PERIMETER INSTITUTE
FOR THEORETICAL PHYSICS

Annual Report to Industry Canada
Covering the Objectives, Activities and Finances
for the period August 1, 2008 to July 31, 2009 and
Statement of Objectives for Next Year and the Future

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Statement of Objectives

Introduction

In 2008-9, the Institute achieved many important objectives of its mandate, which is to advance pure research in specific areas of theoretical physics, and to provide high quality outreach programs that educate and inspire the Canadian public, particularly young people, about the importance of basic research, discovery and innovation.

Full details are provided in the body of the report below, but it is worth highlighting several major milestones. These include:

- In October 2008, Prof. Neil Turok officially became Director of Perimeter Institute. Dr. Turok brings outstanding credentials both as a scientist and as a visionary leader, with the ability and ambition to position PI among the best theoretical physics research institutes in the world.

- Throughout the last year, Perimeter Institute's growing reputation and targeted recruitment activities led to an increased number of scientific visitors, and rapid growth of its research community.

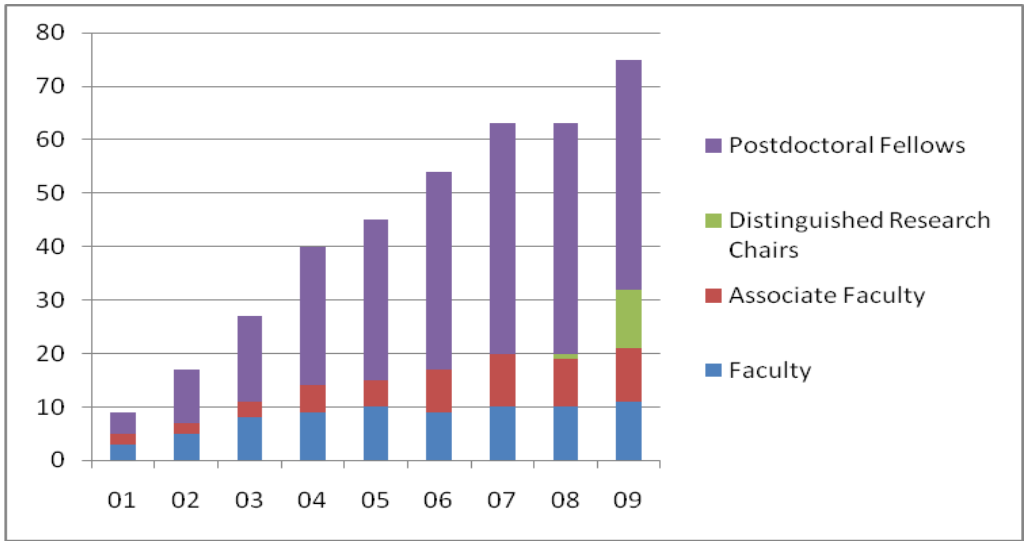

Chart 1. Growth of PI scientific staff and associated researchers since inception, 2001-2009.

- In Summer 2009, funding from federal, provincial and private sources was secured for the Institute's facility expansion, to be named the Stephen Hawking Centre at Perimeter Institute, which will provide greatly expanded space for PI's growing research community.

In addition to the milestones noted above, Perimeter Institute is able to report strong success on the dozen objectives for this fiscal year and the future, which were established in a previous

report to Industry Canada (covering April 2007-July 2008). In this FY08-09 report, we will focus on each objective in the following order:

Objective 1: Broaden its team of researchers in order to promote fundamental progress across the full spectrum of physics

Objective 2: Expand to provide the world's best environment and infrastructure for theoretical physics research

Objective 3: Expand the cluster of top resident scientists to critical mass

Objective 4: Fully establish its program of Distinguished Research Chairs

Objective 5: Recruit the world's most promising graduate students and prepare them for cutting edge research via Perimeter Scholars International (PSI)

Objective 6: Engage with experimental and observational centres

Objective 7: Host timely, focused conferences, workshops, seminars and courses

Objective 8: Increase its role as Canada's focal point for foundational physics research

Objective 9: Develop collaboration agreements and partnerships

Objective 10: Support the emergence of innovative centres of excellence promoting high level math and physics across the developing world

Objective 11: Continue to build its highly regarded outreach program

Objective 12: Showcase Canada as a country that clearly recognizes that virtually every aspect of our modern technological society historically has roots in the ideas generated by theoretical physics

The following pages outline each objective in more detail, including how the objectives were met with specific examples of the activities undertaken. These are reported upon for the Institute's fiscal year, August 1, 2008, to July 31, 2009.

Objective 1: Broaden its team of researchers in order to promote fundamental progress across the full spectrum of physics

Since its inception, the Institute has brought together researchers pursuing varied approaches to the greatest challenges facing fundamental theoretical physics in the 21st century, namely, discovering a deeper understanding of the quantum laws of physics and the spacetime arena in which they operate. PI's strategically chosen combination of research directions is unique worldwide, and its multidisciplinary approach instills a collaborative atmosphere which maximizes cross-fertilization of ideas and increases the probability of breakthroughs.

While retaining its inspiring twin focus, PI is broadening its range of research to combine complementary insights gained from physics on all length scales: from subatomic, to mesoscopic condensed matter systems, to cosmology, and to complex systems, in which many time and length scales are involved. By offering a dynamic, multi-disciplinary environment with maximum research freedom and opportunities to collaborate, PI has been able to successfully build its research team and expand its research programs in cosmology and particle physics. The Institute will continue this expansion into condensed matter and complex systems in 2009-10.

The following information describes scientific progress and accomplishments, as well as steps taken to broaden PI's research into areas targeted for future development.

Summary of Achievements

Six active research groups with prolific research output in the past year as follows:

- 196 Publications[1]
- 1,273 citations to the current year's work[2]
- Since its inception, PI researchers have produced 1,052 publications in 50 different journals, attracting 20,453 citations to November 2009
- 94 resident researchers, including 11 Faculty, 10 Associate Faculty, 45 Postdoctoral Fellows, and 28 Graduate Students
- Held 18 on-site conferences, 172 seminars, 27 colloquia
- Appointment of world-leading cosmologist Neil Turok as Director of the Institute, and a Faculty member in Cosmology
- Appointment of Robert W. Spekkens as junior Faculty member in Quantum Foundations (August 2008)
- Additional recruitment in existing and expanding areas including junior Faculty members Latham Boyle (Cosmology) and Pedro Vieira (Strings/Quantum Field Theory); and the co-recruitment of Faculty members Niayesh Afshordi (Cosmology) and Luis Lehner (General/Numerical Relativity) in cross-appointments with the University of Waterloo and the University of Guelph, respectively
- Appointed 11 eminent Distinguished Research Chairs in existing and expanding areas of research

[1] Note: As of July 31, 2009. Each publication has been counted only once, regardless of how many Perimeter Institute researchers collaborated on it.
[2] As of November 30, 2009, according to Google Scholar and Spires.

1.1 Research Progress

The following section reports on progress in Perimeter's core research areas. It should be noted that much of the research is highly interdisciplinary, and many of these results are applicable across other sub-fields of physics.

Quantum Foundations

The quantum foundations group at PI is the largest and most diverse group of its type in the world. The field investigates the conceptual and mathematical structure of quantum theory, and dovetails with the emerging science of quantum information. Most work in the field falls under the following three areas of research:

- Looking for novel effects in quantum theory;
- Investigation of conceptual issues in quantum theory (such as the measurement problem, nonlocality, and non-contextuality) and of interpretations of quantum theory (such as the Copenhagen interpretation or the many worlds interpretation);
- Developing a deeper understanding of the structure of the theory (both mathematical and conceptual) in order to reconstruct the theory from more basic axioms, and in order to go beyond quantum theory (for example, to a theory of quantum gravity).

Summary of Achievements

- 18 papers produced
- 24 seminars; 3 conferences/workshops held
- Work by faculty member Robert Spekkens *et al* was selected for inclusion in the *New Journal of Physics* "Best of 2008" issue.
- Chris Fuchs obtained $512 K (USD) in grant funding over four years from the U.S. Office of Naval Research for a project titled "SIC Representations for Quantum States and Quantum Channels: Pinpointing the Essence of Quantum Information Processing."
- Chris Fuchs was elected Vice-Chair of American Physical Society's (APS) topical group on quantum information (he will become Chair-Elect and then Chair over a four-year term).

Highlights

Researchers in quantum foundations at PI pursued several fruitful research directions over the course of the year. Examples include the following:

- Lucien Hardy worked on building deeper operational foundations for quantum theory with the hope of applying these ideas to general relativity and, eventually, to quantum gravity.
- Ward Struyve and Samuel Colin examined topics in the pilot wave model for quantum theory, in particular a study of non-equilibrium where the distribution of particle positions is not consistent with the wave function.
- Chris Fuchs worked on solidifying in technical terms the notion that the quantum state represents no more than a Bayesian degree of belief. To this end he has pursued a type of measurement called SICs (symmetric, informationally-complete measurements) which promises to have the correct structure for this purpose.

- Robert Spekkens explored quantum reference frames as a resource as well as investigating operational definitions of contextuality.
- Philip Goyal pursued an information-geometric reconstruction of quantum theory which builds, to some extent, on past ideas of Wootters.
- Adrian Kent conducted a critical analysis of recent attempts (by the Oxford school in particular) to define and confirm Everettian Quantum Theory (the many worlds interpretation). He also proposed a new Lorentz covariant realistic formalism using minimal additional structure to define a solution to the measurement problem.
- Hans Westman investigated the viability of the epistemic interpretation by developing a concrete proposal in which the wavefunction would just represent a probability distribution.
- Rafael Sorkin continued to develop and refine his anhomomorphic logic approach to quantum theory in collaboration with Joe Henson, David Rideout and Cohl Furey and apply it to new situations. He also collaborated with PI associate Raymond Laflamme and coworkers at the Institute for Quantum Computing to test quantum theory in a three slit experiment (this experiment pertains to a proposal by Sorkin in 1994 that quantum theory is the second in a hierarchy of theories characterized by their behaviour in multi-slit interference experiments).

Quantum Gravity

Quantum gravity is concerned with unifying general relativity, Einstein's theory of gravity, with quantum theory. At Perimeter Institute, researchers are actively pursuing a broad variety of approaches to this problem including loop quantum gravity, spin foam models and causal set theory. The major focus of the Perimeter Institute quantum gravity group continues to be diverse approaches to quantum gravity, from a non-perturbative point of view.

Summary of Achievements

- 58 papers published
- Faculty member Lee Smolin was awarded the 2009 Klopsteg Memorial Award from the American Association of Physics Teachers (AAPT) for "extraordinary accomplishments in communicating the excitement of contemporary physics to the general public."
- Faculty member Fotini Markopoulou won a prize from the Foundational Questions Research Institute (FQXi) for her essay "Space does not exist, so time can." PI Affiliate Steve Weinstein and former PI postdoctoral fellows Olaf Dreyer and Florian Girelli also garnered honours.

Highlights

There have been three directions in which significant progress on this problem was led by Perimeter faculty, and several others where new ground was broken.

Highlights from the past year include the following:

- Florian Conrady and Laurent Freidel published a major result showing the existence of a semiclassical approximation to spin foam models, an important step in the ongoing effort to unify Einsteinian and quantum theories, one of the central challenges in physics. In

their paper, “On the semiclassical limit of 4d spin foam models,”[3] the semicclassical limit of quantum spin foam amplitudes of a new class of four dimensional models recently defined is studied. They showed that spin foam amplitudes are in a certain limit approximated by the exponential of a discretizaton of the Einstein action. This shows for the first time that spin foam amplitudes restricted to finite boundary spin network states have the proper semiclassical limit.

- Fotini Markopoulou and collaborators obtained an upper bound on the speed of propagation of information in a spin model with topological order whose low-energy effective theory describes light.[4] In “Lieb-Robinson bounds and the speed of light from topological order,”[5] they showed that the maximum speed of interactions is bounded from above to $\sqrt{2e}$ times the speed of emerging light, giving a strong indication that light is indeed the maximum speed of interactions in string-net condensates. This result is a major step in showing how gauge fields may arise as emergent degrees of freedom in background independent quantum gravity models. They also found that the speed of light depends on the spacetime dimension of the model. Markopoulou and collaborators continued work on a class of such models, called quantum graphity models.[6]
- Lee Smolin proposed a new solution to the cosmological constant problem in the context of a path integral quantization of a class of gravity theories called unimodular gravity.[7] In this theory, first studied by Einstein in 1919, terms in the energy momentum tensor proportional to the metric are not sources of spacetime curvature. Smolin showed that this result also holds in the full quantum effective action, constructed properly from the constrained phase space path integral. This implies that quantum corrections to the cosmological constant decouple from the spacetime geometry.
- Several PI postdoctoral fellows made contributions to a growing interest in asymptotic safety and, in particular, provided evidence that at short distances the spectral dimension of spacetime decreases from 3 + 1 to 1 + 1. Dario Benedetti published a new argument for decrease in the spectral dimension of spacetime as a consequence of quantum group symmetries,[8] while Leonardo Modesto found an argument to the same conclusion from the properties of the area operator in loop quantum gravity.[9] These suggest new ties between these approaches, causal dynamical triangulations and asymptotic safety which deserve further exploration. In related work, postdoctoral fellow Razvan Gurau and visiting researcher Oliver Rosten presented a formulation of the Wilsonian renormalization group to field theory on non-commutative spacetime manifolds.[10]
- In collaboration with mathematician Simone Severini, a postdoctoral fellow at the Institute for Quantum Computing (IQC), Fotini Markopoulou showed that a counting problem for paths of given length on a graph can be expressed in terms of the expectation value of certain quantum mechanical observables in the Hilbert space of their proposed quantum graphity model. [11, 12]

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[3] F. Conrady, L. Freidel. “On the semiclassical limit of 4d spin foam models.” *Phys. Rev. D* 78, 104023 (2008). arXiv:0809.2280 [gr-qc].
[4] see Xiao-Gang Wen, “Artificial light and quantum order in systems of screened dipoles.”*Phys. Rev. B* 68 (2003) 115413, arXiv:0210040.
[5] Alioscia Hamma, Fotini Markopoulou, Isabeau Premont-Schwarz, Simone Severini. “Lieb-Robinson bounds and the speed of light from topological order.” *Phys.Rev.Lett*.102:017204, 2009. arXiv:0808.2495.
[6] Tomasz Konopka, Fotini Markopoulou, Simone Severini. “Quantum Graphity: a model of emergent locality.” *Phys.Rev.D* 77:104029, 2008. arXiv:0801.0861.
[7] L.Smolin.“The quantization of unimodular gravity and the cosmological constant problem.” arXiv:0904.4841.
[8] Dario Benedetti. “Fractal properties of quantum spacetime.” *Phys.Rev.Lett.*102:111303, 2009. arXiv:0811.1396
[9] Leonardo Modesto. “Fractal Structure of Loop Quantum Gravity.” arXiv: 0812.2214.
[10] R. Gurau, O. J. Rosten. “Wilsonian Renormalization of Noncommutative Scalar Field Theory.” arXiv:0902.4888.
[11] F. Markopoulou, S. Severini. “A note on observables for counting Trails and Paths in Graphs.” *Jl of Mathematical Modeling and Algorithms;* accepted April 2009.

