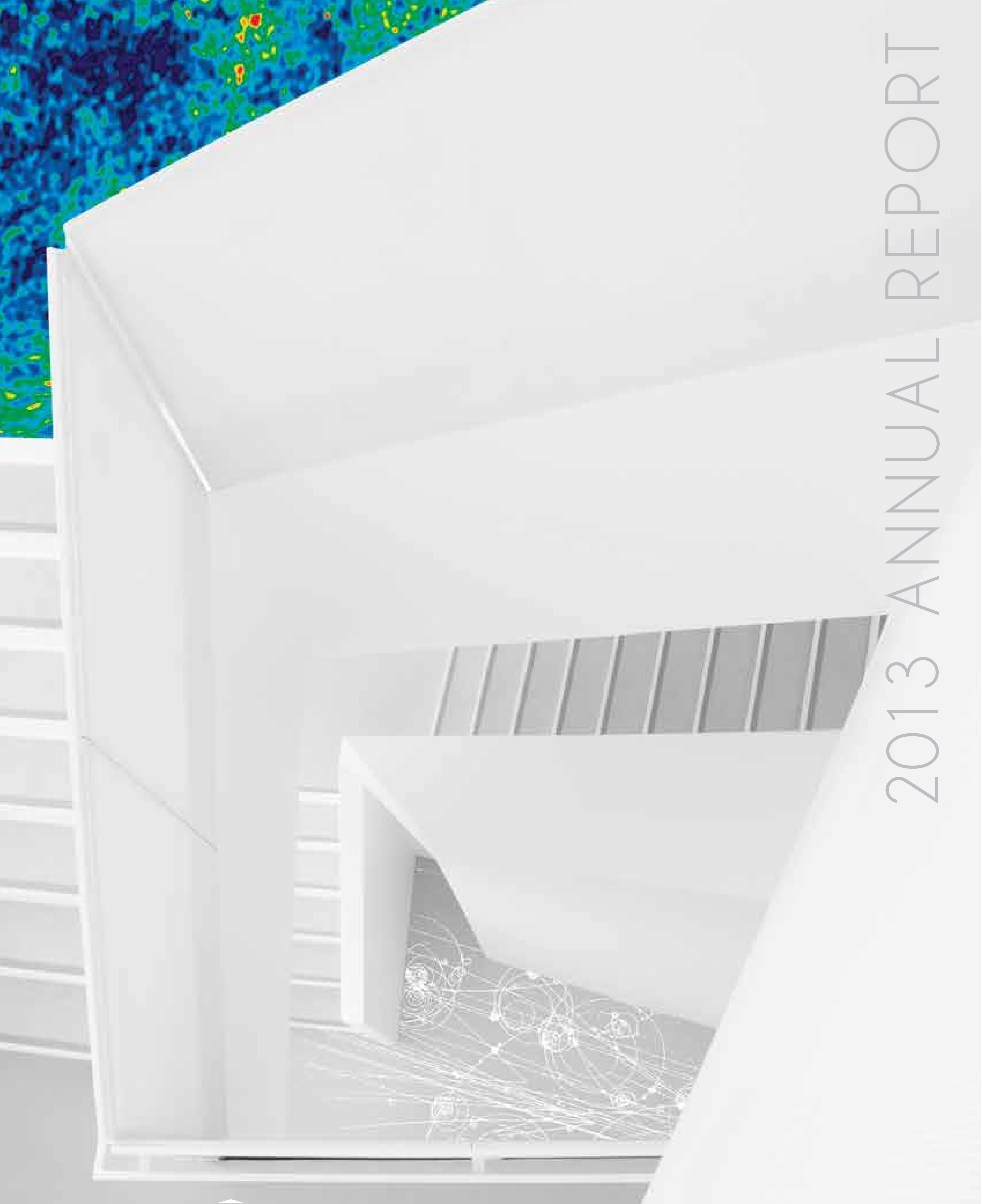
2013 ANNUAL REPORT



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, in a shared enterprise to achieve breakthroughs that will transform our future.

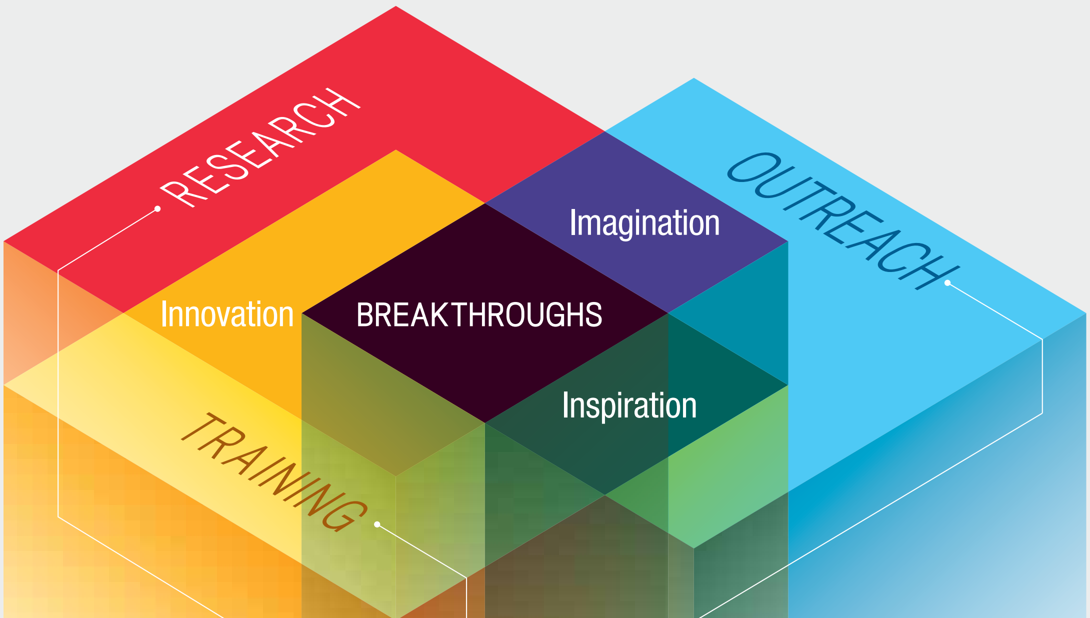
CONTENTS

This report covers the activities and finances of Perimeter Institute for Theoretical Physics from August 1, 2012, to July 31, 2013.

AN ECOSYSTEM OF DISCOVERY

GOALS

- TO ACHIEVE RESEARCH BREAKTHROUGHS THAT WILL TRANSFORM OUR FUTURE
- TO FOSTER THE NEXT GENERATION OF BRILLIANT PHYSICISTS
- TO SHARE THE TRANSFORMATIONAL POWER OF THEORETICAL PHYSICS WITH THE WORLD



150 SCIENTISTS IN RESIDENCE conducting research

11 MAJOR PRIZES awarded to Perimeter scientists in 2012/13

1,000+ VISITING INTERNATIONAL SCIENTISTS annually

2,500+ PAPERS appearing in over 60 journals with 77,000+ citations since 2001

6,700+ ARCHIVED TALKS have been accessed online by viewers in 175 countries to date

14 YEARS after its creation, Perimeter was recently ranked **#2** IN SCIENTIFIC EXCELLENCE in theoretical physics in the world

>2.5 MILLION STUDENTS reached since 2003

8,000+ EDUCATORS trained through Perimeter workshops since 2003

500 TOP HIGH SCHOOL STUDENTS from 44 countries inspired by the International Summer School for Young Physicists since 2003

90 COUNTRIES have broadcast *The Quantum Tamers*, a Perimeter documentary on quantum information science

Perimeter is currently home to **70** PHD & MASTER'S STUDENTS and **44** POSTDOCTORAL RESEARCHERS

Perimeter Scholars International (PSI) Master's Program **125** GRADUATES from **37** COUNTRIES since **2009**

BACKGROUND AND PURPOSE

In 1999, Mike Lazaridis (inventor of the smartphone) made a single philanthropic investment that he hoped might change the world: he provided the seed money for Perimeter Institute. His vision attracted more donors and generous public support, and soon the Institute – located in Waterloo, Ontario, Canada – was up and running.

Why theoretical physics? Because history has shown that ideas developed in physics lead to a cascade of discoveries throughout the sciences. They spark innovation and lead, in time, to the creation of entirely new industries. From Newton to Maxwell to Einstein, physics has spawned the technologies upon which modern society depends – from plumbing to electricity, smartphones to satellites. Today, theoretical physics continues to open doors to the future – from quantum computers to new energy technologies. One breakthrough in theoretical physics can literally change the world.

Perimeter's mission is to make fundamental breakthroughs in our understanding of the universe. Inevitably, these will lay the foundations for the technologies of the future. We bring the world's most brilliant minds together under one roof, to interact and collaborate across disciplinary boundaries and tackle key problems. Perimeter's growing community includes more than 150 resident researchers, ranging from master's students to eminent senior scientists. The Institute is also a global hub for the exchange of ideas, hosting nearly a thousand scientific visitors every year.

The future of physics rests on our ability to inspire and train the next generation of brilliant young people. Therefore, Perimeter has developed intensive education and training programs at all levels. Our innovative master's program, Perimeter Scholars International, trains 30 exceptional graduates from around the world every year. Our faculty supervise about the same number of PhD students. And we are proud to host nearly 50 postdoctoral fellows, one of the world's largest communities of young theoretical physicists.

Perimeter prospers – as all science prospers – by being part of a wider community of people aware of and excited about science. That's why sharing the power and importance of theoretical physics through public engagement has always been a high priority. We open our doors to the general public through lectures and festivals, and we have developed a rich suite of educational materials for students and teachers. We've reached more than 2.5 million students – one million in the past year alone.

Now, we are building a network of advocates and supporters across the world. With the support of our current and future partners – public and private – we seek nothing less than to change the world.

"Perimeter Institute is now one of the world's leading centres in theoretical physics – if not the *leading centre."*

– Stephen Hawking

MESSAGE FROM THE BOARD CHAIR

When I look back on the progress that Perimeter has made over the past year and think about the exciting opportunities ahead over the next year, it's hard to believe that Perimeter is little more than a decade old.

When we started Perimeter in 1999, we recognized the power of theoretical physics to transform society and boldly believed that Perimeter could contribute in a meaningful way.

But physics has gone further, faster, than we had dared to dream. The Higgs boson has been found, dark energy is real, and experimentalists can reliably control systems of near-atomic size. There is hardly a subfield that does not seem poised on the brink of transformation.

Perimeter's ability to contribute has been greater and come sooner than we would have dared to dream. Perimeter has played, and continues to play, a leadership role in the advancement of physics globally. Our researchers, including some exciting new recruits over the past year, are among the top scientists in the world. Fierce competition for student placement in our PSI master's program from around the world was even greater this past year. And our high school physics education materials, which have been used by more than two million students across Canada, are becoming a model internationally.

It is these kinds of accomplishments that led Perimeter to be ranked fifth overall in research excellence in physics – and second in theoretical physics – in an international study by researchers based at the Max Planck Society in Germany in 2013.

In the past year, I have spoken on numerous occasions about the opportunity available to Canada in the quantum technology revolution, which many experts around the world believe will commence in the next few years and which promises to transform society in unimaginable ways. The quantum physics capability that is being developed by Perimeter and its experimental counterpart, the Institute for Quantum Computing, positions the "Quantum Valley of Canada" as one of a handful of centres around the world that will lead this revolution.

I want to congratulate our Director, Neil Turok, and his strong team for all of their hard work and leadership over the past year.

I also want to acknowledge Neil for having been appointed the CBC Massey Lecturer for 2012. More than a million Canadians, including a huge number of youths across this country, were spellbound with a message of scientific optimism about our quantum future,

eloquently and passionately delivered by Neil as part of the Massey Lectures.

This year, we neared the end of Neil's initial five-year term as Perimeter's Director. I am pleased to advise that the Perimeter Board unanimously voted to renew Neil's appointment for another five years and that Neil has graciously accepted. Also, it has been a special privilege for my wife Ophelia and me to support the creation of a new Chair – the Niels Bohr Chair in Theoretical Physics at Perimeter Institute – with Neil as the inaugural chairholder.

I want to personally acknowledge the continued support of the Government of Canada and the Province of Ontario in the public-private partnership that has been a fundamental part of Perimeter since inception.

I also want to thank the many donors who have generously provided funds in support of the very important work being done by Perimeter. I want to specifically acknowledge the Krembil Foundation for their support in connection with the Krembil Foundation Galileo Galilei Chair in Theoretical Physics at Perimeter Institute, to be held by Davide Gaiotto, and the Krembil Foundation William Rowan Hamilton Chair in Theoretical Physics at Perimeter Institute, to be held by Kevin Costello.

With success comes competition. As the rest of the world wakes up to the opportunities associated with physics, competition for the highest level of intellectual capital globally is increasing. As a result, the financial support of private donors and the continued support of the public-private partnership with the Government of Canada and the Province of Ontario will play an essential role in the continued success of Perimeter Institute moving forward.

I would like to thank Perimeter's Board of Directors for their dedication and leadership. Also, as the advancement efforts at Perimeter continue to build momentum, I want to recognize the members of our Leadership Council for all of their efforts.

I believe that we are living in an exciting time for physics and I am confident that Perimeter Institute is positioned perfectly to continue to play a leadership role in the development and understanding of theoretical physics and in the discoveries that will help us toward transformative opportunities.

– Mike Lazaridis

MESSAGE FROM THE INSTITUTE DIRECTOR

From its very beginnings, Perimeter Institute was a surprise – a whole institute devoted to foundational theoretical physics. The first time I heard of it, I laughed. How could an upstart institution in Waterloo, Ontario (where?) be so bold as to take on the problems which lie at the root of science?

Just a few years later, as I learned more about the Institute's strategies and culture, I changed my mind. Through my own experience at more traditional centres, I had seen how, in many ways, academia is slowing down – just as the rest of the world is speeding up. Basic discoveries, and the sharing of advanced learning, are more urgently needed than ever. But new types of institutions are required: I became convinced that Perimeter offered not just Canada but the world an unprecedented opportunity to speed progress in one of the most difficult, but historically fruitful, of fields.

With this conviction, I joined Perimeter five years ago. Since then, our facility has doubled and our faculty has tripled. We launched Perimeter Scholars International and appointed 34 Distinguished Visiting Research Chairs. We have expanded our classroom and public engagement efforts across Canada and worldwide. It has been a thrilling period, serving a great cause. The shared sense of purpose among Perimeter's Board, faculty, and staff is, I believe, unique among academic centres. Our brilliant postdocs and graduate students provide an endless source of energy, vitality, and fun. Waterloo turns out to provide a marvellously supportive community. Together, we have built a phenomenal place.

Perimeter has shot up the global rankings: in a new study, we were ranked second in the world in theoretical physics (see page 8). The result will probably come as a massive surprise to many more established centres. But it shouldn't. The world of physics urgently needs modernizing – refocusing on the big problems, attracting brilliant young people, challenging and enabling them to go beyond current paradigms. There is, I believe, no better place and no better time than right here, right now.

This year, I had the great privilege of travelling across Canada to deliver the CBC Massey Lectures. It was a chance for me to see some of this amazing, huge country and to feel the warmth of its wonderful people. A special thrill was to meet with lots of young people in physics departments across the country, fired up with enthusiasm. I share their excitement – this is an extraordinary time.

In the last two years, we have explored the innermost and outermost realms in the universe. The greatest microscope of all time, the Large Hadron Collider (LHC), probed distances a billionth the size of an atom. The greatest ever telescope, the Planck Satellite, revealed the cosmos on scales 10 trillion times the size of the solar system.

Never before have we had such a complete picture of our universe. It is at once a great triumph, a profound challenge, and a massive opportunity.

The measurements at both the subatomic and cosmic scale reveal a stunning, unexpected simplicity in nature, on the very largest and smallest scales: at the LHC, just the bare minimum – a single Higgs boson, no supersymmetry, no WIMPs (weakly interacting

massive particles) – and for Planck, a perfectly Gaussian sky, with the pattern of fluctuations emerging from the big bang described by just two parameters.

Currently, our theories do not predict or explain this incredible simplicity. In fact, the most popular trends have been running in the opposite direction – seemingly implying a wild, random universe, a "multiverse," where almost anything goes. For me, that makes the situation very exciting because the simplicity we are now seeing may point to a new, fundamental principle of nature. It's an indicator that we may be on the threshold of a revolution.

In the past, similar contradictions led to revolutionary advances. In the early 20th century, the conflict between Maxwell's theories of electromagnetism and light and classical thermodynamics and mechanics led to quantum theory and relativity. Those in turn planted the seeds for new industries, including lasers, computers, CDs, GPS, and more. Our 21st century society is built upon 20th century physics.

What better place than Perimeter to develop the powerful and predictive principles which we need to explain the universe as we observe it today? I am very excited about taking up the Niels Bohr Chair that Mike and Ophelia Lazaridis created, with characteristic generosity. My top priority over the next five years will be focusing our research. Perimeter was launched as a moonshot. We have just been through the "boost" phase. The task now is to aim carefully so that we hit the target.

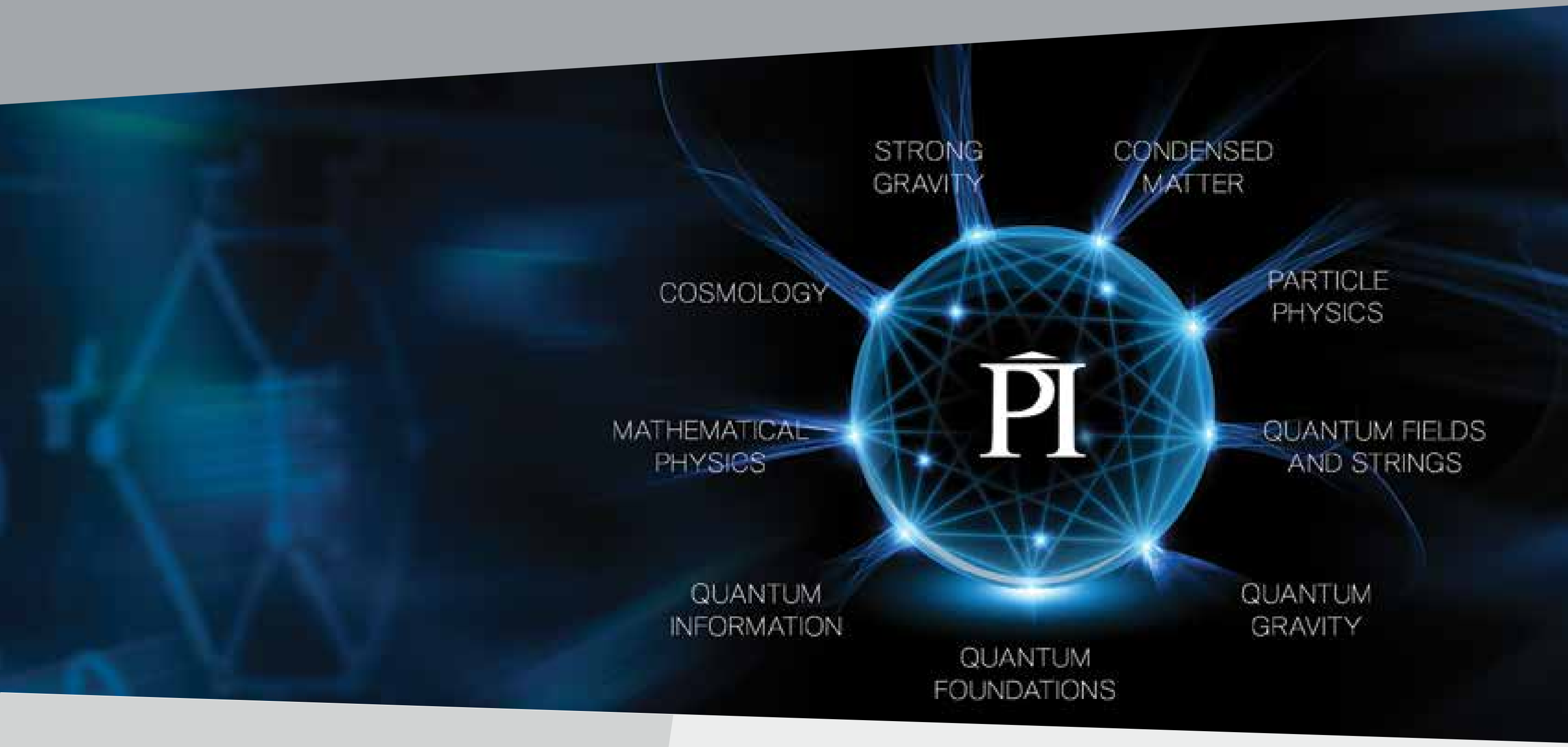
The key to success is to assemble the right people and to create the conditions in which they can do the best science. I am pleased to report that we have been joined by several outstanding scientists this year. Dmitry Abanin and Roger Melko are both young leaders in the effort to understand quantum materials, whose properties hold tremendous potential for use in new technologies. Kendrick Smith and Matthew Johnson are cosmologists whose research spans both basic theory and observation. Kendrick is a member of the pioneering WMAP collaboration which shared in the prestigious 2012 Gruber Cosmology prize. And Luis Lehner, one of the world's leading authorities on strong gravitational phenomena (such as black holes), joined Perimeter's full-time faculty after a three-year term as an associate faculty member cross-appointed with the University of Guelph.

We are likewise thrilled to welcome Kevin Costello, who will arrive next year as the inaugural holder of our new Krembil Foundation William Rowan Hamilton Chair in Theoretical Physics at Perimeter Institute. Kevin is a world leader in the development of powerful mathematical approaches to quantum fields. He is the first bona fide mathematician to join Perimeter's faculty. Davide Gaiotto, inaugural holder of the Krembil Foundation Galileo Galilei Chair in Theoretical Physics at Perimeter Institute, joins Kevin in receiving the support and sponsorship of the Krembil Foundation. It is a pleasure to thank the Krembil family and their foundation, whose visionary support for the Galileo and Hamilton Chairs at Perimeter will support leading-edge research in mathematics and mathematical physics here.

Each of these scientists has joined Perimeter for the same reason I did: we share the conviction that, by focusing on the fundamentals and aiming high, breakthroughs are not only possible, but inevitable.

– Neil Turok

RESEARCH



MAPPING SCIENTIFIC EXCELLENCE

An independent, international study, "Mapping Research Excellence," ranked Perimeter Institute fifth overall in the world of physics, and second in theoretical physics, behind only Princeton's venerable Institute for Advanced Study. Led by a senior researcher at the Max Planck Society in Germany, the study used only objective source data: publications and citations from Scopus, the world's largest publications database.

See www.excellencemapping.net.

