)
- Poisson geometry, integrable systems, topological hydrodynamics

KHOVANSKII, A. (Professor) Ph.D. 1973, Doctorat d'Etat 1987 (Steklov Institute, Moscow)
- Algebra, geometry, theory of singularities

KIM, Henry (Professor) Ph.D. 1992 (Chicago)
- Automorphic L-functions, Langlands' program

KUDLA, S. (Canada Research Chair and Professor) Ph.D. 1971 (Harvard)
- Automorphic forms, Arithmetic geometry and Theta functions

LORIMER, J.W. (Professor) Ph.D. 1971 (McMaster)
- Rings and geometries, topological Klingenberg planes, topological chain rings

LYUBICH, M. (Canada Research Chair and Professor) Ph.D. 1984 (Tashkent State University)
- Dynamical systems, especially holomorphic and low dimensional dynamics

MASSON, D. (Professor Emeritus) Ph.D. 1963 (London)
- Special functions, Jacobi matrices, orthogonal polynomials, difference equations, continued fractions and *q*-series

McCANN, R. (Professor) Ph.D. 1994 (Princeton)
- Mathematical physics, mathematical economics, inequalities, optimization, partial differential equations

McCOOL, J. (Professor Emeritus) Ph.D. 1966 (Glasgow)
- Infinite group theory

MEINRENKEN, E. (Professor) Ph.D. 1994 (Universität Freiburg)
- Symplectic geometry

MENDELSOHN, E. (Professor) Ph.D. 1968 (McGill)
- Block designs, combinatorial structures

MIKHALKIN, G. (Canada Research Chair and Professor) Ph.D. 1993 (Michigan State University)
- Geometry, topology and algebraic geometry

MILMAN, P. (Professor) Ph.D. 1975 (Tel Aviv)
- Singularity theory, analytic geometry, differential analysis

MURASUGI, K. (Professor Emeritus) D.Sc. 1960 (Tokyo)
- Knot theory

MURNAGHAN, F. (Professor) Ph.D. 1987 (Chicago)
- Harmonic analysis and representations of *p*-adic groups

MURTY, V.K. (Professor) Ph.D. 1982 (Harvard)
- Number theory

NABUTOVSKY, A. (Professor) Ph.D. 1992 (Weizmann Institute of Science)
- Geometry and logic

NACHMAN, A. (Professor) Ph.D. 1980 (Princeton)
- Inverse problems, partial differential equations, medical imaging

QUASTEL, J. (Professor) Ph.D. 1990 (Courant Institute)
- Probability, stochastic processes, partial differential equations

PONGE, R. (Assistant Professor) Ph.D. 2000 (University of Paris-Sud)
- Noncommutative geometry, geometric analysis, several complex variables, pseudodifferential operators

PUGH, C. (Distinguished Visiting Professor) Ph.D. (Johns Hopkins) 1965
- Dynamics and topology

PUGH, M. (Associate Professor) Ph.D. 1993 (Chicago)
- Scientific computing, nonlinear PDEs, fluid dynamics, computational neuroscience

REPKA, J. (Professor) B.Sc. 1971 (Toronto), Ph.D. 1975 (Yale)
- Group representations, automorphic forms

ROCHON, F. (Assistant Professor) Ph.D. 2005 (MIT)

- Global analysis, analysis on manifolds, Differential geometry

ROONEY, P.G. (Professor Emeritus) Ph.D. 1952 (Caltech)
- Integral operators, functional analysis

ROSENTHAL, P. (Professor) Ph.D. 1967 (Michigan)
- Operators on Hilbert spaces

ROTMAN, R. (Associate Professor) Ph.D. 1998 (SUNY, Stony Brook)
- Riemannian geometry

SCHERK, J. (Associate Professor) D.Phil. 1978 (Oxford)
- Algebraic geometry

SECO, L. (Professor) Ph.D. 1989 (Princeton)
- Harmonic analysis, mathematical physics, mathematical finance

SELICK, P. (Professor) B.Sc. 1972 (Toronto), M.Sc. 1973 (Toronto), Ph.D. 1977 (Princeton)
- Algebraic topology

SEN, D.K. (Professor Emeritus) Dr.es.Sc. 1958 (Paris)
- Relativity and gravitation, mathematical physics

SHARPE, R. (Professor Emeritus) B.Sc. 1965 (Toronto), M.Sc. 1966 (Toronto), Ph.D. 1970 (Yale)
- Differential geometry, topology of manifolds

SHERK, F.A. (Professor Emeritus) Ph.D. 1957 (Toronto)
- Finite and discrete geometry

SHUB, M. (Professor) Ph.D. 1967 (Berkeley)
- Dynamical systems and complexity theory

SIGAL, I.M. (University Professor, Norman Stuart Robertson Chair in Applied Math) Ph.D. 1975 (Tel Aviv)
- Mathematical physics

SMITH, S.H. (Professor Emeritus) Ph.D. 1963 (London)
- Fluid mechanics, particularly boundary layer theory

STREET, B. (Assistant Professor) Ph.D. 2007 (Princeton)
- Partial differential equations, Several complex variables and analytic spaces

SULEM, C. (Professor) Doctorat d'Etat 1983 (Paris-Nord)
- Partial differential equations, nonlinear analysis, numerical computations in fluid dynamics

SZEGEDY, B. (Assistant Professor) Ph.D. 2002 (Eötvös University, Budapest)
- Group theory, Combinatorics, Computer science

TALL, F.D. (Professor) Ph.D. 1969 (Wisconsin)
- Set theory and its applications, set-theoretic topology

TANNY, S.M. (Associate Professor) Ph.D. 1973 (M.I.T.)
- Combinatorics, mathematical modeling in the social sciences

TODORCEVIC, S. (Canada Research Chair and Professor) Ph.D. 1979 (Belgrade)
- Set theory and combinatorics

VIRAG, B. (Canada Research Chair and Assistant Professor) Ph.D. 2000 (Berkeley)
- Probability

WEISS, W. (Professor) M.Sc. 1972 (Toronto), Ph.D. 1975 (Toronto)
- Set theory, set-theoretic topology

YAMPOLSKY, M. (Associate Professor) Ph.D. 1997 (SUNY, Stony Brook)
- Holomorphic and low-dimensional dynamical systems

3. THE GRADUATE PROGRAM

The Department of Mathematics offers graduate programs leading to Master of Science (M.Sc.) and Doctor of Philosophy (Ph.D.) degrees in mathematics, in the fields of pure mathematics and applied mathematics.

The M.Sc. Program

The M.Sc. program may be done on either a full- or part-time basis. Full-time students normally complete the program in one full year of study; part-time students may take up to three years to complete the program. The degree requirements are as follows:

1a. Completion of 6 half-courses (or the equivalent combination of half- and full-year courses), as described in section 4 of this handbook. The normal course load for full-time graduate students is 3 courses in the fall term and 3 in the spring term. Students who intend to proceed in the Ph.D. program are required to take one full core course, and are strongly advised to take two of the core courses.

1b. Completion of the Supervised Research Project (MAT 4000Y). This project is intended to give the student the experience of independent study in some area of advanced mathematics, under the supervision of a faculty member. The supervisor and the student, with the approval of the graduate coordinator decide the topic and program of study. The project is normally undertaken during the summer session, after the other course requirements have been completed, and has a workload roughly equivalent to that of a full-year course.

2. M.Sc. Thesis Option (less common than option 1). Students who take this option will be required to take and pass two approved full-year courses and submit an acceptable thesis.

The Ph.D. Program

The Ph.D. program normally takes three or four years of full-time study beyond the Master's level to complete. A Master's degree is normally a prerequisite; however, exceptionally strong B.Sc. students may apply for direct admission to the Ph.D. program. Expected progress in the program is outlined in the following table:

Year 1	Completion of course work; Pass the comprehensive exams; Select a thesis advisor.
Year 2	Supervisory committee selected by graduate coordinator; First annual supervisory committee progress report due.
Year 3	Presentation of preliminary thesis results to supervisory committee.
Year 4	Thesis Content Seminar; Departmental PhD Thesis Examination; Final PhD Thesis Examination at the School of Graduate Studies.
Year 4 – October	Students interested in academic employment after the PhD must have major thesis results ready.

1. <u>Coursework</u>**:** Completion of at least 6 half-courses (or the equivalent combination of half- and full-year courses), as described in section 4 of this handbook. Normally, 6 half-courses are taken in the first year of study (3 half-courses in the fall term and 3 in the spring term). It is strongly recommended that the student take some additional courses in other years.

2. <u>Comprehensive Examination</u>: The student is required to pass comprehensive examinations in basic mathematics before beginning an area of specialization. The examinations in the four of the five general areas (real analysis, complex analysis, algebra, topology and partial differential equations) take place during a one-week period in early September. Exemptions from individual exams will be given if the student has obtained a grade of A- or better in the corresponding core course(s). Syllabi for the pure mathematics comprehensive exams appear in *Appendix A.* Copies of mock examination questions and/or past written examination papers are accessible to all candidates at http://www.math.toronto.edu/graduate/pce.

Students with interests in applied mathematics should refer to Appendix B for possible alternate comprehensive exams.

All exams are to be taken within 13 months of entering the Ph.D. program unless the Examination Committee grants permission in writing for a deferral.

