2014 ANNUAL REPORT

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

VISION

Perimeter's vision is 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, 2013, to July 31, 2014.

BACKGROUND AND PURPOSE

In 1999, Mike Lazaridis (the inventor of the smartphone) made a single philanthropic investment which he hoped might change the world: he provided the seed money for Perimeter Institute. His vision attracted more donors and generous public support and, by 2001, the new institute – located in Waterloo, Ontario, Canada – was up and running.

In the years since, Perimeter has become a national asset, a Canadian institution that is world-renowned for the excellence and ambition of its research, for the outstanding training it offers to the world's most promising young scientists, and for the quality and reach of its outreach programs.

Why theoretical physics? Because history has shown that discoveries in physics 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 new 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, thereby laying the foundations for the technologies of the future. Research is the heart of what we do. Our strategy is to bring the world's most insightful minds together under one roof, to interact and collaborate across disciplinary boundaries and tackle key problems. Perimeter's growing community includes over 150 resident researchers, ranging from master's students to eminent senior scientists. The Institute is also a global hub for the interchange of ideas, hosting nearly 1,000 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 approximately 30 exceptional graduates from around the world every year. Our faculty supervise an additional 42 PhD students. More than 40 postdoctoral fellows, the largest such group in the world, are given full freedom to pursue their own independent research programs at the most productive time in their careers, thereby enlivening our research community.

Perimeter prospers – as all science prospers – by being part of a wider community of people engaged by scientific ideas. That is why sharing the power and importance of theoretical physics with students, teachers, and the public has always been a high priority. We open our doors for public lectures and festivals, and have developed a rich suite of educational materials for students and teachers. We have reached more than 4 million students to date – a million in the past year alone.

Science represents our best hopes for the future – for the technologies that brighten our lives, for open enquiry, and for the discovery of knowledge and understanding that become part of humanity's shared inheritance.

Perimeter is working to realize this future.

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

– Stephen Hawking

AN ACCELERATOR OF DISCOVERY

150+ SCIENTISTS IN RESIDENCE conducting research

10 MAJOR PRIZES AND HONOURS awarded to Perimeter scientists in 2013/14

1,000+ VISITING INTERNATIONAL SCIENTISTS annually

2,900+ PAPERS appearing in 100+ journals with 90,000+ citations since 2001

10,000+ ONLINE TALKS and lectures accessed by viewers in 175 countries

15 YEARS after its creation, Perimeter has been ranked **#2** IN SCIENTIFIC EXCELLENCE in the world in theoretical physics

4+ MILLION STUDENTS reached since 2003

10,000+ EDUCATORS trained through Perimeter workshops since 2003

500 TOP HIGH SCHOOL STUDENTS from **44** COUNTRIES have attended the International Summer School for Young Physicists since 2003

90 COUNTRIES have broadcast *The Quantum Tamers*, a documentary on the new science of quantum computing

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

Perimeter Scholars International (PSI) master's program
155 GRADUATES from **48** COUNTRIES since **2009**

THE COMMERCIALIZATION CATALYST OF QUANTUM VALLEY

MESSAGE FROM THE BOARD CHAIR

"New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature, and the application of that knowledge to practical purposes.… This essential, new knowledge can be obtained only through basic scientific research.… Without scientific progress, no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world."

– Vannevar Bush, "Science: The Endless Frontier"

Vannevar Bush, the head of the U.S. Office of Scientific Research and Development during World War II, wrote those words in July 1945, in a report to President Harry Truman called "Science: The Endless Frontier." There are two remarkable things about that report. The first was that President Truman and the U.S. government listened. They founded the National Science Foundation. They invested in universities and in education. They rewrote their tax laws to encourage R&D.

The second remarkable thing, though, is that Bush was right. Reading "Science: The Endless Frontier" today is like reading the work of a prophet. Vannevar Bush predicted the unfolding of an American century, perhaps encapsulated most perfectly in Silicon Valley and the dawn of semiconductors, which drove technological progress valued in the trillions.

Sadly, Canada largely missed the silicon revolution. Where California alone had thousands of silicon companies, Canada had dozens, at best. As the age of silicon begins to draw to a close, we should take a lesson from this. And the silicon age truly is closing. Its forward progress was driven by the shrinking size of the transistor. But transistors have now reached the size of single atoms. They cannot get smaller. This progress is – very nearly – at its end.

What is next? Increasingly, experts and observers around the world expect that there will be another revolution driven, as the transistor was, by fundamental science. Our theoretical understanding of quantum matter, of quantum processes, and of entanglement have become sophisticated enough that we are beginning to be able to harness them to create quantum technologies. The result is inevitable: a second quantum revolution. We should start to see its impact in the next few years.

And this is a revolution in which Canadian institutions can play a leadership role. In Perimeter (and in its sister institute, the Institute for Quantum Computing at the University of Waterloo), we have built Canadian institutions with the capability to create Bush's "essential, new knowledge, which can be obtained only through basic scientific research." At Perimeter, we believe that such research is best done by gathering the best minds under one roof and offering them outstanding support and total scientific freedom.

Hire the best and provide leadership and support – it's a simple principle, but it takes a lot of effort to make it work. As Chair of Perimeter's Board of Directors, it is my happy job to thank some of those who do that work.

I would like to single out Neil Turok, Perimeter's director. His leadership has transformed the Institute; his vision inspires and guides every aspect of its operations. In the past year, he has led the recruitment of several stellar scientists, who you will read about in the pages to come – Kevin Costello, Subir Sachdev, Asimina Arvanitaki, Raffi Budakian, and James Forrest.

I would also like to welcome new Board members Joanne Cuthbertson, former Chancellor of the University of Calgary and a national leader in matters of public education; Michael Serbinis, a technology entrepreneur who is perhaps best known as the founder of Kobo; and Michael Horgan, former Deputy Minister of Finance for Canada and currently a Senior Advisor with Bennett Jones LLP, who will join the Board on May 1. Perimeter is honoured to have the support and guidance of such visionary leaders.

Finally, I would like to thank our public partners from the Governments of Waterloo, of Ontario, and of Canada; our Leadership Council; the Emmy Noether Council; and of course our vibrant and growing family of private donors – individuals, corporations, and foundations. In particular, I would like to express our gratitude to the Krembil Foundation, which this year made a major investment to create two new research chairs here at Perimeter – demonstrating their conviction that fundamental science can help build a prosperous future for Canada and beyond.

What all these supporters share is the same vision that Vannevar Bush once put onto paper: that science is an endless frontier, and that the best of it is not behind us, but in front of us.

– Mike Lazaridis

MESSAGE FROM THE INSTITUTE DIRECTOR

"The most exciting phrase to hear in science,
the one that heralds the most discoveries,
is not 'Eureka!' but, 'That's funny …'"

– Isaac Asimov

This is a remarkable time in physics. Over the last two decades, and especially in the last three years, we've had a series of remarkable discoveries each embodying the uncanny power of the human mind to probe realms far beyond everyday experience. We have discovered dark energy. We found the Higgs boson. We created an exquisitely detailed map of the early universe.

Accompanying these successes are deeply challenging questions – things that make me, at least, tilt my head and say, "That looks funny …." The amount of dark energy we find in any given volume of space is much, much less than our current theories would suggest should be there. The Higgs boson was found as theories predicted, but the slew of other particles that most theorists expected did not turn up. And the map of the early universe, as released by the Planck satellite, has revealed stunning simplicity. None of our theories can explain this.

It seems to me these three clues all point to one thing: we are missing something fundamental. We need to forge a new understanding of nature. To meet this singular moment, we need a critical mass of singular minds – people able to reframe questions in entirely new ways, people with the skill and talent to illuminate new territories.

Over the last five years, Perimeter has succeeded in gathering together many singular minds. This year, for example, we recruited Kevin Costello to Perimeter as the inaugural Krembil William Rowan Hamilton Chair in Theoretical Physics. Kevin is a pure mathematician who has surprised leading physicists by bringing powerful new mathematical tools to bear on quantum field theory, our most basic framework for physical theories. In so doing, he is extending our understanding of nature at its most basic level.

This year, we also welcomed Asimina Arvanitaki, another young pathbreaker. In her field of particle physics, the trend since the 1940s has been to build bigger and bigger colliders in order to probe higher and higher energies. Mina has taken a different path, using extreme precision, not energy, as the probe of new physics. She has designed elegant and ingenious experiments to look for gravitational waves and hypothetical particles called axions, and she has used the observed properties of black holes to infer limits on such particles in the universe.

Subir Sachdev, a giant in the world of condensed matter physics, has joined us as the James Clerk Maxwell Chair in Theoretical Physics (Visiting). He has made profound contributions to our understanding of quantum phase transitions, including high temperature superconductivity – some of which you can read about in the pages ahead. Raffi Budakian, a world leader in high precision quantum condensed matter experiments, who is jointly appointed with the Institute for Quantum Computing at the University of Waterloo, will further add to Perimeter's growing efforts in condensed matter physics.

The history of science teaches us that the greatest advances are made when the time is ripe and when the right people gather. We must gather a community of original and insightful minds, inspiring them to tackle and solve deep puzzles in nature. This is the simple philosophy that drives our research at Perimeter.

It is also why we are committed in equal measure not only to research, but to scientific training and to engaging the public. We know that talented young people are the lifeblood of physics. And we know that public passion for, and appreciation of, science feeds the soil in which physics grows.

The centrepiece of our training program is Perimeter Scholars International (PSI), our ground-breaking master's degree program. This year, we welcomed not only our fifth PSI class, but also a new director for PSI. James Forrest is both a passionate educator and a talented condensed matter researcher. We are looking forward to his leading PSI to new heights.

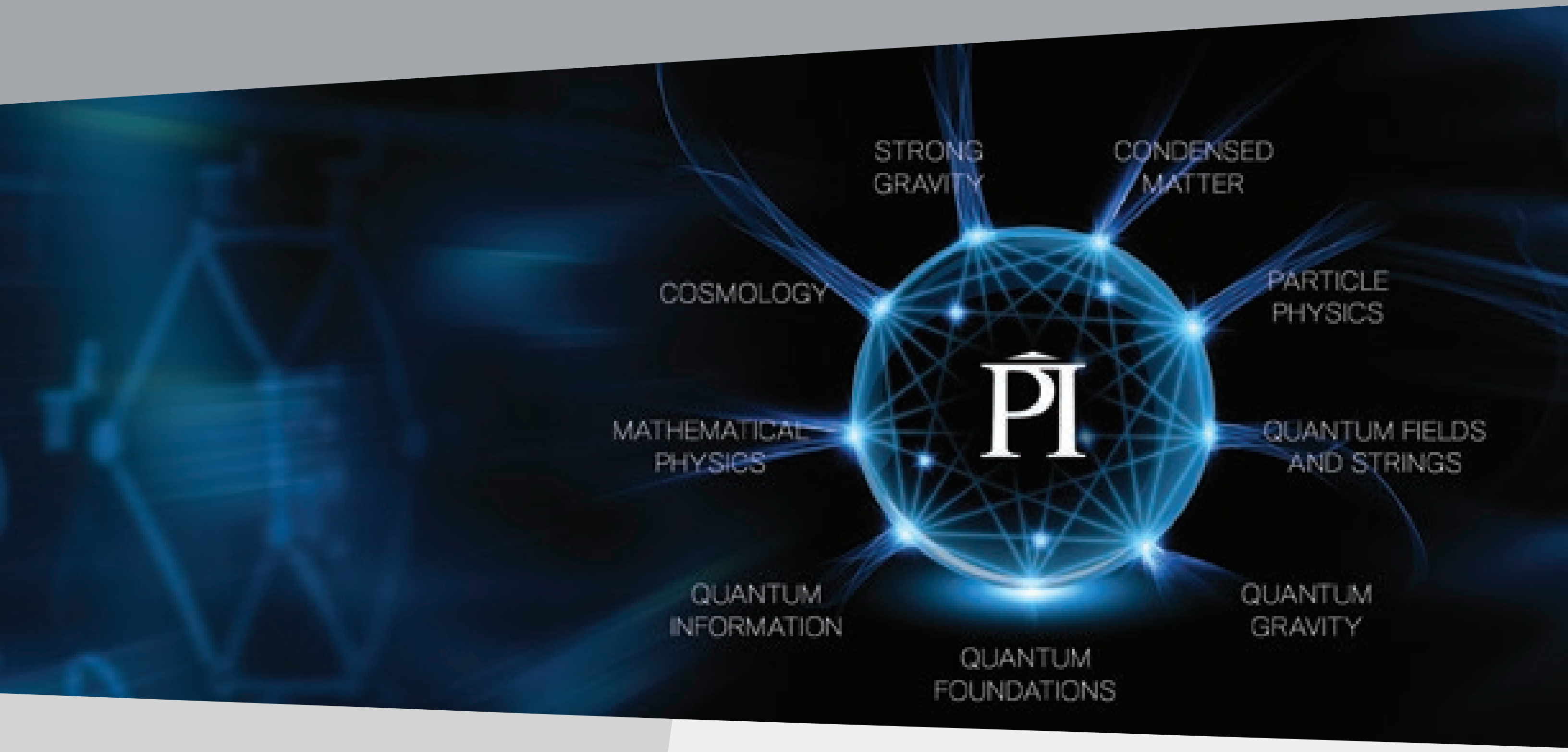
Yeats said that education is not the filling of a bucket, but the lighting of a fire, and through our outreach program in schools, we hope to kindle minds. We reached one million students this year through our classroom modules, teacher training, and a justly renowned summer school for young physicists, ISSYP. It has been running for over a decade. Many of its alumni say that they leave transformed by the people and ideas they encounter here. This year, we also hosted a public festival called BrainSTEM: Your Future is Now that illuminated for the public some of the paths between science and the technologies of the future.

This moment in physics is defined by our urgent need to find the right new idea, the right clue which will lead us to a new and better picture of how our universe works. It is a great challenge, but also a great opportunity.

And there is nowhere better to meet it than at Perimeter.

– Neil Turok

RESEARCH



THE WORLD'S MOST INFLUENTIAL SCIENTIFIC MINDS

In 2014, a study by Thomson Reuters named four Perimeter scientists among the "world's most influential scientific minds": Faculty Chair Robert Myers; Subir Sachdev, the James Clerk Maxwell Chair in Theoretical Physics at Perimeter Institute (Visiting); and Distinguished Visiting Research Chairs Lance Dixon and Dam Thanh Son.

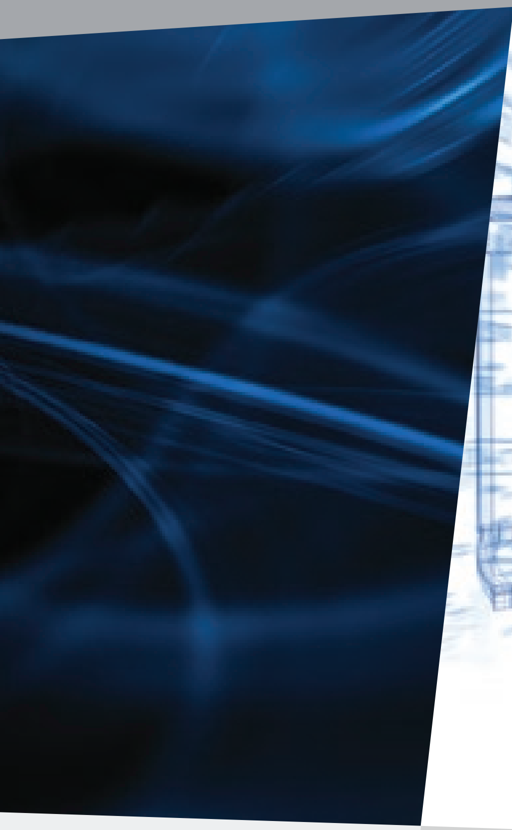
Einstein. Curie. Planck. Faraday. Science has always been synonymous with great names. Inspired individuals could work in solitude, often in more than one field, and make astounding leaps of human understanding.

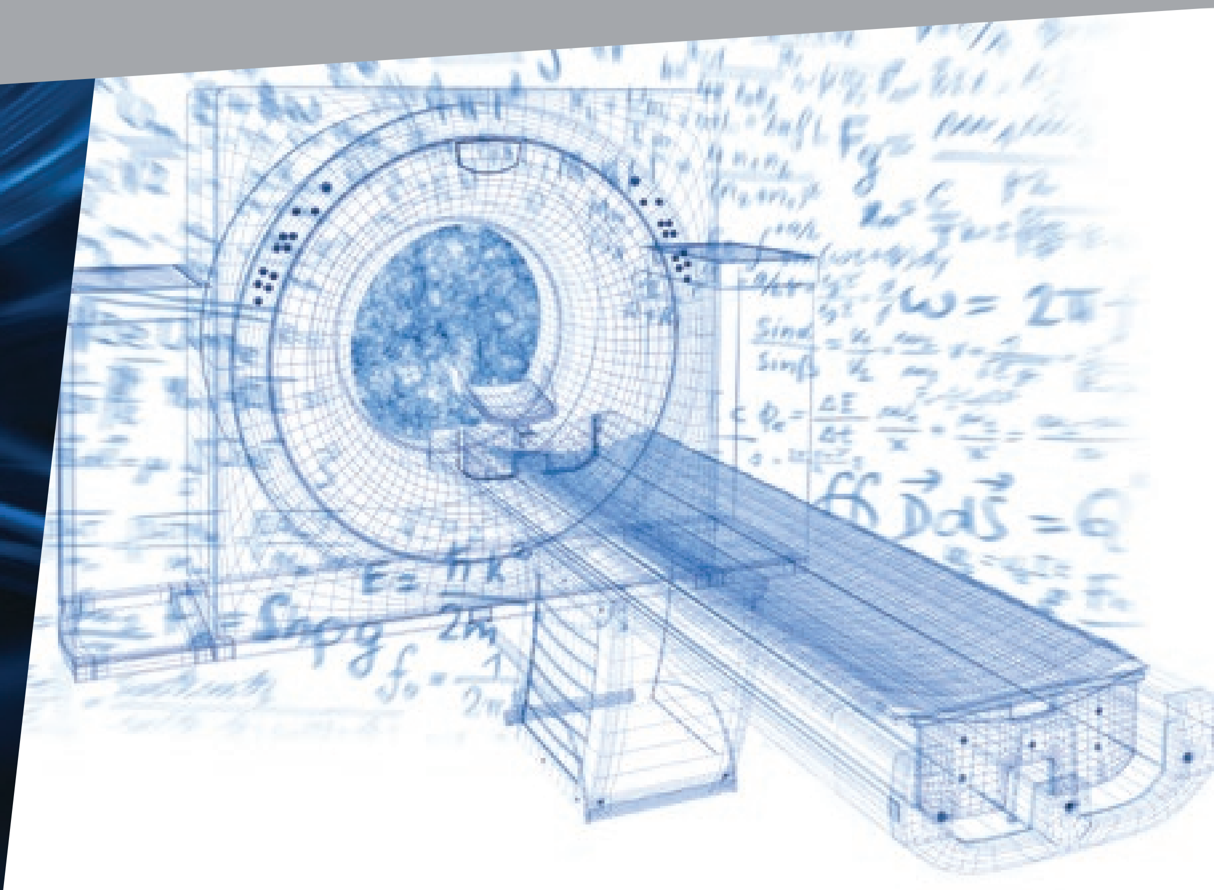
Today's science is arguably much more complex. Advances in knowledge have produced deeper specializations, which have opened up entirely new fields to be explored. The problems we are working to solve are drastically more complex, as are the tools we employ to solve them.

Perimeter's iconic building was specifically designed to foster the teamwork and cross-pollination of ideas that this new landscape demands. Whether at the Bistro's tables, each stocked with paper and pencils, or at blackboards and specially treated glass windows, equations bloom throughout the building. A steady stream of visiting scientists arrive daily from all parts of the world, stowing their suitcases at reception and diving right into the stream of talks, conferences, and ideas.

At all levels, researchers are encouraged to cross traditional discipline boundaries and share ideas in an environment that recognizes the whole is greater than the sum of its parts.

What was once a pursuit of individuals has become a realm of grand collaboration. Transformative breakthroughs today require more than great minds. They demand great places.





THEORY LEADS TO MRI LEADS TO THEORY

In the evolution of science, revolutionary technologies are not the end of the road for curious minds. They are new tools of exploration.

A wonderful example of this is magnetic resonance imaging, or MRI. MRI scans are a common diagnostic tool in modern medicine, but their origins lie with a few quantum theorists trying to understand the structure of atoms.

Early quantum theorists speculated that the protons and neutrons in atoms acted like tiny spinning bar magnets, a property dubbed “spin.” They would thus align in a magnetic field. By the late 1930s, experimentalists showed that, in a strong enough magnetic field, the spins would change: atoms would absorb or emit radio waves – or resonate – at specific frequencies. The “magnetic resonance” of various materials would thus reflect their composition.

As theory and experiment progressed, the technologies that helped explain atomic structure revealed another great potential: the ability to image soft tissue inside humans, without exposure to harmful radiation.

This works because different molecules in tissue resonate at different frequencies, enabling them to be mapped or scanned. In 1977, the first successful MRI scan was performed on a human, and the technology has gone on to save millions of lives by allowing doctors to detect tumours, strokes, blood-vessel blockages, and more.