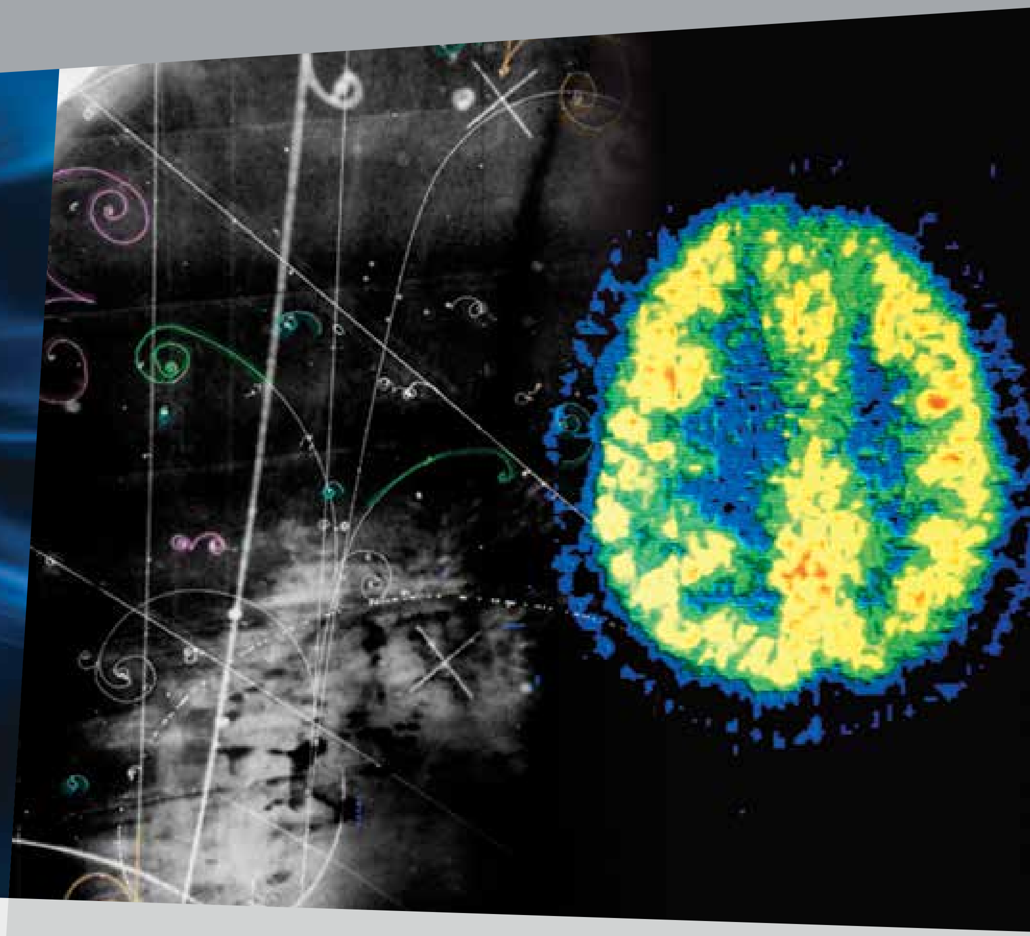
Carl Sagan once wrote, "Somewhere, something incredible is waiting to be known."

Perimeter Institute was created to pursue knowledge of the incredible.

Our universe – from the outer reaches of the cosmos to the infinitesimal realm described by particle physics and string theory – is unveiling itself at an unprecedented rate, thanks to explorers at the forefront of theoretical physics.

Perimeter brings these brilliant minds together under one roof and encourages them to tackle the most vexing questions of nature. They have the freedom and resources they need to do frontier research, and the collaborative opportunities necessary to make transformative breakthroughs.

Perimeter research spans nine strategically chosen fields and the Institute's researchers are leaders in their respective areas. But the true strength of Perimeter's approach lies at the intersections of the fields – the unexpected discoveries that happen when a cosmologist and a mathematical physicist chat at the coffee machine, or a string theorist bumps into a quantum gravity expert at one of the Institute's ubiquitous blackboards.



In most traditional academic settings, with regimented departments and faculties, such chance encounters are unlikely. At Perimeter – a building custom-designed to spark conversation and collaboration across disciplines – the whole is greater than the sum of the parts.

Where intellect and imagination collide, where the traditional boundaries between scientific disciplines are erased, where brilliant minds are invited to explore bold new ideas – this is where something incredible is waiting to be known.

FROM SCIENCE TO SCIENCE FICTION

In 1928, Paul Dirac developed an equation (called the Dirac equation) that predicted the behaviour of electrons near the speed of light. But the Dirac equation also had a shadow side: it worked for something no one had ever seen, a positively charged electron. In other words, the equation implied the existence of antimatter. In 1932, the first positrons – positively charged anti-electrons – were found in cloud chambers.

Today, antimatter is an integral part of physics. It's essential to the particle physics done at colliders like CERN. The puzzle of what happened to the antimatter which theory says should have been produced at the big bang is a driving question in modern cosmology.

And though it sounds science-fictional – it drove the Starship Enterprise, after all – antimatter has surprising practical applications. Positrons are the basis of positron emission tomography, or PET scans, a powerful tool in medical science. Positrons can be used to detect defects in materials – say, semiconductor wafers – that no other probe is sensitive enough to see. They can be added as a tag to track fast-moving, small particles – everything from drugs moving in the bloodstream to lubricant flowing through jet engines.

Antimatter is still mostly a technology of the future – after all, it costs trillions of dollars to produce a gram of it. But perhaps one day the secret side of Dirac's equation will power ships to the stars.

QUANTUM INFORMATION

Quantum computers, which capitalize on quantum effects such as "superposition" and "entanglement" to achieve processing power far surpassing present-day computers, are expected to revolutionize how we work, communicate, and live. Much theoretical research is required, however, before these technologies can emerge. Perimeter researchers explore quantum error correction – the techniques needed to safeguard and verify information amid the errors inherent to quantum computation. Researchers also pursue the foundations of quantum cryptography, which capitalizes on uniquely quantum laws – such as the uncertainty principle – to safeguard private information. Many of Perimeter's quantum information researchers collaborate with scientists at our nearby experimental partner, the Institute for Quantum Computing (IQC) at the University of Waterloo, and some hold joint appointments at both institutes. Together, Perimeter and IQC are transforming the region into the world's "quantum valley."

CHILL OUT, QUBITS!

To err is quantum.

When wrangling the quantum building blocks of nature to perform information processing, mistakes are bound to happen.

Quantum information is very powerful, but also very fragile.

Processors that function according to quantum laws have the potential to be vastly more powerful than even today's most complex supercomputers, but the realization of that potential will hinge on how researchers understand and deal with the errors that inevitably arise during quantum computation.

Perimeter Faculty member Daniel Gottesman is a pioneer in fault-tolerant quantum computation, by which reliable computation can happen if the error rate is kept below a given threshold.

To keep that error rate low, Gottesman and collaborators Michael Ben-Or (Hebrew University of Jerusalem) and Avanitan Hassidim (Bar-Ilan University) have proposed a system called a "quantum refrigerator."

It's a fitting name for a proposed system that gives overheated quantum bits (qubits) a place to chill out before being re-used for error correction.

Quantum error correction often requires that secondary qubits – called ancilla qubits – be utilized to measure information about errors in a quantum computation. Typically, this measurement scrambles the ancilla qubits, making them useful for only a single measurement.

Gottesman and collaborators, however, propose a model whereby used ancillas are shunted into a "refrigerator" where they can cool down, unscramble, and potentially be used again. It's a continual loop of heating and cooling that allows for quantum error correction to be performed longer and more reliably than in the past.

It is, therefore, a crucial step toward stable, reliable quantum computation – the driving motivation behind quantum information research.

A UNIVERSAL TOOLKIT

Of course, quantum error correction is just part of the puzzle. A quantum computer needs stuff to compute – and stuff to compute it with.

Quantum gates are the quantum equivalent of the logic gates in a classical computer. They are the fundamental building blocks of quantum circuits – the "atoms" of quantum computation, in a sense.

In theory, a quantum algorithm (the instructions a computer follows) might use an enormous variety of different quantum gates. The set of possible quantum gates must be "universal" – that is, the various gates allowed in the system can be arranged to closely approximate any gate that might be needed.

However, they must also be fault-tolerant, in order to cope with real-world errors and imprecision. Thus, in reality, the hardware will have a smaller set of built-in gates that enable fault-tolerant quantum computation.

In order to implement a quantum algorithm on a real quantum computer, one must decompose the gates used in the ideal algorithm into the gates that can be implemented fault-tolerantly on the actual hardware.

The most commonly studied fault-tolerant universal gate set consists of the so-called Clifford gates and what is known as the T gate, with the T gate by far the most costly.

Until recently, the state-of-the-art method for synthesizing a given one-qubit gate into a given fault-tolerant gate set was the celebrated Solovay-Kitaev algorithm.

In order to obtain an approximation of a given gate with n digits of precision, the Solovay-Kitaev produced a circuit with over n^3 fault-tolerant gates.

Perimeter Associate Faculty member Michele Mosca, with collaborators Vadym Kliuchnikov and Dmitri Maslov, discovered a much better method for building any gate from a commonly used fault-tolerant set of gates, achieving n bits of precision with a circuit using on the order of n gates, and using the minimum number of T gates required. Interestingly, this method required the use of an efficient algorithm for finding solutions to the Lagrange 4-squares theorem, which states that any integer N can be decomposed into the sum of at most four perfect squares. For example, $39 = 1^2 + 2^2 + 3^2 + 5^2$.

By requiring far fewer gates than the previous state-of-the-art method, this new method allows a quantum algorithm to run much faster – an important innovation toward real-world quantum computing.

The quantum information revolution promises to transform technology and the fundamental research conducted at Perimeter is helping to pave the way to that quantum future.

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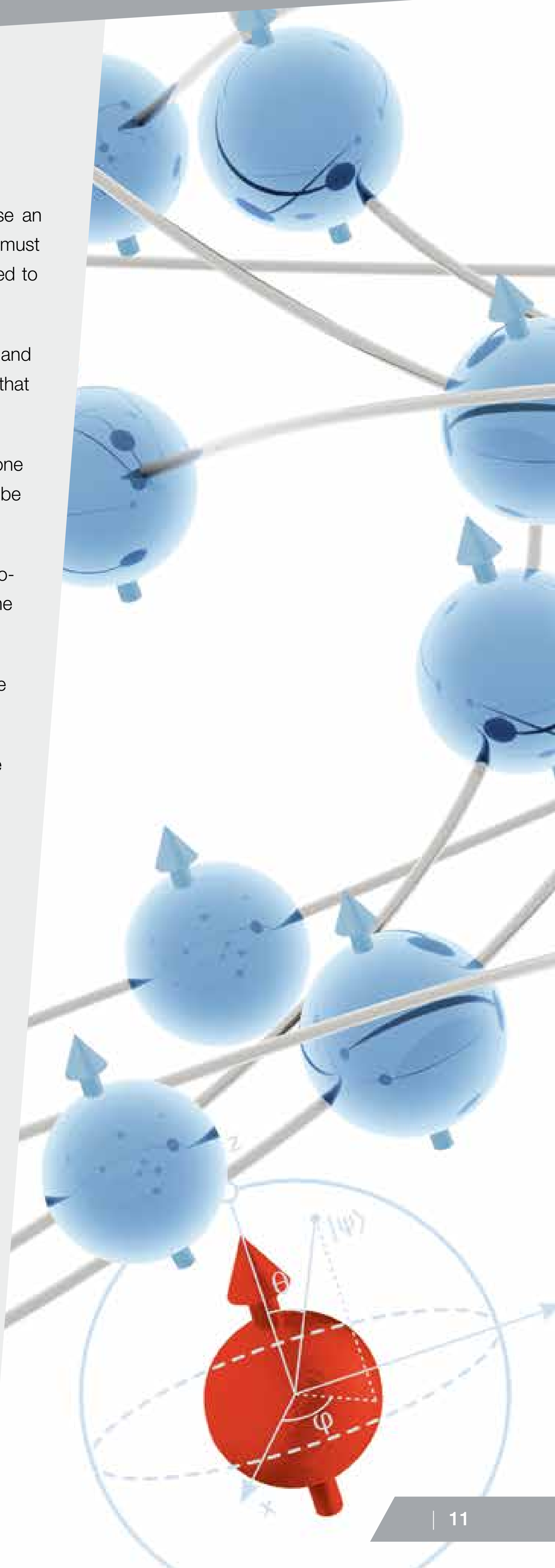
V. Kliuchnikov (Institute for Quantum Computing), D. Maslov (National Science Foundation), and M. Mosca (Perimeter Institute and Institute for Quantum Computing), "Practical approximation of single-qubit unitaries by single-qubit quantum Clifford and T circuits," arXiv:1212.6964.



MATHEMATICAL PHYSICS

In mathematical physics, new problems in physics give rise to new mathematics to solve them and new mathematics open doors to new understanding of the physical universe. Newton invented modern calculus because he needed it to understand mechanics – and calculus went on to redefine all of physics. The development of quantum theory in the 20th century both spurred and was spurred by advances in mathematical fields such as linear algebra and functional analysis. Perimeter's mathematical physics researchers continue this grand tradition.

THE NEW FACE OF FEYNMAN DIAGRAMS

Scattering amplitudes, which predict what happens when two or more particles interact, are the most fundamental calculations in particle physics. For decades, these calculations have been done using Feynman diagrams. Unfortunately, using Feynman diagrams to model even simple collisions of a few particles can involve thousands of diagrams, each introducing many terms into the calculation. As collisions become more complex, the Feynman diagram technique becomes too unwieldy to use.

Now, an international team of researchers, including **Perimeter Faculty member Freddy Cachazo**, has come up with a different and much more user-friendly approach to calculating scattering amplitudes. A landmark paper on the subject, the culmination of a decade of effort, has already attracted widespread attention in the physics community and will likely be a focal point for years to come.

The new system is simpler because it eliminates the great source of redundancy in Feynman diagrams: introduction of off-shell or virtual particles. The new system replaces Feynman diagrams with on-shell diagrams, which use only on-shell particles.

Underlying this new system is the team's discovery of elegant and surprising mathematical structures that govern scattering amplitudes. This work may provide clues that will lead to a much deeper understanding of how elementary particles arise, and perhaps the structure of spacetime itself.

It is a prime example of the kind of research that Perimeter fosters – it is both extremely ambitious and foundational. Over the last several years, faculty members, postdoctoral researchers, and a Distinguished Visiting Research Chair have all contributed to it, and Perimeter has emerged as a leading centre on new approaches to scattering amplitudes.

For his pioneering work, Cachazo won the illustrious 2013 New Horizons in Physics Prize from the Fundamental Physics Prize Foundation for "uncovering numerous structures underlying scattering amplitudes in gauge theories and gravity."

THE ORIGAMI OF QUANTUM FIELD THEORY

Davide Gaiotto, the **Krembil Foundation Galileo Galilei Chair in Theoretical Physics at Perimeter Institute,** plays with quantum field theories the way an origami artist plays with paper – folding up flat sheets to make round objects, collapsing round objects back to flat, moving between the dimensions, and discovering whole classes of objects no one has ever seen before.

Quantum field theories, or QFTs for short, are the language in which modern physicists describe nearly all physical systems. They are essential to fields from particle physics to condensed matter to advanced electronics. But as much as we know about QFTs, there is still a lot to learn. In the last five years, thanks to Gaiotto and others, physicists have learned that the QFTs that they can define and study are only a small corner in the much wider space of all possible QFTs.

Gaiotto is out to chart that space.

His master "origami figures" are a small set of six-dimensional (6-D) field theories, discovered in the 1990s but still mostly mysterious. Starting from that 6-D theory, he has discovered procedures for folding them into simpler forms with fewer dimensions. This is important both because discovering new theories helps chart the wider space of theories and because it is thought that theories with fewer dimensions more closely approximate our world.

Consider, as an analogy, a 2-D theory that exists on a sheet – then roll the sheet into a tube. Look at the tube from far away and it is a line: you have dropped a dimension.

Similarly (though this is mind-bending to picture), you can consider a 3-D theory which gets "rolled" into a 2-D shape. There are several ways to roll it: into a hollow sphere or into a hollow donut shape (or torus), for instance. Those shapes – the sphere and the torus – are called manifolds. Extend either manifold and look at it from some distance and you again get a line. But the theory of the line you reached via a sphere is different from the theory of the line you reached via a torus.

Knowing the path, in other words, tells us important things about the destination. And having new paths lets us find new destinations.

Knowing that the 6-D theory exists and having a procedure to fold away the dimensions allowed Gaiotto to generate immense classes of 3- and 4-D theories, each labeled by the manifold used in the folding. Some of these theories are the familiar ones that have long been known. But some are new and could not have been discovered any other way.

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T. Dimofte (Institute for Advanced Study), D. Gaiotto (Perimeter Institute), and R. van der Veen (Korteweg-de Vries Institute for Mathematics), "RG Domain Walls and Hybrid Triangulations," arXiv:1304.6721.

THE THRILL OF DISCOVERY

I'll never forget the look in the boy's eyes when the beauty of mathematics unveiled itself to him.

It was as if a beautiful new landscape had opened up before him, inviting him to explore. In a sense, that is exactly what happened.

The boy was nine at the time and I was tutoring him in math as a side job during my postdoctoral days at Penn State about 15 years ago.

He was bright and interested in math, but struggling to discern the meanings behind all the equations and formulae. To him, π seemed like an arbitrary jumble of digits – 3.14 followed by endless decimal points – with no connection to the real world.

I asked him to find a bunch of circular objects, like coins and plates, and trace them onto paper. Together, we snipped out the paper circles and began taking measurements.

I asked him to discern the ratio of each circle's circumference to its diameter. Each time, whether measuring a circle traced from a penny or a dinner plate, he arrived at the same answer: 3.14.

You could call it an epiphany or a "eureka moment." I call it the making of a mathematician. For the first time, he saw beautiful unity between equations on a page and the world that surrounded him.

I knew I would not have to tutor him again. I knew that, having once felt the thrill of discovery that mathematics could offer, he would seek it on his own.

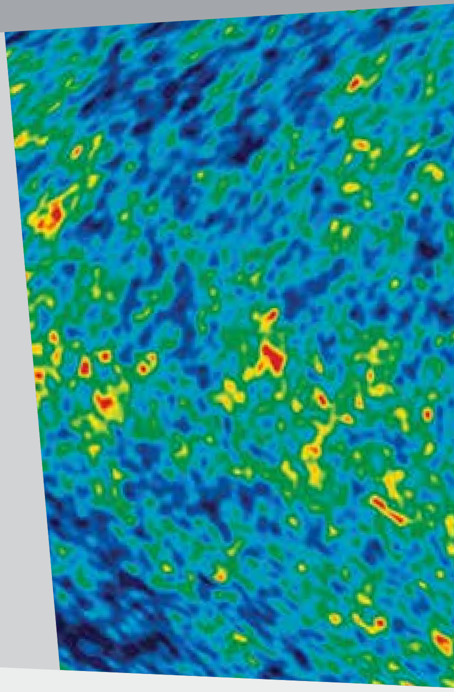
That same elation – the joy that comes from glimpsing the order underlying nature – led me to a career in theoretical physics.

I was right about the boy. He went on to study mathematics at Harvard. I imagine he still seeks that elusive but wonderful joy of discovery. I certainly do.

– Laurent Freidel

Laurent Freidel joined Perimeter in 2006.
He is a senior member of the Institute's faculty.

COSMOLOGY



Cosmologists at Perimeter Institute seek to uncover the distant history and constituents of our universe and decode the rules that govern its origins and evolution. These researchers look for answers to some of the most enduring questions in physics, at scales and energy levels that could never be simulated in an earth-bound lab. Cosmology is intrinsically connected to other branches of research at Perimeter, including particle physics, quantum fields and strings, and strong gravity.

THE FIRST SELF-PORTRAIT

It could be said that the universe took a "selfie."

Like someone holding a camera at arm's length and snapping a self-portrait, the universe took a picture of itself during its infancy.

This picture is, more accurately, the cosmic microwave background (CMB), the oldest light in the universe, imprinted like a photographic negative onto the sky when the universe was a mere 380,000 years old (practically a newborn, considering it is now nearly 14 billion years old).

Thanks to sophisticated telescopes, we can now look at this baby picture of the universe and make out – by interpreting tiny fluctuations in the background that represent areas of different densities – the seeds from which all the stars and galaxies emerged.

Perimeter researchers including **Faculty member Kendrick Smith** seek to explain the universe's distant past by probing clues left behind by the cosmic microwave background.

Scouring new data from the Planck Satellite mission, Smith and collaborators have examined whether tiny density ripples in the early universe are best described by so-called Gaussian (or bell-curve) statistics or by non-Gaussian statistics – a question posed in numerous competing theories.

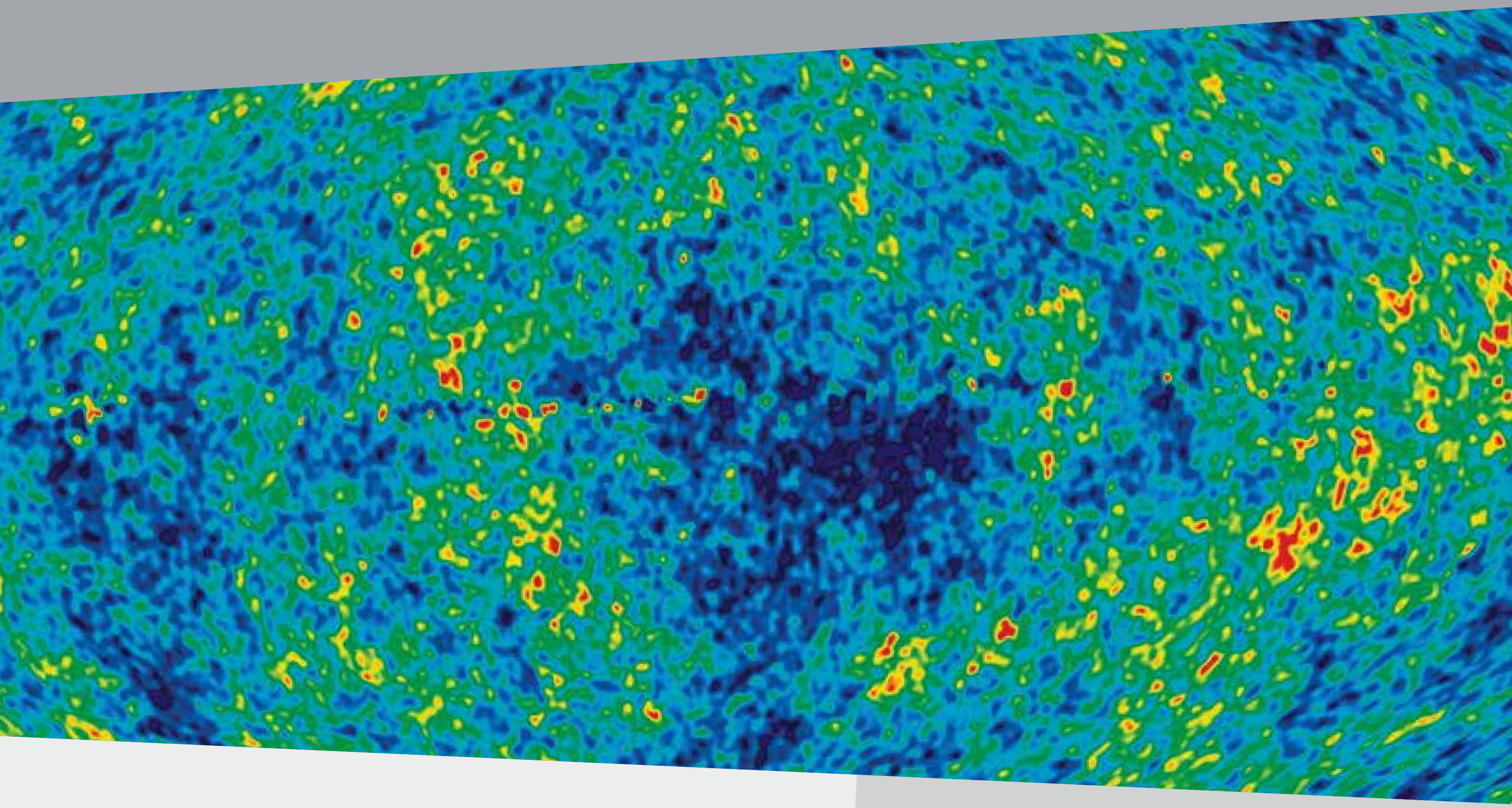
In a frequently cited landmark paper, Smith and co-authors determined that the data are indeed Gaussian, providing a clearer new lens through which scientists can examine our earliest image of the universe.