3. Supervisory Committee: In accordance with School of Graduate Studies regulations, a supervisory committee will be established for each Ph.D. student who has chosen a research area and a supervisor. This committee consists of three faculty members including the supervisor. It is responsible for monitoring the student's progress on an annual basis. By the end of the third year of Ph.D. studies, a student is required to present preliminary results of his/her research work to the supervisory committee. Information about general graduate supervision is available in the SGS document *Graduate Supervision, Guidelines for Students, Faculty, and Administrators.*

4. Thesis: The main requirement of the degree is an acceptable thesis. This will embody original research of a standard that warrants publication in the research literature. It must be written under the supervision of one or more members of the department. The student presents the thesis results in three stages.

   (i) *Thesis Content Seminar.* This is an opportunity for the student to present his/her thesis results to department members. The presentation frequently takes place within one of the regular departmental research seminars.
   (ii) *Departmental Oral Examination.* The student gives a 20-minute summary of the thesis and must defend it before a departmental examination committee. Copies of the thesis should be available two weeks before the departmental oral examination. The committee may approve the thesis without reservations, or approve the thesis on condition that revision be made, or require the student to take another departmental oral examination.
   (iii) *Final Oral Examination.* Eight weeks after the successful completion of the departmental oral, the student proceeds to the final oral examination conducted by the School of Graduate Studies. The thesis is sent to an external reader who submits a report two weeks prior to the examination; this report is circulated to members of the examination committee and to the student. The examination committee consists of four to six faculty members; it is recommended that the external reader attend the examination. The student gives a 20-minute summary of the thesis which is followed by a question period.

5. Students are expected to become extensively involved in departmental life (seminars, colloquia and related activities).

Administration of the Graduate Program

A central administration authority called the School of Graduate Studies establishes the basic policies and procedures governing all graduate study at the University of Toronto. Detailed information about the School is obtained in its calendar, distributed to all graduate students during registration week, and in the admissions package that accompanies the application.

The Department of Mathematics has its own graduate administrative body—the graduate committee—composed of 6-8 faculty members appointed by the chair of the department, and five graduate students elected by the Mathematics Graduate Students Association. One of the faculty members is the graduate coordinator, who is responsible for the day-to-day operation of the program. The graduate committee meets frequently throughout the year to consider matters such as admissions, scholarships, course offerings, and departmental policies pertaining to graduate students. Student members are not permitted to attend meetings at which the agenda concerns confidential matters relating to other students. Information regarding appeals of academic decisions is given in the Grading Procedures section of the Calendar of the School of Graduate Studies. Students may also consult the Graduate Coordinator (or the student member of the departmental Graduate Appeals Committee) regarding information about such appeals.

<u>General Outline of the 2007-2008 Academic Year</u>

Registration	August 11 – September 12, 2008
Fall Term	Monday, September 8 – Friday, December 5, 2008
Spring Term	Monday, January 5 – Friday, April 9, 2009
Reading Week	February 16 – 20, 2009

<u>Official Holidays (University Closed)</u>*:*

Labour Day	Monday, September 1, 2008
Thanksgiving Day	Monday, October 13, 2008
Christmas/New Year	Monday, December 22, 2008 – Friday, January 2, 2009 (inclusive)
Good Friday	Friday, April 10, 2009
Victoria Day	Monday, May 18, 2009
Canada Day	Wednesday, July 1, 2009
Civic Holiday	Monday, August 3, 2009

4. GRADUATE COURSES

The following is a list and description of the core courses offered to graduate students in the 2007-2008 academic year. These are the basic beginning graduate courses. They are designed to help the student broaden and strengthen his/her general background in mathematics prior to specializing towards a thesis. A student with a strong background in the area of any of the core courses should not take that particular course. In addition, graduate students may take several intermediate (300-level) undergraduate courses (listed in the Faculty of Arts and Science Calendar) if their background is felt to be weak in some area; no graduate course credit is given for these courses.

There are three other means by which graduate students may obtain course credit, apart from completing the formal courses listed on the following pages. In each of these cases, prior approval of the graduate coordinator is required.

1. Students may take a suitable graduate course offered by another department. Normally at least two-thirds of the course requirements for each degree should be in the Mathematics Department.
2. It is sometimes possible to obtain course credit for appropriately extensive participation in a research seminar (see *Research Activities* section).
3. It is also possible to obtain a course credit by working on an individual reading course under the supervision of one of the faculty members, provided the material covered is not available in one of the formal courses or research seminars. (Note: this is distinct from the MAT 4000Y Supervised Research Project required of all M.Sc. students.)

Most courses meet for three hours each week, either in three one-hour sessions or two longer sessions. For some courses, particularly those cross-listed with undergraduate courses, the times and locations of classes will be set in advance of the start of term. For other courses, the times and locations of classes will be established at organizational meetings during the first week of term, so that a time convenient for all participants may be arranged. During registration week, students should consult the math department website or the graduate bulletin board outside the mathematics office for class and organization meeting times and locations.

CORE COURSES

MAT 1000YY (MAT 457Y1Y)
REAL ANALYSIS
L. Guth

1. Lebesgue integration, measure theory, convergence theorems, the Riesz representation theorem, Fubini's theorem, complex measures.
2. L^p-spaces, density of continuous functions, Hilbert space, weak and strong topologies, integral operators.
3. Inequalities.
4. Bounded linear operators and functionals. Hahn-Banach theorem, open-mapping theorem, closed graph theorem, uniform boundedness principle.
5. Schwartz space, introduction to distributions, Fourier transforms on the circle and the line (Schwartz space and L_2).
6. Spectral theorem for bounded normal operators.

Textbooks:
Elias Stein and Rami Shakarchi, *Measure Theory, Integration, and Hilbert Spaces*,

References:
H.L. Royden: *Real Analysis,* Macmillan, 1988.
A.N. Kolmogorov and S.V. Fomin: *Introductory Real Analysis*, 1975.
W. Rudin: *Real and Complex Analysis*, 1987.

K. Yosida: *Functional Analysis*, Springer, 1965.

MAT 1001HS (MAT 454H1S)
COMPLEX ANALYSIS
C. Pugh

1. Review of elementary properties of holomorphic functions. Cauchy's integral formula, Taylor and Laurent series, residue calculus.
2. Harmonic functions. Poisson's integral formula and Dirichlet's problem.
3. Conformal mapping, Riemann mapping theorem.
4. Elliptic functions and Riemann surfaces.
5. Analytic continuation, monodromy theorem, little Picard theorem.

<u>*References*</u>:
L. Ahlfors: *Complex Analysis*, 3rd Edition, McGraw-Hill, New York, 1966.
H. Cartan: *Elementary theory of analytic functions of one or several complex variables*, Dover.
W. Rudin: *Real and Complex Analysis,* 2nd Edition, McGraw-Hill, New York, 1974.

MAT 1060HF
PARTIAL DIFFERENTIAL EQUATIONS I
A. Nachman

This course is a basic introduction to partial differential equations. It is meant to be accessible to beginners with little or no prior knowledge of the field. It is also meant to introduce beautiful ideas and techniques which are part of most analysts' basic bag of tools.

Some topics to be covered:

1. Nonlinear first-order PDE. Method of characteristics.
2. The Fourier Transform. Distributions.
3. Sobolev spaces on R^n. Sobolev spaces on bounded domains. Weak solutions.
4. Second order elliptic partial differential operators. The Laplace operator. Harmonic functions. Maximum principle. The Dirichlet and Neumann problems. The Lax-Milgram Lemma. Existence, uniqueness and eigenvalues. Green's functions. Single layer and double layer potentials.
5. Hyperbolic partial differential equations. The wave equation. The Cauchy problem. Energy methods. Fundamental solutions. Domain of influence. Propagation of singularities.

<u>*Textbook*</u>:
Lawrence Evans: *Partial Differential Equations*

MAT 1061HS
PARTIAL DIFFERENTIAL EQUATIONS II
F. Rochon

This course will consider a range of mostly nonlinear partial differential equations, including elliptic and parabolic PDE, as well as hyperbolic and other nonlinear wave equations. In order to study these equations, we will develop a variety of methods, including variational techniques, several fixed point theorems, and nonlinear semigroup theory. A recurring theme will be the relationship between variational questions, such as critical Sobolev exponents, and issues related to nonlinear evolution equations, such as finite-time blowup of solutions and/or long-time asymptotics.

The prerequisites for the course include familiarity with Sobolev and other function spaces, and in particular with fundamental embedding and compactness theorems.

Reference:
Lawrence Evans: *Partial Differential Equations*

MAT 1100YY
ALGEBRA
S. Arkhipov

1. Linear Algebra. Students will be expected to have a good grounding in linear algebra, vector spaces, dual spaces, direct sum, linear transformations and matrices, determinants, eigenvectors, minimal polynomials, Jordan canonical form, Cayley-Hamilton theorem, symmetric, alternating and Hermitian forms, polar decomposition.
2. Group Theory. Isomorphism theorems, group actions, Jordan-Hölder theorem, Sylow theorems, direct and semidirect products, finitely generated abelian groups, simple groups, symmetric groups, linear groups, nilpotent and solvable groups, generators and relations.
3. Ring Theory. Rings, ideals, rings of fractions and localization, factorization theory, Noetherian rings, Hilbert basis theorem, invariant theory,Hilbert Nullstellensatz, primary decomposition, affine algebraic varieties.
4. Modules. Modules and algebras over a ring, tensor products, modules over a principal ideal domain, applications to linear algebra, structure of semisimple algebras, application to representation theory of finite groups.
5. Fields. Algebraic and transcendental extensions, normal and separable extensions, fundamental theorem of Galois theory, solution of equations by radicals.