But that is not the end of the story. Having gone from quantum theory to life-saving practice, magnetic resonance is again heading into the realm of deep science. Quantum theorists today posit that the technology behind MRI could be used to “see” dark matter, which is believed to make up more than a quarter of the universe.

Technological advances are not just the end result of good science. They present new beginnings.

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."

KEEPING QUBITS IN LINE

Building a quantum computer – one that can outstrip its classical counterparts at important information-processing tasks – is no easy task.

Harnessing and controlling quantum "bits" of information – atoms, electrons, photons, or other particles – is a bit like wrangling the rambunctious singers in a children's choir. Synchronizing and conducting them is tricky, but once they lock into the desired groove, the resulting harmony can be greater than the sum of its parts.

Of course, if one or two children drop out of key or forget a line, their mistakes will be drowned out by the majority of others remaining in sync.

In quantum computation, achieving such harmony requires researchers to anticipate and account for similar hiccups – the inevitable errors that occur when dealing with such tiny, fragile bits. Like a choir recital, a quantum computation cannot be expected to go perfectly; the trick is to keep the errors in check, such that the end result is still a success.

Such is the goal of fault-tolerant quantum computation: to achieve the correct result, even when errors pop up (and add up) during the course of the computation.

Current fault-tolerant techniques involve adding extra quantum bits (qubits) for encoding – to build in redundancies. But this approach drastically increases the ultimate cost and difficulty of building a quantum computer.

Perimeter Institute Faculty member **Daniel Gottesman** has proposed a unique solution to this problem that uses only slightly more qubits than would be needed in a perfect quantum computer.

Though the protocols proposed by Gottesman are still not fully practical, they demonstrate that fault-tolerant computation may not require many extra qubits. This research also demonstrates the properties an error-correcting code should have in order to use qubits efficiently – a crucial component in making quantum computers a reality.

FINDING HARMONY IN NOISE

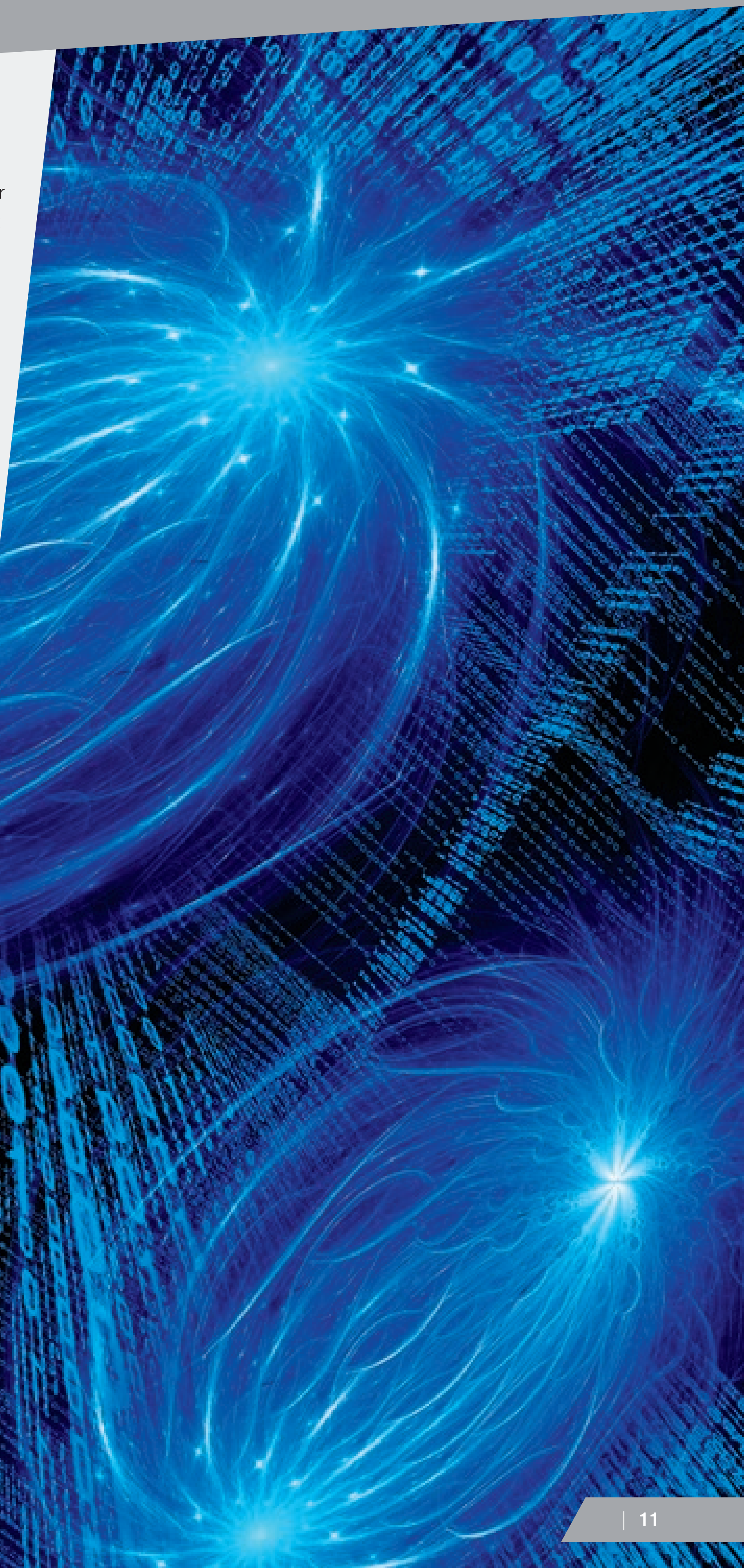
Hector Bombin, a postdoctoral researcher at Perimeter Institute, is particularly interested in fault-tolerant techniques called topological quantum memories, which are generally considered among the most promising approaches to quantum error correction.

For quantum computers to become a practical reality, researchers will need to find ways to perform quantum operations with "noisy" (or error-prone) components and hardware. Researchers must bridge theory and experiment, translating what is mathematically possible on paper to something that can actually be built and operated reliably.

Bombin's key innovation is the introduction of a new kind of topological memory that, unlike conventional quantum error correction techniques, does not require multiple rounds of measurements to detect errors in a quantum computation.

With less time devoted to the error-detection process, fewer errors are allowed to accumulate. To revisit the metaphor of the children's choir, the conductor gets a couple of misbehavers in line quickly and launches everyone into song before the rest of the singers have a chance to get fidgety and distracted.

Quantum computing holds promise for tremendous advances in fields spanning communications, cryptography, medicine, and beyond. Unlocking that promise requires intense research, bridging theory and experiment, into the properties and potential applications of quantum information.



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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 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.

SEEING DEEPER INTO QUANTUM GRAVITY BY ZOOMING OUT

Understanding the interplay of quantum mechanics and gravity at short distances would be a breakthrough in modern physics. However, the traditional techniques for treating fundamental forces quantum mechanically cannot be applied to gravity in a straightforward manner, despite their successful application to other forces, like electromagnetism or the weak force. New, innovative approaches to the problem of quantum gravity are needed.

One such approach is loop quantum gravity (LQG). This ambitious research program treats spacetime like a quantum mechanical system, and one of the most interesting features of the theory is that space and time are quantized. In other words, space and time are made up of discrete, fundamental building blocks. The short-distance behaviour of gravity would be governed by their dynamics.

This is a compelling picture of spacetime at short distances. If it is correct, a successful, microscopic, quantum mechanical theory of spacetime should also reproduce the well-known properties of classical spacetime at long distances, which is governed by Einstein's theory of relativity. However, this is no easy task, as tracking the dynamics of each individual spacetime quantum to understand gravity over large distances would be like tracking the movement of each atom in a cup of water to understand its fluid motion; it is both inefficient and impossible!

Physicists have more effective, highly mathematical means of treating systems with a large number of constituents, and Perimeter Faculty member **Bianca Dittrich** has been developing such techniques for loop quantum gravity. In LQG, spacetime is represented by quantum states, and Dittrich is employing coarse graining methods to extract the relevant, collective properties of many states at once. By essentially zooming out, she has better understood the set of quantum states that are allowed by the theory. This set encodes the possible solutions of the theory, providing insight into the structure of spacetime in LQG. For example, with these tools, Dittrich has uncovered a new possible vacuum state of LQG. Such a vacuum state determines important properties of the theory.

This is a perfect example of the productive work that can happen at the interface between two fields – in this case, quantum gravity and mathematical physics – and a large step towards a full understanding of LQG. In fact, it is expected that these results will allow researchers to understand the long-distance behaviour of LQG, and help quantum gravity researchers achieve their ultimate goal, which is to make testable predictions from this exciting theory.

QUANTUM FIELD THEORY ON A SPHERE

Quantum field theory is the language that describes all many-body interactions in nature, be it particles in a collider or materials on a laboratory bench. In some systems, the interactions between the component parts are weak, and quantum field theory is well understood in these cases. However, many systems interact strongly, and when it comes to strongly interacting systems, quantum field theory begins to fall apart.

In other words, if quantum field theory is a language, then we're missing the words and the grammar that describe everything from the everyday workings of protons to the exotic behaviours of superconductors. It would be as if biology could describe everything except mammals. This is – obviously – a problem.

Perimeter Faculty member **Jaume Gomis** is one of the many people trying to make sense of this puzzle – looking for a new dictionary of what's technically called strongly coupled quantum field theory.

This year, he made some progress by changing the space in which he's looking. Many field theories describe the flat space in which we live – that is, a space in which a pen drawing a straight line on paper will never come back to where it started. Gomis transformed these theories into theories which describe a spherical space, where the space looks less like a piece of paper than a soccer ball.

By putting field theory on a sphere, Gomis found he could get a better view on it. It isolates certain interesting variables mathematically, and makes certain observables better defined. (An observable is something about a system that can be measured, and which gives some insight into the system's state. Temperature, for instance, is an observable.) Specifically, Gomis discovered that by using spherical partition functions, you can compute one such observable exactly, no matter how strong the coupling is. Being able to compute something exactly at arbitrary coupling is, as Gomis notes, "very special, very rare."

So far as we know, we do not actually live on a soccer ball, and the field theory Gomis is working with is not quite as complex as the one we will need to truly write a new dictionary for strongly coupled quantum field theory. But, as Gomis says, "This work helps us develop insights into what kinds of beasts might live at strong couplings."

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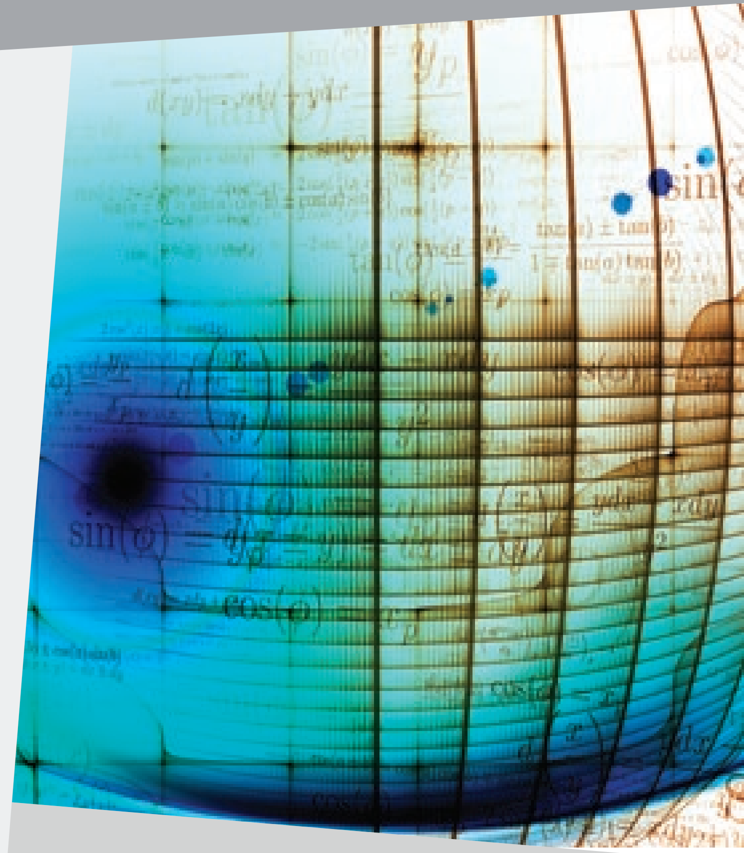

PERIMETER FACULTY

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Jaume Gomis

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Robert Myers

Subir Sachdev, James Clerk Maxwell Chair in Theoretical Physics (Visiting)

Philip Schuster

Kendrick Smith

Lee Smolin

Robert Spekkens

Natalia Toro

Neil Turok, Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics

Guifre Vidal

Pedro Vieira

Xiao-Gang Wen, BMO Financial Group Isaac Newton Chair in Theoretical Physics (on leave)

COSMOLOGY

Cosmologists at Perimeter Institute seek to uncover the distant history and constituents of our universe and decode the rules that govern its 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.

UNDERSTANDING THE EARLY UNIVERSE (OR UNIVERSES)

It is one of the most enduring questions in science: How did the universe begin?

Cosmology is, in a sense, a kind of time travel, as researchers peer nearly 14 billion years into the past to understand the birth, infancy, and growth of our universe.

With telescopes of unprecedented precision scanning the distant reaches of the cosmos, and theorists decoding the mathematical structures of reality, these are exciting times for cosmology.

The universe does not give up its secrets easily, however, and the process of discovery requires tackling questions from many angles, collaborating, seeking repeatable results, and always remaining open to new possibilities.

Case in point: the announcement last March that the Antarctic-based BICEP2 (Background Imaging of Cosmic Extragalactic Polarization) experiment may have detected primordial gravitational waves sparked much excitement among cosmologists and the science media.

The BICEP2 result seemed to constitute a major breakthrough in cosmology – an apparent confirmation of the theory of inflation, which posits a moment of extreme expansion of the universe a tiny fraction of a second after the big bang. But some members of the cosmological community believed it was premature to declare that the BICEP2 results – the detection of “B-mode” polarization in the cosmic microwave background – were caused by gravitational waves.

Just weeks after the announcement, Perimeter Institute hosted the world’s first major conference on the subject, “Implications of BICEP2.”

Amid all this buzz, new collaborative research emerged attempting to interpret the BICEP2 data, its possible interpretations, and its relation to other theoretical and experimental investigations.

Perimeter researchers **Latham Boyle**, **Kendrick Smith**, and **Neil Turok** were among the co-authors of a paper that carefully analyzed the compatibility between the BICEP2 findings and previous data from the Planck satellite, and discovered a surprising statistical tension between them.

The researchers quantified the extent to which the tension may be alleviated by modifications to the current Standard Model, and proposed a novel test that will be able to check the correctness of one such modification in the future.

Their paper also indicated how future experiments should shed new light on the BICEP2 results – which is precisely what happened six months later, when the Planck satellite indicated that cosmic dust, not gravitational waves, could account for some of the intriguing spacetime “ripples” that were attributed to gravitational waves in March.

A SCIENTIFIC TEST FOR THE MULTIVERSE

Such continued experimental advances, driven and interpreted by theoretical research, allow us to peer deeper into our universe's distant past.

But perhaps "our universe" does not sufficiently convey the full extent of reality. Perhaps our universe is just one bubble in a frothing sea of universes, as suggested by the increasingly prevalent multiverse hypothesis.

Proposed barely a decade ago as a consequence of what we think we know about cosmic inflation, the multiverse hypothesis has drawn criticism for being closer to metaphysics than true science. Even if other universes exist outside our own, critics say, how could we possibly know, since they are beyond the limits of our observation?

Perhaps other universes occasionally bump up against ours and leave an observable trace, suggest Perimeter researchers **Matthew Johnson** and **Luis Lehner**.

Using computer simulations, the researchers created a scenario in which another universe collides with ours, leaving a tell-tale "bruise" on the cosmic microwave background (or CMB, the earliest light in the universe).

Their paper on the subject marks the first time anyone has produced a direct, quantitative set of predictions for a collision between two inhabitant universes in the multiverse.

In short, they have moved the multiverse hypothesis from the realm of metaphysics into the domain of testable, empirical science. If we are living in just one universe of many, we may now have a way to tell.

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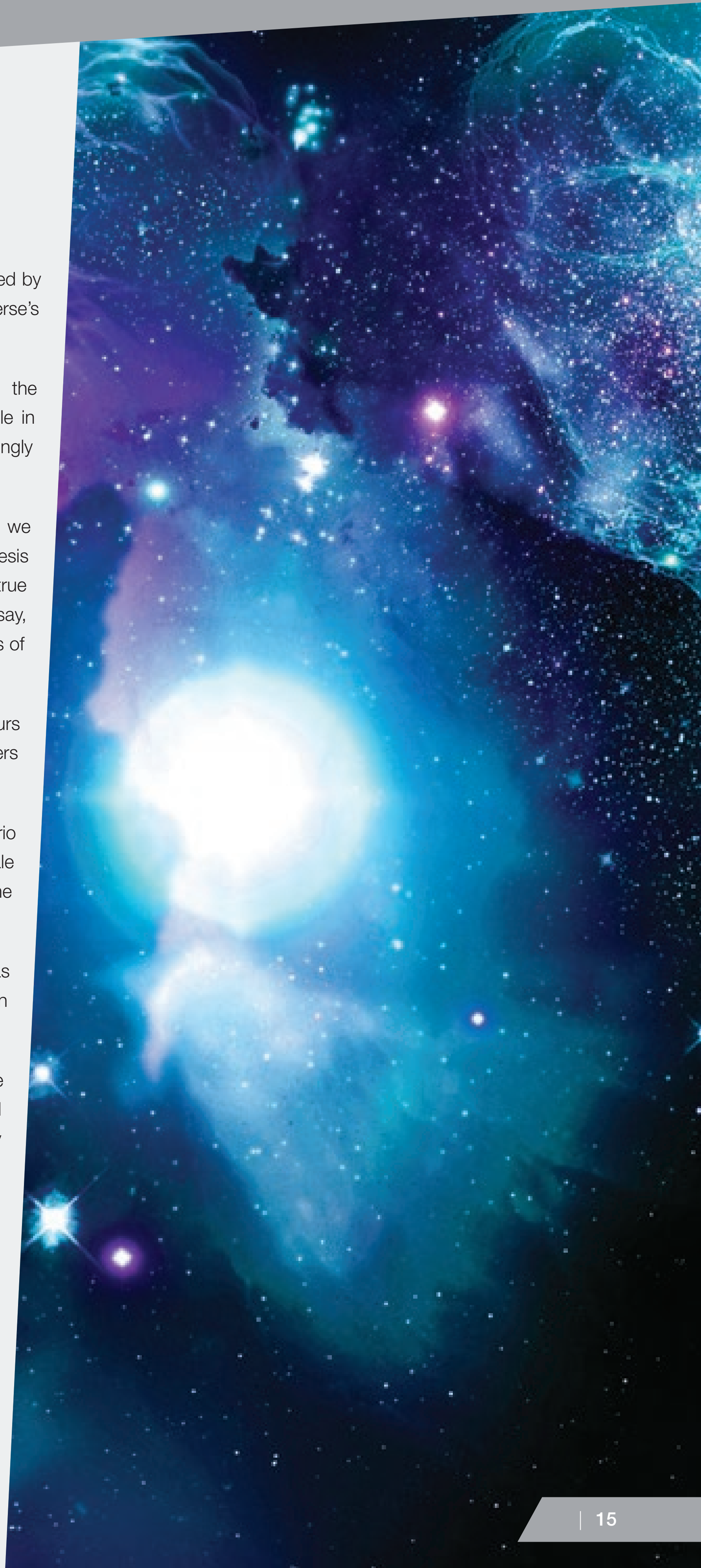
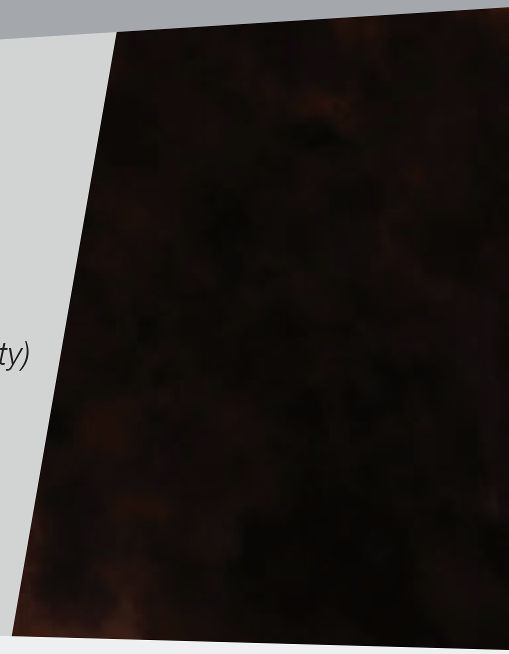


STRONG GRAVITY

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 in which curved or dynamical spacetimes are connected to other fundamental questions of physics.



COULD BLACK HOLES HAVE HAIR?

All black holes with the same mass and spin, general relativity assures us, look exactly the same. This is true even if they are formed in entirely different ways, or made of entirely different material. The short-hand version of this is one of the stranger truisms in physics: black holes have no hair.

If a hairy black hole were found, it would be proof that general relativity was incorrect.

New research from Perimeter Associate Faculty member **Avery Broderick**, Associate Postdoctoral Researcher **Tim Johannsen**, and collaborators is aimed at checking whether black holes could have hair – thereby putting general relativity to the test.