PINNING DOWN GRAVITY

While our understanding of the early universe is continually coming into sharper view, many mysteries persist about the present universe.

Perimeter has long been at the centre of the search for plausible modifications to Einstein's theory of general relativity that reconcile with what is now known about dark energy and dark matter, which are generally believed to constitute 95 percent of the universe.

The search for such modifications to general relativity has proven difficult, but an important step was made in 2011 when former **Perimeter postdoctoral researchers Claudia de Rham** and



Andrew Tolley were part of a team that discovered the full non-linear theory of massive gravity.

This breakthrough sparked the search for a "partially massless" theory of gravity, which yielded a tantalizing result achieved by de Rham, Tolley, and current **Perimeter Templeton Frontiers Program Postdoctoral Fellow Kurt Hinterbichler**. The authors demonstrated that the simplest possibility – a partially massless theory of a single graviton – does not exist.

This result has spurred a multi-faceted effort to find, or eliminate the possibility of, a partially massless theory of gravity. Such a theory, if it exists, would provide a new type of solution to the problem of dark energy.

The answers to such big questions will cast new light on the nature of our universe, just as the universe itself has cast its own ancient light, the cosmic microwave background, onto us.

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STRONG GRAVITY

From the big bang to neutron stars and black holes, Perimeter research into strong gravity explores cosmic cataclysms powerful enough to warp the fabric of spacetime. These areas of space where gravity is extremely strong serve as a natural experiment where researchers can theoretically "test" the validity of our current theory of gravity (Einstein's general relativity) and investigate alternative theories. Perimeter researchers also seek to understand and characterize the ways that curved or dynamical spacetimes are connected to other fundamental questions of physics.

Credit: ESO/L. Calçada

ESCAPE FROM THE BLACK HOLE

It is a cosmic monster of almost unfathomable power.

Gobbling up anything that dares come near it – even light – the black hole at the centre of an elliptical galaxy called Messier 87 (M87) never relinquishes a victim.

It is more than six billion times more massive than our sun. It is 50 million light years from Earth. Nothing that crosses its "point of no return," the event horizon, can escape its grasp.

Peering over this precipice with an enormous network of connected telescopes, a team of international scientists including **Perimeter Associate Faculty member Avery Broderick** has, for the first time ever, measured the event horizon of a black hole outside of our galaxy.

The team observed that the M87 black hole blasts collimated (that is, narrow and extremely fast) jets of material at velocities approaching the speed of light, dramatically altering the environment around it.

The observations – made by linking radio telescopes in Hawaii, Arizona, and California to create a highly precise eye on the cosmos called the Event Horizon Telescope – are the first to capture this jet-launching region of a black hole.

Such measurements, combined with follow-up work that will link even more radio telescopes worldwide, will provide crucial insights into the origins, evolution, and fates of these voracious cosmic giants.

ON A COLLISION COURSE

Whereas Broderick and his international collaborators have tracked the cataclysmic force of a massive black hole, **Perimeter Faculty member Luis Lehner** has, in a sense, listened for the birth cries of black holes.

Lehner and collaborators studied how two compact objects in a binary system, such as black holes or neutron stars, combine to create a single new entity.

In some cases, a neutron star orbiting a black hole gets swallowed up by its neighbour's gravitational pull; sometimes, two neutron stars spiral ever closer to one another before violently colliding to create a new black hole.

The gravitational force behind both events is tremendously powerful, packing masses equivalent to that of the sun into spheres smaller than most cities; electromagnetic forces create powerful electromagnetic signals.

Such forces create distortions in spacetime that ripple with gravitational waves, and the violent collisions induce the emission of electromagnetic radiation as matter is heated to extreme temperatures and the surrounding plasma becomes accelerated.

Though these ripples have never been directly observed, new detectors may soon change that – and Lehner's research into the mergers of compact objects indicates there are excellent chances of receiving more than one type of signal from these events.

In particular, what Lehner and his colleagues have done is show how two signals – the gravitational wave and the electromagnetic radiation from the system – might be related.

Analyzing these two kinds of signals allows astronomers and physicists to cross-check data for comparisons and predictions.

With such crucial information at their disposal, researchers could predict the next cosmic cataclysm and point their telescopes accordingly to catch a gamma ray burst – the beginnings of a black hole – in action.

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CONDENSED MATTER

The challenge of condensed matter physics can be summed up in a single observation: the behaviour of a system with many particles can be very different from that of the particles that make it up. Condensed matter physicists are those who study these many-body systems, especially those that are in a condensed state. At Perimeter, these researchers tackle such fundamental issues as the nature of magnets or the difference between conductors and insulators, as well as questions such as whether we can describe gravity as a property of a material or tailor an exotic form of quantum matter for use inside quantum computers.

A NEW PERIODIC TABLE FOR PHASES OF MATTER

What if we needed a new periodic table?

The periodic table – a staple of classroom walls and first-year chemistry textbooks – classifies the elements and predicts their behaviour. In its early days, though full of gaps, it was powerful enough to predict what should fall in each hole and flexible enough to subsume every new discovery. It has shaped and defined chemistry for almost 150 years.

The equivalent of the periodic table in condensed matter physics is the Landau paradigm, which classifies the phases of matter based on the layout and interaction of their constituent parts – technically speaking, their symmetry. As the periodic table did for the elements, Landau guides researchers in discovering new phases of matter and helps them grapple with the behaviours of the known phases.

But in the 1980s, something was discovered that fell off Landau's table entirely: phases of matter that were different from each other, but had the same symmetry. In 1989, **Xiao-Gang Wen** – then at MIT and now the **BMO Financial Group Isaac Newton Chair in Theoretical Physics at Perimeter Institute** – made a landmark step forward when he discovered that these new states contained a new kind of order: topological order. In topological order, the phases are not described by the patterns of symmetry, but by the patterns of a quantum property called entanglement.

Since discovering and defining topological order, Wen has been developing new mathematical theories. His goal has been to develop a new system, a new table, which would allow condensed matter researchers to understand all possible topological orders and gain insight into the mysteries of quantum entanglement. In 2012, he finally succeeded.

The trick was to use a very abstract mathematical theory called group cohomology theory.

"It was like history repeating itself," says Wen. "More than 70 years ago, the abstract group theory was introduced into physics to describe phases of matter via their symmetry patterns. Now, the abstract group cohomology theory is introduced into physics to describe phases of matter via their entanglement patterns."

The result was a new classification system that can handle most known phases of matter. This system can be used to generate insight about quantum phases of matter, which may in turn increase our ability to design states of matter for use in superconductors or quantum computers.

THE NEW LAWS OF QUANTUM DYNAMICS

Physicists do not know much about how large quantum systems evolve over time. Until now, they've never needed to.

Quantum systems tend to be small, not large. When lots of atoms get together, quantum effects tend to vanish quickly. Technically speaking, they dissipate into the environment. Once that happens, the system looks classical and can be described using statistical mechanics.

Recently, though, this has changed. It has become possible to create and study artificial many-body quantum systems – that is, systems containing a large number of atoms, isolated from the environment, in which quantum effects persist over time.

From observing these systems, researchers learned that they do not obey the conventional laws of statistical mechanics, which ordinarily govern systems with large numbers of variables. It became obvious that physics needed a theory of quantum dynamics in place of statistical mechanics – and **Faculty member Dmitry Abanin** has developed one.

Abanin worked with Maksym Serbyn (a graduate student at MIT and a Perimeter visitor) and Zlatko Papić (now a Perimeter postdoctoral researcher) to not just describe the dynamics of a particular quantum system, but to define general laws of quantum dynamics, which can be applied to any experimental quantum many-body system. These laws are expected to be of widespread use as researchers create and study more such systems.

The laws are quite different from statistical mechanics, but they are also unexpectedly simple. They are deeply connected to questions in quantum information, statistical mechanics, and condensed matter.

One immediate result is a counterintuitive one. While we normally think of quantum systems as needing to be cold and pure and isolated, the new laws show that quantum-ness can thrive on disorder. Introducing disorder into a quantum many-body system can actually increase the coherence times – that is, the length of time quantum effects persist before washing away. Results like these are expected to be vital as scientists work to engineer the first generation of quantum materials for use in quantum information processing devices.

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A PERFECT LANDING

I was a bit late to physics.

As a kid, I was more interested in chess and math. But I grew up in Russia, where International Physics Olympiads are a big deal, and by the time I finished high school I had found my calling. Now, I work on condensed matter physics, usually studying mesoscopic systems – those between the atomic scale and the human scale, ranging in size from tens of nanometers to microns. I focus on systems that exhibit what we think of as textbook single-particle quantum phenomena, with a large number of particles.

One material I've studied intensely is called graphene. A truly two-dimensional material, graphene is a film of carbon atoms in a honeycomb pattern, just a single atom thick. What's so exciting about it is that it exhibits many exotic quantum effects. For instance, electrons in graphene behave in a quasi-relativistic way, more like neutrinos than electrons. When I started studying graphene, not long after it was discovered in 2004, there were a handful of papers on the subject. Now there are roughly 20,000, including a pair that have earned Nobel Prizes.

The new laws and principles we can learn from materials like graphene will be indispensable in the development of new technologies, like quantum computers. The questions I'm trying to answer about the quantum nature of particle interactions – particularly at high temperatures and with a lot of disorder – will solve practical problems down the road.

Perimeter is a very special place for me to conduct this research. People here pursue what excites them, not what's fashionable, and have the passion to push ideas in bold new directions. I may be a latecomer to physics, but I feel like I've landed in exactly the right place.

– Dmitry Abanin

Dmitry Abanin joined Perimeter's faculty in 2013.

PARTICLE PHYSICS

Particle physics is the science which identifies nature's constituents and interactions at the most fundamental level. As such, it has strong overlaps with string theory, quantum gravity, and cosmology. At Perimeter, particle physics researchers often compare theoretical ideas with both astrophysical observations and earth-bound experiments like the ones carried out at the Large Hadron Collider, and study how such results can help us map the physics beyond the Standard Model.

A NEW SPIN ON LONG-RANGE FORCES

There is a hole in our understanding of long-range forces and **Faculty members Philip Schuster** and **Natalia Toro** are out to fill it.

Our universe contains two known forces that can reach across galaxies: electromagnetism and gravity. They are both mediated by massless particles – the photon for electromagnetism, the graviton for gravity.

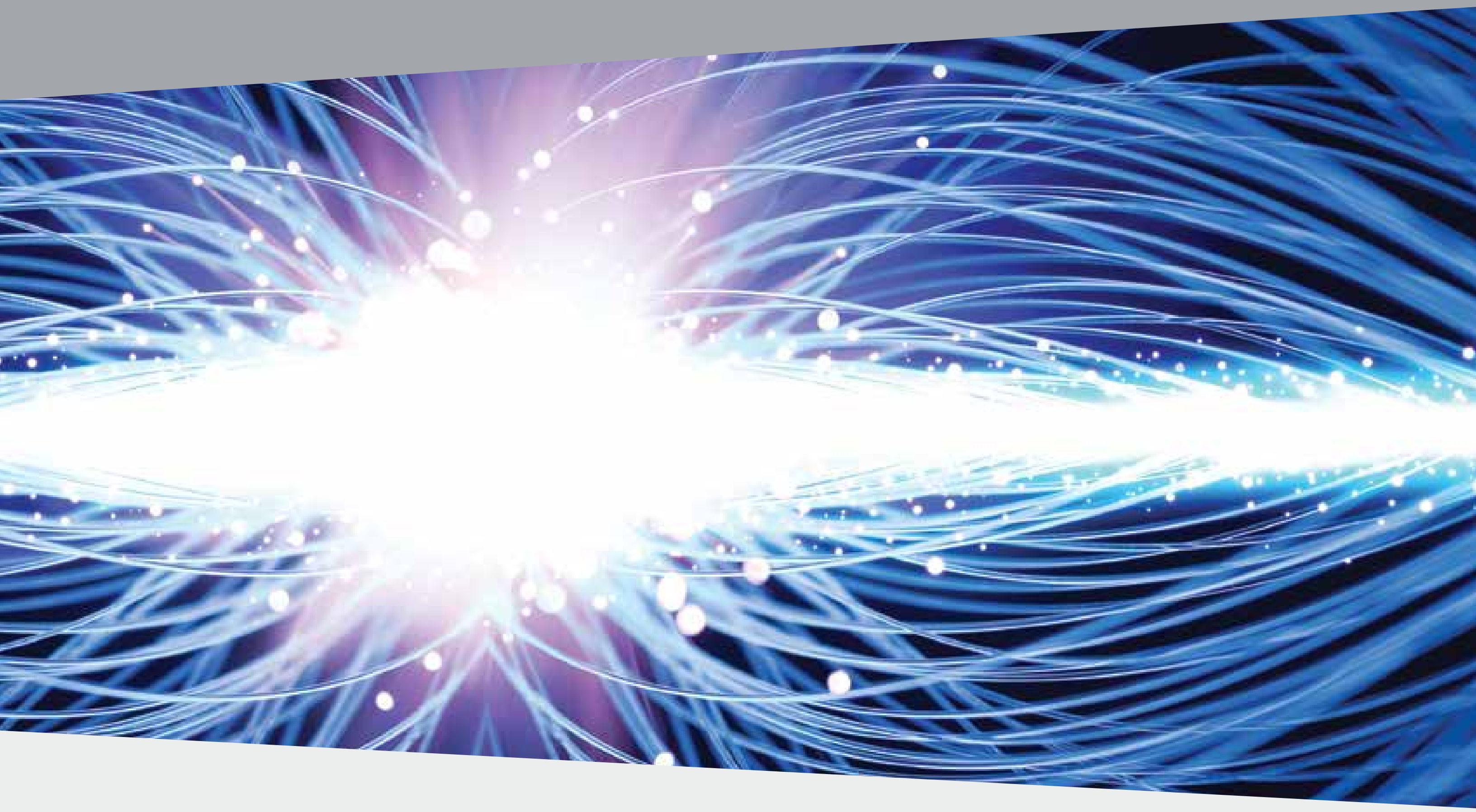
Photons and gravitons (and many other particles) have an intrinsic quality called spin. It is an imperfect analogy, but you can think of spin as nature's smallest bar magnet: it gives the particles something like a north and a south pole, which can point in any direction. When spin is aligned with momentum, it is also called helicity. Spin can have various magnitudes, and so helicity can too: particles can be helicity-1, helicity-2, helicity-3, and so on.

It is also well known that the nature of forces mediated by massless particles is determined by the helicity of those particles. For instance, the fact that electric charges also feel magnetic forces falls naturally out of modelling it with helicity-1 particles. The symmetries of gravity are a consequence of modelling it using helicity-2.

In the 1960s, Steven Weinberg showed that particles with higher helicities (helicity-3 and up) cannot mediate forces. Left open – though rarely noticed – was the possibility that long-range forces could be mediated by particles whose helicity can have any (quantized) magnitude. Such particles are called continuous spin particles, or CSPs. For a variety of reasons, it has been widely assumed that CSPs don't mediate long-range forces, but this assumption remained untested until Schuster and Toro began their work in 2011.

Starting from scratch, using only the basic assumptions of relativity and quantum mechanics as inputs, Schuster and Toro began to develop a model of long-range forces mediated by CSPs. They have uncovered evidence that CSPs are far more consistent, theoretically and phenomenologically, than was previously assumed.

In fact, their findings raise the exciting possibility that the known forces could be mediated by CSPs. Because the helicity of force carriers determines the nature of the force, this would mean that our understanding of forces would change in subtle and interesting ways. This has potential to be a true breakthrough in our understanding of long-range forces in nature.



IS SPACE FOAMY?

A new idea put forward by **Associate Faculty member Maxim Pospelov** suggests that Earth might be crashing through bubble after bubble in a foamy cosmos – and, crucially, that we might be able to detect bubble walls as we pass through them.

The hypothesis that space might be foamy is not new. It begins with a hypothetical field which has several possible ground states. In the hot chaos of the early universe, this ground state value would have been jumbled, with every point having a different ground state. As the universe expanded and cooled, large regions of space would have settled on a single value. Since then, they would have "frozen" into place, in a kind of invisible cosmic foam. The energy locked into these structures could contribute to those mysterious substances, dark matter and dark energy.

In the recent research, Pospelov estimated the size of the domains in the cosmic field – the bubbles in the foam. He found that the bubbles are small enough that the known speed of our solar system would cause it to pass through many domain walls over the course of a few years. Wall-crossing events would, then, be rare, but not impossibly so.

As the Earth passes through a bubble wall, there would be a small and sudden change in the magnetic torque exerted by the hypothetical field. Pospelov and his collaborators predict that the strength of that effect would be about a billionth of the Earth's magnetic field over a millisecond. The current generation of magnetometers are just sensitive enough to pick up such a signal. The team proposed deploying a network of widely separated but synchronized devices, to allow the tiny signals to be cross-checked. A pilot project to develop this detector has been funded by the National Science Foundation (US).

The collaboration, then, has taken two small things – new calculations about the relatively small size of cosmic bubbles and the new small signals that can be picked up by today's magnetometers – and put them into one big new idea: the "cosmic foam" hypothesis can now be directly tested for the first time.

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QUANTUM FIELDS AND STRINGS

Quantum field theory is the modern paradigm with which we understand particle physics, condensed matter systems, and many aspects of early universe cosmology. It is used to describe the interactions of elementary particles, the dynamics of many-body systems, and critical phenomena, all with exquisite accuracy. Perimeter researchers are producing world-leading advances in quantum field theories.

String theory is a theoretical framework which was proposed to produce a unified description of all particles and forces in nature, including gravity. It is based on the idea that at very short distances, all particles should in fact be seen to be extended one-dimensional objects – that is, "strings." Modern string theory has grown to be a broad and varied field of research with strong connections to quantum gravity, particle physics, and cosmology, as well as mathematics.

THE SOAP-BUBBLE SOLUTION

What can soap bubbles teach us about quantum field theory? A lot, as it turns out.

Perimeter Faculty member Pedro Vieira, **postdoctoral researcher Amit Sever**, and **postdoctoral researcher Benjamin Basso** have solved a longstanding problem in quantum field theory by mathematically cutting soap bubbles into pieces.

Quantum field theory is one of the most successful and flexible tools physicists have ever developed, but it has its limits. Notably, the calculations involving strongly-coupled particles – particles like the gluons that "glue" quarks together inside protons and neutrons – are too difficult to perform. This leaves physicists in the unfortunate position of being unable to predict what happens when two gluons collide – they can't calculate the scattering amplitudes, to use the technical phrase.

The problem of gluons is so sticky that researchers study it in a simplified context known as N=4 Super Yang-Mills theory. Inside N=4, researchers can calculate what's likely to happen when gluons collide – can calculate the scattering amplitude – albeit not by using traditional techniques. Instead, they use a geometric shortcut made possible by string theory. At very strong couplings, each scattering amplitude is associated with a polygon.

This polygon technique was discovered in 2007. To use it, researchers count the number of incoming and outgoing particles, and consider a polygon with that number of sides. They then take that polygon and mentally build it out of wire and dip it in soap, as if to blow bubbles. The surface area of soap film is the scattering amplitude.

Unfortunately, up until now, this has only worked for maximally strong coupling, where the soap film is stretched taut. For other couplings, the soap film begins to vibrate quantum mechanically, which makes its area exponentially more difficult to calculate.

The Perimeter researchers were able to simplify this calculation. They broke the polygon up into four-sided pieces they called squares. They then studied the transitions between two adjacent squares and found a way to add two squares together. Using this square-adding method over and over again, the researchers were able to sum over all possible surfaces. The result was a method that could calculate scattering amplitudes at any coupling strength.

This is technically known as solving scattering amplitudes for finite couplings and has long been a stubborn problem in the field. This work lays the foundation for a complete solution.

NEW RECIPES FOR QUANTUM FIELD THEORIES

The recipe for solving most quantum field theories goes like this: start from something simple, add some complications, add some subtler complications, repeat until the complications get too small to matter, and declare the quantum field theory solved.

It sounds simple, but this recipe, technically known as perturbation theory, has helped develop quantum field theory, or QFT, into one of the most flexible and powerful tools physics has ever invented.

But what happens when perturbation theory breaks down?

It's not a hypothetical question. The basic recipe – start from the simple and add increasingly more subtle complications – works well in areas where the real-world complications are indeed small. But there are several major places where the complications aren't subtle, but overwhelmingly large, and where adding more complications does not slowly narrow in on a realistic answer, but instead produces predictions that are self-evidently nonsense.

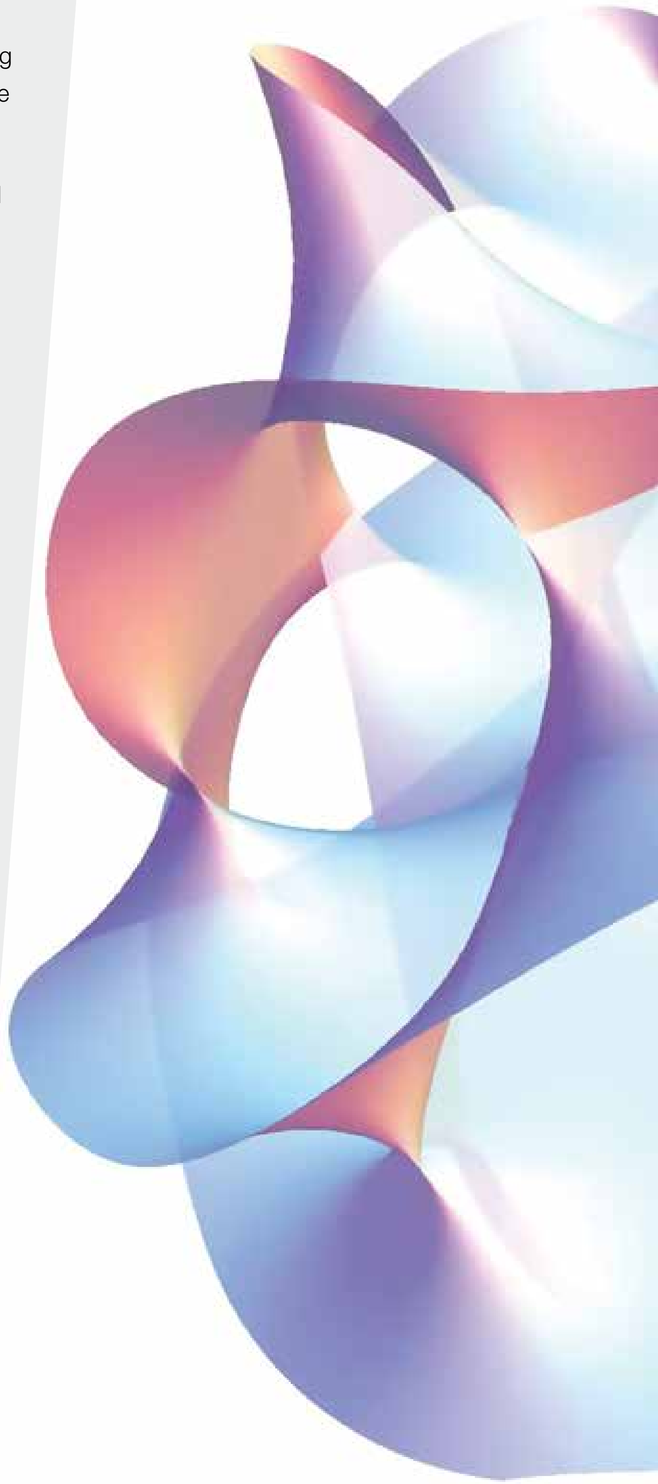
The inability of QFT to handle the low-energy quarks and gluons – to answer the question of why quarks are normally confined inside protons and neutrons, for example – is the most famous example of a place where the perturbation recipe breaks down. Also in the non-perturbative regime are the physics of strongly interacting many-body systems, the physics inside black holes, and the physics of the very early universe.