Textbooks:
Dummit and Foote: *Abstract Algebra,* 2nd Edition
Lang: *Algebra,* 3rd Edition.

Other References:
Jacobson: *Basic Algebra, Volumes I and II.*
Cohn: *Basic Algebra*
M. Artin: *Algebra*.

MAT 1300YY
TOPOLOGY
M. Gualtieri

Main text: Bredon's "Topology and Geometry".

Optimistic plan:

- 8 weeks of local differential geometry: the differential, the inverse function theorem, smooth manifolds, the tangent space, immersions and submersions, regular points, transversality, Sard's theorem, the Whitney embedding theorem, smooth approximation, tubular neighborhoods, the Brouwer fixed point theorem.
- 5 weeks of differential forms: exterior algebra, forms, pullbacks, d, integration, Stokes' theorem, div grad curl and all, Lagrange's equation and Maxwell's equations, homotopies and Poincare's lemma, linking numbers.
- 5 weeks of fundamental groups: paths and homotopies, the fundamental group, coverings and the fundamental group of the circle, Van-Kampen's theorem, the general theory of covering spaces.
- 8 weeks of homology: simplices and boundaries, prisms and homotopies, abstract nonsense and diagram chasing, axiomatics, degrees, CW and cellular homology, subdivision and excision, the generalized Jordan curve theorem, salad bowls and Borsuk-Ulam, cohomology and de-Rham's theorem, products.

The class will be hard and challenging and will include a substantial component of self-study. To take it you must feel at home with point-set topology, multivariable calculus and basic group theory.

TOPICS COURSES AND CROSS-LISTED UNDERGRADUATE/GRADUATE COURSES

A listing is available from the graduate website: http://www.math.toronto.edu/graduate/courses/descriptions.html

INDIVIDUAL READING COURSES

Students requiring individual course numbers:

MAT 1900Y/1901H/1902H
READING IN PURE MATHEMATICS

Numbers assigned for students wishing individual instruction in an area of pure mathematics.

MAT 1950Y/1951H/1952H
READING IN APPLIED MATHEMATICS

Numbers assigned for students wishing individual instruction in an area of applied mathematics.

COURSE IN TEACHING TECHNIQUES

The following course is offered to help train students to become effective tutorial leaders and eventually lecturers. It is not for degree credit and is not to be offered every year.

MAT 1499HS
TEACHING LARGE MATHEMATICS CLASSES
J. Repka

The goals of the course include techniques for teaching large classes, sensitivity to possible problems, and developing an ability to criticize one's own teaching and correct problems.

Assignments will include such things as preparing sample classes, tests, assignments, course outlines, designs for new courses, instructions for teaching assistants, identifying and dealing with various types of problems, dealing with administrative requirements, etc.

The course will also include teaching a few classes in a large course under the supervision of the instructor. A video camera will be available to enable students to tape their teaching for later (private) assessment.

COURSES FOR GRADUATE STUDENTS FROM OTHER DEPARTMENTS

(Math graduate students cannot take the following courses for graduate credit.)

MAT	2000Y	READINGS IN	THEORETICAL MATHEMATICS
MAT	2001H	READINGS IN	THEORETICAL MATHEMATICS I
MAT	2002H	READINGS IN	THEORETICAL MATHEMATICS II

(These courses are used as reading courses for engineering and science students in need of instruction in special topics in theoretical mathematics. These course numbers can also be used as dual numbers for some third and fourth year undergraduate mathematics courses if the instructor agrees to adapt the courses to the special needs of graduate students. A listing of such courses is available in the 2006-2007 Faculty of Arts and Science Calendar.

Students taking these courses should get an enrolment form from the graduate studies office of the Mathematics Department. Permission from the instructor is required.)

5. RESEARCH ACTIVITIES

The Department of Mathematics offers numerous research activities, in which graduate students are encouraged to participate. Research seminars are organized informally at the beginning of each year by one or more faculty members, and are offered to faculty and graduate students on a weekly basis throughout the year. The level and specific content of these seminars varies from year to year, depending upon current faculty and student interest, and upon the availability and interests of invited guest lecturers. The following weekly research seminars have been offered in the past few years:

Research Seminars

- Applied Math/PDE/Analysis/Seminar
- Probability Seminar
- I-AIM Interdisciplinary Math Seminar
- Dynamical Systems Seminar
- Computability and Complexity in Analysis and Dynamics Seminar
- Geometry and Topology Seminar
- Symplectic Seminar
- Operator Theory
- High Energy Physics Seminar
- Joint Math/Physics Seminar
- Algebraic Geometry Seminar
- Ganita Seminar
- Number Theory/Representation Theory Seminar
- Crypto Seminar
- Combinatorics
- Logic Seminar
- Set Theory Seminar
- Graduate Seminar
- Geometric Stories Seminar
- Student Geometry Seminar

Note: It is possible for graduate students to obtain course credit for sufficiently extensive participation in research seminars (see *Graduate Courses* section).

In addition to the weekly seminars, there are numerous special seminars throughout the year, a series of colloquia, and an active program of visiting lecturers. Graduate students are also welcome to attend lectures and seminars offered by other departments.

6. ADMISSION REQUIREMENTS AND APPLICATION PROCEDURES

Due to the large numbers of applications received in the Department of Mathematics each year, serious consideration will only be given to applicants with strong backgrounds in theoretical mathematics and with first class academic standing.

Application materials and admission requirements are available from the Department of Mathematics web-site: http://www.math.toronto.edu/graduate

Please read all instructions carefully and note the deadlines. In addition, the Department of Mathematics requires three letters of reference. The letters must be from *three* people familiar with your mathematical work, giving their assessment of your potential for graduate study and research in mathematics.

It is essential that all incoming graduate students have a good command of English. Facility in the English language must be demonstrated by all applicants educated outside Canada whose primary language is not English. This requirement is a condition of admission and should be met before application. There are three ways to satisfy this requirement: (1) Test of English as a Foreign Language (TOEFL): (a) internet-based test (iBT), minimum score of 22/30 for both the Writing and Speaking sections, with an overall minimum TOEFL score of 93/120, or (b) computer-based test, minimum score 237, with Essay Rating, minimum score 4.0, or (c) paper-based test, minimum score 580, with TWE (Test of Written English), minimum score 4.0; (2) a score of at least 85 on the Michigan English Language Assessment Batter (MELAB); (3) a score of at least 7.0 on the International English Language Testing Service (IELTS). Applicants are required to satisfy this requirement by February (for September admission) so that scores are available at the time applications are considered.

7. FEES AND FINANCIAL ASSISTANCE

Fees

Information concerning fees is in the admissions package that accompanies the application forms; more detailed information and a schedule of fees for 2008-09 will be available in August 2008 from the School of Graduate Studies. Listed below are the fees for the 2008-09 academic session, including incidental fees and the health insurance premium for visa students:

Domestic students:	Full-time	$7,156
Visa students:	Full-time	$15,683

Financial Assistance

Below is a list of those types of financial assistance most commonly awarded to mathematics graduate students in 2008-09. This information should also be applicable for students who wish to apply for the 2009-10 academic year; the deadlines for applications will be altered slightly in accordance with the 2008-09 calendar. Some awards are available from external funding agencies; others come from within the University.

Less common scholarships, offered by smaller or foreign funding agencies, are also available; information about these is generally distributed to the graduate offices of local universities.

Natural Sciences and Engineering Research Council (NSERC) Postgraduate Scholarships and Canada Graduate Scholarships
Value: approx. $17,300-$35,000 for a twelve month period
Eligibility: Canadian citizens, permanent residents; first class academic standing; full-time attendance (restricted almost exclusively to Canadian universities)
Application: apply through the university you are currently attending; application available at www.nserc.ca

Deadline: around mid October. Contact your university for departmental deadline.

Ontario Graduate Scholarships (OGS)
Value: approx. $5,000 per term for two or three terms
Eligibility: no citizenship restrictions; first class academic standing; full-time attendance at an Ontario university
Application: apply through the university you are currently attending or contact the OGS office in Thunder Bay, Ontario directly at 1-800-465-3957 (http://osap.gov.on.ca/eng/eng_osap_main.html).
Deadline: around mid October

University of Toronto Fellowships
Value: minimum $1,000
Eligibility: no citizenship restrictions; at least an A- average; full-time attendance at the University of Toronto (or, in the case of the Master's program and for students with a disability, part-time registration together with a letter from the Director of Special Services to Persons with a Disability confirming that part-time study is de facto full-time study for the student). See below for policy.
Application: graduate school applicants will be considered automatically
Deadline: February 1

Connaught Scholarship
Value: $15,000 plus full fees for first year
Eligibility: no citizenship restrictions; full-time attendance at the University of Toronto; awarded only to exceptionally outstanding scholars
Application: graduate school applicants will be considered automatically
Deadline: February 1

Research Assistantships
Value: a limited amount of funds is available for academically worthy students
Eligibility: no citizenship restrictions; full-time attendance; high academic standing
Application: graduate school applicants will be considered automatically
Deadline: February 1

Teaching Assistantships
Value: $36.35 per hour; number of hours per week will not exceed a maximum average of 8
Eligibility: all full-time students who are accepted by the Mathematics Department (subject to satisfactory performance); may be held in conjunction with other awards
Application: forms available in May from the Graduate Office, Department of Mathematics
Deadline: early June

Conference Travel Grant

An important part of the research process is the presentation of one's work at scholarly conferences. The purpose of this program is to provide additional funds to enable graduate students in the Faculty of Arts and Science to travel to conferences where they will present their work.

