

# Proposal: Institute for Applied and Interdisciplinary Mathematics

## 1. Executive Summary ‘I-AIM’ for excellence!

University of Toronto hosts the strongest collection of mathematical scientists in Canada. Apart from those appointed to the mathematics department, many others are dispersed across three campuses — in engineering, statistics, physics, chemistry, computer science and the biomedical and social sciences. There is also great potential for synergies involving the many researchers whose work stands to benefit from a closer relationship to mathematics. To date links between such researchers have been formed mainly by serendipity, and few resources have been dedicated to nurturing these essential links, or to orienting students excited by the mathematical challenges raised by applications, and the possibilities that advanced modeling strategies, rigorous treatment of formal systems, and mathematical or computational analysis offer to other disciplines.

We plan to establish a dynamic research institute (I-AIM) that will function as an umbrella organization to coordinate and benefit the common interests of these scholars and students. The emphasis will be on the discovery and application of new mathematics, models, and computational methods, inspired by and for science. The institute will be staffed via cross-appointments between existing faculty coupled with dynamic new appointments in vital areas. It will also coordinate the training of students and postdoctoral fellows who are as well-versed in mathematics as in some area of application. This will be done through new interdisciplinary programs of graduate studies and undergraduate internships designed to facilitate joint mentoring by researchers, mathematicians, and computational scientists working in different disciplines.

In prioritized order, the key resources required for this initiative to flourish will be new 1) space; 2) interdisciplinary graduate student and postdoctoral funding; and 3) faculty lines.

## 2. Vision and Priorities

Among the sciences, mathematics is distinguished by its formal nature and deductive methodology. It is a language and a mode of thought; it seeks to distill the essence of a single problem or a range of related phenomena, and to analyze the underlying universal structure using logic, models, and computation. Results of pure mathematics laid the groundwork for many of the triumphs of the last century — such as general relativity, quantum mechanics, game theory, and computing machines — which in turn guided development of the next generation mathematics. But to make progress on the hard and complex problems of the modern technological world, mathematicians must also work closely with experts in other domains. I-AIM brings together top researchers and students from the University and around the world to attack big problems with complementary methodologies: scientific experiment, mathematical modelling and proof, computer simulation. The scientific imperatives and opportunities facing I-AIM are outlined below. Our concrete goals in addressing them are:

- To create an environment of unsurpassed quality for sustained interdisciplinary research, which leads to the discovery and development of fundamental mathematics, new science, and transformative technology, from the crucible of their mutual interaction.
- To unite abstract mathematical expertise with specific domain knowledge: e.g. number theory with cryptography; probability theory with data mining; statistics with finance; partial differential equations with computer vision, new materials, and climate modelling; dynamical systems with pattern formation; geometry with string theory; harmonic analysis with signal processing, inverse problems with medical imaging, computer science with genomics, proteomics, molecular and evolutionary biology; numerical analysis with large-scale simulation.
- To develop an interdisciplinary graduate program in applied mathematics modelled on the successful programs at Princeton, Chicago, and New York University’s Courant Institute, which will grow into a premier global training ground for mathematical and computational scientists in the years to come.
- To create a space for interdisciplinary interactions to occur, welcoming scientists from across campus, and including a permanent home for applied mathematics, cross-appointed graduate students, postdoctoral fellows, undergraduate interns, and the program in mathematical finance.
- To showcase interdisciplinary work already taking place on campus to students and the international community, aiding recruitment of top student and postdoctoral talent.
- To build upon recent hiring successes in applied mathematics which have occurred within the math

department, and in joint-appointments with other departments (ECE, CS, PHYS, STAT, SGS), while creating the infrastructure and working conditions to attract world-class mathematical scientists, theoreticians and practitioners in other disciplines.

- To provide a natural base for national initiatives like the distributed lab in Computational Sciences under consideration by the NRC, thus encouraging maximal investment of federal resources in Toronto.