It's no surprise, then, that the search for new recipes that will work in the non-perturbative regime is a major area of research. **Perimeter Faculty member Jaume Gomis** is hard at work cooking some up.

The way Gomis sees it, part of the problem in building non-perturbative QFTs is that we don't really understand the behaviour the theory is meant to explain. This leaves us trying to figure out a recipe for a dish without tasting the dish first.

Gomis uses powerful mathematical techniques in his quest to define the possible non-perturbative dynamics of QFTs. In particular, he is interested in dualities – places where two different theories, one perturbative and one non-perturbative, look very different, but turn out to be quantum mechanically equivalent. By exploiting these dualities, Gomis has been able to obtain some exact results in four-dimensional QFTs for the first time. These results have yielded new insights into the non-perturbative dynamics of QFTs.

It's like the first taste of the dish – and it gives new hope for the development of new recipes.



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QUANTUM GRAVITY

Quantum gravity is concerned with unifying Einstein's general theory of relativity and quantum theory into a single theoretical framework. Perimeter researchers are actively pursuing a number of approaches to this problem, including loop quantum gravity, spin foam models, asymptotic safety, emergent gravity, string theory, and causal set theory. The search for quantum gravity overlaps with other areas such as cosmology, particle physics, and the foundations of quantum theory.

THE LEFT HAND OF GRAVITY

Parity is the notion that if you do something – anything – then the version of that thing that you'd see when looking in a mirror should also be possible. It is only mostly true. Gravity looks the same when you look at it in a mirror. So does the strong force. So does electromagnetism. But the weak force does not.

As physicists work towards a theory that would unify all the forces – describing them as aspects of a single theory – the asymmetrical nature of the weak force is a problem. How can it be that this force, and only this force, can tell its right hand from its left?

Perimeter Faculty member Lee Smolin and his collaborators Antonino Marciano and Stephon Alexander (both of Dartmouth) have addressed this issue in a new and surprising way. They propose a new unification of the weak and gravitational interactions that explains the asymmetry of the weak interactions under parity as due to a hidden asymmetry in the laws of gravity.

The idea does not come out of left field. Loop quantum gravity is a well-known approach to unifying gravity and the other interactions. Loop quantum gravity researchers often work with a reworking of general relativity known as the Plebanski reformulation. Like any reformulation, Plebanski is not a new theory – it does not describe a new phenomenon or make new predictions – but rather a translation of an existing theory into a new mathematical language. Such reformulations often make theories, in this case the theory of general relativity, easier to work with, or show new ways in which they can be extended.

This is the case with Smolin's new work. The researchers show that an extended Plebanski theory would naturally unify gravity with the weak interactions in a way that explains the asymmetry of weak interactions. Roughly speaking, the gauge fields describing gravity and the weak interactions start off as mirror images of each other. But this symmetric world turns out to be unstable. As a result, the symmetry between left and right breaks spontaneously, which allows nature to find a stable point where the left and right halves of the fields behave very differently. One half becomes gravity and the other half the weak force.

BORN, AGAIN

Perimeter Faculty member Laurent Freidel and his collaborators are following an old trail, and uncovering startling new ideas.

The trail begins in 1938 with Max Born – one of the fathers of quantum mechanics.

Born was seeking, as generations of his scientific successors would, a unification between quantum mechanics and general relativity, because the two successful explanatory frameworks of the universe don't quite work together.

Born had noticed in quantum mechanics an intriguing symmetry between space and momentum – a principle that would become known as Born reciprocity – and he wondered if the elusive unification of quantum mechanics and general relativity might be achieved through a unification of space and momentum in some geometrical structure.

Developing such a structure, however, proved too vexing for Born and for physicists who have attempted it in the seven decades hence.

But that may be about to change. Freidel and colleagues are trying to find a way to build that framework within the context of string theory.

“It’s crazy enough that it might work,” says Freidel. “It’s a radical idea because it necessitates us to relax our notions of locality and question the existence of spacetime.”

Radical, yes, but the ideas seem to work so far. Further research is required to check the ideas for consistency, “but it looks like the pieces are fitting together.”

Freidel and collaborators have shown that Born reciprocity can naturally be implemented in string theory and that string theory predicts that spacetime and energy-momentum space will be curved.

The researchers show how certain aspects of string theory impose a new mathematical structure on phase space, which they call a Born geometry. This Born geometry carries information about how spacetime is quantized.

The potential impact of this work is very high. It could lead to a radical refounding of string theory and will have deep consequences on our understanding of locality and the possible deviation from it.

If true, the findings might even lead to the possibility of testing quantum gravity, with the hope of learning surprising new things about the nature of the universe.

It’s speculative, theoretical work and Freidel is the first to admit there is “much more to be done,” but says that the early results are tantalizing.

“All good ideas in physics come, they die, and they resurface again at the right time,” he says. “I am heir to ideas about Born reciprocity, and I have to push it forward.”

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TACKLING THE BIGGEST QUESTIONS

I have always been interested in science and slightly geeky stuff – like becoming a certified radio ham in my teens – but also many other things, including music. One appealing aspect about studying physics was that it was supposed to be the hardest subject of all; one couldn’t really go wrong there!

Besides a love of geometry, what made me take up quantum gravity after my PhD was doubtless the osmotic influence of my supervisor, who was a quantum gravity guru. There always were people coming and going, asking his opinion of things. They also struck me as a friendly and interesting bunch.

In quantum gravity, we push our theoretical tools to the limit, trying to answer simple but profound questions: What becomes of space and time at the most fundamental, microscopic level? How can we describe quantum spacetime quantitatively? Can we explain gravity from first quantum principles?

Having been involved with Perimeter since the very beginning has added a dimension to my life, professionally and personally. It is exciting to take part in a complex human experiment – “how to create the best possible physics institute out of thin air” – and even more so to see it succeed so spectacularly.

What is remarkable about PI is not only the high degree of professionalism of its scientists and support staff, but their unique level of engagement in shaping the Institute. It gives the place a great vibe and dynamism that makes you feel anything is thinkable and possible.

When talking to fellow scientists, business people, and politicians back home and elsewhere, I often point to Perimeter as a shining example and as setting standards in science and outreach we all should aspire to. Weiter so, PI!

– Renate Loll

Renate Loll is a Professor of Theoretical Physics at the Institute for Mathematics, Astrophysics and Particle Physics of the Radboud University in Nijmegen, Netherlands. She is also a Perimeter Distinguished Visiting Research Chair and Chair of the Institute’s Scientific Advisory Committee.

QUANTUM FOUNDATIONS

The study of quantum foundations concerns the conceptual and mathematical underpinnings of quantum theory. Research in quantum foundations at Perimeter Institute aims to refine and reformulate quantum theory in ways that express its true nature and structure. Research in this field is closely tied with work in quantum gravity and quantum information.

ASSEMBLY INSTRUCTIONS FOR A UNIVERSE

You can't build a car without knowing how all the pieces fit together.

The same goes for the universe. If you don't know how its many pieces combine to make the whole, good luck trying to figure out how it works.

Such is the simple and pragmatic idea behind recent fundamental work by **Perimeter Faculty member Lucien Hardy**. If we understand how the components of something are connected – in this case, the "something" in question could be spacetime itself – then we should gain a better understanding of the thing as a whole.

Like any other composite object, a region of spacetime is made up of smaller regions joined together. Hardy's paper, titled "On the theory of composition in physics," establishes a general theory of such combinations, as well as a common language with which these cosmic composites can be described.

With that groundwork established, Hardy proposes a principle – fittingly called the composition principle – stating that any calculations of physical properties in a composite object (like a car or a galaxy) should take the same form as the description of the object's composition.

What Hardy has outlined is a kind of rulebook – a set of guidelines for defining, describing, and making predictions about composite objects, from the imperceptibly tiny to the astronomically enormous.

This approach has already been applied to quantum theory, and work is now under way to apply such composition ideas to general relativity. This kind of exploration will lead to valuable insights in the quest for a unified theory of quantum mechanics and general relativity – that is, the quest of quantum gravity research.

Given that Perimeter houses clusters of expertise in each of these areas – general relativity, quantum mechanics, quantum gravity, and related fields – the Institute itself is a kind of "composite object." As such, sometimes the biggest discoveries come through probing the interconnectedness of its various parts.

A NEW OUTLOOK ON A CLASSIC LAW

Research by **Perimeter Faculty member Robert Spekkens**, for example, aims to bridge disparate areas of research, including information theories, resource theory, and thermodynamics.

In a recent example, Spekkens and collaborators have taken an old problem – how to properly formulate the second law of thermodynamics – and looked at it through a new lens.

The second law, in basic terms, states that a system will tend to become increasingly uniform – that temperature and heat and pressure are inclined to "even out."

But such definitions are fraught with questions and frequently the subject of debate. More than a half-century ago, Nobel laureate Percy Bridgeman succinctly summarized the problem: "There are almost as many formulations of the second law as there have been discussions of it."

Spekkens and collaborators decided to return to basic questions of thermodynamics, reframing them as a kind of "resource theory," inspired by fruitful work in quantum information research.

Techniques from quantum information theory are now helping us say new things about thermodynamics, explains Spekkens. In particular, a special kind of correlation that can hold between systems, known as "entanglement," has been studied extensively as the thing that powers various information-processing tasks, and results in this area inform the new work.

Information theory is relevant to thermodynamics because, roughly speaking, knowledge is power. Indeed, information can serve as "fuel" for doing useful work; just as it takes power to erase all the data from your hard drive, a wiped hard drive can serve as a battery from which power can be drawn.

Spekkens and collaborators (including former **Perimeter postdoctoral researcher Markus Müller** and former **Perimeter Scholars International student Nicole Halpern**) examined how to quantify a state's deviation from "informational equilibrium" (i.e., a version of the "evened out" mode). They further discerned how that deviation can be put to use for mechanical and computational tasks, and how one state can be converted to another. The research examines various notions of state conversion and different scenarios in which it can arise.

The research not only provides new insight into how the second law can (and cannot) be formulated, it also forges new pathways between different areas of theoretical physics. It is the kind of research that creates new connective tissue between disparate disciplines and exemplifies the interdisciplinary approach to theoretical physics that Perimeter Institute was designed to foster.

References:

L. Hardy (Perimeter Institute), "On the theory of composition in physics," arXiv:1303.1537.

G. Gour (University of Calgary), M.P. Müller (Heidelberg University), V. Narasimhachar (University of Calgary), R.W. Spekkens (Perimeter Institute), and N. Yunger Halpern (California Institute of Technology), "The resource theory of informational nonequilibrium in thermodynamics," arXiv 1309.6586.

F.G. Brandao (University College London), M. Horodecki (University of Gdańsk), J. Oppenheim (University College London), J. Renes (ETH Zurich), and R.W. Spekkens (Perimeter Institute), "The resource theory of quantum states out of thermal equilibrium," arXiv:1111.3882.

HONOURS, AWARDS, AND GRANTS

- The Wilkinson Microwave Anisotropy WMAP team, of which **Faculty member Kendrick Smith** is a member, was awarded the Gruber Prize.

- **Neil Turok**, Perimeter's Director and the **Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics at Perimeter Institute**, was awarded honorary doctorate degrees by Heriot-Watt University in Edinburgh and by the University of Guelph.

- **Davide Gaiotto,** the **Krembil Foundation Galileo Galilei Chair in Theoretical Physics at Perimeter Institute**, was awarded a $100,000 New Horizons in Physics Prize by the Fundamental Physics Prize (FPP) Foundation.

- **Templeton Frontiers Program Distinguished Visiting Research Chair Stephen Hawking** was awarded a $3 million Fundamental Physics Prize by the FPP Foundation.

- **Distinguished Visiting Research Chair S. James Gates Jr.** was awarded the US National Medal of Science, the highest honour bestowed on scientists by the US government.

- **Associate Faculty member Roger Melko** was awarded the International Union of Pure and Applied Physics Young Scientist Prize in Computational Physics by the Council on Computational Physics.

- **Associate Faculty member Roger Melko** was named to the Canada Research Chair in Computational Quantum Many-Body Physics (Tier 2).

- **Associate Faculty member Michele Mosca** was named University Research Chair by the University of Waterloo, the university's highest distinction.

- **Faculty member Daniel Gottesman** and **Senior Researcher Chris Fuchs** were both elected Fellows of the American Physical Society.

- Several members of Perimeter's faculty were honoured with the Queen Elizabeth II Diamond Jubilee Medal for their achievements and contributions:

  - **Neil Turok**
  - **Robert Myers**
  - **Lee Smolin**
  - **Raymond Laflamme**
  - **Michele Mosca**

- **Faculty member Robert Spekkens** won first place in the Foundational Questions Institute (FQXi) essay contest; **Templeton Frontiers Program Postdoctoral Fellow Flavio Mercati** was a fourth prize winner.

- **Faculty member Luis Lehner** was elected as a Fellow of the International Society for General Relativity and Gravitation.

- **Postdoctoral Researcher Chad Hanna** was elected co-chair of the Compact Binary Coalescence group of the international LIGO Scientific Collaboration (LSC).

- Perimeter researchers obtained over $3.3 million in grants from agencies including the Natural Sciences and Engineering Research Council of Canada, the John Templeton Foundation, the Canada Foundation for Innovation, and the Ontario Research Fund.

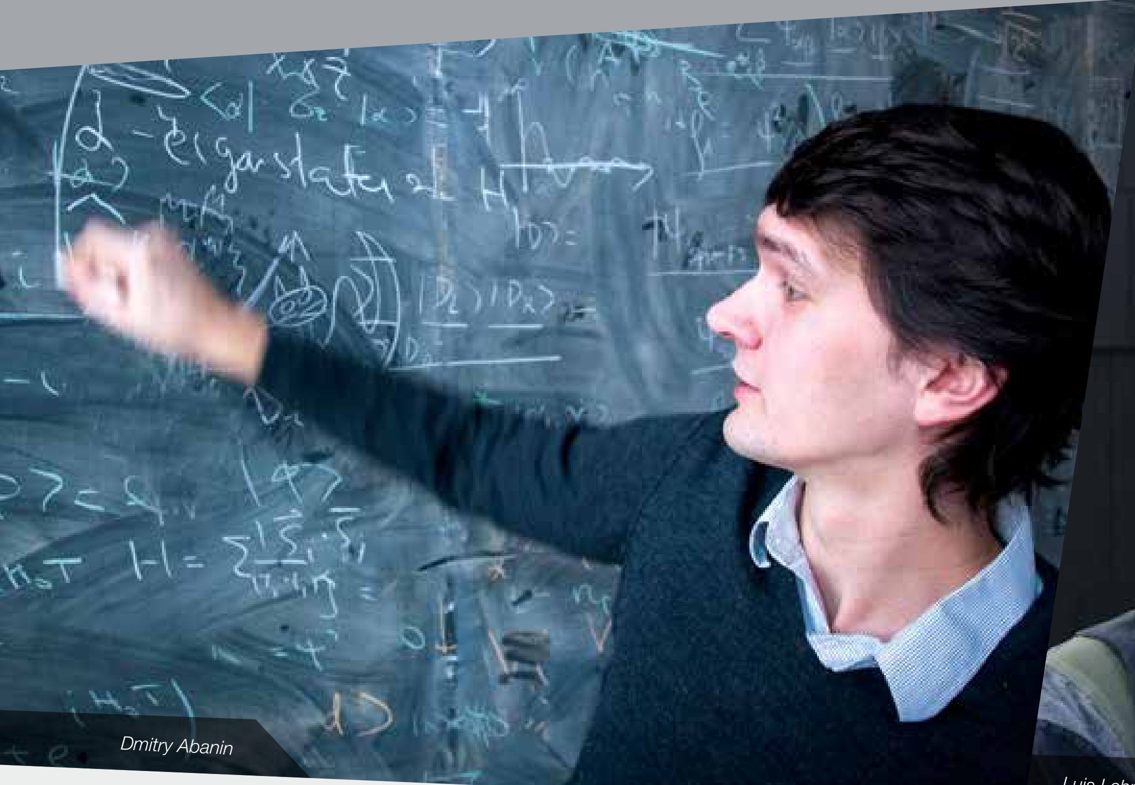
DAVIDE GAIOTTO AND STEPHEN HAWKING AWARDED FUNDAMENTAL PHYSICS PRIZES

This year, two members of Perimeter's scientific community were awarded prizes from the Fundamental Physics Prize (FPP) Foundation. These prizes are intended to recognize researchers who are "dedicated to advancing our knowledge of the universe at the deepest level."

Templeton Frontiers Program Distinguished Visiting Research Chair Stephen Hawking was given a Special Prize in Fundamental Physics for his discovery of Hawking radiation from black holes and for his deep contributions to both quantum gravity and early universe cosmology.

Davide Gaiotto, the Krembil Foundation Galileo Galilei Chair in Theoretical Physics at Perimeter Institute, was awarded the New Horizons in Physics Prize, which recognizes exceptionally promising young researchers. Gaiotto has achieved important conceptual advances in our understanding of the behaviour of strongly coupled quantum fields, within a unified framework known as supersymmetry.

RECRUITMENT



Dmitry Abanin

Luis Lehner

Great science can only happen through the collaboration of brilliant people. Since inception, Perimeter has attracted and retained the very brightest minds in theoretical physics from around the world. In the past year, Perimeter welcomed several leading scientists in fields spanning cosmology, condensed matter physics, quantum gravity, and more, as well as ensured the continued leadership of **Director Neil Turok**.

PERIMETER DIRECTOR REAPPOINTED

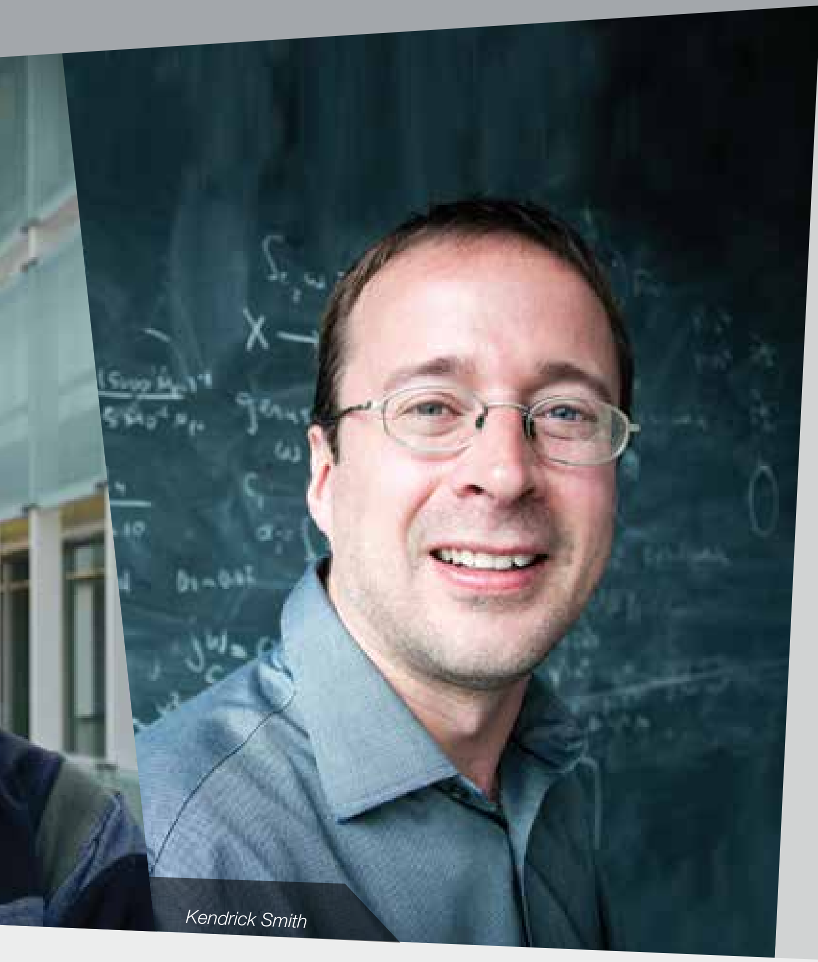
In March 2013, Perimeter's Board of Directors unanimously voted to re-appoint Neil Turok to a second five-year term as Director of Perimeter Institute. Since his arrival from the University of Cambridge in 2008, Turok has led Perimeter's strategic growth and development, helping the Institute grow rapidly in both size and international stature. During this time, with Turok's guidance, Perimeter has launched the Distinguished Visiting Research Chairs program, created the Perimeter Scholars International (PSI) program, and established the Perimeter Research Chairs program.

PERIMETER RESEARCH CHAIRS

In addition to his reappointment as Perimeter's Director, Neil Turok was appointed as the **Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics at Perimeter Institute**. Turok is the third chairholder to be appointed as part of the Perimeter Research Chairs program, designed to attract senior researchers of the highest international calibre to Perimeter and to Canada.

Turok's appointment followed the appointments of **Xiao-Gang Wen** as the **BMO Financial Group Isaac Newton Chair in Theoretical Physics at Perimeter Institute** and **Davide Gaiotto** as the **Galileo Galilei Chair in Theoretical Physics at Perimeter Institute**. Each holder of a Perimeter Research Chair forms the nucleus of a "powerhouse" research group able to make rapid, important progress on key questions in theoretical physics.

Finally, one of the world's leading young mathematicians, **Kevin Costello**, was recently recruited as the **Krembil Foundation William Rowan Hamilton Chair in Theoretical Physics at Perimeter Institute**. Costello will join the Institute from the Mathematics Department at Northwestern University. He has


Kendrick Smith

PI BY THE NUMBERS

Perimeter is the world's largest theoretical physics research community:

20 full-time faculty

12 associate faculty cross-appointed with partner universities

34 Distinguished Visiting Research Chairs

44 postdoctoral researchers

70 graduate students[1]

authored a pathbreaking monograph, *Renormalization and Effective Field Theory*, which introduced powerful new mathematical tools into the theory of quantum fields. Costello will join Perimeter's intensifying efforts in mathematical physics, working on some of the field's most challenging problems. The appointments of Costello and Gaiotto were made possible thanks, in part, to a generous $4 million investment by the Krembil Foundation.