The team began by trying to decide how hairy black holes would look. The researchers tweaked the equations of general relativity to allow for hairy black holes, and then used complex computer models to generate images of what such holes would look like. Then, they examined these images, searching for features caused by their alterations of general relativity, rather than factors such as the size, spin, or the exact process by which matter fell into the black holes.

They found that altering general relativity would alter the shape of the shadow cast by the event horizon.

The team compared the real image data from the black hole Sag A* with the lineup of black hole mugshots generated by their models. This allowed them to put limits on how big a tweak to general relativity would be permitted by the data – how hairy black holes could possibly be.

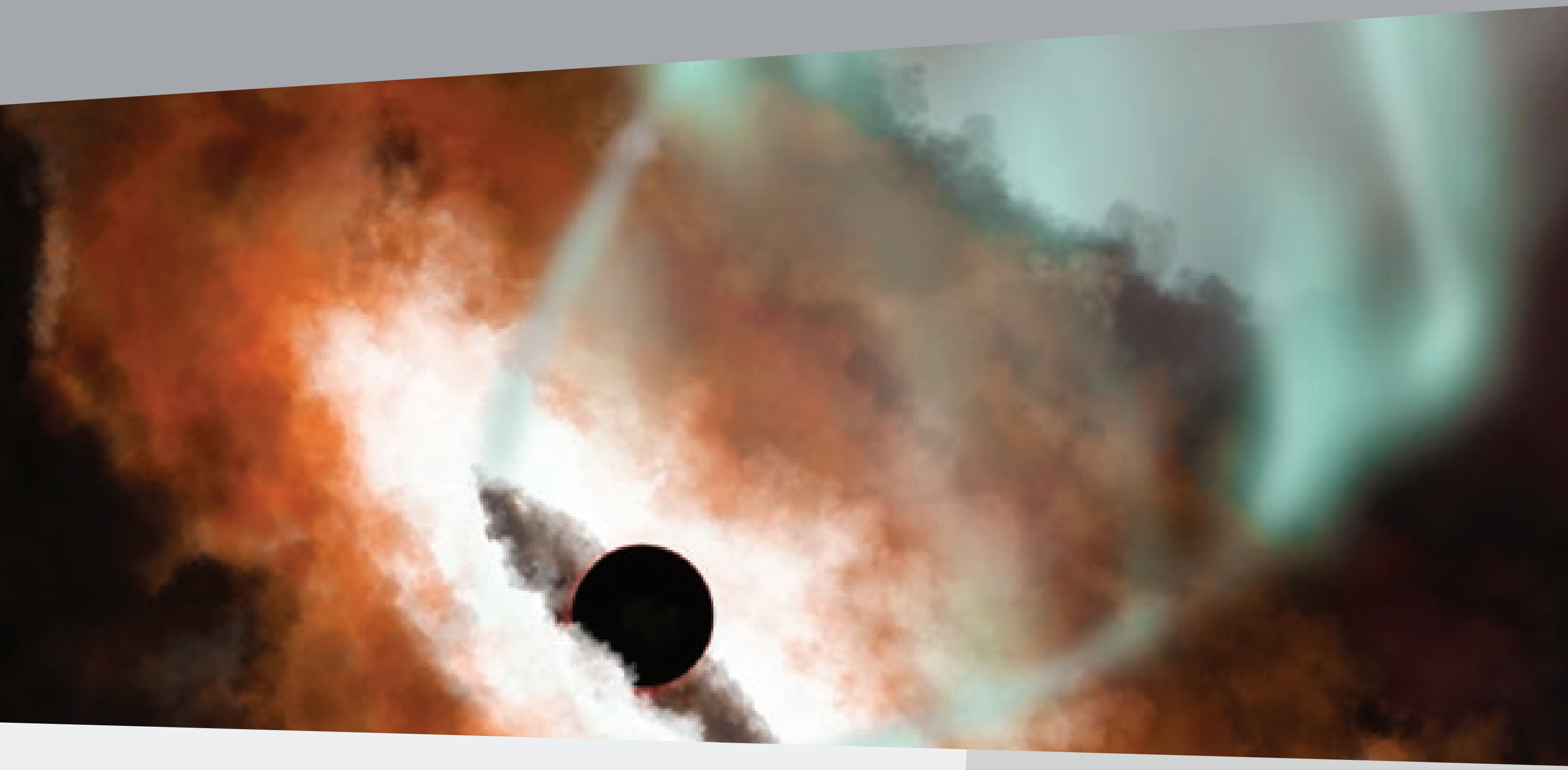
So far, the team can rule out big effects – black holes can't have a mop of hair like Einstein's – but not small ones. The real importance of this work is that it's a proof of concept – it shows definitively that physicists can use black holes as natural experiments to test ideas about spacetime.

TURBULENT BLACK HOLES

Can gravity become turbulent? The conventional answer is no, but new Perimeter research may have you buckling your seatbelt.

In physics, a duality is a pair of theories which are mathematically equivalent, even though they appear to be describing different things using different languages. Dualities are powerful ways of generating new approaches to difficult problems and producing fresh insights into old fields. One such duality is the gravity/fluids duality, which asserts that gravitational fields can be described with the language of fluid dynamics.

The gravity/fluids duality is not new work – it's been developing over the past six years. But hidden at its heart is a tension. If gravity can be treated as a fluid, then what about turbulence?



The conventional wisdom is that gravity is described by a set of equations that are so different from fluid dynamics equations that there would not be turbulence under any circumstances.

This research was done by Perimeter postdoctoral fellow **Huan Yang**, Faculty member **Luis Lehner**, and Aaron Zimmerman, a postdoctoral fellow at the Canadian Institute for Theoretical Astrophysics. Lehner highlights the emerging paradox: “Either there was a problem with the duality, and gravity really can’t be fully captured by a fluid description, or there was a new phenomenon in gravity, and turbulent gravity really can exist.”

The researchers set out to find out which was true. Specifically, they studied non-linear perturbations of black holes. Gravitational systems are rarely analyzed at this level of detail, as the equations are fiendishly complex. But, knowing that turbulence is fundamentally non-linear, the team decided a non-linear perturbation analysis was exactly what was called for.

They were stunned when their analysis showed that spacetime around fast-spinning black holes does become turbulent. “We have gone from a serious doubt about whether gravity can ever go turbulent, to pretty high confidence that it can,” says Lehner.

So if your travels take you to the vicinity of a black hole, be sure to buckle up.

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H. Yang (Perimeter Institute), A. Zimmerman (Canadian Institute for Theoretical Astrophysics), and L. Lehner (Perimeter Institute), “Turbulent Black Holes,” arXiv: 1402.4859.

PERIMETER ASSOCIATE FACULTY

(cross-appointed with other institutions)

Niayesh Afshordi (University of Waterloo)

Avery Broderick (University of Waterloo)

Alex Buchel (Western University)

Raffi Budakian (Institute for Quantum Computing/University of Waterloo)

Cliff Burgess (McMaster University)

David Cory (Institute for Quantum Computing/University of Waterloo)

James Forrest (University of Waterloo)

Matthew Johnson (York University)

Raymond Laflamme (Institute for Quantum Computing/University of Waterloo)

Sung-Sik Lee (McMaster University)

Roger Melko (University of Waterloo)

Michele Mosca (Institute for Quantum Computing/University of Waterloo)

Maxim Pospelov (University of Victoria)

Itay Yavin (McMaster University)

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 up the system. Condensed matter physicists 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 cutting-edge 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.

DIALLING IN ON QUBITS

There are two kinds of particles in our three-dimensional world: fermions (such as electrons), where two identical particles can't occupy one state, and bosons (such as photons), where two identical particles actually want to occupy one state. In three dimensions, fermions are fermions and bosons are bosons, and never the twain shall meet.

But in condensed matter, there's an exception. The wonder material graphene is a crystal form of carbon that's only one atom thick. From the perspective of the particles and charges within it, graphene doesn't have three dimensions – it has two. It's effectively a tiny two-dimensional universe and, in that universe, new phenomena can occur. Fermions and bosons can meet halfway – becoming anyons, which can be anywhere in between fermions and bosons.

Perimeter postdoctoral fellow **Zlatko Papić** and Faculty member **Dmitry Abanin** are investigating the properties of graphene, looking for a particular kind of anyon called non-Abelian anyons. Non-Abelian anyons are important because they can be used in the making of qubits.

Qubits are to quantum computers what bits are to ordinary computers: both a basic unit of information and the basic piece of equipment that stores that information. A way of building stable qubits has been urgently sought for a decade.

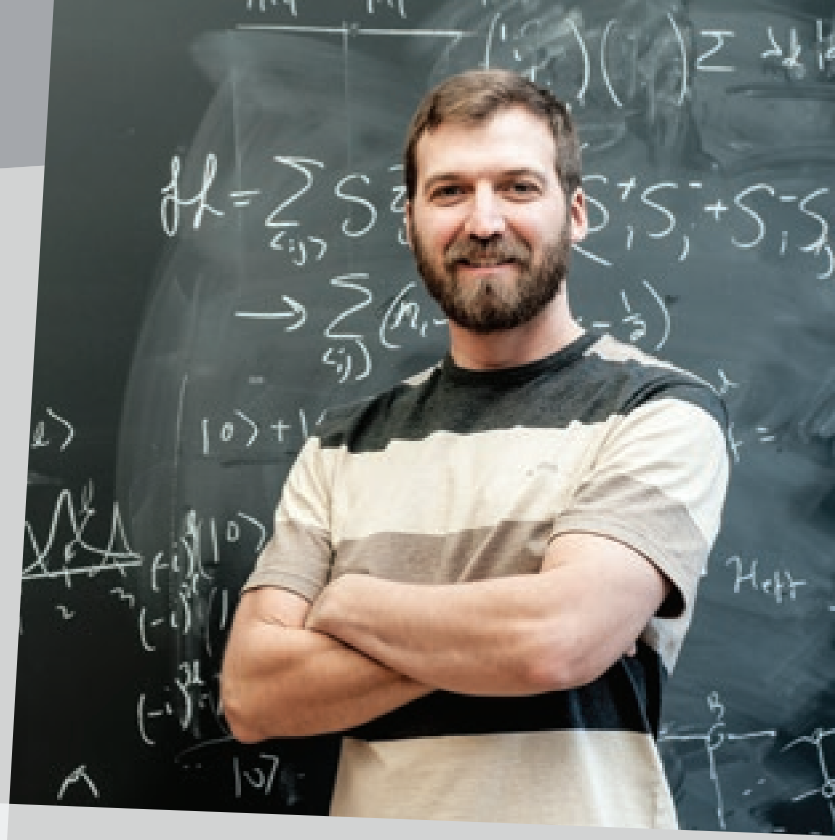
Papić and Abanin hope that the strange properties of graphene's pocket universe may allow non-Abelian anyons, and thus qubits, to emerge. Specifically, they investigated what happens when two sheets of graphene are laid one on top of another and the resultant bilayer graphene is placed in a strong perpendicular magnetic field. They discovered that, applying an electric field across the surface of bilayer graphene, one can tune the material to – in theory – produce non-Abelian anyons.

Three experimental groups are now following up on the work, using this unique experimental knob to dial in on qubits. Early results seem promising. With Abanin and Papić's knob, we are tuning up, perhaps, for a new world of quantum computers.

WAITER, THERE'S A BLACK HOLE IN MY CONDENSED MATTER ...

Subir Sachdev (the James Clerk Maxwell Chair in Theoretical Physics at Perimeter Institute), **William Witczak-Krempa** (a Perimeter postdoctoral fellow), and Erik Sørensen (a faculty member at McMaster University) are condensed matter physicists. They study exotic but tangible systems, such as superfluids. And their latest paper about one such system has a black hole in it.

Black holes are a fairly exotic ingredient in condensed matter papers. Normally, condensed matter physicists add a far more conventional (though still imaginary) ingredient to their models: something called "quasiparticles." Using the quasiparticle approach, physicists describe the behaviour of materials as if electrons or other particles were moving freely inside them. But there have always been a handful of systems which can't be described by quasiparticles – and the broad problem of modelling them has been stumping condensed matter physicists for decades.



So Witczak-Krempa and Sachdev decided to try something new. They studied one of the simplest no-quasiparticles systems, a quantum phase transition between a superfluid and an insulator. They used one of the basic tools of string theory – holography – to turn the quantum field theory which describes that system into a theory of gravity with one extra dimension.

To study the system at a temperature other than zero, they had to add a black hole.

Witczak-Krempa admits it's unorthodox: "Most condensed matter people would go, 'Why is there a black hole in this paper?' It's crazy. But what's even crazier is that this mathematical machinery works quite well. It gives you answers that make a lot of sense."

Witczak-Krempa and Sachdev were able to compare their string theory-flavoured results with the results of a more traditional simulation of the system carried out by Sørensen. It's the first time results from a traditional large-scale condensed matter simulation have been compared to results from the new string theory approach.

The proof of the pudding: the two results matched.

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CONSTRUCTING THE FUTURE

I'm a blue-collar physicist. I'm just working at this for a living. I picked physics – and specifically condensed matter – because it really did seem to me the best way to contribute to the world and to the advancement of science.

I'm a theorist, but in my own way I'm trying to run experiments. Say an experimentalist wants to understand a certain kind of crystal. They will walk over to their crystal growth facility, chip one off, and study it. I can't do that, because I'm studying crystals that don't exist. So my "experiments" are actually large-scale computer models.

But I've got a good reason for studying things that don't exist. I'm interested in predicting future materials we may be able to manufacture one day, that have interesting quantum properties.

If you cool helium to two degrees above absolute zero, it exhibits a single, beautiful quantum wave function, and it becomes superfluid. That's an example of a quantum material. I am looking for new quantum materials that don't have to be cold, or small, or exotic. I'm looking for a quantum material you could hold in your hands. This is why I call myself a blue collar physicist: I'm looking for quantum physics you can really use.

Condensed matter is going to be the field that defines new technologies. It's more than just pushing the boundaries of academic knowledge. I truly believe that our field will define the future of the human race.

– Roger Melko

Roger Melko joined Perimeter as an associate faculty member in 2012.

PARTICLE PHYSICS

Particle physics is the science which identifies nature's constituents and interactions at the most fundamental level, with an emphasis on comparing theoretical ideas with both terrestrial experiments and astrophysical observations. This mandate gives it a strong overlap with string theory, quantum gravity, and cosmology. Particle physicists at Perimeter identify how cosmological observations and experiments at Earth-based accelerators and underground laboratories constrain the theoretical possibilities for physics beyond the Standard Model.

SEEKING NATURE'S HIDDEN BUILDING BLOCKS

The Standard Model of particle physics is the master theory that describes all of the elementary particles and their interactions. Since being finalized in the 1970s, the Standard Model has had huge success in predicting the results of particle physics experiments, culminating last year with the discovery of the Higgs boson, the last of the 17 particles predicted by the model to be observed.

Though the Standard Model is widely celebrated as "the theory of (almost) everything," that "almost" is important. The model does not account for gravity, dark matter, or dark energy, among other things. Physicists are therefore eager to find any cracks in the model to be filled with new discoveries. This past year, the Large Hadron Collider experiment at CERN observed what may be such a crack when the rate at which they measured semileptonic decays of B-mesons differed slightly from the rate predicted by the Standard Model.

Perimeter researchers – including Associate Faculty members **Itay Yavin** and **Maxim Pospelov** and postdoctoral researchers **Wolfgang Altmannshofer** and **Stefania Gori** – have demonstrated that this deviation may be the result of a new force acting on the muon and tau leptons, and the muon and tau neutrinos. If this deviation is indeed the sign of new physics beyond the Standard Model, this explanation is perhaps the most natural. The researchers were able to identify additional rare decays where this new force should make itself known. The proposed tests include measurements of the properties of muon and tau leptons.

Also, importantly, the new force will contribute to the process of muon pair-production by muon neutrinos, which is an extremely rare process first observed 25 years ago at CERN and Fermilab.

The work on fully exploring this piece of long-forgotten experimental data, as well as on prospects of detecting this process again in the upcoming neutrino experiments, is ongoing at Perimeter, and has led to follow-up work published in *Physical Review Letters*.

DARK MATTER IN THE DUMPS?

Four other Perimeter researchers – Faculty members **Philip Schuster** and **Natalia Toro**, along with postdoctoral researchers **Eder Izaguirre** and **Gordan Krnjaic** – are engaged in the search for the most pervasive, yet most elusive, stuff of the universe. Dark matter is generally believed to account for the majority of all mass in the universe, even though it has never been directly detected or measured (it neither emits nor absorbs light, hence the name).

Finding it, according to Schuster and Toro, might require looking where particles typically go to die: an electron beam dump.

Particle accelerator experiments blast billions of energetic electrons at focused points in order to measure and interpret the ensuing subatomic shrapnel. All of that energy needs to be safely diffused after the experiment, so it is shunted off to a dump – a dense block of metal that absorbs most of the particles and tamps down the energy they carry.

It's possible, Schuster and Toro theorize, that some unusual particles interact so weakly with others that they might just zip through the dump and be detected on the other side. If so, such particles could be candidates for dark matter.

A beam dump is an ideal place to search for dark matter, they argue, because there is very little background "noise" (such as the typical bombardment of cosmic radiation), thanks to its shielded, underground location.

The researchers are working closely with collaborators at particle accelerator facilities to implement the proposed experiment (and they have already demonstrated the feasibility of such an experiment at the SLAC National Accelerator Laboratory).

Although it's quite possible such an experiment will find no dark matter (the experiment would only detect lightweight, weakly interacting particles), it will regardless clarify our understanding of nature's building blocks.

"The results will fit into a larger story – the patchwork of our understanding," says Toro.

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CHALLENGING THE NORM

It's not easy being an outsider, but somehow that's where I always end up. As a girl growing up in rural Greece, I loved science but had no interest in taking the usual route into teaching. Instead, I wanted to be a research scientist.

For a village kid, and a girl at that, it was a rather strange desire, but what made little sense to others was, to me, a natural fit. I was insatiably curious about how the universe worked. Physics fed that curiosity.

Today, I work in the space between disciplines. I use new technologies to test theories, and push for alternative ways to look for fundamental physics. It's an outsider's approach, and my interest can shift rapidly as new technologies and theoretical ideas emerge.

What seems unusual to others is what makes my work fun. I get to study how atomic clocks, the current standard of time, can be used as dark matter detectors, or explore whether the technology used in MRI scanners can detect new interactions in matter. Some of these ideas could not be conceived of 10 or 15 years ago, and do not fit in the usual norm of particle physics experiments.

My home today is very different from my small Greek village. At Perimeter, it's okay to take the unusual path. As I put theoretical physics to the test, I may be an outsider, but I know I am not alone.

– Asimina Arvanitaki

Asimina Arvanitaki joined Perimeter's faculty in 2014.

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 other 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.

A BRIDGE BETWEEN STRINGS AND FIELDS

What happens when two or more particles meet?

It's perhaps the most fundamental question in particle physics. To answer it, physicists calculate what are technically known as scattering amplitudes, which give the probability for each possible outcome.

Historically, calculating scattering amplitudes has been cumbersome, requiring researchers to take into account every possible result of an interaction individually and add together all those possibilities, to make even the simplest prediction. In many cases, the complexity of these calculations made them impossible.

Fortunately, the last decade has seen dramatic progress – much of it based at Perimeter – in the way scattering amplitudes are understood and calculated. This is particularly true of the scattering of massless "force-carrying" particles, such as photons, gluons, and gravitons, moving in our familiar four-dimensional (three dimensions plus time) space.

Perimeter Faculty member **Freddy Cachazo**, postdoctoral fellow **Song He**, and PhD student **Ellis Yuan** wondered if the new methods of calculating scattering amplitudes had to stop at four dimensions. They embarked on a program of research to examine whether the new techniques can be applied to the scattering of particles in other kinds of spaces.

The researchers found that the new understandings of scattering can indeed be extended to higher dimensions. They wrote a very compact formula for the scattering of massless scalars, gluons, and gravitons, which is valid in any number of dimensions. This includes the 10- and 11-dimensional spaces often described by string theory.

The new formula builds some surprising bridges between string theory and more commonplace quantum field theory. It even implies existence of a string theory-like description of pure quantum field theory.

This is exciting new work at the foundation of mathematical physics. It has inspired 42 follow-up papers so far, leading to advances in quantum field theory, string theory, and even pure mathematics.

KICKING A QUANTUM CLOCK

Systems that are far from equilibrium are difficult to understand. For instance, consider clocks. Describing the way the pendulum swings in a ticking clock is fairly easy. Describing the pendulum swing of a stopped clock is easier still. But what if you kicked the clock? Could you then predict the swing of the pendulum as the clock wobbled and toppled and crashed to the floor?

The kicked clock embodies the challenge of studying systems far from equilibrium. Suffice it to say, it's hard. Add a quantum twist to it, and it's harder still. Physicists have made some progress, but are still searching for broadly applicable theoretical techniques – or, ideally, a set of universal principles – for describing far-from-equilibrium systems. Now, it appears that Perimeter researchers may have found one such principle.

Perimeter Faculty member **Robert Myers**, Associate Faculty member **Alex Buchel**, and PhD student **Anton van Neikerk** decided to look at far-from-equilibrium systems through one of the lenses of string theory, technically known as the AdS/CFT correspondence. AdS/CFT says some quantum field theories – which would usually be the go-to language in which quantum systems are described – can instead be translated into a very different language: a language of gravity.