- In collaboration with Chanda Prescod-Weinstein (a graduate student at the University of Waterloo), Lee Smolin developed a novel explanation of dark energy, due to Markopoulou,[13] according to which dark energy is a remnant of disordered locality arising from loop quantum gravity and similar theories of quantum gravity in which locality is an emergent property.[14]

Quantum Information

Researchers in the quantum information group are working to understand the properties of quantum information and study which information processing tasks are feasible, and which are infeasible or impossible. This includes research in quantum cryptography which studies the trade-off between information extraction and disturbance, and its applications. It also includes research in quantum error correction, the study of methods for protecting information against decoherence.

Summary of Achievements

- 38 papers published
- 1 conference/workshop held
- PI Associate Faculty member Raymond Laflamme was inducted into the Royal Society of Canada, the highest academic honour in Canada.
- PI Associate Faculty member Raymond Laflamme's Canada Research Chair (Tier 1) was renewed.

Highlights

Quantum information research over the past year spanned a broad array of topics. A few examples include the following:

- In work published in the *New Journal of Physics*, PI Associate Raymond Laflamme, with IQC graduate students Colm Ryan and Martin Laforest, used nuclear magnetic resonance to experimentally perform a randomized benchmarking protocol to measure the error rates in their quantum gates, finding an error rate of just above 1 in 10,000 gates.[15] For a large quantum computer, it is impractical to measure every detail of the quantum state created in the experiment, but by choosing a random sequence of operations, it is possible to get a good statistical estimate of the errors. Building a large quantum computer will require a good understanding of the experimental errors in order to counteract them with better equipment or error correction.
- PI postdoctoral fellows Steve Flammia and Nick Menicucci, along with Oliver Pfister, have written a series of papers[16] about performing quantum computing using light trapped in optical cavities. They propose to create a quantum state of light entangling

[12] See also: Tomasz Konopka, Fotini Markopoulou, Simone Severini, "Quantum Graphity: a model of emergent locality." *Phys.Rev.D* 77:104029, 2008. arXiv:0801.0861.
[13] F. Markopoulou. "New directions in Background Independent Quantum Gravity." arXiv:gr-qc/0703097. In *Approaches to Quantum Gravity - Toward a New Understanding of Space, Time, and Matter.* Edited by D. Oriti. Published by Cambridge University Press, 2009.
[14] C. Prescod-Weinstein, L. Smolin. "Disordered Locality as an Explanation for the Dark Energy." arXiv:0903.5303.
[15] C.A. Ryan, M. M. Laforest, and R. Laflamme. "Randomized benchmarking of single and multi-qubit control in liquid-state NMR quantum information processing." *New J. Phys.* 11 (2009) 013034 arXiv:0808.3973v1.
[16] See for example: Steven T. Flammia, Nicolas C. Menicucci, Oliver Pfister. "The Optical Frequency Comb as a One-Way Quantum Computer." *J. Phys. B* 42, 114009 (2009). arXiv:0811.2799

many different frequencies, which would then provide the answer to a quantum computation through an appropriate sequence of measurements. Most approaches to building a quantum computer with light use multiple different beams of light, which do not interact strongly with each other. By using different frequencies instead of different beams, this difficulty can be avoided.

- PI postdoctoral fellow Sarah Croke, with David Menzies, has recently studied non-deterministic noiseless linear amplification. Their work draws from several different ideas – weak values, concepts from quantum optics, and quantum information – and shows that weak measurements may be used to produce useful transformations.[17]
- PI postdoctoral fellow Rolando Somma, PI Associates Richard Cleve and Michele Mosca, and PI faculty member Daniel Gottesman, with IQC graduate student David Yonge-Mallo, showed that continuous-time and discrete-time oracles are nearly equivalent.[18] In computer science, it is frequently convenient to study the computational complexity of tasks by abstracting the specification of the question to one about an "oracle," a black box that performs some computation. In quantum mechanics, it also makes sense to consider continuous oracles, where the black-box computation is performed continuously over some finite time rather than all in one chunk. In principle, a continuous oracle might be more efficient than a regular discrete-time oracle, since it gives more flexibility in how the oracle is used. However, this paper, presented at *QIP 2009* (and appearing in the proceedings of *STOC 2009*), showed that an algorithm using discrete-time oracles can simulate one using continuous-time oracles with only a small increase in the amount of oracle access used.

Superstring Theory

String theory is a broad and varied field with strong connections to quantum gravity, particle physics and cosmology, as well as mathematics. Topics of ongoing research include: string cosmology, supersymmetric gauge theories, matrix models, gauge/gravity duality and twistors. The scientific output of the string theory group the past year was very strong, not only in the number of publications but also in the visibility of several, with results being presented in seminars and conferences around the world.

Summary of Achievements

- 34 publications
- Held 1 highly successful workshop/conference, "Black Holes and Quantum Physics" (January 2009)
- PI Faculty member Freddy Cachazo was awarded the 2009 Gribov Medal from the European Physical Society (EPS)
- PI Faculty member Jaume Gomis received an Early Researcher Award (2009) from the Ministry of Research and Innovation of Ontario

[17] S. Croke, David Menzies. "Noiseless linear amplification via weak measurements." arXiv:0903.4181.
[18] R. Cleve, D. Gottesman, M. Mosca, R. D. Somma, D. L. Yonge-Mallo. "Efficient discrete-time simulations of continuous-time quantum query algorithms." To appear in *Proceedings of the 41st Annual ACM Symposium on Theory of Computing (STOC 2009)*. arXiv:quant-ph/0604141v2.

Highlights

A few research highlights coming out of PI's string group from the past year include the following:

- In two papers, "What is the Simplest Quantum Field Theory,"[19] and "The S-matrix in Twistor Space,"[20] Freddy Cachazo and collaborators at the Institute for Advanced Study (including PI Distinguished Research Chair Nima Arkani-Hamed) found a "holographic" formulation of scattering amplitudes in which locality and thus spacetime itself are emergent. In this formulation the most constrained and therefore the simplest theory in four-dimensions is N=8 supergravity. Dr. Cachazo was invited to present the results of the first paper at Strings08 at CERN.
- In a recent collaboration, Alex Buchel, Rob Myers and Aninda Sinha (PI postdoc) examined possible violations of the famous conjecture of a viscosity bound: $\eta/s \geq 1/4\pi$. In "Beyond eta/s = 1/4 π"[21] they reported that not only did they find that such violations can occur in a controllable setting in string theory but further that they are in fact generic. Various members of the collaboration were invited to speak on these results at a variety of venues, including Harvard, Caltech, KITP, and University of Washington, as well as *Quark Matter 2009*.

Particle Physics

Particle physics, a growing research area at PI, seeks to identify nature's constituents and interactions at the most fundamental level, with an emphasis on comparing theoretical ideas with both terrestrial experiments and astrophysical observations. As such, it has a large overlap with cosmology, since cosmological observations provide one of the only observational windows into the laws of nature at the very high energies that lie beyond the reach of the Standard Model. The field is presently holding its collective breath in anticipation of the long-awaited start of the Large Hadron Collider at CERN that is expected to provide new insights into the nature of the new physics that lies at these high energies.

Summary of Achievements

- 17 papers published
- Held one conference
- Faculty member Cliff Burgess was inducted as a Fellow of the Royal Society, the highest academic honour in Canada

Highlights

Three highlights of last year's research in this area were the following:

- "Fibre Inflation: Observable Gravity Waves from IIB String Compactifications,"[22] by Cliff Burgess and collaborators at Cambridge University, proposed a mechanism for obtaining observably large gravitational waves from the earliest cosmological epoch

[19] Nima Arkani-Hamed, Freddy Cachazo, Jared Kaplan. "What is the Simplest Quantum Field Theory?" Arxiv: 0808.1446[hep-th].
[20] Nima Arkani-Hamed, Freddy Cachazo, Clifford Cheung, Jared Kaplan."The S-Matrix in Twistor Space." ArXiv 0903.2110 [hep-th].
[21] A. Buchel, R. C. Myers, A. Sinha. "Beyond eta/s = 1/4 π." *JHEP* 0903:084, 2009. (arXiv:0812.2521 [hep-th]).
[22] M. Cicoli, C.P. Burgess, F. Quevedo. "Fibre Inflation: Observable Gravity Waves from IIB String Compactifications." *JCAP* 0903:013, 2009. arXiv:0808.0691.

known as inflation within string theory, providing one of only two contemporary mechanisms known for doing so. Next generation telescopes able to perform precise polarization measurements of the cosmic microwave background will be able to test this theory.

- "Astrophysical Signatures of Secluded Dark Matter,"[23] by Maxim Pospelov and collaborators, describes the indirect astrophysical signatures of models of WIMP dark matter, for which the dark matter is "secluded" from ordinary matter. This class of models, which had been proposed earlier by Pospelov, sparked considerable interest through their use by Pospelov and others to describe anomalies in the flux of cosmic-ray positrons, as recently measured by the PAMELA, ATIC and FGST experiments.
- "Naturalness of CP Violation in the Standard Model,"[24] by Gary Gibbons, Steffen Gielen, Chris Pope, and Neil Turok, discovered that a uniform distribution, using a natural measure in the space of CKM matrices (which characterize mixing between different sectors of the standard model of particle physics), leads to a level of CP violation comparable to the observed value. The CP violation is what distinguishes matter from antimatter and is essential to understanding why matter predominates over antimatter in the natural world.

Cosmology

Members of the cosmology group at PI investigate and address some of the most fundamental puzzles in our understanding of the universe. They combine recent developments at the interface of astrophysics and fundamental physics to shed light on some of the major puzzles in the field: What is causing the observed cosmic acceleration? What is the nature of dark matter? What can be learned from microwave background and large scale structure observations about theories of fundamental physics? Is inflation the correct paradigm of early-universe cosmology?

Summary of Achievements

- 31 papers produced
- Held 7 conferences and workshops
- Recruited 5 outstanding Distinguished Research Chairs in Cosmology
- World-renowned Cosmologist Dr. Neil Turok, recruited in FY07-08, officially began as a Perimeter Institute Faculty member in October 2008.
- Recruited two new Faculty members − Latham Boyle and Niayesh Afshordi (cross-appointed at the University of Waterloo)

Highlights

Two notable examples of recent research include:

- "Primordial non-Gaussianity, statistics of collapsed objects, and the integrated Sachs-Wolfe effect,"[25] published in *Physical Review D*, by Niayesh Afshordi and Andrew Tolley, introduced a novel method to predict the effect of deviations from Gaussian initial

[23] Maxim Pospelov, Adam Ritz. "Astrophysical Signatures of Secluded Dark Matter." *Phys.Lett.B* 671:391-397, 2009. ArXiv: 0810.1502.
[24] Gibbons, Gielen, Pope, Turok. "Naturalness of CP Violation in the Standard Model," *Phys.Rev.Lett*.102:121802, 2009. Arxiv: 0810.4368.
[25] Niayesh Afshordi, Andrew J. Tolley. "Primordial non-Gaussianity, statistics of collapsed objects, and the integrated Sachs-Wolfe effect." *Phys.Rev.D* 78:123507, 2008. ArXiv: 0806.1046

conditions on the statistics of galaxies/clusters, and how it leads to unique signatures in observations of large scale structure.

- "The Return of the Phoenix Universe," by Prof. Neil Turok, Paul J. Steinhardt, and Jean-Luc Lehners, was awarded an Honourable Mention in the 60th annual Gravity Research Foundation Essay contest

1.2 Broadening Areas of Research

Increasingly, cutting edge research involves the overlap between several fields: for example, recent discoveries connect condensed matter systems to quantum gravity; quantum phase transitions connect quantum theory to condensed matter and particle physics; and numerical general relativity connects cosmology, quantum gravity, string theory, and even quantum information. While retaining its twin focus on quantum theory and spacetime, PI is therefore broadening its range of research to incorporate complementary insights gained from physics on all length scales: from subatomic, to mesoscopic condensed matter systems, to cosmology, and to complex systems in which many time and length scales are involved.

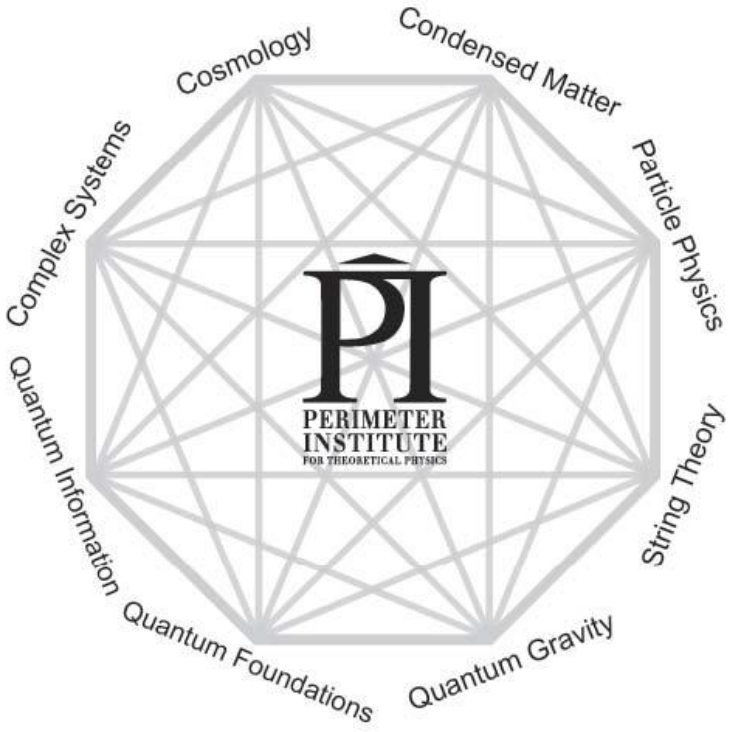


Fig. 1. A single research community gaining complementary insights from eight key fields.