Value: varies to a maximum of $1,000
Eligibility: no citizenship restrictions; award holders must be in the funded cohort. Graduate students may hold only one Travel Grant during their time in the department.
Eligible Expenses: Conference registration and abstract submission costs, travel and living expenses.
Application: Applications available from the Math Graduate Office; deadline October 1.
Selection Criteria: Past academic performance. Need to attend conference for professional development. Quality of abstract. Preference will be given to students near the end of their degrees.

Department of Mathematics Policy on Financial Support of Graduate Students

Ph.D. Students: At the time of admission to the Ph.D. program, students will normally be guaranteed support for a period of four years (five years in the case of students admitted directly from a Bachelor's program), except that students who complete their degree requirements earlier will not be supported past the end of the academic year in which they finish. This guarantee will be made up of a mix of fellowships (including external awards such as NSERC), teaching assistantships and other sources of funding, at the discretion of the Department; and is subject to satisfactory academic progress, the maintenance of good standing, and in the case of teaching assistantships, satisfactory performance in that role, as judged by the Department. Absent this, support may be reduced, suspended, or discontinued.

In exceptional circumstances some funding may be provided to students in a subsequent year, but the Department expects that students will normally have completed their degree requirements within the four year period.

M.Sc. Students: Students who are granted provisional admission to the Ph.D. program at the time of admission will receive financial support, normally for one year only.

All full-time students in the first or second year of a Master's program are eligible for teaching assistant work (subject to satisfactory performance).

8. OTHER INFORMATION

The Department of Mathematics is located in the heart of the University of Toronto, which in turn is located in the heart of downtown Toronto. Students therefore have access to a wide range of facilities and services. A list of these appear below.

Facilities and Services

Library Facilities

The University of Toronto Library System is the 4th largest academic research library in North America. It has over 4 million volumes. The Mathematical Sciences Library (MSL) is in the same building as the Mathematics Department. The vast majority of Mathematics journals are held at the MSL with some being held at the GSIC. The MSL also houses a selective collection of over 17,000 titles of mathematical books. The resources of the Library System are electronically linked by UTLink. It includes the catalogues of all libraries on campus, electronic abstracts and indexes, and other electronic resources such as electronic journals and internet. The MSL has computers with Netscape which give access to MathSciNet, UTLink and other electronic resources. It has study spaces for reading journals/books and studying. The Library has a photocopier for copying library materials. The MSL gives each graduate student a photocopying allowance. The Gerstein Science Information Centre (GSIC) also has a comprehensive collection of mathematical books up to 1998.

Computer Facilities

All faculty and graduate students are provided with accounts on the main departmental server and the departmental computer server (these servers are quad-processor SunFire 4200's with 16GB of RAM running the most recent version of Red Hat Enterprise Linux). These accounts give access to electronic mail facilities, which are also accessible via IMAPS or webmail, to the internet including the ability to put a webpage on the departmental webserver, many mathematical software packages (for example, Maple, Matlab, Mathematica, pari/gp, idl, octave, axiom), scientific and other graphics programs (most of the symbolic manipulators, gimp), computer language compilers (for example, fortran77, fortran95, C, C++, java), a rich mathematical software library, mathematical typesetting programs (TeX, LaTeX), etc. A dedicated compute lab with 14 machines is available. There are over 100 microcomputers currently available to the faculty and students. University managed wireless connectivity is available for most people in the department. There are plans to add NAS storage in order to increase user storage resources, to consolidate locations for efficiency, and to expand access to IT supported teaching.

Housing

The university operates five graduate student residences-apartment complexes on or near the campus, ranging from unfurnished family apartments to the more conventional bed-and-board residences. In addition, the University Housing Service provides a listing of privately owned rooms, apartments and houses available for students to rent (see *Contacts* below). More detailed information about these facilities may be found in the admissions package which accompanies the application forms.

Students should keep in mind that accommodation could be expensive and limited, particularly in downtown Toronto. It is therefore advisable to make inquiries well in advance and to arrive in Toronto a few days prior to the start of term. Students can expect to pay anywhere between $500 to $900 per month on accommodation and from $300 to $500 per month on food, travel and household necessities.

Health Services

The University of Toronto Health Service offers medical services and referrals to private physicians for University of Toronto students. Most of these services are free of charge if you are covered under Ontario Health Coverage (OHIP), or the University Health Insurance Plan (UHIP) for visa students. OHIP application forms and information are available from the University Health Services (see *Contacts* below).

UHIP coverage for visa students is compulsory and is arranged during registration at the International Student Centre.

Disabled Students

Services and facilities for disabled students are available at the University of Toronto. Further information may be obtained from the Coordinator of Services for Disabled Persons (see *Contacts* section below).

Foreign Students

The International Student Centre offers many services to foreign students, including an orientation program in late August – early September, individual counselling whenever appropriate, and an English language program. In addition, the International Student Centre contacts all foreign students once they have been accepted into the graduate program, to provide information and advice concerning immigration procedures (visa and student authorization forms), employment restrictions and authorization while in Canada, and other relevant matters (see *Contacts* below).

Athletics & Recreation

A wide range of athletic facilities are available within the university, including an arena and stadium, playing fields, swimming pools, squash, tennis, badminton, volleyball and basketball courts, running tracks, archery and golf ranges, fencing salons, exercise and wrestling rooms, dance studios, saunas, lockers and a sports store. Instruction courses, exercise classes and fitness testing are regularly offered, and there is an extensive intramural program with several levels of competition in more than 30 sports.

Other recreational activities and facilities are also available within the university, such as theatre, music, pubs, dances, art exhibitions, a wide range of clubs, debates lectures and seminars, reading rooms, cafeterias and chapels.

University of Toronto students also enjoy easy access (walking distance or only a few minutes by subway) to symphony concerts, theatres, ballet, operas, movies, restaurants and shopping.

Graduate Student Associations

Every graduate student at the University of Toronto is automatically a member of the Graduate Student Union (GSU). Graduate students in the Department of Mathematics are also members of the Mathematical Graduate Students Association (MGSA). Between them, these associations sponsor many events every year, including parties, pubs, dances, outings and more serious endeavours such as seminars and lectures.

Contacts and Sources of Information

Graduate Office
Department of Mathematics
University of Toronto
40 St. George St., Room 6291
Toronto, Ontario M5S 3G3
(416) 978-7894
(416) 978-4107 (Fax)
ida@math.toronto.edu
http://www.math.toronto.edu/graduate

- all matters relating to graduate studies in mathematics at the University of Toronto
- location of registration in September/January

Mathematics Library
University of Toronto
40 St. George Street, Room 6141
Toronto, Ontario M5S 3G3
(416) 978-8624
(416) 978-4107 (Fax)
mathlib@math.toronto.edu

School of Graduate Studies
University of Toronto
63 St. George Street
Toronto, Ontario
Canada M5S 2Z9
(416) 978-5369
(416) 978-4367 (Fax)
graduate.information@utoronto.ca
http://www.sgs.utoronto.ca

- general information concerning graduate studies at the University of Toronto

Fees Department
Office of the Comptroller
University of Toronto
215 Huron Street, 3rd Floor
Toronto, Ontario M5S 1A1
(416) 978-2142
(416) 978-2610 (Fax)
fees@finance.utoronto.ca
http://www.students.utoronto.ca/Money_Money_Money/Tuition_and_Fees.htm

- enquiries concerning fees
- payment of fees

Accessibility Services
1st Floor (ground entrance off St. George St.)
130 St. George Street, Toronto, ON M5S 3H1
(north-west corner of St. George Street and Harbord Street)
Voice: (416) 978-8060
Fax: (416) 978-8246
TTY: 416-978-1902
http://studentlife.utoronto.ca/accessibility.htm

- facilitates the inclusion of students with hidden or obvious disabilities and health conditions into university life

University Housing Service
University of Toronto
214 College Street, 1st Floor
Toronto, Ontario M5T 2Z9
416-978-8045
416-978-1616 (Fax)
housing.services@utoronto.ca
http://link.library.utoronto.ca/StudentHousing/

- information concerning university residences and rental accommodations

University Health Service
University of Toronto
214 College Street, 2nd Floor
Toronto, Ontario M5T 2Z9
416-978-8030
416-978-2089 (Fax)
http://www.utoronto.ca/health/

- medical assistance for University of Toronto students
- application forms for Ontario Health Coverage

International Student Centre
University of Toronto
33 St. George Street
Toronto, Ontario M5S 2E3
(416) 978-2564
(416) 978-4090 (Fax)
http://www.isc.utoronto.ca/

- information and assistance for international students, including UHIP registration

The Athletic Centre
University of Toronto
55 Harbord Street
Toronto, Ontario M5S 2W6
(416) 978-3437
416-978-6978 (Fax)
http://www.ac-fpeh.com/

- athletics and recreation information

Hart House
University of Toronto
7 Hart House Circle
Toronto, Ontario M5S 3H3
416-978-4411
colin.furness@utoronto.ca
http://www.utoronto.ca/harthouse

- athletics and recreation information

Graduate Students' Union
University of Toronto
16 Bancroft Avenue
Toronto, Ontario M5S 1C1
416-978-2391 or -6233
416-971-2362 (Fax)
gsunion@chass.utoronto.ca
http://www.utoronto.ca/gsunion/

Sexual Harassment Office
University of Toronto
3rd Floor, 40 Sussex Avenue
416-978-3908
http://www.utoronto.ca/sho/

- Students are covered by the Sexual Harassment Policy while on university premises or carrying on a university-related activity. Complaints and requests for information are confidential.

