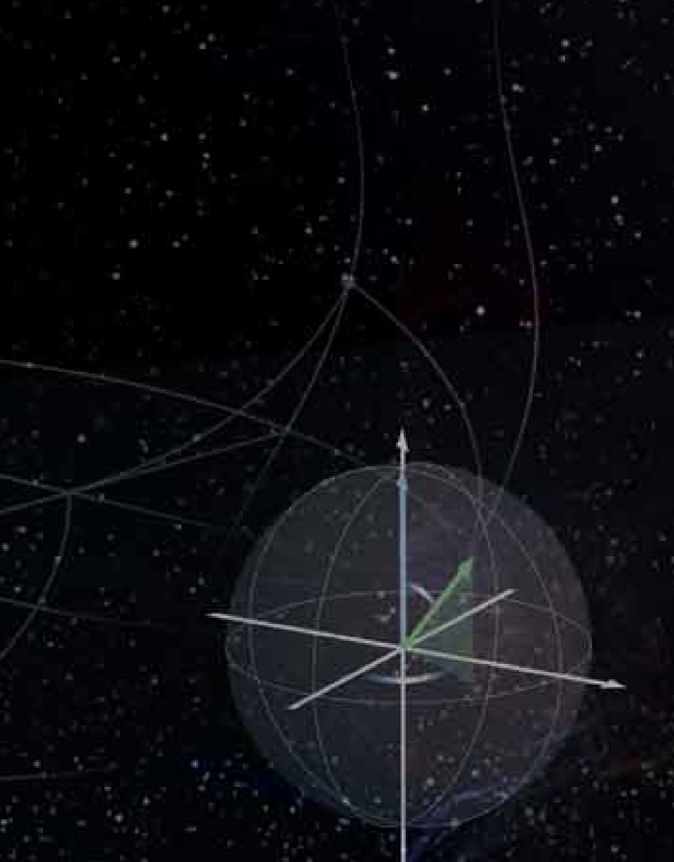
2010 ANNUAL REPORT

PERIMETER INSTITUTE
FOR THEORETICAL PHYSICS

Vision

To create the world's foremost centre for foundational theoretical physics, uniting public and private partners, and the world's best scientific minds to enable research breakthroughs that will transform our future.

CONTENTS



This report covers the activities and finances of Perimeter Institute for Theoretical Physics for the period August 1, 2009 to July 31, 2010.

MESSAGE FROM THE BOARD CHAIR

Ideas are powerful things.

In just 10 years, PI has gone from an idea to an international force in theoretical physics. It has become a hub for many of the world's deepest and most creative thinkers, and a phenomenal training ground for young researchers. At the same time, it has pioneered new ways of reaching out to communicate the importance of fundamental research to people of all ages.

"Today's theoretical physics is tomorrow's technology."

I am sometimes asked, why theoretical physics? The answer is simple: today's theoretical physics is tomorrow's technology. Time and again, its breakthroughs have deepened our understanding of the universe, and ultimately led to technologies that have transformed the way we communicate, the way we travel, how we heat our homes, how we treat illness. A hundred years ago, for example, Einstein picked up on a radical new idea that light comes in packets, called quanta, and used it to understand a puzzling phenomenon called the photoelectric effect. This new understanding became the foundation of quantum mechanics, and led to semiconductors, computers, lasers, digital cameras, the Internet – all of modern communications and computing.

There is nothing more practical or visionary that we can do for our society than invest in our own capacity to innovate, and PI was designed as a crucible of new ideas. It challenges some of the world's best minds to ask, and try to answer, some of the deepest questions in science: How do we reconcile the quantum behaviour of the universe on microscopic scales with the classical picture of space and time on the largest scales? What is dark energy? How do particles acquire mass? Are there new states of matter we don't know about? Breakthroughs in our understanding of these phenomena will transform our future in ways that we cannot imagine.

Over the last decade, it has been incredibly gratifying to see how leaders at every level of government, private sector partners, and the broader Canadian public have all recognized PI's enormous long-term value to our society. Their steadfast support continues to be essential to PI's success.

The last year, in particular, has been one of amazing progress on every front. Outstanding scientists have joined the staff, the new Masters program graduated its first class, and PI held the largest and most fascinating science festival ever held in Canada. The campaign to build PI's endowment has gained steam, and the new *Stephen Hawking Centre at Perimeter Institute* is rising steadily. To top it all off, PI's first Distinguished Research Chair, Stephen Hawking himself, came for a six-week visit, during which he shared his belief that transformative discoveries will be made here. I have every confidence that he is right.

As Chair, I would like to express my deep gratitude to departing Board members Ken Cork and Douglas Wright, both of whom have served PI with great energy and dedication since its founding, and to welcome two new Board members. Kevin Lynch is a distinguished former public servant who served most recently as the Clerk of the Privy Council, Secretary to the Cabinet and Head of the Public Service of Canada. Dr. Steven MacLean is the President of the Canadian Space Agency, one of Canada's first astronauts, and a physicist by training. They are both exceptional additions to the Board.

Finally, I would like to pay tribute to Founding Board member Lynn Watt, who passed away on July 7, 2010. Lynn played a key role in PI's development from its founding. As a graduate student at the University of Chicago, Lynn learned theoretical physics from Enrico Fermi. Decades later, I was lucky enough to take his course on relativity and quantum mechanics at the University of Waterloo. In addition to the lectures, he used to give optional evening tutorials on the latest discoveries, which were always packed and invariably led to animated discussions about those amazing new ideas. Those tutorials marked the beginning of my own fascination with theoretical physics. When Lynn met Stephen Hawking this summer, it was a brilliant moment.

It's been a thrilling decade, and we're just getting started. PI is opening new windows into our future. I can't wait to see what the next ten years will bring.

– Mike Lazaridis

MESSAGE FROM THE INSTITUTE DIRECTOR

Just two years ago I was drawn to PI by what I saw as an unprecedented opportunity here for the development of basic physics. The Institute seemed to me to combine the energy and enterprise of a startup with the culture of excellence of the strongest scientific institutions. Its ambitious scientific focus was matched by a strong commitment to public outreach. The challenge, as I saw it, was to take the Institute to the next level, realizing its potential to become a world-leading centre capable of sparking major scientific breakthroughs.

PI's achievements were already remarkable. To come from nowhere and achieve global recognition within less than a decade, against competition from traditional centres like Cambridge, Harvard and Princeton, was very surprising. PI had done this because its founders saw clearly what others had missed: that theoretical physics is one of the most cost-effective and impactful fields in all of science, for the simple reason that for the purpose of unveiling the laws governing the universe, the human mind is both the most powerful piece of apparatus we possess and the cheapest to operate. The breakthroughs made by Newton, Maxwell and Einstein cost almost nothing but seeded essentially every technology which underlies modern society.

PI's scientific focus on quantum physics and spacetime was visionary. The former led to the creation of our experimental partner centre, the Institute for Quantum Computing (IQC) at the University of Waterloo. The latter attracted a unique combination of theorists pursuing competing approaches to quantum gravity, the most challenging problem in basic physics. Ten years on, Perimeter has become one of the most attractive destinations for young researchers, receiving over 600 applications for the 12-15 postdoctoral fellowships awarded here each year.

The progress of theoretical physics rests, more than anything, on enabling brilliant young people to pursue their ideas. Soon after I arrived, we launched Perimeter Scholars International (PSI), an innovative Masters program designed to attract the brightest students from around the world and bring them to the cutting edge of research. The first class of 28 students from 16 countries recently graduated. They are a remarkable group, and we know they will go on to great things. In the future, we hope PSI will be seen as a valuable new model for scientific training at the highest level, as well as a global stimulus for theoretical physics.

At the other end of the spectrum, the wisdom and experience of senior theorists is invaluable in guiding and inspiring excellent research. So we created Perimeter's Distinguished Research Chairs (DRCs), visiting positions for the world's most distinguished theorists. We were delighted with the acceptance rate, and with how often our DRCs visit: PI has gained a wonderful reputation as a place to visit and do research. This summer, we were especially happy to host Perimeter's first DRC, Stephen Hawking. Twenty DRCs have so far been appointed: ten more will be added next year.

Building our resident faculty is also a central goal. Over the past year we have been joined by five outstanding scientists: Niayesh Afshordi, Latham Boyle, David Cory, Luis Lehner, and Pedro Vieira. They are adding to our strength in cosmology, quantum information, quantum field theory, and the study of black holes and gravitational waves – the next great frontier in astronomy and cosmology. We are planning to grow in condensed matter, especially in the realm of strongly quantum-correlated systems, an area which connects well to our existing strengths as well as to emerging technological frontiers.

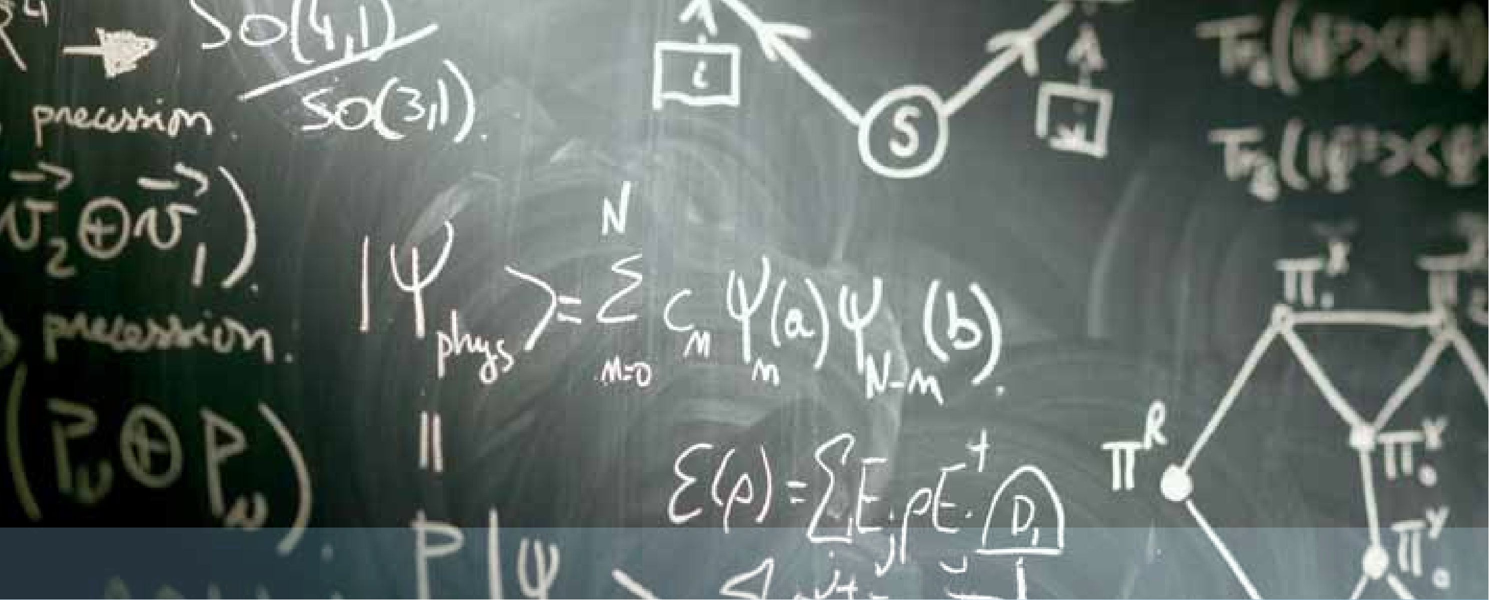
We have strategically broadened the scope of PI's research to eight fields, each offering complementary insights into quantum theory and spacetime. The combination is unique worldwide. We actively encourage interaction and even collisions between disciplines, since these are frequently the key to new discoveries. And we resist the fragmentation of our research community into narrowly specialized groups, a phenomenon which is all too common in academia. Likewise, since a continuous interaction between theory and experiment is an essential part of good science, we are building connections with major experimental and observational centres in Canada and beyond.

We are also adding to our Outreach program by supporting the emergence of scientific centres of excellence in the developing world, where great pools of talent lie waiting to be tapped. Our first efforts have focused on the African Institute for Mathematical Sciences (AIMS), in Cape Town, South Africa. Last July, we were delighted to host Prime Minister Stephen Harper at PI as he announced CDN $20 million in funding from the government of Canada to support the creation of a network of five AIMS centres, with partnership from PI and from the International Centre for Theoretical Physics (ICTP) in Italy. This is a visionary investment that will bring Africa a giant step closer to realizing her potential for science and for home-grown innovation, which will I believe be the key to her development.

If I had to point to one thing which already sets PI apart from any major scientific institution worldwide, it would be our public outreach program, motivated by our commitment to and passion for sharing scientific ideas. Last fall's *Quantum to Cosmos: Ideas for the Future* festival was a huge, audacious undertaking: dozens of talks broadcast over the Internet, a giant tent filling Waterloo's town square with hands-on exhibits and a 3-D film narrated by Stephen Hawking, the world première of the PI-produced documentary *The Quantum Tamers*, concerts, a film festival, and live TV broadcasts from PI's atrium. Its success exceeded our wildest hopes, with 40,000 on-site visitors, and over a million TV and online viewers.

I see *Quantum to Cosmos* as emblematic of what Perimeter is trying to do. History encourages us to think boldly, plan carefully, and shoot for the stars. Sometimes, magic can happen.

– Neil Turok



RESEARCH

Theoretical physics is one of the highest impact, yet lowest cost areas of basic research. Its powerful ideas have seeded innovations across all of science and technology, from mechanical engineering to wireless communication, from electronics to power generation. Quantum mechanics, for example, was invented to explain the nature of radiation and the structure of the atom. Yet, over the course of the 20th century, it led to the development of lasers, CDs, DVDs, semiconductors, LEDs and more. And, in the 21st century, it offers the prospect of a revolution in information technology, driven by quantum computers and quantum encryption for secure communication.

"The importance of special places and special times, where magical progress can happen, cannot be overstated.… It seems to me, the same ingredients are being assembled here, at Perimeter Institute. Perimeter's chosen scientific focus, connecting quantum theory and spacetime, is central to new insights, which are emerging, concerning not only black holes and the beginning of the universe, but also nuclear and particle physics, quantum computers, and the science of new materials. Perimeter is a grand experiment in theoretical physics. I am hoping, and expecting, great things will happen here."

– Stephen Hawking, PI Distinguished Research Chair and Emeritus Lucasian Professor, University of Cambridge

Recognizing theoretical physics' fundamental role in science and innovation, Perimeter Institute was founded in 1999 as a strategic investment to speed the rate of discovery and open new avenues. Its scientific focus was farsighted, namely the development and reconciliation of quantum theory, which describes the behaviour of nuclei, atoms and matter, with general relativity, which describes the space, time and gravity governing the behaviour of stars, galaxies and the universe. Obtaining a deeper understanding of both the laws and the arena for physics will drive the big science experiments and the technologies of tomorrow, and it will help to us to resolve fundamental questions about the cosmos, such as where it came from and where it is going.

Expanding the Most Promising Interfaces

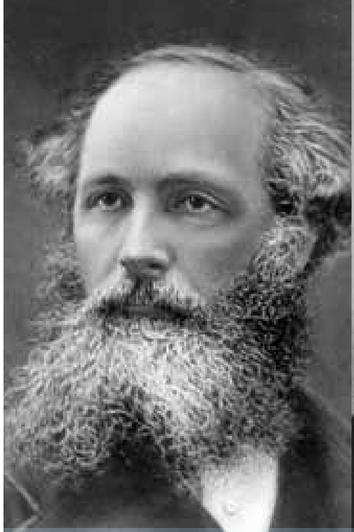
Foundational physics is advancing rapidly. Over the past decade, powerful astronomical observations have transformed our understanding of the universe, for example by revealing the presence of dark energy which is now driving cosmic expansion. Simultaneously, with the Large Hadron Collider (LHC), we are probing the structure of matter on the tiniest accessible scales. With the LHC operating at unprecedented energies, we stand on the threshold of discovering whether the standard model of particle physics, arguably the most successful theoretical model in all of science, is actually correct or must be replaced. Similarly, quantum information is rapidly emerging as a new science with a stream of ideas for how to implement quantum computers and absolutely secure transmission of information. And powerful new concepts like holography, linking quantum theory to general relativity in unexpected ways, are bringing dramatic new insights into diverse areas of physics.

> *"I take great interest in the work done by your Institute, and I know that your growing research, training and outreach activities will culminate in the breakthroughs of tomorrow."*
>
> *– Prime Minister Stephen Harper*

As a research institute, PI is unusual in actively promoting interactions and new connections between different disciplines. Discoveries often result from collisions between different approaches, when ideas combine to yield entirely new insights. The Institute has strategically expanded its research to encompass eight fields, each offering complementary views of the basic laws governing the universe. The chosen set of research areas is unique worldwide, forming a whole far greater than the sum of its parts and enabling advances in one area to promote progress in others. PI already hosts the largest group of independent postdoctoral researchers in theoretical physics worldwide, as well as over a thousand visiting researchers from around the world each year, adding to the vibrant interchange of ideas.

Basic research is by its very nature unpredictable: we cannot know in advance which avenues will be fruitful and which will ultimately turn out to be dead ends. Nor can we tell in advance how long breakthroughs will take. But we do know the lesson of history: that the pursuit of ambitious and unconstrained research within an excellent environment has paid off, time and again. By offering researchers the support and opportunity for interaction they need to pursue their work, PI's overriding goal is to enable major scientific breakthroughs.

The following is a snapshot of some exciting new directions emerging from PI research over the past year.



James Clerk Maxwell

Heinrich Hertz

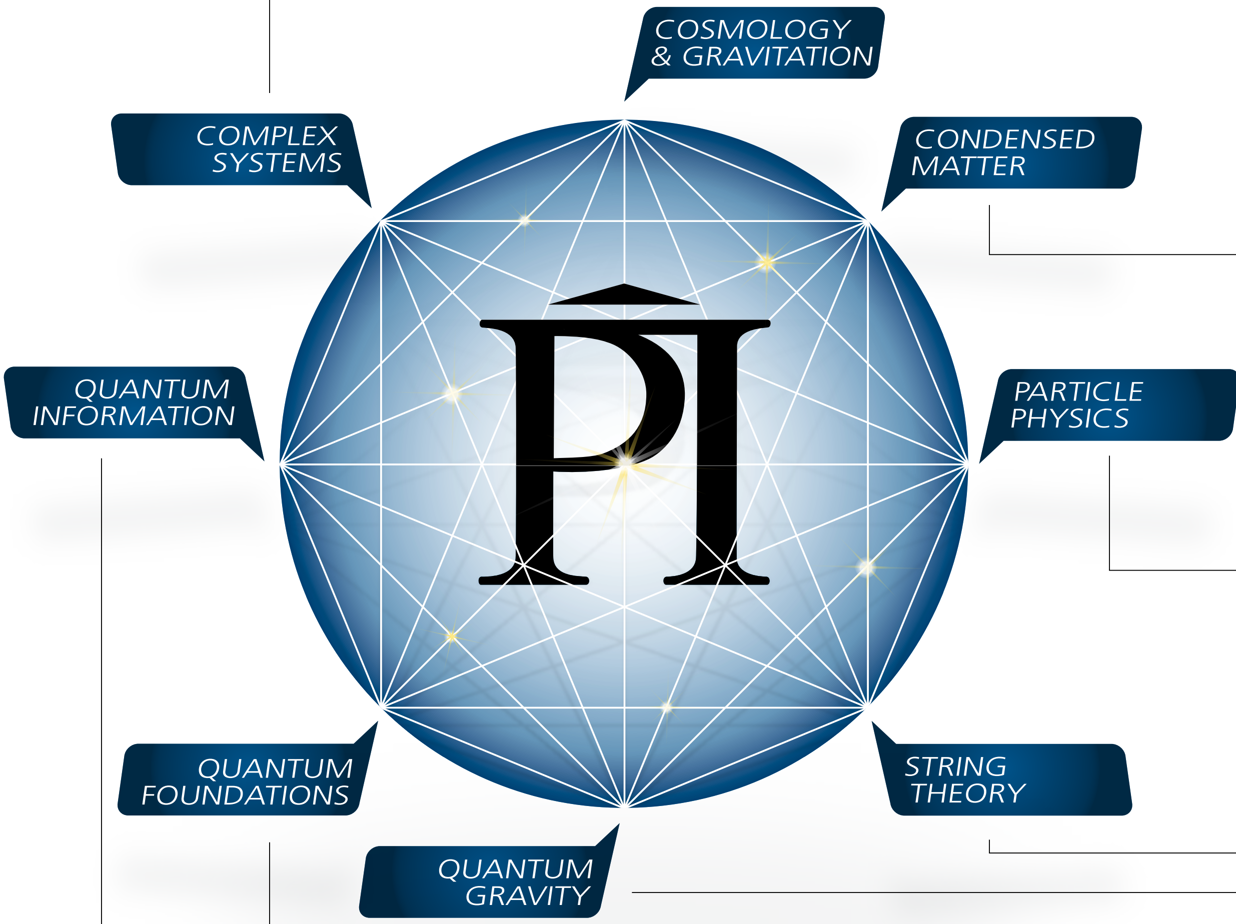
Theoretical Physics: Magic That Works

Motivated by Maxwell's equations describing electromagnetic radiation, in 1887 Heinrich Hertz constructed a machine that could make a spark jump between two metal prongs separated by a finger's width. On the far side of a room he suspended a single loop of wire and snipped it, creating a narrow gap. He then energized his spark generator, which rhythmically zapped out a series of tiny sparks between the two metal prongs. Returning to the wire loop across the room, he bent down and inspected the little gap in the wire. There it was, a tiny spark jumping from one edge to the other. Energy was traveling through the air, across the room, from his machine to the receiving wire loop, just as Maxwell's equations had predicted.

The wireless revolution, which would soon change the world, had begun.

Seeking New Answers To Big Questions

Complex systems includes the description of complex phenomena, from statistical physics to nonlinear dynamics, to novel mathematical tools for describing phenomena on all length scales.



Quantum foundations and **quantum information** aim to develop our understanding of quantum reality. Quantum theory is the most precisely tested theory we possess, but its meaning remains mysterious. Can we understand it more deeply? Can we harness its power to build *quantum* computers?

Cosmology and gravitation looks at the really big picture: how did the universe form, and how were the stars, galaxies, and black holes we now observe created? What are dark matter and dark energy? What really occurred at the big bang singularity?

Condensed matter studies physics on intermediate scales, where atoms combine into solids and liquids. Why do materials exhibit exotic properties like magnetism or superconductivity? Are there new states of matter we have not yet observed?

Particle physics aims to discover the laws governing matter and forces on the tiniest subatomic scales. What are the basic building blocks of nature, and what holds them together?

String theory and **quantum gravity** both seek to unify quantum theory and the laws of particle physics with general relativity, Einstein's theory of gravity which describes space and time. This unification is central to resolving fundamental questions such as what fixed the pattern of particles and forces, how the universe evolved in its earliest moments and what is the nature of the dark energy now shaping its evolution.

PI By The Numbers

In 2009-10, PI had 12 Faculty, 12 Associate Faculty, 47 postdoctoral fellows, and 25 PhD students.