Specifically, AdS/CFT shows that a quantum system falling toward equilibrium can also be described as a hollow shell of energy collapsing to form a black hole. That sounds like an unnecessary complication, but it actually makes the system easier to describe mathematically.

At first, using this black hole approach, the researchers were able to calculate how much energy is added to the system after it is given a (mathematical) kick of various strengths. Even better, the researchers – this time including Myers, Sumit Das (University of Kentucky), and Perimeter PhD student **Damian Galante** – were able to generalize this result. They extracted from the string theory approach one simple behaviour of a system falling toward equilibrium, which holds true for a broad class of systems.

The researchers published papers on this topic in *Physical Review Letters* in 2013/14, and work is ongoing.

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MY SCIENTIFIC LIFT-OFF

As the black-and-white images flickered on the silver screen, I was transported.

I was no longer a four-year-old boy sitting with his mother and siblings in a darkened cinema in St. John's, Newfoundland. I was an astronaut, blasting into orbit alongside the cast of *Spaceways*.

After the credits rolled, as we made our way home to Ft. Pepperell, Newfoundland, where my father was stationed, my mind was abuzz with questions: *How do rockets work? Do people really fly above the sky?*

Though I didn't realize it at the time, that afternoon spent watching a sci-fi melodrama was a pivotal moment in my life.

It sparked a thirst for discovery that, six decades later, has thankfully not yet been quenched.

Of course, my four-year-old self had no clue he'd grow up to investigate supersymmetry and superstring/M-theory – they hadn't yet been proposed, after all – but my curiosity about the universe had been set alight.

Nor could my four-year-old self have imagined that, one day, I'd become a member of the U.S. National Academy of Sciences, or propose ideas about relations among evolution, error-correcting computer codes, and the universe.

I certainly had no inkling that the President of the United States would one day appoint me to his trusted council of science advisors. Can you blame mini-me for not seeing that one coming?

So much of what has happened in my scientific career – both the breakthroughs and the struggles – would have seemed as fantastical to my childhood self as the rockets and robots of *Spaceways*.

In hindsight, however, I understand how that movie launched my life as a scientist.

Even now, as I did then, I approach the mysteries of the universe with a wide-eyed sense of awe.

– S. James Gates, Jr.

S. James Gates, Jr. has been a Perimeter Distinguished Visiting Research Chair since 2011.

QUANTUM GRAVITY

Quantum gravity is concerned with unifying Einstein's theory of general 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 PULL TO UNIFICATION

Much like our everyday experience of gravity itself, the field of quantum gravity tends to pull things together.

Think of how gravity unites two very different things – your feet and planet Earth, for instance – in a way that seems completely natural, even if you don't fully understand the forces at play.

Quantum gravity research also aims to unify disparate things: the theory of the extraordinarily small (quantum mechanics) with the theory of the extraordinarily massive (general relativity). The missing puzzle piece in our understanding of nature lies between these fields, in the realm of things that are very heavy yet very small (such as black holes or the big bang singularity). This is the realm of quantum gravity research.

Because the phenomena under consideration are so foreign to our everyday experience – and so difficult to measure experimentally – a wide range of theoretical research is under way in hopes of sharpening our understanding of the field.

Perimeter Faculty member **Laurent Freidel**, for example, has recently conducted research that makes a major advance on an old topic – namely, the relationship between gravity and thermodynamics suggested by Stephen Hawking's discovery that black holes are hot.

The possibility of a deep link between gravity, quantum physics, and thermodynamics has been a subject of much interest since the 1970s. Freidel's work extends the correspondence in two important ways: first, to situations that are out of thermodynamic equilibrium (previous studies treat black holes as being in equilibrium), and second, it demonstrates that the correspondence extends to general spacetimes.

Freidel's innovative approach was to posit a screen – a kind of membrane stretched through spacetime – to show that, as spacetime evolves in time (according to Einstein's equations), the matter in the membrane obeys the laws of non-equilibrium thermodynamics.

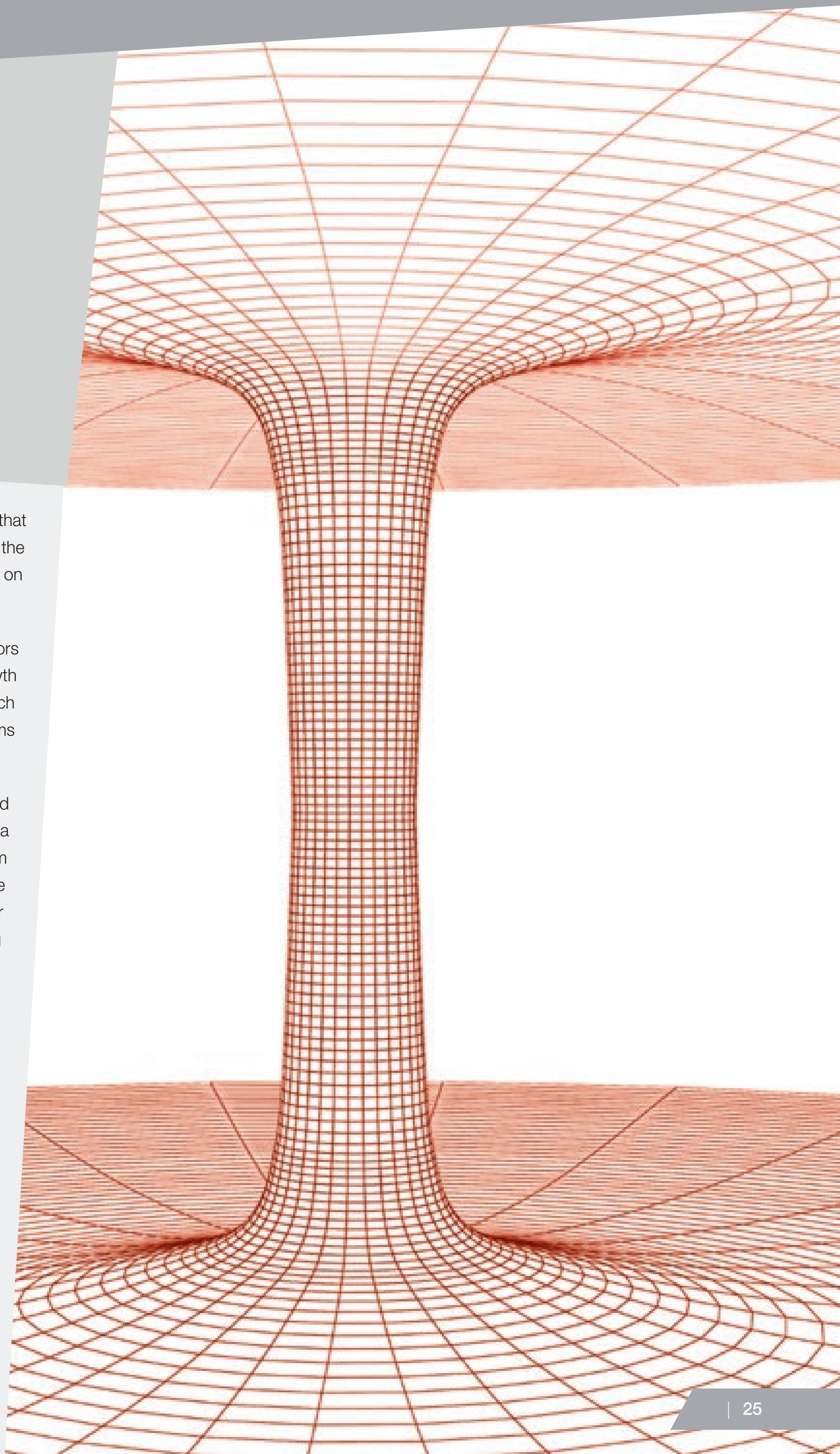
HOW TIME FLIES

Whereas Freidel's work looks at processes that unfold over time, **Flavio Mercati**, a Templeton Frontiers Program Postdoctoral Fellow at Perimeter, has recently tackled the question of why time itself unfolds the way it does.

Mercati, with collaborators Julian Barbour and Tim Koslowski, posited a new explanation of the so-called "arrow of time," which describes the universal progression from past through present to future.

Exactly *why* time should fly straight ahead like an arrow has been the subject of much investigation and debate. The arrow of time is often explained by the so-called "past hypothesis," which presumes that the universe began with a very special low-entropy state – a tidy scenario in which the baby universe was neatly ordered before getting progressively messier.

But observations suggest that our universe actually started quite messily (a "plasma soup" close to thermal equilibrium), then evolved into the beautifully ordered structures we now see, such as galaxies and solar systems.



Mercati and co-authors argue that a more tenable explanation of the arrow of time is, therefore, based on complexity.

The model Mercati and collaborators studied exhibits an irreversible growth of complexity in all its solutions, which implies that the flow of time streams necessarily from past to future.

Research programs like Freidel's and Mercati's are crucial components in a multi-faceted approach to quantum gravity – bridging once-disparate fields and ideas – in the search for a cohesive, unified understanding of our universe on the tiniest and grandest scales.

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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.

EXTENDING NOETHER'S THEOREM

Noether's theorem is one of the best known and most powerful mathematical tools in physics, showing that every symmetry in the laws of motion implies a conservation law. For instance, the fact that physical laws do not change over time implies conservation of energy, and the fact that they are the same everywhere implies conservation of momentum.

Noether's theorem is important not only because of the insight it gives into conservation laws, but also as a practical calculation tool. It is widely used, for instance, when the evolution of a system is too complicated to solve exactly, or some of the details of the dynamics are unknown. In these cases, it allows researchers to use the symmetries of the dynamics to still derive strong constraints on the system's evolution despite these limitations.

However, in spite of its widespread use, Noether's theorem is deficient in two respects. First, it applies only to systems that are not interacting with their environments. Second, even in the case of isolated systems, it does not capture all of the consequences of symmetries.

In a recent paper, Perimeter Faculty member **Robert Spekkens** and graduate student **Iman Marvian** extend Noether's theorem. They derive measures of the extent to which a quantum state breaks a given symmetry and demonstrate that such measures are non-increasing under laws of motion respecting that symmetry, even if the system interacts with its environment. In the case of isolated systems, this yields new conservation laws.

This result is of immediate interest to physicists, but also has many practical applications in emerging quantum technologies. It can, for instance, be used in measuring quantum coherence, deriving model-independent bounds on the performance of quantum amplifiers, and assessing quantum schemes for achieving high-precision standards.

The authors' work in deriving various interesting measures of asymmetry is based on ideas from quantum information theory. This is an outstanding example of the value of supporting quantum information theory within a broader framework of theoretical physics research, as Perimeter Institute has done since inception.

THE WHYS OF QUANTUM MECHANICS

Quantum mechanics works. The trouble is that no one knows why it works. Contrast this with special relativity, which is built up from just two fundamental principles about the nature of physical laws and the speed of light. If quantum mechanics does have such fundamental principles underlying it, we don't yet know what they are.

This becomes a problem when physicists try to extend or generalize quantum theory beyond quantum mechanics. Since we don't have the underlying principles of quantum mechanics, we also don't know which parts of it are fundamental, and which parts are artifacts of the way we've constructed the story. When we strike out from the known in quantum theory, it's not clear what direction we should take.

Perimeter postdoctoral researcher **Ryszard Kostecki** is hoping to find that direction, and ultimately derive the structure unifying quantum mechanics and nonperturbative quantum field theory from conceptually meaningful principles of information theory.

In this recent work, Kostecki investigated a connection between how quantum states change when you make measurements and how probability measures change when you gain knowledge. More technically, he reconsidered the idea that Lüders' rule, central to quantum mechanics, is the analog of Bayes' rule, central to probability theory.

In recent decades, researchers have discovered that Bayes' rule can be derived as a special case of a more general, and information-theoretic, principle. Called the constrained maximization of relative entropy, it states that, when we learn something new, our new state of knowledge should agree with this information, while being maximally noncommittal to everything else.

So, Bayes' rule has an underlying principle: maximum entropy. Kostecki and his collaborators proved that Lüders' rule can also be derived from this principle. This turns the conceptual analogy between Bayes' rule and Lüders' rule to an exact mathematical property: they are two cases of a single unifying principle. The next step is to investigate other special cases of this principle, as potential new forms of quantum information dynamics.

The attempt to build quantum theory from the ground up, on the model of probability theory, is a very large project. But any success Kostecki and his colleagues have would also have a very large payoff: making quantum theory mathematically more general and conceptually clearer.

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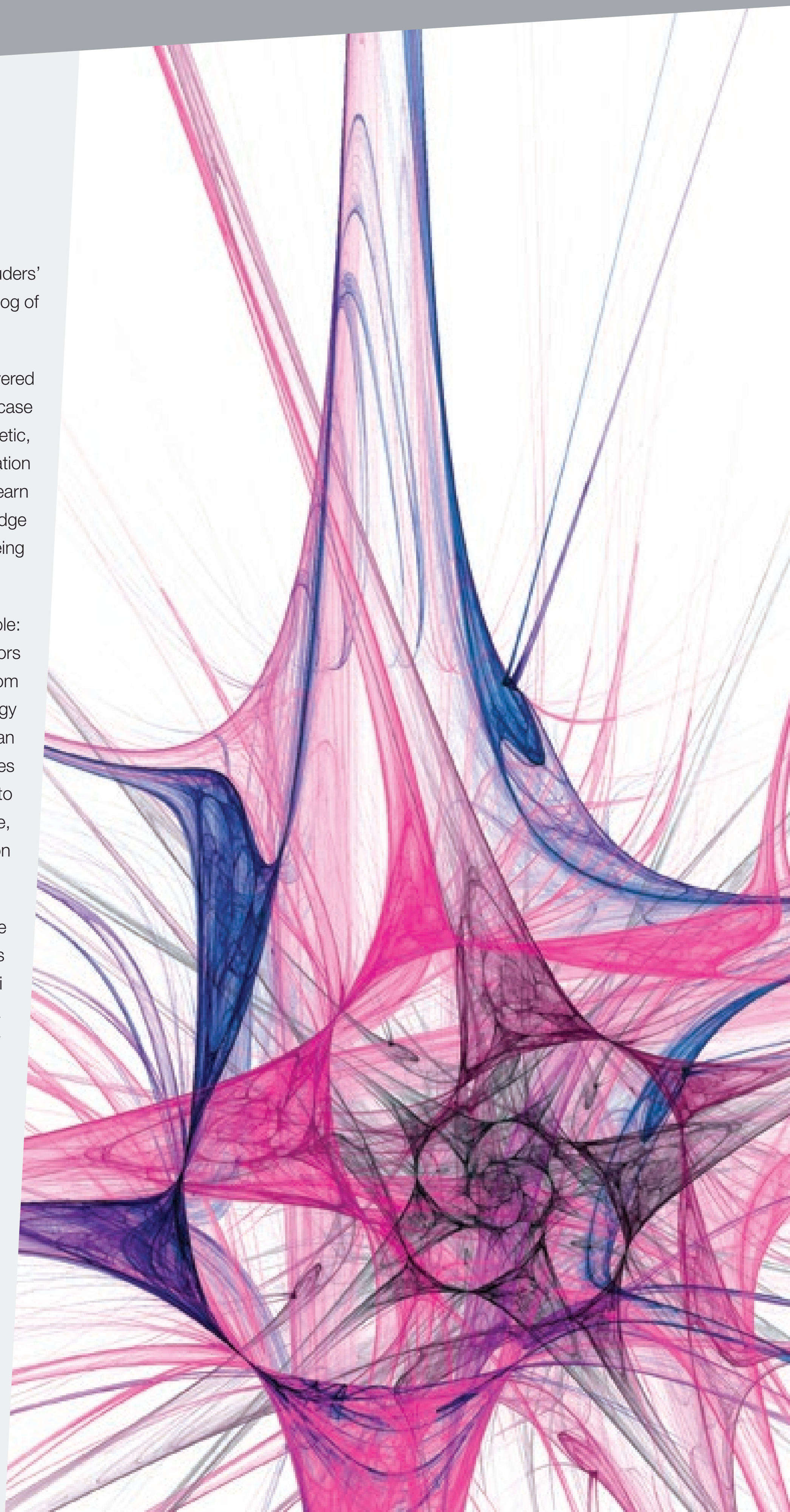


HONOURS, AWARDS, AND GRANTS

- Faculty member **Freddy Cachazo** was awarded a $100,000 2014 New Horizons in Physics Prize by the Fundamental Physics Prize Foundation.
- Faculty member **Dmitry Abanin** received a $50,000 2014 Sloan Research Fellowship.
- Founder and Board Chair **Mike Lazaridis** was elected as a Fellow of the Royal Society (UK).
- Director **Neil Turok** was elected as a Fellow of the Royal Society of Canada.
- Director **Neil Turok** won the 2013 Lane Anderson Award for Canadian science writing for his book, *The Universe Within: From Quantum to Cosmos*.
- Director **Neil Turok** was awarded honorary doctorate degrees by Rhodes University and Nelson Mandela Metropolitan University, both in South Africa, and Saint Mary's University in Halifax.
- Distinguished Visiting Research Chairs **Leon Balents**, **Joel Moore**, **Senthil Todadri**, and **Ashvin Vishwanath** were elected Fellows of the American Physical Society.
- Postdoctoral Researcher **Eugenio Bianchi** received the inaugural Bronstein Prize "for his insightful contributions to black hole entropy, the discrete geometry of quantum spacetime and the propagation of gravitons thereon, and for his inspiring enthusiasm and collaborative spirit."
- Visiting Fellow **David Skinner** received a 2013 "Best Paper Prize" from the *Journal of Physics A* for his paper, "Amplitudes at weak coupling as polytopes in AdS_5."
- Associate Graduate Student **Lauren Hayward** was named one of "Canada's future leaders of 2014" by *Maclean's* magazine.

- Four Perimeter researchers were awarded Early Researcher Awards worth $140,000 each by the Province of Ontario:

  - Faculty member **Dmitry Abanin**

  - Faculty member **Bianca Dittrich**

  - Krembil Galileo Galilei Chair in Theoretical Physics **Davide Gaiotto**

  - Faculty member **Natalia Toro**

- Perimeter researchers obtained over $2.6 million in grants from agencies including the Natural Sciences and Engineering Research Council of Canada (NSERC), the John Templeton Foundation, the Foundational Questions Institute (FQXi), and the Simons Foundation.

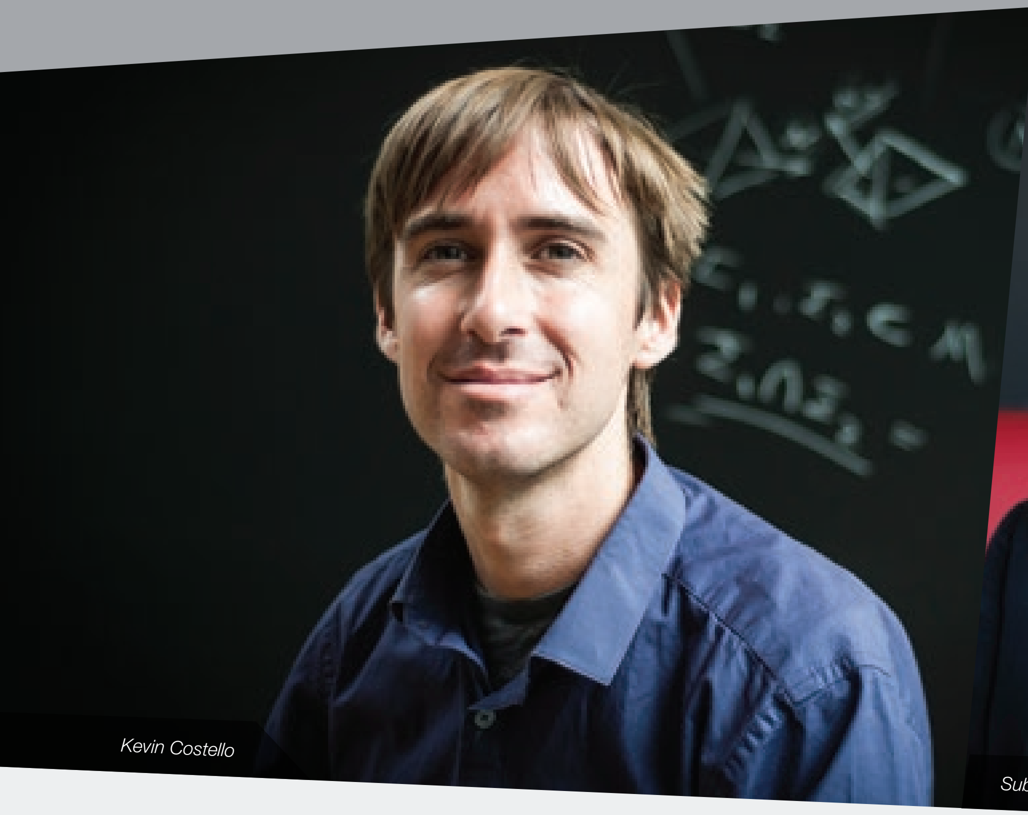
FREDDY CACHAZO WINS NEW HORIZONS IN PHYSICS PRIZE

Perimeter Faculty member Freddy Cachazo became the Institute's second recipient of the New Horizons in Physics Prize in as many years, receiving the 2014 honour after Davide Gaiotto won for 2013.