### 3. Self-study

I-AIM is interdisciplinary by nature, and will focus on the long-term support and development of the scientific programs which reside at the University of Toronto. This provides a strong complement to the **Fields Institute for Research in the Mathematical Sciences**, a seven-university consortium located on the St. George campus, with no permanent faculty or degree programs, whose main activity is to host revolving one-year (and shorter) programs of a topical nature, selected to balance the needs of the regional, national, and international communities in pure and applied mathematics. It carries out longer term network-building activities in selected areas, but at a much more modest level. Fields' activities are invaluable to the local community, but its mandate leaves no room for sustained support to research and teaching activities (interdisciplinary or otherwise) purely internal to the University of Toronto — the role to be filled by I-AIM.

*Undergraduate and graduate study:* Currently, programs and courses in applied mathematics are offered by the mathematics department, but these are not always well-integrated with faculty expertise and program offerings in the many departments which provide natural areas of application. Other departments — including life sciences and medicine — suffer from a lack of students with strong quantitative skills. Scientific computing has been taught in an ad hoc and as needed manner by various departments — computer science, mathematics, statistics, astronomy, chemistry, electrical and aerospace engineering. I-AIM addresses the student experience by bringing cross-appointed graduate students, postdoctoral fellows, undergraduate students and research assistants under a single roof, where they may profit from each other's experiences, discovering new skills and challenging problems looking over each other's shoulders. Coordination of course offerings in areas of overlap — scientific computation, control theory, general relativity, quantum mechanics, statistical mechanics, fluid mechanics, complexity theory — promises many advantages, but its main purpose is to bring students from different application areas together and position them to communicate with and learn from each other. The breadth of its faculty gives I-AIM a unique potential to arrange team taught course sequences by members of different disciplines. This widens scientific exposure and increases student diversity, by bringing life science students in contact with hard sciences, where underrepresentation of minorities and women have tended to be more extreme. I-AIM looks to the new MPC specialist program to attract top undergraduate talent, and expects to play a strong role in supporting this program, and in maintaining an online database of NSERC summer internship opportunities to lure the best students into Toronto's scientific research enterprise. Finally, cross-appointed graduate students open new research frontiers, and provide a means of initiating multi-disciplinary collaborations among faculty members, which although presently possible, have not been widely encouraged.

*Research:* Sample research areas representing I-AIM's interests are listed below. On April 22, I-AIM's Planning Committee hosted a one day workshop at the Fields Institute attended by 30 faculty members. Working groups discussed elements of a successful structure of I-AIM, which are reflected in this proposal. Others worked to identify common research interests that might define new directions which go beyond straightforward extensions of existing programs. One such topic is discussed here as an example of novel research potential that transcends the stated interests of individual participants:

A commonly occurring, overarching theme in many disciplines is the need for descriptions of large, complex systems that transcend multiple scales, granularities and levels of hierarchical decomposition. Statistical physics has developed renormalization group theory to handle such challenges. Systems of interest for control theory, biology or medicine are comparatively large and we may have only approximate descriptions of their state-space. We propose to jointly explore whether analogous rescaling strategies can be devised for such systems, to yield a detailed predictive model. This requires both an extension of mathematical methods and of the descriptions of systems to which these are applied, a task which could not be undertaken from either of the foundational disciplines alone: scientists in the applications domain have less familiarity with the latest mathematical techniques and little experience in developing new ones, while mathematicians

lack intuition concerning which simplifications might be acceptable, or which data could be obtained.

Advances in this direction would be exciting and have profound consequences. The fact that this topic of interest was identified from a randomly composed group of researchers in a four hour discussion underscores the generality and potential of the I-AIM concept. Indeed, there is a history of researchers from other fields, not only mathematics but also physics and computer science, making significant contributions to biology, engineering and the social sciences. But no mechanism at Toronto exists for catalyzing such interactions. Other areas in which I-AIM plans a substantial effort include:

**(A) Communications and Control:** (*Blake, Brumer, Broucke, Colliander, Francis, Feuerverger, Jurdjevic, Kschischang, Lidar, Lo, Maggiore, Mann, Murty, Nachman, Penn, Sargent, Tall, Valaee*). The digital age heralds a revolution in communications technology, serving vital commercial and national interests. With these technologies come new challenges: data encryption for security, verification, and privacy; protocols for error detection and correction; fighting dispersion and dissipation to maximize transmitted information with minimal resources. The possibility of quantum computing changes the rules of the game, turning established protocols on their heads. I-AIM will provide a natural framework for coordinating activities of number theorists from the GANITA laboratory, computer scientists specializing in cryptography, and the Communications group in ECE, while bringing expertise on nonlinear waves and solitons within the mathematics department into contact with the design problems facing engineers. The Quantum Information and Quantum Control initiative would be a valuable participant in I-AIM.