FACULTY

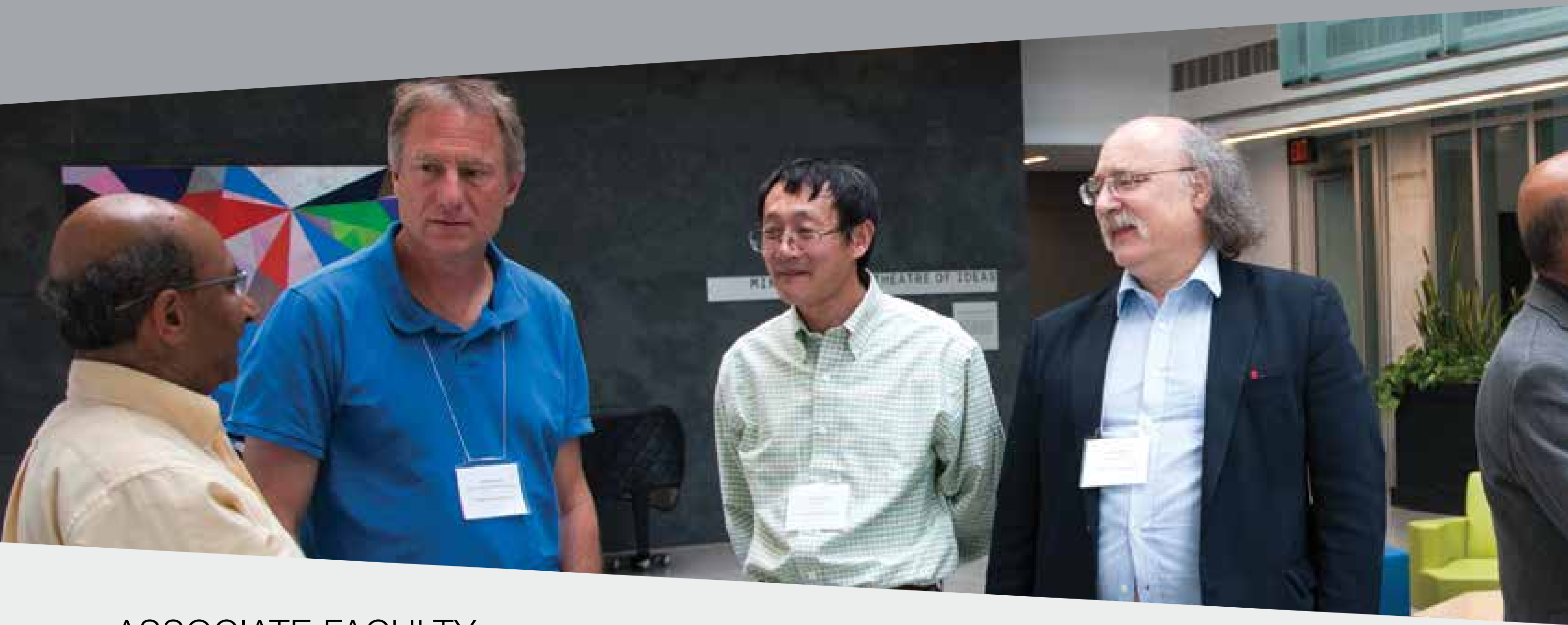
Perimeter welcomed several outstanding faculty members in 2012/13:

Dmitry Abanin joined Perimeter following postdoctoral positions at Princeton and Harvard. Abanin is a leading young condensed matter theorist whose research aims to more deeply understand so-called Dirac materials, whose unique quantum and electronic properties hold tremendous potential for use in an array of new technologies. Much of his theoretical work has been experimentally confirmed by groups at the Max Planck Institute, University of California, Harvard University, University of Manchester, Columbia University, and other top institutions.

Luis Lehner joined Perimeter's full-time faculty after a three-year position as a Perimeter associate faculty member cross-appointed with the University of Guelph. Lehner is an authority on strong gravity whose research explores cosmic phenomena that create strong gravitational and electromagnetic events, such as the violent collisions of binary systems. He has earned many honours, including fellowships from the Sloan Foundation, the Canadian Institute for Advanced Research (CIFAR), the Institute of Physics, the International Society for Relativity and Gravitation, and the American Physical Society.

Kendrick Smith joined Perimeter after postdoctoral fellowships at the University of Cambridge and Princeton University. He is a cosmologist whose research spans both pure theory and observation, most notably in his work mapping the cosmic microwave background – a "snapshot" of the oldest light in the universe. Smith collaborated with experimental teams on a number of landmark projects including the WMAP collaboration (which won the prestigious 2012 Gruber Cosmology prize), as well as QUIET and the Planck collaboration.

[1] This includes 39 PhD students and 31 Perimeter Scholars International (PSI) master's students. All numbers reflect the Perimeter community as of July 31, 2013.



ASSOCIATE FACULTY

In addition to full-time faculty, Perimeter frequently works with nearby universities to make joint hires through its Associate Faculty program, which enables the Institute to attract top talent to Canada and spread the benefit among multiple institutions. Associates spend up to 50 percent of their time at Perimeter, in addition to teaching and conducting research at a partner university.

This year, Perimeter made two such joint appointments, each of which has added significant research strength and breadth to the Institute.

Matthew Johnson is a cosmologist whose interdisciplinary research seeks to decode how the universe began, how it evolved, and where it's headed. He does this by designing sophisticated algorithms that bring the predictions of fundamental theory into sharper focus with experimental observations of the cosmic microwave background – the oldest light of the universe. Following two years as a postdoctoral fellow at Perimeter, he became an associate faculty member in 2012, jointly appointed with Toronto's York University.

Roger Melko is a condensed matter theorist who uses computational models to probe the unique properties of strongly correlated many-body systems. Melko's research provides new insights into emergent phenomena, ground state phases, phase transitions, quantum criticality, and entanglement. Melko earned his PhD in 2005 from the University of California, Santa Barbara, and was a Wigner Fellow at Oak Ridge National Laboratory before joining the University of Waterloo in 2007. He earned an Early Researcher Award in 2010 and joined Perimeter in fall 2012, while retaining his appointment with the University of Waterloo.

Matthew Johnson

Roger Melko

From left to right: Distinguished Visiting Research Chairs Senthil Todadri, Matthew Fisher, Zhenghan Wang, Duncan Haldane, Ganapathy Baskaran, and Subir Sachdev.

DISTINGUISHED VISITING RESEARCH CHAIRS

Perimeter's unique Distinguished Visiting Research Chairs (DVRC) program enables many of the world's most eminent scientists to spend weeks or months at the Institute for periods of fruitful research and collaboration, while retaining their permanent positions at their home institutions. During their terms as DVRCs, they can participate in all facets of the Perimeter community, from collaborating with colleagues to organizing conferences, teaching in the PSI program, and contributing to outreach activities. Time spent at Perimeter is highly productive for the DVRCs, as they are freed from their usual administrative and teaching duties.

Perimeter's DVRCs include such luminaries as **Stephen Hawking**, **Leonard Susskind**, **Mark Wise**, and Nobel laureate **Gerard 't Hooft**, with expertise spanning every branch of theoretical physics.

Twelve exceptional scientists became Perimeter DVRCs this year, greatly enhancing Perimeter's overall research community.

DISTINGUISHED VISITING RESEARCH CHAIRS

Dorit Aharonov, Hebrew University

Yakir Aharonov, Chapman University and Tel Aviv University

Nima Arkani-Hamed, Institute for Advanced Study

James Bardeen, University of Washington

Ganapathy Baskaran, Institute of Mathematical Sciences, Chennai

Juan Ignacio Cirac, Max Planck Institute of Quantum Optics

Matthew Fisher*, University of California, Santa Barbara

S. James Gates, University of Maryland, College Park

Alexander Goncharov*, Yale University

Duncan Haldane*, Princeton University

Stephen Hawking**, University of Cambridge

Patrick Hayden, Stanford University

Ted Jacobson*, University of Maryland, College Park

Leo Kadanoff, University of Chicago

Adrian Kent*, University of Cambridge

Renate Loll, Radboud University, Nijmegen

Ramesh Narayan*, Harvard University

Sandu Popescu**, University of Bristol

Frans Pretorius, Princeton University

Subir Sachdev, Harvard University

Peter Shor*, Massachusetts Institute of Technology

Eva Silverstein, Stanford University

Dam Thanh Son*, University of Chicago

Paul Steinhardt, Princeton University

Andrew Strominger*, Harvard University

Raman Sundrum*, University of Maryland, College Park

Leonard Susskind, Stanford University

Gerard 't Hooft**, Utrecht University

Senthil Todadri, Massachusetts Institute of Technology

William Unruh, University of British Columbia

Ashvin Vishwanath, University of California, Berkeley

Zhenghan Wang*, Microsoft Research Station Q

Steven White*, University of California, Irvine

Mark Wise, California Institute of Technology

* Indicates DVRC appointed in 2012/13

** Indicates Templeton Frontiers Program DVRC

POSTDOCTORAL RESEARCHERS

Many of the great discoveries in physics are made by surprisingly young researchers who approach big questions from novel directions. To foster and benefit from the intellectual energy of early-career scientists, Perimeter has assembled the world's largest group of independent postdoctoral researchers in theoretical physics.

These bold young minds are given the freedom and collaborative opportunities they need to push research into uncharted territory. As full members of Perimeter's research community, they are encouraged to pursue new, ambitious lines of inquiry, invite collaborators, travel, and organize conferences.

Perimeter appointed 20 new postdoctoral researchers in 2012/13 from over 600 applications and recruited an additional 18 to begin the following year.

Training at Perimeter pays off. Over the last year, despite an extremely competitive global academic market, six departing Perimeter postdoctoral researchers obtained tenure-track positions. Others obtained highly sought-after positions throughout academia, finance, and the tech sector.

SUPPORTING WOMEN IN PHYSICS

Perimeter is committed to supporting women in physics and, to this end, created **The Emmy Noether Circle**. Noether was a 20th century German mathematician described by Einstein as "the most important woman in the history of mathematics" thanks to her ground-breaking contributions. The Emmy Noether Circle has attracted support from the Bluma Appel Community Trust and the Ira Gluskin and Maxine Granovsky Gluskin Charitable Foundation to support students in the Perimeter Scholars International master's program (see p. 36).

This year, Perimeter created the **Emmy Noether Fellowships** to bring exceptional early career physicists to Perimeter for extended periods to pursue their research within Perimeter's stimulating environment and to interact with the resident research community.

The first two Emmy Noether Fellows are young physicists of exceptional promise:

Claudia de Rham is an Assistant Professor of Physics at Case Western Reserve University. She is a cosmologist working on very early universe cosmology and dark energy.

Sara Pasquetti is a Lecturer in Physics at the University of Surrey whose research interests lie at the interface between physics and mathematics.

"Perimeter is like being at a big conference every day. I can just go down to the Bistro, meet someone I was not expecting, start a discussion, and soon be tackling a problem from a completely new angle. I think this is unique."

– Eugenio Bianchi,
Perimeter Postdoctoral Researcher

"PI gives you ample room for the ideas to be built. As a postdoc, you are at the early stage of your career and that's really important."

– Joseph Ben Geloun,
Perimeter Postdoctoral Researcher

THE RICHNESS OF COLLABORATION

When I got the news that I had landed a three-year postdoctoral position at Perimeter Institute, I celebrated the best way I could imagine: I went straight to the supermarket and bought meat.

That might not seem decadent, but after a few years of conducting research with meagre financial means – sleeping on couches and borrowing train fare – a hearty steak was a king's feast.

Though I was financially strapped when I applied for a postdoctoral job at Perimeter in 2011, I was already scientifically rich.

I was working with Julian Barbour, a British theoretical physicist who operates outside of the traditional academic setting, but is renowned as the world's leading expert on Mach's principle and a brilliant mind in quantum gravity and other fields that fascinate me.

Julian, having recently received a grant from the Foundational Questions Institute (FQXi), invited me to join him on a project at his research headquarters – a 16th century farmhouse in Oxfordshire called College Farm.

I had recently earned my PhD from the University of Rome La Sapienza in my native Italy, and a meagre travel grant barely covered the rent of my new flat in Nottingham.

Julian covered the costs of my frequent train trips to his farmhouse. He hosted and fed me while we worked on some papers about shape dynamics. I'll always be grateful for his kindness and generosity.

Former Perimeter postdoctoral researcher Tim Koslowski and I recently received a $140,000 FQXi grant to advance our research program, "Information, Complexity, and the Arrow of Time in Shape Dynamics." Thanks to the grant, we can continue working with Julian for the next two years (some of the time at College Farm!). Together, we can push our research in new directions.

I'm overjoyed to be at Perimeter, where such international collaborations on adventurous topics are part of daily life. And the steaks are great, too.

– Flavio Mercati

Flavio Mercati is a Templeton Frontiers Program Postdoctoral Fellow. He joined Perimeter in 2012.

RESEARCH TRAINING

BLACKBOARDS TO BUSINESSES

Although theoretical physics explores realms we can hardly imagine – from the outer reaches of the universe to the world of subatomic particles – its mathematical tools and scientific rigour have immediate, practical applications.

Of the six graduates of Perimeter's PhD program this past year, two put their training to work by founding Canadian start-up companies (while their peers all obtained highly sought-after positions in academia).

Jorge Escobedo is using his talents in mathematical modelling as Co-Founder and Chief Technology Officer at Toronto-based Canopy Labs, which helps businesses predict consumer behaviour and target sales accordingly through sophisticated data analytics. He is using expertise he honed at Perimeter, where he created unique analytical and numerical tools to compute physical properties in string theory.

PhD graduate Cozmin Ududec is the Co-Founder and Risk Management Lead of Winnipeg-based Invenia Technical Computing, responsible for quantifying and managing financial risk in energy arbitrage markets.

The skills required for leading-edge theoretical physics – mathematics, algorithms, unconventional thinking, and boundless creativity – will become increasingly valuable in the 21st century economy.

PERIMETER SCHOLARS INTERNATIONAL

Perimeter recognizes that brilliant young people are the lifeblood of theoretical physics. Perimeter Scholars International (PSI), the Institute's master's program, brings exceptional university graduates from around the world to the cutting edge of theoretical physics in one academic year.

The program is structurally innovative, with courses taught in three-week modules by Perimeter faculty and other top lecturers from around the world, providing a broad range of expertise and perspectives. Students not only experience the full spectrum of theoretical physics, but also learn key skills such as computer-based model development, independent thinking, and collaborative problem solving. In the latter part of the program, students defend original research theses, many of which are later accepted for publication. The program is run in partnership with the University of Waterloo, which confers a master's degree to graduates upon completion.

Perimeter Scholars International trained 29 students from 15 countries in 2012. Notably, 10 of these graduates were women, reflecting the Institute's strong commitment to gender equity in the field. In the four years since the PSI was launched, the program has graduated 125 students from 37 countries – a testament to PSI's international renown as a sought-after master's program.

The PSI program was generously supported in 2012/13 by: The Bluma Appel Community Trust, The Henry White Kinnear Foundation, The Ira Gluskin and Maxine Granovsky Gluskin Charitable Foundation, The Kitchener and Waterloo Community Foundation – The John A. Pollock Family Fund, Brad and Kathy Marsland, and Margaret and Larry Marsland.

PSI 2012/13 FACULTY

John Berlinsky (Director), Perimeter Institute

Dmitry Abanin, Perimeter Institute

Assa Auerbach, Technion – Israel Institute of Technology

Latham Boyle, Perimeter Institute

Andrew Childs, University of Waterloo/Institute for Quantum Computing (IQC)

David Cory, Perimeter Institute and University of Waterloo/IQC

François David, CEA-Saclay/Institute of Theoretical Physics

Bianca Dittrich, Perimeter Institute

Michael Duff, Imperial College London

Joseph Emerson, University of Waterloo/IQC

Ruth Gregory, Durham University

Alioscia Hamma, Perimeter Institute

Matthew Johnson, Perimeter Institute and York University

David Morrissey, TRIUMF

Robert Spekkens, Perimeter Institute

Natalia Toro, Perimeter Institute

Guifre Vidal, Perimeter Institute

Pedro Vieira, Perimeter Institute

Xiao-Gang Wen, BMO Financial Group Isaac Newton Chair in Theoretical Physics at Perimeter Institute

Mark Wise, California Institute of Technology (Caltech)

Itay Yavin, Perimeter Institute and McMaster University

Konstantin Zarembo, NORDITA (Nordic Institute for Theoretical Physics)

Barton Zwiebach, Massachusetts Institute of Technology (MIT)

PHD STUDENTS

Perimeter's PhD program continues to grow, with 39 PhD students in residence at the Institute in 2012/13. As Perimeter is not a degree-granting institution, doctoral students ultimately receive their degrees from a partnering university where their faculty supervisor has an affiliation. Perimeter's collaborative environment offers students unparalleled opportunities to interact with scientific leaders from around the world and develop their careers. Of this year's six graduates, for example, two founded Canadian start-up companies, while the others obtained highly competitive postdoctoral positions at institutions around the world.

VISITING GRADUATE FELLOWS

Perimeter's innovative Visiting Graduate Fellows program, which brings advanced PhD students from around the world to work for several months at the Institute, hosted 19 fellows for a total of 22 visits in 2012/13. The program gives students the invaluable opportunity, at a pivotal time in their training, to work among and collaborate with leading researchers in their field. At any given time, the Institute hosts six to eight Visiting Graduate Fellows, who greatly benefit from and enrich Perimeter's research ecosystem.

UNDERGRADUATE RESEARCH

The Undergraduate Student program exposes promising young science undergraduates to high-level research by pairing them on research projects with Perimeter postdoctoral researchers. It's a valuable experience for all involved: a mentorship opportunity for postdoctoral researchers, a learning experience without equal for the undergraduates, and a means of recruitment for the Institute (**Emily Adlam**, for example, first came to Perimeter as an undergraduate for a summer project and later returned as a master's student in Perimeter Scholars International).

RESEARCH EVENTS

BY THE NUMBERS

In 2012/13 …

- Held 10 timely, focused conferences and workshops, attended by nearly 700 scientists from around the world
- Partnered on 6 joint workshops and conferences held at Perimeter and sponsored an additional 10
- Presented 301 scientific talks, all available online at www.pirsa.org

PIRSA

All talks and courses held at Perimeter are freely available to the wider scientific community through PIRSA, Perimeter's online video archive (www.pirsa.org).

CONFERENCES, WORKSHOPS, AND SUMMER SCHOOLS

Breakthroughs rarely happen in isolation. Much more frequently, they're sparked when a diverse group of brilliant minds, each approaching a difficult problem from a different angle, come together and collaborate. At Perimeter scientific conferences and gatherings – where international researchers discuss, debate, and pursue unexpected ideas – the whole is greater than the sum of its parts.

There is no substitute for the intense focus and unexpected interactions that happen at scientific gatherings. Perimeter's flexibility enables it to rapidly identify and capitalize on promising new areas, and the Institute is often the first in the world to host a conference on an emerging area or new discovery.

In 2012/13, the Institute held 10 conferences and workshops, attended by nearly 700 scientists from around the world. By strategically choosing timely, focused topics, Perimeter aims to accelerate progress and act as a major node of exchange for ground-breaking research.


Participants at “Loops 13” conference

COLLOQUIA AND SEMINARS

Perimeter provides a rich environment for knowledge exchange, with 257 seminars and 44 colloquia held over the last year. Talks were presented by some of the world’s most eminent scientists, including **Perimeter Distinguished Visiting Research Chairs Ganapathy Baskaran**, **Ted Jacobson**, **Renate Loll**, **Subir Sachdev**, **Paul Steinhardt**, **Steven White**, and **Mark Wise**.

PERIMETER INSTITUTE RECORDED SEMINAR ARCHIVE

Perimeter’s searchable and citable video library of more than 6,700 scientific seminars, conferences, workshops, and courses attracted over 80,000 unique visitors from 170 countries over the past year. The free online resource, www.pirsa.org, was developed by the Institute to share knowledge with the international scientific community and has become an important resource in the theoretical physics community.

CONFERENCE HIGHLIGHT: EMERGENCE AND ENTANGLEMENT II

Forty brilliant physicists from around the globe converged on Perimeter Institute in spring 2013 to sort out what’s the matter – specifically, what’s the *quantum* matter.

The study of quantum matter – that is, stuff that exhibits quantum effects not merely at the tiny scale of individual particles, but at the big scales of our everyday world – is one of the most dynamic and potentially transformative areas of contemporary physics. Whereas most states of matter are described by patterns of their atoms or electrons, quantum states of matter are described by patterns of quantum properties, particularly entanglement. It’s a bit like describing a city not with a map of its streets, but with the ideas being exchanged in phone calls between its citizens.

The international group of experts that assembled for five days at Perimeter discussed new mathematical approaches to understanding and describing exotic phases of quantum matter. Like any good sequel, the 2013 conference picked up where its predecessor, the inaugural “Emergence and Entanglement” of 2010, left off. Speakers and panelists (including eight Perimeter Distinguished Visiting Research Chairs – one of the largest single gatherings of these eminent minds) offered perspectives from string theory, condensed matter, quantum information, and computational physics – each providing important new insights about what’s the quantum matter.

LINKAGES

BY THE NUMBERS

In 2012/13 …
- Nearly 1,000 scientists visited Perimeter to carry out research and attend conferences

VISITOR PROGRAM

Collaboration is often key to discovery, which is why Perimeter hosts top scientists from all corners of the globe for scientific visits. During their time at Perimeter, visiting scientists are given the time, space, and opportunities to attend conferences and talks, exchange ideas, and spark new collaborative projects with colleagues.

In 2012/13, Perimeter hosted 427 visiting scientists for a total of 457 collaboration visits. These guests, who enriched Perimeter's research ecosystem and output, included 387 short-term visitors, 15 Distinguished Visiting Research Chairs, and eight Visiting Fellows. In addition, 17 longer-term Visiting Researchers worked at Perimeter during leaves, such as sabbaticals, from their home institutions.

AFFILIATES

Through the Institute's Affiliate member program, Perimeter has strengthened its relationship with more than 25 of Canada's top research centres while simultaneously enriching the Institute's research environment. Select faculty from universities across the country are invited to make regular visits, attend research events, and collaborate with Perimeter's resident scientists. In 2012/13, Perimeter renewed the terms of 12 Affiliates, giving the program 117 Affiliates in total.

COLLABORATIONS AND PARTNERSHIPS

Perimeter's institutional partnerships with other leading research centres in Canada and worldwide create new research and training opportunities and enable Perimeter to serve as a global research hub. Perimeter Institute signed three new partnerships and renewed existing agreements with TRIUMF, Canada's national laboratory for particle and nuclear physics, and the Centre for Theoretical Cosmology (CTC) at the University of Cambridge.

NEW PARTNERSHIPS

TRISEP

Perimeter has partnered with fellow Canadian institutes TRIUMF and SNOLAB to hold a new international summer school for graduate students and postdoctoral researchers on hot topics in particle physics. The first Tri-Institute Summer School on Elementary Particles (TRISEP) happened at TRIUMF in July 2013, featuring lectures and workshops by leading experts in collider physics, neutrinos, dark matter, and physics beyond the Standard Model. TRISEP will be held in 2014 and 2015 at SNOLAB and Perimeter respectively.

WEIZMANN INSTITUTE OF SCIENCE

Like Perimeter, the Weizmann Institute of Science in Rehovot, Israel, is a multidisciplinary research institution seeking to improve our understanding of nature. In 2013, the two institutes signed a three-year agreement to promote research visits and collaboration, and to encourage cooperation on educational outreach programming.