Human Resources Development Canada (HRDC)
811 Danforth Avenue, 1st Floor, or
25 St. Clair Avenue East, 1st Floor
1-800-206-7218

- To obtain a Social Insurance Number (in person only). Office hours: Monday-Friday, 08:30-16:00
- Applications available from http://www.hrdc-drhc.gc.ca/sin-nas/0300/0300_000_e.shtml. Supporting documentation must be original, e.g. student authorization and an offer of employment letter
- Takes an average of 4 weeks to process

APPENDIX A: COMPREHENSIVE EXAMINATION SYLLABI

Algebra

1. Linear algebra. Students will be expected to have a good grounding in linear algebra, vector spaces, dual spaces, direct sum, linear transformations and matrices, determinants, eigenvectors, minimal polynomials, Jordan canonical form, Cayley-Hamilton theorem, symmetric, alternating and Hermitian forms, polar decompositon.
2. Group Theory. Isomorphism theorems, group actions, Jordan-Hölder theorem, Sylow theorems, direct and semidirect products, finitely generated abelian groups, simple groups, symmetric groups, linear groups, nilpotent and solvable groups, generators and relations.
3. Ring Theory. Rings, ideals, rings of fractions and localization, factorization theory, Noetherian rings, Hilbert basis theorem, invariant theory, Hilbert Nullstellensatz, primary decompositon, affine algebraic varieties.
4. Modules. Modules and algebras over a ring, tensor products, modules over a principal ideal domain, applications to linear algebra, structure of semisimple algebras, application to representation theory of finite groups.
5. Fields. Algebraic and transcendental extensions, normal and separable extensions, fundamental theorem of Galois theory, solution of equations by radicals.

No reference is provided for the linear algebra material.

References for the other material:
Dummit & Foote: *Abstract Algebra,* Chapters 1-14 (pp. 17-568).
Alperin & Bell: *Groups and Representations,* Chapter 2 (pp. 39-62), 5, 6 (pp. 107-178).

Complex Analysis

1. Review of elementary properties of holomorphic functions. Cauchy's integral formula, Taylor and Laurent series, residue calculus.
2. Harmonic functions. Poisson integral formula and Dirichlet's problem.
3. Conformal mapping, Riemann mapping theorem.
4. Analytic continuation, monodromy theorem, little Picard theorem.

L. Ahlfors, *Complex Analysis,* Third Edition, McGraw-Hill, Chapters 1-4, 5.1, 5.5, 6.1, 6.2, 6.3.
W. Rudin, *Real and Complex Analysis,* Second Edition, Chapter 16 (except 16.4-16.7).
Note: The material in Ahlfors can largely be replaced by Chapters 10, 11, 12.1-12.6, and 14 of Rudin. But Ahlfors is the official syllabus for this material. The second edition of Ahlfors can be used if it is noted that Section 5.5 in the third edition is Section 5.4 in the second edition.)

Real Analysis

References:
H.L. Royden, *Real Analysis,* Third Edition, Prentice Hall, 1988.
Gerald B. Folland, *Real Analysis, Modern Techniques and Their Applications,* John Wiley & Sons, 1984.
Yitzhak Katznelson, *An Introduction to Harmonic Analysis,* Dover, 1976.

1. Background: Royden, Chapters 1 and 2; Folland (Prologue).
2. Basic Measure Theory: Royden, Chapters 3 and 4, for the classical case on the real line (which contains all the basic ideas and essential difficulties), then Chapter 11, Sections 1-4, for the general abstract case; Folland, Chapters 1 and 2.
3. Differentiation: Royden, Chapter 5, for the classical case, then Chapter 11, Sections 5 and 6 for the general case; Folland, Chapter 3 (For differentiation on $\mathbb{R}^n$ one can restrict the attention to the one dimensional case, which contains all the basic ideas and essential difficulties.)
4. Basic Functional Analysis: Royden, Chapter 10, Sections 1,2,3,4,8; Folland, Chapter 5, Sections 1,2,3,5.
5. L^p-Spaces: Royden, Chapter 6 for the classical case, and Chapter 11, Section 7 for the general case, Chapter 13, Section 5 for the Riesz Representation Theorem; Folland, Chapter 6, Sections 1 and 2, Chapter 7, Section 1.
6. Harmonic Analysis: Katznelson, Chapter 1, Chapter 2, Sections 1 and 2, and Chapter 6, Sections 1 to 4; Folland, Chapter 8, Sections 1,2,3,4,5, and 8. One can restrict the attention to the one dimensional case, as done in Katznelson.

Topology

1. local differential geometry: the differential, the inverse function theorem, smooth manifolds, the tangent space, immersions and submersions, regular points, transversality, Sard's theorem, the Whitney embedding theorem, smooth approximation, tubular neighborhoods, the Brouwer fixed point theorem.
2. differential forms: exterior algebra, forms, pullbacks, d, integration, Stokes' theorem, div grad curl and all, Lagrange's equation and Maxwell's equations, homotopies and Poincare's lemma, linking numbers.
3. fundamental groups: paths and homotopies, the fundamental group, coverings and the fundamental group of the circle, Van-Kampen's theorem, the general theory of covering spaces.
4. homology: simplices and boundaries, prisms and homotopies, abstract nonsense and diagram chasing, axiomatics, degrees, CW and cellular homology, subdivision and excision, the generalized Jordan curve theorem, salad bowls and Borsuk-Ulam, cohomology and de-Rham's theorem, products.

Partial Differential Equations

Note: This is meant to be an exam syllabus not a course outline.
As such, topics are not necessarily ordered as in a logical development.

1) ***Basic Notions in Ordinary Differential Equations:*** Fundamental theorem on existence and uniqueness of solutions of y' = f(x,y) when f is Lipschitz w.r.t. y. Fixed point theorem, Picard iterates. (Various topics in PDE will also assume familiarity with undergraduate ODE material.)
2) ***Basic Notions in Linear Partial Differential Equations***
   a) ***Elliptic PDEs:*** *Laplacian*: fundamental solution, properties of harmonic functions, Dirichlet and Neumann problems, Green's function, Poisson kernel representation for solution of Dirichlet problem on the unit disk in $\R^2$, Fourier series, Poisson's equation. *Weak solutions of second order elliptic PDE*: Lax-Milgram Theorem, ellipticity, energy estimates. *Regularity of weak solutions*: interior and at the boundary. *Maximum principle*: weak, strong, Harnack inequality *Eigenvalues for second order linear elliptic operators*.
   b) ***Parabolic PDEs:*** Heat Equation, fundamental solution of the heat equation, mean value property, maximum principle, regularity properties, initial value problem for the heat equation, semigroups, gradient flows
   c) ***Hyperbolic PDEs***: Wave equation, fundamental solution of the wave equation, spherical means, Huygen's principle, conservation of energy, finite speed of propagation, initial value problem for the wave equation, other hyperbolic PDEs.
3) ***Distributions; Fourier Transform***

4) ***Sobolev spaces; Weak Solutions:*** Weak derivatives, Sobolev spaces W^{k,p}, L^2 based fractional Sobolev spaces H^s, Approximation properties, Extensions, Traces, Sobolev inequalities, Poincaré lemma *Weak solutions and regularity theory is enmeshed with the topics on the exam.*
5) ***Nonlinear PDEs*****:** *First-Order***:** Method of characteristics, Hamilton-Jacobi equations, Conservation laws, weak solutions, shocks and rarefactions, uniqueness and entropy solutions, *Second-Order:* gradient flows, linearization around special solutions, vanishing viscosity limit of Burger's equation.
6) ***Calculus of variations*****:** direct methods, convexity, weak-* continuity and compactness, first and second variations, Euler-Lagrange equation, Lagrange multipliers, constraints

References:
V. I. Arnold: *Ordinary differential equations* 1992
L.C. Evans: *Partial differential equations* 1998
G.B. Folland: *Introduction to partial differential equations* 1995
W. Hurewicz: *Lectures on ordinary differential equations* 1990

APPENDIX B: APPLIED MATHEMATICS COMPREHENSIVE EXAMINATION SYLLABI

A student planning to specialize in applied mathematics must pass three comprehensive exams, at least two of which are a general written exam (algebra, analysis (real and complex), topology, or partial differential equations (PDE I and PDE II)). The following are samples of other exam topics.

Combinatorics

1) ***Enumeration****:* Ordinary and exponential generating functions. Difference equations and recursions. Partition and permutations. Polya counting, Fruchts Theorem, systems of distinct representatives.
2) ***Graph Theory***: Trees, connectivity, bipartite graphs, minimal spanning trees, Eulerian and Hamiltonian graphs, travelling salesman and chinese postman problems, matchings, chromatic number, perfect graphs.
3) ***Design Theory***: Definitions, examples, finite fields, finite affine and projective spaces, Fisher's inequality, symmetric designs, statement of Wilson's Theorem and Wilson's Fundamental Construction.
4) ***Coding Theory***: Linear codes, sphere packing, Hamming and Plotkin bounds, perfect codes, polynomial over finite fields.
5) ***Algorithms and Complexity****:* Algorithms for listing permutations, combinations, subsets. Analysis of algorithms, basic concepts such as NP, and #P, and NPC.

References:
P.J. Cameron: *Combinatorics: Topics, Techniques Algorithms,* Cambridge Univ. Press, ISBN 0521457610.