The eight fields above have been carefully chosen to take PI towards critical mass, incorporating expertise over the full spectrum of physics. The Institute may also develop complementary disciplines, especially at the intersections of these fields. The eight established and emerging areas at PI form a whole far greater than the sum of its parts, enabling insights gained from each of these fields to promote progress and innovation in all of them. Furthermore, PI seeks to hire faculty whose research spans more than one field: for example, particle physics phenomenology and cosmology, or numerical general relativity which overlaps with quantum gravity, string theory, cosmology and particle physics, or mathematical and statistical physics

which interface with all eight fields. This strategy greatly magnifies the research strength at Perimeter, an effect that will continue to grow as its research staff increases.

Broadening the range of expertise will enrich and strengthen PI's research, ultimately enabling its relevance to a wider range of applications. This long-term vision ensures that Canada plays a leading role in foundational physics research, and the technologies that may arise from it, over the long term. As the research community builds to critical mass, one can expect an upsurge of innovative, interdisciplinary work which would be impossible within a smaller, specialized institute.

Summary of Achievements

- Additional recruitment in existing and expanding areas including junior Faculty members Latham Boyle (Cosmology) and Pedro Vieira (Strings/Quantum Field Theory); and the co-recruitment of Faculty members Niayesh Afshordi (Cosmology) and Luis Lehner (General/Numerical Relativity) in cross-appointments with the University of Waterloo and the University of Guelph, respectively
- Appointed 11 Distinguished Research Chairs in areas of expansion
- Held "4 Corners–Southwest Ontario Condensed Matter Symposium" (April 23, 2009)

Highlights

<u>New Appointments</u>

Several permanent faculty and Distinguished Research Chair appointments were made in FY08-09 in areas of research expansion and development. (Please note that full information on recruitment appears under Objective 3, while the Distinguished Research Chair program is described in detail under Objective 4.)

Faculty

Dr. **Niayesh Afshordi** will join Perimeter as an Associate Faculty member in Cosmology, and will hold a joint appointment with the University of Waterloo. Dr. Afshordi's research concerns Astrophysics, Cosmology, and the physics of gravity, with particular focus on observational findings that can help address problems in fundamental physics. He is also a member of the PSI Faculty (see further information under Objective 5).

Dr. **Latham Boyle** has confirmed that he will join Perimeter as a junior Faculty Member in Cosmology in January, 2010. He received his PhD in physics in 2006 from Princeton University, under the direction of Paul Steinhardt. Dr. Boyle's research concerns early universe cosmology–the scientific and mathematical study of how the universe began and what took place during the first moments after the Big Bang.

Dr. **Luis Lehner** joined Perimeter as an Associate Faculty member in a joint appointment with the University of Guelph. Dr. Lehner is an expert in numerical general relativity whose work overlaps with several areas of research at Perimeter.

Dr. **Robert Spekkens** joined Perimeter as a Junior Faculty member in the Quantum Foundations program, officially beginning in November 2008. In addition to his accomplishments in Foundations he has also completed notable work in Quantum Information.

Dr. **Pedro Vieira** joins the Institute as a Junior Faculty member in the Strings program. Dr. Vieira's research concerns the development of new mathematical techniques for Gauge and String theories, ultimately aiming toward the solution of a realistic four-dimensional gauge theory.

Distinguished Research Chairs

Prof. **Yakir Aharonov** (Chapman University and Tel Aviv University) has made seminal contributions in quantum mechanics, relativistic quantum field theories and interpretations of quantum mechanics. In 1998, he received the prestigious Wolf Prize for his 1959 co-discovery of the Aharonov-Bohm effect.

Prof. **Nima Arkani-Hamed** (Institute for Advanced Study) is a leading particle physicist who has proposed new theoretical models that can be tested using the Large Hadron Collider (LHC) at CERN. He is also a member of the PSI Faculty (see further information under Objective 5).

Prof. **Neta Bahcall** (Princeton University) is an observational cosmologist who has pioneered quantitative approaches to the understanding of astronomical data, and will strengthen Cosmology research at Perimeter.

Prof. **Juan Ignacio Cirac** (Max Planck Institute of Quantum Optics) is a leading quantum information theorist whose research aims to characterize quantum phenomena, and to develop a new theory of information based on quantum mechanics, work which may ultimately contribute to the development of quantum computers.

Prof. **Gia Dvali** (New York University and CERN) investigates fundamental questions at the intersection between particle physics and cosmology, including quantum gravity, and the very early universe.

Prof. **Stephen Hawking** (University of Cambridge) is the emeritus Lucasian Professor of Mathematics at the Department of Applied Mathematics and Theoretical Physics at Cambridge. In his work, Prof. Hawking seeks to better understand the basic laws which govern the universe.

Prof. **Leo Kadanoff** (University of Chicago) has made major contributions to theoretical condensed matter physics, and complex systems theory (as a pioneer of chaos theory), both developing research areas at PI. He is also a member of the PSI Faculty (see further information under Objective 5).

Prof. **Subir Sachdev** (Harvard University) has made prolific contributions to quantum condensed matter physics, including research on quantum phase transitions and their application to correlated electron materials like high temperature superconductors.

Prof. **Ashoke Sen** (Harish-Chandra Research Institute) is a pioneering string theorist whose many contributions include the famous Sen Conjecture as well as numerous insights about string dualities and entropy in black holes.

Prof. **Leonard Susskind** (Stanford University) is regarded as one of the fathers of string theory, and has also made seminal contributions to particle physics, black hole theory, and cosmology. His current research centers upon questions in theoretical particle physics, gravitational physics and quantum cosmology.

Prof. **Xiao-Gang Wen** (MIT) is an eminent theoretical condensed matter physicist who has proposed new topological phases of matter and explored their applications. Dr. Wen is also a member of the PSI Faculty (see Objective 5).

Objective 2: Expand to provide the world's best environment and infrastructure for theoretical physics research

In order to support its objective of creating the world's best environment for theoretical physics research, and to accommodate the anticipated growth of faculty, research staff, and the research training program, the Institute has embarked upon a major expansion of its facility. $10M in funding has been committed by the Canada Foundation for Innovation (CFI) with matching funds pledged from the Ministry of Research and Innovation (MRI) of the Province of Ontario. In addition, a private investor has been secured.

The 55,000 square foot expansion will more than double the Institute's research and training facilities and is being designed by Governor General Award-winning Teeple Architects. The addition will include 81 research spaces (singles, doubles and multi-user) with individual research stations to accommodate an additional 130 scientists; a large space for up to 50 trainee researchers in Perimeter's PSI training program; 4 new informal interaction areas; and 4 new formal presentation spaces for research seminars and workshops. The expansion will provide the IT infrastructure needed to support advanced research and training, including visualization and analysis of complex calculations and very large data sets, and remote collaboration with international colleagues to reduce the need for arduous and carbon intensive travel. The entire expansion will be seamlessly integrated with the existing facility.

The ambitious expansion, which commenced in July 2009, is critical to realizing the Institute's bold vision of becoming the world's leading research centre in theoretical physics and advancing Canada's scientific role and impact internationally in the knowledge economy. A major focus of 2009-10 will be on executing this major construction project in order to fully realize and sustain the many objectives outlined in this document.

Summary of Achievements

- Developed, refined and finalized detailed architectural plans in accordance with future needs projections
- Followed industry Best Practices to achieve Leadership in Energy and Environmental Design (LEED) standards
- Contracted Ball Construction as primary site manager following competitive bidding process
- Obtained infrastructure investments from CFI and MRI following independent, peer review of proposals. Secured additional private funds toward expansion
- Broke ground on the expansion on July 27, 2009

Highlights

<u>Efficiencies Realized Through Planning</u>

As articulated in previous years' reports, a critical element in PI's strategy as a leading centre for theoretical physics research is to provide a variety of types of research spaces (individual, collaborative, presentation) equipped with state-of-the-art tools that enable researchers to realize maximal research productivity. Given the need to provide this as prudently and cost-effectively as possible, Institute staff assembled a General Design Team (GDT) in FY08-09. The GDT conducted detailed needs assessments, and worked closely with the architects to achieve

maximal utility in the most cost-effective manner possible. The resulting facility will support up to triple the current number of researchers and trainees with only an approximate doubling of the building's footprint. Furthermore, the General Design Team (GDT) followed industry Best Practices to achieve maximal energy efficiency and environmentally responsible design and construction. The design incorporates energy saving technologies and environmentally responsible building materials that will meet, and possibly exceed, LEED Silver certification parameters. This will enable the Institute to realize significant operational and energy cost savings year over year.

Objective 3: Expand the cluster of top resident scientists to critical mass

Perimeter Institute continuously and aggressively recruits researchers of the highest international calibre. The Institute positions itself as a highly attractive destination in the international theoretical physics community by offering a dynamic environment with maximum research freedom, and collaboration opportunities second to none. When feasible, the Institute actively seeks to collaborate with other institutions to recruit outstanding scientific talent, an approach that enables the regional universities to share in the benefits of attracting energetic research 'stars' to Canada.

Summary of Achievements

- Conducted Faculty searches in Quantum Foundations and Cosmology, leading to the appointment of Robert W. Spekkens (August 2008).
- Hired Latham Boyle as a junior faculty member in Cosmology, and Pedro Vieira as a junior faculty member in Strings/Quantum Field Theory
- Co-recruited Luis Lehner (General/Numerical Relativity) as an Associate Faculty member with the University of Guelph and Niayesh Afshordi (Cosmology) with the University of Waterloo, with an additional Associate Faculty hire planned with the University of Waterloo.
- Fostered ongoing discussions with the University of Toronto, McMaster University, the University of Guelph, the University of Waterloo, and the University of Western Ontario on the creation of joint positions.
- World-renowned Cosmologist Dr. Neil Turok, recruited in FY07-08, officially began as Perimeter's new Director in October 2008.
- Recruited 18 new Postdoctoral Fellows
- Attracted 8 new PhD Students
- Recruited 28 Master's students for PSI program

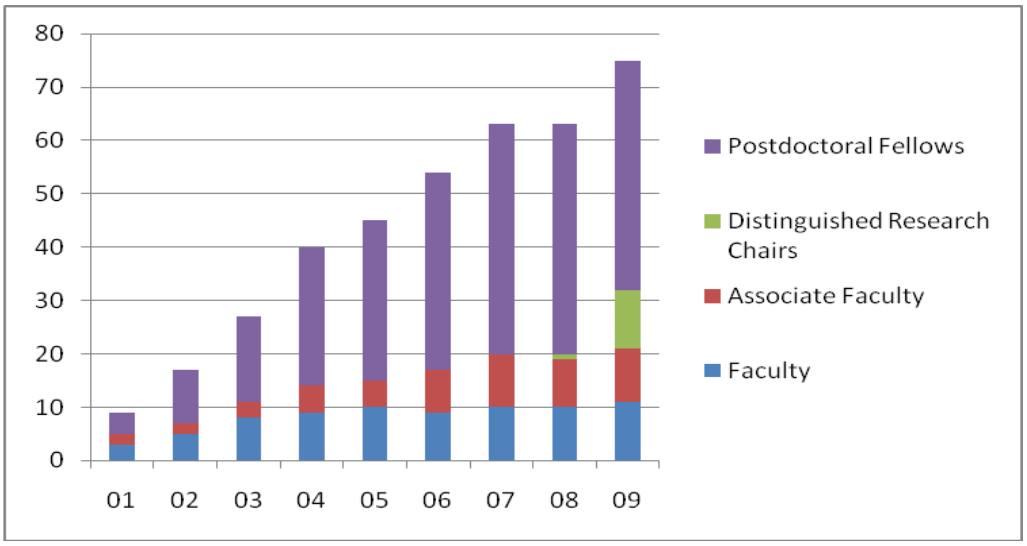


Chart 1. Growth of PI scientific staff and associated researchers since inception, 2001-2009.

Highlights

Faculty Recruitment

Following the successful recruitment of Robert W. Spekkens as a Faculty member (August 2008), the Institute launched two international searches for junior Faculty members in Cosmology and Quantum Information.

The Cosmology search resulted in the successful recruitment of Latham Boyle, currently a Postdoctoral Fellow at the Canadian Institute for Theoretical Astrophysics (CITA). Dr. Boyle is expected take up his position in early 2010. Dr. Pedro Vieira was also successfully recruited as a junior Faculty member in Strings/Quantum Field Theory. Dr. Vieira comes to PI from a Junior Scientist position at the Max Planck Institute (Potsdam), and will take up his position in October 2009.

Perimeter's new Director, Prof. Neil Turok, has of course also joined its faculty, and given his scientific achievements, will strengthen Perimeter's Cosmology group. Dr. Turok previously held the Chair of Mathematical Physics at Cambridge University, where he was also the Director of the Centre for Theoretical Cosmology. He has made numerous scientific contributions to theoretical physics and cosmology, focusing on observational tests of fundamental physics. In the early 1990s, his group showed how the polarization and temperature anisotropies of the cosmic background radiation would be correlated, a prediction which has been confirmed in detail by recent precision measurements. The team also developed a key test for the presence of the cosmological constant, also recently confirmed. With Stephen Hawking, he later developed the Hawking-Turok instanton solutions describing the birth of inflationary universes. Recently, with Paul Steinhardt at Princeton, he has been developing a cyclic model for cosmology, according to which the big bang is explained as a collision between two "brane-worlds" in M-theory. In 2006, Steinhardt and Turok showed how the model naturally allowed the cosmological constant to relax to very small values, consistent with current observations. Steinhardt and Turok co-authored the popular science book *Endless Universe: Beyond the Big Bang*.

Associate Faculty Recruitment

The Associate Faculty program was designed to recruit world-class researchers to Canada and Perimeter through part-time appointments, and it has proved very successful. It has increased the diversity and quality of research activities at the Institute, and strengthened the faculties of our partner universities in Canada.

Luis Lehner (General/Numerical Relativity) was hired as an Associate Faculty member in a collaborative recruitment effort with the University of Guelph. Dr. Lehner is a pioneer of modern efforts to extract definite predictions for the behaviour of black holes and other strongly gravitating systems from Einstein's equations. With observational tests using gravitational wave astronomy expected in the near future, Dr. Lehner's recruitment positions Perimeter to become a leading centre in this field.

In October 2008, Perimeter reached an agreement with the University of Waterloo to hire two new Associates in Cosmology. The search resulted in offers being made to two excellent candidates. Niayesh Afshordi, formerly a postdoc at PI, accepted the first position and will

formally begin his new role on September 1, 2009. We hope to be able to report a second successful outcome within the expected timeline of three years.