Faculty

Latham Boyle
Freddy Cachazo
Laurent Freidel
Jaume Gomis
Daniel Gottesman
Lucien Hardy
Fotini Markopoulou
Robert Myers
Lee Smolin
Robert Spekkens
Neil Turok
Pedro Vieira

Associate Faculty

(cross-appointed with other institutions)

Niayesh Afshordi
(University of Waterloo)

Alex Buchel
(University of Western Ontario)

Cliff Burgess
(McMaster University)

Richard Cleve
(University of Waterloo)

David Cory
(University of Waterloo)

Adrian Kent
(University of Cambridge)

Raymond Laflamme
(University of Waterloo)

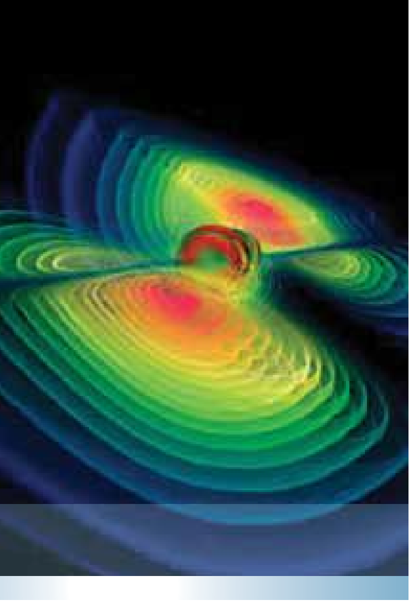
Luis Lehner
(University of Guelph)

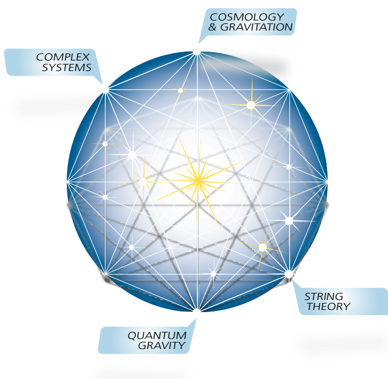
Michele Mosca
(University of Waterloo)

Ashwin Nayak
(University of Waterloo)

Maxim Pospelov
(University of Victoria)

Thomas Thiemann
(Max Planck Institute for Gravitational Physics)





STRONG GRAVITY

Four hundred years ago, the classical view of an earth-centred cosmos was upended by a combination of precision measurements and mathematical theory, culminating in Newton's laws of gravity and motion. In the 20th century, even more powerful observations and basic theory again drove a flood of discoveries, including the expansion of the cosmos, pulsars and supermassive black holes, and, most dramatically, the cosmic microwave background, providing a direct picture of our universe in its infancy.

Within the coming decade, gravitational wave detectors such as the Laser Interferometer Gravitational Wave Observatory (LIGO) are expected to open an entirely new window on the universe, revealing the structure of the most violent gravitational events including black holes in collision and, in time, the big bang singularity itself.

Predicted by Einstein's theory of general relativity, gravitational waves are faint ripples in the fabric of space and time that are produced by the interaction of huge masses, such as when two black holes orbit around each other and merge.

Unlike electromagnetic radiation (such as visible light or radio waves), gravitational waves are hardly affected by intervening gas and matter as they travel through space, so they carry 'pristine' information to us about the physical systems that created them. Detecting gravitational waves will allow us to test the strange and beautiful predictions of Einstein's theory of general relativity for exotic objects like supermassive black holes, as well as providing valuable clues to the behaviour of the universe in its first instants, where Einstein's theory is known to fail.

What Do Gravitational Wave Telescopes and Porcupines Have in Common?

Although an individual gravitational wave antenna, by itself, is a poor astronomical instrument, it is possible to design *networks* of antennas that function collectively as effective gravitational wave *telescopes*, capable of determining the direction and polarization of any gravitational wave signal that they detect. In thinking about such networks, it is important to realize that the gravitational waves they observe have very long wavelengths – much longer than distances between the antennas – we will likely distribute antennas around the Earth to detect gravitational wavelengths far longer than the Earth's diameter.

"Black holes are the most extreme cases of gravity, signaling a region inside of which everything breaks apart. I want to understand what happens there."

– Associate Faculty member Luis Lehner

Faculty member Latham Boyle has recently worked out the theory of such networks, which he calls 'porcupines' because the arms of the antennas may be thought of as emanating outward from a central point like the quills of a frightened porcupine. He has presented the basic design principles and has derived the optimal way to use the network's 'output' to reconstruct the 'input' (namely, the gravitational wave signal being measured).

Boyle has also found a number of special network configurations ('perfect porcupines') whose sensitivity to a gravitational wave signal is optimal, in particular being independent of the direction or polarization of the signal.

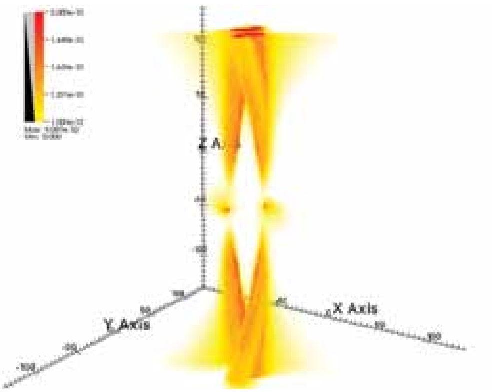
Perhaps in the future, we will see the universe anew through the eyes of a porcupine.

References: Latham Boyle, "Perfect porcupines: ideal networks for low frequency gravitational wave astronomy," arXiv:1003.4946.
Latham Boyle, "The general theory of porcupines, perfect and imperfect," arXiv:1008.4997.

Can We Develop an Early Warning System for Black Hole Mergers?

Black holes are the most extreme phenomena in the universe, yet observations indicate they are surprisingly common – there's even one sitting in the centre of our own galaxy, the Milky Way. Their gravity is so strong that no light can escape, making them hard to see directly. But this same feature – an enormously strong gravitational pull – causes them to drive the most violent, energetic, and easily observed phenomena in astronomy, including quasars, gamma ray bursts, and radio jets, and to play a central role in regulating the formation of galaxies.

Most galaxies are believed to contain 'supermassive' black holes at their centres, which attain their size through mergers with other black holes. Astronomers hope to observe direct evidence of these mergers by detecting the gravitational waves they emit but, in the immensity of the universe, how will they know exactly which merger is producing the signal? Unfortunately, gravitational wave detectors will have relatively poor directional resolution, so it will be hard to tell precisely which direction the waves emanate from.



Visualization showing electromagnetic jets emitted prior to black hole merger (image credit L. Lehner, C. Palenzuela, S. Liebling).

Research recently published in *Science* by PI Associate Faculty member Luis Lehner and collaborators may provide a vital clue. They produced the first computer simulation incorporating the effects of the extreme dynamics of the merging black holes on the charged plasma that surrounds them. The orbital motion of the merging black holes stirs the plasma, causing powerful jets of radiation to be emitted.

These jets amount to warning beacons, since they would be emitted days or weeks ahead of the merger itself, and they are theoretically detectable from two to six billion light years away. Even better, since the emitted waves are electromagnetic, their source can be precisely localized. By combining the electromagnetic signals from powerful radio telescopes and the gravitational wave signals from future gravitational wave telescopes, scientists should one day be able to peek deep into black hole systems. What they learn is likely to profoundly affect our understanding of gravity, space and time.

Reference: C. Palenzuela, L. Lehner, S. Leibling, "Dual Jets From Binary Black Holes," Science *20 August 2010:Vol. 329. no. 5994, pp. 927-930, DOI: 10.1126/science.1191766.*

PI Profile: Latham Boyle

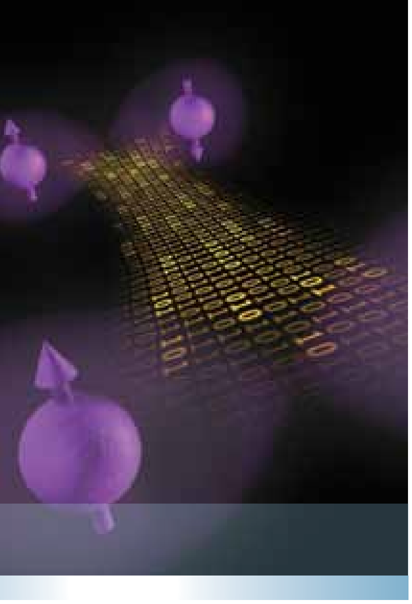
As a kid, I liked nothing better than climbing around on rocks or in caves; my parents must have imagined that my career path was more likely to be "caveman" than "physicist." For some reason I had a rather negative attitude toward science when I was young, and my interest in it blossomed late (in college).

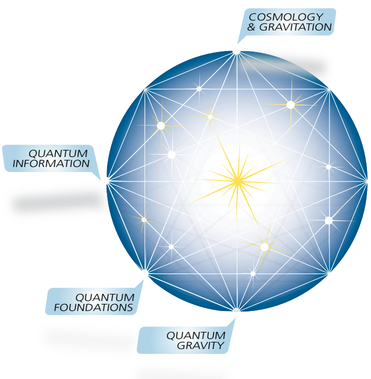
The subject of cosmology is full of fundamental puzzles and unanswered questions, like, "Why is the universe full of matter rather than anti-matter?" and "What generated the tiny temperature fluctuations that we observe in the cosmic microwave background?" These puzzles can all be regarded as clues, and my hope is to give an account of the early universe that resolves as many of these puzzles as possible, all at once. I'm currently fascinated by a recent paper by Edward Witten, "A New Look at the Path Integral of Quantum Mechanics," and the possibility that some of the ideas in it might be usefully applied to cosmology.

PI has a very distinctive environment. I feel that I'm surrounded by a lot of people making progress on very ambitious projects. The Institute contains a range of expertise in theoretical physics that is very broad, but also very unique. The flow of visitors and seminars is more than one can keep up with. A theorist's dream!

– Latham Boyle

Latham Boyle earned his PhD from Princeton University in 2006, and was a Postdoctoral Fellow at the Canadian Institute for Theoretical Astrophysics (CITA) in Toronto from 2006-2009. In 2008, he was named a CIFAR Junior Fellow. He joined PI as a junior Faculty member in 2010.





QUANTUM FRONTIERS

Quantum mechanics provides a fantastically accurate description of the subatomic world, but it is in stark contradiction with many common sense notions. For example, according to quantum mechanics, a single particle behaves as if it were in more than one place at a time. Our notion of which phenomena are connected and which are independent of one another also breaks down: particles can be kilometres apart and still, in some respects, combined into a single, 'entangled' entity. Although quantum theory continues to pose deep conceptual challenges, its predictions, so far as we have been able to test them, have been completely confirmed.

Many anticipate that we are on the brink of a new quantum revolution in technology built on these very same counterintuitive features, which could reshape the 21st century in dramatic ways. Over the last 15 years, it has become clear that quantum mechanics is far more powerful for manipulating information than the classical physics used by today's computers. A quantum computer with just 50-60 quantum bits, or qubits, would exceed the computational power of today's largest supercomputers. Likewise, quantum cryptography offers the potential for ultra-secure communications, immune to eavesdropping.

How do quantum interactions give rise to the reality we perceive? What are the properties of quantum information, and which information processing tasks will be feasible with a quantum computer? PI researchers are working all along the quantum frontier, seeking new insights into the conceptual and mathematical foundations of the theory, developing new approaches to the description of large quantum systems as well as novel experimental tests and applications.

What Are the Limits and Potentials of Quantum Computers?

One of the key motivations for building a quantum computer is to enable us to solve problems beyond the reach of today's classical computers. It is important to clearly demarcate exactly which problems will be easier to solve on a quantum computer, and which will not.

The field of computational complexity sorts problems into various classes according to how hard they are to solve, for example, by how long it will take to find the solution, and how large the computational resources required are.

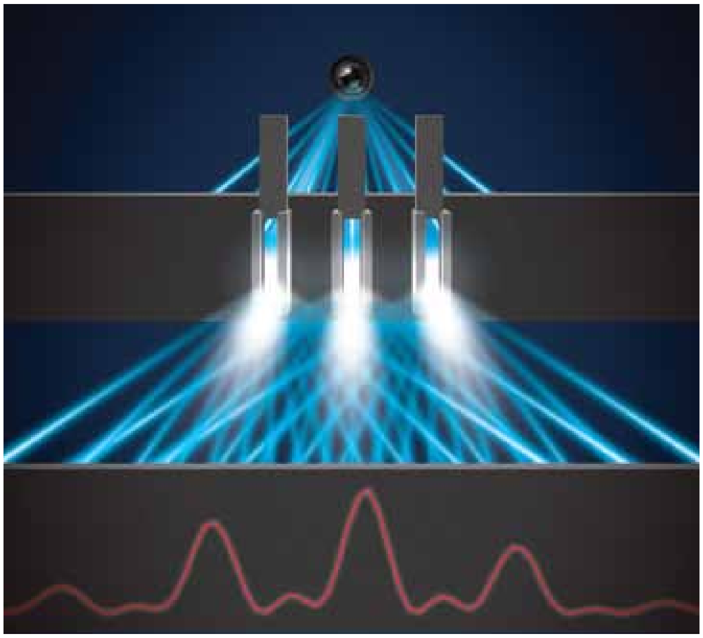
Recently, PI Postdoctoral Researcher Zhengfeng Ji and collaborators John Watrous and Sarvagya Upadhyay (both of the Institute for Quantum Computing) and Rahul Jain (University of Southern California) studied a set of computational problems that arise in the area of secure storage, transfer and processing of information, known as cryptography. They compared two types of computational problems, one based on cryptographic interactions between classical computers, and one based on the same type of interactions between quantum computers. They proved that these two types of problems are equivalent, meaning that the power of a quantum computer is not a significant advantage for solving them. The result was considered a breakthrough, because it helps to clarify how quantum computational complexity classes relate to classical ones. This helps researchers better understand both the promise and limits of quantum information processing.

Reference: "QIP = PSPACE," Rahul Jain (University of Southern California), Zhengfeng Ji (Perimeter Institute), Sarvagya Upadhyay (Institute for Quantum Computing), John Watrous (Institute for Quantum Computing), Proceedings of the 42nd ACM Symposium on Theory of Computing (STOC), 2010, [arXiv:0907.4737]

Can a Particle Be in Three Places at Once?

In work published in *Science*, PI Associate Faculty member Raymond Laflamme and collaborators from the Institute for Quantum Computing (IQC) and the University of Innsbruck performed the most rigorous experimental test to date of Born's rule, one of the central postulates of quantum mechanics, which defines the probability that a measurement on a quantum system will yield a certain result.

The researchers developed a variation on the famous 'double slit' experiment, in which a beam of subatomic particles such as photons or electrons is fired toward two closely-spaced slits on a screen. Over many firings, a characteristic pattern builds up; strangely, it is precisely the pattern that would be expected if a wave had been sent at the slits, even though the particles travel through the apparatus one at a time. Somehow, each particle travels as a wave, passing simultaneously through both slits, even though it is finally observed as a single particle: this is an example of the 'wave-particle' duality predicted by quantum mechanics.



Artist's visualization of the triple slit experiment.

A precise relation, known as Born's rule, states that the probability of observing a particle is proportional to the intensity of the wave. The simplest way to see the wavelike interference effects is to use two slits, but the new experiment sent individual photons through three slits to be observed on a screen: the results confirmed standard quantum theory to within one percent, reinforcing our current understanding, while opening new avenues for probing quantum mechanics at even higher degrees of precision.

Reference: "Ruling Out Multi-Order Interference in Quantum Mechanics," Urbasi Sinha, Christophe Couteau, Thomas Jennewein, Raymond Laflamme, Gregor Weihs, Science*, 23 July 2010: Vol. 329. no. 5990, pp. 418 – 421. DOI: 10.1126/ science.1190545*

PI Profile: Freddy Cachazo

In my first year of high school, I found a book in a used book stand under a bridge in Caracas, the city in Venezuela where I grew up. It was about the space of velocities as a Lobachevsky plane. The combination of an exotic geometry and physics was what caught my attention for years to come. In fact, every year I went back to it until I finally understood it (or probably just got used to the concepts).

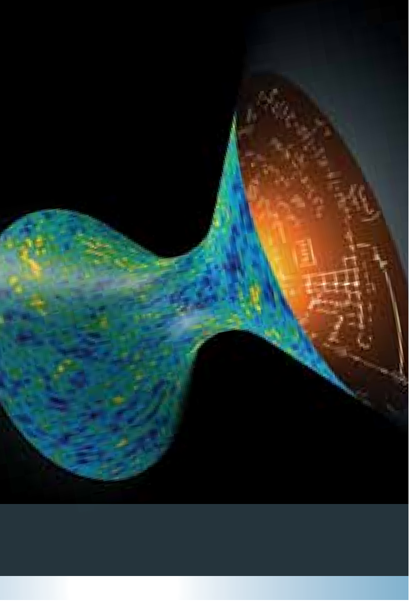
I want to understand the structure of spacetime and how the physics we experience can be translated into mathematical terms. In my current research, I am finding new hidden and fascinating structures in theories we thought we understood very well, called gauge theories. These theories describe the interactions of photons with electrons, and also the cousins of photons and electrons, called gluons and gluinos.

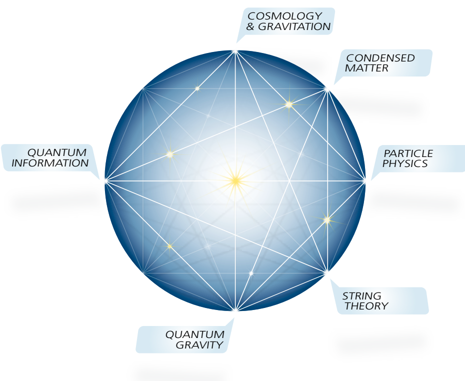
I am collaborating in this research with Nima Arkani-Hamed, a faculty member at the Institute for Advanced Study in Princeton and one of PI's Distinguished Research Chairs. This work is very intense. We make it that way because somehow we are lucky enough to have a job which happens to be our favourite hobby.

What makes PI different and special is the flux of visitors and the exposure to the many different ideas they bring. I see PI as a very interesting experiment. I am a theoretical physicist so this is probably the closest I will ever get to participating in one! PI's potential is so high that it is actually hard to imagine where it could be in ten years from now.

– Freddy Cachazo

Professor Cachazo is a senior Faculty member. He received his PhD from Harvard University in 2002, and joined PI's faculty in 2005.





Particle physics allows us to describe the basic constituents of the universe with astonishing precision and power. The mathematical framework we use to describe elementary particles is known as quantum field theory, born from the synthesis of quantum mechanics with Maxwell's theory of electromagnetic fields and light. Quantum fields describe all of nuclear and particle physics, condensed matter, and early universe cosmology, so foundational progress in this area is likely to have a major impact across all of physics.

HOLOGRAPHY AND NEW APPROACHES TO QUANTUM FIELD THEORY

You can't peer around corners in regular photographs, but when you turn the bird hologram on your credit card, you can see it from other angles – the hologram encodes three-dimensional visual information on a flat two-dimensional surface. Similarly, the 'holographic principle' is the idea that a theory describing a system in a certain number of dimensions of space may be translatable into another theory in one less dimension.

Holography offers an entirely new way of approaching quantum field theory (QFT), the mathematical framework for describing the interactions of elementary particles in the subatomic realm. QFT is used to describe both high energy elementary particle physics as well as low energy condensed matter physics relevant for the everyday world with numerous technological applications. While QFT describes many processes in the subatomic realm with great precision and power, it becomes unmanageably complicated in many important problems where quantum effects dominate, for example in describing how nuclear constituents – protons and neutrons – are formed out of quarks and then glued together into nuclei. Understanding this 'strong coupling' region is key to understanding the properties of nuclear matter.

Is there a simpler and more powerful way to address these problems? A number of PI researchers are leading explorations at this frontier, developing new holographic approaches to understanding quantum fields, combining insights from quantum gravity, particle physics, cosmology, and condensed matter. The surprises they are uncovering may provide deep, long-sought connections between the nature of space and time, and quantum physics.

Can We Use 'Quantum Magnets' to Understand the Strong Force?

The 'strong nuclear force' is one of the four fundamental forces in nature (along with gravity, the electromagnetic force and the 'weak nuclear force'). It makes protons and neutrons stable – it's the reason nuclear matter doesn't fall apart.

Faculty member Jaume Gomis, in collaboration with PI Postdoctoral Researcher Takuya Okuda and international collaborators, has developed new tools to probe the strong force. Building on work by Nobel laureate Gerard 't Hooft, they have precisely calculated novel physical observables in models that are well-suited to probing quark confinement.

This result represents one of the very few exactly computed observables in strongly coupled quantum field theory, and may ultimately produce signals that could be found in experiments. Moreover, it makes a deep connection between theories formulated in four dimensions and two-dimensional conformal field theories, akin to those describing critical phenomena such as the liquid-vapour phase transition in water at high temperatures. Using these new insights, Gomis and his collaborators are now working to directly study the exact dynamics of four-dimensional theories.

Reference: "Gauge Theory Loop Operators and Liouville Theory," Jaume Gomis (Perimeter Institute), Takuya Okuda (Perimeter Institute), Nadav Drukker (Humboldt-Universität zu Berlin), Joerg Teschner (DESY), Journal of High Energy Physics, JHEP 1002:057,2010 [arXiv:0909.1105].

What Can Soap Bubbles Teach Us About the Quantum Scattering of Particles?

To reveal the basic building blocks of matter, particle accelerators like the Large Hadron Collider (LHC) at CERN smash subatomic particles together at near light speeds. The particles collide, bounce off each other, and emit or absorb additional particles in a process called scattering. 'Scattering amplitudes' are precise theoretical predictions about the probabilities for obtaining various outgoing particles when a given set of incoming particles collide. For collisions like those at the LHC, processes involving the strong nuclear force dominate: these depend only on a single free parameter, termed the interaction coupling.

Generations of physicists have spent much of their lives calculating these processes using 'Feynman diagrams,' a clever mnemonic invented by the famous US physicist Richard Feynman. However, over the last few years, more succinct and powerful techniques have been pioneered by physicists including PI's Freddy Cachazo. Along with DRC Nima Arkani-Hamed and other collaborators at the Princeton Institute for Advanced Study (IAS), Cachazo has identified powerful relations between amplitudes which allow them to be computed far more efficiently than through Feynman's methods, when the interaction coupling is small.

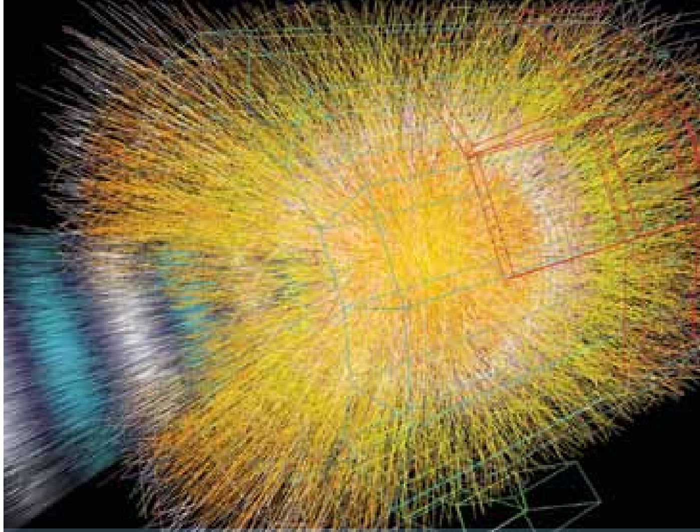
Particle colliders like the LHC can probe the strong nuclear force in exquisite detail, but new theoretical tools are needed to make predictions that they can test.