Awarded by the Fundamental Physics Prize (FPP) Foundation (now known as the Breakthrough Prize Foundation), the $100,000 New Horizons Prize is considered the top prize worldwide for young theoretical physicists, intended to recognize researchers who are "dedicated to advancing our knowledge of the universe at the deepest level." Perimeter is the only institution to have won two.

In trying to understand nature's most fundamental constituents, Cachazo has made several discoveries widely characterized as breakthroughs. The award recognized Cachazo for his work in developing elegant new systems for calculating scattering amplitudes, which are the most fundamental calculation in particle physics, predicting what happens when two or more particles interact. The new systems have created widespread excitement in both the particle physics and mathematical physics communities, and are expected to be a focal point for years to come.

RECRUITMENT



Kevin Costello

Subir Sachdev

The most reliable way to spur research breakthroughs is to hire brilliant people. Since its early days, Perimeter has been attracting the brightest minds in theoretical physics from around the world; the past year was especially successful in this regard. From early-career researchers to giants of the field, Perimeter welcomed leading scientists across the full spectrum of theoretical physics, with special focus on targeted areas of opportunity such as quantum information and condensed matter physics.

PERIMETER RESEARCH CHAIRS

The Perimeter Research Chairs program was designed to attract world-leading scientists in strategically chosen fields to Perimeter's faculty. The program has been instrumental in attracting and retaining three top scientists around whom the Institute is building "powerhouse" research groups capable of making rapid progress on key problems: **Xiao-Gang Wen**, the BMO Financial Group Isaac Newton Chair in Theoretical Physics; **Neil Turok**, the Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics; and **Davide Gaiotto**, the Krembil Galileo Galilei Chair in Theoretical Physics.

Over the past year, **Kevin Costello** was appointed as the Krembil William Rowan Hamilton Chair in Theoretical Physics and **Subir Sachdev** as the James Clerk Maxwell Chair in Theoretical Physics (Visiting). In addition, Perimeter received a $4 million investment from the Krembil Foundation to fund Costello and Gaiotto's Chairs.

Costello joins Perimeter from Northwestern University, where he established himself as one of the world's leading young mathematicians. He authored a path-breaking monograph, *Renormalization and Effective Field Theory*, which introduced powerful new mathematical tools into the theory of quantum fields. Costello will be a crucial component of the Institute's intensifying efforts in mathematical physics, working on challenging problems with implications for quantum field theory and string theory.

Sachdev has been a Professor of Physics at Harvard University since 2005 and his appointment adds to Perimeter's growing strength in condensed matter physics. He has made prolific contributions to research on quantum phase transitions and their application to correlated electron materials like high temperature superconductors, and authored a seminal text, *Quantum Phase*

Asimina Arvanitaki

PI BY THE NUMBERS

Perimeter is the world's largest theoretical physics community.

22 full-time faculty

14 associate faculty cross-appointed with partner universities

42 Distinguished Visiting Research Chairs

14 Visiting Fellows

44 postdoctoral researchers

73 graduate students[1]

[1] This includes 42 PhD students and 31 Perimeter Scholars International (PSI) master's students. All numbers reflect the Perimeter community as of July 31, 2014.

Transitions. In recent years, Sachdev has exploited a remarkable connection between the electronic properties of materials near a quantum phase transition and the quantum theory of black holes.

In the three years since its creation, the Perimeter Research Chairs program has appointed five top international scientists, who have, in turn, made the Institute a more attractive research destination than ever.

FACULTY

In addition to its two new Perimeter Research Chairs, the Institute welcomed an outstanding new faculty member, **Asimina Arvanitaki**, in 2013/14.

Arvanitaki joined Perimeter following research positions at the Stanford Institute for Theoretical Physics at Stanford University and the Lawrence Berkeley National Laboratory at the University of California, Berkeley. She is a particle physicist who specializes in designing new experiments to test fundamental theories beyond the Standard Model. Arvanitaki pioneered the use of optically levitated dielectric objects to detect gravitational waves. She also works on theoretical challenges raised by experimental results, such as a model of particle physics influenced by string theory called "split SUSY."

ASSOCIATE FACULTY

To complement its full-time faculty, Perimeter partners with Canadian universities to attract top scientific talent through its associate faculty program. Associate faculty spend up to 50 percent of their time at Perimeter, in addition to teaching and conducting research at the partner university. The program has brought many highly respected international scientists to Canada, enhancing the country's growing strength in fundamental physics.

This year, Perimeter made two such joint appointments, strengthening its position as a world-leader in quantum information and furthering ties with experimentalists at the Institute for Quantum Computing.

Raffi Budakian is an experimental condensed matter physicist whose research focuses on developing ultra-sensitive spin detection techniques for single spin imaging and quantum readout. In 2005, he won a World Technology Award for his work in the detection and manipulation of quantum spins. Budakian comes to Waterloo from the University of Illinois at Urbana-Champaign. He joined Perimeter in June 2014, jointly appointed with the Institute for Quantum Computing at the University of Waterloo. He also holds the Nanotechnology Endowed Chair in Superconductivity at IQC and the Waterloo Institute for Nanotechnology (WIN).

James Forrest's research focuses on the physics of soft matter on the nanoscale, with particular emphasis on polymers and proteins, glass transition in confined geometry, and surface and interfacial properties of polymers. Among his many honours, he is a Fellow of the American Physical Society and co-recipient of the 2013 Brockhouse Medal of the Canadian Association of Physicists. Forrest joined Perimeter in February 2014 as the Institute's Academic Programs Director and an associate faculty member. He is jointly appointed at the University of Waterloo, where he has been a professor since 2000.

DISTINGUISHED VISITING RESEARCH CHAIRS

Perimeter's Distinguished Visiting Research Chairs (DVRC) program brings leading scientists to Perimeter for extended periods of fruitful research and collaboration. DVRCs are appointed to renewable terms of three to four years, while retaining permanent positions at their home institutions.

During their visits, DVRCs enhance Perimeter's overall research environment, participating in all facets of the Perimeter community – from research and collaborating with colleagues, to organizing

conferences, teaching in the PSI program, and participating in the Institute's outreach activities. For DVRCs, time spent at Perimeter is highly productive, since they are free from their usual administrative and teaching duties.

Over the past year, Perimeter appointed 11 DVRCs and renewed an additional five. The Institute now has 42 DVRCs spanning every branch of theoretical physics, including luminaries such as Stephen Hawking, Yakir Aharonov, Savas Dimopoulos, and Renate Loll.

DISTINGUISHED VISITING RESEARCH CHAIRS

Yakir Aharonov, Chapman University and Tel Aviv University
Nima Arkani-Hamed, Institute for Advanced Study
Abhay Ashtekar*, Pennsylvania State University
Leon Balents*, University of California, Santa Barbara
James Bardeen, University of Washington
Ganapathy Baskaran, Institute of Mathematical Sciences, Chennai
Patrick Brady*, University of Wisconsin-Milwaukee
Alessandra Buonanno*, University of Maryland, College Park
Juan Ignacio Cirac, Max Planck Institute of Quantum Optics
Savas Dimopoulos*, Stanford University
Lance Dixon*, Stanford University
Matthew Fisher, University of California, Santa Barbara
S. James Gates, Jr., University of Maryland, College Park
Alexander Goncharov, Yale University
Gabriela Gonzalez*, Louisiana State University
Duncan Haldane, Princeton University
Stephen Hawking**, University of Cambridge
Patrick Hayden, Stanford University
Ted Jacobson, University of Maryland, College Park
Shamit Kachru*, Stanford University
Leo Kadanoff, University of Chicago
Adrian Kent, University of Cambridge
Renate Loll, Radboud University, Nijmegen
Matilde Marcolli*, California Institute of Technology
Joel Moore*, University of California, Berkeley
Ramesh Narayan, Harvard University
Sandu Popescu**, University of Bristol
Frans Pretorius, Princeton University
Peter Shor, Massachusetts Institute of Technology
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
Barbara Terhal*, RWTH Aachen 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 2013/14

** Indicates Templeton Frontiers Program DVRC

POSTDOCTORAL RESEARCHERS

Carl Sagan wrote, “The great discoveries are almost entirely made by youngsters.”

Early-career researchers often approach big questions from novel directions – precisely the kind of ambitious science that can result in major breakthroughs.

To tap into the intellectual energy of early-career researchers, Perimeter has assembled the world’s largest group of independent postdoctoral researchers in theoretical physics. In 2013/14, Perimeter appointed 16 new postdoctoral researchers and recruited an additional 21 for 2014/15, from among a record applicant pool of 735.

But that’s only part of the formula. At Perimeter, postdoctoral researchers are given the freedom and collaborative opportunities they need to push research into uncharted territory. They are full members of the Institute’s research community, with full autonomy to pursue their own research programs. They can invite collaborators, travel, and organize conferences, workshops, and scientific talks.

This approach pays off. In spite of an extremely competitive academic market worldwide, seven departing postdoctoral researchers accepted tenure-track faculty positions over the last year. Several others obtained continuing academic positions at international institutions or sought-after positions in industry.

"Perimeter is a very exciting place. As a research institution, it's unique in the world. There are so many people here doing so many interesting things. The possibilities for interaction are really exciting. The great thing for us postdocs is that we get great freedom to follow any line of research we want to follow."

– Steffen Gielen,
Postdoctoral Researcher

"The way people interact here at Perimeter, it's pretty special. The environment is really interesting, and it makes people of different disciplines talk to each other."

– Flavio Mercati,
Templeton Frontiers Program Postdoctoral Fellow

FORGING NEW PATHS

My work is all about making connections. As a mathematician with a background in theoretical physics and computer science, I spend most of my time helping others navigate unfamiliar terrain. Sometimes, I help find suitable mathematical models for their work. Other times, I help analyze the mathematical structures they encounter.

These collaborations can take me into foreign territory, but that's okay. I've lived in seven cities on two continents so far, and I enjoy exploring the unfamiliar.

This is good, because my work is heading in new directions, too. After years of applying mathematics to quantum physics, I am working with biologists who are applying more precise mathematical methods to areas like population dynamics and mating systems. We're looking at monogamy versus polygamy, and how that is influenced by environmental factors. It's certainly a long way from quantum theory.

I'm also wading into category theory and knowledge integration. Category theory is a unifying language for different kinds of math, trying to find similar patterns in different contexts. Knowledge integration is the process we use to make sense of different sets of data. If, for example, a tourist asks five locals how to get from one town to the next and is given five different routes, how that person assembles the information into a coherent picture, and then decides which path to take, is knowledge integration.

That example also sums up my own path up to this point. I like finding connections between things that mathematicians have studied and new frontiers other scientists are exploring. I like integrating knowledge. Where this research leads is still a mystery, though. That's kind of how I like it.

– Tobias Fritz

Tobias Fritz has been a Templeton Frontiers Program Postdoctoral Fellow since 2012.

RESEARCH TRAINING

BUSY = CHALLENGE = FUN

James Forrest's busy life recently got busier. Perimeter's new Academic Programs Director is a father of six who raises chickens on his family farm, as well as an esteemed researcher at the University of Waterloo, leading its soft polymer physics group.

It's a schedule many would find daunting, but one Forrest views as an irresistible challenge – a lifelong theme. Forrest found physics in his final year of high school and was drawn to the challenge, going on to do a PhD at the University of Guelph in proton-irradiated solid hydrogen because "it sounded neat at the time."

Forrest has often taken on demanding administrative roles in addition to his research and teaching duties. Among them, he was Associate Dean of Research for the Faculty of Science at the University of Waterloo (2010-12) and Director of the Guelph-Waterloo Physics Institute (2005-10), where he helped launch the Perimeter Scholars International (PSI) program for which he's now directly responsible.

At Perimeter, he is excited by the opportunity to have an impact beyond his immediate field of research. "Perimeter has a single vision and is very driven to succeed," Forrest says. "We have all this freedom. It's a great, fast-paced environment where everybody seems to be on the same page."

PERIMETER SCHOLARS INTERNATIONAL

Perimeter understands that brilliant young people are not just the future of physics, but also a crucial element in any dynamic scientific community. It was with that in mind that the Institute created its master's program, Perimeter Scholars International (PSI), in 2009, and it has been attracting exceptional university graduates from around the world ever since.

PSI brings these promising students to the cutting edge of theoretical physics in one academic year. The innovative curriculum features three-week modules taught by Perimeter faculty and other top international lecturers, with tutorial support from postdoctoral-level PSI Fellows and graduate teaching assistants. Students are exposed to the full spectrum of theoretical physics, while learning skills that will serve them well in both academia and industry – such as independent thinking, collaborative problem solving, and computer-based model development. Upon completion of the program, students receive a master's degree from the University of Waterloo and a PSI certificate.

In 2013/14, PSI trained 31 students from 17 countries. Eleven of this year's graduates – more than one-third of the class – are remaining in Canada for their doctoral studies, eight of them with Perimeter faculty. Many others have gone on to top international institutions, including the University of Cambridge, Princeton University, and Stanford University.

The PSI program was generously supported in 2013/14 by: The Bluma Appel Community Trust, 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, Margaret and Larry Marsland, and The Scott Griffin Foundation.

PSI FACULTY, 2013/14

James Forrest (Director), Perimeter Institute and University of Waterloo

Latham Boyle, Perimeter Institute

Anton Burkov, University of Waterloo

Freddy Cachazo, Perimeter Institute

Anushya Chandran, Perimeter Institute

Andrew Childs, Institute for Quantum Computing/University of Waterloo

David Cory, Perimeter Institute and Institute for Quantum Computing/University of Waterloo

François David, Institute of Theoretical Physics/CEA-Saclay

Bianca Dittrich, Perimeter Institute

Joseph Emerson, Institute for Quantum Computing/University of Waterloo

Davide Gaiotto, Perimeter Institute

Ruth Gregory, Durham University

Alioscia Hamma, Tsinghua University

Lucien Hardy, Perimeter Institute

Matthew Johnson, Perimeter Institute and York University

Paul Langacker, Institute for Advanced Study

Roger Melko, Perimeter Institute and University of Waterloo

David Morrissey, TRIUMF

Andrei Starinets, University of Oxford

Natalia Toro, Perimeter Institute

Neil Turok, Perimeter Institute

Guifre Vidal, Perimeter Institute

Xiao-Gang Wen, Perimeter Institute

Itay Yavin, Perimeter Institute and McMaster University

PHD STUDENTS

Perimeter's PhD program continues to grow, bringing top students not only to Perimeter, but also to the partner universities where they ultimately receive their degrees. Much of the program's growth can be attributed to the pool of highly talented graduates provided by the PSI program. At year's end, Perimeter had 42 PhD students in residence, 25 of whom had received their master's through PSI. Six additional PhD students were supervised by Perimeter associate faculty while in residence at partner universities. During their time at Perimeter, PhD students receive unparalleled opportunities to interact with international scientific leaders and develop their careers in a supportive, collaborative environment. All three students who graduated from partner universities over the last year went on to competitive postdoctoral fellowships.

VISITING GRADUATE FELLOWS

Perimeter's Visiting Graduate Fellows program allows advanced PhD students from around the world to spend several months at the Institute. These young researchers both benefit from and enrich Perimeter's vibrant research community, while interacting with leading researchers in their field at a pivotal time in their training. Perimeter hosted 24 Visiting Graduate Fellows for a total of 26 visits in 2013/14.

UNDERGRADUATE RESEARCH

Perimeter's Undergraduate Student program exposes select undergraduate students to high-level research through two- to four-month projects with Perimeter postdoctoral researchers. The promising young students receive an unparalleled preview of life as a physicist, while the postdoctoral researchers accrue valuable mentoring experience. The program also acts as a means of attracting talent to the Institute. Alumni that have returned to Perimeter include PSI student Emily Adlam, PhD student Dalimil Mazac, and postdoctoral researcher Matteo Smerlak. Over the past year, Perimeter provided research training to eight exceptional undergraduates from top institutions.

RESEARCH EVENTS

BY THE NUMBERS

In 2013/14 …

- Held 17 timely, focused conferences and workshops, attended by more than 800 scientists from around the world
- Partnered on 8 joint workshops and conferences held at Perimeter and sponsored an additional 12 off-site
- Presented 286 scientific talks, available online at **www.perimeterinstitute.ca/video-library**

CONFERENCES, WORKSHOPS, AND SUMMER SCHOOLS

The history of physics is overwhelmingly one of discussion, debate, and collaboration – of brilliant minds approaching difficult problems from disparate angles in order to spur scientific advances. Major breakthroughs in early quantum physics, for example, can be traced to the famous Fifth Solvay Conference in 1927, where 17 of the 29 scientists in attendance already had or would soon receive Nobel Prizes – Einstein, Bohr, Curie, Heisenberg, and Schrödinger among them.

Perimeter's internationally renowned conference program seeks to build on this tradition. The Institute selects only those topics with high potential for stimulating significant outcomes, often at the interfaces where progress is most likely – between different research disciplines, for instance, or between theory and experiment. Perimeter's flexibility also allows it to rapidly identify and capitalize on promising new areas; the Institute is often the first in the world to host a conference on an emerging field or new discovery (see sidebar on the next page about the "Implications of BICEP2" conference).

In 2013/14, Perimeter held 17 conferences and workshops, attended by 844 scientists from around the world. By continuing to choose timely, focused topics that allow for unexpected interactions, Perimeter will continue to accelerate progress and act as a major node of exchange for ground-breaking research.

Participants at "New Ideas in Low-Energy Tests of Fundamental Physics" conference

GRAVITATING TO COLLABORATE

Last March, the Antarctica-based BICEP2 (Background Imaging of Cosmic Extragalactic Polarization) team announced the detection of what appeared to be primordial "B-mode" polarization in the earliest light of the universe, the cosmic microwave background (CMB).

The announcement drew widespread attention because it seemed to provide strong support for inflationary theory – the idea that the universe underwent a period of accelerated expansion in the first trillionth of a trillionth of a trillionth of a second after the big bang. Such explosive expansion would excite gravitational waves from the vacuum, causing spacetime itself to resonate long afterwards – a ripple effect that would potentially be detectable as faint gravitational waves.

Just three weeks after the BICEP2 announcement, Perimeter Institute hosted the world's first international conference on the subject, "Implications of BICEP2." The conference brought together 80 of the world's leading cosmologists, including Perimeter Distinguished Visiting Research Chairs Nima Arkani-Hamed, James Bardeen, and Eva Silverstein.

Among the topics discussed were whether the BICEP2 results reliably pointed toward gravitational waves or whether other factors could have led to the data. One possible explanation – later confirmed by follow-up research – was that the contamination from cosmic dust could have been misidentified as the signature ripples of cosmic inflation.

The conference and subsequent experimental findings mean that a longstanding bet between Perimeter Director Neil Turok and Stephen Hawking – about whether gravitational waves would be detected in the CMB – remains unsettled. Though Hawking initially claimed victory, determining the winner of the wager (for roughly $200) will hinge on data now being acquired by experiments around the world.

SEMINARS AND COLLOQUIA

Perimeter fosters collaboration and knowledge exchange through its scientific talks; over the last year, the Institute hosted 247 seminars and 39 colloquia. Talks were presented by some of the world's most eminent scientists, including Gilles Brassard, co-founder of quantum cryptography; Robbert Dijkgraaf, Director of the Institute for Advanced Study in Princeton; and S. James Gates, Jr., a Perimeter Distinguished Visiting Research Chair and member of President Barack Obama's Council of Advisors on Science and Technology.

ONLINE VIDEO ARCHIVE

Perimeter's searchable and citable video library of more than 10,000 scientific seminars, conferences, workshops, and courses attracted over 75,000 unique visitors from over 170 countries in the past year. The talks can be freely accessed on the Perimeter Institute Recorded Seminar Archive (PIRSA) at www.pirsa.org or directly through the Perimeter Institute website, the latter of which is a new portal for accessing this content made available over the past year. The Institute's video archive continues to be an important knowledge-sharing resource in the global scientific community.

LINKAGES

VISITOR PROGRAM

Discovery is a collaborative effort, and not just for the great minds already working at Perimeter. Throughout the year, Perimeter hosts top scientists from around the world, providing them with the time and space to attend conferences and talks, exchange ideas, and pursue new projects with colleagues.

In 2013/14, Perimeter hosted 424 visiting scientists, for a total of 465 collaboration visits. Guests included 374 short-term visitors, 30 Distinguished Visiting Research Chairs, and eight Visiting Fellows. In addition, 12 long-term Visiting Researchers came to work at Perimeter during leaves (e.g., sabbaticals) from their home institutions. These visits introduce many scientists from around the world to PI's unique environment; some eventually return to stay. In the past year, visits ultimately led to several new appointments, including Perimeter Research Chairs Kevin Costello and Subir Sachdev, as well as Faculty member Asimina Arvanitaki.