Postdoctoral Fellows

Perimeter had an extremely successful postdoctoral recruitment season, with 18 of the brightest young researchers across PI's fields of research chosen from a field of over 400 applicants. These junior researchers will be moving to PI from leading institutions including Oxford, Cambridge, ETH (Zurich), Kavli Institute of Theoretical Physics (Santa Barbara), and Caltech among others.

PI's success is also marked by placement of postdoctoral fellows into permanent positions following their three-year terms at PI. Within the last year, for example, in the Quantum Gravity group alone, six of the Institute's recent Postdoctoral Fellows were offered faculty positions (Bianca Dittrich, Sabine Hossenfelder, Catherine Meusburger, Daniele Oriti, Parampreet Singh and Simone Speziale).

Graduate Students

8 new PhD and 2 new Master's students arrived in FY08-09. The graduate program at PI offers excellent students advanced research training, and unparalleled opportunities to interact with, and learn from, top resident and visiting physicists from around the world. Mentorship is provided by PI Faculty or Associate Faculty members, and, in some cases, graduate students of Visiting Researchers may also spend a considerable amount of the year at PI. Since PI is not a degree-granting institution, students must also be enrolled at a university. In many cases, the university at which the student is enrolled is near Waterloo, but students have also come to PI from the University of Pisa, Princeton, Max Planck, and the University of Winnipeg, to name a few.

There are 28 PhD and 5 Master's students currently in residence at PI, with plans to expand these numbers significantly in the coming years, in tandem with faculty growth. In addition to the aforementioned students, the new PSI program attracted a further 28 Master's students. PSI has been strategically designed to facilitate a new flow of top Master's graduate students from around the world to PI and to Canada (see Objective 5). Some of these exceptional students will undoubtedly pursue advanced training at Perimeter.

Notably, Perimeter's PhD students have successfully obtained continuing postdoctoral positions at elite institutions including the Kavli Institute at UCSB (USA), the Max Planck Institute (Germany), Kinki University (Japan), and the Institute for Theoretical Physics at Utrecht University (Netherlands), as well as top Canadian institutes such as University of Waterloo and Carleton University.

Objective 4: Fully establish its Distinguished Research Chairs program

Past experience shows that when complementary insights are brought to bear and critical mass is reached, major advances are possible. With this in mind, Perimeter Institute established the Distinguished Research Chairs program in FY08-09 to bring additional world-class researchers to the Institute for extended research stays at PI, typically for over a month each year. The appointments are for three years. As PI grows, it plans to reach a steady state of 30 Distinguished Research Chairs.

In November 2008, Prof. Stephen Hawking was announced as Perimeter's first Distinguished Research Chair, followed by an additional nine Chairs announced just 3 months later, and one more in July (full list below).

This program is expected to yield enormous dividends scientifically. The presence of the Distinguished Research Chairs will spark new scientific collaborations, and provide invaluable guidance to the Institute's resident researchers, as well as mentorship to our students.

In a larger sense, the program will also help to raise Canada's stature as a leader in science able to build our "people advantage" with international superstars in science. The announcement, for example, that Prof. Stephen Hawking would be coming to Canada for extended periods each year made national and international headlines, and effectively showcased Canada as one of the top research destinations in the world.

Summary of Achievements

- Garnered worldwide attention with the announcement of the first Distinguished Research Chair, Prof. Stephen Hawking, in November 2008
- Appointed an additional 10 eminent international researchers to the new Distinguished Research Chair program, nine in February 2009 and one more in July:
    - Yakir Aharonov, Chapman University and Tel Aviv University
    - Nima Arkani-Hamed, Institute for Advanced Study
    - Neta Bahcall, Princeton University
    - Juan Ignacio Cirac, Max Planck Institute
    - Gia Dvali, New York University and CERN
    - Leo Kadanoff, University of Chicago
    - Subir Sachdev, Harvard University
    - Ashoke Sen, Harish-Chandra Research Institute
    - Leonard Susskind, Stanford University
    - Xiao-Gang Wen, Massachusetts Institute of Technology

Highlights

<u>Appointment of Prof. Stephen Hawking as First PI Distinguished Research Chair</u>

"I am honoured to accept the first Distinguished Research Chair at the Perimeter Institute..."

- Prof. Stephen Hawking

In November 2008, PI announced the appointment of internationally regarded scientist Prof. Stephen Hawking to the position of PI Distinguished Research Chair. His commitment to Perimeter is further demonstrated by the fact that he has also agreed to be a Patron of the new Perimeter Scholars International (PSI) program (see Objective 5).

Stephen Hawking has held the post of Lucasian Professor of Mathematics at the Department of Applied Mathematics and Theoretical Physics at Cambridge since 1979, and, independent of his new role at PI, recently announced that he will step down from this position in keeping with university policy.

In his work, Prof. Hawking seeks to better understand the basic laws which govern the universe. With Roger Penrose he showed that Einstein's General Theory of Relativity implied space and time would have a beginning in the big bang and an end in black holes. These results indicated it was necessary to unify general relativity with quantum theory, the other great scientific development of the first half of the 20th century. One consequence of such a unification that he discovered was that black holes should not be completely black, but should emit radiation and eventually evaporate and disappear. Another conjecture is that the universe has no edge or boundary in imaginary time. This would imply that the way the universe began was completely determined by the laws of science.

Stephen Hawking has three popular books published: his bestseller *A Brief History of Time*, as well as *Black Holes and Baby Universes and Other Essays* and most recently in 2001, *The Universe in a Nutshell*.

Prof. Hawking has twelve honorary degrees, was named a Commander of the British Empire in 1982, and was made a Companion of Honour in 1989. He is the recipient of many awards, medals and prizes and is a Fellow of The Royal Society and a Member of the US National Academy of Sciences.

Objective 5: Recruit the world's most promising graduate students and prepare them for cutting edge research via Perimeter Scholars International (PSI)

In December 2008, the Institute began developing Perimeter Scholars International (PSI), a new 10-month Master's level training course designed to bring some of the best young scientific talents in the world to Perimeter at the earliest stage of their research careers. This major initiative is a collaborative effort with partnering Canadian universities. The nearby University of Waterloo is the primary partner and will grant Master's degrees to the students upon completion, in addition to a Perimeter Scholars International Certificate from PI. Over time, PSI hopes to attract and train 50 highly qualified persons per annum, helping to seed Canada's high-skills community. The program will bring a flow of exceptionally talented students to PI and Canada; top students graduating from PSI will be recruited for further PhD studies at PI.

PSI is designed to bring talented students rapidly to the cutting edge of theoretical physics, transforming them into young researchers. The innovative syllabus will expose students to the full spectrum of theoretical physics through short courses to be taught, two or three at a time, in three-week modules by visiting lecturers. Several dedicated professional tutors will guide the course and provide continuity throughout.

The inaugural PSI recruitment effort attracted over 220 applications from around the world. A pilot class of 28 outstanding research-trainees from 17 countries, including 6 women, has been coordinated, and sessions will begin in August 2009.

Summary of Achievements

- Planned Perimeter Scholars International (PSI) to train the next generation of young researchers, including recruitment for launch of the program in summer 2009.
- Prof. John Berlinsky, an eminent condensed matter physicist from McMaster University, was recruited as the program's Academic Director.
- Several of the world's most distinguished theoretical physicists agreed to be patrons of the innovative program, including Stephen Hawking, Yakir Aharonov, Philip Anderson, James Bjorken, James Peebles and Sir Roger Penrose. They have committed to visiting PI once per year to interact with the PSI students.
- Recruited a first class of 28 exceptional candidates from a field of over 220 applicants.

Highlights

<u>PSI Faculty</u>

One of the most innovative aspects of the PSI program is the fact that its syllabus will be taught by top visiting scientists who come to Perimeter for several weeks to teach in the areas of their greatest expertise. This enables Perimeter to offer outstanding training across the entire spectrum of theoretical physics through a virtual "dream team" of faculty comprising many of the world's top physicists. As many of the leading scientists conduct research collaborations of their own at PI, their participation in PSI is able to take place in an extremely cost-effective manner.

It is worth highlighting this outstanding group of leading scientists from PI and top centres around the world who have agreed to contribute their knowledge to PSI as lecturers.

They include:

- Niayesh Afshordi (Perimeter Institute)
- Ben Allanach (Cambridge University)
- Philip Anderson (Princeton University)
- Nima Arkani-Hamed (Institute for Advanced Study)
- Katrin Becker (Texas A&M University)
- Melanie Becker (Texas A&M University)
- Carl Bender (Washington University)
- Freddy Cachazo (Perimeter Institute)
- Matt Choptuik (University of British Columbia)
- Sue Coppersmith (University of Wisconsin at Madison)
- David Cory (MIT)
- Kari Dalnoki-Veress (McMaster University)
- François David (Institut de Physique Théorique, CEA-Saclay)
- Jaume Gomis (Perimeter Institute)
- Daniel Gottesman (Perimeter Institute)
- Ruth Gregory (Durham University)
- Leo Kadanoff (University of Chicago)
- Luis Lehner (Perimeter Institute, University of Guelph)
- Renate Loll (Universiteit Utrecht)
- Rob Myers (Perimeter Institute)
- Hiranya Peiris (Cambridge University)
- Malcolm Perry (Cambridge University)
- Michael Peskin (Stanford Linear Accelerator Center)
- Frans Pretorius (Princeton University)
- Sid Redner (Boston University)
- Anders Sandvik (Boston University)
- Erik Sorensen (McMaster University)
- Robert Spekkens (Perimeter Institute)
- Andrew Tolley (Perimeter Institute)
- David Tong (Cambridge University)
- Neil Turok (Perimeter Institute)
- Xiao-Gang Wen (MIT)

Perimeter's ability to recruit such eminent lecturers for a new Master's program is strong evidence of the Institute's excellent reputation internationally, and the excitement that this innovative approach to research training has generated throughout the international scientific community.

Objective 6: Engage with experimental and observational centres

The interconnections between theoretical, observational and experimental physics are as vital as ever. The recent discovery of dark energy through observational data, for example, has raised far-reaching questions to be answered by theorists. Similarly, upcoming experiments at the Large Hadron Collider (LHC) at CERN are expected to yield fundamental new insights into theoretical models of matter's basic constituents. (Indeed, PI faculty member Freddy Cachazo recently won the Gribov Medal of the European Physical Society for his contributions to simplifying the theoretical calculations essential to the design and interpretation of LHC and other accelerator experiments—see Objective 12).

Perimeter is well positioned to take advantage of these developments. A prime example is PI's long-standing and synergistic relationship with the nearby Institute for Quantum Computing (IQC) at the University of Waterloo, which has helped to propel Canada to world leadership in the emerging science of quantum information. Perimeter has likewise forged strong ties with the Canadian Institute for Theoretical Astrophysics (CITA), Canada's world-class centre in theoretical astrophysics, that position it well for key upcoming data from gravitational wave detectors and space-based telescopes.

The Institute is expanding its engagement with applied and experimental programs regionally, nationally, and internationally. The Institute is initiating discussions aimed at establishing linkages with experimental and observational centres such as the LHC, SNOLab, and the Planck satellite; VISTA, VLT, the SKA and other giant observatories; and LIGO, LISA and other gravitational wave detectors. By encouraging PI postdoctoral fellows and other researchers to visit these facilities and collaborate with observers and experimentalists, PI can help to stimulate new experimental and observational tests of fundamental theory, making its science more relevant and important.

Summary of Achievements

- Further developed ongoing research engagement with the Institute for Quantum Computing and CITA
- Appointed several eminent scientists with key roles in observational/experimental research as PI Distinguished Research Chairs

Highlights

<u>Research Engagement with IQC</u>

PI researchers are deeply engaged with colleagues at the Institute for Quantum Computing (IQC) at the University of Waterloo—indeed, founding PI faculty member Raymond Laflamme is the Director of IQC. The many productive PI-IQC research interactions have helped to make Canada a world leader in the emerging science of quantum information processing.

PI's focus on foundational issues in quantum information is entirely complementary to IQC's experimental and applied research, and scientific progress noted under Objective 1 furnishes numerous examples of joint research. PI's collaborative engagement with IQC accelerates research, enables young researchers to be trained in both theory and experiment, and

magnifies research impact. One illustrative recent example is the “Triple Slit Test” of quantum mechanics by PI founding faculty member and IQC Director Raymond Laflamme, PI researcher Rafael Sorkin, and collaborators. The experiment, still ongoing, tests Sorkin’s 1994 proposal on quantum mechanical theory, which raised the possibility of three-way interference. Another example is the experimental quantum cryptographic apparatus that literally ties the two Institutes, in which a source of entangled photon pairs located on the roof of a building on the University of Waterloo campus sends one of the entangled photons to a receiver located at PI, and another to a receiver at IQC, enabling distance-dependent tests of entanglement and other fundamental quantum mechanical principles. Finally, since June 2009, PI has hosted visiting scientist Dr. David Cory, a world-leading researcher in the field of nuclear magnetic resonance, who is developing a close collaboration with IQC researchers.

DRC Links to Experiment

Several of the Distinguished Research Chair appointments made in FY08-09 are expected to be important in the coming years as PI deepens its engagement with observational and experimental centres. Prof. Nima Arkani-Hamed, of the Institute for Advanced Study, will be a key figure in the analysis of data coming from the LHC. Likewise, PI Distinguished Research Chair Neta Bahcall is a leading observational cosmologist with long-standing ties to NASA’s key observational resources, including the Hubble Space Telescope and the James Webb Space Telescope, NASA's next orbiting observatory and the successor to the Hubble Space Telescope. Her presence at PI will strengthen the Institute’s connections with the observational cosmology community.

PI /CITA Partnership

Perimeter continued to foster its partnership with the Canadian Institute for Theoretical Astrophysics (CITA) in Toronto. CITA’s research strengths in observational cosmology, particularly data analysis, complement PI’s focus on fundamental cosmological theory and the development of new observational tests. This complementarity has led to fruitful research interactions, exemplified by the ongoing series of PI/CITA workshops held at least twice yearly.

Objective 7: Host timely, focused conferences, workshops, seminars and courses

Perimeter Institute recognizes that a lively program of high-level conferences, workshops, seminars and courses is essential to maintaining a dynamic research centre that stimulates research results and innovation.

7.1 Conferences and Workshops

PI's flexibility, combined with the goodwill it has generated among the global theory community, places it in an excellent position to host exciting gatherings in cutting-edge fields. However, PI is not a conference centre; rather, it chooses topics of workshops and conferences strategically, by identifying new areas of exceptional promise where an event is likely to have a significant outcome. The major focus is on workshops that do not happen anywhere else—gatherings of top people discussing the hottest topics.

Not all conferences, workshops and summer schools are held on-site. PI also partners with several Canadian and international organizations, or sponsors specific events, as part of its conference program. These arrangements allow the organizations to share resources, target regional research groups and build scientific progress by creating cooperative, rather than competitive, events.