Simultaneously, work at PI by Faculty member Pedro Vieira and Postdoctoral Researcher Amit Sever, along with other Princeton IAS collaborators including Davide Gaiotto and Juan Maldacena, have allowed the amplitudes to be calculated when the interaction coupling is large. In this regime, quantum effects dominate, and Feynman's approach fails. Vieira and collaborators have combined holography with a set of mathematical tools called quantum integrability to develop a new method for calculating scattering amplitudes, which turn out to be given by the areas of certain two-dimensional 'soap film' surfaces lying within a curved spacetime known as 'anti-de Sitter' spacetime. By calculating these areas, Vieira *et al.* have for the first time determined the general scattering amplitude when quantum effects are very large. Their results furthermore hint at an alternative description which may be valid for any value of the interaction coupling.

The discovery of new mathematical structures that control quantum field theory is likely to be of enormous significance, allowing researchers not only to calculate complex physical processes relevant to real experiments, but also to tackle fundamental questions such as the quantum structure of space and time.

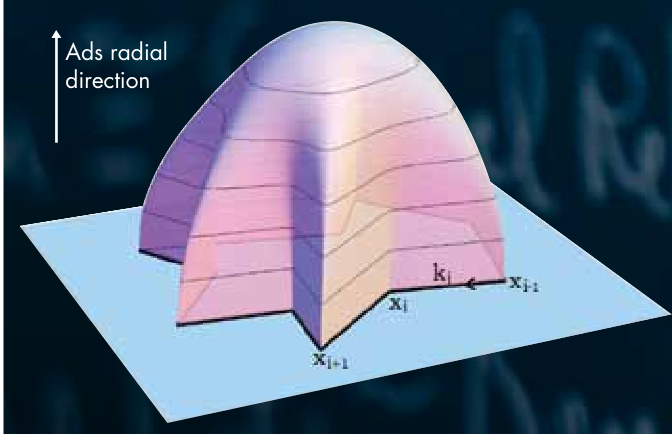
References: "Y-system for Scattering Amplitudes," Luis F. Alday (Institute for Advanced Study (IAS)), Juan Maldacena (IAS), Amit Sever (Perimeter Institute), Pedro Vieira (Perimeter Institute), J.Phys.A43:485401, 2010

"An Operator Product Expansion for Polygonal null Wilson Loops," Luis F. Alday (IAS), Davide Gaiotto (IAS), Juan Maldacena (IAS), Amit Sever (Perimeter Institute), Pedro Vieira (Perimeter Institute), [arXiv:1006.2788]

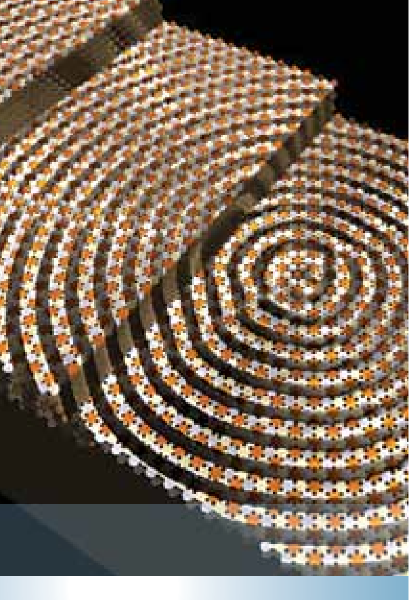


A simulated collision of lead ions, courtesy of the ALICE experiment at CERN.

In nature, the quarks that make up every proton and neutron in each atomic nucleus are 'confined,' bound so tightly together by the 'strong nuclear force' that they are never found in isolation. Although the theory of the strong nuclear force (called quantum chromodynamics) has been very well tested in certain regimes, the equations of the theory are very hard to solve, and so far progress has relied on supercomputer calculations. Finding precise mathematical formulae describing the confinement of quarks is still a major unsolved puzzle. A related mystery is how strongly interacting particles such as protons, neutrons, and pions acquire their masses. Understanding quark confinement, and why all particles built from strongly interacting quarks are massive, is one of the Clay Mathematical Institute's million dollar Millennium Prize Questions.



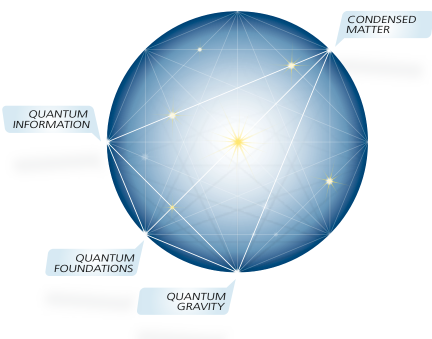
The most quantum regime of scattering amplitudes in holographic theories turns out to be described by soap film surfaces in anti-de Sitter spacetime.



EMERGENCE AND ENTANGLEMENT

An individual water molecule doesn't flow, or exhibit buoyancy – but large collections of them do flow freely and float boats. *Emergent* properties are those that arise in systems of many particles, but are not present in the individual particles that make them up. Moreover, the behaviour of a large system is often quite insensitive to the details of the small components making it up. For example, the specific molecular interactions determine details such as the precise temperature at which a solid melts into a liquid, but more general properties, such as the ability of a liquid to flow, are shared by a wide variety of substances.

In normal materials, quantum mechanics is critical to the detailed interactions of the atoms, but does not affect the emergent properties of the system. However, there are some exotic materials where quantum behaviour is so strong that it persists even in very large systems, giving them extraordinary, and potentially very useful, emergent *quantum* properties.



Examples are quantum spin liquids and topological insulators, recently predicted by theorists and subsequently found in the laboratory. These materials hold great technological potential, and may be the right materials from which to build quantum computers. Systems with emergent quantum properties are also found at several other frontiers: in the quark-gluon plasmas produced in some particle accelerators, in exotic quasiparticles (called anyons) found in some ultracold materials, and even in the fabric of space and time in some theories of quantum gravity.

Finding better techniques to study and understand emergence and entanglement could therefore lead to advances in many different areas of physics. PI researchers are investigating these new phases of matter, seeking to better understand how their quantum properties can reveal themselves in very large systems.

What is the Right Material to Build a Quantum Computer With?

A major hurdle to building quantum computers is that they will likely be very vulnerable to errors or unintended interactions with the world outside the computer. One proposal for dealing with this is to build a quantum computer using a topologically ordered system. Topological order is an exotic new phase of matter that is completely resistant to any process which only affects a small region of the substance. Consequently, a topologically ordered system could store quantum information for a very long time, since errors will only occur after the time needed for them to spread over the whole system. However, by the same token, the simplest topologically ordered systems are hard to use as quantum computers, since it is hard to deliberately alter the stored quantum information. More complicated systems can be used as quantum computers, but they are difficult to make or find.

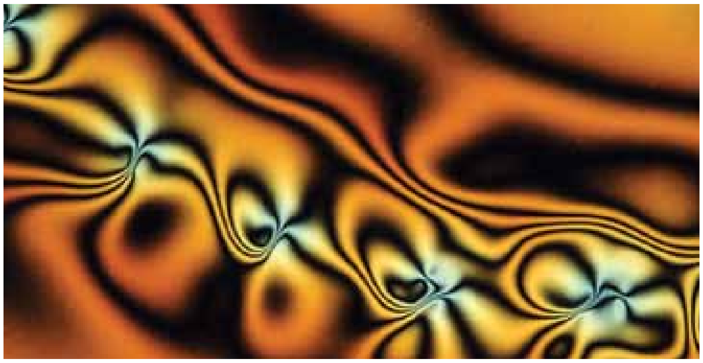
PI researcher Hector Bombin recently showed how, by adding 'twists' which change the regular lattice structure of the atoms composing some simple topologically ordered systems, one can substantially increase the types of computation that can be performed with them. Even with these twists, the systems are not yet theoretically capable of the full range of quantum computation, but research is ongoing into similarly improving other simple topologically ordered systems.

Reference: arXiv:1004.1838, Phys. Rev. Letters vol. 105, 030403 (2010).

Can We Hear the Shape of a Quantum Drum?

Topologically ordered systems are important not only because they could make good quantum computers, but also because they are such exotic phases of matter that the usual conceptual framework for materials based on symmetry is not capable of describing them. Understanding topological order is thus of key importance to condensed matter theory and may open the way to many novel materials.

More than 40 years ago, mathematician Mark Kac asked whether it would be possible to tell apart two differently shaped drums by the sound they make. The answer is that no, this is not possible – two differently shaped drums may have exactly the same sound. So when it was discovered that topological order has a particular pattern of quantum entanglement, the question that arose was, "Can two different topological orders (quantum drums) be told apart by the patterns of entanglement (sounds) they have?"



Topological defects created when a particle is placed in a liquid crystal (photo by Oleg Lavrentovich, Israel Lazo and Oleg Pishnyak).

PI Postdoctoral Researchers Alioscia Hamma and Steven Flammia, with PI Distinguished Research Chair Xiao-Gang Wen (MIT) and Taylor Hughes (Stanford), have shown that different topological orders can have the same pattern of quantum entanglement. So for the moment, the answer is no, we cannot hear the shape of a quantum drum. In other words, there is still much to understand about topological order and quantum phases of matter. The researchers' work is ongoing, aiming at a complete understanding and classification of the different types of topological order.

Reference: "Topological Entanglement Renyi Entropy and Reduced Density Matrix Structure," Steven T. Flammia, Alioscia Hamma, Taylor L. Hughes, Xiao-Gang Wen, Phys. Rev. Lett. 103, 261601 (2009). arxiv:0909.3305.

PI Profile: Leonard Susskind

I was always curious about how things work and how they got to be the way they are. I think it was George Gamow's book One, Two, Three, Infinity *that first did it for me when I was about 15. But it wasn't until I got to college that I really found out that physics was something I could do.*

The biggest question that drives my research is, "What are the principles that govern the universe?" That of course is too big a question, so I would narrow it down. Is the universe a multiverse and how do we prove it one way or another? If there is a multiverse is it governed by the usual rules of quantum mechanics and relativity, or is something entirely new needed? Currently, I am focused on formulating a precise mathematical description of a quantum universe based on the idea of eternal inflation.

I have made many visits to PI over the years. Its trajectory has been spectacular. Over the last few years PI has developed a very powerful faculty. That and its visitor program have made it one of the world's great centers for theoretical physics. What is special about PI is the openness to ideas, the power of the in-house researchers, the opportunity to interact with other visitors, the comfortable atmosphere.

This past summer, I attended the "Cosmological Frontiers" conference – it was definitely exciting. I have learned almost everything new at small, focused conferences. These kinds of workshops are the most important venues for finding out what the new directions are, and will be in the future.

I think the future will bring surprises that we can't predict. PI will be one of the fertile places where those surprises will hatch. It will also play a prominent role in disseminating the new ideas and concepts, not only to researchers, but also through the visionary educational programs that it has started.

– Leonard Susskind

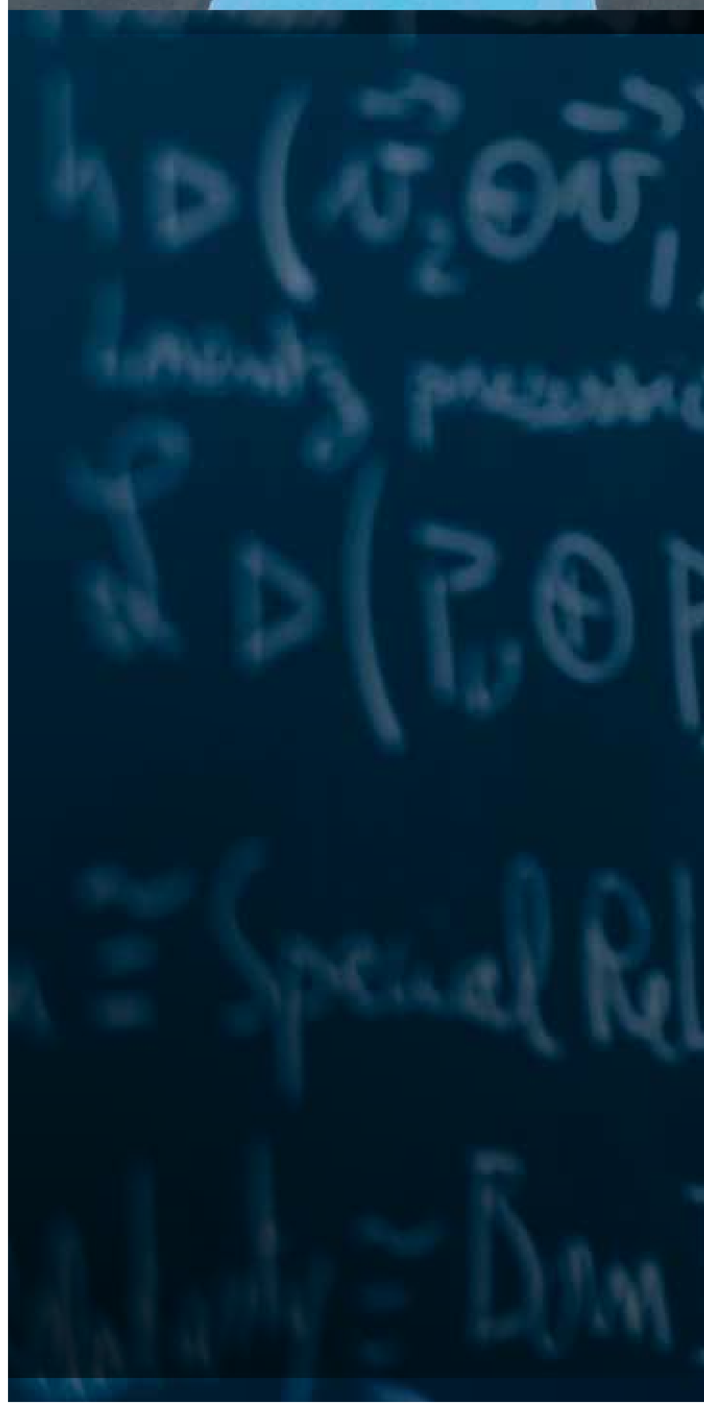
Professor Leonard Susskind is the Felix Bloch Professor of Theoretical Physics at Stanford University, and a PI Distinguished Research Chair. Regarded as one of the fathers of string theory, Professor Susskind has also made seminal contributions to particle physics, black hole theory, and cosmology.

Detail of "Untitled (One Year)" Elizabeth Macintosh, 2005-2006, Perimeter Institute Collection.

HONOURS, AWARDS AND MAJOR GRANTS

Many PI researchers received national and international recognition for their work in 2009-10. Notable among these were the following:

- Associate Faculty member Cliff Burgess was awarded the 2010 Canadian Association of Physicists-Centre de recherches mathématiques (CAP-CRM) Prize in Theoretical and Mathematical Physics, the highest honour in theoretical physics in Canada, for his "broad and deep contributions to theoretical physics"
- PI researcher Christopher Fuchs won the International Quantum Communication Award from the International Conference on Quantum Communication, Measurement and Computation (QCMC) for "outstanding contributions to the theory of quantum communication"
- Postdoctoral Researcher Zhengfeng Ji and collaborators won the "Best Paper Award" at *STOC 2010* for having solved a major open problem in quantum computational complexity
- Postdoctoral Researcher Giulio Chiribella was awarded the 2010 Hermann Weyl Prize from the International Colloquium for Group-Theoretical Methods in Physics
- Associate Faculty member Michele Mosca was named a Canadian Institute for Advanced Research (CIFAR) Fellow in the Quantum Information program, and one of Waterloo Region's 'Top 40 Under 40'
- PI Director Neil Turok was named a Canadian Institute for Advanced Research (CIFAR) Fellow in the Cosmology and Gravitation program
- Faculty member Jaume Gomis was given an Early Researcher Award from the Ontario Ministry of Research and Innovation
- Associate Faculty member Niayesh Afshordi was awarded a Discovery Accelerator Supplement from the Natural Sciences and Engineering Research Council of Canada (NSERC), one of only eight given nationally in physics
- Faculty member Fotini Markopoulou was awarded an Alexander von Humboldt Foundation Fellowship (to be held at the Albert Einstein Institute)



- An NSERC Collaborative Research and Development (CRD) grant of $750,000 over three years was awarded to Associate Faculty member Michele Mosca and partners in Waterloo, Calgary, and Montreal to support research on fundamental and applied quantum key distribution networks
- A US Army Research Office (ARO) grant of US$600,000 over three years was awarded to Associate Faculty member Richard Cleve and partners, including Associate Faculty members Michele Mosca and Ashwin Nayak, who are developing quantum computing algorithms
- Parampreet Singh was awarded the 2010 S. Chandrasekhar Award of the International Society on General Relativity in Gravitation
- "The Return of the Phoenix Universe" by Director Neil Turok *et al.* received an Honourable Mention at the 2009 Gravity Research Foundation competition
- Postdoctoral Researcher Federico Piazza's paper "The IR-completion of gravity: what happens at Hubble scales?" was named among the "Best of 2009" by the *New Journal of Physics*
- "Quark Soup al dente: Applied Superstring Theory" by Robert Myers and S.E. Vasquez and "Are loop quantum cosmos never singular?" by Postdoctoral Researcher Parampreet Singh were both selected among the "Highlights of 2008-2009" by the editorial board of *Classical and Quantum Gravity (CQG)*

PI Distinguished Research Chair Stephen Hawking and Associate Faculty member Cliff Burgess.

In 2009-10…

- *Latham Boyle and Pedro Vieira joined PI as full-time Faculty members*
- *David Cory and Niayesh Afshordi joined PI as Associate Faculty members jointly appointed with the University of Waterloo*
- *Luis Lehner joined PI as an Associate Faculty member jointly appointed with the University of Guelph*
- *Nine new Distinguished Research Chairs were appointed*
- *14 new Postdoctoral Researchers were recruited*

RECRUITMENT

FACULTY

PI welcomed five new Faculty members in 2009-10:

Niayesh Afshordi joined PI as a junior Faculty member jointly appointed with the University of Waterloo. Professor Afshordi specializes in interdisciplinary problems in fundamental physics, astrophysics, and cosmology, with particular focus on observational findings that can help address problems in fundamental physics. In 2010, Professor Afshordi was awarded a Discovery Accelerator Supplement from the Natural Sciences and Engineering Research Council of Canada (NSERC), one of only eight awarded in physics nationally.

Pedro Vieira joined PI from the Max Planck Institute for Gravitational Physics, where he was a Junior Scientist. Dr. Vieira's research concerns the development of new mathematical techniques for gauge and string theories, and he has recently made important advances which may yield new insights into both gauge theories and quantum gravity, and for calculating scattering amplitudes in particle physics.

"My inclination to look at problems outside of my comfort zone is what brought me to PI."

– Associate Faculty member Luis Lehner

Two outstanding researchers in gravitation joined PI's faculty over the last year. **Luis Lehner**, who is jointly appointed with the University of Guelph, 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. **Latham Boyle**, who joined PI as a junior Faculty member, studies what gravitational wave measurements can teach us about the beginning of the universe. With observational tests using gravitational wave astronomy expected in the near future, these new Faculty members position Perimeter to become a leading centre in the developing field of gravitational wave astronomy, which is expected to open an entirely new window on the universe.

In June 2010, **David Cory**, a renowned pioneer in quantum computing and a former professor of nuclear engineering at the Massachusetts Institute of Technology, joined PI in a joint appointment with the Institute for Quantum Computing at the University of Waterloo, where he holds the Canada Excellence Research Chair in Quantum Information Processing. Professor Cory is tackling the experimental and conceptual challenges of building small quantum processors based on nuclear spins, electron spins, neutrons, persistent current superconducting devices and optics.

Recently, PI recruited several young researchers of exceptional promise, who will arrive in the coming year. **Philip Shuster** and **Natalia Toro** are particle physics theorists who have forged close links to experimentalists at several leading centres. Their broad expertise will enable PI to play a leading role in major experimental efforts at the Large Hadron Collider at CERN and other particle accelerators. Finally, **Davide Gaiotto**, who will join PI in 2011 from the Institute for Advanced Study, is an exceptionally talented young theorist whose recruitment will greatly strengthen PI research in the increasingly important area of strongly quantum-correlated systems.

"The people of Ontario are honoured, thrilled in fact, to host Stephen Hawking and we're very proud to have him at the Perimeter Institute, where people from around the world, from across disciplines, can work together to push out the boundaries of our shared knowledge even further. That's the kind of collaboration Ontarians are so proud to support."

– The Hon. Dalton McGuinty, Premier of Ontario

Distinguished Research Chair Stephen Hawking's Inaugural Visit to PI

Among the many eminent scientific visitors of 2009-10, Stephen Hawking, PI's first Distinguished Research Chair, made his first visit to PI in June and July 2010. The visit was a highlight of the summer, and Professor Hawking was welcomed to PI and Canada by the Prime Minister of Canada and by the Premier of Ontario. While he focused mainly on research during his six-week stay, Professor Hawking participated in all aspects of life at PI. He attended and presented new work with Thomas Hertog at the "Cosmological Frontiers in Fundamental Physics" conference, celebrated PSI's first graduation (he is a PSI Patron), and contributed to PI's Outreach program with a nationally broadcast talk about his life and research, which he ended by saying, "I am hoping, and expecting, great things will happen here."

THE PI DISTINGUISHED RESEARCH CHAIRS

When complementary insights are brought to bear, major advances are possible. With this in mind, PI's Distinguished Research Chairs (DRC) program was created in 2008 to bring more of the world's top theorists to PI each year for extended periods of research while retaining their permanent positions at home. This year, PI appointed nine new Distinguished Research Chairs, bringing the current total to 20, each appointed to a three-year term.

The DRCs add an enormous depth and range of expertise from virtually every branch of physics to our resident research community. They include world-leading figures such as Stephen Hawking, as well as bright young stars such as Patrick Hayden (McGill University) and Dorit Aharonov (Hebrew University).

Dorit Aharonov · *Christopher Isham* · *Guifre Vidal* · *Patrick Hayden* · *Malcolm Perry* · *Renate Loll* · *William Unruh* · *Sandu Popescu* · *Mark Wise*

The continuous flow of top scientists sparks new scientific research and collaborations, and is part of the excitement of working at PI. While the focus of the DRC program is on providing the time and space needed for intense research, DRCs participate in all aspects of PI life – several have taught in the PSI Masters program, others organize cutting-edge conferences and workshops, or share their wisdom in public lectures through PI's Outreach program.

POSTDOCTORAL RESEARCHERS

There were 47 Postdoctoral Researchers in residence at PI in 2009-10. Postdoctoral Researchers at PI follow independent research programs and are encouraged to be full partners in the research community – organizing conferences and workshops, hosting visitors, and giving talks. Appointments are for three-year and five-year terms, and PI now hosts the largest community of independent postdoctoral researchers in theoretical physics worldwide. In 2009-10, 14 new Postdoctoral Researchers were selected from over 500 applicants, joining PI from Princeton, Caltech, the Albert Einstein Institute (Potsdam), ETH (Zurich), and the Kavli Institute for Theoretical Physics (Santa Barbara), among others.

PI postdocs have an excellent track record of obtaining positions after they have trained at PI. Within the last year, for example, several departing Postdoctoral Researchers obtained faculty positions at prestigious institutions, including the University of Geneva, the Nordic Institute for Theoretical Physics (NORDITA) in Stockholm, the University of Albany-SUNY, Loyola University, and the Indian Institute of Science, Bangalore.