DRAWING GLOBAL STRANDS OF SCIENCE TOGETHER

Perimeter has formal partnership agreements with:

Centre for Theoretical Cosmology at the University of Cambridge

Weizmann Institute of Science, Rehovot, Israel

Centro de Fisica do Porto, University of Porto, Portugal

Institute of Mathematical Sciences, Chennai, India

International Centre for Theoretical Physics – South American Institute for Fundamental Research (ICTP-SAIFR), Sao Paulo, Brazil

Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy

International Solvay Institutes, Brussels, Belgium

AFFILIATES

Perimeter's Affiliate program has been crucial to connecting the foundational physics research community across Canada, bringing select researchers from around the country to Perimeter for regular informal visits. Affiliates gain access to an active community of researchers spanning the spectrum of physics, and Perimeter strengthens its connections with more than 25 of Canada's top research centres. In 2013/14, Perimeter appointed four new Affiliates and renewed an additional 16 through 2016, bringing the total number of Affiliates to 120. (Refer to page 70 for a complete list.)

COLLABORATIONS AND PARTNERSHIPS

Collaborations that draw ideas together are woven into the culture of science. Perimeter's partnerships with centres in Canada and worldwide reinforce its role as a global research hub. The Institute's partners range from venerable institutions like the University of Cambridge and the Weizmann Institute of Science in Israel, to emerging centres such as the International Centre for Theoretical Physics in Sao Paulo, Brazil. Closer to home, the Tri-Institute Summer School on Elementary Particles (TRISEP), a two-week summer school in particle physics for graduate students and postdoctoral researchers, is a collaborative partnership between Perimeter, TRIUMF (Canada's national laboratory for particle and nuclear physics), and SNOLAB. Each year, it is held at one of the three centres – the 2015 edition will be at PI.

FIELDS-PERIMETER INSTITUTE AFRICA POSTDOCTORAL FELLOWSHIP

Perimeter partnered with The Fields Institute for Research in Mathematical Sciences at the University of Toronto to fund four one-year joint postdoctoral fellowships for African nationals who have recently completed their PhD. In 2013/14, Perimeter welcomed Dine Ousmane Samary from Benin as the first such fellow, conducting research in quantum gravity. The second fellow, Cyril Batkam of Cameroon, will arrive in fall 2014.

THE WATERLOO GLOBAL SCIENCE INITIATIVE (WGSI)

This independently funded, non-profit partnership between Perimeter Institute and the University of Waterloo promotes dialogue on complex global issues and seeks to advance ideas, opportunities, and strategies for a secure and sustainable future. A key element of this is the Equinox Summit Series, *Equinox Blueprints*, and related impact activities. In 2013/14, the WGSI team hosted the Equinox Summit: Learning 2030, a gathering of delegates from six continents who discussed the shifting needs and opportunities in high school education.

At the World Literacy Summit in Oxford in April 2014, the WGSI team released the *Equinox Blueprint: Learning 2030*, summarizing the Summit's findings and recommendations. An interactive website (learning2030.org) was also launched to allow education communities around the world to share and discuss their stories, challenges, and successes in education reform.

GLOBAL OUTREACH

Perimeter's Global Outreach initiative offers something far more powerful than funding: expertise to support 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 by Perimeter Director Neil Turok in 2003 to establish a network of centres providing advanced mathematical and scientific education to exceptional African graduates.

In 2013/14, Perimeter continued to leverage the expertise of both its research and administrative staff in support of the flourishing AIMS-NEI network. Perimeter helped plan the start-up of both AIMS-Cameroon (launched in February 2014) and AIMS-Tanzania (slated to launch in October 2014). Several Perimeter researchers also taught at AIMS centres, and Perimeter co-hosted a 10th anniversary celebration for AIMS in Ottawa to raise awareness with the Canadian government and other potential supporters.

BUILDING CANADA'S QUANTUM VALLEY

The pace of progress in quantum information is accelerating, as theorists and experimentalists work together to advance our understanding of a technological leap that promises to transform society. The quantum technologies on the horizon will soon become an integral part of our everyday lives, just as large-scale passenger flight went from unimaginable to indispensable in under a century. And the ground-breaking work fuelling this coming revolution is happening here in Canada, with Waterloo's "Quantum Valley" as ground zero.

Perimeter researchers catalyze innovation in this burgeoning industry by investigating the profound technological possibilities of quantum information. They work closely with experimental partners at the nearby Institute for Quantum Computing (IQC) and the Waterloo Institute for Nanotechnology (WIN) to test and prototype devices based on these principles. Progress is rapid, and a vibrant quantum start-up community is emerging, fuelled in part by Quantum Valley Investments (QVI), a breakthrough-focused venture capital firm led by Perimeter Founder Mike Lazaridis.

Together, these elements have created an ecosystem primed to discover, develop, and commercialize breakthroughs, building a quantum industry in Canada.

In the past year alone, Perimeter research has yielded important discoveries. Perimeter Associate Faculty member Roger Melko, graduate student Lauren Hayward, and Subir Sachdev, the James Clerk Maxwell Chair in Theoretical Physics at Perimeter Institute (Visiting), together explained a crucial transition phase to superconductivity – a vital step toward practical superconductivity for a broad range of technological applications. Faculty member Daniel Gottesman achieved new milestones in his research into correcting quantum errors – the primary challenge to overcome on the road toward quantum computing. And in July 2014, an international workshop on quantum error correction brought together top theorists to explore the techniques needed to safeguard and verify information amid the errors inherent to quantum computation.

At the heart of Quantum Valley, Perimeter Institute sparks the research, discovery, and innovation that will shape our new reality.

EDUCATIONAL OUTREACH AND PUBLIC ENGAGEMENT

"Science should be a part of fulfilling society's goals and creating the kind of world we would like to inhabit.… I can think of no better cause than for us to join together to make the 21st century unique as the era of the first Global Enlightenment."

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

Theoretical physics seeks answers to some of humanity's universal questions: What is the universe made of? What are the forces that bind it? How did it begin, and how does it evolve? In seeking answers to these questions, physics discoveries have underpinned technologies that have changed the world, and inevitably will again.

Ultimately, science belongs to everyone. This is why educational outreach and public engagement are central to Perimeter's mission. By sharing the power and excitement of theoretical physics, and connecting it to our shared experience, Perimeter aims to inspire the next generation of scientific explorers and involve the public in the transformational power of science.

More than four million students have been reached through Perimeter's award-winning educational outreach efforts to date – approximately one million in the past year alone, thanks to enhanced programs and distribution. The Institute's many other outreach initiatives – public lectures, festivals, educational networks, and media engagement – are instilling a passion and understanding for physics among more people than ever.

As we push the limits of understanding, we begin to discover the future.

THE INTERNATIONAL SUMMER SCHOOL FOR YOUNG PHYSICISTS (ISSYP)

Every year, the International Summer School for Young Physicists (ISSYP) immerses 40 exceptional high school students in the world of theoretical physics for two intense, fulfilling weeks at Perimeter Institute. This year, the 12th class of ISSYP – evenly split between girls and boys, and between Canadian and international students – learned first-hand from leading scientists, toured research labs, and forged friendships that will last a lifetime. More than 500 students from more than 45 countries have participated in ISSYP since its inception, and more than 70 percent of them credit the program with inspiring them to pursue careers in math and science.

The 2013/14 edition of ISSYP was made possible by the generous support of RBC Foundation. Additional support was provided by the Beatrice Snyder Foundation.

"ISSYP has shown me that no matter how vast the universe is or no matter how small we are, there is nothing more profound and humbling than partaking in a journey for truth."

– Yeorgia Kafkoulis, USA

Participants at ISSYP 2014

"Not only did I meet like-minded people, but the resources and experts are of such high calibre, I'm in awe. I'm leaving inspired, full of knowledge and food, and my arms are full of their amazing resources. They really take care of everything to the smallest, quantum detail."

– Louis Cheng,
Connect Charter School, Calgary, Alberta

"It completely changed the way I teach physics; it was inspiring and motivating. I feel that being at Perimeter Institute's EinsteinPlus is truly an investment in my professional teaching career. I continue to share my experiences with the hope of inspiring and motivating some of the teachers back home while continuing to inspire my physics students."

– Olga Michalopoulos,
Georgetown District High School, Halton Hills, Ontario

TEACHER NETWORK AND ON-LOCATION WORKSHOPS

The Perimeter Teacher Network, made up of more than 50 teachers across Ontario and Canada, equips educators with classroom resources and new techniques to share modern science with students. Network members are trained by Outreach staff and go on to conduct resource training workshops in their home districts, using Perimeter in-class resources. This past year, members of the Teacher Network delivered 90 workshops to more than 2,000 educators across Canada, ultimately reaching 150,000 students with cutting-edge STEM (science, technology, engineering, and mathematics) education.

Outreach staff also delivered 18 on-location workshops at teacher conferences in Canada and abroad, reaching more than 1,000 educators. Over the past year in particular, Perimeter's Outreach team has engaged grade 9 and 10 teachers by expanding the Institute's resources to include younger students.

IN-CLASS RESOURCES

Perimeter seeks to inspire the next generation of scientific explorers through high-quality in-class materials aimed at introducing high school students to physics. In 2013/14, Perimeter's Outreach team created *Perimeter Inspirations: The Expanding Universe*, which takes students through topics like the big bang, emission spectra, the cosmic microwave background radiation, and more. Perimeter's collection of teaching kits has already reached four million students across Canada. The program's international reach was further extended to students across the United Kingdom thanks to a new partnership with the Institute of Physics. The kits encourage hands-on engagement in physics and aim to spark a passion in students for STEM subjects (science, technology, engineering, and math).

In addition to these in-class resources and activities, Perimeter gave 18 Physica Phantastica presentations – connecting foundational science to the cutting-edge technologies it makes possible – reaching over 5,500 students across Canada.

The production of the new Inspirations *module was supported by The Cowan Foundation.*

BRAINSTEM: YOUR FUTURE IS NOW

The BrainSTEM initiative – designed to foster 21st century STEM skills and entrepreneurial thinking among youth – engaged millions during the fall of 2013. More than 400,000 students in classrooms, 25,000 parents and children, and 1.5 million TV/online viewers got involved in the suite of BrainSTEM activities and products. These included *Career Moves: Skills for the Journey* (a new classroom educational kit), training workshops, and the BrainSTEM: Your Future is Now Festival, a science and discovery event that celebrated emerging technologies and the entrepreneurial spirit that will drive innovation and prosperity in the 21st century.

The BrainSTEM: Your Future is Now Festival was supported by the Federal Economic Development Agency for Southern Ontario (FedDev) and TVO. Additional support was provided by Sun Life Financial, Linamar, The Waterloo Region Record Community Partnerships Program, and Toyota Motor Manufacturing Canada Inc.

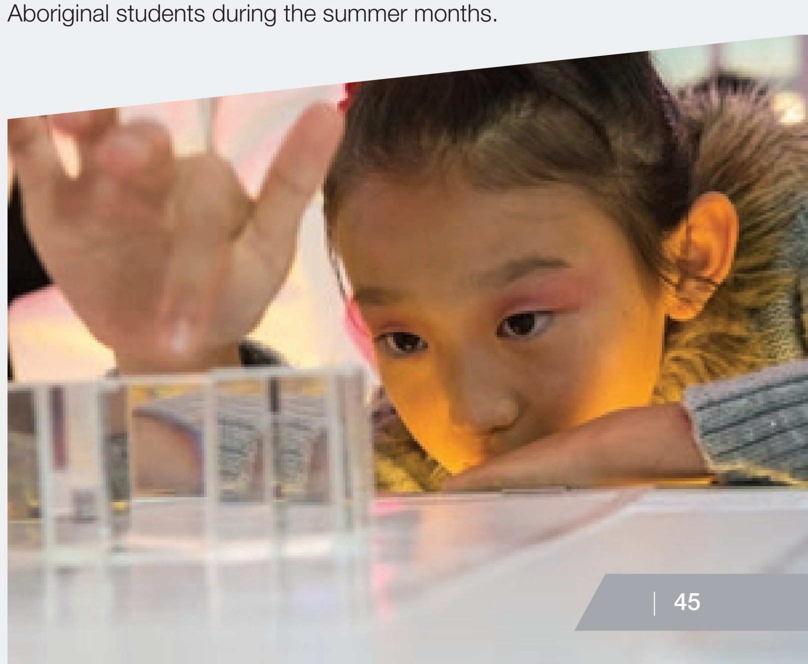
PUBLIC LECTURES

The public's fascination with science is driven home every time Perimeter issues tickets to its Public Lecture Series, presented by Sun Life Financial – the free tickets are snapped up in minutes. In the past year, Perimeter hosted 10 public lectures covering topics like quantum mechanics, black holes, dark matter, space exploration, and more, all tailored to a general audience. The June 2014 talk by S. James Gates, Jr. was webcast live – a pilot project for online streaming since adopted for all lectures, enabling them to reach wider audiences than ever before. The series also featured talks by theoretical astrophysicist Avery Broderick and laser physics expert Edward Moses, as well as a panel discussion in which emerging scientists discussed the future of physics, presented in conjunction with *Maclean's* magazine and moderated by journalist Kate Lunau.

The 2013/14 Perimeter Institute Public Lecture Series was presented by Sun Life Financial. Perimeter is grateful that Sun Life has renewed their support for the 2014/15 season.

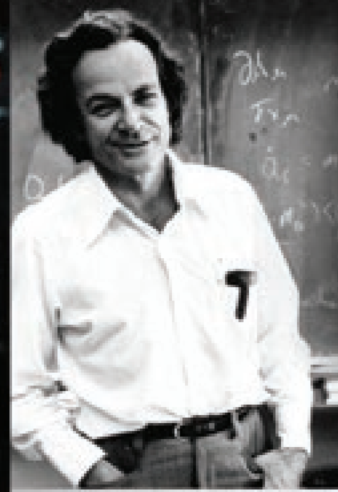
ABORIGINAL ENGAGEMENT

In 2013/14, Perimeter continued its partnership with Actua, one of Canada's leading STEM outreach organizations for youth, particularly among Aboriginal Canadians. Perimeter Outreach staff trained Actua associates from across the country on Perimeter resources and the Actua associates then delivered the content to Aboriginal students during the summer months.



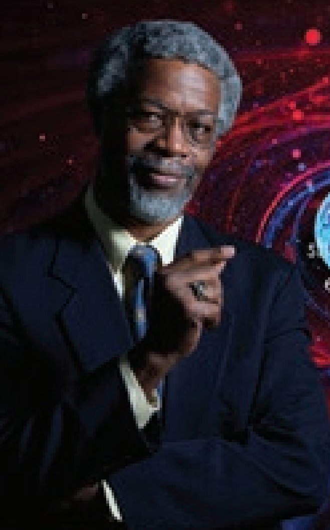
SLICE OF PI TEACHERS WHO INSPIRED GREAT SCIENTISTS

Stephen Hawking, at age 14, was inspired by his teacher Dikran Tahta to do "mathematics, more mathematics, and physics." Tahta's 2007 obituary in *The Guardian* said he "inspired love and an increase of intellectual energy in everyone who came within his ambit."



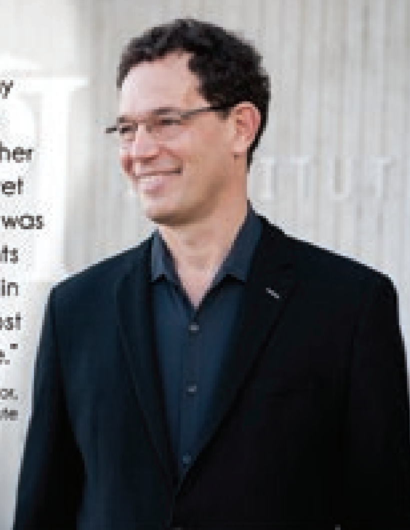
"Dear Mr. Bader: You certainly knew how to stretch a young boy's mind to the utmost of achievement ... and knew how to handle (excuse my immodesty) an exceptional student."

- Letter from Richard Feynman to high school physics teacher Abram Bader



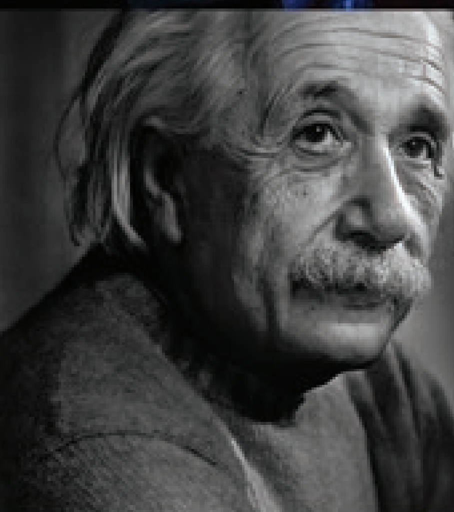
"When I was a student at Jones High School, my physics teacher wrote an equation on the blackboard and then performed a very simple experiment — rolling a ball down an inclined plane. He showed that what I saw there in front of my eyes was described by the mathematical equation he had written on the blackboard. This was, and is, the closest thing I have ever seen to magic."

- Sylvester James Gates Jr., Distinguished Visiting Research Chair, Perimeter Institute



"Miss Margaret Carnie, my grade school teacher in Tanzania, had devoted her life to teaching. The secret of Margaret's approach was not to instruct her students but to gently point them in interesting directions. Most of all, she believed in me."

- Neil Turok, Director, Perimeter Institute



"No one has ever wanted to know who was my teacher, who showed me the way to the higher mathematical science, thought, and research. I simply say that my teacher was the unrivalled Greek Konstantinos Karatheodoris, to whom we owe everything."

- Albert Einstein

"His name was Henry Tillott ... and he had come out of retirement for a second time to teach us. He encouraged us. He let me have the run of the physics laboratory out of hours. He was a really good teacher and showed me, actually, how easy physics was."

- Jocelyn Bell Burnell, discoverer of pulsars, on her high school physics teacher

"I learned a lot about the universe from Stephen (Hawking), but I believe I learned even more about spirit. He taught me as much about courage and humility as he did about black holes and quantum mechanics. It's a debt I fear I'll never be able to repay."

- Raymond Laflamme, Director, Institute for Quantum Computing, University of Waterloo

"Mr. Ledger's classroom was an amazing atmosphere that wasn't replicated for me until well into my college years. At a very truly fundamental level, it started me off in the sort of frame of mind that I keep and carry with me today."

- Nima Arkani-Hamed, theoretical physicist, on his Grade 4 teacher Charles Ledger

CULTURAL EVENTS

Art and science share natural symmetries, each pushing us to move beyond what is known to explore what is possible. This is evident not just in the artistic extracurricular efforts of our researchers, but in the strong support for Perimeter's cultural events. These concerts complement the Institute's research and outreach activities, and connect with the community at large. Made possible through paid ticketing and private support, last year's concerts featured Apollo's Fire (The Cleveland Baroque), pianists Andrew Von Oeyen and Jean-Philippe Collard, and cellist Christian Poltéra.

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

MEDIA COVERAGE

Perimeter shares the excitement of theoretical physics with major media around the world, and the Institute has become a go-to source of insight, commentary, and high-quality content related to theoretical physics. In the past year, the Institute received major coverage in national and international media, including articles, videos, and editorials in *Maclean's*, *Scientific American*, *WIRED*, *The Globe and Mail*, *Nature*, *New Scientist*, *The Wall Street Journal*, *Physics World*, BBC News, *The Guardian*, *National Geographic*, Buzzfeed, *Quanta Magazine*, *Forbes*, *Discovery News*, CBC, and more.

DIGITAL AND SOCIAL MEDIA OUTREACH

Perimeter aims to be the leading source of fascinating, accurate physics content online. During 2013/14, Perimeter substantially increased its digital and social media outreach efforts. The Institute's Facebook and Twitter channels roughly doubled their follower bases in the past year, and creative new videos on PI science attracted hundreds of thousands of views. New digital creations like the monthly Slice of PI – fun, shareable memes, infographics, and videos – are attracting large new online audiences to Perimeter science content.

A great teacher can change the world. In celebration of UNESCO World Teachers' Day, Perimeter Institute's "Slice of PI" shared reflections from some of the world's greatest physicists, past and present, on the teachers who inspired them.

BRAINSTEM: YOUR FUTURE IS NOW

A wisecracking robot, mind-controlled electronics, and an invisibility cloak – once the stuff of science fiction, these and other high-tech innovations wowed visitors to the BrainSTEM: Your Future is Now Festival in fall 2013.

More than 25,000 scientific explorers of all ages (including 2,500 students who arrived by the busload from around Ontario) visited Perimeter during the week-long festival, which showcased how a passion for STEM subjects (science, technology, engineering, and mathematics), combined with entrepreneurial drive, will equip today's youth to build a more prosperous future.

The festival featured a series of sold-out public lectures that highlighted the themes of discovery, innovation, and imagination. James Grime demonstrated an original World War II Enigma Machine and explained how the English genius Alan Turing cracked its seemingly unbreakable code. Raymond Laflamme, a founding Perimeter researcher and Executive Director of the Institute for Quantum Computing, shared how scientists are harnessing the forces of quantum mechanics to build new technologies of unprecedented power. Journalist and author Lucy Hawking, daughter of Perimeter Distinguished Visiting Research Chair Stephen Hawking, urged young people to use their imaginations to build a better future for humankind.

"The goal of BrainSTEM was to share the amazing things that can happen when curiosity and exploration meet imagination and an entrepreneurial spirit," said Greg Dick, Perimeter's Director of Educational Outreach. "Judging by the enthusiastic participation of students and families, the future seems very bright for science, education, and innovation."