**(B) Nonlinear Dynamics:** (*Brumer, Colliander, Dhirani, Fraser, Ivrii, Jerrard, Kapral, Khesin, Kofman, Matzner, McCann, Mitrovica, Morris, Murray, Peltier, Pugh, Sargent, Schofield, Shepherd, Sulem, Shub, Wu*). Nonlinear dynamics play a crucial role in scientific modelling, from nanoscale to biosphere, and from tabletop experiment to cosmological scale. There is a natural synergy of mathematicians studying partial differential equations, dynamical systems, bifurcations, singularities, and Hamiltonian mechanics, with scientists using these equations and related techniques to model the atmosphere and oceans, geological and environmental processes, pattern formation, reaction chemistry, population biology, and dynamical cosmology. Toronto already boasts great strength arrayed around these areas, but a gap separates cultures between mathematics and the sciences. I-AIM is the vehicle for bridging this gap. An appointment in fluid or solid dynamics spanning interests between mathematics, physics, CITA and chemistry is critical for consolidating existing strengths into a cohesive interdisciplinary group.

**(C) String Theory, Gravitation and Cosmology:** (*Bond, Hori, Kofman, Peet, Pen, Poppitz, Khesin, Thompson*). String theory, gravitation and cosmology address the most fundamental questions about the underlying structure of the physical universe. As far as answers to these questions are understood, they reduce surprisingly often to geometry and symmetry. Thus mass is curvature, motion is geodesic, and particles correspond to excitation of vibrations with different symmetries in the fabric of our universe. Mathematics — particularly geometry — has a significant role to play in understanding these issues. Recent spectacular progress includes proofs of the Riemannian Penrose inequalities and the stability of the spacetime vacuum. New challenges include fleshing out the connection between local and global notions of mass, the large scale geometry and topology of the universe, detecting gravity waves, deriving testable predictions of string theory, and understanding its implications for cosmology. We propose new positions in geometric analysis and general relativity, to fill a vacuum between the the recent joint appointments in string theory, strong mathematical groups in nonlinear partial differential equations and symplectic geometry, and the gravitational expertise in Astronomy and Astrophysics and CITA.

**(D) Discrete Math: Algorithms, Complexity, Geometry, Graph Theory, Statistical Mechanics.** (*Borodin, Fraser, Molloy, Rackoff, Shub, Virag, Whittington, Wodak*). Fundamental problems in computer science with widespread ramifications revolve around the discovery of fast algorithms or proofs that no fast algorithm exists. These are intimately connected to measuring the complexity of tasks, finding clever geometrical and graph theoretic constructions, and accounting for the limiting behaviour of these structures as the task size increases without bound. Similar problems arise in statistical mechanics, where the manifested behaviour of macroscopic systems is well described by the infinite particle number limit. The discontinuities realized in this limit are called “phase transitions” and familiar in everyday life. At larger scales such phenomena apply to the self-organisation of biological systems, from the behaviour of macromolecules to the cell. The same mathematics underlies these phenomena, accounting for the successes of

probabilistic methods of proof, Monte Carlo simulation, and renormalization group methods. I-AIM will provide a venue for cross-fertilization between theoretical chemistry, biology and computer science, with discrete mathematics, combinatorics, geometry and statistical mechanics stimulating both sides. Appointments in statistical mechanics and discrete mathematics are the keys to consolidating strength.

**(E) Probability and Statistics, Data Mining:** (*Almgren, Bond, Carlberg, Christara, Feuerverger, Fraser, Hogg, Jackson, Jaimungal, Kramer, Knight, Quastel, Rosenthal, Seco*). Uncertainty is an essential aspect of the world. As theoretical tools for modeling randomness developed, and large datasets began to permit quantitative analyses, probabilistic and statistical techniques moved to the fore in many areas of science. Finance is a paradigmatic example because of its relevance to society, but the same problems — modelling and managing randomness, coping with enormous data sets, implementing large-scale and distributed computation — recur in engineering, bioinformatics and genome-scale data analysis, economics, and the natural sciences. I-AIM presents an opportunity for addressing these problems on a united front, sharing experiences acquired in the different disciplines to carve out better solutions and new discoveries. The mathematics involved includes analysis, probability and statistics, areas in which we have a young and active group built with recent hires, and scientific computation — an area which needs further development. The TPAC and CNCA initiatives<sup>1</sup> of Astronomy and CITA represent two positive steps, whose multidisciplinary benefits and potential for success will be significantly enhanced through I-AIM.