Control Theory and Optimization

1) ***Control Theory***: Qualitative properties of the reachable sets, Lie bracket and Lie determined systems, linear theory, stability and feedback. (*Reference*: V. Jurdjevic: *Geometric Control Theory,* Cambridge University Press, Chapters 1,2 and 3)
2) ***Optimal Control***: Linear-quadratic problems, symplectic form, Lagrangians, the Riccati equation, the Maximum Principle and its relation to the calculus of variations. (*Reference*: V. Jurdjevic: *Geometric Control Theory,* Cambridge University Press, Chapters 7, 8 ,11)
3) ***Linear Programming***: Convex analysis, simplex algorithm, duality, computational complexity and Karmarkar's Algorithm. (*Reference*: Bazaraa, Jarvis & Sherali: *Linear Programming and Network Flows,* Wiley, 1990, Chapters 2,3,4,6,8)
4) ***Nonlinear Programming***: Unconstrained and constrained nonlinear problems. Introduction to computational methods. (*Reference*: Luenberger: *Linear and Nonlinear Programming,* Addison-Wesley, 1984, Chapters 6,7,10)

Fluid Mechanics

It is expected that a student has a basic knowledge of real and complex analysis including ordinary differential equations. The extra mathematics required includes:

1) ***Partial differential equations***: Laplace's equation, properties of harmonic functions, potential theory, heat equation, wave equation. Solutions through series and transform techniques. Bessel functions and Legendre functions. Distributions. (e.g. Duff and Naylor)
2) ***Asymptotic and perturbation techniques***: Asumptotic series solutions of ordinary differential equations, asymptotic expansion of integrals. Singular perturbation problems, boundary layer methods, WKB theory, multiple time-scale analysis. (e.g. Bender and Orszag)

Basic physical properties of fluids. Derivation of the Navier-Stokes equations for a viscous compressible fluid; vorticity; energy balance. Simple exact solutions of the Navier-Stokes equations. Slow viscous motions; Stokes flows; Oseen flow. Irrotational flow; sources and sinks; complex variable methods. Boundary layer approximation. Blasius flow; separation; jets and wakes. Rotating flows; geostrophic behaviour. Free surface flows; wave propagation. Simple unsteady boundary layer flows; Stokes layers. Shock waves in a tube; supersonic flow.

General Relativity and Classical Mechanics

1) Space-times as Lorentz manifolds. Differential geometry (curvature, etc.) and local and global properties of Lorentz manifolds.
2) Field equations of general relativity, stationary and static space-times. Exact solutions. Schwarzschild, Kruskal, Kerr solutions. Cosmological models: Robertson-Walker and Friedman models and their properties.
3) Cauchy problem for the field equations. Classification of space-times.
4) Symplectic geometry, symplectic structure of cotangent bundles, Poisson brackets.
5) Hamiltonian equations, canonical transformations, Legendre transformations, Lagrangian systems, Hamilton-Jacobi theory.

References:

Hawking & Ellis: *Large Scale Structure of Space-Time,* Chapters 2,3,4,5.
O'Neill: *Semi-Riemannian Geometry with Applications to Relativity.*
Abraham & Marsden: *Foundations of Mechanics,* Chapters 3,4,5.
Wald: *General Relativity*, Chapters 1-6 and Appendices A-C and E

Mathematical Finance

1) ***Stochastic calculus***: Martingales, Ito's lemma, Girsanov's theorem, stochastic differential equations, stopping times. *(Reference*: Baxter & Rennie, *Financial Calculus)*
2) ***Finance***: Equity derivatives, interest rate derivatives, market risk, credit risk, portfolio theory, numerical methods. (*References*: D. Duffie: *Dynamic Asset Pricing Theory.* P. Wilmott et al.: *Mathematics of Financial Derivatives.* RiskMetrics and CreditMetrics documents.)

Probability

The Probability Exam is a written exam and is administered by the Department of Statistics. It is based on material covered in STA 2111F and STA 2211S.

Topics covered include:

1) ***Elementary probability theory****:* Bernoulli trails, combinatorics, properties of standard probability distributions, Poisson processes, Markov chains
2) ***Probability spaces****:* measure theory and Lebesgue integration, extension theorems, Borel-Cantellis lemmas, product measures and independence, Fubini's Theorem
3) ***Random variables and expectations****:* probability distributions, Radon-Nikodym derivatives and densities, convergence theorems such as dominated convergence, monotone convergence, etc
4) ***Limit theorems****:* inequalities, weak and strong laws of large numbers for sums of i.i.d. random variables, Glivenko-Cantelli Theorem, weak convergence (convergence in distribution), continuity theorem for characteristic functions, Central Limit theorems
5) ***Conditional probability and expectation****:* definitions and properties, statistical applications, martingales
6) ***Basics of Brownian motion and diffusions***

References

Most of the above material is covered in any one of the following texts:
P. Billingsley: *Probability and Measure* 1995
L. Breiman: *Probability* 1992

K.L. Chung: *A Course in Probability Theory* 1974
R.M. Dudley: *Real Analysis and Probability* 1989
R. Durrett: *Probability: Theory and Examples* 1996
B. Fristedt and L. Gray: *A Modern Approach to Probability Theory* 1997
J.S. Rosenthal: *A First Look at Rigorous Probability Theory* 2000

Quantum Field Theory

Nonrelativistic quantum mechanics: Quantum observables are self-adjoint operators. The spectral theorem for self-adjoint operators in terms of spectral measures, and the physical interpretation of the quantum formalism. Complete sets of observables. The essential self-adjointness of the Schrödinger operator: the Kato and Rellich theorems. Eigenvalue problems and the energy spectrum: the harmonic oscillator; the hydrogen atom. The Schrödinger, Heisenberg and interaction pictures. Regular and singular perturbation theory. Canonical commutation relations and von Neumann's theorem. *Statistical operators and the trace class. *The Hilbert-Schmidt class as Liouville space and von Neumann's equation.

1) ***Group theory and quantum mechanics***: Representations of space and time translations. Stone's theorem for one-parameter. Abelian groups of unitary operators. $SU(2)$ and the concept of spin. The Heisenberg-Weyl group and canonical commutation relations. Ray representations of the Galilei group. Relativistic invariance and representations of the Poincaré group. The Lie algebras of the Galilei and Poincaré groups, and of their main kinematical subgroups. *Systems of imprimitivity and particle localization.
2) ***Quantum scattering theory:*** Time-dependent scattering theory, wave operators and their intertwining properties. The S-operator and scattering cross-sections. Stations. The Coulomb potential and scattering for long-range interactions. Eigenfunction expansions and Green functions. The T-matrix, the scattering amplitude and the Born series. *Asymptotic completeness. *Channel wave operators and asymptotic states.
3) ***Relativistic quantum field theory:*** The Klein-Gordon and Dirac equations. Fock space for spin 0 and spin ½ particles. Creation and annihilation operators. Quantum fields as operator-valued distributions. The Gupta-Bleuler formalism for photons and gauge freedom.

References:
Intermediate:
J.M. Jauch: *Foundations of Quantum Mechanics,* 1968.
W. Miller, Jr.: *Symmetry Groups and their Applications,* 1972.
E. Prugovecki: *Quantum Mechanics in Hilbert Space,* 2nd Edition, 1981.
S.S. Schweber: *An Introduction to Quantum Field Theory,* 1961.
Advanced:
A.O. Barut & R. Raczka: *Theory of Group Representations and Applications,* 1978.
N.N. Bogulubov, A.A. Logunov & I.T. Todorov: *Introduction to Axiomatic Quantum Field Theory,* 1975.
T. Kato: *Perturbation Theory for Linear Operators,* 2nd Edition, 1976.
M. Reed & B. Simon: *Methods of Modern Mathematical Physics,* vols. 1-4, 1972-78.

APPENDIX C: PH.D. DEGREES CONFERRED FROM 1994-2008

1994
BODNAR, Andrea (Fluid Mechanics) *Low Reynolds Number Particle-Fluid Interactions*
FERRANDO, Sebastian (Ergodic Theory) *Moving Convergence for Superadditive Processes and Hilbert Transform*
FRY, Robb (Functional Analysis) *Approximation on Banach Spaces*
HA, Minh Dzung (Ergodic Theory) *Operators with Gaussian Distributions, L^2 -Entropy and a.e. Convergence*
HA, Xianwei (Representation Theory) *Invariant Measure on Sums of Symmetric Matrices and its Singularities and Zero Points*
ŁABA, Izabella (Mathematical Physics) *N-Particle Scattering in a Constant Magnetic Field*
LISI, Carlo (Operator Theory) *Perturbation by Rank-Two Projections*
MA, Kenneth (Fluid Mechanics) *Low Reynolds Number Flow in the Presence of a Corrugated Boundary*
PRANOTO, Iwan (Control Theory) *Distributed Parameter System: Controllability and its Related Problems*
STEVENS, Ken (Operator Algebras) *The Classification of Certain Non-Simple Approximate Interval Algebras*

1995
GUZMAN-GOMEZ, Marisela (PDE) *Regularity Properties of the Davey-Stewartson System for Gravity-Capillary Waves*
LI, Liangqing (Operator Algebras) *Classification of Simple C*-Algebras: Inductive Limit of Matrix Algebras over 1-Dimensional Space*
LOUKANIDIS, Dimitrios (Algebraic Groups) *Bounded Generation of Certain Chevalley Groups*
MONROY-PEREZ, Felipe (Control Theory) *Non-Euclidean Dubins' Problem: A Control Theoretic Approach*
PYKE, Randall (PDE) *Time Periodic Solutions of Nonlinear Wave Equations*
STANLEY, Catherine (Algebra) *The Decomposition of Automorphisms of Modules over Rings*
TIE, Jingzhi (PDE) *Analysis on the Heisenberg Group and Applications to the $\overline{\partial}$ -Neumann Problem*