In the past year, 18 different conferences, workshops and summer schools were held at PI, drawing almost 900 attendees. Additionally, 9 events held off-site were supported by sponsorship or partnership.

Summary of Achievements

- 18 conferences and workshops held, including five events in research areas under development at PI, or in multidisciplinary areas
- 1 student-oriented conference held
- 881 scientists attended PI conferences and workshops
- Partnered on 4 joint workshops with surrounding universities (detailed in Objective 9)
- Sponsored or partnered in 9 off-site conferences and symposia
- All on-site conferences and talks were recorded online as an ongoing resource for the international scientific community

Highlights

Quantum Estimation: Theory and Practice (August 25 - 30, 2008)

Quantum estimation techniques (broadly known as "tomography") are increasingly important to quantum information science. This workshop brought together leading experts in quantum theory, including experimentalists, theorists, mathematicians, and statisticians, to establish the state of the art in quantum state/process estimation. All talks can be viewed online at: www.pirsa.org/C080200**.**

Black Holes and Quantum Physics (January 23 - 25, 2009)

Recent advances made in describing quantum black holes were the impetus for this gathering of 24 experts from fields including quantum gravity, quantum information and string theory. Highlights included talks by Rafael Sorkin, and a remote presentation by Don Marolf of the University of California Santa Barbara (UCSB) on unitarity and holography in gravitational physics, delivered very successfully via video link. The link allowed for outstanding interactivity between the presenter and participants, and it is hoped that it will lay the foundation for similar collaborative activities with UCSB and other centres in the future. All talks can be viewed online at: www.pirsa.org/C09002.

Connections in Geometry and Physics (May 8 - 10, 2009)

This workshop gathered researchers from Canada and around the world working at the interface between geometry and physics, in order to increase Canada's presence and visibility in geometry in the wider international mathematical community, and to bring together geometers in the region with common interests. With 18 invited speakers and 64 participants, the conference's secondary aim of strong graduate student participation was also achieved. All talks can be viewed online at: www.pirsa.org/C09007.

New Lights on Dark Matter (June 11 - 13, 2009)

This workshop focused on recent experimental and theoretical results in the field of dark matter. Interest in this topic is high, since recent astrophysical signals from cosmic rays may be providing indirect evidence of the non-gravitational interactions of dark matter particles. The workshop was by all measures a success with many top theorists working in the area, including Dan Hooper (Fermilab), Alessandro Strumia (INFN-Pisa), and Maxim Pospelov (Perimeter Institute) attending. There were also presentations from representatives of several experimental collaborations, including PAMELA, who reported on their results and prospects, giving local Canadian physicists access to experimentalists. All talks can be viewed online at: www.pirsa.org/C09012.

Summer School: Exploring the Cosmological Frontiers (June 24 - July 1, 2009)

More than 50 graduate students from around the world took part in the seventh edition of this annual Canadian summer school for theoretical physics. Students attended courses on Early Universe Cosmology, from the theoretical (Paolo Creminelli and Jean-Luc Lehners) to the observational (Olivier Dore), on Dark Matter (Neil Weiner) and on Gravitational Wave Astronomy (Alessandra Buonanno). Jointly organized with the Asia Pacific Center for Theoretical Physics and the Centre for Quantum SpaceTime, this year's theme was "Exploring the Cosmological Frontiers." Students heard guest lectures from several visiting faculty, including Distinguished Research Chair Neta Bahcall, and PI Director Neil Turok. Several students also organized talks on their own research, gaining valuable presentation experience. All lectures can be viewed online at: www.pirsa.org/C09013.

Holographic Cosmology (June 22 - July 24, 2009)

Holography is one of the most powerful ideas to emerge in recent years from String/M-theory, and has led to a radical new approach to quantum gravity, combined with a remarkably powerful calculational tool. This was the first workshop on this exciting new area, and many leading scientists (e.g., Das, Craps, Lawrence, Creminelli, Nicholis, etc.) came to PI to attend for time

periods ranging from a few days to weeks. The four-week workshop brought together leading researchers working in cosmology, string theory and quantum gravity in order to understand and develop the implications of holography for the cosmology of the early universe. All talks from this conference can be viewed online at: www.pirsa.org/C09015 (conference) and www.pirsa.org/C09014 (workshop).

7.2 Seminars and Colloquia

Perimeter's eight active weekly seminar series continued to foster collaborations in Canada and disseminate knowledge from leading researchers around the globe. All talks can be viewed on PIRSA, the Perimeter Institute Recorded Seminar Archive.

Summary of Achievements

- Presented 199 scientific talks (172 seminars; 27 colloquia) in FY08-09.
- Continued to develop PIRSA (Perimeter Institute Recorded Seminar Archive) as a leading international scientific archive resource for recorded seminars.

Highlights

Distinguished Speakers

Speakers over the past year included such eminent scientists as Sir Michael Berry (University of Bristol), Xiao-Gang Wen (MIT), Raphael Bousso (University of California), Ramesh Narayan (Harvard), Leo Kadanoff (James Franck Institute), Abhay Ashtekar (Pennsylvania State University), Pedro Vieira (Max Planck Institute for Gravitational Physics) and many others.

PIRSA (Perimeter Institute Recorded Seminar Archive)

Launched in 2008 and growing steadily since, PIRSA is a permanent, free, searchable, and citable archive of video recorded seminars, conferences, workshops, and courses developed by Perimeter Institute to foster knowledge sharing and deliver the most recent research to the international scientific community.

PIRSA continues to grow as a key resource for building Canada's knowledge advantage and interfacing with scientists worldwide by enabling students and researchers to view PI's scientific events on demand. In the past fiscal year, 33,359 unique visitors from 136 countries accessed PIRSA 63,166 times. During the first four months of 2009, traffic increased nearly 60% over the same period last year, indicating that PIRSA is playing an increasingly valuable role as a digital focal point for the international scientific community.

7.3 Courses

The Institute offers credit courses at both the undergraduate and graduate levels in collaboration with surrounding universities, as well as special topic courses delivered by distinguished visiting scientists. All courses are recorded and made available for viewing on the PIRSA archive.

Summary of Achievements

- Delivered 5 high-level courses in collaboration with surrounding universities
- Provided summer internships to 5 undergraduate students

Highlights

Advanced Courses

Highlights from the courses offered this past year included a high-level short course taught by Pedro Vieira of the Max Planck Institute for Gravitational Physics (Germany); an advanced graduate course taught by PI Faculty member Freddy Cachazo, a leading string theorist; and a course on string theory taught by Associate Faculty member Alex Buchel (University of Western Ontario and PI), all of which were delivered remotely via AccessGrid to students at several area universities.

Courses attracted students from among the 8 regional universities, in person and remotely via AccessGrid technology. In addition, senior PI postdoctoral researchers taught advanced undergraduate and graduate level courses on some of the most exciting ideas in research. Niayesh Afshordi and Mark Wyman taught a course on Astrophysics and Cosmology, and Volodya Miransky (University of Western Ontario) taught an advanced course on quantum field theory.

Undergraduate Student Internships

In this successful ongoing program, Perimeter postdoctoral fellows developed 2-4 month research projects requiring the assistance of an undergraduate student. Five projects with corresponding top international undergraduate students were selected in 2008, giving these students invaluable training in scientific research.

Objective 8: Increase its role as Canada's focal point for foundational physics research

Prior to the establishment of PI, Canada was one of the few developed countries that did not have an obvious and established focal point for foundational theoretical physics research. Perimeter has taken definite steps to become this centre by developing partnerships with Canadian research universities to attract and retain the best established researchers and develop the top young minds that will be future innovators.

PI facilities are accessible to the Canadian theoretical physics community through a variety of programs, most of which have already been described in other sections of this document. These include the Affiliate program (described below), facilitating visits of faculty from across Canada; the conference/workshop program, which not only offers outside researchers the opportunity to use facilities and staff to organize meetings at PI, but also brings many major international meetings to Canada for the first time; the long-term visitors program (described in Objective 12), which facilitates sabbatical leaves at PI and encourages international visitors to teach mini-courses for the training of graduate students in the region; PIRSA, which makes all PI research activities available digitally; and the PSI program, which will facilitate a new flow of top graduate students from around the world to PI and to Canada.

Summary of Achievements

- Recruited 25 new Affiliate Members, forging links across the country by encouraging members to visit and increasing scientific collaborations and ties with Perimeter researchers.
- Delivered on-site courses remotely via AccessGrid to students at several area universities.
- Expanded internet capabilities to improve access to online collaboration, and installed new AV equipment for high quality transmission of lectures.
- Co-recruited Luis Lehner (General/Numerical Relativity) as an Associate Faculty member with the University of Guelph and Niayesh Afshordi (Cosmology) with the University of Waterloo, with an additional Associate Faculty hire planned with the University of Waterloo. (see Objective 4)
- Fostered ongoing discussions with McMaster University, the University of Guelph, the University of Waterloo, and the University of Western Ontario on the creation of joint positions.

Highlights

<u>Affiliate Recruitment</u>

25 new Affiliate Members were added in 2008-09, bringing the total to 92 Affiliate Members drawn from universities across Canada. Perimeter's Affiliate program has become an important resource for the national physics community, adding to the critical mass of first rate researchers, and increasing research activity and productivity nationally. The appointments, from across Canada, include Andrzej Czarnecki (University of Alberta), Keshab Dasgupta (McGill University), Stephen Godfrey (Carleton University), Sung-Sik Lee (McMaster University), Randy Lewis (York University), Manu Paranjape (University of Montreal), Ue-Li Pen (University of

Toronto-CITA), David Poulin (Université de Sherbrooke), Veronica Sanz-Gonzalez (York University), and Achim Schwenk (TRIUMF), among many others.

Technological Access

Many courses offered at PI are open to students from regional universities who can attend in person or via AccessGrid. Several courses were delivered remotely in FY08-09 via AccessGrid to students at several area universities including a high-level short course taught by Pedro Vieira of the Max Planck Institute for Gravitational Physics (Germany) and an advanced graduate course taught by PI Faculty member Freddy Cachazo.

During this past year, PI's IT department undertook research and planning to ensure that the Institute remains on the cutting edge of IT-enabled long-distance collaboration, Internet access, and high quality capture and archiving of lectures, events, and educational resources. Specific actions taken included the expansion of PI's Internet bandwidth capability to a 100Mbps connection, and installation of Audio/Visual equipment to support High Definition capture of lectures and content for the new PSI program (see Objective 5). This system is being used as a test-bed for an expansion of PI's live web streaming capabilities that will be spearheaded at the *Quantum to Cosmos Festival* (see Objective 11). The resulting best practices will guide future decisions on distance collaboration approaches, further enhancement of PIRSA, and equipment procurement for our building expansion.

Objective 9: Develop collaboration agreements and partnerships

Perimeter has developed a number of strategic partnerships both within Canada and at an international level. These partnerships are manifested through official inter-institution agreements, jointly held scientific conferences and workshops, scientific exchange visits, collaboration on advanced training, jointly recruited postdoctoral researchers, etc. These linkages with international research groups enhance the research activities both at Perimeter and abroad and have raised the calibre of research in the broader Canadian community, helping position Canada at the leading edge of global science and technology.

Summary of Achievements:

- Developed a new partnership with the Asia Pacific Center for Theoretical Physics
- Finalized a collaborative agreement with the University of Cambridge Centre for Theoretical Cosmology (CTC)
- Further developed ongoing Perimeter Institute − Australia Foundations Collaboration (PIAF) with three leading Australian universities
- Co-organized, sponsored or partnered in 15 national and international conferences
- Sponsored 7 awards, prizes, and scholarships
- Partnered on 4 joint workshops with surrounding universities

Highlights

New Partnership with the Asia Pacific Center for Theoretical Physics

In 2009, Perimeter Institute signed an agreement with the Asia Pacific Center for Theoretical Physics to encourage collaborative research at the two institutions. The agreement provides for faculty members and postdoctoral fellows to conduct scientific exchange visits, and to jointly sponsor annual workshops in theoretical and mathematical physics.

Collaborative Agreement with the University of Cambridge

This year, Perimeter Institute finalized a partnership agreement with the Centre for Theoretical Cosmology (CTC) at Cambridge University to encourage collaborative research at the two institutions. The agreement provides for faculty members and postdoctoral fellows to conduct regular scientific exchange visits of up to several months.

Perimeter Institute − Australia Foundations Collaboration (PIAF)

The ongoing PIAF partnership between PI and the University of Sydney, the University of Queensland, and Griffith University is a strategic effort to strengthen the field of quantum foundations. It has held two conferences and workshops, created a scientific exchange program, and sponsored four new postdoctoral training positions, with research fellows spending part of their time in Australia and part of their time at PI. Both Canada and Australia have emerged as hubs of scientific activity in quantum foundations and the closely related areas of quantum information and quantum computing. By providing support for new researchers dedicated to the area of quantum foundations, the PIAF partnership will catalyze new discoveries in this strategically important area.

PI/C-QUEST/Asia Pacific Center for Theoretical Physics Partnership

In this ongoing partnership with the Pacific Institute for the Mathematical Sciences (PIMS) at UBC, Perimeter organizes an annual summer school to introduce Canadian and international graduate students to cutting-edge topics in theoretical physics research. The 2009 summer school, "Exploring the Cosmological Frontiers," the seventh in the series, focused on early universe cosmology and was held at PI from June 24–July 1, 2009 in conjunction with the Asia-Pacific Center for Theoretical Physics and the Center for Quantum Spacetime (C-QUEST).

Debates in Cosmology Partnership

Debates in Cosmology is a partnership between Perimeter Institute, Columbia University, and the University of North Carolina to organize a series of conferences to focus on key outstanding issues in cosmology and foundational physics. The first of these conferences, *Origins of Time's Arrow,* was held in October 2007 at the New York Academy of Sciences in New York City. The second, called *The Multiverse*, was hosted at Perimeter in September 2008.

PI /APC/Solvay Institute Partnership

This partnership with the Laboratoire Astroparticule et Cosmologie (APC) and the Solvay Institute (Brussels) was developed to jointly organize a series of informal workshops to discuss and exchange ideas on recent developments at the interface of modern cosmology and fundamental physics. The third *Cosmological Frontiers in Fundamental Physics* workshop was held at the Solvay Institute in Brussels in May 2009, and the next workshop will be held at Perimeter in 2010.