The BrainSTEM: Your Future is Now Festival was supported by the Federal Economic Development Agency for Southern Ontario (FedDev) and TVO. Additional support was provided by Sun Life Financial, Linamar, The Waterloo Region Record Community Partnerships Program, and Toyota Motor Manufacturing Canada Inc.

ADVANCING PERIMETER'S MISSION

"We are delighted each time we receive a letter or email from students who attended Perimeter's International Summer School for Young Physicists. These high school students come from around the world to share their passion for physics, and they get to learn from the best. It makes us proud to be involved, to support their dreams, and to perhaps lead to breakthrough discoveries that one day might benefit us all."

– Shari Austin, Vice President, Corporate Citizenship and Executive Director, RBC Foundation

Science breakthroughs are made through a combination of intellect, imagination, and inspiration. At Perimeter Institute, these are the same qualities that drive our valued supporters.

Perimeter is a collaborative entity, in every sense. A non-profit research institute and a registered charity, Perimeter's operations are funded through a combination of government and foundation grants, and corporate and private donations.

Together, we are partners in the pursuit of world-leading scientific inquiry. Our donors, friends, and champions understand that today's fundamental discoveries will power tomorrow's technological and medical advances.

Contributions big and small are powering outstanding science, and enabling great leaps in human understanding.

PERIMETER INSTITUTE LEADERSHIP COUNCIL

The 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 (Council Co-Chair)
Founder and Board Chair, 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

Alexandra (Alex) Brown
President, AprilAge Inc.

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

Savvas Chamberlain
CEO and Chairman, Exel Research Inc.

Jim Cooper
President and CEO, Maplesoft

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

Jon Dellandrea
President and CEO, Sunnybrook Foundation

Arlene Dickinson
CEO, Venture Communications Ltd.

Ginny Dybenko
Executive Director – Stratford Campus, University of Waterloo

H. Garfield Emerson
Principal, Emerson Advisory

Edward S. Goldenberg
Partner, Bennett Jones LLP

Tim Jackson
Lead Executive, MaRS Centre for Impact Investing

Tom Jenkins
Chairman, OpenText

Farsad Kiani
President and CEO, Ensil Canada Ltd.

Carol A. Lee
Co-Founder and CEO, Linacare Cosmetherapy Inc.

Michael Lee-Chin
Executive Chairman and CEO, Portland Investment Counsel Inc.

Patrice E. Merrin
Director, Glencore PLC and Stillwater Mining Company

Gerry Remers
President and COO, Christie Digital Systems Canada Inc.

Bruce M. Rothney
President and Country Head, Barclays Capital Canada Inc.

Maureen J. Sabia
Chairman of the Board, Canadian Tire Corporation Ltd.

Kevin Shea
Chair, Ontario Media Development Corporation

Harry Zarek
President and CEO, Compugen

THE RIGHT PLACE, THE RIGHT TIME

At an event in Toronto, Robert Krembil was fascinated to hear Perimeter Director Neil Turok speak about the wonders of quantum science, and motivated by Perimeter Founder Mike Lazaridis about the game-changing potential of quantum technologies.

During a subsequent visit to Perimeter, he and his son Mark, President of the Krembil Foundation, met Stephen Hawking – an encounter that galvanized their desire to support theoretical physics research.

Investing in theoretical physics at Perimeter, they realized, would be another valuable way to enrich the intellectual capital of Canada and foster breakthroughs.

"Who wouldn't want to get involved with an endeavour like that?" says Robert Krembil.

In 2013, the Krembil Foundation made a visionary investment of $4 million (matched by $4 million from Perimeter) to fuel the research of two extraordinary scientists: Davide Gaiotto and Kevin Costello, who explore the vital intersections of mathematics and physics.

Davide Gaiotto holds the Krembil Galileo Galilei Chair in Theoretical Physics and Kevin Costello holds the Krembil William Rowan Hamilton Chair in Theoretical Physics.

"We see this as an intellectual and educational investment that will benefit all Canadians," says Mark Krembil. "Canada is the right place, and this is the right time for this remarkable scientific endeavour to happen."

CELEBRATING A LEGACY, BUILDING THE FUTURE

Emmy Noether was a pioneer of abstract algebra, a thinker so brilliant that Albert Einstein called her the "most important woman in the history of mathematics." Yet Noether's legacy goes far beyond connecting the laws of conservation with symmetries in other laws of nature: She also refused to accept that, as a woman, she should not join the pursuit of knowledge.

Today, Perimeter Institute's Emmy Noether Visiting Fellowship Program supports female physicists from around the world as they pursue research within PI's dynamic environment. It is one of Perimeter's initiatives to support women in physics, a mission supported by the Emmy Noether Council (see below) and donors to the Emmy Noether Circle.

It is essential support, says Catherine Pépin, a French condensed matter physicist and one of five Emmy Noether Fellows for 2014/15. Despite the example set by Noether and other female pioneers of science, Pépin says, "It is still difficult for women to be extremely competitive with men."

"Prizes and excellence grants for women who deserve it are absolutely necessary," she says. "This program is a formidable opportunity for a European scientist to get some long-lasting involvement and collaborations with the North American community."

The Emmy Noether Council is a group of volunteers that provides expertise, donations and other support to help drive the Emmy Noether Circle and increase the number of women in physics and mathematical physics at Perimeter.

Patrice E. Merrin (Council Co-Chair)
Director, Glencore PLC and Stillwater Mining Company

Jennifer Scully-Lerner (Council Co-Chair)
Vice President – Private Wealth Management, Goldman Sachs

Nyla Ahmad
Vice President – Incubation, Rogers Communications Inc.

Katherine Barr
General Partner, Mohr Davidow Ventures

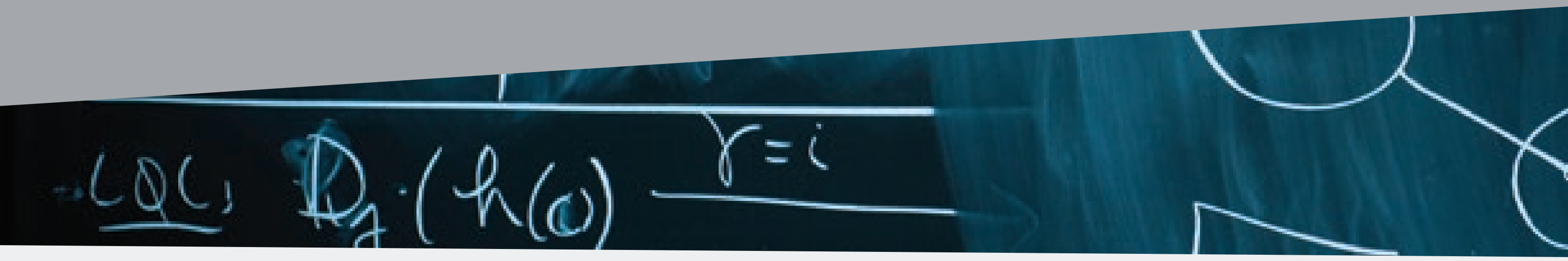
Michelle Osry
Partner – Canadian Business Family Advisory and BC Real Estate, Deloitte Canada

Vicki Saunders
Founder, SheEO

Sherry Shannon-Vanstone
President and CEO, TrustPoint Innovation Technologies

Suzan Snaggs-Wilson
Community Manager, Scotiabank

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 and 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 to 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), comprised of eminent international scientists, offers independent scrutiny and advice, helping to ensure objectivity and a high standard of excellence in all of Perimeter's activities.

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.

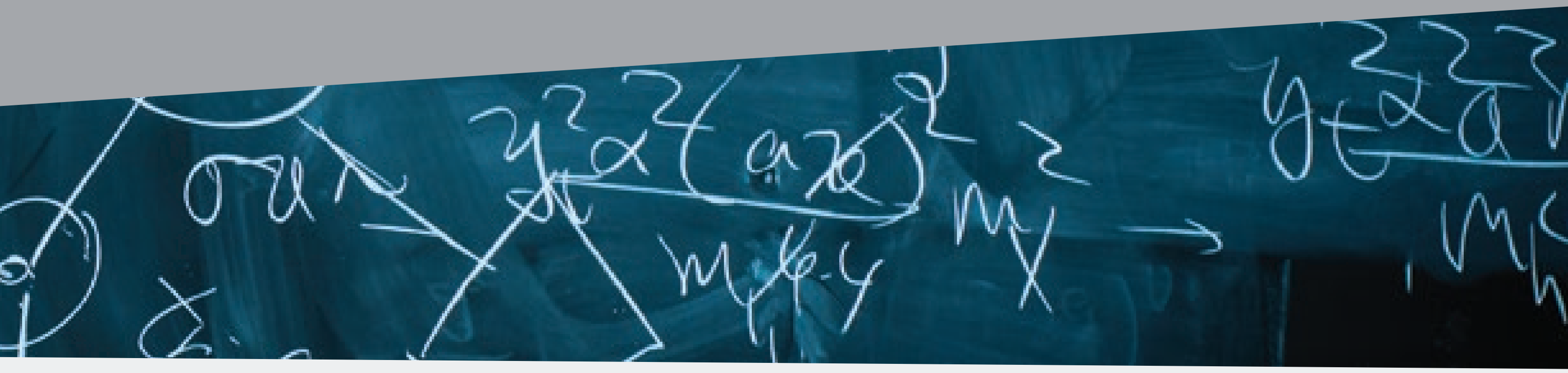
In 1984, Mr. Lazaridis co-founded BlackBerry (formerly Research In Motion) with Mr. Fregin. They invented the BlackBerry device, created the smartphone industry, and built Canada's largest global tech business. Mr. Lazaridis served in various positions including Co-Chairman and Co-CEO (1984-2012) and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



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.

Joanne Cuthbertson, LL.D., was the first elected Chair of EducationMatters (Calgary's unique public education trust), founder of SPEAK (Support Public Education – Act for Kids), and a recipient of the Calgary Award (Education). She is Chancellor Emeritus of the University of Calgary, Co-Chair of the Scholars' Academy she established upon retirement, and Dean's Circle Chair in the Faculty of Environmental Design. Ms. Cuthbertson serves as a Fellow of Glenbow Museum and as Director of the Alberta Bone & Joint Health Institute, and she is a Queen Elizabeth II Diamond Jubilee Medal recipient.

Peter Godsoe, O.C., O.Ont., is the former Chairman and 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.

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.

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.

Michael Serbinis is the Founder and CEO of LEAGUE, a new digital health start-up launching in 2015. He is a leader known as a visionary entrepreneur who has built several transformative technology platforms across industries. Mr. Serbinis was the Founder and CEO of Kobo, a digital reading company that burst onto the publishing scene in 2009, driving $110 million in sales in its very first year and becoming the only global competitor to Amazon's Kindle with 20 million customers in 190 countries. He is currently the Founder of Three Angels Capital, a member of the Board of Trustees at the Ontario Science Centre, and a member of YPO. He holds a BSc in engineering physics from Queen's University and an MSc in industrial engineering from the University of Toronto.

SCIENTIFIC ADVISORY COMMITTEE

Perimeter Institute's Scientific Advisory Committee (SAC) provides key support in achieving the Institute's strategic research objectives, particularly in the area of recruitment.

Renate Loll, Radboud University, Nijmegen (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.

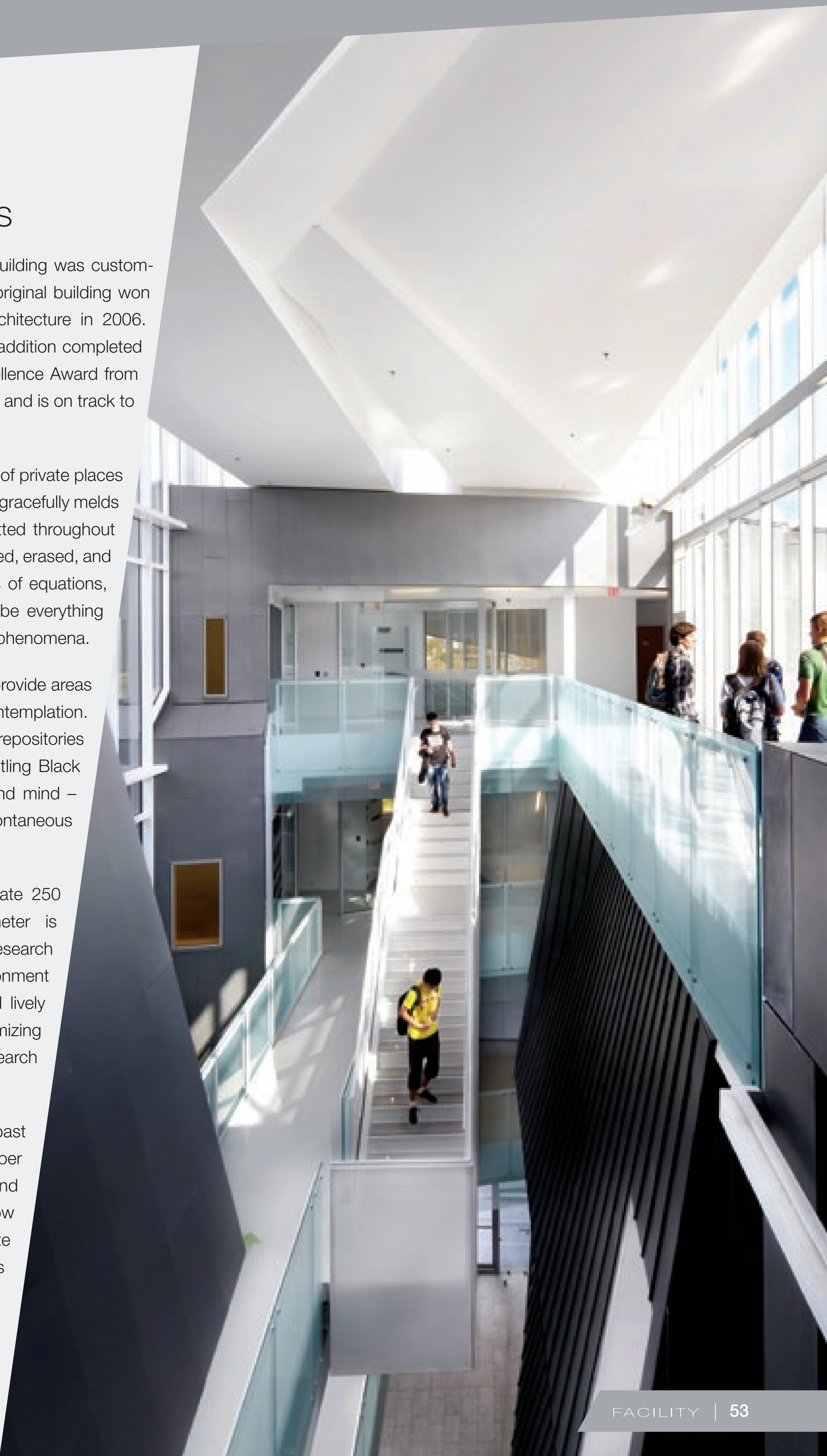
Ganapathy Baskaran, Institute of Mathematical Sciences, Chennai (2013-Present)

Professor Baskaran is an Emeritus Professor at the Institute of Mathematical Sciences, Chennai in India, where he recently founded the Quantum Science Centre. He has made important contributions to the field of strongly correlated quantum matter. His primary research focus is novel emergent quantum phenomena in matter, including biological ones. He is well known for his contributions to the theory of high temperature superconductivity and for discovering emergent gauge fields in strongly correlated electron systems. He predicted p-wave superconductivity in Sr_2RuO_4, a system believed to support Majorana fermion mode, which is a popular qubit for topological quantum computation. In recent work, he predicted room temperature superconductivity in optimally doped graphene. From 1976 to 2006, Dr. Baskaran contributed substantially to the Abdus Salam International Centre for Theoretical Physics in Trieste, Italy. He is a past recipient of the S.S. Bhatnagar Award from the Indian Council of Scientific and Industrial Research (1990); the Alfred Kasler ICTP Prize (1983); Fellowships of the Indian Academy of Sciences (1988), the Indian National Science Academy (1991), and the Third World Academy of Sciences (2008); and the Distinguished Alumni Award of the Indian Institute of Science, Bangalore (2008).

Mark Wise, California Institute of Technology (2013-Present)

Professor Wise is the John A. McCone Professor of High Energy Physics at the California Institute of Technology. He has conducted research in elementary particle physics and cosmology, and shared the 2001 Sakurai Prize for Theoretical Particle Physics for the development of the "Heavy Quark Effective Theory" (HQET), a mathematical formalism that enables physicists to make predictions about otherwise intractable problems in the theory of the strong interactions of quarks. He has also published work on mathematical models for finance and risk assessment. Dr. Wise is a past Sloan Research Fellow, a Fellow of the American Physical Society, and a member of the American Academy of Arts and Sciences and of the National Academy of Sciences.

FACILITY



DESIGN THAT WORKS

Perimeter's iconic, award-winning building was custom-designed to inspire big ideas. The original building won a Governor General's Medal in Architecture in 2006. The Stephen Hawking Centre – an addition completed in 2011 – won a 2012 Design Excellence Award from the Ontario Association of Architects and is on track to attain LEED Silver Certification.

Made up of a carefully curated array of private places and collaborative spaces, the facility gracefully melds form and function. Blackboards dotted throughout the three levels are perpetually covered, erased, and re-covered in evolving permutations of equations, formulae, and diagrams that describe everything from subatomic particles to cosmic phenomena.

Quiet nooks, lounges, and alcoves provide areas for small meetings and secluded contemplation. The two-storey library houses vast repositories of physics knowledge, and the bustling Black Hole Bistro nourishes both body and mind – providing the perfect venue for spontaneous discussions and working lunches.

With enough space to accommodate 250 researchers and students, Perimeter is the largest theoretical physics research centre in the world. It is an environment that encourages deep thinking and lively exchanges of ideas. By maximizing innovative spaces, we maximize research productivity.

This has not gone unnoticed. In the past year, Perimeter has welcomed a number of delegations, from universities and corporations, seeking to learn how to effectively use space to generate creativity and momentum. Perimeter's combination of innovative design and use stands as a leading example of a research facility that works.

FINANCIALS

RESULTS OF OPERATIONS

Perimeter Institute strengthened its financial positon in the 2013/14 fiscal year, remaining firmly on track to achieve its long-term vision.

The Institute continued to spend strategically on its core mission, with strategic recruitment of research faculty and advancing fundamental research as major priorities. In keeping with Perimeter's growth plans, research expenditure increased by more than five percent.

Perimeter's research training programs accounted for approximately nine percent of annual expenditures. Its core programs – Perimeter Scholars International (the Institute's master's program, a collaboration with the University of Waterloo) and the PhD program (in partnership with a number of Ontario universities) – remained intact and attracted a number of highly talented graduates from around the world. These innovative programs not only train the next generation of leading physicists, but also provide highly skilled problem solvers and creative thinkers to the wider innovation ecosystem.

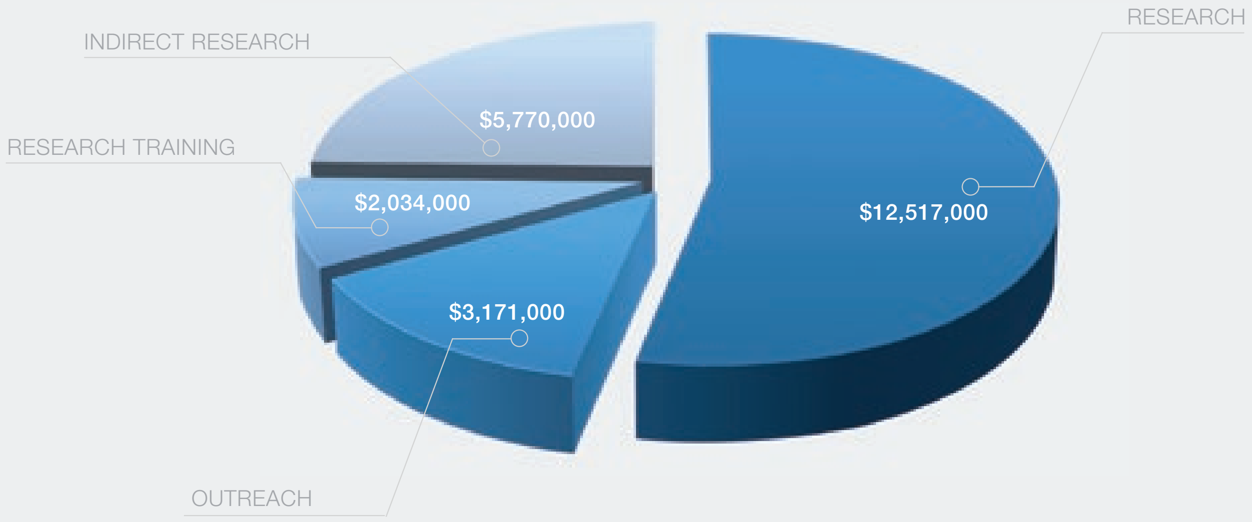
Outreach remained a key component of Perimeter's mission in 2013/14. The Institute once again strategically invested over 13 percent of its annual expenditures in inspirational programs and products for students, teachers, and the general public.

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, demonstrating effective cost management while maintaining a world-class research centre. 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 2013/14 fiscal year with revenues exceeding expenditures by $36 million. This excess can be fully attributed to investment returns which exceeded 17 percent. Returns such as these are prudently managed to further enhance the Institute's long-term financial sustainability.