1996
DEPAEPE, Karl (Lie Algebras) *Primitive Effective Pairs of Lie Algebras*
JUNQUEIRA, Lucia (Set Theory) *Preservation of Topological Properties by Forcing and by Elementary Submodels*
SCHANZ, Ulrich (PDE) *On the Evolution of Gravity-Capillary Waves in Three Dimension*

1997
AKBARY-MAJDABADNO, Amir (Number Theory) *Non-Vanishing of Modular L-functions with Large Level*
AUSTIN, Peter (Group Theory) *Products of Involutions in the Chevalley Groups of Type $F_4(K)$*
CLOAD, Bruce (Operator Theory) *Commutants of Composition Operators*
CUNNINGHAM, Clifton (Automorphic Forms) *Characters of Depth-Zero Supercuspidal Representations of $Sp_4(F)$: From Perverse Sheaves to Shalika Germs*
DOOLITTLE, Edward (PDE) *A Parametrix for Stable Step Two Hypoelliptic Partial Differential Operators*
FARAH, Ilijas (Set Theory) *Analytic Ideals and their Quotients*
HOMAYOUNI-BOROOJENI, Soheil (Set Theoretic Topology) *Partition Calculus for Topological Spaces*
STANLEY, Donald (Algebraic Topology) *Closed Model Categories and Monoidal Categories*
SUN, Heng (Automorphic Forms) *The Residual Spectrum of $\overline{GL(N)}$: The Borel Case*
THERIAULT, Stephen (Algebraic Topology) *A Reconstruction of Anick's Fibration $S^{2n-1} \rightarrow T^{2n-1}(p^r) \rightarrow \Omega S^{2n+1}$*

1998
BALLANTINE, Cristina (Automorphic Forms) *Hypergraphs and Automorphic Forms*
CENTORE, Paul (Differential Geometry) *A Mean-Value Laplacian for Finsler Spaces*
CHEN, Qun (Algebraic Geometry) *Hilbert-Kunz Multiplicity of Plane Curves and a Conjecture of K. Pardue*
GRUNBERG ALMEIDA PRADO, Renata (Set-theoretic Topology) *Applications of Reflection to Topology*
HILL, Peter *(Knot Theory) On Double-Torus Knots*
LI, Mingchu (Combinatorics) *Hamiltonian Properties of Claw-Free Graphs*

MEZO, Paul (Automorphic Forms) *A Global Comparison for General Linear Groups and their Metaplectic Coverings*
STEVENS, Brett (Combinatorics) *Transversal Covers and Packings*
STEVENS, Irina (C*-Algebras) *Hereditary Subalgebras of AI Algebras*
TRAVES, William (Algebraic Geometry) *Differential Operators and Nakai's Conjecture*

<u>1999</u>
DEAN, Andrew (C*-Algebras) *A Continuous Field of Projectionless C*-Algebras*
FRIIS, Peter (C*-Algebras) *Normal Elements with Finite Spectrum in C*-Algebras of Real Rank Zero*
GUSTAFSON, Stephen (Mathematical Physics) *Some Mathematical Problems in the Ginzburg-Landau Theory of Superconductivity*
MAHMOUDIAN, Kambiz (Number Theory) *A Non-Abelian Analogue of the Least Character Nonresidue*
MAHVIDI, Ali (Operator Theory) *Invariant Subspaces of Composition Operators*
SCHIPPERS, Eric (Complex Variables) *The Calculus of Conformal Metrics and Univalence Criteria for Holomorphic Functions*
YANG, Q. (Lie Algebras) *Some Graded Lie Algebra Structures Associated with Lie Algebras and Lie Algebroids*

<u>2000</u>
CALIN, Ovidiu (Differential Geometry) *The Missing Direction and Differential Geometry on Heisenberg Manifolds*
DERANGO, Alessandro (C*-Algebras) *On C*-Algebras Associated with Homeomorphisms of the Unit Circle*
HIRSCHORN, James (Set Theory) *Cohen and Random Reals*
MADORE, Blair (Ergodic Theory) *Rank One Group Actions with Simple Mixing* **Z** *Subactions*
MARTINEZ-AVENDAÑO, Rubén (Operator Theory) *Hankel Operators and Generalizations*
MERKLI, Marco (Mathematical Physics) *Positive Commutator Method in Non-Equilibrium Statistical Mechanics*
MIGHTON, John (Knot Theory) *Topics in Ramsey Theory of Sets of Real Numbers*
MOORE, Justin (Set Theory) *Topics in Ramsey Theory of Sets of Real Numbers*
RAZAK, Shaloub (C*-Algebras) *Classification of Simple Stably Projectionless C*-Algebras*
SCOTT, Jonathan (Algebraic Topology) *Algebraic Structure in Loop Space Homology*
ZHAN, Yi (PDE) *Viscosity Solution Theory of Nonlinear Degenerate*

<u>2001</u>
COLEMAN, James (Nonlinear PDE's) *Blowup Phenomena for the Vector Nonlinear Schrödinger Equation*
IZADI, Farz-Ali (Differential Geometry) *Rectification of Circles, Spheres, and Classical Geometries*
KERR, David (C*-Algebras) *Pressure for Automorphisms of Exact C*-Algebras and a Non-Commutative Variational Principle*
OLIWA, Chris (Mathematical Physics) *Some Mathematical Problems in Inhomogeneous Cosmology*
PIVATO, Marcus (Mathematical Finance) *Analytical Methods for Multivariate Stable Probability Distributions*
POON, Edward (Operator Theory) *Frames of Orthogonal Projections*
SAUNDERS, David (Mathematical Finance) *Mathematical Problems in the Theory of Incomplete Markets*
SOLTYS-KULINICZ, Michael (Complexity) *The Complexity of Derivations of Matrix Identities*
VASILIJEVIC, Branislav (Mathematical Physics) *Mathematical Theory of Tunneling at Positive Temperatures*
YUEN, Waikong (Probability) *Application of Geometric Bounds to Convergence Rates of Markov Chains and Markov Processes on* $\mathbf{R}^n$

<u>2002</u>
HERNANDEZ-PEREZ, Nicholas (Math. Finance) *Applications of Descriptive Measures in Risk Management*
KAVEH, Kiumars (Algebraic Geometry) *Morse Theory and Euler Characteristic of Sections of Spherical Varieties*
MOHAMMADALIKANI, Ramin (Symplectic Geometry) *Cohomology Ring of Symplectic Reductions*
SOPROUNOV, Ivan (Algebraic Geometry) *Parshin's Symbols and Residues, and Newton Polyhedra*
SOPROUNOVA, Eugenia (Algebraic Geometry) *Zeros of Systems of Exponential Sums and Trigonometric Polynomials*
TOMS, Andrew (Operator Algebras) *On Strongly Performated* K_0 *Groups of Simple C*-Algebras*
VUKSANOVIC, Vojkan (Set Theory) *Canonical Equivalence Relations*
ZIMMERMAN, Jason (Control Theory) *The Rolling Stone Problem*

2003
ADAMUS, Janus (Analytic Geometry) *Vertical components in fibre powers of analytic mappings*
BUBENIK, Peter (Algebraic Topology) *Cell attachments and the homology of loop spaces and differential graded algebras*
HO, Nan-Kuo (Symplectic Geometry) *The moduli space of gauge equivalence classese of flat connections over a compact nonorientable surface*
JONG, Peter (Ergodic Theory) *On the Isomorphism Problem of p-Endomorphisms*
PEREIRA, Rajesh (Operator Theory) *Trace Vectors in Matrix Analysis*
STAUBACH, Wolfgang (PDE) *Path Integrals, Microlocal Analysis and the Fundamental Solution for Hörmander Laplacians*
THERIAULT, Nicolas (Algebraic Number Theory) *The discrete logarithm problem in the Jacobian of algebraic curves*
TING, Fridolin (Mathematical Physics) *Pinning of magnetic vortices by external potential*
TSANG, Kin Wai (Operator Algebras) *A Classification of Certain Simple Stably Projectionless C*-Algebras*

2004
AHMAD, Najma (Applied Math) *The geometry of shape recognition via the Monge-Kantorovich optimal transportation problem* (in conjunction with Brown University)
BRANKER, Maritza (Several Complex Variables) *Weighted approximation in* $\mathbf{R}^n$
CHEN, Oliver (Mathematical Finance) *Credit barrier models*
ESCOBAR AÑEL, Marcos (Mathematical Finance) *Mathematical treatment of commodity markets*
HUNG, Ching-Nam (Operator Algebras) *The numerical range and the core of Hilbert-space operators*
IVANESCU, Cristian (Operator Algebras) *On the classification of simple* C**-algebras which are inductive limits of continuous-trace* C**-algebras with spectrum the closed interval [0,1]*
KIRITCHENKO, Valentina (Analytic Geometry) *A Gauss-Bonnet Theorem, Chern Classes and an Adjunction Formula for Reductive Groups*
KUZNETSOV, Alexey (Mathematical Finance) *Solvable Markov processes*
LAWI, Stephan (Mathematical Finance) *Exactly solvable stochastic integrals and q-deformed processes*
SAVU, Anamaria (Probability) *Hydrodynamic scaling limit of the continuum solid on solid model*
SHAHBAZI, Zohreh (Differential Geometry) *Differential Geometry of Relative Gerbes*
SONG, Joon-Hyeok (Symplectic Geometry) *Intersection Numbers in q-Hamiltonian Spaces*
TIMORIN, Vladlen (Analytic Geometry) *Rectifiable Pencils of Conics*