PI/University of Guelph/McMaster/University of Toronto Partnership

The *4-Corners Southwest Ontario Condensed Matter Symposium* (April 23, 2009) was hosted at Perimeter to encourage interactions between condensed matter physicists from four major research groups in southern Ontario, i.e., University of Guelph, McMaster University, University of Toronto, and University of Waterloo. In addition to seminars by local researchers, keynote seminars were given by leading international researchers. The event was also part of PI's commitment to furthering the development of condensed matter at PI, as set out in Objective 1.

PI/AARMS/TPI-Alberta/WITP/CITA/IPP/CINP/INTRIQ co-sponsorship

Theory Canada 5 (June 3-6, 2009; held off-site) was the fifth of a series of annual conferences organized by the Division of Theoretical Physics of the Canadian Association of Physicists. The conferences are held annually, immediately preceding the CAP Congress, and this year the host institute for the 2009 conference was University of New Brunswick. The event enabled researchers to get together and interact with colleagues from across Canada as well as from across the spectrum of theoretical physics.

Objective 10: Support the emergence of innovative centres of excellence promoting high level math and physics across the developing world

Perimeter believes that the Government of Canada's sound investment to date in the Institute can, and in fact should, be further leveraged by sharing with the developing world what it has done so successfully at home − building prosperity by investing in world-leading scientific research and training facilities such as Perimeter. PI's Director Neil Turok has key expertise in this area, having founded the African Institute for Mathematical Sciences (AIMS), a successful and widely-lauded initiative which garnered him a TED Prize in 2008. Given Perimeter's leadership, its institution-building experience, its many partnerships around the world, and the very international character of its research community, it is well placed to lead a "Smart Aid" effort for Canada.

Summary of Achievements:

- Developed "Smart Aid" plan

Highlights

Smart Aid Proposal

The Institute recently submitted a proposal to the Government of Canada which outlines a plan to help unleash the potential of Africa by assisting with the establishment of centres of excellence in science and math across the continent. Such centres can play a pivotal role in expanding science and technology capacity by promoting the emergence of highly skilled people, while generating a two-way flow of scientific talent between Canada and developing nations. PI proposes to coordinate the involvement of academic partners in both developed and developing countries, and to share its knowledge and expertise with the appropriate Canadian international aid agencies, such as CIDA, IDRC and others, to ensure a sound, high impact investment and provide a high visibility opportunity for Canada. If adopted, this initiative will put Canada at the forefront of international Smart Aid efforts and contribute to branding the country internationally as a knowledge nation.

Objective 11: Continue to build its highly regarded outreach program

Educational outreach is a core component of Perimeter Institute's mission and has been since inception. Scientific outreach can do much to nurture a culture of innovation from the ground up, by conveying scientific principles in understandable terms, by helping to develop reasoning and problem solving skills, and by demonstrating the links between basic research and innovation. The Institute's unique and award-winning outreach programs have become an international model for sharing the excitement and importance of basic research, and the power of theoretical physics.

PI is continuously refining its outreach activities to increase impact and scale content to maximize the number of people reached. The broad range of activities can be categorized into those targeting students, teachers and the general public, many of which have benefited from national and international partnerships.

11.1 Programs for Students

Re-focused initiatives for students include the development and distribution of inspirational content that better shares the overall importance of theoretical physics. At the same time, efforts to scale content have been initiated, such that the Institute will be able to reach greater numbers of students over the coming years, particularly throughout Canada. Much of this has been accomplished through partnerships with leading provincial and national education groups. The content for students is also being versioned digitally for the web, making it possible to efficiently reach vast numbers of youth throughout the world.

Summary of Achievements

- Held the International Summer School for Young Physicists (ISSYP) for 77 elite Canadian and international high school students.
- Reached 2,065 students across Canada through "Physica Phantastica" presentations.
- Initiated 5 new web-based content enhancements to better serve youth.

Highlights

International Summer School for Young Physicists (ISSYP)

In refining its flagship summer program for advanced students, the Institute attracted several hundreds of applications (as planned), and chose to focus on the top 77 young people from across Canada and around the world who expressed an intention of pursuing post-secondary physics. This was a test-run of a 'quality over quantity' approach: selecting students who have already shown a strong affinity and talent for science instruction at a higher level, thereby better preparing these students for post-secondary studies, and providing an early introduction to an elite research environment they may one day wish to join. This year's ISSYP lasted for two weeks and included advanced lessons on modern physics, mentoring sessions with researchers and an introduction to experimental physics through lab tours at the Institute for Quantum Computing and SNOLab. The progress of these scientifically-inclined young people (aged 16-17) will be tracked over time.

Physica Phantastica

Enrichment activities for high school students were held on location in classrooms and at large science fair gatherings in Canada. Over 2,000 students from all parts of Canada were reached in face-to-face settings with highly trained PI Outreach staff.

At the same time, new and inspirational content was tested and introduced to intermediate level students. In particular, "The Physics of Innovation" presentation was completed. This PowerPoint talk, which features images and animations to make abstract ideas come alive, helped thousands of students understand important connections between fundamental knowledge and technological innovations. By request, PI gave this presentation to large numbers of youth at the nation's Tulip Festival in Ottawa, and at the Canada Wide Science Fair in Winnipeg, both held in May 2009. Due to popular demand, all of the elements (including the images, animations and video) were also made available to educators with an accompanying teacher guide. This way, the inspirational lesson can be widely shared with additional students – part of the *Perimeter Explorations* in-class module series for use by teachers, further described later in this document.

Enhanced Web-based Content for Youth

In 2008, PI outreach began to enhance its online offerings, in accordance with feedback to (a) provide short, inspirational content for Canadian youth that introduces the importance of modern physics, and (b) better leverage existing content through digital means for the benefit of international audiences.

Improvements (finished or nearing completion) include:

- "Meet a Scientist" video interviews aimed at young people curious about pursuing scientific careers. The videos are linked to additional detailed information on specific research areas.
- A '60 Second Science' series, known as "Alice & Bob in Wonderland," consisting of one-minute animations designed to stimulate questions in young viewers and encourage them to use their reasoning abilities.
- Highly interactive resources that include the "Dark Matter" video game and a "Power of Ideas" section on how discoveries and unifications in physics have advanced technology. These will provide the basis for future quizzes and other in-class resources for teachers.
- All new "Black Hole Sessions." A new format provides 20-minute introductions to complex topics, followed by interactive discussions with leading researchers. Of several tested, two editions have been posted online and more editions are planned.
- The "Virtual ISSYP," providing "best of" content from PI's successful ISSYP summer student camps. This online edition reaches out to all interested youth across Canada and around the world, dramatically scaling up the accessibility and impact of ISSYP.

11.2 Programs and Products for Teachers

Initiatives for teachers were also refined during this year to maximize efforts to scale content. Content creation, testing and distribution benefited significantly from new and established relationships with leading provincial, national and international education groups. On the international front, PI has partnered with leading physics education associations (including the

American Association of Physics Teachers and the Physics Teaching Resource Agents), garnering important endorsements and influence as a leader in modern physics outreach. Similar to student initiatives, all content for teachers is also available worldwide on the internet.

Summary of Achievements

- Interacted with 82 highly motivated physics teachers from across Canada and beyond tied to activities involving the EinsteinPlus Teachers' Workshop on Modern Physics.
- Participated in on-location teacher workshops in Canada and internationally, reaching 840 physics educators. In addition, 15 remote workshops were tested, involving EinsteinPlus alumni reaching an additional 385 teachers and thereby scaling PI's reach.
- Distributed the first *Perimeter Explorations* in-class resource to over 3,000 teachers throughout Canada and around the world while developing other full and mini-modules for future deployment.

Highlights

EinsteinPlus Teachers' Workshop on Modern Physics

The Institute's "EinsteinPlus Teachers' Workshop on Modern Physics" (E+), held in summer 2008, attracted well over 100 applications. Top teachers from this group were invited to attend a one-week, intensive, residential workshop for high school educators focused on how to better convey key concepts in modern physics. An important outcome of the most recent camps was the launch of a new "PI Teacher Network" made up of selected E+ alumni who return home to conduct remote workshops for fellow physics educators. Fifteen test workshops yielded significant scaling effects among greater numbers of teachers than PI outreach could achieve on its own. This successful "training the trainer" approach will be expanded upon in coming years by focusing on those educators who have the interest and means to conduct teacher-training sessions upon their return home, thereby substantially extending the impact of EinsteinPlus to hundreds of teachers annually.

On-location Teacher Workshops

Canadian workshops held on location by PI outreach staff and teacher network members reached into Vancouver, Calgary, Edmonton, Winnipeg, Ottawa, Toronto, Kingston, Waterloo Region, Montreal, and Halifax. The presentations not only inspired large numbers of high school science teachers with techniques to convey the importance of modern physics, the sessions also served as distribution nodes for specific *Perimeter Explorations* content (below) and provided valuable forums to receive feedback on new material in development by PI.

PI outreach also delivered select workshops internationally to members of North America's major physics education groups, including presentation of three workshops on "The Challenge of Quantum Reality" and "Updates for The Mystery of Dark Matter" during the American Association of Physics Teachers' (AAPT) annual meeting consisting of 80 members of the Physics Teaching Resource Agents (PTRA) group in Michigan, USA (July 2009). In addition, PI piloted a "Mini-EinsteinPlus" on-location workshop in Geneva, Switzerland to build links with leading European educators at the High School Teacher (HST) Workshop at CERN, involving 40 physics teachers from over 30 countries. Similar activities in both London and Surrey reached 60 physics educators associated with the UK's Institute of Physics (IOP).

Perimeter Explorations Teaching Resources

Perimeter Explorations was conceived as an efficient knowledge transfer tool, consisting of turn-key, in-class resources that convey challenging ideas in modern physics in highly visual and hands-on ways. This allows educators to provide PI's proven content to greater numbers of students than outreach staff could reach on their own. The first module, *The Mystery of Dark Matter*, consists of a purpose-built, 20-minute, indexed video with teacher manual. Initial distribution targets were surpassed and, as of year-end 2009, over 3700 kits were delivered to educators across Canada (and over 24 countries) and an additional 1270 downloads were provided to others interested in this unique science communication resource. At the same time, a second module known as *The Challenge of Quantum Reality*, which required highly sophisticated animations, was completed and launched in July 2009 at the AAPT/PTRA events. Distribution of 3500 units began at that time. Polling of teachers indicates that each of the two modules will reach over 100,000 students annually; this impact will continue year over year as each module is re-used.

11.3 Programs and Products for the General Public

In terms of programming for general audiences, the Institute continued its tradition of presenting compelling PI Public Lectures to capacity audiences and leveraging the talks on television and via the web for the benefit of others. In addition, extensive planning has taken place in preparation for a 10th Anniversary celebration to be known as "Quantum to Cosmos: Ideas for the Future." This public festival, which has already attracted significant sponsorship and a broadcast partner, will be held on-site, online and on television in October 2009, with a goal of reaching hundreds of thousands of people of all ages. Finally, the international broadcast documentary, *"The Quantum Tamers: Revealing Our Weird & Wired Future,"* is nearing completion. Distribution efforts have already begun and there is every expectation that the documentary will be seen by millions of people around the world over its broadcast lifetime, generating significant interest in quantum theory and quantum communications.

Summary of Achievements

- Production of a one-hour broadcast documentary, *"The Quantum Tamers: Revealing Our Weird & Wired Future,"* for future national and international release
- Presentation of the PI Public Lecture Series
- Development of an upcoming, live and online science festival to be called *Quantum to Cosmos: Ideas for the Future*

Highlights

"The Quantum Tamers" Broadcast Documentary

The high-definition broadcast documentary, "*The Quantum Tamers: Revealing Our Weird & Wired Future,"* is nearing completion, following two years of research, interviews and production. The program was shot in 16 cities in six countries around the world and features a creative mix of conversations, animation and even dance sequences to introduce lay audiences to ideas involving quantum theory and the potential of a new era of quantum technologies that may well change our world.

Seventeen leading researchers, including Prof. Stephen Hawking, will appear in the broadcast. The behind-the-scenes effort involves PI members Raymond Laflamme and Joseph Emerson as lead scientific consultants, John Matlock of PI and Frank Taylor of Title Entertainment as co-Executive Producers, and the UK distribution firm of Electric Sky for international television placement. The program will air on television in Canada in October 2009, followed by international rollout. It will also be entered into several high level television documentary festivals to raise visibility and draw attention to its scientific content.

Public Lectures

The Institute's flagship event series attracted over 600 people to each scientific lecture in Waterloo. The talks were viewed by wider audiences on-demand over Perimeter's website and through a wide range of television playback agreements that included not only Discovery Channel, but also TVO, Rogers and Rogers On Demand. Lecturers this season included Brian Schmidt (Australian National University), Leonard Mlodinow (Caltech), Brian Greene (Columbia University), Frank Wilczek (MIT), Ben Schumacher (Kenyon College), Rob Cook (Pixar), Roger Penrose (University of Oxford), and Patrick Hayden (McGill University). In addition, a "Best of" lecture series set (22 DVDs) was packaged and is now available to international broadcasters as well as educational organizations and libraries around the world via Distribution Access.

Quantum to Cosmos: Ideas for the Future (Q2C)

A significant amount of planning has occurred tied to the *Quantum to Cosmos: Ideas for the Future* festival, which will take place in Waterloo from October 15-25, 2009. The festival will not only celebrate the 10th anniversary of PI, it will also help anchor Canada's National Science and Technology Week and will be one of North America's most ambitious outreach events during the 2009 International Year of Astronomy.

The Festival will showcase the power of human understanding and ingenuity − from our current scientific knowledge to anticipated innovations in the years ahead. Q2C's wide-ranging presentations will involve topics that include quantum communication, scientific visualization, green technologies and space exploration. A full 10 days of presentations, exhibits and cultural performances are expected to attract up to 40,000 people on-site. All activities will also be broadcast, streamed online and made available through on-demand and re-broadcast services in order to reach 400,000 viewers or more.

Several major partners have already been secured. These include two Ontario government agencies that are providing significant funding for the festival. In addition, TV Ontario (TVO) will be host broadcaster and will provide television and website transmission of most events.

11.4 National and International Outreach Partnerships and Relationships

In keeping with PI outreach's goal to offer global outreach in the most efficient and cost-effective manner, several key partnerships have been developed. Partnerships range from official endorsement of outreach products, to conference events where products can be tested or introduced to large numbers of students or teachers, to training sessions for groups of scientifically-minded teachers.