**(F) Scientific Computation and Modelling:** (*Almgren, Bailey, Bond, Buchweitz, Bussman, Carlberg, Christara, Enright, Ethier, Groth, Hansen, Jackson, Lavers, Martin, Martins, Matzner, Mitrovica, Nachman, Peltier, Pen, Pugh, Repka, Sargent, Sarris, Schofield, Sulem, Whittington, Zingg*). Scientific computation and numerical simulation provide a new methodology in science and engineering whose importance can scarcely be overestimated. Current groups on campus employ this methodology to design everything from molecules to aeroplanes and telescopes, to reconstruct three dimensional data from two-dimensional observations, and to model the spreading of disease, environmental contaminants, climate change, the evolution of matter in the universe. Other groups are active in the development of reliable general purpose numerical software to accurately approximate and visualize the solutions of these important mathematical models. I-AIM presents an opportunity for technical and intellectual exchange between these groups, which share different goals but a common methodology. I-AIM appointments in scientific computation and modelling would help to complement and unite strong expertise in the departments of computer science, physics, astronomy, CITA and the Computational Cluster in Applied Science.

**(G) Biochemistry, Biology, Genetics, Biomedical Research:** (*Abrams, Emili, Ethier, Feuerverger, Friesen, Hogg, Joy, Lewis, Nachman, Pugh, Repka, Schofield, Shub, Steipe, Tall, Tillier, Tropak, Wodak, Yip*). University of Toronto may have the largest group of Bioinformatics faculty active in North America. Mathematical contributions to Proteomics and Functional Genomics, and their applications to Biology and Biomedical research, are underdeveloped. The breadth of the models and abstractions that can be applied give this area tremendous potential for breakthroughs. Demands of large datasets coupled with the imperative to complement observation- and technology-driven programs with hypothesis-driven research are responsible for the exceptionally strong faculty interest in I-AIM. Obvious areas of application stem from bioinformatics and biostatistics: vast quantities of epidemiological, genomic, and protein folding data demand models, organizing principles, and data mining approaches. Other topics represented in Toronto include Computational Systems Biology and Computational Neuroscience — booming areas of research with computer scientists, physicists, mathematicians, and neurologists working in concert. Another focus is medical imaging technology: reconstructing 3-d images from noisy two dimensional slices, solving inverse problems, matching problems, feature identification and segmentation. The challenge is to translate and define biological problems to make them accessible to rigorous analysis. The teams of theoreticians and experimentalists who succeed in doing so will have enormous impact.

*Faculty and staff:* I-AIM is a multidisciplinary undertaking currently involving 83 faculty supporters spread over three Faculties and a dozen different departments (Appendix A). It includes 3 University Professors and 10 CRC chairs. About one quarter of these faculty hail from the Mathematics Department, while a slightly larger number (28) come from other Arts and Science departments. The remainder are affiliated with the Faculties of Applied Science & Engineering, Medicine, or the School of Graduate Studies. I-AIM

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<sup>1</sup>Toronto Processing and Analysis Center falls into (E); Canadian Network for Computational Astrophysics into (F).

presently has no staff; an administrator (phase 1) and systems administrator (phase 2) are proposed.

*Space and facilities:* Generating interdisciplinary interactions depends crucially on an adequate physical location. This facility should include offices and workspace for the applied core of the mathematics faculty, jointly sponsored postdoctoral fellows and cross-appointed graduate students, undergraduate research assistants, and visitors from across campus and around the world. It must include classroom and seminar space, a lounge or meeting area, administrative offices, and computer and laboratory space for interdisciplinary projects, including “multi-way” space where a physicist might encounter a biologist. This space must be attractive and welcoming enough to induce I-AIM members to spend time on site, locating their interdisciplinary graduate courses and seminars here. Proximity to participating departments such as computer science, engineering, physics, chemistry, biochemistry, medical sciences, the Fields Institute, and the new mathematics and statistics complex planned for 215 Huron Street are essential. The space must possess reliable and modern infrastructure for data networking and computer installation.