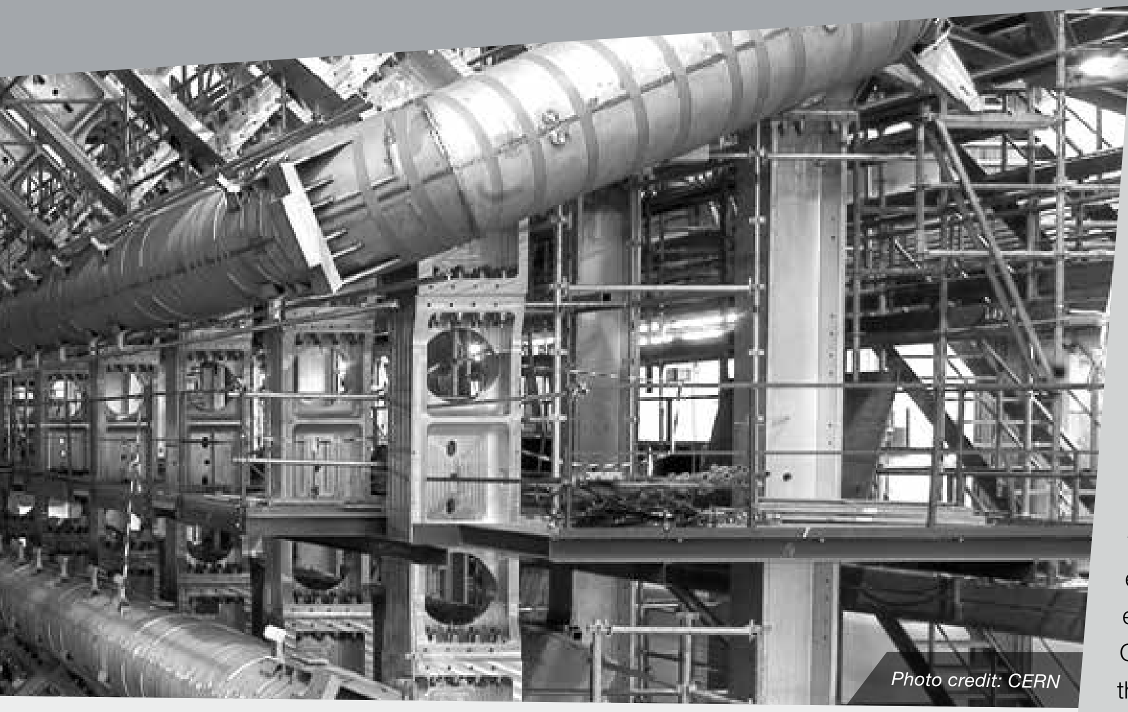


Photo credit: CERN

INTERNATIONAL SCHOOL FOR ADVANCED STUDIES (SISSA)

Located in Trieste, Italy, the International School for Advanced Studies (SISSA) is a centre of excellence whose research focuses on physics, mathematics, and neuroscience. Perimeter and SISSA have signed an agreement to facilitate scientific visits and promote collaborations between researchers in areas of common interest.

Perimeter also pursued other partnerships that benefitted the international physics community, including "LHC Search Strategies" (a workshop on Large Hadron Collider data), the Fields-Perimeter Africa Postdoctoral Fellowship (funding one-year fellowships for African mathematicians and scientists), and "Cosmological Frontiers in Fundamental Physics 2013" (a conference jointly organized with the Solvay Institutes in Brussels and the AstroParticle and Cosmology (APC) laboratory at the University of Paris VII).

Finally, Perimeter hosted several important international conferences in 2012/13 and jointly sponsored 10 workshops and conferences with national and international partners.

GLOBAL OUTREACH

Perimeter's Global Outreach initiative shares expertise to assist the growth of scientific centres of excellence around the world. The current focus of these efforts is the African Institute for Mathematical Sciences – Next Einstein Initiative (AIMS-NEI), a pan-African project founded in 2003 by Perimeter Director Neil Turok to establish a network of centres providing advanced mathematical and scientific training to exceptional African graduates.

AIMS-NEI has become a flourishing pan-African network. In August 2012, the third centre opened in Ghana, with AIMS-Cameroon following in 2013. Perimeter supported this success over the past year through courses taught at AIMS centres by Perimeter researchers, management and fundraising support, and help in building international partnerships.

FOSTERING QUANTUM VALLEY

Quantum information science is progressing rapidly from theory to experiment to prototype components and devices. It is now widely believed that quantum technologies will transform society much as the first wave of classical computers did.

Perimeter researchers do crucial theoretical work that underpins the entire field, working closely with experimentalists at the Institute for Quantum Computing (IQC). Many of the field's pioneers are located at one or both of these centres. The surrounding academic community (including IQC, the Waterloo Institute of Nanotechnology, and the Quantum-Nano Centre at the University of Waterloo), an innovative and vibrant start-up community, and the presence of venture capital (including Mike Lazaridis' latest venture, Quantum Valley Investments) all combine to create an ecosystem primed to develop and commercialize breakthroughs. There is thus good reason to believe that Waterloo Region possesses the infrastructure and leading minds to become the next Silicon Valley – or "Quantum Valley."

Perimeter is seeding this emerging ecosystem and is working strategically with partners to realize this rare opportunity for Canada. In the last year, for example, recruitment has emphasized quantum specialists including **Faculty members Dmitry Abanin** and **Roger Melko**, **Distinguished Visiting Research Chairs Peter Shor**, **Steven White**, **Matthew Fisher**, **Duncan Haldane**, and **Zhenghan Wang**, as well as numerous postdoctoral researchers. Together with other key players in Waterloo Region, Perimeter is working to ensure Canada remains at the forefront of the international quantum race.

OUTREACH

"There's an inspirational aspect of science and of understanding our place in the universe which enriches society and art and music and literature and everything else. Science, in its turn, becomes more creative and fruitful when it is challenged to explain what it is doing and why, and when scientists better appreciate the importance of their work to wider society."

– Neil Turok,
The Universe Within: From Quantum to Cosmos

Great science deserves to be shared with the people whose lives it will touch. By spreading the wonder and excitement of physics, Perimeter aims to inspire the next generation of scientific explorers and inform the public about the transformational role physics continues to play in our society.

Educational outreach is central to Perimeter's mission. The Institute has developed a wealth of accessible, engrossing materials and programs to ignite passion for physics among students, teachers, and the general public. More than two million students have been reached through Perimeter's award-winning outreach programs and resources to date.

By instilling a passion and understanding for physics among young people, we are investing in a brighter and more prosperous future.

THE INTERNATIONAL SUMMER SCHOOL FOR YOUNG PHYSICISTS

The International Summer School for Young Physicists (ISSYP) brings exceptional high school students to Perimeter every summer to live and breathe physics for two intense weeks. This year, the Institute hosted 40 students from 12 countries, who learned about modern physics, met scientists, toured research labs, and forged lasting friendships. More than 500 students from 44 countries have participated in ISSYP since the program began and more than 70 percent of alumni surveyed credit ISSYP with inspiring them to pursue careers in math and science.

ISSYP was generously supported in 2012/13 by RBC Foundation.

Neil Turok delivers Massey Lecture in Toronto.
Photo credit: Jens Langen

"I took it all in, stretched my mind, and do not regret even a single second. I walk out of this building completely different from how I was when I took my first step in."

– 2013 ISSYP participant Lerato Mannya, age 17, South Africa

"ISSYP has given me an entirely new perspective on physics. It has been a wonderful experience in every aspect."

– 2013 ISSYP participant Rebecca Bauer, age 17, USA

THE MASSEY LECTURES

Perimeter Director Neil Turok shared the inspiring power of science during a coast-to-coast speaking tour of Canada delivering the prestigious Massey Lectures. More than one million Canadians heard Turok's five lectures, presented jointly by the Canadian Broadcasting Company (CBC), the House of Anansi Press, and Massey College. The companion book to the lectures, *The Universe Within: From Quantum to Cosmos*, became a Canadian bestseller and won the 2013 Lane Anderson Award for excellence in Canadian science writing.

Perimeter's outreach team visited each city that hosted a Massey Lecture – St. John's, Montreal, Toronto, Calgary, and Vancouver – in advance of Turok's lectures, giving presentations in local schools on science connected to the Massey Lectures.

Singaporean teachers learning Perimeter educational modules

THE SCIENCE ROADSHOW: PHYSICA PHANTASTICA AND GOPHYSICS!

This year, Perimeter Teacher Network associates and outreach staff scientists hosted five day-long GoPhysics! camps to exceptional high school students across Canada, providing a snapshot of the ISSYP experience.

More than 2,200 students in Grades 7 to 12 – as well as a general public group of more than 200 – participated in Perimeter's Physica Phantastica presentations, which connect foundational science to the cutting-edge technologies it makes possible.

ABORIGINAL ENGAGEMENT

More than 1,500 Aboriginal youth in dozens of remote communities explored Perimeter educational resources in 2012/13. Outreach staff provided training to associates from partner organizations, who delivered the content to Aboriginal youth across Canada through their established channels. Perimeter has worked closely with Actua – Canada's leading organization for STEM (science, technology, engineering, and math) outreach for youth, particularly Aboriginal Canadians – for almost two years. Perimeter has also trained associates from the Indigenous Education Coalition to inspire even more youth to pursue scientific studies and careers.

IN-CLASS RESOURCES

Perimeter seeks to educate and inspire the next generation of scientific explorers with in-class modules aimed at introducing high school students to physics. These interactive kits have reached more than two million students to date, earning resoundingly positive feedback from teachers and students alike.

This year, the outreach team completed a new Perimeter Explorations module, *Career Moves: Skills for the Journey*, created with support from the Federal Economic Development Agency for Southern Ontario (FedDev Ontario). The new resource is designed to inspire students with the career possibilities opened by STEM subjects and show them the power of creativity, critical thinking, and the entrepreneurial spirit.

PERIMETER TEACHER NETWORK

More than 60 teachers from across Ontario and Canada are members of the Perimeter Teacher Network, trained to share Perimeter's resources with fellow educators. Most are alumni of Perimeter's EinsteinPlus Teachers' Workshop, an annual one-week summer gathering of high school educators, which shares effective strategies for teaching modern physics. Network members conducted 50 workshops in their home districts this year, thereby greatly extending the reach of the Institute's resources to some 65,000 Canadian high school students.

"The Perimeter workshop I attended was simply the best professional development session I have had in my entire career. Thank you for clarifying, challenging, and re-energizing my teaching practice."

– Trevor Taylor, West Park Secondary School, District School Board of Niagara

INTERNATIONAL REACH

Perimeter aims to share its resources with young people worldwide. This past year, the outreach team travelled to Singapore – a country already highly ranked in math and sciences – to train 100 teachers on a large suite of Perimeter educational models. Those teachers then shared the resources and training with colleagues to begin building a Perimeter-trained teachers' network across Singapore.

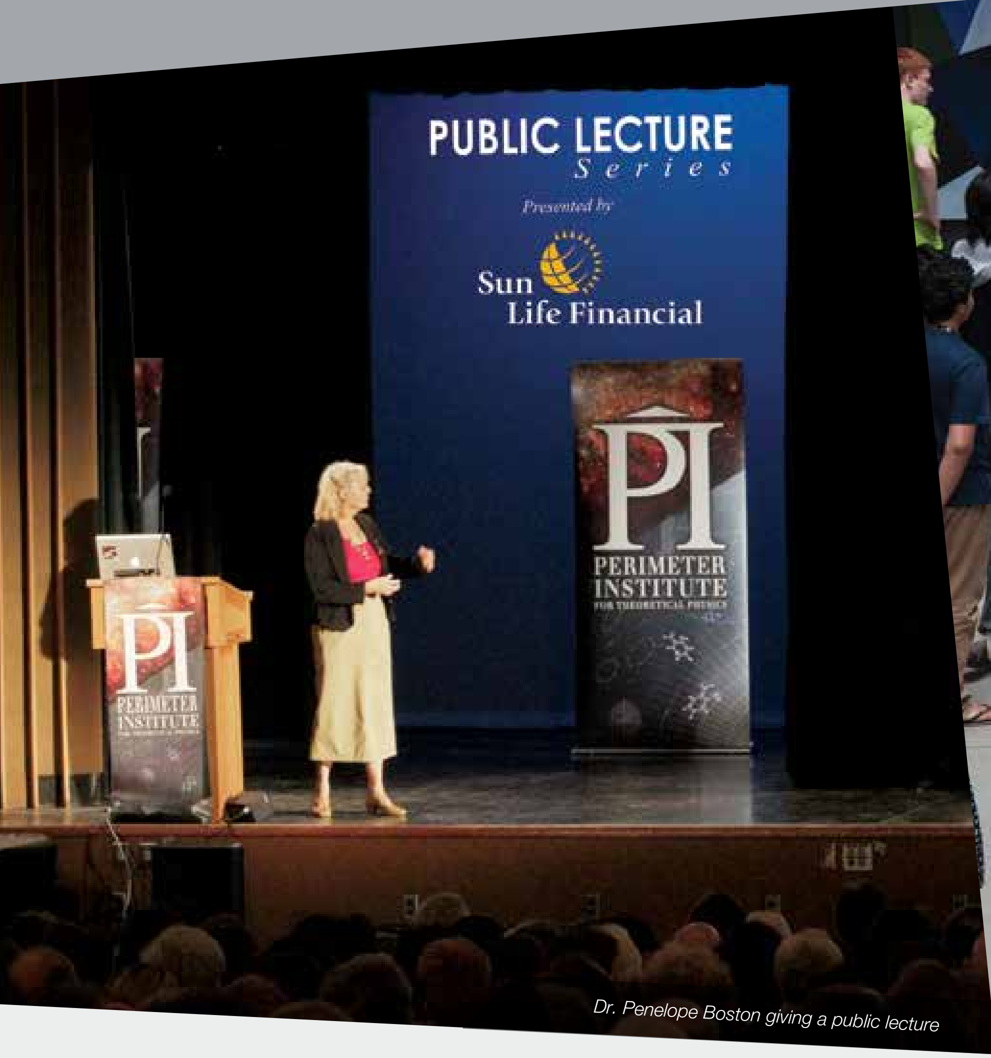
BEYOND THE BLACKBOARD: SCIENCE FOR ALL

Benjamin Franklin once wrote, "An investment in knowledge pays the best interest." Perimeter was founded on the belief that the pursuit of pure, curiosity-driven science benefits all people. That is why the Institute is committed to sharing its research and breakthroughs with the public that supports it and benefits from it.

Perimeter takes theoretical physics beyond the blackboard to pubs and living rooms with public festivals and other public outreach efforts designed to engage and fascinate.

MEDIA ENGAGEMENT

Perimeter actively shares the wonder and discovery of theoretical physics with major media. In 2012/13, the Institute received major coverage in both national and international media, including *The Globe and Mail*, *Toronto Star*, *National Post*, *Calgary Herald*, *The Vancouver Sun*, *The Huffington Post*, *Maclean's*, *The Walrus,* CBC, CTV, *The Economist*, *Nature*, *Time*, *Physics Today*, *Popular Mechanics*, and *Wired UK*, among others.



Dr. Penelope Boston giving a public lecture

TALKING SCIENCE: PERIMETER PUBLIC LECTURES

Six-hundred tickets are snapped up immediately every time Perimeter announces another talk in its renowned Public Lecture Series, presented by Sun Life Financial. Over the past year, Perimeter hosted 10 of these accessible, free, engaging talks on a variety of scientific topics. Two of the talks, by Neil Turok and Lee Smolin, were held at the Institute and simulcast online. In other popular talks, Paul Steinhardt took the packed audience along on his epic search for the world's first naturally occurring quasi-crystal, and popular science writer Jennifer Ouellete demonstrated the many ways calculus has practical, sometimes unexpected, applications. The lectures are professionally recorded and shared online through Perimeter's website and iTunes University.

WATERLOO GLOBAL SCIENCE INITIATIVE

The Waterloo Global Science Initiative (WGSI) is an independently funded, non-profit partnership between Perimeter Institute and the University of Waterloo. Every two years, WGSI fosters international, multigenerational, and interdisciplinary collaborations aimed at advancing new ideas for a better, more prosperous future.

Throughout 2012, the WGSI team continued the important follow-up activities tied to the successful inaugural conference in 2011, Equinox Summit: Energy 2030, and organized the next summit for fall 2013 on the theme of effective high school education reform.

ISSYP 2013 poster session

TORQ: THROWN FOR A LOOP

The quest for a unified theory of space and time brought dozens of international scientists to Perimeter Institute for the “Loops 13” conference.

For one evening, they put away their equations and formulae to experience time in a more visceral way: a concert of rhythmically sophisticated percussion music.

The Toronto-based TorQ Percussion Quartet performed “A Shift in Time,” an eclectic concert that took the audience of quantum gravity experts on a wild ride of new sounds, complex time signatures, and a refreshing dose of silliness.

“It turned out that our theme, A Shift in Time, worked beautifully with this conference,” said TorQ member Jamie Drake.

“Our perceptions of time – how it speeds up, slows down, and whether it really exists at all – is an important concept in music, particularly for percussionists, who are the so-called keepers of time.”

The concert was a refreshing change of pace for attendees of “Loops 13,” who spent the week immersed in the search for a unification between the two great pillars of modern physics, general relativity and quantum mechanics.

One scientist, former **Perimeter postdoctoral researcher Simone Speziale**, was even invited by TorQ to be a guest conductor, using his body movements to prompt improvisational percussion.

It was an inspiring evening of music for the audience and a one-of-a-kind gig for the TorQ Percussion Quartet.

“Playing in a theoretical physics institute is definitely a first for us,” said Drake. “The building has such a great energy; it’s really exciting to play here.”

CULTURAL EVENTS

Cultural events complement the Institute’s research and outreach activities and provide a way to connect with the community at large. Made possible through paid ticketing and private support, presentations are designed to stimulate and enthrall. This year’s concerts featured renowned soloists and groups such as violinist Karen Gomyo, cellist Alisa Weilerstein, guitarist Milos Karadaglic, the JACK Quartet, and the TorQ Percussion Quartet.

The Classical World Artists series at Perimeter is generously supported by The Kitchener and Waterloo Community Foundation – Musagetes Fund.

ADVANCING PERIMETER'S MISSION

"With Perimeter, I know I'm supporting basic science. I decided to support Perimeter because I realized that we know there will be breakthroughs, but we don't know where, when, or how they will manifest themselves. You don't have to have millions of dollars to support the Institute. We all have a stake in a better future, and I think Perimeter will be an enduring legacy for Canada if we support it now."

– Dorian Hausman, retired computer professional and business owner, Perimeter supporter

The goal of great science is to benefit society, whether through advances in medicine or information technology, or through the search for a deeper understanding of the universe we inhabit.

It is fitting, then, that great science can only happen with the support of a great society.

Perimeter Institute is the direct result of a culture that values curiosity, the illuminative power of the scientific process, and the desire to build a brighter, more prosperous world for future generations.

Perimeter exists because its supporters – from founding philanthropists and government agencies to individual donors – have peered beyond the here-and-now to envision what is possible when brilliant minds tackle the biggest questions imaginable.

As a public-private partnership and registered charity, Perimeter's operations are funded through a combination of government grants and donations from private individuals, companies, and foundations. They know that the best investment we can make is in our own capacity to question, to explain, and to understand.

PERIMETER INSTITUTE LEADERSHIP COUNCIL

The Perimeter Institute Leadership Council is a group of prominent individuals who volunteer their time, offer their guidance, and act as ambassadors for Perimeter to the business and philanthropic communities.

This exceptional group of volunteers is helping Perimeter grow strategically and internationally.

Mike Lazaridis, O.C., O.Ont.
Council Co-Chair
Founder and Chair, Board of Directors, Perimeter Institute
Managing Partner and Co-Founder, Quantum Valley Investments

Cosimo Fiorenza
Council Co-Chair
Vice Chair, Board of Directors, Perimeter Institute
Vice President and General Counsel, Infinite Potential Group

Jon S. Dellandrea, C.M.
Council Co-Chair
President and CEO, Sunnybrook Foundation

Alexandra (Alex) Brown
President, Aprilage Inc.

David Caputo
Co-Founder, President, and CEO, Sandvine

Savvas Chamberlain, C.M.
CEO and Chairman, Exel Research Inc.

Jim Cooper
President and CEO, Maplesoft

Catherine A. (Kiki) Delaney, C.M.
President, C.A. Delaney Capital Management Ltd.

CONTINUING A FAMILY TRADITION

My grandfather is a physics professor in my hometown in China. When I was growing up, I was fascinated by his jammed shelves of physics books.

I remember one of my schoolteachers, who knew about my grandfather, once asked me to explain our lesson to the class. I got to talk about physics with all of my classmates and show them why it excited me. Teaching has been a passion ever since and the opportunity to work with an outreach team to bring this research to the public is one of the reasons I've decided to stay at Perimeter.

The main reason, though, is the chance to work with so many great people. Some of the best scientists in the world work here. I can find an answer to just about any question I have, and people are truly glad to help. It's a very special place, and I'm glad to be here.

– Yangang Chen

Yangang Chen graduated from Perimeter Scholars International in 2013. His participation in the PSI program was generously supported by Brad and Kathy Marsland, and Margaret and Larry Marsland. He is now working on his PhD with Perimeter Faculty member Guifre Vidal on topics at the intersection of condensed matter physics and quantum information.

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 and Finance & Audit Committees. The Board also forms other committees as required to assist it in performing 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., is Managing Partner and Co-Founder of Quantum Valley Investments (QVI), which he and Doug Fregin established in Waterloo. In March 2013, they launched QVI with $100 million to provide financial and intellectual capital for the development and commercialization of quantum physics and quantum computing breakthroughs. QVI aims to help transform ideas and early-stage breakthroughs into commercially viable products, technologies, and services. It is Mr. Lazaridis' latest venture in more than a decade's work aimed at creating a "Quantum Valley" in Waterloo by bringing the world's best minds in physics, engineering, mathematics, computer science, and materials science together to collaborate on cutting-edge quantum research.

In 1984, Mr. Lazaridis co-founded BlackBerry (formerly Research In Motion) with Mr. Fregin. They invented the BlackBerry device, created the smartphone industry, and built Canada's largest global tech business. Mr. Lazaridis served in various positions including Co-Chairman and Co-CEO (1984-2012) and Board Vice Chair and Chair of the Innovation Committee (2012-13).

Mr. Lazaridis is the Founder and Board Chair of Perimeter Institute, where he helps generate important private and public sector funding for the Institute. He also founded the Institute for Quantum Computing and the Quantum-Nano Centre, both at the University of Waterloo. He has donated more than $170 million to Perimeter and more than $100 million to IQC.

Among his many honours, Mr. Lazaridis is a Fellow of the Royal Society of Canada and has been named to both the Order of Ontario and the Order of Canada. He was listed on the *Maclean's* Honour Roll as a distinguished Canadian in 2000, named as one of *Time*'s 100 Most Influential People, honoured as a *Globe and Mail* Nation Builder of the Year in 2010, selected as the 2013 Visionary of the Year by the Intelligent Community Forum, and awarded the Ernest C. Manning Principal Award, Canada's most prestigious innovation prize.

Mr. Lazaridis holds an honorary doctoral degree in Engineering from the University of Waterloo (where he formerly served as Chancellor), as well as a Doctor of Laws from McMaster University, the University of Windsor, and Laval University. In addition to his many professional and personal accomplishments, Mr. Lazaridis won an Academy Award and an Emmy Award for technical achievements in the movie and TV industries for developing a high-speed barcode reader that greatly increased the speed of editing film.

Mr. Lazaridis was born in Istanbul, Turkey. He moved to Canada in 1966 with his family, settling in Windsor, Ontario.

Photo credit: Tom Arban Photography Inc.

Cosimo Fiorenza, Vice Chair, is the Vice-President and General Counsel of the Infinite Potential Group. Previously, he spent approximately 20 years with major Toronto law firms, where he specialized in corporate tax. During his tenure on Bay Street, he advised some of Canada's largest corporations and biggest entrepreneurs on income tax and commercial matters with a focus on technology and international structure. Mr. Fiorenza helped establish and is a Founding Director of Perimeter Institute. In addition to his current role as Vice Chair, he is Co-Chair of the Perimeter Leadership Council and a member of the Perimeter Finance Committee. In these capacities, he regularly assists and supports Perimeter's management team in a variety of contexts including financial, legal, and advancement matters. Mr. Fiorenza is also a member of the Board of Directors of the Institute for Quantum Computing at the University of Waterloo. He holds a degree in Business Administration from Lakehead University and a law degree from the University of Ottawa. He was called to the Bar in Ontario in 1991.