PI's Distinguished Research Chairs

** Indicates DRC appointed in 2009-10*

Dorit Aharonov, Hebrew University*

Yakir Aharonov, Chapman University & 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

Stephen Hawking, University of Cambridge

Patrick Hayden, McGill University*

Christopher Isham, Imperial College London*

Leo Kadanoff, University of Chicago

Renate Loll, Utrecht University*

Malcolm Perry, University of Cambridge*

Sandu Popescu, University of Bristol*

Subir Sachdev, Harvard University

Ashoke Sen, Harish-Chandra Research Institute

Leonard Susskind, Stanford University

William Unruh, University of British Columbia*

Guifre Vidal, University of Queensland*

Xiao-Gang Wen, Massachusetts Institute of Technology

Mark Wise, California Institute of Technology*

RESEARCH TRAINING

PERIMETER SCHOLARS INTERNATIONAL

Last year, PI launched Perimeter Scholars International (PSI) in partnership with the University of Waterloo. This innovative new Masters program is designed to attract talented university graduates from around the world and bring them to the cutting edge of theoretical physics in an intense ten-month program.

Courses are given by visiting lecturers, with daily tutorials provided by four full-time postdoctoral level Tutors. The syllabus exposes students to the full spectrum of theoretical physics, while teaching the skills young researchers need most: how to develop models on computers, how to think independently, and how to collaborate to solve unfamiliar problems. In the latter part of the program, students complete and defend original research theses. In the last year, several of these were accepted for publication at competitive international conferences.

"The best part of PSI was the opportunity we had to interact with some of the great people in the field. Over many such conversations spread throughout the year, I slowly formed a mental picture of what it is like to do research, and what I wanted to do myself."

– 2010 PSI graduate Prasanna Bhogale

The program's first year was a resounding success, with an excellent first class of 28 students from 16 countries. Most graduates have continued on to doctoral training at top Canadian and international institutions including Harvard, Stanford, Imperial College, Perimeter, UW and McMaster, while some obtained industry positions at companies including Google and Amazon. For 2010-11, 31 top students from 15 countries, including 14 women, have been selected, and the program is slated to grow over time.

COURSES

In addition to courses held through the PSI program, PI capitalizes on the expertise of its resident researchers and visiting scientists to provide topical courses for researchers and to enhance the course offerings of surrounding universities. In 2009-10, the Institute continued to expand its course offerings to residents and students with a mix of focused short courses and longer accredited courses offered in conjunction with surrounding universities. Highlights included "Beyond the Standard Model Physics and the LHC," given by James Wells of CERN, "Foundations and Interpretation of Quantum Theory," given by Raymond Laflamme and Joseph Emerson of PI and the Institute for Quantum Computing, and "New Developments in N=2 Supersymmetric Gauge Theories," given by Davide Gaiotto of the Institute for Advanced Study.

As with all PI research happenings, these courses are available to the wider scientific community through PIRSA, Perimeter's online video archive.

PHD STUDENTS

There were 25 PhD students in residence over the past year pursuing full-time graduate studies under the supervision of PI faculty members. Students receive their degree from a partnering university where the PI faculty member has an affiliation. The graduate program at PI offers students excellent opportunities to interact with both resident and visiting physicists from around the world. Eight new PhD students arrived in 2009-10, and there are plans to expand these numbers significantly in the coming years, in tandem with faculty growth. Perimeter's PhD students have successfully obtained continuing postdoctoral positions at institutions including the Kavli Institute for Theoretical Physics at UCSB (USA), NASA Goddard Space Flight Center (USA), the Max Planck Institute (Germany), Kinki University (Japan), as well as Canadian institutions such as the University of British Columbia, McGill University, the University of Toronto, and others.

UNDERGRADUATE RESEARCH

Perimeter postdoctoral researchers have the opportunity to gain mentoring experience while furthering their research programs by developing two- to four-month research projects requiring the assistance of an undergraduate student. Over the summer months, undergraduates recruited from around the world join PI's research community, gaining research skills, learning about specific research areas in depth and more generally about being a theoretical physicist.

PSI's 2009-10 Faculty

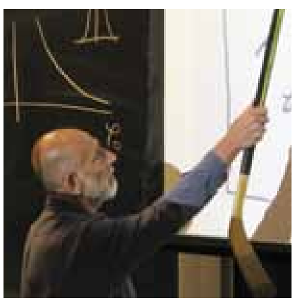
John Berlinsky, Director
Niayesh Afshordi, Perimeter Institute & University of Waterloo
Ben Allanach, University of Cambridge
Philip Anderson, Princeton University
Nima Arkani-Hamed, Institute for Advanced Study
Katrin Becker, Texas A&M University
Melanie Becker, Texas A&M University
Carl Bender, Washington University
Freddy Cachazo, Perimeter Institute
Matt Choptuik, University of British Columbia
Susan Coppersmith, University of Wisconsin at Madison
David Cory, Massachusetts Institute of Technology
Kari Dalnoki-Veress, McMaster University
François David, Institute of Theoretical Physics, 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, Utrecht University
Robert Myers, Perimeter Institute
Hiranya Peiris, University of Cambridge
Malcolm Perry, University of Cambridge
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, University of Cambridge
Neil Turok, Perimeter Institute
Xiao-Gang Wen, Massachusetts Institute of Technology

Participants at "Connections in Geometry and Physics 2010"

PI by the Numbers

In 2009-10, PI …

- *Hosted 387 visiting scientists, including 350 short-term scientific visitors, and 17 longer-term Visiting Researchers*
- *Held 15 conferences, workshops and summer schools attended by 691 researchers from around the world, in addition to 242 scientific talks*



The PI Hockey Stick

Here in Canada, we say, who needs laser pointers? The hockey stick pointer is a PI tradition and has been wielded by hundreds of researchers to present their findings to our scientific community.

RESEARCH EVENTS

CONFERENCES, WORKSHOPS AND SUMMER SCHOOLS

The great physicist Robert Oppenheimer once said, "What we don't understand we explain to each other." The intense topical focus and unexpected human interactions at scientific gatherings are all part of the living process that catalyzes new scientific insights.

PI has become known for hosting scientific conferences and workshops that do not happen anywhere else – gatherings of top people discussing 'hot' topics in cutting-edge fields. The Institute's flexibility enables it to rapidly identify and capitalize on new areas of exceptional promise, and several conferences held at PI over the year were the first to be held worldwide on new discoveries and topics.

By strategically choosing areas where a conference or workshop is likely to have a significant outcome, PI aims to accelerate scientific progress and act as a major node of exchange for cutting-edge research in theoretical physics.

COLLOQUIA AND SEMINARS

Perimeter hosts eight active weekly seminar series, fostering collaborations and sharing knowledge with leading researchers around the globe. Nearly all scientific events at Perimeter are recorded and made freely available via the Perimeter Institute Recorded Seminar Archive (PIRSA), which now holds over 4,000 seminars, talks, courses and colloquia.

Speakers at the 242 seminars and colloquia over the past year included Yakir Aharonov (Chapman University), Juan Maldacena (Institute for Advanced Study), Mark Wise (Caltech), Ashoke Sen (SUNY, Stony Brook), Leon Balents (KITP), Erik Verlinde (University of Amsterdam), Sir Anthony Leggett (University of Illinois), and many others. PI also participates in the International Loop Quantum Gravity Seminar, which virtually brings together researchers from 15 quantum gravity groups across Europe, North America, and South America each week.

Over 4,000 PI seminars, talks, courses and colloquia are accessible to the global scientific community via the online Perimeter Institute Recorded Seminar Archive (PIRSA), a permanent, free, searchable, and citable archive of recorded seminars, conferences, workshops, and outreach events. All lectures in the PSI Masters course may be found on PIRSA and are accessed by students around the world.

On-demand seminars with video and presentation materials (such as slides) can be accessed in Windows and Flash formats and offer MP3 audio files and PDFs of the supporting materials. Scientific talks are presented with a split-screen image that enables viewers to watch the seminar from the perspective of an audience member, with the added advantage of being able to zoom in, pause, and examine specific slides, equations, or figures more closely.

PIRSA has become a key resource for the international scientific community. During 2009-10, 45,004 unique visitors from 151 countries accessed PIRSA. See http://pirsa.org/

Conference Highlights

"Gravity at a Lifshitz Point" (November 8 - 10, 2009)

This was the first gathering to be held worldwide on the implications of Petr Hořava's recent proposal for a modified theory of gravity, which has generated great excitement internationally. The workshop was co-organized by PI Postdoctoral Researcher Dario Benedetti and Professor Hořava himself. It enabled a clear picture of the status of this theory to emerge among key researchers and has stimulated new ideas and collaborations both within and outside PI. All talks can be viewed online at: http://pirsa.org/C09026

"Emergence and Entanglement" (May 25 - 29, 2010)

This was widely regarded as a pioneering workshop in a very exciting area which brought together, for the first time, researchers in quantum information, condensed matter, and string theory to present and discuss new research into strongly quantum new phases of matter. These exotic materials, which include topological insulators and quantum spin liquids, have novel properties that are likely to be of great technological importance, and the research is uncovering surprising connections between high and low energy physics. The program included talks from 30 high profile researchers, including Nobel laureate Sir Anthony Leggett (University of Illinois), Xiao-Gang Wen (MIT), Subir Sachdev (Harvard), and Guifre Vidal (University of Queensland). All talks can be viewed online at: http://pirsa.org/C10012/3

Participants at PI-LHC-CITA Day.

RESEARCH LINKAGES

VISITOR PROGRAM

An active scientific visitor program enables PI researchers to stay abreast of new developments, exchange new ideas, and spark new collaborations with colleagues. Coming to PI gives visiting scientists the time and space to do the intense, daily research with collaborators that is often needed to 'crack' tough problems. During the past year, Perimeter hosted 387 scientific visitors, including 350 short-term scientific visitors. Nineteen Visiting Researchers chose Perimeter as their research destination during longer-term leaves from their home universities.

"The amplitude workshop was a very stimulating and productive gathering of the best people working on this field. Some of the best results were produced by PI researchers, such as Freddy Cachazo, Pedro Vieira, and their postdocs. PI has had great success at attracting an outstanding group of young researchers. They are making PI a world-class centre. There have been very interesting recent collaborations between us (the Institute for Advanced Study) and PI. We organized joint workshops, but more importantly we have had very productive scientific collaborations."

– Juan Maldacena, Institute for Advanced Study

AFFILIATES

Affiliates are select faculty members at Canadian universities who are invited for regular informal visits to PI for scientific collaboration and the opportunity to be involved in the Institute's research activities.

The aim of the Affiliate program is to foster regional and national research links between PI and Canadian universities, strengthening the Canadian physics community as a whole, while broadening the base of research at PI. In 2009-10, PI added 29 new Affiliate members, bringing the total to 95 drawn from universities across the country.

NATIONAL LINKAGES

Perimeter Institute aims to serve as a focal point for theoretical physics in Canada. In addition to our long-standing and synergistic relationship with the nearby Institute for Quantum Computing (IQC) at the University of Waterloo, the Institute engages with all relevant members of Canada's physics community, cooperating with our academic partners via cross-appointments, adjunct appointments, joint postdoctoral fellowships, and graduate training.

Perimeter has forged strong ties with the Canadian Institute for Theoretical Astrophysics (CITA), the Canadian Institute for Advanced Research (CIFAR), the Fields Institute, the Institute for Particle Physics (IPP), the Centre de Recherches Mathématiques (CRM), the Pacific Institute for Mathematical Sciences (PIMS), Mathematics of Information Technology and Complex Systems research networks (MITACS) and the Shared Hierarchical Computing Network (SHARCNET).

PI continues to provide unique resources to the national scientific community through courses, conferences, workshops and numerous research events, such as the popular "PI-CITA Days." The Institute also has important links with Canadian experimental centres, including TRIUMF, Canada's National Laboratory for Particle and Nuclear Physics, and SNOLAB at the Sudbury Neutrino Observatory. In 2009-10, "PI-ATLAS-LHC Days" were launched to link PI researchers and the ATLAS experimental collaboration at the University of Toronto, which has ties with ongoing work at the Large Hadron Collider (LHC) at CERN.

INTERNATIONAL LINKAGES

PI continued to strengthen existing international links – such as those with the Laboratoire Astroparticule et Cosmologie (APC) and the Solvay Institute (Brussels) – and to establish new ones. In 2009-10, PI established a new collaboration with the Center for Theoretical Science (CTS) at Princeton to hold a biannual workshop series on problems in inflationary cosmology. Ongoing work between researchers at PI and the Institute for Advanced Study (IAS) also led to a new series of workshops alternating between PI and IAS on N=4 supersymmetric gauge theory.

Computation is increasingly important in theoretical physics research for both numerical and analytical work. In 2009, PI entered into a five-year partnership with the Centro de Fisica do Porto (CFP) to hold an innovative annual summer school for theoretical physicists at all levels to learn *Mathematica*, a leading scientific software, while focusing on various topical research problems. The first edition, which focused on integrability and gauge/string dualities, a 'hot' topic with connections to condensed matter and mathematical physics, proved extremely popular.

PI is increasing its engagement with key experimental centres internationally, such as the LHC at CERN, the Planck satellite team, VISTA, VLT, the SKA and other observatories, and upcoming gravitational wave detectors such as LIGO and LISA. By encouraging PI postdoctoral fellows and faculty to visit these facilities and collaborate with observers and experimentalists, PI aims to stimulate new experimental and observational tests of fundamental theory.

Physics in Canada *Special Issue*

In 2009, PI was asked to author a special theme issue of Physics in Canada*, the peer-reviewed journal of the Canadian Association of Physicists (CAP). The resulting 'peek' inside Perimeter included 18 articles (including one in French) and has been enthusiastically received. The full issue is available for download at the CAP website: http://www.cap.ca/en/publications/physics-canada-pic/issue/66/2*

Since 2000, PI Outreach has...

- Held 110 on-location workshops for over 3,000 teachers across Canada and beyond on teaching concepts in modern physics
- Hosted 11 EinsteinPlus Teacher Workshops for 440 educators from Canada and 20 other countries, and developed a PI Teacher Network that provides peer-to-peer educator training
- Distributed over 4,500 Perimeter in-class resources (via hard kit and web downloads) featuring custom videos, worksheets, and teacher guides

PI By the Numbers

Over 470 students from across Canada and 25 countries around the world are ISSYP alumni. To learn more or to attend a "Virtual ISSYP" go to: www.issyp.ca

OUTREACH

Sharing the mystery, fun and importance of scientific research is one of the cornerstones of PI's mission, and has been since its inception. As the world becomes more inextricably tied to technology and the science behind it, the need for high quality scientific outreach becomes imperative.

PI's threefold strategy focuses on communicating the importance and power of theoretical research to the general public, developing young Canadians for the field, and serving as an international resource for outreach expertise through a variety of programs and resources. PI's Outreach team, which includes two PhDs, develops all materials in collaboration with leading scientists and educators to ensure content is accurate, cutting edge and accessible for the desired audiences.

INSPIRING YOUNG PEOPLE

It is estimated that 80% of future jobs will emerge from science, technology, engineering and mathematics; getting young people inspired about science is therefore critical. Science instills key skills: thinking for oneself, asking tough questions, devising solutions, testing them rigorously and openly. Best of all, science is fun.

Through outreach, PI strives to play a key role throughout Ontario and across Canada in seeding a culture that is not only scientifically literate, but also scientifically creative. With this in mind, Perimeter Outreach develops inspirational content for junior high school grades to get youth excited about physics, and more detailed content on modern physics for senior high school students.

Developed by Outreach scientist Dr. Richard Epp, ***Physica Phantastica*** provides entertaining and accessible introductions to modern physics in classrooms and science fairs across Canada, featuring images and animations to make abstract ideas come alive. These presentations have helped thousands of students see the connections between fundamental knowledge and technological innovations: last year, over 6,000 students across Canada participated in *Physica Phantastica*.

The **International Summer School for Young Physicists (ISSYP)** brings approximately 40 promising Canadian and international students aged 16 -18 to PI for two weeks each year. At a time when they are actively weighing career directions, they get a first-hand view of leading-edge research, including lessons on modern physics, mentoring sessions with top scientists, and lab tours. Last year, students were thrilled to visit SNOLAB, an experimental facility located deep underground in a northern Ontario mine.

"ISSYP was one of the best experiences of my life. It extended my knowledge greatly, and made me certain that physics is what I want to do for the rest of my life. Personally, meeting so many like-minded people was amazing, and I made friends I will never forget."

– 2007 ISSYP Participant Steffanie Freeman, now pursuing Physics degree at the University of Waterloo

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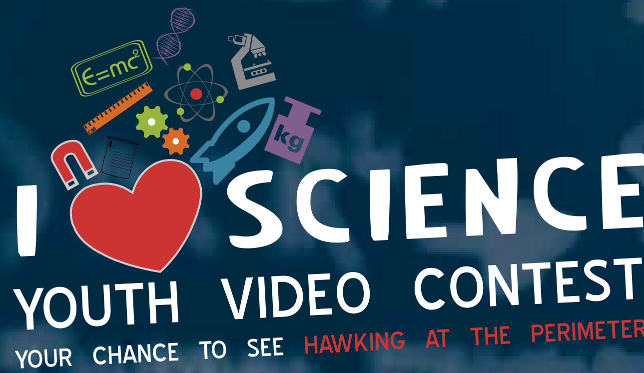
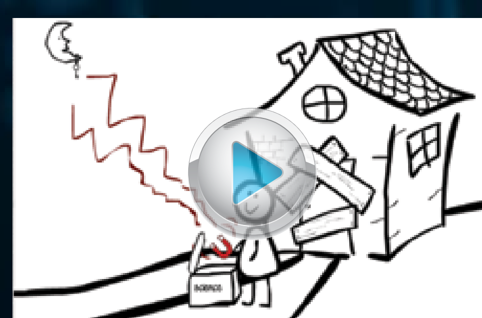
Science transcends national and cultural boundaries, and ISSYP reflects this. According to students, one of the most valuable aspects of the program is the fact that it brings together young people from all over the world who share a passion for science, forging lasting friendships and building cross-cultural bridges. In order to share the ISSYP experience more widely, **Go Physics!** provides intensive one-day 'mini-ISSYP' camps to keen students in Grades 11 and 12. Last year, six camps were held across Canada for approximately 30 students each time.

ISSYP participants at SNOLAB



"I Love Science" Youth Video Contest

The "I Love Science" video contest challenged youth to use their creative genius and – in 30 seconds or less – explain why they love science in thought-provoking and entertaining ways. Over 60 entries were received from students across Canada, and two grand prize winners received all-expenses paid round trips to Perimeter Institute, where they were part of the special "Hawking at the Perimeter" televised outreach broadcast.



PARTNERING WITH TEACHERS

Every summer, approximately 40 teachers from across Canada and around the world come to PI to attend the **EinsteinPlus National Teachers' Workshop** on modern physics. This one-week, intensive, residential workshop for high school educators focuses on how to better convey key concepts in modern physics. Last year, Outreach staff also delivered on-location workshops to educators in Canada and abroad at gatherings including the Science Teachers' Association of Ontario (STAO) conference, British Columbia's Science Teaching Catalyst conference, the Physics Teaching Resource Agents' (PTRA) annual Summer National Leadership meeting in Portland, Oregon, and a 'Mini-EinsteinPlus' at CERN in Switzerland for 40 European physics teachers from 30 countries.

"I am always impressed with the outreach that Perimeter is doing. Their Exploration packages have been very well designed and are full of activities and explanations that make them accessible to both teachers and students…The topics themselves are very advanced in concept but both the activities and explanations supplied make them easy for high school students to grasp."

– Patrick A Kossmann, Greenall High School, Balgonie, SK

A June 2010 CFI/Ipsos Reid study indicates that there is a critical window of opportunity between the ages of 12 and 18 in which to inspire young people about science.

"PI has had a huge effect on the physics curriculum in Ontario."

– Roberta Tevlin, Teacher and winner of the 2010 Canadian Association of Physicists Award for Excellence in Teaching High School Physics

PI's Teacher Network is extending the reach of our Outreach programs. Selected teachers from EinsteinPlus go on to conduct workshops with educators in their home districts on using PI resources in the classroom. This 'train the trainer' approach is rapidly scaling up the reach of our in-class resources across Canada – over the last year, the PI Teacher Network members gave 51 workshops in eight provinces and territories across Canada, reaching 1,011 more educators and at least 45,000 more students than PI staff could have served on their own. Outreach staff are now evaluating webinar technology as a vehicle for delivering teacher training cost-effectively to remote Canadian regions and internationally.

INSPIRATIONS AND EXPLORATIONS

"It is not only the best explanation of one of the great puzzles of modern science I have ever seen, it was hugely entertaining."

– Pioneering string theorist Leonard Susskind on The Challenge of Quantum Reality Explorations *Module*

Einstein lives inside every computer, GPS unit, and cell phone. With this in mind, *Inspirations* programming is designed to spark the interest and imagination of junior high school students by making connections between their everyday lives and fundamental physics, motivating them to continue to take math and science in Grades 11 and 12. The first module in the series, *Everyday Einstein: GPS and Relativity*, was released in July of 2010.

For senior high school students, *Explorations* modules delve deeper into more challenging ideas and technical content, providing excellent preparation for post-secondary education in math, science and engineering. Released last year, *The Challenge of Quantum Reality*, which includes a 30-minute video and teacher guide containing hands-on activities, was distributed to over 1,000 teachers.

A Growing Impact

Over 4,500 Explorations kits, including The Mystery of Dark Matter, The Challenge of Quantum Reality, *and* Measuring Planck's Constant *have been distributed across Canada and beyond. This translates to reaching 200,000 students annually, and continues year over year as each module is re-used.*

Surveys of teachers who attend PI workshops indicate that over 90% of attendees use the resources with their students.

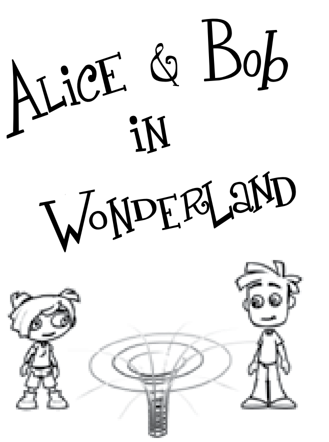
Developed by Outreach scientist Dr. Damian Pope, Everyday Einstein: GPS and Relativity *was released in 2010*

ONLINE RESOURCES

Beyond the classroom, PI Outreach offers a variety of high-quality online content that is scaling up our reach across Canada and around the world. ***Virtual ISSYP*** provides 'best of' content from the student summer camps that is accessible to students everywhere. ***The Power of Ideas*** is an interactive digital experience that demonstrates how discoveries and unifications in physics have in turn become the basis of powerful technologies. For students wondering what it might be like to be a scientist, over 30 ***Meet a Scientist*** video interviews give students personal stories and insights from researchers themselves.

"The Alice and Bob in Wonderland series' willingness to tackle oddball questions, instead of expected ones, is the ethos of PI distilled into cartoon form. Who knows, perhaps the cartoon will slyly influence kids to think outside the box – I love it! Bravo to the Perimeter Institute."

– scappucino, on PhysicsBuzz



Are you ready to question reality? Wonder about the universe with Alice & Bob at perimeterinstitute.ca/outreach

Released last year, ***Alice and Bob in Wonderland*** is a series of catchy one-minute animations created for junior and intermediate level students. Each episode starts with a deceptively simple question – for example, "Why is the sky blue?" In an age when kids can Google up answers with just a few clicks, these animations are designed to spark curiosity in young viewers and encourage them to use their own reasoning abilities to try to answer questions about the world around them. The popular series draws over 3,000 hits a month, and the project's next phase will develop classroom-ready resources around selected animations over the next three years.

COMMUNICATING THE FASCINATION AND IMPORTANCE OF SCIENCE TO THE PUBLIC

It's been called "the Woodstock of science festivals": the largest and most comprehensive science outreach festival ever held in Canada. From October 15-25, 2009, PI held *Quantum to Cosmos: Ideas for the Future*, an all-out celebration of the power and fun of scientific ideas, to mark PI's tenth anniversary.