Summary of Achievements

- Partnered ”Physica Phantastica” with the Canada Wide Science Fair (CWSF) in Winnipeg, Manitoba to provide lessons for participating students and teachers (May 2009).
- Trained Canadian teachers in partnership with the Saskatchewan Science Teachers Society (October 2008); Calgary Science Network and Telus Science Centre (March 2009); and Ontario Association of Physics Teachers (May 2009, Kingston).
- Collaborated with CERN on PI outreach training of European science teachers (July 2009).
- Presented two workshops at the Institute of Physics (IOP) for 75 members of the Physics Teacher Network consisting of regional coordinators from the Surrey and London regions of the UK.
- Presented three workshops on “The Challenge of Quantum Reality” and “The Mystery of Dark Matter” during the American Association of Physics Teachers’ (AAPT) annual meeting consisting of 80 members of the Physics Teaching Resource Agents (PTRA) group in Michigan, USA (July 2009).
- Presented two panel sessions and a plenary session at the World Federation of Science Journalists conference (June-July 2009).

Highlights

Physica Phantastica collaboration with Canada Wide Science Fair (May 2009)

Perimeter’s popular on-location and in-class presentations for youth were tailored to meet the needs of larger audiences. Specifically, PI was invited to provide a keynote presentation to hundreds of scientifically-minded students from across Canada who gathered in Winnipeg for the annual national science fair competition. An enhanced version of “The Physics of Innovation” was professionally presented by a PI outreach specialist. Feedback was excellent, so much so that the presentation received a standing ovation and a related teacher-oriented session the next day was filled to capacity. The lesson was also made available as a resource to take home and share with other educators for the benefit of their students. PI has already been invited to present at future CWSF gatherings.

World Federation of Science Journalists Panel Sessions (June-July 2009)

In addition to student and teacher training across Canada, the Institute is occasionally asked to conduct professional development workshops for the benefit of journalists and did so again via three sessions at the June-July 2009 World Federation of Science Journalists (WFSJ) conference in London, UK. Held once every two years, the WFSJ is the largest international gathering of science media in the world, and this year’s conference hosted some 700 science journalists from around the world. Perimeter’s invited participation reflects the reputation it has built for providing high quality scientific information in an accessible manner. The three panel sessions covered the topics of Quantum Information, Cosmology and Philanthropy in Science.

Objective 12: Showcase Canada as a country that clearly recognizes that virtually every aspect of our modern technological society historically has roots in the ideas generated by theoretical physics

Theoretical physics is one of the highest impact, yet lowest cost, fields in science. Its breakthroughs–such as those due to Newton, Maxwell and Einstein–enabled the creation of new technologies which have literally transformed society. In pursuing the Objectives described in this report, Perimeter Institute has actively shared Canada's belief in the importance and future benefits of ongoing, basic research.

PI has earned its reputation for scientific excellence in the international research community through the quality of its science, the calibre of its recruits, the numbers of productive research visits and conferences, and the awards and honours received by its scientists—all of which bring credit to Canada. At the same time, the Institute's educational outreach efforts have increased the awareness of the role of basic science among the lay community, particularly among youth, with clear content that links ideas generated by theoretical physics with our modern, technological society (described in Objective 11). In addition to these highly visible examples that showcase Canada's forward-looking approach to science, there were many positive stories about Perimeter in media around the world in FY08-09 that significantly helped to brand Canada as a knowledge nation dedicated to research, discovery and innovation.

Summary of Achievements

- Recruited four elite-calibre researchers to PI's permanent faculty, and 11 of the world's most eminent physicists, including Stephen Hawking, as Distinguished Research Chairs, showcasing Canada internationally as a destination of choice for top scientific talent
- Hosted 335 Short-Term Scientific Visitors, and 20 longer-term Visiting Researchers, demonstrating Canada as a leader in basic science and a cutting-edge research hub.
- Received international recognition and endorsement via awards and honours including:
    - Faculty members Cliff Burgess and Raymond Laflamme were inducted as Fellows of the Royal Society, the highest scholarly accolade awarded in Canada.
    - Faculty member Freddy Cachazo was awarded the Gribov Medal from the European Physical Society (EPS).
    - Faculty member Jaume Gomis received an Early Researcher Award (2009) from the Ministry of Research and Innovation of Ontario.
    - Faculty member Lee Smolin was awarded the 2009 Klopsteg Memorial Award from the American Association of Physics Teachers (AAPT).
    - Visiting Researcher Chris Fuchs was elected Chair of American Physical Society's (APS) topical group on quantum information.
    - Work by Faculty member Robert Spekkens *et al* was selected for inclusion in the New Journal of Physics "Best of 2008" issue.
    - Faculty member Fotini Markopoulou won an essay prize from the Foundational Questions Institute (FQXi); PI Affiliate Steve Weinstein and former PI postdoctoral fellows Olaf Dreyer and Florian Girelli also garnered honours.
    - Several PI researchers were honoured at the Gravity Research Foundation's 60th annual awards. Fourth Prize went to recent Associate postdoctoral fellow Gonzalo Olmo and colleagues. Honourable Mentions went to PI Director Neil

Turok, PI postdoctoral fellow Federico Piazza, and PI Affiliates Viqar Husain and Mark Van Raamsdonk.
    - Postdoctoral fellow Sarah Croke won the 2008 QEP group thesis prize from the Institute of Physics, the 2008 Fred Stern Memorial Prize from the University of Strathclyde, and an Honourable Mention for the 2008 Votruba prize for best doctoral thesis in theoretical physics from the Doppler Institute.
    - Perimeter Institute as a whole co-received the ”2009 Global City Award” from the Canadian Urban Institute (CUI)
- Passed independent, scientific peer review that re-affirmed PI’s important role to Canada and the international scientific community via the CFI grant process that, ultimately, provided investment for *The Stephen Hawking Centre at Perimeter Institute*.
- Generated media interest in Perimeter Institute, bringing positive international attention to Canada via national and international coverage.

Highlights

Long- and Short-Term Visiting Researchers

During the past fiscal year Perimeter hosted 335 short-term scientific visitors, in addition to 20 long-term Visiting Researchers who chose Perimeter as their research destination during longer leaves of absence from their home universities. The Institute receives extremely positive feedback regarding the care and attention shown to visiting researchers, in addition to the stimulating scientific atmosphere they encounter. They bring these positive impressions back to their home institutions, crucially advancing Canada’s reputation in the elite international scientific community. Just a few visitors of note at Perimeter over the past year included David Cory (MIT), Robert Brout (Université Libre de Bruxelles), Victor Novikov (ITEP Moscow), and Herman Verlinde (Princeton).

Recruitment

Five outstanding researchers joined Perimeter’s faculty in FY08-09, choosing PI and Canada as the most promising place to advance their careers. The Distinguished Research Chairs program has also helped to raise Canada’s stature as a leader in science able to build our “people advantage” with international superstars in research. The announcement, for example, that Prof. Stephen Hawking would be coming to Canada for extended periods each year made national and international headlines, and effectively showcased Canada as one of the top research destinations in the world.

Training

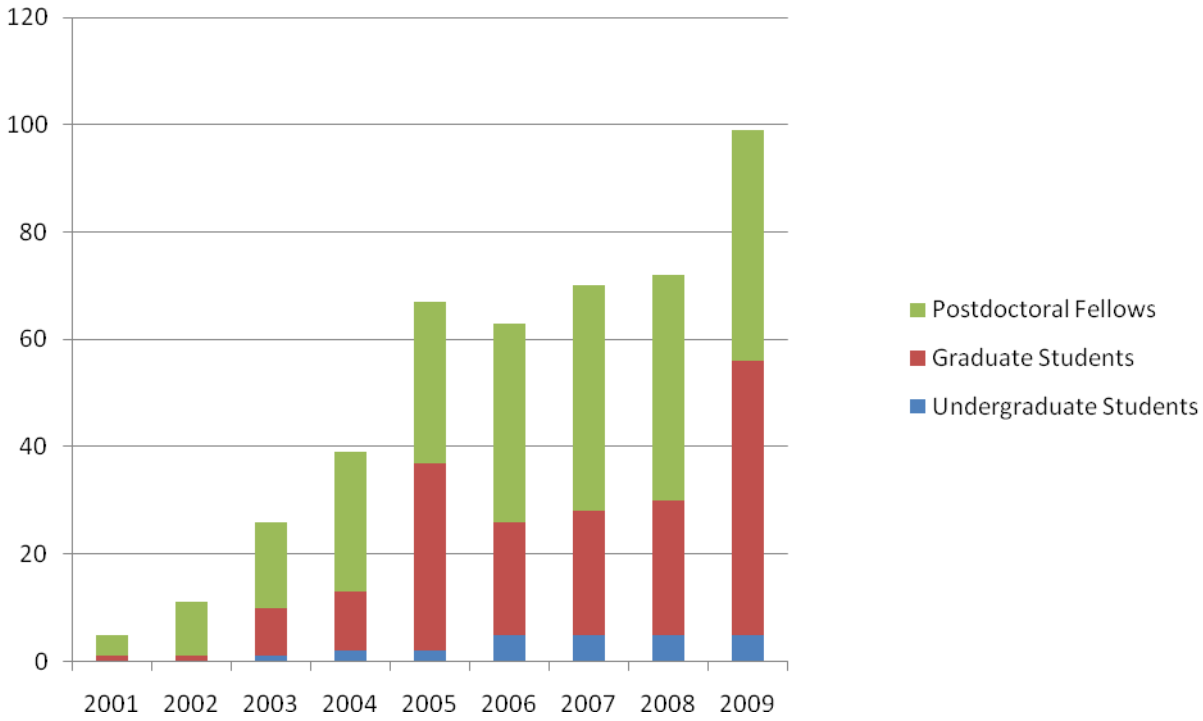


Chart 2. Growth of PI training activities since inception, 2001-2009.

Perimeter now hosts and trains the largest group of independent postdoctoral fellows in theoretical physics in the world, making a major contribution to advanced scientific skills training. The field of theoretical physics naturally attracts brilliant and ambitious young men and women, and highly qualified graduate students no longer need to look solely to Cambridge, MIT or Princeton to further their careers.

Awards

Freddy Cachazo, Gribov Medal of the European Physical Society

Perimeter Institute Faculty member Freddy Cachazo was awarded the prestigious Gribov Medal from the European Physical Society (EPS), given once every two years for outstanding work in Theoretical Particle Physics and/or Field Theory by a physicist under 35. Cachazo and his collaborators developed techniques greatly simplifying the complex calculations essential to the design and interpretation of particle accelerator experiments, such as those at the Large Hadron Collider, probing the fundamental constituents of matter.

Lee Smolin, Klopsteg Memorial Award of the American Association of Physics Teachers (AAPT)

Faculty member Lee Smolin was honoured by the American Association of Physics Teachers (AAPT) for his “extraordinary accomplishments in communicating the excitement of contemporary physics to the general public.” AAPT is an international organization for physics educators, physicists, and industrial scientists with more than 10,000 members worldwide. In addition to his three books, Dr. Smolin has written more than 140 scientific papers, and has

been a regular contributor to PI outreach programs including EinsteinPlus teacher workshops and the International Summer School for Young Physicists (described under Objective 11).

Jaume Gomis, Ministry of Research and Innovation Early Researcher Award

Faculty member Jaume Gomis was awarded $100,000 from Ontario's Ministry of Research and Innovation to support his work into new phases of matter and string theory. Given Dr. Gomis' international standing, his receipt of this award further demonstrates that Canada values foundational research on provincial and national levels. Dr. Gomis and his team are developing new theoretical tools to study observables in gauge theories with the aim of predicting previously unknown states of matter, which can ultimately be investigated experimentally.

Perimeter Institute, 2009 Global City Award from the Canadian Urban Institute

In June 2009, PI co-received the "2009 Global City Award" from the Canadian Urban Institute (CUI) as an institution that "cements the Waterloo Region's identity for excellence in scientific research and educational outreach."

Media Coverage

Canada's scientific leadership is highlighted through frequent national and international media coverage of PI activities. The appointment of Stephen Hawking as a PI Distinguished Research Chair was covered by media around the world, and provided a powerful endorsement of PI and Canada from the world's most famous living physicist. Two further examples of coverage which drew attention to Canadian research activity include:

- "I'm not looking, honest!" in the UK publication *The Economist* (March 5, 2009) covered experimental confirmation of PI faculty member Lucien Hardy's famous theorem, known as Hardy's Paradox, by two independent international experimental teams.

- "Will the next Einstein come from Africa?" in the popular American magazine *New Scientist* (November 22, 2008) featured an interview with Director Neil Turok, and postulated that Perimeter Institute *"…may be the most ambitious intellectual experiment on Earth."*

Overview of Financial Statements, Expenditures, Criteria and Investment Strategy

AUDITORS' REPORT

To the Directors of
Perimeter Institute

The accompanying summarized statement of financial position and summarized statement of operations and changes in fund balances are derived from the complete financial statements of Perimeter Institute as at July 31, 2009 and for the year then ended on which we expressed an opinion without reservation in our report dated September 30, 2009. The fair summarization of the complete financial statements is the responsibility of management. Our responsibility, in accordance with the applicable Assurance Guideline of The Canadian Institute of Chartered Accountants, is to report on the summarized financial statements.

In our opinion, the accompanying financial statements fairly summarize, in all material respects, the related complete financial statements in accordance with the criteria described in the Guideline referred to above.

These summarized financial statements do not contain all the disclosures required by Canadian generally accepted accounting principles. Readers are cautioned that these statements may not be appropriate for their purposes. For more information on the entity's financial position, results of operations and cash flows, reference should be made to the related complete financial statements.