Within the mathematics department, space has become a crisis, and there is little space to spare in cognate disciplines. Finding a suitable home for the Institute would allow us to unite the group of applied mathematics faculty and students currently divided between Earth Sciences, Sid Smith, Spadina Crescent, and various colleges, as well as the CFI-funded computer laboratory in Whitney Hall; all of these locations would be freed for use by other departments. It would provide a resource center for students doing scientific computation throughout the university to encounter each other and pass on practical knowledge concerning high performance software and hardware at Toronto. This space might also permit relocation of the Mathematical Finance Program back onto campus, with its substantial computer laboratory and database servers; sharing of these facilities with the Institute could lead to substantial economies of scale.

A perfect location for the Institute would be the sixth floor of the Bahen Information Technology Center: it is ideally located, has sophisticated technology infrastructure, and — unique on campus — a large contiguous area currently unoccupied. Activities of the Institute could launch into full swing as soon as construction is complete.

*Governance, climate and culture:* I-AIM will consist of a core of Organizing Members, together with a larger group of Affiliated Faculty. Its Director will be advised by an Advisory Board, consisting of representatives of the Affiliated Faculty approved by their units, who will also serve as liaisons between their home departments and I-AIM. Members of Planning and Advisory Committees listed in Appendix A are natural candidates for this Board. As the institute grows, an External Board may also be appointed to maintain global standards of excellence.

As with other interdisciplinary activities at the University, administrative affiliation will be determined jointly between the participating faculties and departments. A natural lead in this process will be taken by the Department of Mathematics, since I-AIM’s mandate and graduate program concern it closely. While we do not anticipate that the Director of I-AIM would necessarily be a mathematician, the administrative costs involved in starting up a new institute can be partly ameliorated by building on existing departmental infrastructure, such as the APM program and course designation. From the outset, tenure-stream appointments and graduate student admissions to I-AIM would flow through participating departments, but with I-AIM playing a key role e.g. in providing interdisciplinary representation on hiring committees. Other resources, such as postdoctoral support and CLTA positions would be administered directly through I-AIM.

#### 4. Specific Initiatives

**Phase 1 — Consolidation.** The first task of I-AIM is to consolidate existing strengths across campus in the mathematical sciences and related disciplines. This includes the cultivation and strengthening of partnerships through research collaboration, the organization of interdisciplinary seminars, and the recruitment and training of jointly supervised graduate students, postdoctoral fellows, and undergraduate summer interns. Novel possibilities for teaching and research will be identified through an ongoing dialog between interested and knowledgeable participants. However, this effort will not yield returns unless a focal point can be provided, including adequate space to house I-AIM and its activities: weekly seminars, research projects, HQP. This will include reworking the graduate program in applied mathematics, with special attention to recruitment, course offerings, and program requirements, and coordinating a unified

approach to the sharing, acquisition, and development of high-performance computing resources at Toronto. Suitable course offerings throughout the University will be incorporated into the Institute program, and adapted for accessibility and relevance to cognate disciplines. Here there may be opportunities for economy when similar course offerings by different units can be eliminated, relieving pressures on teaching, exposing students to different perspectives, and resulting in a net gain in faculty research time. On the other hand, new courses which bridge between disciplines, some of them team taught, will also be required. At this stage of development, I-AIM will require a Director to implement the recommendations of the advisory councils (internal and external), report to the University, lobby funding agencies (CIAR, MITACS, NCE, NSERC, NRC, the Fields Institute) and industry, and to coordinate the institute activities and postdoctoral program with the various departments and units. It will also require a Graduate Coordinator to oversee and actualize the revision of the curriculum in applied mathematics; to coordinate with the graduate directors of the cognate departments, and to provide academic advice to cross-appointed graduate students from the departments which choose to participate. An administrative assistant will be necessary to assist the Director and Graduate Coordinator with their responsibilities, to assist students and postdoctoral fellows, and to provide all feasible support to Affiliated Faculty with their initiatives in applied mathematics. Release time will be provided to the Director of I-AIM and the Graduate Coordinator by their respective departments. Salary for an administrative assistant will need to be provided by the University — half-time in phase 1 and full-time by phase 2. The availability of university matching funds for faculty contributions are necessary to catalyze interdisciplinary graduate student and postdoctoral offers.