Q2C brought people into the big tent of science – literally – with a 5,000 square foot exhibit centre filled with demonstrations, hands-on activities, experiments and an immersive 3-D tour of the universe narrated by PI Distinguished Research Chair Stephen Hawking. The festival's rich tapestry of events included lectures, panel discussions, pub talks, cultural activities, a documentary premiere, and a science film festival. Virtually all events were streamed live in high definition over the Internet.

The Quantum to Cosmos exhibit centre featured a scale model of the next Mars rover, Curiosity, supplied by NASA.

With 40,000 on-site and over one million TV and online viewers, *Q2C* tuned in and turned on vast new audiences of all ages and from all walks of life to the fascination of science and the power of theoretical physics.

"I'm thinking I'm going to want to learn some physics when I get older."

– Aaron E., aged 10, after attending PI's Quantum to Cosmos Science Festival

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Q2C *by the Numbers:*

1 documentary premiere of The Quantum Tamers: Revealing Our Weird & Wired Future

2 satellite events in Ottawa and Toronto

4 cultural events (3 concerts and 1 art talk)

5 nights of "The Agenda with Steve Paikin" broadcast live from PI's atrium

6 nights of Science in the Pub

14 science-inspired films

30 talks and panel discussions

79 presenters

120 tireless volunteers

5,000 square feet of exhibits and presentations

40,000 on-site attendees

Over 1,000,000 online and TV broadcast viewers

Check out www.q2cfestival.com

THE QUANTUM TAMERS: REVEALING OUR WEIRD & WIRED FUTURE BROADCAST DOCUMENTARY

Who says quantum mechanics isn't the stuff of prime time fun? Last year, PI released *The Quantum Tamers: Revealing Our Weird & Wired Future*, taking viewers from deep inside the sewers of Vienna to cutting-edge quantum computing labs to introduce key concepts in quantum mechanics and quantum information through an entertaining made-for-TV documentary, which features over a dozen leading scientists, including Stephen Hawking. *The Quantum Tamers* is viewable in 60 countries through global distribution to TV networks and educational groups, and has won four international film festival awards.

The Quantum Tamers *has won four international film festival awards:*

- Best of Show, TV Feature Documentary *at the Accolades Awards in La Jolla, California*
- Grand Jury Award for Best Documentary *at the Washington DC Independent Film Festival*
- *The* Prix Audace *at the Pariscience International Film Festival*
- *The* Golden Palm Award *at the Mexico International Film Festival*

"The Quantum Tamers reinvents the scientific documentary."

– Dr. Jozée Sarrazin, Grand Jury member, Pariscience International Film Festival

PUBLIC TALKS ON SCIENCE

From "The Galaxy Zoo" to "Top Quark: The Elusive Truth," PI Public Lectures share the intrigue and fascination of science, attracting standing-room only crowds of over 600 to each talk. The lectures are enjoyed by wider audiences through broadcasts on satellite and cable television stations and on-demand over Perimeter's website. Partnerships with broadcasters such as TVO and CBC Radio help share these talks with all Canadians. Last year, PI co-produced an episode of CBC Radio's *Quirks & Quarks* on the "Top Unanswered Questions in Physics," which has been heard by over 1 million CBC listeners via rebroadcasts and podcast downloads.

During his six-week visit to PI in June-July 2010, PI Distinguished Research Chair Stephen Hawking participated in PI Outreach with a talk about his life and research that was broadcast (in both English and French) on TVO, CPAC and via satellite viewable across Canada.

AN INTERNATIONAL RESOURCE

Most PI Outreach resources are placed online and are freely available throughout the world. In addition to sharing PI *Explorations*, ISSYP and other content over the Internet with young people internationally, Outreach team members also deliver on-location workshops at key gatherings of educators, such as the Physics Teaching Resource Agents, North America's largest physics education group. Last year, for the third year in a row, the team also delivered a 'Mini-EinsteinPlus' at CERN for 40 top European physics teachers drawn from over 30 countries.

PI also provides professional development activities and information for international journalists when requested. The Institute maintains close ties with the Canadian Association of Science Writers (CASW) and the World Federation of Science Journalists (WFSJ), and last year became a charter member of the new Science Media Centre of Canada (SMCC).

Participants at 2010 'Mini-EinsteinPlus' held at CERN in Switzerland.

A Tradition of Engaging Talks on Science

- *PI has held over 160 talks on science through its Public Lecture series and at festivals including* Quantum to Cosmos *and* EinsteinFest.
- *PI's 2009-10 Public Lecture season included:*

  "Searching for the Quantum Origins of Space and Time," given by Renate Loll, Utrecht University

  "The Science of Galaxy Zoo, or What 250,000 Astronomers Can Tell Us About the Universe," given by Chris Lintott, Oxford University

  "The Quantum World: From Weird to Wired," given by Joseph Emerson, Institute for Quantum Computing, University of Waterloo

  "The Robotic Scientist: Mining experimental data for scientific laws, from cognitive robotics to computational biology," given by Hod Lipson, Cornell University

  "Top Quark: The Elusive Truth," given by Michael Peskin, Stanford Linear Accelerator Laboratory

  "The Ubiquitous Bell Curve: What it Does and Doesn't Tell Us," given by John Mighton, Fields Institute, University of Toronto

- *To view past Public Lectures, go to: www.perimeterinstitute.ca/Outreach*

AIMS graduate Daphney Singo speaking at the 2010 TED Conference in Long Beach, California.

GLOBAL OUTREACH

AIMS NEXT EINSTEIN

PI seeks to act as a hub for theoretical physics internationally, and in this spirit, in 2009, PI launched a Global Outreach effort. The program's mandate is to share knowledge and expertise in research, training and outreach with innovative teaching and research centres in math and physics in the developing world. By building strong relationships with these emerging centres, the Institute ultimately aims to create a two-way flow of exceptional young researchers into Canada for training and research and back to their home countries with widely applicable skills.

PI Director Neil Turok with AIMS graduates Dessalegn Melesse (left), and Eric-Martial Takougang (right).

The African Institute for Mathematical Sciences-Next Einstein Initiative (AIMS-NEI, www.nexteinstein.org) has been adopted as the first focus of PI's global outreach efforts. Founded by PI's Director Neil Turok in 2003, AIMS is a pan-African centre of excellence which delivers advanced mathematical and scientific education to exceptional African graduates.

Outstanding lecturers from around the world train AIMS students to become independent thinkers and problem solvers with the advanced skills needed for a range of priority sectors in Africa. Since mathematics pervades every facet of modern economies, from finance, to computing, to transportation, to energy and health, the training that AIMS provides rapidly propels African development forward. Since 2003, the first AIMS centre has graduated over 300 students, over a third of them women, who are already making a substantial difference to the development of science across the continent.

In fall 2009, the Global Outreach team at PI submitted a proposal to the Canadian government to expand AIMS into a pan-African network of centres and to coordinate academic partners in the developed and developing world with aid agencies to ensure a sound, high impact investment.

On July 6, 2010, Prime Minister Stephen Harper announced during a visit to PI that Canada would provide $20 million in funding to support the establishment of five new AIMS centres across Africa, calling the plan a "revolutionary approach to international development."

By delivering targeted, high quality scientific training, these new AIMS centres will rapidly and dramatically increase science and technology capacity in Africa by developing the talent of its brightest young minds. PI is proud to have played a role in catalyzing this visionary investment.

"History shows that our world becomes safer, healthier and more stable through advances made in science and technology… That's why our government is supporting scientific and technological research, as well as development at home and abroad."

– Prime Minister Stephen Harper, during his July 2010 visit to PI, at which he announced $20 million in funding for AIMS-NEI, the centrepiece of PI's Global Outreach initiative

FACILITY

PI is located in the heart of Waterloo, Ontario, Canada. Its award-winning 65,000 square foot main building overlooks Silver Lake in Waterloo Park, and researchers can step out and enjoy contemplative walks through the park, or stroll to the restaurants, shops and cafés in Uptown Waterloo. The University of Waterloo and Wilfrid Laurier University are both located within a 10-minute walk. The PSI Masters training course and PI Outreach are housed nearby in a century-old clock tower building.

Designed with extensive input from scientists, PI's main building was conceived to actively foster research. There are three types of space throughout: quiet offices with an abundance of natural light to encourage contemplation; interactive 'think' spaces where researchers can spontaneously meet and discuss ideas; and formal areas, including a two-storey library, seminar rooms and a 200-seat theatre. Presentation spaces are wired to record talks, which are then archived on the Perimeter Institute Recorded Seminar Archive (PIRSA) and shared with the international research community over the Internet. Blackboards, the iconic tool of the theorist, are found everywhere throughout the building. Long after lectures have ended, many spirited scientific discussions continue at PI's excellent Black Hole Bistro, a welcoming meeting spot for the entire community.

The Stephen Hawking Centre at Perimeter Institute

To accommodate PI's expanding research, training, and outreach activities, *The Stephen Hawking Centre at Perimeter Institute* (SHC) is a 55,000 square foot addition to PI's main building, now under construction and scheduled to open in fall 2011.

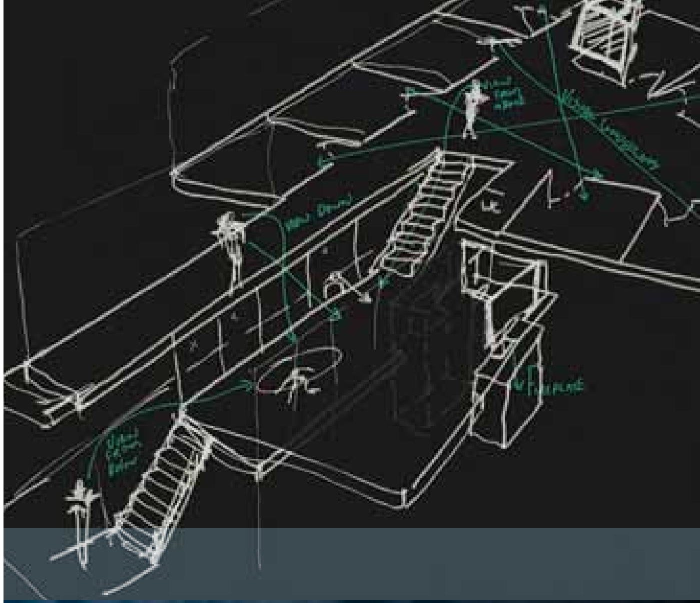
Governor General Award-winning firm Teeple Architects has designed the expansion such that it will nearly double PI's current research space, yet still retain the productive research environment and amenities featured in the original structure. When complete, the building will accommodate up to 250 researchers and students, all under one roof and operating as a single community. State-of-the-art IT infrastructure will support visualization, analysis of complex calculations, and remote collaboration with international colleagues to reduce the need for carbon-intensive travel.

The Stephen Hawking Centre at Perimeter Institute

Ontario's Ministry of Research and Innovation (MRI) and the Canada Foundation for Innovation (CFI) provided a total of $20.8 million toward the expansion, which has been matched by private funds raised by the Institute.

Construction is being managed by Ball Construction and, in spring 2010, the SHC project was certified as Ontario's first-ever 'Gold Seal project,' a national award for high quality construction. The project is also on track to attain LEED Silver certification for environmental sustainability.

When complete, the SHC will be a spectacular facility, designed not only to house research and training, but to optimize it.

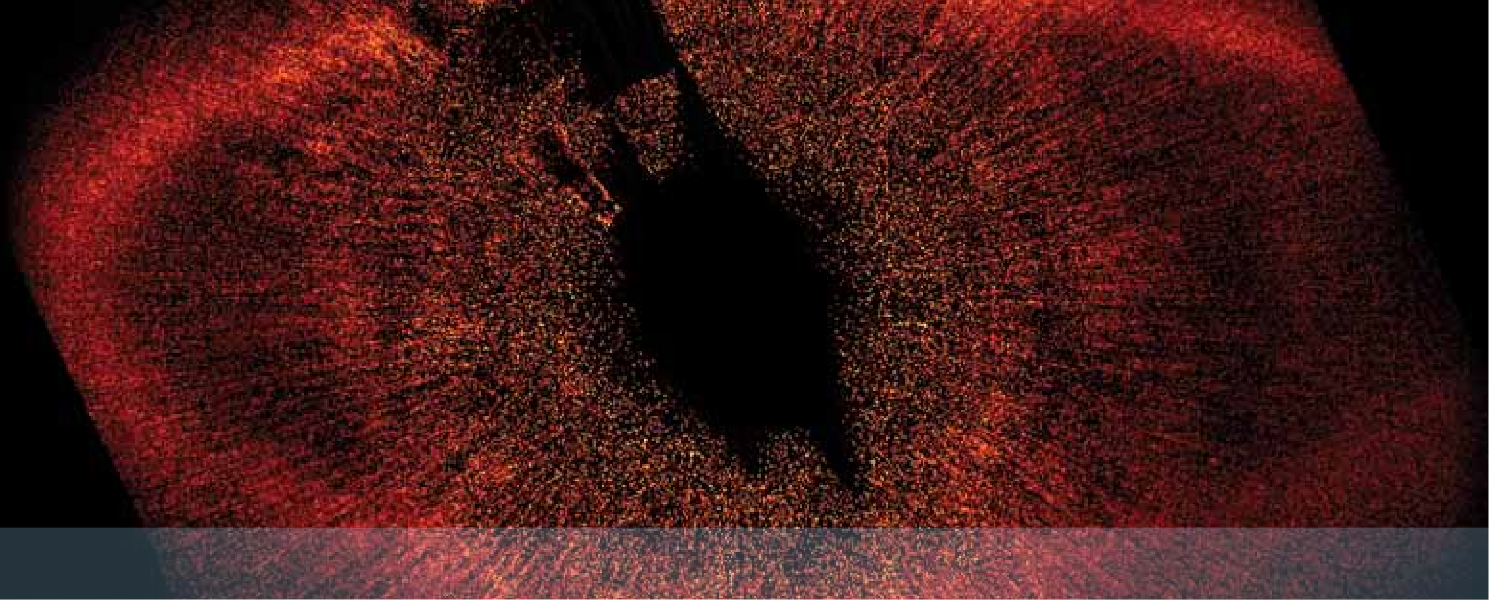


We were inspired by the challenges of this project. First, the existing PI facility is well-known as a remarkable architectural space, having won a Governor General's Medal in Architecture in 2006; therefore, we worked diligently to ensure that the expansion would improve upon its world-class reputation. Second, the expansion and existing building would need to interact and function as a singular whole, without greatly increasing the size of the building's footprint.

Achieving these goals required exceptional thoughtfulness and ingenuity. The addition 'hovers' such that it occupies virtually no additional site area, and merges the new and existing structures seamlessly. We created three central research pods, with postdoctoral and graduate offices to support independent research while enabling grads to have a visual link to their research partners. Interaction areas are situated at half levels between floors, to bring researchers from different areas together and to create acoustically separate zones. Finally, the Bistro was moved to the ground level, allowing for planned and spontaneous discussions immediately upon arrival into the building.

It is a unique design solution, and will be exciting, with dramatic three-dimensional experiences and engaging vistas from all areas.

– Stephen Teeple, Teeple Architects



EXPANDING THE PERIMETER

PI is grounded upon a unique public-private partnership that shares the opportunities, benefits and responsibility for long-term investment in fundamental research.

As PI looks to the future, it has embarked upon an ambitious strategic plan to fully establish itself as the world's foremost centre for foundational theoretical physics research, training and outreach. In support of this vision, during fall 2009, the Institute launched *Expanding the Perimeter*, a multi-year advancement initiative to build its endowment and broaden its base of private support. The campaign has set a target of $200 million as an initial goal.

In concert with PI's public partners, *Expanding the Perimeter* will enable PI to:

- Build a critical mass of scientific talent, capable of fostering fundamental breakthroughs
- Attract and train the world's brightest young research talents
- Build its innovative educational outreach programs, informing and inspiring students, teachers and the general public with the power and importance of scientific ideas

Leading the Way

The *Expanding the Perimeter* Leadership Council, led by PI Chair Mike Lazaridis and Vice-Chair Cosimo Fiorenza, was created to bring business and community together to assist others to understand the impact they can have on moving science forward through financial support of Perimeter Institute. We are honoured to have an exceptional group of volunteers leading the Council, which will continue to grow as new members are sought locally, nationally and abroad. We are grateful for their energy and dedication.

EXPANDING THE PERIMETER LEADERSHIP COUNCIL

Mike Lazaridis, *O.C., O.Ont.* *(Council Co-Chair)*	*Founder, Perimeter Institute and President & Co-CEO, Research in Motion Ltd. (RIM)*
Cosimo Fiorenza *(Council Co-Chair)*	*Vice Chair, Board of Directors, Perimeter Institute and Vice-President and General Counsel, Infinite Potential Group*
Alexandra (Alex) Brown	*President, Aprilage Inc.*
David Caputo	*President & CEO, Sandvine*
Jim Cooper	*President & CEO, Maplesoft*
Catherine (Kiki) Delaney, *C.M.*	*President, C.A. Delaney Capital Management Ltd.*
Arlene Dickinson	*CEO, Venture Communications Ltd.*
Ginny Dybenko	*Executive – Strategic Initiatives, Wilfrid Laurier University*
Jim Estill	*Partner, Canrock Ventures*
Edward S. Goldenberg	*Partner, Bennett Jones LLP*
Tim Jackson	*CEO, Accelerator Centre*
Tom Jenkins	*Executive Chairman & Chief Strategy Officer, Open Text*
Carol Lee	*CEO and Co-Founder, Linacare Cosmetherapy Inc.*
Michael Lee-Chin, *O.J.*	*Executive Chairman & CEO, Portland Investment Counsel Inc.*
Don Morrison	*Chief Operating Officer, Research in Motion Ltd.*
Gerry Remers	*President & COO, Christie Digital Systems Canada Inc.*
Bruce Rothney	*President & Country Head, Canada, Barclays Capital Canada Inc.*
Maureen Sabia	*Chairman of the Board, Canadian Tire Corporation Ltd.*
Kevin Shea	*Chair, Ontario Media Development Corporation*

THANKS TO OUR SUPPORTERS

Perimeter Institute wishes to thank the following individuals and federal, provincial and municipal government representatives for recognizing the need to invest in foundational scientific research, training and outreach:

FOUNDING DONORS

Mike Lazaridis
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Doug Fregin

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The Government of Ontario
The Honourable Dalton McGuinty, Premier
The Honourable Glen Murray, Minister of Research and Innovation
The Honourable John Milloy, Minister of Training, Colleges and Universities
(formerly Minister of Research and Innovation)

The City of Waterloo
Mayor Brenda Halloran and the Waterloo City Council

Perimeter Institute wishes to thank the following organizations and individuals for their generous support over the last year:

BMO Financial Group
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The Ministry of Research and Innovation
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Murray Shephard
Henry Slofstra
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Nancy Theberge
Stephen E. Traviss
United Way
Helen Waind
Washington Federal
Peter Woolstencroft

LOOKING AHEAD: PRIORITIES AND OBJECTIVES FOR THE FUTURE

In the coming year, the Institute will continue to advance its core mission and goals, based upon the following strategic objectives:

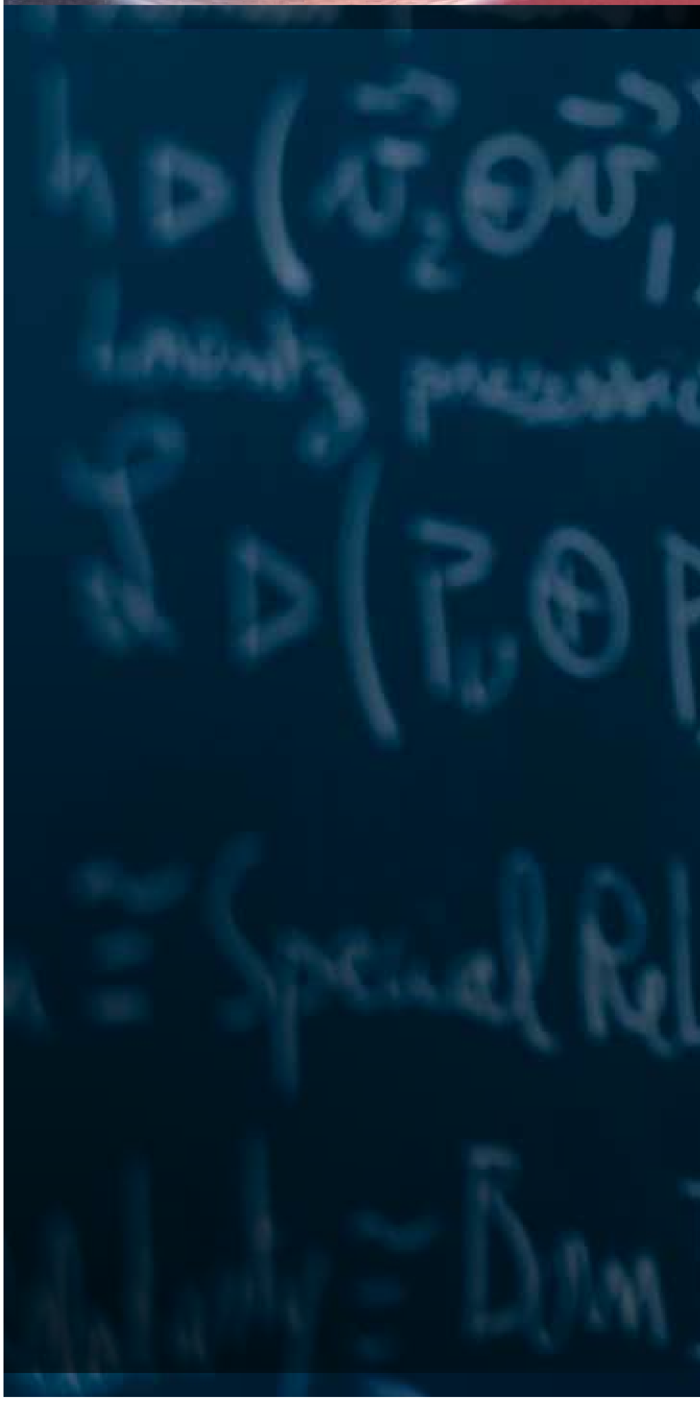
Deliver world-class research discoveries by continuing to focus on advancing fundamental research across PI's research areas, encouraging complementary and multidisciplinary approaches, and instilling a collaborative atmosphere which maximizes cross-fertilization of ideas and increases the probability of breakthroughs.

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

Create the world's best environment and infrastructure for theoretical physics research, training and outreach through completion of *The Stephen Hawking Centre at Perimeter Institute*.

Generate a flow-through of the most promising talent by recruiting top-calibre 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.

Become the 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.