Zeifmans LLP

Toronto, Ontario
September 30, 2009

Chartered Accountants
Licensed Public Accountants

PERIMETER INSTITUTE
(Incorporated Under the Laws of Canada Without Share Capital)
SUMMARIZED STATEMENT OF FINANCIAL POSITION
AS AT JULY 31, 2009

ASSETS

	2009 Total	2008 Total
Current Assets:		
Cash and cash equivalents	$ 4,885,927	$ 24,641,307
Investments	207,877,993	214,638,903
Government grants receivable	5,072,000	—
Other current assets	1,476,919	310,988
	219,312,839	239,591,198
Other receivable	57,024	78,422
Property and equipment	28,656,950	28,132,045
TOTAL ASSETS	$ 248,026,813	$ 267,801,665

LIABILITIES AND FUND BALANCES

Current liabilities:		
Bank overdraft	$ 615,232	$ —
Bank indebtedness	3,275,000	—
Accounts payable and other current liabilities	1,959,209	3,718,005
	5,849,441	3,718,005
Obligation under capital lease	—	9,482
TOTAL LIABILITIES	5,849,441	3,727,487
Fund balances:		
Invested in capital assets	28,069,304	27,660,028
Externally restricted	131,019,937	107,051,771
Internally restricted	82,903,934	121,660,474
Unrestricted	184,197	7,701,905
TOTAL FUND BALANCES	242,177,372	264,074,178
	$ 248,026,813	$ 267,801,665

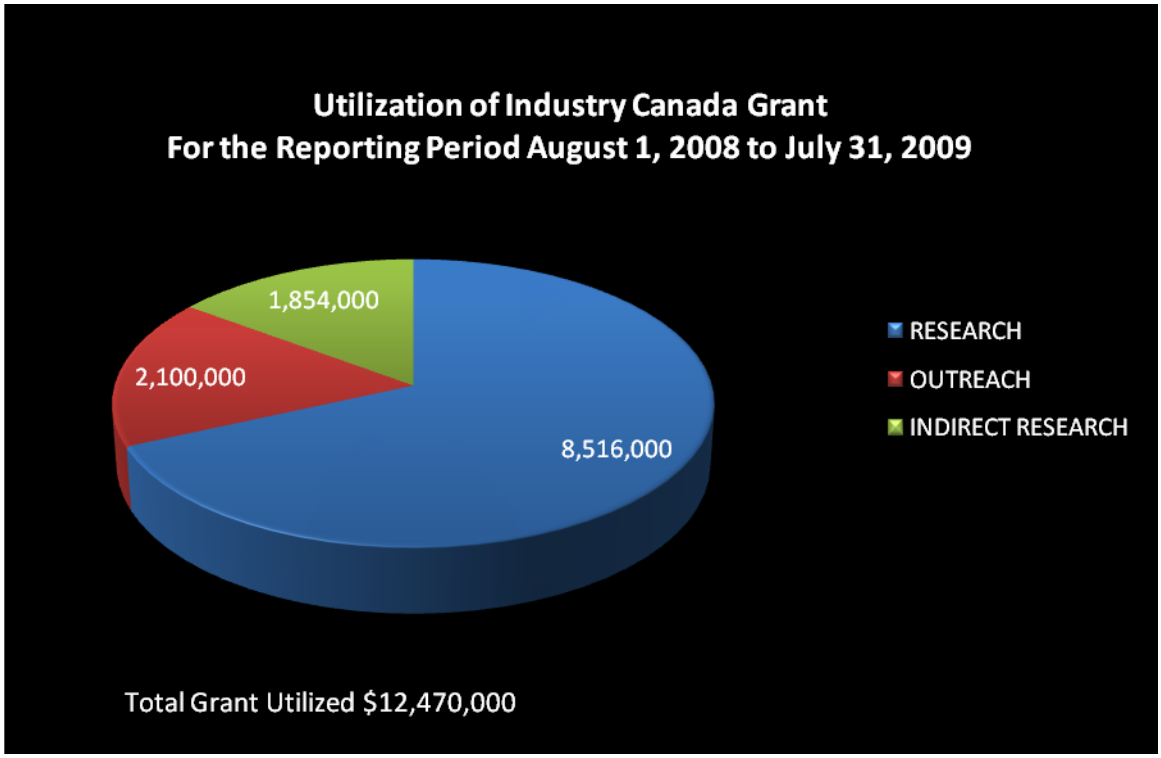
ZEIFMANS LLP
CHARTERED ACCOUNTANTS

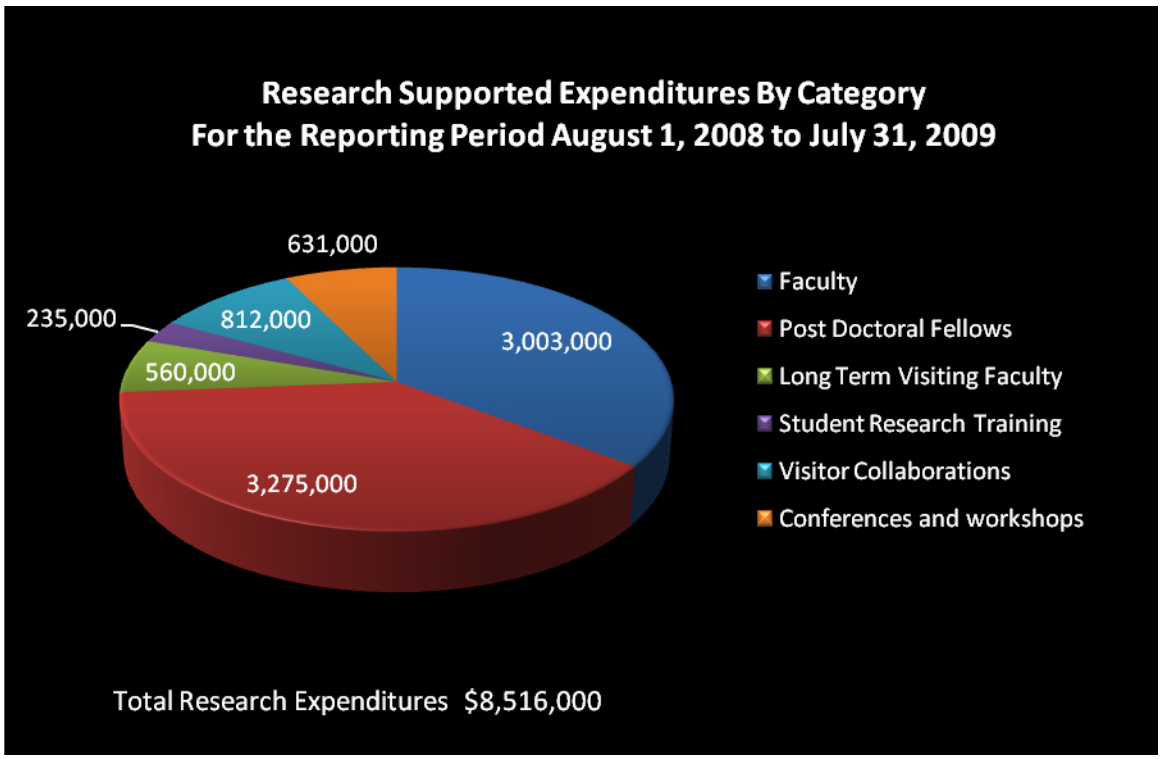
PERIMETER INSTITUTE
SUMMARIZED STATEMENT OF OPERATIONS AND CHANGES IN FUND BALANCES
FOR THE YEAR ENDED JULY 31, 2009

	2009 Total	2008 Total
Revenue:		
Donations	**$ 40,087,038**	$ 50,005,164
Grants	**5,713,200**	21,290,448
	45,800,238	71,295,612
Expenditures:		
Research	**9,643,807**	8,778,288
Outreach	**3,151,042**	2,001,465
Indirect Research and Operations	**3,706,447**	3,354,712
Total Operating Expenditures	**16,501,296**	14,134,465
Excess of revenue over expenses (expenses over revenue) before investment income and amortization	**29,298,942**	57,161,147
Amortization	**(1,763,308)**	(1,728,000)
Investment loss	**(49,432,440)**	(2,036,427)
Excess of revenue over expenses (expenses over revenue)	**(21,896,806)**	53,396,720
Fund balances, beginning of year	**264,074,178**	210,677,458
Fund balances, end of year	**$ 242,177,372**	$ 264,074,178

ZEIFMANS LLP
CHARTERED ACCOUNTANTS

Expenditures by Activity





Criteria Applied to Eligible Activities

Perimeter Institute uses a wide array of performance-monitoring and evaluation policies, systems and processes (both internal and external) that have been developed over the years and are re-evaluated and updated on a regular basis. Tools used to measure outcomes, results, and impact include:

Performance Monitoring – Internal

- Annual Reports on research activity submitted to the Director by all researchers for evaluation
- Annual Reports on research activity submitted to the Director by all research groups for evaluation
- Ongoing monitoring of publication and citation records
- Monthly updates and monitoring of progress of all scientific programs
- Post-conference reports and evaluation
- Annual evaluation of all scientific programs
- Mid-term researcher performance reviews
- Postdoctoral Fellow and Junior Faculty mentorship program
- Visitor research activity reports and on-going tracking of all output
- Monitoring of Postdoctoral Fellow post-PI placement success
- Monitoring of researcher international presence and impact through collaborations and invitations to lecture
- Internal review and evaluation of all outreach programs and products

Performance Monitoring – External

- Annual reporting to international Scientific Advisory Committee with subsequent performance assessment and recommendations. The Committee consists of the following members: Gerard Milburn, chair; Abhay Ashtekar; Sir Michael Berry; Matthew Fisher; Gerard ’t Hooft; Igor Klebanov; Michael Peskin; John Preskill; and David Spergel.
- Review of all Faculty and Associate Faculty hires, renewals, and promotions by Scientific Advisory Committee
- Peer review of publications
- Performance audits as per granting agreements
- External review and evaluation process of all outreach programs and products

Investment Strategy

Public-Private Partnership

Perimeter Institute exists through a cooperative and highly successful public-private approach to investment that provides for ongoing operations while, at the same time, safeguarding future opportunities.

Public partners finance the core research operations and outreach activities and, in keeping with individual grant requirements, receive ongoing updates, reports, and yearly audited financial statements as required to ensure value for money while remaining aware of the Institute's research productivity and outreach impact.

Private funds, including initial and subsequent philanthropic donations by Mike Lazaridis to the Institute, are protected in an endowment that is primarily designed to receive and increase donated monies by maximizing growth and minimizing risk in order to contribute to the strongest possible long-term financial health of the Institute.

Following the establishment of the Institute in 2000 with $120 million in personal commitments from Mike Lazaridis ($100 million) and fellow RIM executives ($10 million each), contributions totalling in excess of $57 million have been received to date from multiple public sources involving all levels of government. In addition to the funds above, and illustrating a strong resolve by public funders for Perimeter's success, the governments of Ontario and Canada, in 2006 and 2007 respectively, renewed and increased their commitment to Perimeter Institute by contributing $50 million each for expanded research and outreach operations over the next five years. These most recent government commitments were matched by further donations from Mr. Lazaridis of $50 million in 2008, and $20 million in 2009, bringing his contribution to $170 million.

This successful public-private strategy will also support the expansion of Perimeter's award-winning facility, with new commitments from the Government of Canada and the Province of Ontario totaling $20 million, and a matching donation from a private donor that has now been secured.

Perimeter Institute continues to be an innovative example of a public-private partnership, uniting government and philanthropists in a common quest to secure the transformative potential of scientific research in Canada.

Governance

Perimeter Institute is an independent not-for-profit corporation governed by a volunteer Board of Directors drawn from the private sector and academic community. The Board is the final authority on all matters related to the general structure and development of the Institute. Financial planning, accountability, and investment strategy are carried out by the Board's Investment Committee and its Finance and Audit Committee. The Board also forms other committees as required to assist it in discharging its duties. Reporting to the Board of Directors, the Executive Director is a pre-eminent scientist responsible for developing and implementing the overall strategic direction of the Institute. The Chief Operating Officer (COO) reports to the

Executive Director and is in charge of day-to-day operations of the Institute. Support of the COO is provided by a team of senior directors and administrative staff.
The Institute's Resident Scientists play an active role in scientific operational issues via participation on various committees in charge of scientific programs. Committee chairs report to the Executive Director.

The international Scientific Advisory Committee (SAC) is an integral oversight body, deliberately created to assist the Board of Directors and Executive Director to ensure objectivity and a high standard of scientific excellence. The SAC meets on an annual basis and submits detailed reports with recommendations to the Board and Executive Director following each meeting. The SAC is composed of eminent scientists drawn from the international community.

Financial − Investment and Management of Funds

The Board of Directors of Perimeter Institute is supported in fulfilling its fiduciary responsibilities with respect to financial management through two Board committees. The Investment Committee is responsible for overseeing the investment and management of funds received according to a Board-approved investment policy that outlines guidelines, standards and procedures for the prudent investment and management of funds. The Finance and Audit Committee is responsible for overseeing Perimeter Institute's policies, processes and activities in the areas of accounting, internal controls, risk management, auditing and financial reporting.

Statement of Objectives for Next Year and Future

With the arrival of Dr. Turok in October 2008, the Institute undertook a long-term planning process in order to articulate a more complete set of strategic and operational objectives for the future. The resulting objectives are aimed at conceptualizing and then realizing the best research environment for fundamental theoretical physics in the world, in a well-planned and integrated manner.

The objectives articulated in PI's new Five Year Plan are as follows:

- **Achieve major research breakthroughs** – by continuing to focus on advancing fundamental research, encouraging complementary and multidisciplinary approaches, and instilling a collaborative atmosphere which maximizes cross-fertilization of ideas and increases the probability of breakthroughs.

- **Become the research home of a critical mass of the world's leading theoretical physicists** – by continuing top level recruitment initiatives, offering collaboration and interaction opportunities second to none, and fostering cooperative links throughout the Canadian and international research community.

- **Generate a flow-through of the most promising talent** – by furthering its commitment to recruiting the most promising postdoctoral researchers, facilitating researcher engagements with experimental and observational centres, attracting and training brilliant young graduate students through the PSI program and recruiting the best for further PhD training, and providing research training opportunities to promising undergraduate students.

- **Provide a second "research home" for many of the world's outstanding theorists** – by continuing to recruit top scientists to the Distinguished Research Chairs program, by attracting Visiting Researchers, and through agreements that encourage joint activities between researchers at PI and leading centres throughout the world.

- **To act as a hub for a network of theoretical physics centres around the world –** by developing partnerships and collaboration opportunities with centres for theoretical physics in both the developed and developing world. PI is well placed to assist in the creation of an international network of such centres, in the process branding Canada as a leader in the promotion of fundamental science worldwide.

- **Increase PI's role as Canada's focal point for foundational physics research** – by continuing to develop national and international relationships, maximizing technologies allowing remote participation, and fostering research interaction opportunities for Faculty members and Affiliates across the country.

- **Host timely, focused conferences, workshops, seminars and courses** – by concentrating on workshops that do not happen anywhere else with top scientists discussing the hottest topics and sharing their research results, as well as through an active seminar program and carefully selected advanced graduate courses for credit at surrounding universities.

- **Engage in high impact outreach** – by communicating the importance of basic research and the power of theoretical physics to general audiences, developing brilliant young Canadians for the field by supporting a network of educators across the country with professional development and resources, and by guiding the very best scientifically-minded students toward a career in theoretical physics. PI will also serve as an international resource for outreach expertise to emerging centres of excellence in the developing world, and will provide resources on-line and through selective presentations at major international educational gatherings.

- **Create the ultimate environment and infrastructure to support excellence in theoretical physics research** – by continuing construction of *The Stephen Hawking Centre at Perimeter Institute*, an expanded facility with the productive research areas and technologies necessary to maximize the possibilities of scientific breakthroughs.