**Phase 2 — Growth.** The lifeblood of any research institute is a constant infusion of new ideas. For I-AIM, this means having a steady stream of top-quality postdoctoral talent, distinguished long-term sabbatical visitors, and dynamic interdisciplinary speakers passing through the institute, and contributing to its research and teaching missions. In addition to faculty grant and departmentally sponsored postdoctoral fellows leveraged by Institute funds, we propose to start a program of prestigious assistant professorships, which will have a CLTA status within the university, but enjoy favorable teaching and research conditions which attract the best international talent. At least one of these three-year positions would be offered each year, coordinated in turn between mathematics and a second host department from (a) physical sciences, (b) biomedical sciences, (c) computational sciences and engineering, allocated on a rotating basis. Interdisciplinary appointments of this nature do not happen in the absence of a program to nurture them.

With this postdoctoral program in place, it becomes feasible to broaden the mission of the institute to include undergraduate training in applied and interdisciplinary mathematics. A computational science designation would be developed either as a separate degree, or more likely as a an additional certification to various existing degrees. The Institute will then require an Undergraduate Coordinator to advise students and undertake a curriculum revision to the undergraduate programs in computational science and applied mathematics, similar to the revisions to the graduate program described above, and a half-time systems administrator to maintain computer laboratories, going to full-time as necessary by phase 3.

**Industrial links:** Connections with industry have the potential to add unique elements to the institute activities. Much of the research proposed is of interest to industries in sectors like communications, security, forecasting, finance and banking, pharmacy and health care — and this interest will increase as our economy shifts from resources and technology to information and ideas. As part of Phase 2, I-AIM proposes to channel this interest into various dimensions of research activity, ranging from joint seminars with industrial partners, internship programs for young researchers, problem solving sessions, case studies, to technology transfer through contracted research. We plan to build on the success of our members, which have generated spin-off companies such as Khartika, RiskLab and Sigma, in the secure data storage and financial analysis sectors. Industrial partnerships stimulate research through cross-fertilization and generation of novel perspectives and ideas. They also contribute significantly to the training and placement of students, and can play a pivotal role in securing governmental support for I-AIM.

**Phase 3 — Global Leadership.** To achieve a position of global leadership in interdisciplinary mathematics, new appointments are necessary to fill in critical gaps in our base of expertise, bind together existing strengths and open new directions on our research agenda. Six key areas are identified below:

1. solid and fluid dynamics (linked to physics or chemistry)
2. geometric analysis and general relativity (ideally linked to CITA, astronomy, string theory)

3. discrete math, probability, and statistical mechanics (linked to medicine, statistics or computer science)
4. scientific computation (linked as appropriate, or to engineering)
5. mathematical modelling (materials science, biological, biomedical, environmental)
6. data mining, bioinformatics, and harmonic analysis (linked to engineering, computer science or medicine)

These are supported by nine position requests by the mathematics department<sup>2</sup>, as well as a request for I-AIM linked positions in *computational astronomy* by the department of astronomy and astrophysics, and in *bioinformatics* by the department of computer science. However, because of its interdisciplinary mandate, I-AIM can also envision several of the mathematics position requests being filled as joint or cross appointments which couple MATH with an appropriate partner department.

## 5. Measures of Success

The primary measure of success of the Institute will be to track how its proposed initiatives come to fruition. Its research success can be quantified and assessed dynamically through traditional means: number, quality, and impact of publications by I-AIM affiliated faculty, visitors, and HQP; scholarly recognition accorded to institute members in the form of prestigious awards and invitations to present research, number and value of research contracts awarded, number and quality of long-term visitors attracted, number of seminars. Of especial relevance to I-AIM will be the quantity and quality of interdisciplinary collaborations initiated, and the publications and research contracts which result. The success of HQP training can also be tracked in terms of number and quality of graduate students, postdoctoral fellows, and undergraduate interns who choose to affiliate with I-AIM, their subsequent placement, and completion rate of degree programs by these students. Further indicators will be the number of courses offered through I-AIM, their enrollments, and student satisfaction ratings on exit surveys.