Peter Godsoe, O.C., O.Ont., is the former Chairman & Chief Executive Officer of Scotiabank, from which he retired in March 2004. He holds a BSc in Mathematics and Physics from the University of Toronto, an MBA from the Harvard Business School, and is a CA and a Fellow of the Institute of Chartered Accountants of Ontario. Mr. Godsoe remains active through a wide range of corporate boards and non-profit directorships.

Kevin Lynch, P.C., O.C., is a distinguished former public servant with 33 years of service with the Government of Canada. Most recently, Dr. Lynch served as Clerk of the Privy Council, Secretary to the Cabinet, and Head of the Public Service of Canada. Prior roles included Deputy Minister of Finance, Deputy Minister of Industry, and Executive Director (Canada, Ireland, Caribbean) of the International Monetary Fund. He is presently the Vice-Chair of BMO Financial Group.

Steve MacLean recently stepped down as 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.

Art McDonald, O.C., has been the Director of the Sudbury Neutrino Observatory (SNO) experiment for over 20 years. He holds the Gordon and Patricia Gray Chair in Particle Astrophysics at Queen's University and works on the new SNO+ and DEAP experiments at the international SNOLAB, researching an accurate measurement of neutrino mass and seeking to observe directly dark matter particles making up a large fraction of the universe. Professor McDonald has received numerous awards for his research, including the 2011 Henry Marshall Tory Medal from the Royal Society of Canada and the 2007 Benjamin Franklin Medal in Physics, alongside researcher Yoji Totsuka. He was named an Officer of the Order of Canada in 2007.

Barbara Palk is the former President of TD Asset Management Inc., one of Canada's leading money management firms, and former Senior Vice-President of TD Bank Financial Group. She is a Fellow of the Canadian Securities Institute, a CFA Charterholder, and a member of both the Toronto Society of Financial Analysts and the Institute of Corporate Directors. Ms. Palk is Chair of the Board of Queen's University and a member of the Boards of the Ontario Teachers' Pension Plan, TD Asset Management, USA Funds Inc., and Greenwood College School. She is a recipient of the Ontario Volunteer Award and was honoured by the Women's Executive Network in 2004 as one of Canada's Most Powerful Women: Top 100 in the Trailblazer category.

John Reid is the Audit Leader for KPMG in the Greater Toronto area. During his 35-year career, he has assisted both private and public sector organizations through various stages of strategic planning, business acquisitions, development, and growth management. His experience spans all business sectors and industries with a focus on mergers and acquisitions, technology, and health care. Mr. Reid has served on many hospital boards throughout Canada and has also been a director on many university and college boards.

SCIENTIFIC ADVISORY COMMITTEE

Renate Loll, Radboud University (2010-Present), Chair
Professor Loll is a Professor of Theoretical Physics at the Institute for Mathematics, Astrophysics and Particle Physics of the Radboud University in Nijmegen, Netherlands. Her research centres on quantum gravity, the search for a consistent theory that describes the microscopic constituents of spacetime geometry and the quantum-dynamical laws governing their interaction. She has made major contributions to loop quantum gravity and, with her collaborators, has proposed a novel theory of quantum gravity via "Causal Dynamical Triangulations." Professor Loll heads one of the largest research groups on non-perturbative quantum gravity worldwide and is the recipient of a prestigious personal VICI-grant of the Netherlands Organization for Scientific Research. Professor Loll is also a Perimeter Distinguished Visiting Research Chair.

Matthew Fisher, Kavli Institute for Theoretical Physics/University of California, Santa Barbara (2009-Present)
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. He received the Alan T. Waterman Award from the National Science Foundation in 1995 and the National Academy of Sciences Award for Initiatives in Research in 1997. He was elected as a Member of the American Academy of Arts and Sciences in 2003 and to the National Academy in 2012, and became a Perimeter Distinguished Visiting Research Chair in 2013. Professor Fisher has more than 160 publications.

Brian Greene, Columbia University (2010-Present)
Professor Greene is a Professor of Mathematics and Physics at Columbia University, where he is co-Director of the Institute for Strings, Cosmology, and Astroparticle Physics (ISCAP). Professor Greene has made ground-breaking discoveries in superstring theory, exploring the physical implications and mathematical properties of the extra dimensions the theory posits. His current research centres on string cosmology, seeking to understand the physics of the universe's first moments. Professor Greene is well known for his work on communicating theoretical physics for general audiences, and his books include *The Elegant Universe*, which has sold more than a million copies worldwide; *The Fabric of the Cosmos*, which spent six months on The New York Times Best Seller list; and *The Hidden Reality*, which debuted at number four on The New York Times Best Seller list. A three-part NOVA special based on *The Elegant Universe* won both the Emmy and Peabody Awards.

Erik Peter Verlinde, Institute of Theoretical Physics/University of Amsterdam (2010-Present)
Professor Verlinde is a Professor of Theoretical Physics at the Institute for Theoretical Physics at the University of Amsterdam. He is world renowned for his many contributions, including Verlinde algebra and the Verlinde formula, which are important in conformal field theory and topological field theory. His research centres on string theory, gravity, cosmology, and black holes. Professor Verlinde recently proposed a holographic theory of gravity which appears to lead naturally to the observed values of dark energy in the universe.

Birgitta Whaley, Berkeley Quantum Information and Computation Center/University of California, Berkeley (2010-Present)
Professor Whaley is a Professor in the Department of Chemistry at the University of California, Berkeley, where she is Director of the Berkeley Quantum Information and Computation Center. Professor Whaley's research centres on understanding and manipulating quantum dynamics of atoms, molecules, and nanomaterials in complex environments to explore fundamental issues in quantum behaviour. She has made major contributions to the analysis and control of decoherence and universality in quantum information processing, as well as to the analysis of physical implementations of quantum computation. Professor Whaley is also known for her theory of molecular solvation in nanoscale superfluid helium systems. Her current research includes theoretical analysis of quantum information and computation, coherent control and simulation of complex quantum systems, macroscopic quantum coherence, and quantum effects in biological systems.

FACILITY

Photo credit: Tom Arban Photography Inc.

DESIGNED FOR DISCOVERY

Perimeter's iconic, award-winning building is a state-of-the-art facility designed specifically to inspire deep thinking, encourage discussion, and maximize research productivity.

Blackboards are everywhere. These canvases for collaboration are perpetually covered with the language of theoretical physics – equations, formulae, and diagrams describing everything from subatomic particles to the vastness of the universe itself. Serene, comfortable nooks and alcoves provide areas for quiet contemplation; cutting-edge information technology and a two-storey library enable access to vast repositories of physics knowledge; and the bustle of the Black Hole Bistro provides nourishment for both body and mind.

THE STEPHEN HAWKING CENTRE AT PERIMETER INSTITUTE

The spectacular Stephen Hawking Centre at Perimeter Institute – which Hawking himself helped inaugurate and to which he makes extended research visits – opened in 2011. With the 55,000-square-foot expansion, Perimeter can accommodate up to 250 researchers and students, making it the largest theoretical physics research centre in the world.

The Government of Canada (via the Canada Foundation for Innovation) and Ontario's Ministry of Research and Innovation provided a total of $20.8 million toward the expansion, and the balance came from private funds raised by the Institute.

Designed by Teeple Architects, the Stephen Hawking Centre won a 2012 Design Excellence award from the Ontario Association of Architects and was selected for the William G. Dailey Award of Excellence as "the best overall project in the city" at the City of Waterloo's 2012 Urban Design Awards.

Perimeter Institute is a brilliant realization of form and function, custom-built to inspire big ideas.

FINANCIALS

RESULTS OF OPERATIONS

Perimeter Institute ended its 2012/13 fiscal year in a strong financial position and remained firmly on course to achieve its ambitious growth plans and long-term goals.

The Institute continued to spend strategically on its core mission, with recruitment of research faculty as a major priority. In keeping with Perimeter's growth plans, expenditures in this area increased by more than eight percent. Strategic recruitment will remain a key priority as the Institute continues to build a critical mass of researchers over the coming years.

Growth in Perimeter's research training programs also continued according to plan. Together, the Institute's master's program, Perimeter Scholars International (a collaboration with the University of Waterloo), and PhD program (in partnership with a number of Ontario universities) attracted a growing number of highly talented graduates from around the world. Expenditures on training programs increased by eight percent, expanding innovative programs that not only train the next generation of leading physicists, but also provide highly skilled problem solvers and creative thinkers to the wider innovation ecosystem.

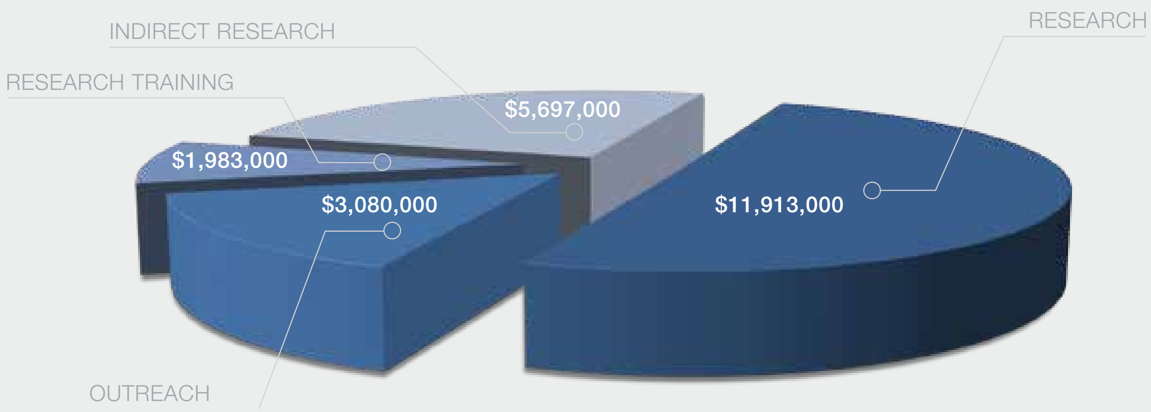
Outreach remained a key component of Perimeter's mission in 2012/13. The Institute continued to strategically invest over 13 percent of its annual expenditures in inspirational programs and products for students, teachers, and the general public.

Indirect research and operating expenditures cover the costs of core support areas, including administration, information technology, and facilities. These expenditures remained flat over the previous year, allowing the Institute to focus investment on its core missions of research, training, and outreach. The Institute's advancement activities – which are also included under indirect research and operations – continued to successfully grow Perimeter's public-private funding model.

Perimeter Institute completed its 2012/13 fiscal year with an increase over the previous year in revenues over expenditures. This resulted from the timing in the receipt of certain committed government funds and investment returns in excess of 13 percent, which will enhance the Institute's long-term financial sustainability.

OPERATING EXPENDITURE SUMMARY

For the year ended July 31, 2013



FINANCIAL POSITION

Perimeter Institute continues to experience a strong working capital position. This position provides the Institute with near-term flexibility whereby it can react to research opportunities that may present themselves.

The endowment fund primarily allows for the accumulation of private funds to address the Institute's future needs. The $233 million in this fund consists of a portfolio mix of domestic equities, international equities, fixed income, and alternative investments specifically designed in accordance with Perimeter'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.

New funding commitments of $50 million from the federal government (ending March 31, 2017) and $50 million from the provincial government (ending July 31, 2021) reinforce Perimeter's strong collaboration with public partners and the value they see in investing in the Institute.

The multi-year government commitments totalling $100 million clearly demonstrate that the Institute is perceived by government as an excellent investment; however, no guarantee of future funding beyond the above commitment exists.

Perimeter Institute is also seeking to expand its sources of funds from the private sector through an ambitious private sector fundraising initiative to raise yearly operating funds for the Institute, as well as increase endowment assets over the coming years.

Private sector donations, in accordance with donor requests, are either utilized as contributions towards operational expenditures or are protected in an endowment fund. The endowment fund is designed to maximize growth and minimize risk in order to contribute to the strongest possible long-term financial health of the Institute. However, investment returns are volatile and susceptible to economic conditions. Under the direction of the Investment Committee, funds are invested in accordance with the Board-approved Investment Policies and Procedures.

Photo credit: Tom Arban Photography Inc.

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CHARTERED ACCOUNTANTS

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REPORT OF THE INDEPENDENT AUDITORS ON THE SUMMARY FINANCIAL STATEMENTS

To the Directors of
Perimeter Institute

The accompanying summary financial statements, which comprise the summary statement of financial position as at July 31, 2013 and the summary statement of operations and changes in fund balances for the year then ended, are derived from the audited financial statements of Perimeter Institute (the "Institute") for the year ended July 31, 2013. We expressed an unmodified audit opinion on those financial statements in our report dated December 6, 2013. Those financial statements, and the summary financial statements, do not reflect the effects of events that occurred subsequent to the date of our report on those financial statements.

The summary financial statements do not contain all the disclosures required by Canadian accounting standards for not-for-profit organizations. Reading the summary financial statements, therefore, is not a substitute for reading the audited financial statements of the Institute.

Management's Responsibility for the Summary Financial Statements

Management is responsible for the preparation of a summary of the financial statements in accordance with Canadian accounting standards for not-for-profit organizations.

Auditor's Responsibility

Our responsibility is to express an opinion on the summary financial statements based on our procedures, which were conducted in accordance with Canadian Auditing Standard (CAS) 810, "Engagements to Report of Summary Financial Statements."

Opinion

In our opinion, the summary financial statements derived from the audited financial statements of the Institute for the year ended July 31, 2013 are a fair summary of those financial statements, in accordance with Canadian accounting standards for not-for-profit organizations.

Zeifmans LLP

Toronto, Ontario
December 6, 2013

Chartered Accountants
Licensed Public Accountants

Zeifmans LLP is a member of Nexia International, a worldwide network of independent accounting and consulting firms.

NEXIA INTERNATIONAL

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PERIMETER INSTITUTE
SUMMARIZED STATEMENT OF FINANCIAL POSITION
AS AT JULY 31, 2013

	2013	2012
ASSETS		
Current assets:		
Cash and cash equivalents	$ 11,774,000	$ 1,697,000
Marketable securities	232,514,000	211,417,000
Government grants receivable	2,321,000	4,294,000
Assets held for sale	---	1,235,000
Other current assets	1,599,000	1,151,000
	248,208,000	219,794,000
Property and equipment	52,808,000	55,281,000
TOTAL ASSETS	$ 301,016,000	$ 275,075,000
LIABILITIES AND FUND BALANCE		
Current liabilities:		
Bank overdraft	$ ---	$ 732,000
Bank indebtedness	---	2,245,000
Accounts payable and other current liabilities	2,487,000	2,331,000
TOTAL LIABILITIES	$ 2,487,000	$ 5,308,000
Fund balances:		
Invested in capital assets	52,319,000	56,495,000
Externally restricted	126,801,000	105,589,000
Internally restricted	78,840,000	78,840,000
Unrestricted	40,569,000	28,843,000
TOTAL FUND BALANCES	298,529,000	269,767,000
	$ 301,016,000	$ 275,075,000

ZEIFMANS LLP
CHARTERED ACCOUNTANTS

PERIMETER INSTITUTE

SUMMARIZED STATEMENT OF OPERATIONS AND CHANGES IN FUND BALANCES

FOR THE YEAR ENDED JULY 31, 2013

	2013	2012
Revenue:		
Government grants	$ 23,837,000	$ 14,412,000
Other income	1,446,000	741,000
Donations	909,000	1,142,000
	26,192,000	16,295,000
Expenditures:		
Research	11,913,000	11,025,000
Research training	1,983,000	1,838,000
Outreach and science communications	3,080,000	3,350,000
Indirect research and operations	5,697,000	5,649,000
	22,673,000	21,862,000
Excess of revenue over expenses (expenses over revenue) before investment income, amortization and gain on disposal of property and equipment	3,519,000	(5,567,000)
Amortization	(4,129,000)	(4,098,000)
Gain on disposal of property and equipment	771,000	8,000
Investment income	28,601,000	7,645,000
Excess of revenue over expenses (expenses over revenue)	28,762,000	(2,012,000)
Fund balances, beginning of year	269,767,000	271,779,000
Fund balances, end of year	$ 298,529,000	$ 269,767,000

ZEIFMANS LLP
CHARTERED ACCOUNTANTS

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 continually seeking to advance fundamental research across Perimeter's areas of focus, encouraging complementary approaches and a collaborative atmosphere which maximizes cross-fertilization and the probability of breakthroughs.

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

Generate a flow-through of the most promising talent by recruiting the world's top postdoctoral researcher talent, facilitating researcher engagement 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 Visiting Research Chairs program, attracting Visiting Researchers and Visiting Fellows of exceptional calibre, and developing agreements that encourage joint activities between researchers at Perimeter and leading centres throughout the world.

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

Increase Perimeter'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 on cutting-edge topics.

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

Create the world's best environment and infrastructure for theoretical physics research, training, and outreach by providing an inspiring physical space, cutting-edge information technology, and high-quality professional support.

Continue to build on Perimeter's highly successful public-private partnership funding model by broadening the Institute's donor base, both in Canada and internationally.

APPENDICES

FACULTY

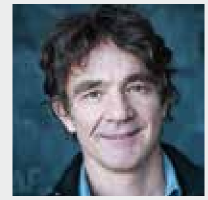
Neil Turok (PhD Imperial College London, 1983) was Professor of Physics at Princeton University and Chair of Mathematical Physics at the University of Cambridge before assuming his current position as Director of Perimeter Institute, where he is also the Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics at Perimeter Institute. Turok's research focuses on developing fundamental theories of cosmology and new observational tests. His predictions for the correlations of the polarization and temperature of the cosmic background radiation (CBR) and of the galaxy-CBR correlations induced by dark energy were recently confirmed. With Stephen Hawking, he discovered instanton solutions describing the birth of inflationary universes. His work on open inflation forms the basis of the widely discussed multiverse paradigm. With Paul Steinhardt, he developed an alternative, cyclic model for cosmology, whose predictions are so far in agreement with all observational tests. Among his many honours, Turok was awarded Sloan and Packard Fellowships and the James Clerk Maxwell medal of the Institute of Physics (UK). He is a Canadian Institute for Advanced Research (CIFAR) Fellow in Cosmology and Gravity and a Senior Fellow of Massey College in the University of Toronto. In 2012, Turok delivered the CBC Massey Lectures. The lectures were published as *The Universe Within*, a bestseller which won the 2013 Lane Anderson Award, Canada's top prize for popular science writing. Born in South Africa, Turok founded the African Institute for Mathematical Sciences (AIMS) in Cape Town in 2003. AIMS has since expanded to a network of four centres – in South Africa, Senegal, Ghana, and Cameroon – and has become Africa's most renowned institution for postgraduate training in mathematical science. For his scientific discoveries and his work founding and developing AIMS, Turok was awarded a TED Prize in 2008. He has also been recognized with awards from the World Summit on Innovation and Entrepreneurship (WSIE) and the World Innovation Summit on Education (WISE).

Dmitry Abanin (PhD Massachusetts Institute of Technology, 2008) joined Perimeter in 2012 from Harvard University, where he had been a postdoctoral fellow since 2011. Previously, he was a Research Scholar at the Princeton Center for Theoretical Science from 2008 to 2011. Abanin is a leading young condensed matter theorist whose research has focused on developing a theoretical understanding of Dirac materials, focusing on quantum transport of charge and spin and finding new ways of controlling their electronic properties. Some of his theoretical work has been experimentally confirmed by groups at Harvard University, University of Manchester, Columbia University, University of California, Riverside, the Max Planck Institute, and elsewhere.

Latham Boyle (PhD Princeton University, 2006) joined Perimeter's faculty in 2010. From 2006 to 2009, he held a Canadian Institute for Theoretical Astrophysics (CITA) Postdoctoral Fellowship; he is also a Junior Fellow of the Canadian Institute for Advanced Research (CIFAR). Boyle has studied what gravitational wave measurements can reveal about the universe's beginning; with Paul Steinhardt, he derived "inflationary bootstrap relations" that – if confirmed observationally – would provide compelling support for the theory of primordial inflation. He co-developed a simple algebraic technique for understanding black hole mergers and recently constructed the theory of "porcupines": networks of low-frequency gravitational wave detectors that function together as gravitational wave telescopes.

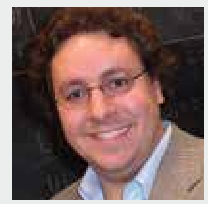
Freddy Cachazo (PhD Harvard University, 2002) has been a faculty member at Perimeter since 2005. From 2002 to 2005, he was a Member of the School of Natural Sciences at the Institute for Advanced Study in Princeton. Cachazo is one of the world's leading experts in the study and computation of scattering amplitudes in quantum chromodynamics (QCD) and N=4 super Yang-Mills (MSYM) theories. His many honours include an Early Researcher Award (2007), the Gribov Medal of the European Physical Society (2009), the Rutherford Memorial Medal in Physics from the Royal Society of Canada (2011), and the Herzberg Medal (2012).

Bianca Dittrich (PhD Max Planck Institute for Gravitational Physics, 2005) joined Perimeter's faculty in January 2012 from the Albert Einstein Institute in Potsdam, Germany, where she led the Max Planck Research Group "Canonical and Covariant Dynamics of Quantum Gravity." Dittrich's research focuses on the construction and examination of quantum gravity models. Among other important findings, she has provided a computational framework for gauge invariant observables in canonical general relativity. In 2007, Dittrich received the Otto Hahn Medal of the Max Planck Society, which recognizes outstanding young scientists.

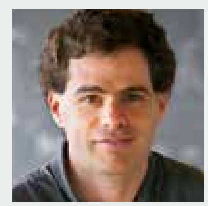


Laurent Freidel (PhD L'École Normale Supérieure de Lyon, 1994) joined Perimeter Institute in September 2006. Freidel is a mathematical physicist who has made many notable contributions in the field of quantum gravity; he possesses outstanding knowledge of a wide range of areas including integrable systems,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

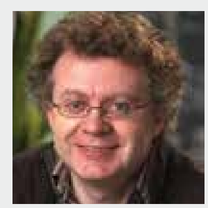
Davide Gaiotto (PhD Princeton University, 2004) joined Perimeter in May 2012 and has since become the Krembil Foundation Galileo Galilei Chair in Theoretical Physics at Perimeter Institute. Previously, he was a postdoctoral fellow at Harvard University from 2004 to 2007 and a long-term Member at the Institute for Advanced Study in Princeton from 2007 to 2012. Gaiotto works in the area of strongly coupled quantum fields and has already made several major conceptual advances that have potentially revolutionary implications. His honours include the Gribov Medal of the European Physical Society (2011) and a New Horizons in Physics Prize from the Fundamental Physics Prize Foundation (2012).



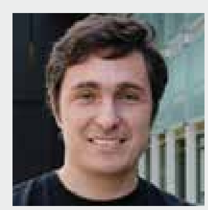
Jaume Gomis (PhD Rutgers University, 1999) joined Perimeter Institute in 2004, declining a European Young Investigator Award by the European Science Foundation to do so. Prior to that, he worked at the California Institute of Technology as a Postdoctoral Scholar and as the Sherman Fairchild Senior Research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



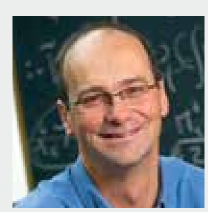
Daniel Gottesman (PhD California Institute of Technology, 1997) joined Perimeter's faculty in 2002. From 1997 to 2002, he held postdoctoral positions at the Los Alamos National Laboratory, Microsoft Research, and the University of California, Berkeley (as a long-term CMI Prize Fellow for the Clay Mathematics Institute). 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 has published over 40 papers, which have attracted well over 4,000 citations to date. He is also a Senior Fellow in the Quantum Information Processing program of the Canadian Institute for Advanced Research (CIFAR) and a Fellow of the American Physical Society (APS).