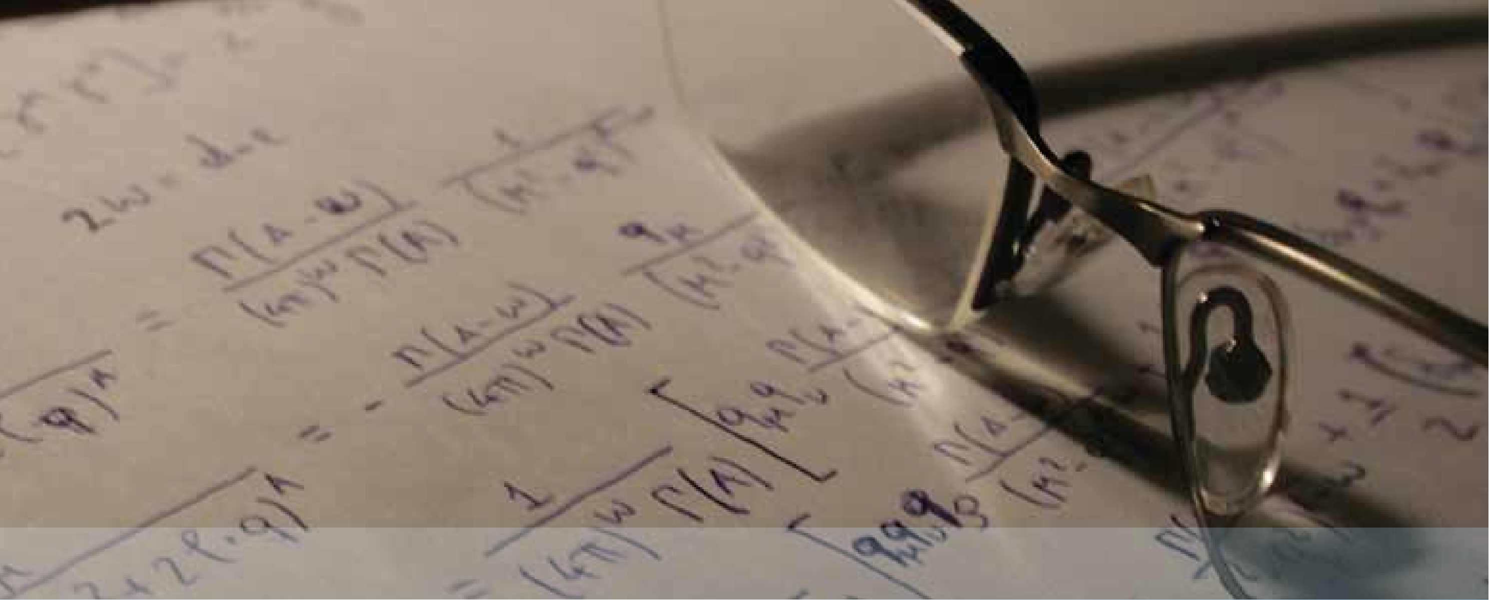
Act as a hub for a network of theoretical physics centres around the world seeking partnership and collaboration opportunities that can help accelerate the creation of centres of excellence in math and physics.

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 between Faculty members and Affiliates across the country.

Host timely, focused conferences, workshops, seminars and courses focusing on cutting-edge topics, as well as through an active seminar program and delivery of advanced courses.

Engage in high impact outreach by communicating the importance of basic research and the power of theoretical physics to general audiences, providing unique opportunities and high quality resources to educators and students.

Continue to build on PI's highly successful public-private partnership funding model.



FINANCIALS

MANAGEMENT DISCUSSION AND ANALYSIS OF FINANCIAL RESULTS

Results of Operations

The 2010 fiscal year saw Perimeter Institute continue to make good progress on all its initiatives, increasing its investment in research by over 18% in accordance with the priorities set out in its ambitious Five Year Plan.

As in past years, both public and private monies continued to support the operational activities of the Institute in 2010.

In addition to operational revenue provided through granting agreements with the provincial and federal governments, new infrastructure revenue of $7.6 million was recognized related to grants received from the Canada Foundation for Innovation (CFI) and the Ministry of Research and Innovation (MRI). This revenue forms part of a commitment of $10.375 million from each of CFI and MRI made in 2009 toward the construction and infrastructure costs of *The Stephen Hawking Centre at Perimeter Institute*.

Donations represent the commitment of private stakeholders to PI's mission. Reflected in the prior year donations are gifts totalling $40 million, a significant portion of which were earmarked towards the costs of the expansion project incurred during 2010.

Recognition of public funding in the financial statements is identified as government grant revenue and, in accordance with our revenue recognition policy, is recorded in the year the funds are received or receivable. Disclosure of the revenue recognition policy avoids incorrect interpretations when comparing grant revenue of 2009-10 to that of 2008-09. While the current year reflects federal government grant revenue of $10 million, 2008-09 identifies only $5 million with the remaining $5 million received in advance and accordingly included in 2007-08 statements.

Continued success towards achieving the goals outlined in the Five Year Plan is reflected in the $1.7 million increase in research expenditures, more specifically costs relating to a full year's implementation of new programs such as Perimeter Scholars International and the Distinguished Research Chairs.

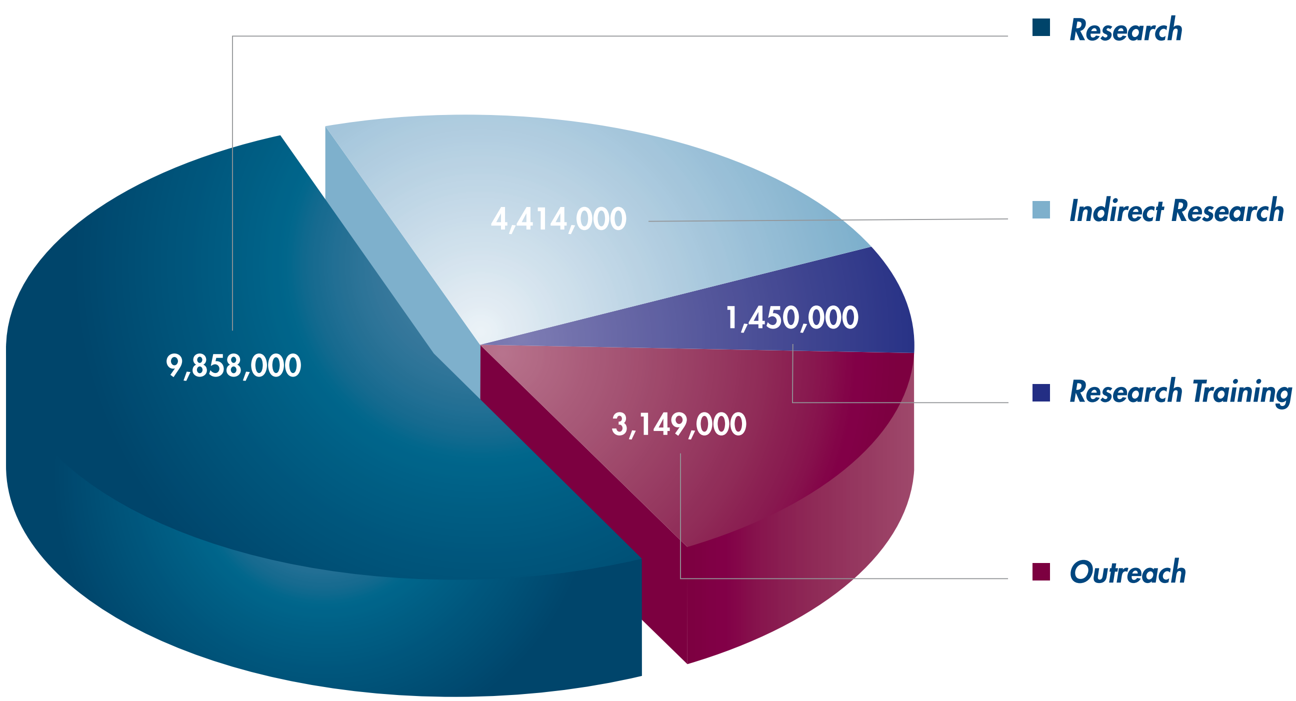
Outreach expenditures reflect PI's ongoing commitment to educational products and programs. In 2010 these expenditures included delivering PI's *Quantum to Cosmos Festival*, and releasing a full length broadcast documentary, *The Quantum Tamers*, among various other activities and events provided for students, teachers and the general public.

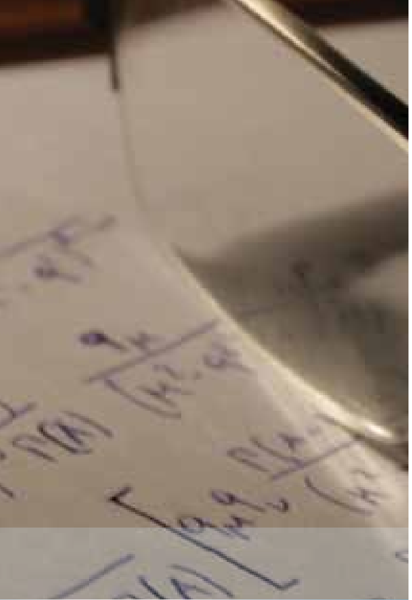
Indirect research and operations expenses account for 23% of the total operating expenditures of the Institute and cover the costs of core support areas including administration, information technology, and facilities. Costs pertaining to the Institute's *Expanding the Perimeter* development campaign were also included in this category and primarily account for the increase over the prior year.

In 2009, PI was not immune to the financial crisis and suffered investment losses, which were comparable to those suffered by domestic and global indices. Strong oversight, a cohesive investment strategy and a balanced portfolio resulted in a recovery of some of the previous year's losses to the endowment fund with PI experiencing investment gains of over 5% or $11.4 million in 2010.

OPERATING EXPENDITURE SUMMARY

For the year ended July 31, 2010.





Balance Sheet

The balance sheet reflects an exceptionally strong working capital position. This position allows PI to act quickly on targets of opportunity, giving the Institute a considerable competitive advantage in accelerating its research and outreach goals.

With PI's expansion project well underway in 2010, an increase of $9.5 million to Property and Equipment over the prior year is reflected. Accordingly there was an increase of $3 million to Accounts Payable and Accrued Liabilities pertaining to building construction costs (for which there exists a commitment of $19 million).

Bank indebtedness was unutilized at year end; however, it is strategically used occasionally throughout the year as a temporary measure, while consciously targeting optimization of working capital.

The endowment fund primarily allows for the accumulation of private funds to address the future needs of PI. The $211 million fund consists of a portfolio mix of domestic equities, international equities, fixed income and alternative investments specifically designed in accordance with PI's risk return objectives.

Risks and Uncertainties

Perimeter Institute exists through a cooperative and highly successful public-private partnership that provides for ongoing operations while safeguarding future opportunities. Private partners and the Governments of Canada and Ontario have recognized PI's value through sustained investment, building on a partnership which has gained global recognition as a model for sharing the opportunities, benefits, and responsibility for long-term investment in fundamental research.

The funding model to date has included investment by the Government of Ontario of approximately $90 million, by the Government of Canada of approximately $90 million and by the private sector of over $180 million.

During fiscal 2010, multi-year funding commitments from the provincial and federal governments remained in place, removing uncertainty through March 2011 (provincial commitment) and March 2012 (federal commitment). PI is actively seeking to renew these public sector funding commitments. While the Institute has met and exceeded its public funding requirements in the past and all indications are that it is perceived by government as an excellent investment, there is no guarantee of future funding.

Perimeter Institute is also seeking to raise additional funds from the private sector through *Expanding the Perimeter*, an ambitious endowment campaign which aims to double endowment assets over the coming years.

Private sector donations are protected in an endowment fund designed to maximize growth and minimize risk in order to contribute to the strongest possible long-term financial health of the Institute. Although the endowment is invested in a diversified portfolio and managed by an active investment committee of experts, market values do vary over time.

ZEIFMANS
LLP
CHARTERED ACCOUNTANTS

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www.zeifmans.ca

AUDITORS' REPORT

To the Directors of
Perimeter Institute

The accompanying summarized statement of financial position and operations and changes in fund balances are derived from the complete financial statements of Perimeter Institute as at July 31, 2010 and for the year then ended on which we expressed an opinion without reservation in our report dated September 24, 2010. 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 24, 2010

Chartered Accountants
Licensed Public Accountants

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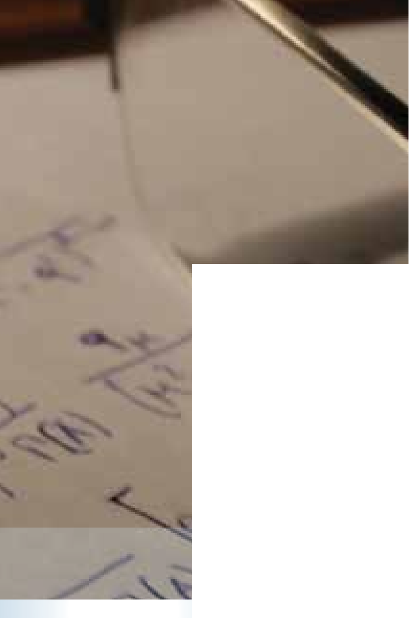


PERIMETER INSTITUTE

(Incorporated Under the Laws of Canada Without Share Capital)

SUMMARIZED STATEMENT OF FINANCIAL POSITION AS AT JULY 31, 2010

ASSETS

	2010 Total	2009 Total
Current assets:		
Cash and cash equivalents	$ 5,063,149	$ 4,270,695
Investments	209,002,595	207,877,993
Government grants receivable	3,611,299	5,072,000
Other current assets	1,169,549	1,476,919
	218,846,592	218,697,607
Other receivable	29,938	57,024
Property and equipment	38,197,202	28,656,950
TOTAL ASSETS	$ 257,073,732	$ 247,411,581

LIABILITIES AND FUND BALANCES

	2010 Total	2009 Total
Current liabilities:		
Bank indebtedness	$ ---	$ 3,275,000
Accounts payable and other current liabilities	4,916,602	1,959,209
TOTAL LIABILITIES	$ 4,916,602	$ 5,234,209
Fund balances		
Invested in capital assets	38,114,396	28,069,304
Externally restricted	136,180,155	131,019,937
Internally restricted	77,409,778	82,903,934
Unrestricted	452,801	184,197
TOTAL FUND BALANCES	$ 252,157,130	$ 242,177,372
	$ 257,073,732	$ 247,411,581

ZEIFMANS LLP
CHARTERED ACCOUNTANTS

PERIMETER INSTITUTE
SUMMARIZED STATEMENT OF OPERATIONS AND CHANGES IN FUND BALANCES
FOR THE YEAR ENDED JULY 31, 2010

	2010 Total	2009 Total
Revenue:		
Government grants	$ 18,072,639	$ 5,588,200
Donations	625,753	40,087,038
Other income	435,366	125,000
	19,133,758	45,800,238
Expenditures:		
Research	$ 11,308,093	$ 9,643,807
Outreach	3,148,718	3,151,042
Indirect research and operations	4,414,583	3,706,447
TOTAL OPERATING EXPENDITURES	$ 18,871,394	$ 16,501,296
Excess of revenue over expenses before investment income (loss) and amortization	262,364	29,298,942
Amortization	(1,656,934)	(1,763,308)
Investment income (loss)	11,374,328	(49,432,440)
Excess of revenue over expenses (expenses over revenue)	9,979,758	(21,896,806)
Fund balances, beginning of year	242,177,372	264,074,178
FUND BALANCES, END OF YEAR	$ 252,157,130	$ 242,177,372

ZEIFMANS LLP
CHARTERED ACCOUNTANTS

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 Institute's 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 Director and is in charge of day-to-day operations. Support for the COO is provided by a team of 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 Director.

The Scientific Advisory Committee (SAC), composed of eminent scientists drawn from the international community, is an integral oversight body, created to assist the Board of Directors and the Director to ensure objectivity and a high standard of scientific excellence.

BOARD OF DIRECTORS

Mike Lazaridis, O.C., O.Ont., Chair, is Founder, President and Co-CEO of Research In Motion Ltd. (RIM). A visionary, innovator and engineer of extraordinary talent, he is the recipient of many technology and business awards. At RIM, Mr. Lazaridis leads R&D, product strategy and manufacturing for the world-renowned BlackBerry® wireless solution.

Donald W. Campbell is the senior strategy advisor at Davis LLP. Prior to joining Davis, he was Executive Vice-President of CAE Inc., where he led the company's world-wide government procurement activities. Mr. Campbell joined CAE after a distinguished career with Canada's Department of Foreign Affairs and International Trade, including serving as Canada's Ambassador to Japan.

Ken Cork is President of Sentinel Associates Ltd. He is a past Senior Vice-President of Noranda Inc. and former Director of numerous organizations including Empire Life, The Bank of Nova Scotia, University of Toronto Press and Dominion of Canada General Insurance Company. He is a Director of Scotia Investments; an Honorary Director of The Bank of Nova Scotia; and a Director Emeritus of Research in Motion. Mr. Cork retired from PI's Board July 31, 2010.

Cosimo Fiorenza, Vice Chair and member of the Finance Committee, is the Vice-President and General Counsel of the Infinite Potential Group. He is actively involved at several public and private non-profit and charitable institutions in addition to Perimeter Institute, including the Law Society of Upper Canada, the Centre for International Governance Innovation, the Institute for Quantum Computing, and several private family foundations. Mr. Fiorenza holds a degree in Business Administration from Lakehead University and a law degree from the University of Ottawa.

Peter Godsoe, O.C., O.Ont., is a former Chairman of Scotiabank, from which he retired in March 2004. He holds a B.Sc. in Mathematics and Physics from the University of Toronto, an M.B.A. from the Harvard Business School, and is a C.A. and a Fellow of the Institute of Chartered Accountants of Ontario. Mr. Godsoe holds honourary degrees from University of King's College (1993), Concordia University (1995), University of Western Ontario (2001) and Dalhousie University (2004). In 2002, he became a member of the Canadian Business Hall of Fame and an Officer of the Order of Canada and in 2010 he was honoured with the Order of Ontario. Mr. Godsoe remains active throughout a wide range of corporate boards and non-profit directorships.

Kevin Lynch, PC, is a distinguished former public servant with 33 years of service with the Government of Canada. Most recently, Dr. Lynch was the Clerk of the Privy Council, Secretary to the Cabinet and Head of the Public Service of Canada. His prior roles include Deputy Minister of Finance, Deputy Minister of Industry and Executive Director of the International Monetary Fund.

Dr. Steven MacLean is President of the Canadian Space Agency (CSA). A physicist by training, in 1983 he was selected as one of the first six Canadian astronauts and he has participated in missions on the Space Shuttles Columbia (1992) and Atlantis (2006) to the International Space Station. In addition to senior roles within the CSA and extensive experience with NASA and the International Space Station, he is a strong supporter of science literacy and child education.

John Reid is a Senior Partner with KPMG responsible for managing the Ontario Region. He mainly focuses on mergers and acquisitions, high technology and health care. Mr. Reid is the Chairman of the Grand River Hospital Board of Directors and a member of the Board of Governors of Conestoga College of Applied Arts and Technology.

Douglas T. Wright, O.C., is President Emeritus and Adjunct Professor of Engineering at the University of Waterloo. His numerous honours include becoming an Officer in the Order of Canada, and a Chevalier dans l'Ordre National du Merite de France, and receiving the Gold Medal of the Canadian Council of Professional Engineers. Mr. Wright retired from PI's Board July 31, 2010.

In Memoriam: Lynn Watt, PI Board Member, 2000-2010

Professor Lynn Watt was a founding member of Perimeter Institute's Board of Directors, and contributed to the Institute's development from its inception until his passing in July 2010. Dr. Watt enjoyed a distinguished career as a Professor of Electrical and Computer Engineering at the University of Waterloo, where he served in several leadership positions, including Dean of Graduate Studies. He was also Chairman and Executive Vice-Chairman of the Ontario Council on Graduate Studies, President of the Canadian Association of Graduate Schools, and a member of the Natural Sciences and Engineering Research Council (NSERC) Committee on Grants and Scholarships. Dr. Watt was also Coordinator of the Ontario Centres of Excellence, Coordinator of the Group of Ten, Policy Analyst for Industry Science and Technology Canada, and a member of several provincial and federal committees dealing with graduate studies and research. His distinctions included an Honourary D. Eng from Carleton University, and the Honourary Member Award from the University of Waterloo.

SCIENTIFIC ADVISORY COMMITTEE

Gerard Milburn, Chair, University of Queensland (joined 2007). Professor Milburn's research interests include quantum optics, quantum measurement and stochastic processes, quantum information and quantum computation. He has published over 200 papers in international journals, with over 6,000 citations. He is also the author or co-author of several books, two of which seek to explain quantum phenomena and their potential to a general audience.

Abhay Ashtekar, Pennsylvania State University (joined 2008). Professor Ashtekar is Eberly Professor of Physics and the Director of the Institute for Gravitational Physics and Geometry at Pennsylvania State University. As the creator of Ashtekar variables, he is one of the founders of loop quantum gravity. He has written a number of descriptions of loop quantum gravity that are accessible to non-physicists.

Sir Michael Berry, University of Bristol (joined 2009). Sir Michael Berry is Professor Emeritus at Bristol University. He has made numerous important contributions to semi-classical physics (asymptotic physics, quantum chaos) applied to wave phenomena in quantum mechanics and other areas such as optics. Among other work, he is well-known for the Berry phase, a phenomenon which has found applications in atomic, condensed matter, nuclear, and elementary particle physics, as well as optics. He was elected a fellow of the Royal Society of London in 1982, and was knighted in 1996. Sir Berry's previous honours include the Dirac Medals of both the Institute of Physics (1990) and the ICTP (1996), the Lilienfeld Prize (1990), the Wolf Prize (1998) and the London Mathematical Society's Polya Prize (2005).

Matthew Fisher, California Institute of Technology (joined 2009). Professor Fisher is a condensed matter theorist whose research has focused on strongly correlated systems, especially low-dimensional systems, Mott insulators, quantum magnetism and the quantum Hall effect. In 1995, he received the Alan T. Waterman Award from the National Science Foundation, and he has also been the recipient of the National Academy of Sciences Award for Initiatives in Research (1997). In 2003, he was elected as a Member of the American Academy of Arts and Sciences. Professor Fisher has over 150 publications.

Gerard 't Hooft, Utrecht University (joined 2008). Professor 't Hooft's research focuses on gauge theories in elementary particle physics, quantum gravity and black holes, and fundamental aspects of quantum physics. In addition to the Ben Franklin Medal, Professor 't Hooft's contributions to science have been recognized with many awards, including the 1999 Nobel Prize in Physics, with the citation "for elucidating the quantum structure of electroweak interactions in physics."

Igor R. Klebanov, Princeton University (joined 2007). Professor Klebanov's research has touched on many aspects of theoretical physics and is presently centred on relations between superstring theory and quantum field theory. He is currently Thomas D. Jones Professor of Mathematical Physics at Princeton University. He has made many highly regarded contributions to the duality between gauge theories and strings.

Michael Peskin, Stanford Linear Accelerator Center (joined 2008). Professor Peskin's research interests include all aspects of theoretical elementary particle physics, but particularly the nature of new elementary particles and forces that will be discovered at the coming generation of proton and electron colliders. He was a Junior Fellow at the Harvard Society of Fellows from 1977-80 and was elected to the American Academy of Arts and Sciences in 2000. He is co-author of a popular textbook on quantum field theory.

John Preskill, California Institute of Technology (joined 2009). Professor Preskill is the Richard P. Feynman Professor of Theoretical Physics and the Director of the Institute for Quantum Information at the California Institute of Technology (Caltech). Until the mid-1990s, Professor Preskill's research focused on elementary particles, cosmology, and gravitation. His many contributions include work on superheavy magnetic monopoles in the early universe which led to the inflationary universe, the proposal that axions may comprise the universe's cold dark matter, and the theory of local discrete symmetries. Since the mid-1990s, his research has focused on mathematical issues related to quantum computation and quantum information theory. Among his numerous honours, Professor Preskill is a past Alfred P. Sloan Fellow, a two-time recipient of the Associated Students of Caltech Teaching Award, and an elected Fellow of the American Physical Society. He was also the Morris Loeb Lecturer at Harvard University in 2006.