The success of Phases 2 and 3 can also be measured by similar signals from our undergraduate program, as well as the number and quality of new faculty recruited by affiliated departments in conjunction with I-AIM, their research success and subsequent placement (in the case of non-stream faculty), scholarly recognition obtained, and the quality of institutions who compete with us to recruit and retain these scholars. Attracting federal investments to Toronto, such as an NRC lab, would be a strong success signal.

Industrial program success can be measured by its activity level, including number of joint activities organized, contracts awarded, projects and partnerships established, internships arranged, their subsequent placement rates, and the transfer of technology and dissemination of research through incorporation into commercial products, patents and spin-offs.

## 6. Contingency Plans

Some steps are possible with a modest investment of funds: support for an administrative assistant plus departmental release time for a Director and Graduate coordinator would enable a virtual Institute to be created, based on a network of affiliated faculty, a regular seminar series including brown bag lunches, and a website, which would probably attract graduate student interest and help orient students and researchers to multidisciplinary sources of advice and expertise. It would surely enhance current programs in applied mathematics and computational science, the proposed MPC program, and the coordination of placement possibilities for NSERC summer undergraduate interns. However the potential for sustained and amplified progress on genuinely interdisciplinary research challenges will be greatly diminished in the absence of shared space where cross-appointed students, faculty and postdoctoral fellows regularly have the opportunity to encounter and interact with each other. The absence of a dynamic environment and sense of shared goals will hamper recruitment of quality students and federal funds, and the absence of peer learning opportunities will impede the progress of students who undertake research in the institute. The possibility of coordinated efforts by different departments — on scientific questions, faculty recruitment, education in shared subject areas and common methodologies, such as numerical analysis and scientific computing — recedes dramatically. The opportunity for I-AIM to fulfil its potential to become a major force driving science forward in Canada and the world will be lost. The incentives for individuals to devote time to nurturing the institute will be diminished, and the outcome of such an investment, although better than the status quo, might not wind up being very different from it.

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<sup>2</sup>Codes POJQFXMTW in the MATH department plan, where seven additional positions CHIUYZ also relate to I-AIM.

## Appendix A:

The scope and shape of I-AIM continue to evolve, but the intellectual relevance of applied mathematics across the university is reflected by the widespread interest and broad support which this proposal has garnered. The following 83 faculty members have expressed strong support for the concept and their interest in affiliation with I-AIM. They include 19 members of the Department of Mathematics, 28 additional faculty from Arts and Science, 20 members of the Faculty of Applied Science, 8 members of the Faculty of Medicine, 7 from the School of Graduate Studies, plus the Deputy Director of the Fields Institute. This document was prepared by a Planning committee consisting of ten representatives,\* in consultation with an Advisory committee consisting of 19 additional faculty.†

†Peter Abrams, Zoology

†Robert Almgren, Computer Science and Mathematics; Mathematical Finance Program

Richard Bailey, Geology and Physics

Ian Blake, Electrical and Computer Engineering

†Richard Bond, Canadian Institute of Theoretical Astrophysics

Allan Borodin, Computer Science

Mireille Broucke, Electrical and Computer Engineering

Paul Brumer, Chemistry

Ragnar Buchweitz, Mathematics

Markus Bussman, Mechanical and Industrial Engineering

Ray Carlberg, Astronomy and Astrophysics

†Christina Christara, Computer Science

James Colliander, Mathematics

Al-Amin Dhirani, Chemistry

Andrew Emili, Medical Research, Medical Genetics & Microbiology; Proteomics & Bioinformatics