Lucien Hardy (PhD University of Durham, 1992) joined Perimeter's faculty in 2002, having previously held research and lecturing positions at various European universities including the University of Oxford, Sapienza University of Rome, 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.



Luis Lehner (PhD University of Pittsburgh, 1998) began a joint appointment with Perimeter and the University of Guelph in 2009 and became a full-time faculty member at Perimeter in 2012. He previously held postdoctoral fellowships at the University of Texas at Austin and the University of British Columbia, and he was a member of Louisiana State University's faculty from 2002 to 2009. 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 a Sloan Research Fellow, and he is currently a Fellow of the Institute of Physics, the American Physical Society, the International Society for General Relativity and Gravitation, and the Canadian Institute for Advanced Research (CIFAR) in the Cosmology and Gravity program.



Robert Myers (PhD Princeton University, 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 Institute for Theoretical Physics at the University of California, Santa Barbara, and a Professor of Physics at McGill University, before moving to Perimeter in 2001. He has made seminal contributions to our understanding of black hole microphysics and D-branes. Among Myers' many honours, he has received the Herzberg Medal (1999), the CAP-CRM Prize (2005), and the Vogt Medal (2012). He is also a Fellow of both the Royal Society of Canada and the Cosmology and Gravity program of the Canadian Institute for Advanced Research (CIFAR).

Philip Schuster (PhD Harvard University, 2007) joined Perimeter's faculty in 2010. He was a Research Associate at SLAC National Accelerator Laboratory from 2007 to 2010. Schuster's area of specialty is particle theory, with an emphasis on physics beyond the Standard Model. He has close ties to experiment and has investigated various theories that may be discovered at experiments at the Large Hadron Collider (LHC) at CERN. With members of the Compact Muon Solenoid (CMS) experiment at the LHC, he developed methods to characterize potential new physics signals and null results in terms of simplified models, facilitating more robust theoretical interpretations of data. He is also a co-spokesperson for the APEX collaboration at the Thomas Jefferson National Accelerator Facility in Virginia.

Kendrick Smith (PhD University of Chicago, 2007) joined Perimeter in September 2012 from Princeton University, where he was the Lyman P. Spitzer Postdoctoral Fellow since 2009. Prior to that, he held the PPARC Postdoctoral Fellowship at the University of Cambridge from 2007 to 2009. Smith is a cosmologist with a foot in the worlds of both theory and observation. He is a member of several experimental teams, including the WMAP collaboration, which won the 2012 Gruber Cosmology Prize, as well as QUIET and the Planck collaboration. Smith has achieved several landmark results, including the first detection of gravitational lensing in the cosmic microwave background (CMB) radiation. He participated in the start-up phase of the major Hyper-Suprime Cam project at the Hawaii-based Subaru Telescope, bringing full data rights to Perimeter. Smith holds a second PhD in mathematics from the University of Michigan.

Lee Smolin (PhD Harvard University, 1979) is one of Perimeter Institute's founding faculty members. Prior to joining Perimeter, Smolin held research positions at the Institute for Advanced Study, the Institute for Theoretical Physics at the University of California, Santa Barbara, the Enrico Fermi Institute at the University of Chicago, Yale University, Syracuse University, and Pennsylvania State University. 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. His papers have generated over 7,400 citations to date and he has written four non-technical books. Smolin's many honours include the Majorana Prize (2007), the Klopsteg Memorial Award (2009), 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 Perimeter's faculty in 2008 after holding a postdoctoral fellowship at Perimeter and an International Royal Society Fellowship at the University of Cambridge. His 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. Spekkens is a previous winner of the Birkhoff-von Neumann Prize of the International Quantum Structures Association.

Natalia Toro (PhD Harvard University, 2007) joined Perimeter in 2010 after completing a postdoctoral fellowship at the Stanford Institute for Theoretical Physics. Toro has developed a framework for few-parameter models of possible new physics signals and has played a major role in integrating new techniques, called "on-shell effective theories," into the program of upcoming searches at the Compact Muon Solenoid experiment at the Large Hadron Collider (LHC) at CERN. She is an expert in the study of "dark forces" that couple very weakly to ordinary matter. Toro is also co-spokesperson for APEX, an experiment searching for such forces at the Thomas Jefferson National Accelerator Facility.

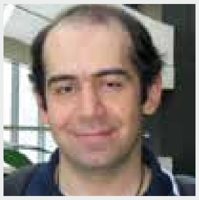
Guifre Vidal (PhD University of Barcelona, 1999) joined Perimeter's faculty in 2011 from the University of Queensland in Brisbane, where he was an Australian Research Council Federation Fellow and Professor in the School of Mathematics and Physics. He did postdoctoral fellowships at the University of Innsbruck in Austria and the Institute for Quantum Information at the California Institute of Technology before joining the University of Queensland. Vidal works at the interface of quantum information and condensed matter physics, using tensor networks to compute the ground state of quantum many-body systems on a lattice and to issue a classification of the possible phases of quantum matter or fixed points of the renormalization group flow. His past honours include a Marie Curie Fellowship, awarded by the European Union, and a Sherman Fairchild Foundation Fellowship.

Pedro Vieira (PhD École Normale Supérieure, Paris, and the Theoretical Physics Center at University of Porto, 2008) joined Perimeter in 2009 from the Max Planck Institute for Gravitational Physics (Albert Einstein Institute), where he was a Junior Scientist from 2008 to 2009. Vieira's research concerns the development of new mathematical techniques for gauge and string theories, ultimately aiming at 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. "Y-system for scattering amplitudes," a paper by Vieira and his collaborators, won the 2012 Best Paper Prize from the Institute of Physics (IOP) and the Editorial Board of *Journal of Physics A*. He also won an Early Researcher Award in 2012.

Xiao-Gang Wen (PhD Princeton University, 1987) joined Perimeter's faculty in May 2012 as the BMO Financial Group Isaac Newton Chair in Theoretical Physics at Perimeter Institute. Widely recognized as one of the world's leaders in condensed matter theory, he pioneered the new paradigm of quantum topological order, used to describe phenomena from superconductivity to fractionally charged particles, and he has invented many new mathematical formalisms. Wen authored the textbook *Quantum Field Theory of Many-body Systems: From the Origin of Sound to an Origin of Light and Electrons*. He was previously a Distinguished Moore Scholar at the California Institute of Technology and the Cecil and Ida Green Professor of Physics at the Massachusetts Institute of Technology, as well as one of Perimeter's own Distinguished Visiting Research Chairs. He is also a Fellow of the American Physical Society.

ASSOCIATE FACULTY

Niayesh Afshordi (PhD Princeton University, 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 to 2007 and a Distinguished Research Fellow at Perimeter Institute from 2008 to 2009. Afshordi began his appointment as an associate faculty member in 2010. He specializes in interdisciplinary problems in fundamental physics, astrophysics, and cosmology. In 2010, he was awarded a Discovery Accelerator Supplement from the Natural Sciences and Engineering Research Council of Canada (NSERC).



Avery Broderick (PhD California Institute of Technology, 2004) began a joint appointment with Perimeter and the University of Waterloo in 2011. He previously held postdoctoral positions at the Institute for Theory and Computation at the Harvard-Smithsonian Center for Astrophysics (2004-07) and the Canadian Institute for Theoretical Astrophysics (2007-11). Broderick is an astrophysicist with broad research interests, ranging from how stars form to the extreme physics in the vicinity of white dwarfs, neutron stars, and black holes. He has recently been part of an international effort to produce and interpret horizon-resolving images of supermassive black holes, studying how black holes accrete matter, launch the ultra-relativistic outflows observed, and probe the nature of gravity in their vicinity.

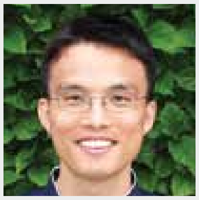
Alex Buchel (PhD Cornell University, 1999) is jointly appointed with Western University. Before joining Perimeter's faculty in 2003, he held research positions at the Institute for Theoretical Physics at the University of California, Santa Barbara (1999-2002), and the Michigan Center for Theoretical Physics at the University of Michigan (2002-03). 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 Perimeter'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, 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. Burgess' recent honours include a Killam Fellowship, Fellowship of the Royal Society of Canada, and the CAP-CRM Prize in Theoretical and Mathematical Physics.

David Cory (PhD Case Western Reserve University, 1987) is jointly appointed with the Institute for Quantum Computing and 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 the Massachusetts Institute of Technology. He also led research and development activities in nuclear magnetic resonance at Bruker Instruments. Since 1996, 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. Cory chairs the advisory committee for the Quantum Information Processing program at the Canadian Institute for Advanced Research (CIFAR).

Matthew Johnson (PhD University of California, Santa Cruz, 2007) began a joint appointment with Perimeter and York University in August 2012. Prior to that, he was a Moore Postdoctoral Scholar at the California Institute of Technology and a postdoctoral researcher at Perimeter. Johnson is a cosmologist whose interdisciplinary research seeks to understand how the universe began, how it evolved, and where it is headed. To this end, he designs data analysis algorithms to confront fundamental theory with observations of the cosmic microwave background radiation. In 2012, Johnson was awarded a New Frontiers in Astronomy and Cosmology grant from the University of Chicago and the John Templeton Foundation.

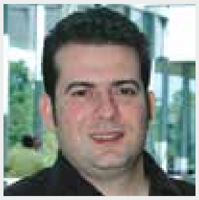
Raymond Laflamme (PhD University of Cambridge, 1988) is a founding faculty member of Perimeter Institute and founding Director of the Institute for Quantum Computing, where he is jointly appointed. He held research positions at the University of British Columbia and Peterhouse College, University of Cambridge, before moving to the Los Alamos Research Laboratory in 1992, where his interests shifted from cosmology to quantum computing. Since the mid-1990s, Laflamme has elucidated theoretical approaches to quantum error correction and in turn implemented some in experiments. Laflamme has been Director of the Quantum Information Processing program at the Canadian Institute for Advanced Research (CIFAR) since 2003. He is a Fellow of CIFAR, the American Physical Society, and the American Association for the Advancement of Science, and holds the Canada Research Chair in Quantum Information. With colleagues, he founded Universal Quantum Devices, a start-up commercializing spin-offs of quantum research.



Sung-Sik Lee (PhD Pohang University of Science and Technology, 2000) joined Perimeter in 2011 in a joint appointment with McMaster University, where he is an Associate Professor. He previously worked as a postdoctoral researcher at the Pohang University of Science and Technology, the Massachusetts Institute of Technology, and the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara. Lee's research focuses on strongly interacting quantum many-body systems using quantum field theory, as well as the intersections between condensed matter and high energy physics. His recent work has included using gauge theory as a lens through which to examine the phenomenon of fractionalization, efforts to apply the AdS/CFT correspondence from string theory to quantum chromodynamics and condensed matter, and building a non-perturbative approach to understanding unconventional metallic states of matter.

Roger Melko (PhD University of California, Santa Barbara, 2005) joined Perimeter in September 2012, while retaining his appointment with the University of Waterloo, where he has been since 2007. Prior to that, he was a Wigner Fellow at Oak Ridge National Laboratory (2005-07). Melko is a condensed matter theorist who develops new computational methods and algorithms to study strongly correlated many-body systems, focusing on emergent phenomena, ground state phases, phase transitions, quantum criticality, and entanglement. Among his honours, he has received an Early Researcher Award, the International Union of Pure and Applied Physics Young Scientist Prize in Computational Physics from the Council on Computational Physics, and the Canada Research Chair in Computational Quantum Many-Body Physics (Tier 2).

Michele Mosca (DPhil University of Oxford, 1999) is jointly appointed with the Institute for Quantum Computing at the University of Waterloo. He is a founding member of Perimeter Institute, as well as co-founder and Deputy Director of the Institute for Quantum Computing. Mosca has made major contributions to the theory and practice of quantum information processing, including several of the first implementations of quantum algorithms and fundamental methods for performing reliable computations with untrusted quantum apparatus. His current research interests include quantum algorithms and complexity, and the development of cryptographic tools that will be safe against quantum technologies. Mosca's numerous academic honours include Canada's Top 40 Under 40 award (2010), the Premier's Research Excellence Award (2000-05), Fellow of the Canadian Institute for Advanced Research (CIFAR) since 2010, Canada Research Chair in Quantum Computation (2002-12), and University Research Chair at the University of Waterloo (2012-present).



Maxim Pospelov (PhD Budker Institute of Nuclear Physics, 1994) is jointly appointed with the University of Victoria and became an associate faculty member at Perimeter in 2004. He previously held research positions at the University of Quebec at Montreal, the University of Minnesota, McGill University, and the University of Sussex. Pospelov works in the areas of particle physics and cosmology.

Itay Yavin (PhD Harvard University, 2006) began a joint appointment with Perimeter and McMaster University in 2011. Previously, he was a Research Associate at Princeton University and a James Arthur Postdoctoral Fellow at New York University. Yavin's research focuses on particle physics and the search for physics beyond the Standard Model. In particular, he is interested in the origin of electroweak symmetry breaking and the nature of dark matter. Most recently, he has worked on interpreting puzzling data coming from experiments looking for dark matter in the lab.

SENIOR MANAGEMENT

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Michael Duschenes

Chief Advancement Officer
Jonathan Braniff

Chief Information Officer
Ben Davies

Director of Academic Programs
John Berlinsky

Director of Educational Outreach
Greg Dick

Director of External Relations and Public Affairs
John Matlock

Director of Finance
Sue Scanlan

Director of Financial Operations
Stefan Pregelj

Director of People and Culture
Sheri Keffer

Director of Publications
Natasha Waxman

RESIDENT RESEARCHERS

Resident Research Affiliate
John Moffat

Senior Researcher
Rafael Sorkin

POSTDOCTORAL RESEARCHERS, 2012/13

Haipeng An
Lilia Anguelova
Denis Bashkirov
Benjamin Basso
Joseph Ben Geloun
Eugenio Bianchi
Hector Bombin
Valentin Bonzom
Oliver Buerschaper
Lukasz Cincio
William Edwards
Astrid Eichhorn
Adrienne Erickcek
Cecilia Flori
Tobias Fritz*
Steffen Gielen
Gus Gutoski
Alioscia Hamma
Chad Hanna
Song He
Kurt Hinterbichler*
Philipp Hoehn
Eder Izaguirre
Tim Johannsen
Wojciech Kaminski
Peter Koroteev
Ryszard Kostecki
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Eduardo Martin-Martinez
Paul McFadden
Flavio Mercati*
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Robert Pfeifer
Luiz Santos
Amit Sever
Brian Shuve
Ajay Singh
Misha Smolkin
Carlos Tamarit
William Witczak-Krempa
Peng Ye
Huangjun Zhu

** Indicates Templeton Frontiers Program Postdoctoral Fellow*

SCIENTIFIC VISITORS, 2012/13

** Indicates Distinguished Visiting Research Chair*
*** Indicates Visiting Fellow*
**** Indicates long-term Visiting Researcher*
Please note that researchers who made multiple visits are listed only once.

Dmitry Abanin, Harvard University

Rana Adhikari, California Institute of Technology (Caltech)

Peter Adshead, University of Chicago

Ofer Aharony, Weizmann Institute of Science

Nahid Ahmadi***, University of Tehran

Andrea Marie Albert, Ohio State University

Andrea Allais, Massachusetts Institute of Technology (MIT)

Asma Al-Qasimi, University of Toronto

Jan Ambjorn, University of Copenhagen/Niels Bohr Institute

Giovanni Amelino-Camelia, Sapienza University of Rome

Luigi Amico***, University of Catania

Edward Anderson, University of Cambridge

Damiano Anselmi***, University of Pisa

Marcus Appleby***, Queen Mary University of London

Francesco Aprile, University of Barcelona

Asimina Arvanitaki, Stanford University/Stanford Institute for Theoretical Physics

Sujay Ashok, Institute of Mathematical Sciences, Chennai

Benjamin Assel, École Normale Supérieure (ENS)

Steve Avery, Institute of Mathematical Sciences, Chennai

John Baez, University of California, Riverside

Cosimo Bambi, Ludwig Maximilian University of Munich/Arnold Sommerfeld Center for Theoretical Physics

Shamik Banerjee, Stanford University/Stanford Institute for Theoretical Physics

Hans Bantilan, Princeton University

Jie Bao, Brown University

Aristide Baratin, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Enrico Barausse, Institute of Astrophysics of Paris (IAP)

Fernando Barbero, Spanish National Research Council (CSIC)/Institute of the Structure of Matter (IEM)

James Bardeen*, University of Washington

Howard Barnum, University of New Mexico

Ganapathy Baskaran*, Institute of Mathematical Sciences, Chennai

Bela Bauer, Microsoft Station Q

Chris Beem, Stony Brook University

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Edo Berger, Harvard University

Stefano Bianco, Sapienza University of Rome

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Robin Blume-Kohout, Sandia National Laboratories

Julien Bolmont, Pierre-and-Marie-Curie University

Pavel Bolokhov, University of Minnesota

Jacob Bourjaily, Institute for Advanced Study (IAS)

Fernando Brandao**, Federal University of Minas Gerais

Robert Brandenberger, McGill University

Duncan Brown, Syracuse University

Martin Bucher, University of Paris XI/Laboratory of Theoretical Physics

Michel Buck, Imperial College London

Mathew Bullimore, University of Oxford

Philipp Burda, Durham University

Mark Byrd, Southern Illinois University

Earl Campbell, Free University of Berlin/Institute for Theoretical Physics

Miguel Campiglia, Raman Research Institute

Kipp Cannon, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)

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Vitor Cardoso***, University of Lisbon/Higher Technical Institute (IST)

Federico Carrasco, National University of Córdoba

Juan Carrasquilla, Georgetown University

Sylvain Carrozza, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Hilary Carteret, Wilfrid Laurier University

Sarah Chadburn, Durham University

Anushya Chandran, Princeton University

Alan Chen, McMaster University

Xie Chen, Massachusetts Institute of Technology (MIT)

Sasha Chernyshev, University of California, Irvine

Giulio Chiribella**, Tsinghua University

Eric Chitambar***, Southern Illinois University

Jens Chluba, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)

Debanjan Chowdhury, Harvard University

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Isaac Chuang, Massachusetts Institute of Technology/MIT-Harvard Center for Ultracold Atoms

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Marina Cortes, University of Edinburgh/Royal Observatory

Miguel Costa, University of Porto/Theoretical Physics Center

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Nathaniel Craig, Institute for Advanced Study (IAS)

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Pau Figueras, University of Cambridge

Raphael Flauger, Institute for Advanced Study (IAS)

Gary Forrester, University of Massachusetts, Dartmouth

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Andrew Frey, University of Winnipeg

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Janet Hung, Harvard University

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Viqar Husain, University of New Brunswick

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Stephen Jordan, National Institute of Standards and Technology

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Andrey Katz, Harvard University

Alexandros Kehagias, National Technical University of Athens

Adrian Kent*, University of Cambridge

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Nima Khosravi, African Institute for Mathematical Sciences (AIMS) – South Africa

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Alexey Kovalev, University of California, Riverside

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Kunal Kumar, Carleton University

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Suzanne Lanery, University of Erlangen-Nuremberg

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Callum Quigley, University of Alberta

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Suvrat Raju, Tata Institute of Fundamental Research/International Centre for Theoretical Sciences

Sanjaye Ramgoolam***, Queen Mary University of London/Centre for Research in String Theory

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Michael Reisenberger, University of Montevideo

Adam Rej, Institute for Advanced Study (IAS)

Martin Reuter, Johannes Gutenberg University of Mainz/Institute of Physics

Michael Revzen, Technion – Israel Institute of Technology

David Rideout, University of California, San Diego

Vincent Rivasseau**, University of Paris XI/ Laboratory of Theoretical Physics

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Rachel Rosen, Columbia University

Terry Rudolph, Imperial College London

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Paul Steinhardt*, Princeton University

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Jean-Marie Stephan, University of Virginia

James Stone, Princeton University

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Michael Strauss, Princeton University

Sichun Sun, University of Washington

Paul Sutter, Institute of Astrophysics of Paris (IAP)

Jedrzej Swiezewski, University of Warsaw

Brian Swingle, Harvard University

Philip Tanedo, Cornell University

Ewan Tarrant, University of Nottingham

Alexander Tchekhovskoy, Princeton University

Emily Thompson, European Organization for Nuclear Research (CERN)

Senthil Todadri*, Massachusetts Institute of Technology (MIT)

Andrew Tolley, Case Western Reserve University

Casey Tomlin, Pennsylvania State University

Viktor Toth, Independent

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Yuhsin Tsai, University of California, Davis

Artur Tsobanjan, American University

Ari Turner, University of Amsterdam

Bill Unruh*, University of British Columbia

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Masahide Yamaguchi, Tokyo Institute of Technology

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Marco Zaopo, University of Pavia

Andrew Zayakin, University of Santiago de Compostela

Hao Zhang, University of Toronto

Peng Zhao, University of Cambridge

Antonia Zipfel, University of Erlangen-Nuremberg/Institute for Quantum Gravity

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Leslie Ballentine, Simon Fraser University

Richard Bond, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)

Ivan Booth, Memorial University

Vincent Bouchard, University of Alberta

Robert Brandenberger, McGill University

Gilles Brassard, University of Montreal

Anne Broadbent, University of Waterloo/Institute for Quantum Computing (IQC)

Anton Burkov, University of Waterloo

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Benoit Charbonneau, St. Jerome's University

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CONFERENCES AND WORKSHOPS, 2012/13

LHC Search Strategies
August 2-4, 2012

Experimental Search for Quantum Gravity: The Hard Facts
October 22-25, 2012

Applications of Jet Substructure to New Physics Searches
February 21-23, 2013

New Mathematical Structures in Supersymmetric Gauge Theory?
March 1-3, 2013

Women and Physics: Past, Present, and Future – A Celebration of International Women's Day
March 8, 2013

4-Corner Southwest Ontario Condensed Matter Symposium 2013
April 25, 2013

Emergence and Entanglement II
May 6-10, 2013

The Quantum Landscape
May 27-31, 2013

Cosmological Frontiers in Fundamental Physics 2013
July 8-11, 2013

Loops 13
July 22-26, 2013

COURSES, 2012/13

Introduction to Supersymmetry
Instructor: Alex Buchel, Western University and Perimeter Institute
January 17-April 11, 2013

Elements of General Relativity
Instructor: Rafael Sorkin, Perimeter Institute
January 22-April 11, 2013
Viewable at: http://pirsa.org/C13001

Fuzzballs to Firewalls: A Post-Firewall Review of the Fuzzball Proposal
Instructor: Steve Avery, Institute of Mathematical Sciences, Chennai
May 30-June 4, 2013
Viewable at: http://pirsa.org/13050087/

SPONSORSHIPS, 2012/13

Perimeter sponsored the following Canadian and international scientific events and activities in 2012/13.

"8th Conference on Theory of Quantum Computation, Communication, and Cryptography," University of Guelph

"13th Canadian Summer School on Quantum Information and Student Conference," University of Calgary

"Black Holes 9," University of Saskatchewan

"Complex Quantum Networks," University of Waterloo/Institute for Quantum Computing

"GAP 2013," University of Montreal/Mathematical Research Centre (CRM)

"Lake Louise Winter Institute," University of Alberta

"Symbolic Computation in Theoretical Physics: Integrability and Super-Yang Mills," International Centre for Theoretical Physics – South American Institute for Fundamental Research

"Theory Canada 8," Bishop's University

"TRISEP," TRIUMF

"Women in Physics Canada," Simon Fraser University

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

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