David Spergel, Princeton University (joined 2009). Professor Spergel is the Charles Young Professor of Astronomy at Princeton, as well as the Chair of the Department of Astrophysical Sciences. He is known for his work on the Wilkinson Microwave Anisotropy Probe (WMAP) mission. Professor Spergel is a MacArthur Fellow as well as a member of the US National Academy of Sciences. He is currently the chair of the Astrophysics Subcommittee of the NASA Advisory Council. He was co-awarded the 2010 Shaw Prize in Astronomy, along with Charles L. Bennett and Lyman A. Page Jr. for his leadership of the WMAP experiment, which has enabled precise determinations of the fundamental cosmological parameters, including the geometry, age and composition of the universe.

Emeritus Scientific Advisory Committee

Ian Affleck [2001-2004]
University of British Columbia

Artur Ekert [2001-2008]
University of Cambridge

James Hartle [2001-2003]
University of California, Santa Barbara

Christopher Isham [2001-2005]
Imperial College London

Cecilia Jarlskog [2001-2006]
CERN, Lund Institute

Sir Anthony Leggett [2004-2008]
University of Illinois (2003 Nobel Laureate)

Sir Roger Penrose [2001-2007]
University of Oxford

Joseph Polchinski [2001-2004]
University of California, Santa Barbara

Jorge Pullin [2003-2007]
Louisiana State University

Paul Steinhardt [2003-2007]
Princeton University

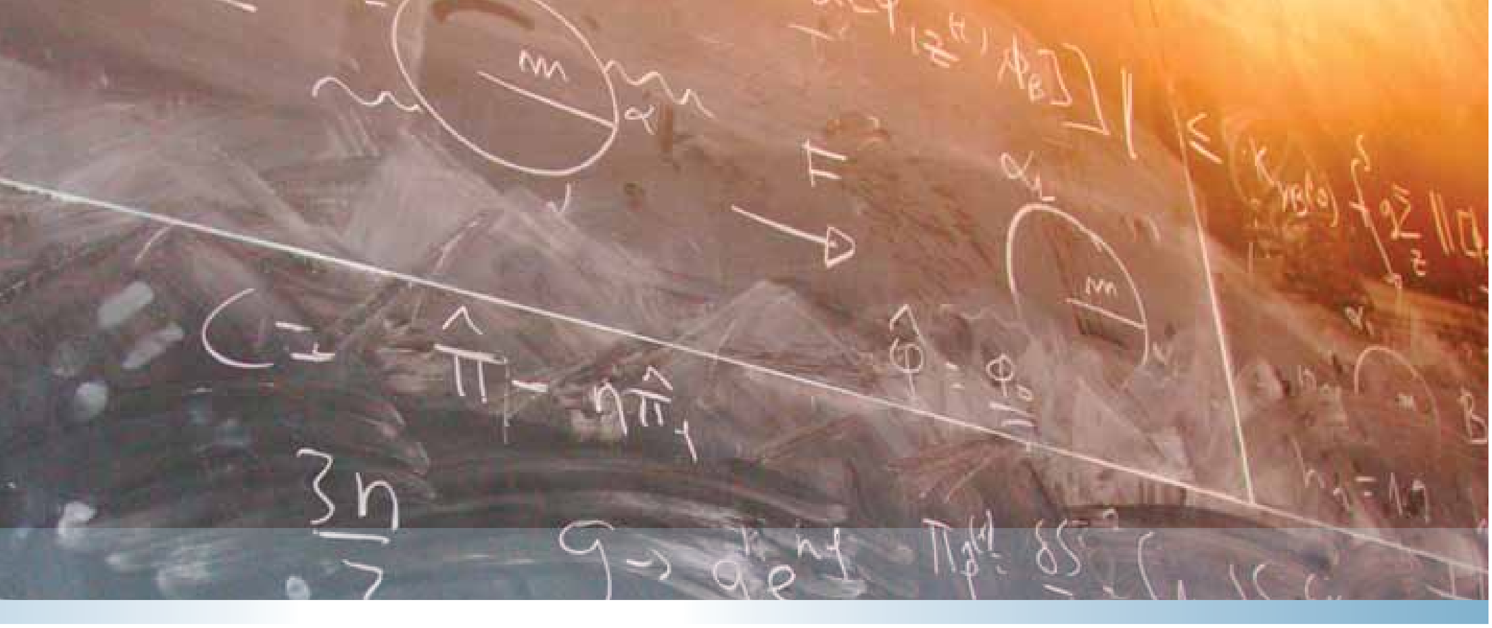
Scott Tremaine [2001-2006]
Princeton University

Neil Turok [2008]
University of Cambridge

Frank Wilczek [2003-2007]
Massachusetts Institute of Technology
(2004 Nobel Laureate)

Founding Executive Director

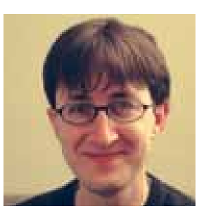
Howard Burton [1999-2007]



APPENDICES

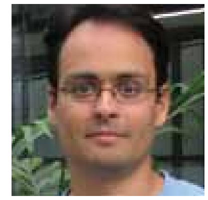
FACULTY

Neil Turok (PhD Imperial College, 1983) is the Director and a senior Faculty member at Perimeter Institute. Upon completing his PhD, he held a postdoctoral fellowship in Santa Barbara and was then an Associate Scientist at Fermilab before moving to Princeton University, where he became Professor of Physics in 1994. In 1997, he was appointed to the Chair of Mathematical Physics in the Department of Applied Mathematics and Theoretical Physics (DAMTP) at the University of Cambridge. In October 2008, he joined Perimeter Institute as its Director. Among his many honours, Professor Turok was awarded Sloan and Packard Fellowships and the 1992 James Clerk Maxwell medal of the UK Institute of Physics. In 2009, he was named a Canadian Institute for Advanced Research (CIFAR) Fellow in the Cosmology and Gravitation program. Professor Turok has worked in a number of areas of theoretical physics and cosmology, focusing on developing fundamental theories and new observational tests. Highlights of his research include showing how the polarization and temperature anisotropies of the cosmic background radiation would be correlated, developing a key test for the presence of the cosmological constant, formulating the Hawking-Turok instanton solutions describing the birth of inflationary universes, and advancing a cyclic model for cosmology, according to which the big bang is explained as a collision between two 'brane-worlds' in M-theory. Born in South Africa, Professor Turok founded the African Institute for Mathematical Sciences (AIMS) in Cape Town in 2003, a postgraduate educational centre that supports the development of mathematics and science across the African continent. For this work and his contributions to theoretical physics, he was awarded the TED Prize and a "Most Innovative People" award at the 2008 World Summit on Innovation and Entrepreneurship (WSIE).



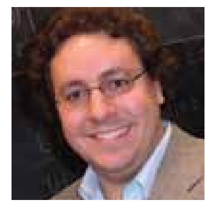
Latham Boyle (PhD Princeton, 2006) joined PI as a junior Faculty member in 2010. From 2006-2009, Dr. Boyle held a Canadian Institute for Theoretical Astrophysics (CITA) Postdoctoral Fellowship; he is also a Junior Fellow of the Canadian Institute for Advanced Research (CIFAR). Dr. Boyle has studied what gravitational wave measurements can teach us about the beginning of the universe; his specific areas of focus include understanding black hole mergers, the theory of primordial inflation, and low-frequency gravitational wave detectors.

Freddy Cachazo (PhD Harvard, 2002) has been a Faculty member at PI since 2005. From 2002-2005, he was a Member of the School of Natural Sciences at the Institute for Advanced Study in Princeton. Dr. Cachazo is one of the world's leading experts in the study and computation of scattering amplitudes in quantum chromodynamics (QCD) and N=4 super Yang-Mills (MSYM) theories. In 2007, he was awarded an Early Researcher Award and, in 2009, he was awarded the Gribov Medal of the European Physical Society.

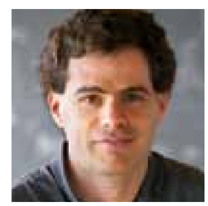


Laurent Freidel (PhD, L'École Normale Supérieure de Lyon, 1994) joined Perimeter Institute in September 2006. Dr. Freidel is a mathematical physicist who has made many notable contributions in the field of quantum gravity; he possesses outstanding knowledge of a wide range of areas including integrable systems, topological field theories, 2d conformal field theory and quantum chromodynamics. Dr. Freidel has held positions at Penn State University and L'École Normale and has been a member of France's Centre National de la Recherche Scientifique (CNRS) since 1995. Dr. Freidel is also the recipient of several awards including two ACI-Blanche grants in France.

Jaume Gomis (PhD Rutgers, 1999) joined Perimeter Institute in 2004, declining a European Young Investigator Award by the European Science Foundation to do so. Prior to that, he worked at the California Institute of Technology as a Postdoctoral Scholar and as the Sherman Fairchild Senior Research Fellow. His main areas of expertise are string theory and quantum field theory. In 2009, Dr. Gomis was awarded an Early Researcher Award for a project aimed at developing new techniques for describing quantum phenomena in nuclear and particle physics.

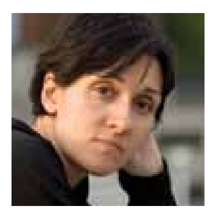


Daniel Gottesman (PhD Caltech, 1997) joined PI's faculty in 2002. From 1997-2002, he held postdoctoral positions at Los Alamos National Lab, Microsoft Research, and UC Berkeley (as a long-term CMI Prize Fellow for the Clay Mathematics Institute). Dr. Gottesman has made seminal contributions which continue to shape the field of quantum information science through his work on quantum error correction and quantum cryptography. He is also a Fellow in CIFAR's Quantum Information Processing program.



Lucien Hardy (PhD Durham University, 1992) joined PI as a Faculty member in 2002, having previously held research and lecturing positions at various European universities including the University of Oxford, La Sapienza University, the University of Durham, the University of Innsbruck, and the National University of Ireland. In 1992, he found a very simple proof of non-locality in quantum theory which has become known as Hardy's theorem. He currently works on characterizing quantum theory in terms of operational postulates and applying the insights obtained to the problem of quantum gravity.

Fotini Markopoulou (PhD Imperial College, 1998) joined PI as one of its first Faculty members in 2001, prior to which she held postdoctoral positions at the Albert Einstein Institute (2000-2001), Imperial College London (1999-2000), and Penn State University (1997-1999). Dr. Markopoulou is a past recipient of First Prize in the Science and Ultimate Reality Young Researchers Competition in honour of J.A. Wheeler (2001). She currently holds an Alexander von Humboldt Fellowship for Experienced Researchers at the Albert Einstein Institute in Germany.



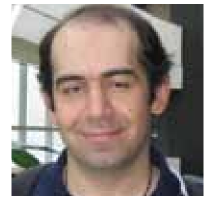
Robert Myers (PhD Princeton, 1986) is one of the leading theoretical physicists working in string theory in Canada. After attaining his PhD, he was a postdoctoral researcher at the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara. He moved to McGill University in 1989, where he was a Professor of Physics until moving to Perimeter Institute in 2001. Among Dr. Myers' many honours, he received the Herzberg Medal in 1999 for seminal contributions to our understanding of black hole microphysics and D-branes, won the 2005 CAP-CRM Prize, and is a Fellow of the Cosmology and Gravity program of the Canadian Institute for Advanced Research (CIFAR).

Lee Smolin (PhD Harvard, 1979) is one of Perimeter Institute's founding Faculty members. Prior to joining PI, Professor Smolin held postdoctoral positions at the Institute for Advanced Study, Princeton, the Institute for Theoretical Physics, Santa Barbara, and the Enrico Fermi Institute at the University of Chicago, and was a professor at Yale, Syracuse and Penn State Universities. Professor Smolin's research is centred on the problem of quantum gravity, with particular focus on loop quantum gravity and deformed special relativity, though his contributions span many areas. Professor Smolin's many honours include the Majorana Prize, the Klopsteg Memorial Award, and election as a Fellow of both the American Physical Society and the Royal Society of Canada.

Robert Spekkens (PhD University of Toronto, 2001) joined PI's faculty in 2008, after holding a postdoctoral fellowship at PI and an International Royal Society Fellowship at the University of Cambridge. Dr. Spekkens' research is focused upon identifying the conceptual innovations that distinguish quantum theories from classical theories and investigating their significance for axiomatization, interpretation, and the implementation of various information-theoretic tasks. He is a previous winner of the Birkhoff-von Neumann Prize of the International Quantum Structures Association.

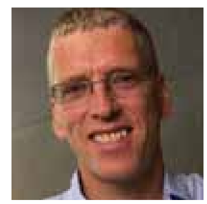
Pedro Vieira (PhD École Normale Supérieure Paris and the Centro de Fisica do Porto, Universidade do Porto, 2008) joined PI in 2009 from the Max-Planck-Institut für Gravitationsphysik (Albert Einstein Institute), where he was a Junior Scientist from 2008-2009. Dr. Vieira's research concerns the development of new mathematical techniques for gauge and string theories, ultimately aiming toward the solution of a realistic four-dimensional gauge theory. His research interests also include the related areas of the AdS/CFT correspondence and theoretical calculations of scattering amplitudes.

ASSOCIATE FACULTY



Niayesh Afshordi (PhD Princeton, 2004) is jointly appointed with the University of Waterloo. He was the Institute for Theory and Computation Fellow at the Harvard-Smithsonian Center for Astrophysics from 2004-2007, and a Distinguished Research Fellow at Perimeter Institute from 2008-2009. Professor Afshordi joined PI as an Associate Faculty member in 2010. He specializes in interdisciplinary problems in fundamental physics, astrophysics, and cosmology. In 2010, Professor Afshordi was awarded a Discovery Accelerator Supplement from the Natural Sciences and Engineering Research Council of Canada (NSERC).

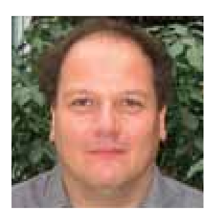
Alex Buchel (PhD Cornell, 1999) is jointly appointed with the University of Western Ontario. He held research positions at the Institute for Theoretical Physics, UCSB (1999-2002) and the Michigan Center for Theoretical Physics, University of Michigan (2002-2003) before joining PI's faculty in 2003. Professor Buchel's research efforts focus on understanding the quantum properties of black holes and the origin of our universe, as described by string theory, as well as developing analytical tools that could shed new light on strong interactions of subatomic particles. In 2007, he was awarded an Early Researcher Award from Ontario's Ministry of Research and Innovation.



Cliff Burgess (PhD University of Texas at Austin, 1985) joined PI's faculty as an Associate member in 2004, and was jointly appointed to McMaster University's faculty in 2005. Prior to that, he was a Member in the School of Natural Sciences at the Institute for Advanced Study in Princeton, and a Faculty member at McGill University. Over two decades, Professor Burgess has applied the techniques of effective field theory to high-energy physics, nuclear physics, string theory, early universe cosmology and condensed matter physics. With collaborators, he developed leading string theoretic models of inflation that provide its most promising framework for experimental verification. Professor Burgess' recent honours include a Killam Fellowship, Fellowship of the Royal Society of Canada, and the CAP-CRM Prize in Theoretical and Mathematical Physics.

Richard Cleve (PhD University of Toronto, 1989) joined PI's faculty in 2004, jointly appointed with the Institute for Quantum Computing (IQC), where he holds the IQC Endowed Chair in Quantum Computing. Prior to coming to Waterloo, he was a postdoctoral fellow at Berkeley's International Computer Science Institute and then a Faculty member in the Department of Computer Science at the University of Calgary. Professor Cleve has made numerous important contributions to quantum algorithms and information theory. He is a Founding Fellow of the Canadian Institute for Advanced Research (CIFAR) Quantum Information Processing Program, winner of the CAP-CRM Prize in Theoretical and Mathematical Physics, and an elected Fellow of the Royal Society of Canada.

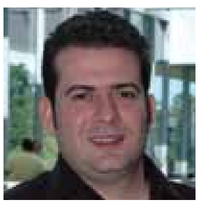
David Cory (PhD Case Western Reserve University, 1987) is jointly appointed with the Institute for Quantum Computing and the Department of Chemistry at the University of Waterloo. He held research positions at the University of Nijmegen in The Netherlands, the National Research Council at the Naval Research Laboratory in Washington, D.C., and MIT. He also led research and development activities in nuclear magnetic resonance at Bruker Instruments. Since 1996, Professor Cory has been exploring the experimental challenges of building small quantum processors based on nuclear spins, electron spins, neutrons, persistent current superconducting devices and optics. In 2010, he was named the Canada Excellence Research Chair in Quantum Information Processing. Professor Cory chairs the advisory committee for CIFAR's Quantum Information Processing program.



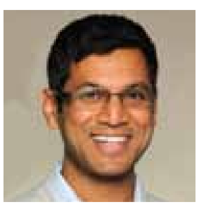
Adrian Kent (PhD Cambridge, 1996) is jointly appointed with the University of Cambridge. Prior to joining PI's faculty, he was an Enrico Fermi postdoctoral fellow at the University of Chicago, a member of the Institute for Advanced Study, and a Royal Society University Research Fellow at the University of Cambridge. Professor Kent's research focuses on the foundations of physics, quantum cryptography and quantum information theory, including the physics of decoherence, novel tests of quantum theory and alternative theories, and new applications of quantum information.

Raymond Laflamme (PhD Cambridge, 1988) is a founding Faculty member of Perimeter Institute and founding Director of the Institute for Quantum Computing, where he is jointly appointed. He held research positions at UBC and Peterhouse College, University of Cambridge before moving to Los Alamos Research Laboratory in 1992, where his interests shifted from cosmology to quantum computing. Since the mid-1990s, Professor Laflamme has elucidated theoretical approaches to quantum error correction. Professor Laflamme is the Director of QuantumWorks, Canada's national research consortium on quantum information science, and has been Director of the Quantum Information Program at the Canadian Institute for Advanced Research (CIFAR) since 2003, and a CIFAR Fellow since 2001. He also holds the Canada Research Chair in Quantum Information.

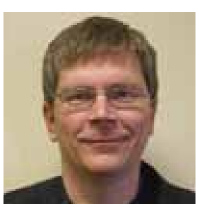
Luis Lehner (PhD University of Pittsburgh, 1998) began a joint-appointment with PI and the University of Guelph in 2009. He held postdoctoral fellowships at the University of Texas at Austin and the University of British Columbia, and was a member of Louisiana State University's faculty from 2002-2009. Professor Lehner's many honours include the Honor Prize from the National University of Cordoba, Argentina, a Mellon pre-doctoral fellowship, the CGS/UMI outstanding dissertation award, and the Nicholas Metropolis award. He has been a PIMS fellow, a CITA National Fellow, and an Alfred P. Sloan Fellow, and he is currently a CIFAR associate member and a fellow of the Institute of Physics.



Michele Mosca (DPhil University of Oxford, 1999) is jointly appointed with the University of Waterloo. He is a founding member of Perimeter Institute, and co-founder and Deputy Director of the Institute for Quantum Computing. Professor Mosca has made major contributions to the theory and practice of quantum information processing, particularly in the areas of quantum algorithms, techniques for studying the limitations of quantum computers, quantum self-testing and private quantum channels. Professor Mosca has won numerous academic awards and honours, including the Commonwealth Scholarship, the Premier's Research Excellence Award, and a Canada Research Chair in Quantum Computation. He was named a Canadian Institute for Advanced Research (CIFAR) Fellow in 2010.



Ashwin Nayak (PhD University of California, Berkeley, 1999) is also appointed at the University of Waterloo and the Institute for Quantum Computing. He has held positions at DIMACS Center (Rutgers University) and AT&T Labs-Research (California Institute of Technology), and at the Mathematical Sciences Research Institute, Berkeley. Professor Nayak was a recipient of an Early Researcher Award from Ontario's Ministry of Research and Innovation in 2006, and a Discovery Accelerator Supplement from the Natural Science and Engineering Research Council (NSERC) of Canada in 2008.



Maxim Pospelov (PhD Budker Institute of Nuclear Physics, Russia, 1994) is jointly appointed with the University of Victoria, and became an Associate Faculty member at PI in 2004. He previously held research positions at the University of Quebec at Montreal, University of Minnesota, McGill University, and University of Sussex, UK. Professor Pospelov works in the area of particle physics and has recently made detailed studies of Catalyzed Big Bang Nucleosynthesis (CBBN), a novel idea which he proposed to alleviate persistent discrepancy of theoretical predictions and experimental observations of lithium abundance in the universe.

Thomas Thiemann (PhD RWTH Aachen University, 1993) is jointly appointed with the Max Planck Institute for Gravitational Physics in Germany. His research centres on non-perturbative quantum field theory, in particular quantum gauge field theory and quantum gravity; non-perturbative aspects of quantum string theory; constructive and algebraic quantum field theory; Euclidean quantum field theory and its connection with statistical mechanics; semiclassical quantum field theory; and non-perturbative approximation methods.

POSTDOCTORAL FELLOWS, 2009-10

Brian Batell
Joseph Ben Geloun
Dario Benedetti
Robin Blume-Kohout
Hector Bombin
Giulio Chiribella
Roger Colbeck
Florian Conrady
Sarah Croke (on leave)
Claudia de Rham
Eleonora Dell'Aquila
Adrienne Erickcek
Steve Flammia
Cecilia Flori
Ghazal Geshnizjani
John Giblin
Philip Goyal
Razvan Gurau
Alioscia Hamma
Joe Henson
Janet Hung
Zhengfeng Ji
Tim Koslowski
Louis Leblond
Nicolas Menicucci
Akimasa Miyake
Leonardo Modesto
Alberto Montina
Takuya Okuda
Yutaka Ookouchi
Federico Piazza
Pier Gian Luca Porta Mana
Josef Pradler
David Rideout
Natalia Saulina
Amit Sever
Sarah Shandera
Yanwen Shang
Parampreet Singh
Aninda Sinha
David Skinner
Misha Smolkin
Rolando Somma (on leave)
Andrew Tolley
Michael Trott
Mark Wyman
Tom Zlosnik

SCIENTIFIC VISITORS

** indicates Distinguished Research Chair*
*** indicates longer-term Visiting Researcher*

Please note that researchers who made multiple visits are only listed once.