2005
DE LOS SANTOS, Alejandro (Mathematical Finance) *Liquidity risk estimation: non-gaussian AR models and quantile expansions*
HAMILTON, Mark (Symplectic Geometry) *Singular Bohr-Sommerfeld Leaves and Geomertic Quantization*
NIU, Zhuang (Operator Algebras) *A classification of the tracially approximately sub-homogeneous C*-algebras*
PATANKAR, Vijay (Number Theory) *Splitting of Abellian Varieties*
POLLANEN, Marco (Probability) *Low discrepancy sequences in probability spaces*

2006
CALLAGHAN, Joe (Several Complex Variables) *A Green's function for* θ*-incomplete polynomials*
CHAN, Jackson (Harmonic Analysis) *Methods of variations of potential of quasi-periodic Schroedinger equation*
DEJAK, Steven (Nonlinear PDE) *Long-time dynamics of KdV solitary waves over a variable bottom*
DOUGLAS, Andrew (Representation Theory) *A classification of the finite dimensional indecomposable representations of the Euclidean algebra* $\mathfrak{e}(2)$
FU, Guangyu (Probability) *Random walks and random polynomials*
HERNANDEZ CORTES, Janko (Mathematical Finance) *Ergodic properties of some hidden Markov models with applications to mathematical finance*
HO, Toan Minh (Operator Algebras) *On the inductive limits of homogeneous algebras with diagonal morphisms between building blocks*
KNAFO, Emmanuel (Number Theory) *Variance of distribution of almost primes in arithmetic progressions*
ROBERT GONZALEZ, Leonel (Operator Algebras) *Classification of nonsimple approximate interval C*-algebras:*

the triangular case

2007

BAIRD, Thomas (Symplectic Geometry and Algebraic Topology) Moduli spaces of flat G-bundles over nonorientable surfaces
COWARD, Kristofer (Operator Algebras) The Cuntz semigroup as a classification functor for C*-algebras
FUCHS, Shay (Geometric Quantization) Spin^c quantization, prequantization and cutting
LANGRIDGE, Allan (Number Theory) *Values of Artin L-functions at s=1*
LYNCH, Geoffrey (Algebraic Geometry) The Local Monodromy Operator as an Algebraic Cycle
NAOT, Gad (Knot Theory) *The Universal* sl_2 *link homology theory*
ZHOU, Gang (Mathematical Physics) *Asymptotic dynamics of trapped solitons of nonlinear Schroedinger equations with external potentials*

2008

BROOKE, David (Representation Theory) Resolving Multiplicities in the Tensor Product of Irreducible Representations of Semisimple Lie Algebras
CIUPERCA, Alin (Operator Algebras) Some Properties of the Cuntz Semigroup and an Isomorphism Theorem for a Certain Class of Non-simple C*-algebras
DONIN, Dmitry (Representation Theory and Differential Geometry) Lie Algebras of Differential Operators and D-Modules
GERACI, Joseph (Quantum Information and Statistical Physics) On the Relation between Quantum Computation and Classical Statistical Mechanics
KLEIN, David (Symplectic geometry) Goldman Flows on Moduli Spaces of Flat Connections on Surfaces
KLEPER, Dvir (Operator Theory) Invariant Subspaces of Composition Operators on Weighted Hardy-Hilbert Spaces
QUINTANILLA, Maria Teresa (Mathematical Finance) Asymptotic Optimization of Risk Measures
SANTIAGO, Luis (Operator Algebras) Classification of Non-simple C*-algebras: Inductive Limits of Splitting Interval Algebras
SYLVESTRE, Jeremy (Representation Theory) Twisted Characters of Depth-zero Supercuspidal Representations of GL(n)
TIPU, Vicentiu (Number Theory) Polynomial Divisor Problems

APPENDIX D: THE FIELDS INSTITUTE FOR RESEARCH IN MATHEMATICAL SCIENCES

The Fields Institute for Research in Mathematical Sciences was created in November 1991 with major funding from the Province of Ontario, the Natural Sciences and Engineering Research Council of Canada, and McMaster University, the University of Toronto, and the University of Waterloo. In September 1996 it moved from its temporary location in Waterloo to its permanent site, a new building located at 222 College Street in Toronto, next to the University of Toronto Bookstore. In addition to the three principal sponsoring universities about twenty universities across Canada are affiliated with it.

The mandate of the Fields Institute specifically includes the training of graduate students and this function is given a higher profile than at other similar mathematics research institutes. All major programs run at the institution contain graduate courses which students at any university affiliated with the institute may take for credit and the organizers of major programs are expected to set aside some money to make it possible for graduate students to participate in their program.

APPENDIX E: SGS ACADEMIC CALENDAR 2008-2009

2008	
M August 4	Civic Holiday
M August 11	Registration for September session begins
F August 29	Last date for payment of tuition fees to meet registration deadline
M September 1	Labour Day
M September 8	Most formal graduate courses and seminars begin in the week of September 8 [(1)]
F September 12	Registration for September session ends; after this date, a late registration fee will be assessed
M September 15	Final date to submit Ph.D. theses to SGS to avoid fee charges for 2008-09
F September 19	Coursework must be completed and grades submitted for summer session courses and extended courses
W September 24	Summer Session grades available for viewing by students on the Student Web Service
F October 3	Final date for receipt of degree recommendations and submission of any required theses for master's degrees for Fall Convocation
F October 3	Final date to submit final Ph.D. thesis for Fall Convocation
F October 3	Final date to add full-year and September session courses [(4)]

M October 13	Thanksgiving Day
F October 31	Final date to drop September session full or half courses without academic penalty
November	Fall Convocation Information and Dates are posted at: www.utoronto.ca/convocation, choose Fall
December	For last day of classes before Winter break, consult graduate units concerned
2009	
M January 5	Most formal graduate courses and seminars begin in the week of January 5th [(1)]
F January 9	Final date for registration of students beginning program in January session; after this date, a late registration fee will be assessed
T January 13	Final date to submit Ph.D. theses without fee payment for January session
F January 16	Coursework must be completed and grades submitted for September session courses [(2)]
F January 16	Final date to add January session courses [(4)]
W January 21	September Session grades available for viewing by students on the Student Web Service
F January 30	Final date for receipt of degree recommendations and submission of any required theses for March or June graduation for master's students without fees being charged for the January session [(3)]
F January 30	Final date for all students to request that their degrees be conferred *in absentia* in March
F January 30	September dual registrants must be recommended for the master's degree by this date to maintain their Ph.D. registration [(3)]
F February 27	Final date to drop full-year or January session courses without academic penalty [(4)]

March	March Graduation *In absentia* Information is posted at: www.utoronto.ca/convocation, choose March *in absentia*
F April 10	Good Friday
F April 24	For students obtaining degrees at June Convocation, course work must be completed and grades submitted for full-year and January session courses
F April 24	Final date for receipt of degree recommendations and submission of any required theses for master's degrees for June Convocation[(3)]
F April 24	Final date for submission of final Ph.D. thesis for students whose degrees are to be conferred at the June Convocation
F April 24	Final date for degree recommendations of January dual registrants for the master's degree to maintain their Ph.D. registration [(3)]
May	For first day of summer classes, consult graduate unit concerned
F May 8	Final date for registration for May session
F May 15	Final date to enrol in May-June or May-August session courses
F May 15	Course work must be completed and grades submitted for full-year and January session courses (except for extended courses) [(2)]
M May 18	Victoria Day
W May 20	January Session grades available for viewing by students on the Student Web Service
June	Spring Convocation Information and Dates are posted at: www.utoronto.ca/convocation, choose Spring
F June 5	Final date to drop May/June F section courses without academic penalty
F June 26	Final date for registration for July-August courses

F June 26	Final date to drop May-August session Y section courses without academic penalty
W July 1	Canada Day Holiday
F July 24	Final date to drop July-August S section courses without academic penalty
F July 24	Coursework must be completed and grades submitted for May/June F Section Courses [(2)]
W July 29	Grades for May/June F Section Courses available for viewing by students on the Student Web Service
	Note [(1)]The precise dates of commencement of courses are determined by the graduate units; students are urged to contact the relevant graduate units for information. The University policy states that the first day of classes in the September session in all teaching divisions should not be scheduled on the first and second days of Rosh Hashanah (from 1 1/2 hours before sunset on Monday, September 29 to about 1 1/2 hours after sunset on Wednesday, October 1) or on Yom Kippur (from about 1 1/2 hours before sunset on Wednesday, October 8 to about 1 1/2 hours after sunset on Thursday, October 9). [(2)] Graduate units may establish earlier deadlines for completion of course work and may prescribe penalties for late completion of work and for failure to complete work, provided that these penalties are announced at the time the instructor makes known to the class the methods by which student performance shall be evaluated. [(3)] For final dates for completing degree requirements, students should consult their own departments. [(4)] Graduate units may establish earlier deadlines to add/drop courses. Please note that the last date to cancel a course or registration with no academic penalty is not the same as the last date to be eligible for a refund.