\*Wayne Enright, Computer Science

Ross Ethier, Mechanical and Industrial Engineering

Andrey Feuerverger, Statistics

Bruce Francis, Electrical and Computer Engineering

Simon Fraser, Chemistry

Jim Friesen, Banting and Best Department of Medical Research

†Clinton Groth, Institute for Aerospace Studies

Jorn Hansen, Institute for Aerospace Studies

David Hogg, Medicine and Medical Biophysics

Kentaro Hori, Mathematics and Physics

Victor Ivrii, Mathematics

Ken Jackson, Computer Science

Sebastian Jaimungal, Statistics

Robert Jerrard, Mathematics

Mike Joy, Institute of Biomaterials and Biomedical Engineering

Velimir Jurdjevic, Mathematics

†Raymond Kapral, Chemistry

Boris Khesin, Mathematics

\*Keith Knight, Statistics

Lev Kofman, Canadian Institute for Theoretical Astrophysics

Lisa Kramer, Rotman School of Management

†Frank Kschischang, Electrical and Computer Engineering

J. Douglas Lavers, Electrical and Computer Engineering

†Peter Lewis, Biochemistry and Medicine

Daniel Lidar, Chemistry

†Hoi-Kwong Lo, Electrical and Computer Engineering and Physics

†Manfredi Maggiore, Electrical and Computer Engineering

Steve Mann, Electrical and Computer Engineering

†Peter Martin, Astronomy and Canadian Institute for Theoretical Astrophysics

Joaquim Martins, Institute for Aerospace Studies  
 Christopher Matzner, Astronomy  
 \*Robert McCann, Mathematics  
 Jerry Mitrovica, Physics  
 Michael Molloy, Computer Science  
 Stephen Morris, Physics  
 Norman Murray, Canadian Institute of Theoretical Astrophysics  
 †Kumar Murty, Mathematics  
 \*Adrian Nachman, Electrical and Computer Engineering and Mathematics  
 †Amanda Peet, Physics  
 \*Richard Peltier, Physics  
 Gerald Penn, Computer Science  
 \*Ue-Li Pen, Canadian Institute for Theoretical Astrophysics  
 Erich Poppitz, Physics  
 \*Mary Pugh, Mathematics  
 Jeremy Quastel, Mathematics and Statistics  
 †Charles Rackoff, Computer Science  
 Joe Repka, Mathematics  
 Jeffrey Rosenthal, Statistics  
 †Tom Salisbury, Fields Institute  
 †Ted Sargent, Electrical and Computer Engineering  
 Costas Sarris, Electrical and Computer Engineering  
 \*Jeremy Schofield, Chemistry  
 †Luis Seco, Mathematics  
 †Theodore Shepherd, Physics  
 †Michael Shub, Mathematics  
 \*Boris Steipe, Biochemistry, Molecular & Medical Genetics; Proteomics & Bioinformatics  
 Catherine Sulem, Mathematics  
 Frank Tall, Mathematics  
 Christopher Thompson, Canadian Institute for Theoretical Astrophysics  
 Elisabeth Tillier, Medical Biophysics  
 Michael Tropak, Hospital for Sick Kids  
 Shahrokh Valaee, Electrical and Computer Engineering  
 Balint Virag, Mathematics and Statistics  
 Stuart Whittington, Chemistry  
 †Shoshana Wodak, Biochemistry, Structural Biology, and Medical Genetics  
 Yanqin Wu, Astronomy and Astrophysics  
 Christopher Yip, Biomaterials, Biomedical & Chemical Engineering, Applied Chemistry, Biochemistry  
 \*David Zingg, Institute for Aerospace Studies

**Contact person:** Robert McCann, (416) 978-4658, [mccann@math.utoronto.ca](mailto:mccann@math.utoronto.ca)

## Appendix B: Crude estimate for resource costs

### Phase 1 (Consolidation):

SPACE

Half-time administrative assistant \$ 22,500 / year + benefits

Interdisciplinary postdoctoral matching funds \$120,000 / year for six postdocs.

High profile interdisciplinary seminar series \$25,000 / year

Release time for a Director and Graduate coordinator to be provided by their departments.

### Phase 2 (Growth):

Administrative assistant to full time \$ 22,500 / year + benefits

I-AIM interdisciplinary junior faculty (CLTA) program  $3 \times \$60,000 = \$180,000$  / year

Sabbatical visitor program =  $3 \times \$40,000 = \$120,000$  / year

Half-time systems administrator \$31,000 / year + benefits

Release time for an Undergraduate coordinator to be provided by his or her department.

### Phase 3 (Global leadership):

11 tenure stream positions.

Systems administrator to full-time \$31,000 /year + benefits

Increased graduated student / postdoctoral / CLTA support, as merited.