Scott Aaronson, Massachusetts Institute of Technology (MIT)

Raul Abramo, Universidade de Sao Paulo

Dorit Aharonov*, Hebrew University

Yakir Aharonov*, Chapman University

Maqbool Ahmed, National University of Sciences and Technology, Islamabad

Fernando Alday, Institute for Advanced Study (IAS)

Emanuele Alesci, Institut für Theoretische Physik III, Erlangen

Stephon Alexander, Haverford College

Sergey Alexandrov**, Montpellier University

Ben Allanach, University of Cambridge

Shanta de Alwis, University of Colorado

Jan Ambjorn, Utrecht University

Martin Ammon, Max Planck Institute

Matt Anderson, Louisiana State University

Lilia Anguelova, University of Cincinnati

Nima Arkani-Hamed*, Institute for Advanced Study (IAS)

Pablo Arrighi, University of Grenoble

Michele Arzano, Institute for Theoretical Physics, Utrecht University

Sujay Ashok, Institute of Mathematical Sciences, Chennai

Amjad Ashoorioon, Uppsala University

Valentina Baccetti, Universita degli Studi Roma Tre

Dave Bacon, University of Washington

Arjun Bagchi, Harish-Chandra Research Institute

Shant Baghramian, Sharif University

Leon Balents, Kavli Institute for Theoretical Physics

Julian Barbour, independent

Howard Barnum**, Los Alamos National Laboratory

Marie-Pierre Barre, African Institute for Mathematical Sciences

Jonathan Barrett, University of Bristol

Stephen Bartlett**, University of Sydney

Bruce Bassett**, University of Cape Town

Rachel Bean, Cornell University

Melanie Becker, Texas A&M

Joseph Ben Geloun, Laboratoire de Physique Théorique d'Orsay and University Paris-Sud XI

Dionigi Benincasa, Imperial College London

Raphael Benichou, Vrije Universiteit Brussel

Emanuele Berti, University of Mississippi

Lev Bishop, Yale University

Sergio Boixo, California Institute of Technology (Caltech)

Valentin Bonzom, École Normale Supérieure de Lyon

Richard Bower, University of Durham

Patrick Brady, University of Wisconsin-Milwaukee

Courtney Brell, University of Sydney

Jeandrew Brink, California Institute of Technology (Caltech)

Brielin Brown, University of Virginia

Todd Brun**, University of Southern California

Ramy Brustein, Ben-Gurion University of the Negev

Mathew Bullimore, Oxford University

Joao Caetano, Universidade do Porto

Yi-fu Cai, Institute of High Energy Physics, Chinese Academy of Sciences

Gianluca Calcagni, Albert Einstein Institute, Potsdam

Vincenzo Calo, Queen Mary, University of London

Bernard Carr, Queen Mary, University of London

Ariel Caticha, University of Albany

Eric Cavalcanti, Griffith University, Brisbane

Gregory Chaitin, IBM Research Division

Philip Chang, CITA, University of Toronto

Xie Chen, Massachusetts Institute of Technology (MIT)

Matthew Choptuik, University of British Columbia

Ignacio Cirac*, Max Planck Institute

Chris Clarkson, University of Cape Town

Tim Clifton, Oxford University

Jim Cline, McGill University

Bob Coecke, Oxford University

Alan Coley, Dalhousie University

Jacques Colin, Institut d'Astrophysique de Paris

Samuel Colin, Griffith University

Joe Conlon, Oxford University

David Cory**, Massachusetts Institute of Technology (MIT)

Fabio Costa, University of Vienna

Miguel Costa, Universidade do Porto

David Craig, Le Moyne College, Syracuse

Gregory Crosswhite, University of Washington

Csaba Csaki, Cornell University

Yanou Cui, Harvard University

Neal Dalal, CITA, University of Toronto

Naresh Dadhich, Inter-University Centre for Astronomy and Astrophysics (IUCAA)

Giacomo Mauro D'Ariano, Universita degli Studi di Pavia, Italy

Saurya Das, University of Lethbridge

Sumit Das**, University of Kentucky

Arundhati Dasgupta, University of Lethbridge

Domenic Denicola, California Institute of Technology (Caltech)

Oscar Dias, University of Cambridge

Bianca Dittrich, Max Planck Institute

Brian Dolan**, National University of Ireland, Maynooth

Alexander Dolgov, Instituto Nazionale di Fisica Nucleare, Sezione di Ferrara

Patrick Dorey, Durham University

Richard Dowdall, University of Nottingham

Fay Dowker, Imperial College London

Andrzej Dragan, University of Warsaw

Runyao Duan, University of Technology, Sydney

Artur Ekert, National University of Singapore

Adrienne Erickcek, California Institute of Technology (Caltech)

Glen Evenbly, University of Queensland

J. Doyne Farmer, Santa Fe Institute

Ruggero Ferrari, Instituto Nazionale di Fisica Nucleare

Hassan Firouzjahi**, Institute for Research in Fundamental Sciences (IPM)

Brendan Foster, Utrecht University

Patrick Fox, Fermilab

Rouven Frassek, Humboldt University of Berlin

John Friedman, University of Wisconsin-Milwaukee

Ernesto Galvao, Universidade Federal Fluminense – Instituto de Fisica

Jose Tomas Galvez Ghersi, Universidad Nacional de Ingenieria, Peru

David Garfinkle, Oakland University

S. James Gates Jr., University of Maryland

Davide Gaiotto, Institute for Advanced Study (IAS)

Viktor Galliard, ETH Zurich

Jerome Gauntlett, Imperial College London

Jack Gegenberg, University of New Brunswick

Bruno Giacomazzo, University of Maryland, College Park

Tom Giblin, Kenyon College

Scott Glancy, National Institute of Standards and Technology

James Gray, Oxford University

Hilary Greaves, Oxford University

Thomas Gregoire, Carleton University

Ruth Gregory, Durham University

Jesper Grimstrup, Neils Bohr Institute

Daniel Grin, California Institute of Technology (Caltech)

Zheng-Cheng Gu, Massachusetts Institute of Technology (MIT)

Stanley Gudder, University of Denver

Abba Gumel, University of Manitoba

Benjamin Gutierrez Garcia, University of British Columbia

Martin Haehnelt, University of Cambridge

Gabor Halasz, University of Cambridge

Muxin Han, Albert Einstein Institute

Kentaro Hanaki, University of Michigan

Chad Hanna, California Institute of Technology (Caltech)

Juho Happola, Aalto University of Technology

Aram Harrow, University of Bristol

Patrick Hayden*, McGill University

Stephen Hawking*, University of Cambridge

Richard Healey**, University of Arizona

Jonathan Heckman, Institute for Advanced Study (IAS)

Simeon Hellerman, Institute for the Physics and Mathematics of the Universe (IPMU)

Adam Henderson, Pennsylvania State University

Mark Hertzberg, Massachusetts Institute of Technology (MIT)

Chris Hirata, California Institute of Technology (Caltech)

Renee Hlozek, Oxford University

Jason Hofgartner, University of Waterloo

Richard Holman, Carnegie Mellon University

Sabine Hossenfelder, NORDITA

Su Hu, Tsinghua University

Taylor Hughes, University of Illinois Urbana-Champaign

Lam Hui, Columbia University

Viqar Husain, University of New Brunswick

Dragan Huterer, University of Michigan

Masahiro Ibe, University of California, Irvine

Radu Ionicioiu, Humboldt University of Berlin

David Jacobs, Case Western Reserve University

Daniel Jafferis, Rutgers University

Karan Jani, Pennsylvania State University

Dileep Jatkar**, Harish-Chandra Research Institute

Steven Johnston, Imperial College London

Kate Jones-Smith, Case Western Reserve University

Samo Jordan, Institute for Theoretical Physics, Utrecht University

Simon Judes, Columbia University

Leo Kadanoff*, The James Franck Institute, University of Chicago

Yevgeny Kats, Harvard University

Andrey Katz, University of Maryland

Louis Kauffman, University of Illinois at Chicago

Brian Keating, University of California, San Diego

Cynthia Keeler, Harvard University

Mike Kesden, CITA, University of Toronto

Elias Kiritsis, University of Crete

Aleksandra Klimek, August Witkowski School

Kevin Knuth, University of Albany

Zohar Komargodski, Institute for Advanced Study (IAS)

Jurek Kowalski-Glikman, University of Wroclaw

Kirill Krasnov, University of Nottingham

Graham Kribs, University of Oregon

Michael Kroyter, Massachusetts Institute of Technology (MIT)

Jason Kumar, University of Hawaii

Gabor Kunstatter, University of Winnipeg

Pablo Laguna, Georgia Tech

Chris Laumann, Princeton University

Sung-Sik Lee, McMaster University

Jean-Luc Lehners, Princeton University

Matthew Leifer, Institute for Quantum Computing

Rob Leigh, University of Illinois

Michael Levin, Harvard University

Yeong-Cherng Liang, University of Sydney

Steve Liebling, Long Island University

Etera Livine, Centre National de la Recherche Scientifique (CNRS)

Renate Loll*, Utrecht University

Ian Low, Argonne National Laboratory

Michael Luke, University of Toronto

Lorenzo Maccone, Massachusetts Institute of Technology (MIT)

Pedro Machado, Institute for Theoretical Physics, Utrecht University

Joao Magueijo, Imperial College London

Anshuman Maharana, Cambridge University

Rachel Maitra, Michigan Center for Theoretical Physics

Seth Major**, Hamilton College

Juan Maldacena, Institute for Advanced Study (IAS)

Vinothan Manoharan, Harvard University

Elisa Manrique, Institute for Physics Mainz

Owen Maroney, University of Sydney

Joseph (Joe) Marsano, University of Chicago

Kiyoshi Masui, CITA, University of Toronto

David Mateos, University of Barcelona

Dalimil Mazac, Cambridge University

David McKeen, University of Chicago

Paul McFadden, Universiteit van Amsterdam

Tristan McLoughlin, Max Planck Institute for Gravitational Physics

Thomas Mehen, Duke University

Dessalegn Melesse, University of Manitoba

Max Metlitski, Harvard University

Godfrey Miller, University of Pennsylvania

Jacob Miller, Franklin W. Olin College of Engineering

Roya Mohayaee, Institut d'Astrophysique de Paris

David Morrissey, TRIUMF Canada

Ramis Movassagh, Massachusetts Institute of Technology (MIT)

Markus Mueller, University of Potsdam

Shinji Mukohyama, Institute for the Physics and Mathematics of the Universe (IPMU)

Romain Murenzi, AIMS-NEI

Yuichiro Nakai, Yukawa Institute of Theoretical Physics

Yu Nakayama, University of California, Berkeley

Bess Ng, Case Western Reserve University

Piero Nicolini, Institute for Theoretical Physics, Johann Wolfgang Goethe University, Frankfurt

David Neilsen**, Brigham Young University

Scott Noble, Rochester Institute of Technology

Jay Olson, University of Queensland

Garnet Ord, Ryerson University

Carlos Ordonez, University of Houston

Gerardo Ortiz, Indiana University Bloomington

Thanu Padmanabhan, Inter-University Centre for Astronomy and Astrophysics (IUCAA)

Enrico Pajer, Cornell University

Prakash Panangaden, McGill University

Manu Paranjape, Université de Montreal

Chang-Soon Park, California Institute of Technology (Caltech)

Subodh Patil, Centre de Physique Théorique de l'Ecole Polytechnique (CPHT)

Miguel Paulos, University of Cambridge

Jan Pawlowski, University of Heidelberg

Ue-Li Pen, CITA, University of Toronto

Joao Penedones, Kavli Institute for Theoretical Physics (KITP)

Roberto Percacci**, Scuola Internazionale Superiore di Studi Avanzati (SISSA)

David Perez-Garcia, Universidad Complutense de Madrid

Paolo Perinotti, Universita degli Studi di Pavia, Italy

Malcolm Perry*, University of Cambridge (DAMTP)

Vasily Pestun, Harvard University

Annika Peter, California Institute of Technology (Caltech)

Patrick Peter, Institut d'Astrophysique de Paris

Frank Petriello, University of Wisconsin-Madison

Robert Pfeifer, University of Queensland

Dan Phalen, University of Michigan

Levon Pogosian, Simon Fraser University

David Poulin, Université de Sherbrooke

Frans Pretorius, Princeton University

Tomislav Prokopec, Utrecht University

Eliot Quataert, University of California, Berkeley

Fernando Quevedo**, University of Cambridge (DAMTP)

Babar Qureshi, Dublin Institute for Advanced Studies

Suvrat Raju, Harish-Chandra Research Institute

Sumathi Rao, Harish-Chandra Research Institute

David Rapetti, Stanford University

Leonardo Rastelli, Stony Brook University

Sergei Razamat, Stony Brook University

Harvey Reall, Cambridge University

David Reid, University of Chicago

Joseph Renes, Technical University of Darmstadt

Ali Rezakhani, University of Southern California

Claudia de Rham, University of Geneva

Lidia del Rio, ETH Zurich

Adam Ritz, University of Victoria

Vincent Rivasseau, Laboratoire de Physique Théorique d'Orsay and Université Paris-Sud XI

Fabio Rocha, Princeton University

Jeremie Roland, NEC Laboratories

Paul Romatschke, University of Washington

Terry Rudolph, Imperial College London

Shinsei Ryu, University of California, Berkeley

Subir Sachdev*, Harvard University

Mairi Sakellariadou, King's College London

Grant Salton, University of Waterloo

Jorge Santos, University of Cambridge

Omid Saremi, McGill University

Frank Saueressig, Institute of Physics, Johannes Gutenberg University of Mainz

Sakura Schafer-Nameki, Kavli Institute for Theoretical Physics (KITP)

Alexander Schenkel, Universität Würzburg

Bernd Schroers**, Heriot-Watt University, Edinburgh

Norbert Schuch, Max Planck Institute

Philip Schuster, Stanford Linear Accelerator Center (SLAC)

David Seery, University of Cambridge

Yasuhiro Sekino, Okayama Institute for Quantum Physics

Ashoke Sen*, Harish-Chandra Research Institute

Nick Setzer, University of Melbourne

Alessandro Sfondrini, University of Padova

Ilya Shapiro, Universidade Federal de Juiz de Fora

Arun Sharma, AIMS-NEI

Jonathan Sharman, University of Victoria

Kris Sigurdson, University of British Columbia

Sukhbinder Singh, University of Queensland

John Skilling, Maximum Entropy Consultants

Anze Slosar, Brookhaven National Laboratory

Dam Thanh Son, University of Washington

Yong-Seon Song, Institute of Cosmology and Gravitation, University of Portsmouth

Julian Sonner, Imperial College London

Simone Speziale, Centre de Physique Théorique de l'Université de Marseille

Christoph Stephan, University of Potsdam

Dejan Stojkovic, State University of New York at Buffalo

Riccardo Sturani, Università di Urbino

Ward Struyve, K.U.Leuven

Sumati Surya, Raman Research Institute

Leonard Susskind*, Stanford University

Brian Swingle, Massachusetts Institute of Technology (MIT)

Yuji Tachikawa, Institute for Advanced Study (IAS)

Morgan Tait, University of Western Ontario

Tim Tait, University of California, Irvine

Eric Takougang, Simon Fraser University

Johannes Tambornino, Albert Einstein Institute

Adrian Tanasa, Centre de Physique Théorique de l'Ecole Polytechnique (CPHT)

Javier Tarrio, University of Santiago de Campostela, Spain

Natalia Toro, Stanford University

Viktor Toth, Independent

Slava Turyshev, NASA Jet Propulsion Laboratory

Bret Underwood, McGill University

Deepak Vaid, Pennsylvania State University

Lev Vaidman, Tel Aviv University

Alberto Vallinotto, Fermilab

Ali Vanderveld, California Institute of Technology (Caltech)

Pascal Vaudrevange, Case Western Reserve University

David Vegh, Stony Brook University

Erik Verlinde, University of Amsterdam

Guifre Vidal*, University of Queensland

Pedro Vieira, Max Planck Institute for Gravitational Physics

Dmytro Volin, Pennsylvania State University

Robert Wald, University of Chicago

Aron Wall, University of Maryland

Yidun Wan, Kinki University

Stephanie Wehner, California Institute of Technology (Caltech)

Silke Weinfurtner, University of British Columbia

James Wells, CERN

Xiao-Gang Wen*, Massachusetts Institute of Technology (MIT)

Daniel Wesley, University of Pennsylvania

Hans Westman, University of Sydney

Mark Wise*, California Institute of Technology (Caltech)

Derek Wise, University of California, Davis

Howard Wiseman, Griffith University, Brisbane

William Wootters**, Williams College

Beni Yoshida, Massachusetts Institute of Technology (MIT)

Nico Yunes, Princeton University

Cenke Xu, Harvard University

Konstantin Zarembo, École Normale Supérieure

Chi Zhang, Columbia University

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CONFERENCES, 2009-10

Reconstructing Quantum Theory
August 9 - 16, 2009

PIAF '09: New Perspectives on the Quantum State
September 27 - October 2, 2009

PI-ATLAS LHC Day
October 30, 2009

Asymptotic Safety - 30 Years Later
November 5 - 8, 2009

Gravity at a Lifshitz Point
November 8 - 10, 2009

Compact binaries and GRBs
November 19 - 21, 2009

PI CITA Day
December 8, 2009

4-Corner Southwest Ontario Condensed Matter Symposium
April 22, 2010

Fundamental Physics and Large Scale Structure
April 28 - 30, 2010

Connections in Geometry and Physics
2010, May 7 - 9, 2010

Laws of Nature: Their Nature and Knowability
May 20 - 22, 2010

Emergence and Entanglement
May 25 - 29, 2010

Cosmological Frontiers in Fundamental Physics
June 15 - 18, 2010

Theory Meets Data Analysis at Comparable and Extreme Mass Ratios
June 20 - 26, 2010

Random Matrix Techniques in Quantum Information Theory
July 4 - 6, 2010

COURSES

General Relativity for Cosmology
Instructor: Achim Kempf, University of Waterloo and PI Affiliate
September 21 - December 11, 2009
Viewable at: http://www.pirsa.org/C09019

Introduction to Effective Field Theory
Instructor: Cliff Burgess, Perimeter Institute and McMaster University
September 16 - December 11, 2009
Viewable at: http://www.pirsa.org/C09020

Introduction to AdS/CFT Correspondence
Instructor: Rob Myers, Perimeter Institute
September 29 - December 11, 2009

Scattering in AdS and CFT Correlation Functions
Instructor: João Penedones, KITP/UCSB
November 19 - 20, 2009
Viewable at: http://www.pirsa.org/C09023

Quantum Field Theory for Cosmology
Instructor: Achim Kempf, University of Waterloo and PI Affiliate
January 12 - April 12, 2010
Viewable at: http://www.pirsa.org/C10003

Foundations and Interpretation of Quantum Theory
Instructors: Raymond Laflamme, IQC & Perimeter Institute and Joseph Emerson, University of Waterloo
January 12 - April 12, 2010
Viewable at: http://www.pirsa.org/C10002

Aspects of Moduli in String Compactifications
Instructor: Joe Conlon, University of Oxford
January 26 - 28, 2010
Viewable at: http://www.pirsa.org/C10004

New Developments in N=2 Supersymmetric Gauge Theories
Instructor: Davide Gaiotto, Institute for Advanced Study
February 22 - 26, 2010
Viewable at: http://www.pirsa.org/C10005

Beyond the Standard Model Physics and the LHC
Instructor: James Wells, CERN
March 29 - April 1, 2010
Viewable at: http://www.pirsa.org/C10007

Cosmology Mini-Course
Instructors: Adrienne Erickcek, Perimeter Institute; Latham Boyle, Perimeter Institute; Louis Leblond, Perimeter Institute; and Ghazal Geshnizjani, Perimeter Institute
April 13 - May 10, 2010
Viewable at: http://www.pirsa.org/C10008

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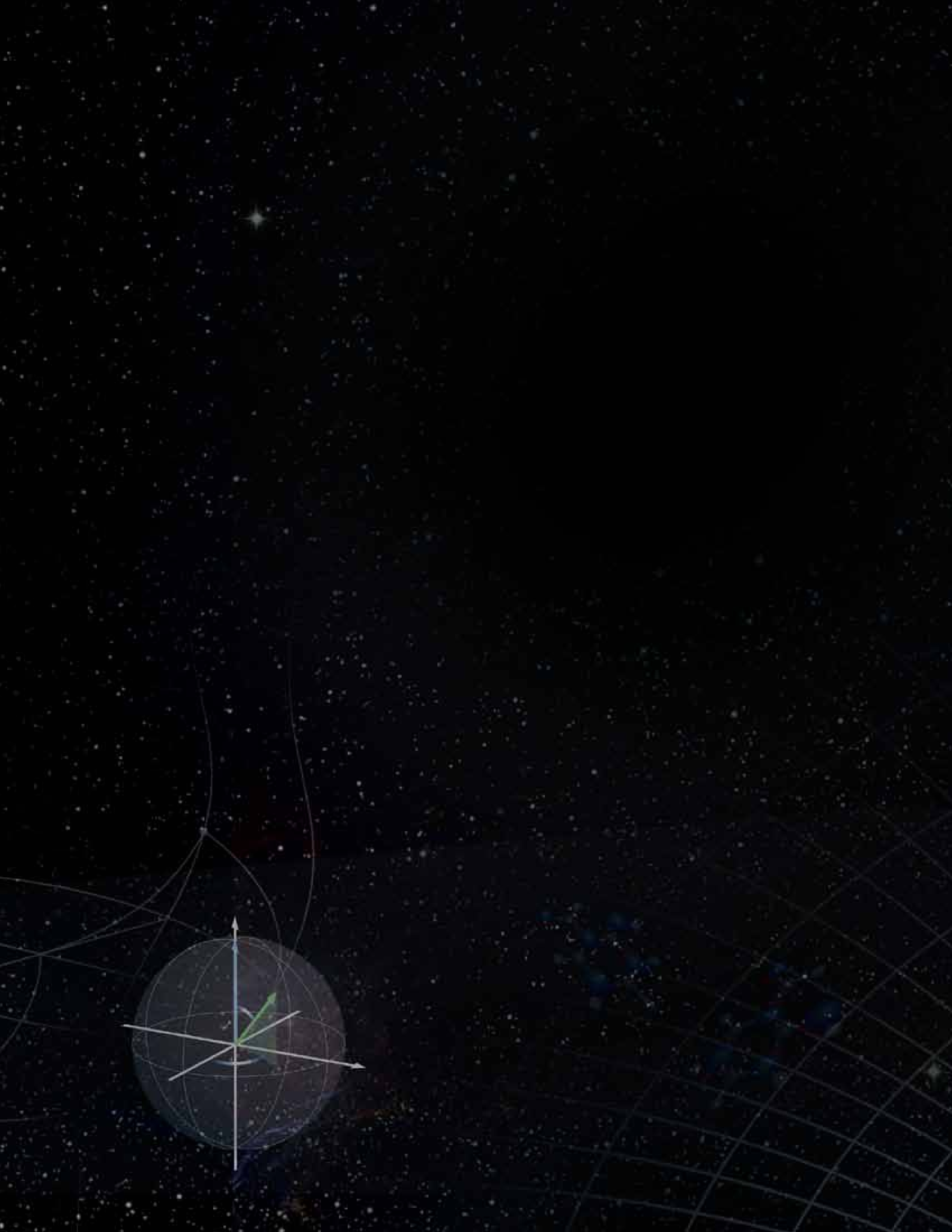
PI partnered with the following Canadian and international organizations to support scientific events and activities:

- The Banff Centre, Science Communications Program Scholarship
- Canadian Association of Physicists, CAP Award for Excellence in Teaching High School
- Canadian Institute for Theoretical Astrophysics (CITA) and the Canadian Centre for Advanced Research (CIFAR), PI-CITA Days
- Canadian Science Writers Association, 39th Annual Conference
- Communitech, Science Superheroes
- Fields Institute, Canadian Quantum Information Summer School/Canadian Quantum Information Conference and Random Matrix Techniques in Quantum Information Theory Conference
- Laboratoire Astroparticule et Cosmologie (APC) and the Solvay Institute, Cosmological Frontiers in Fundamental Physics
- McGill University, Strong and Electroweak Matter 2010 Conference
- Perimeter Institute-Australia Foundations (PIAF), New Perspectives on the Quantum State
- Universidade do Porto, Mathematica Summer School
- University of Alberta, Lake Louise Winter Institute
- University of British Columbia, Emergent Gravity IV Conference
- University of Toronto, Canadian Chemistry and Physics Olympiad
- University of Waterloo, Workshop of Theory of Quantum Computation, Communication and Cryptography
- Waterloo Education Foundation, Southwood Science Olympiad
- Waterloo Wellington Science & Engineering Fair, WWSEF 2010
- Youth Science Foundation Canada, International Summer School for Young Physicists Award



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"My goal is simple. It is a complete understanding of the universe, why it is as it is and why it exists at all."

– Stephen Hawking, Perimeter Institute Distinguished Research Chair and Emeritus Lucasian Professor, University of Cambridge

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