OPERATING EXPENDITURE SUMMARY

For the year ended July 31, 2014



FINANCIAL POSITION

Perimeter Institute strengthened its working capital position. This position provides the Institute with near-term flexibility whereby it can react to targeted 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 $264 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

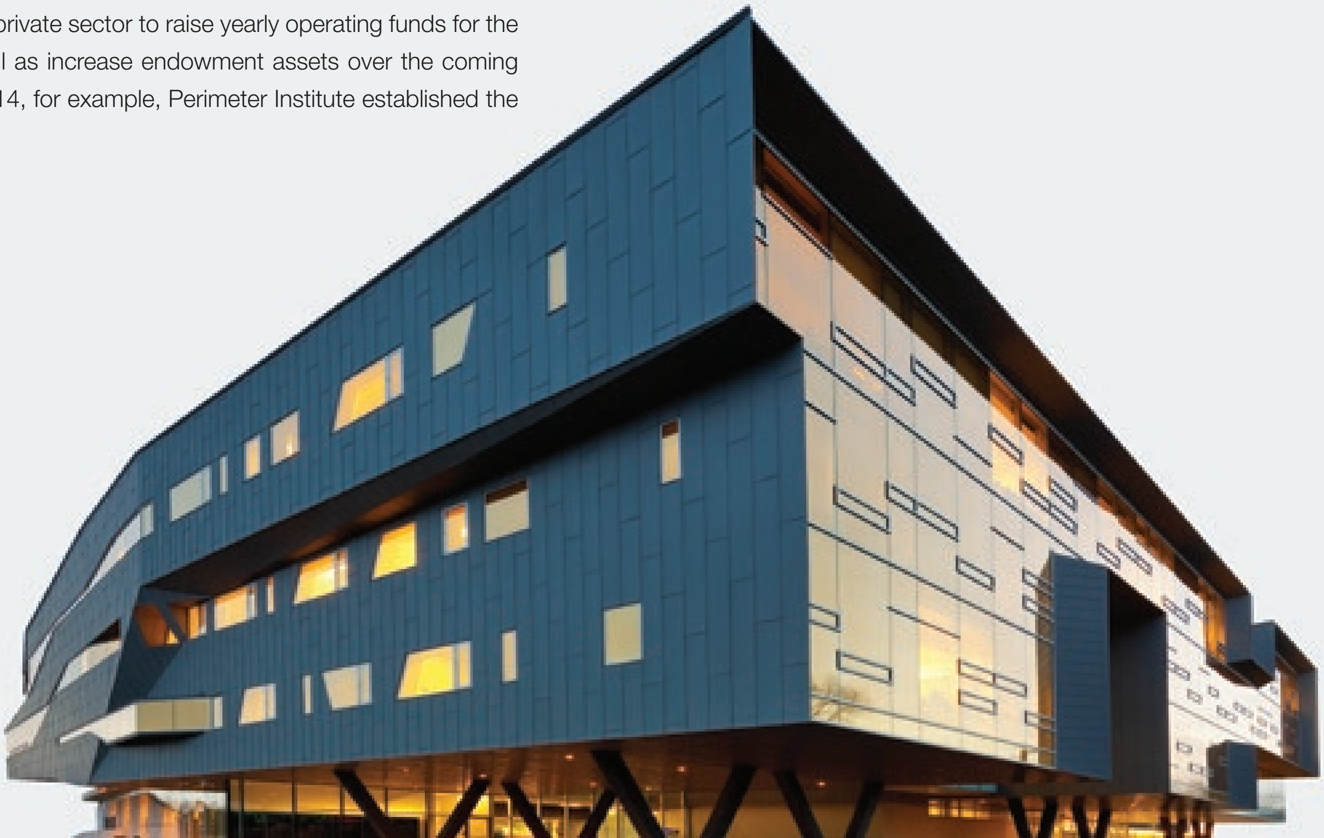
Perimeter Institute exists through a cooperative and highly successful public-private partnership that provides for ongoing operations while safeguarding future opportunities.

Funding commitments of $50 million from the federal government and $50 million from the provincial government (both up for renewal in 2017) 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 an excellent and strategic government investment; however, no guarantee of future funding beyond the above commitment exists.

Perimeter Institute is innovatively seeking to expand its sources of funds from the private sector to raise yearly operating funds for the Institute, as well as increase endowment assets over the coming years. In 2013/14, for example, Perimeter Institute established the Emmy Noether Circle and Emmy Noether Council to foster and support female physicists.

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.



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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, 2014 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, 2014. We expressed an unmodified audit opinion on those financial statements in our report dated December 12, 2014. 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, 2014 are a fair summary of those financial statements, in accordance with Canadian accounting standards for not-for-profit organizations.

Zeifmans LLP

Toronto, Ontario
December 12, 2014

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, 2014

	2014	2013
ASSETS		
Current assets:		
Cash and cash equivalents	$ 15,958,000	$ 11,774,000
Marketable securities	264,333,000	232,514,000
Government grants receivable	5,680,000	2,321,000
Other current assets	809,000	1,599,000
	286,780,000	248,208,000
Property and equipment	49,457,000	52,808,000
TOTAL ASSETS	$ 336,237,000	$ 301,016,000
LIABILITIES AND FUND BALANCE		
Current liabilities:		
Accounts payable and other current liabilities	1,692,000	2,487,000
TOTAL LIABILITIES	$ 1,692,000	$ 2,487,000
Fund balances:		
Invested in capital assets	49,974,000	52,319,000
Externally restricted	121,873,000	126,801,000
Internally restricted	78,840,000	78,840,000
Unrestricted	83,858,000	40,569,000
TOTAL FUND BALANCES	334,545,000	298,529,000
	$ 336,237,000	$ 301,016,000

ZEIFMANS LLP Chartered Accountants

PERIMETER INSTITUTE

SUMMARIZED STATEMENT OF OPERATIONS AND CHANGES IN FUND BALANCES

FOR THE YEAR ENDED JULY 31, 2014

	2014	2013
Revenue:		
Government grants	$ 19,526,000	$ 23,837,000
Other income	1,424,000	1,446,000
Donations	761,000	909,000
	21,711,000	26,192,000
Expenditures:		
Research	12,517,000	11,913,000
Research training	2,034,000	1,983,000
Outreach and science communications	3,171,000	3,080,000
Indirect research and operations	5,770,000	5,697,000
	23,492,000	22,673,000
Excess of revenue over expenditures (expenditures over revenue) before investment and amortization impacts	(1,781,000)	3,519,000
Amortization	(3,838,000)	(4,129,000)
Investment income	41,635,000	29,372,000
Excess of revenue over expenditures	36,016,000	28,762,000
Fund balances, beginning of year	298,529,000	269,767,000
Fund balances, end of year	$ 334,545,000	$ 298,529,000

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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 second-to-none research opportunities, 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 researchers, facilitating researcher engagement with experimental and observational centres, attracting and training brilliant young graduate students through the PSI program and retaining the best for further PhD studies, and providing research training opportunities to promising graduate and undergraduate students on a visiting basis.

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 partnerships, while fostering research interaction opportunities between Perimeter researchers and affiliates across the country.

Host timely, focused conferences, workshops, seminars, and courses on cutting-edge topics, making the majority freely available online for the broader scientific community.

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 in Canada and abroad.

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.

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. 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 at 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 five centres – in South Africa, Senegal, Ghana, Cameroon, and Tanzania – 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 after postdoctoral positions at Harvard University and the Princeton Center for Theoretical Science. 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, the University of Manchester, Columbia University, the University of California, Riverside, the Max Planck Institute, and elsewhere. In 2014, he received a Sloan Research Fellowship.

Asimina Arvanitaki (PhD Stanford University, 2008) joined Perimeter's faculty in March 2014. She previously held research positions at the Lawrence Berkeley National Laboratory at the University of California, Berkeley (2008-11), and the Stanford Institute for Theoretical Physics at Stanford University (2011-14). Arvanitaki is a particle physicist who specializes in designing new experiments to test fundamental theories beyond the Standard Model. She pioneered the use of optically levitated dielectric objects to detect gravitational waves. Arvanitaki also works on theoretical challenges raised by experimental results, such as a model of particle physics influenced by string theory called "split SUSY."

Latham Boyle (PhD Princeton University, 2006) joined the Institute'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), the Herzberg Medal (2012), and a New Horizons in Physics Prize from the Fundamental Physics Prize Foundation (2014).

Bianca Dittrich (PhD Max Planck Institute for Gravitational Physics, 2005) joined Perimeter's faculty in 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. Dittrich has received the Otto Hahn Medal of the Max Planck Society, which recognizes outstanding young scientists, and an Early Researcher Award from the Province of Ontario.

Laurent Freidel (PhD L'École Normale Supérieure de Lyon, 1994) joined Perimeter Institute in 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 2012 and holds the Krembil Galileo Galilei Chair in Theoretical Physics. 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 (2013).

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 45 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).

Subir Sachdev (PhD Harvard University, 1985) became the James Clerk Maxwell Chair in Theoretical Physics at Perimeter Institute (Visiting) in February 2014. He has been a Professor of Physics at Harvard University since 2005. Sachdev has made prolific contributions to quantum condensed matter physics, including research on quantum phase transitions and their application to correlated electron materials like high-temperature superconductors, and he authored the seminal book, *Quantum Phase Transitions*. In recent years, he has exploited a remarkable connection between the electronic properties of materials near a quantum phase transition and the quantum theory of black holes. Sachdev's previous honours include an Alfred P. Sloan Foundation Fellowship and a John Simon Guggenheim Memorial Foundation Fellowship. He is a Fellow of the American Physical Society and a member of the U.S. National Academy of Sciences, and he was a Perimeter Distinguished Visiting Research Chair from 2009 to 2014.

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 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. He was also involved in the start-up phase of the major Hyper-Suprime Cam project at the Hawaii-based Subaru telescope. Smith has achieved several landmark results, including the first detection of gravitational lensing in the cosmic microwave background (CMB) radiation. He holds a second PhD in mathematics from the University of Michigan.

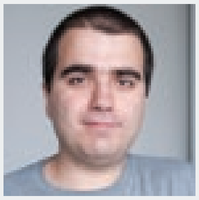
Lee Smolin (PhD Harvard University, 1979) is one of Perimeter Institute's founding faculty members. Prior to joining Perimeter, Smolin held research positions at the Institute for Advanced Study, the Institute for Theoretical Physics at the University of California, Santa Barbara, the Enrico Fermi Institute 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 6,500 citations to date and he has written or co-written five 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 and is 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.

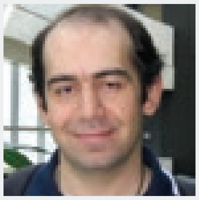
Pedro Vieira (PhD École Normale Supérieure Paris and the Theoretical Physics Center at University of Porto, 2008) joined Perimeter in 2009 from the Max Planck Institute for Gravitational Physics (Albert Einstein Institute), where he was a Junior Scientist from 2008 to 2009. Vieira's research concerns 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.



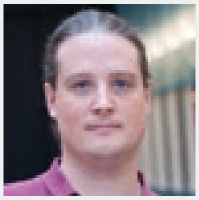
Xiao-Gang Wen (PhD Princeton University, 1987) joined Perimeter's faculty in 2012 as the BMO Financial Group Isaac Newton Chair in Theoretical Physics. Widely recognized as one of the world's leaders in condensed matter theory, he pioneered the new paradigm of quantum topological order, used to describe 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.

Raffi Budakian (PhD University of California, Los Angeles, 2000) joined Perimeter in June 2014, jointly appointed with the Institute for Quantum Computing (IQC) at the University of Waterloo. He also holds the Nanotechnology Endowed Chair in Superconductivity at IQC and the Waterloo Institute for Nanotechnology (WIN). Budakian comes to Waterloo from the University of Illinois at Urbana-Champaign. Prior to joining the faculty there, he held research positions at the University of California, Los Angeles, and the IBM Almaden Research Center in San Jose. Budakian is an experimental condensed matter physicist whose research focuses on developing ultra-sensitive spin detection techniques for single spin imaging and quantum readout. In 2005, Budakian won a World Technology Award for his work in the detection and manipulation of quantum spins.

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 previously 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).

James Forrest (PhD University of Guelph, 1994) joined Perimeter in February 2014 as the Institute's Academic Programs Director and an associate faculty member. He is jointly appointed at the University of Waterloo, where he's been a professor since 2000. His research focuses on the physics of soft matter on the nanoscale, with particular emphasis on polymers and proteins, glass transition in confined geometry, and surface and interfacial properties of polymers. Among his many honours, Forrest is a Fellow of the American Physical Society and co-recipient of the 2013 Brockhouse Medal of the Canadian Association of Physicists.

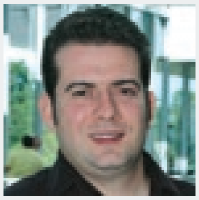
Matthew Johnson (PhD University of California, Santa Cruz, 2007) began a joint appointment with Perimeter and York University in 2012. Prior to that, he was a Moore Postdoctoral Scholar at the California Institute of Technology and a postdoctoral researcher at Perimeter. Johnson is a cosmologist, whose 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 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.

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James Forrest

Director of Advancement
Maria Antonakos

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 Information Technology
Ben Davies

Director of People and Culture
Sheri Keffer

Director of Publications
Natasha Waxman

RESIDENT RESEARCHERS

Resident Research Affiliate
John Moffat

Senior Research Affiliate
Steve MacLean

Senior Researcher
Rafael Sorkin

POSTDOCTORAL RESEARCHERS, 2013/14

Wolfgang Altmannshofer
Haipeng An
Denis Bashkirov
Nikolay Bobev
Héctor Bombín
Oliver Buerschaper
Mathew Bullimore
Juan Carrasquilla
Anushya Chandran
Lukasz Cincio
William (Bill) Edwards
Astrid Eichhorn
Cecilia Flori
Tobias Fritz*
Steffen Gielen
Stefania Gori
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Kurt Hinterbichler*
Philipp Hoehn
Eder Izaguirre
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Gordan Krnjaic
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Edwin (Miles) Stoudenmire
Carlos Tamarit
Yidun Wan
William Witczak-Krempa
Huan Yang
Peng Ye
Huangjun Zhu

** Indicates Templeton Frontiers Program Postdoctoral Fellow*

SCIENTIFIC VISITORS, 2013/14

** 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.

Antonio Acin, Institute of Photonic Sciences (ICFO)

Allan Adams, Massachusetts Institute of Technology (MIT)

Dorit Aharonov*, Hebrew University of Jerusalem

Sergei Alexandrov, Montpellier 2 University/ Charles Coulomb Laboratory

Yacine Ali-Haimoud, California Institute of Technology (Caltech)

Wolfgang Altmannshofer, Fermi National Accelerator Laboratory (Fermilab)

Lilia Anguelova, National Centre of Scientific Research (NCSR) “Demokritos”/Institute of Nuclear Physics

Claudia Antolini, International School for Advanced Studies (SISSA)

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

Alex Arkhipov, Massachusetts Institute of Technology (MIT)

Daniel Arovas, University of California, San Diego

Asimina Arvanitaki, Stanford University/ Stanford Institute for Theoretical Physics

Remi Avohou, University of Abomey-Calavi

Arif Babul, University of Victoria

Ibrahima Bah, University of Southern California

Benjamin Bahr, Max Planck Institute of Quantum Optics

Aristide Baratin, University of Paris XI

Enrico Barausse, Institute of Astrophysics of Paris (IAP)

James Bardeen*, University of Washington

Ganapathy Baskaran*, Institute of Mathematical Sciences, Chennai

Benjamin Basso, École Normale Supérieure (ENS)

John Beamish, University of Alberta

Federico Becca, International School for Advanced Studies (SISSA)

Christopher Beem, Institute for Advanced Study (IAS)

Edo Berger, Harvard University

Daniele Bertolini, Massachusetts Institute of Technology (MIT)

Florian Beutler, Lawrence Berkeley National Laboratory

Atri Bhattacharya, University of Arizona

Jishnu Bhattacharyya, University of Nottingham

Lorenzo Bianchi, Humboldt University of Berlin

Ana Blasco, Complutense University of Madrid

Martin Bojowald***, Pennsylvania State University

Robert Brandenberger, McGill University

Gilles Brassard, University of Montreal/ Mathematical Research Centre (CRM)

Alexander Braverman, Brown University

Sergey Bravyi, IBM Watson Research Center

Richard Brito, University of Lisbon/Higher Technical Institute (IST)

Anne Broadbent, University of Ottawa

Daniel Brod, Fluminense Federal University/ Institute of Physics

Joachim Brod, University of Cincinnati

Adam Brown, Princeton University

Harvey Brown, University of Oxford

Christopher Brust, Johns Hopkins University

Pablo Bueno Gomez, Autonomous University of Madrid

Matthew Buican, European Organization for Nuclear Research (CERN)

Phil Bull, University of Oslo

Dean Buonomano, University of California, Los Angeles (UCLA)

Sheldon Campbell, Ohio State University

Jennifer Cano, University of California, Santa Barbara

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

Sylvain Carrozza, Aix-Marseille University/ Centre of Theoretical Physics (CPT)

Marc Casals, University College Dublin

Alejandra Castro, McGill University

Claudio Chamon, Boston University

Gang Chen, University of Toronto

Meng Cheng, Microsoft Research Station Q

Clifford Cheung, California Institute of Technology (Caltech)

Andrew Childs, University of Waterloo

Juan Ignacio Cirac*, Max Planck Institute of Quantum Optics

Christopher Coleman-Smith, Duke University

Alan Coley, Dalhousie University

Joshua Combes, University of New Mexico

Carlo Contaldi***, Imperial College London

Clay Cordova, Harvard University

Marina Cortes***, University of Edinburgh/ Royal Observatory

Axel Cortes Cubero, City University of New York (CUNY)

Kevin Costello, Northwestern University

Ricardo Couso Santamaria, University of Santiago de Compostela

Yanou Cui, University of Maryland, College Park

Pouria Dadras, Sharif University of Technology

Mihalis Dafermos, Princeton University

Alex Dahlen, Princeton University

Sergio Dain, National University of Cordoba

Luca D’Alessio, Boston University

Saurya Das, University of Lethbridge

Arundhati Dasgupta, University of Lethbridge

Ghanashyam Date, Institute of Mathematical Sciences, Chennai

Fabio de Colle, National Autonomous University of Mexico (UNAM)

Gemma De Las Cuevas, Max Planck Institute of Quantum Optics

Robert de Mello Koch***, University of the Witwatersrand, Johannesburg

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Vincent Desjacques, University of Geneva

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Savas Dimopoulos*, Stanford University

Babette Doebrich, German Electron Synchotron (DESY)

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Maïté Dupuis, University of Erlangen-Nuremberg/Institute for Quantum Gravity

Ethan Dyer, Massachusetts Institute of Technology (MIT)

Anatoly Dymarsky, Skolkovo Institute of Science and Technology

Sonia El Hedri, Stanford University

Shmuel Elitzur, Hebrew University of Jerusalem

Henriette Elvang, University of Michigan

Dalit Engelhardt, University of California, Los Angeles (UCLA)

Jared Evans, Rutgers University

Valerio Faraoni, Bishop's University

Matteo Fasiello, Case Western Reserve University

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Stephen Feeney, University College London

Joshua Feinberg, Technion – Israel Institute of Technology

Daniel Fernandez-Fraile, Goethe University Frankfurt

Simone Ferraro, Princeton University

Guido Festuccia, Institute for Advanced Study (IAS)

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Jamison Galloway, New York University

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David Garfinkle***, Oakland University

S. James Gates, Jr.*, University of Maryland, College Park

Jack Gegenberg, University of New Brunswick

Marc Geiller, Pennsylvania State University

Yvonne Geyer, University of Oxford

Amir Masoud Ghezelbash, University of Saskatchewan

Lisa Glaser, University of Copenhagen/Niels Bohr Institute

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Roman Gold, University of Maryland, College Park

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Humberto Gomez, Sao Paulo State University

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Jess Riedel, IBM Watson Research Center

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Julian (Jose) Rincon, Oak Ridge National Laboratory

Tanja Rindler-Daller, University of Michigan

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

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Louis Vervoort, University of Montreal

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Spenta Wadia, Tata Institute of Fundamental Research

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Johannes Walcher, McGill University

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Andrew Waldron, University of California, Davis

Aron Wall, University of Maryland, College Park

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Yuan Wan, Johns Hopkins University

Zhenghan Wang*, Microsoft Research Station Q

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Scott Watson, Syracuse University

Hans Westman, Spanish National Research Council (CSIC)/Institute for Theoretical Physics (IFT)

Christopher Wever, National Centre of Scientific Research (NCSR) “Demokritos”/ Institute of Nuclear Physics

Steven White*, University of California, Irvine

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Long Zhang, Tsinghua University

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Arundhati Dasgupta, University of Lethbridge

Keshav Dasgupta, McGill University

Rainer Dick, University of Saskatchewan

Joseph Emerson, University of Waterloo/IQC

Valerio Faraoni, Bishop’s University

Marcel Franz, University of British Columbia

Doreen Fraser, University of Waterloo

Andrew Frey, University of Winnipeg

Andrei Frolov, Simon Fraser University

Valeri Frolov, University of Alberta

Jack Gegenberg, University of New Brunswick

Ghazal Geshnizjani, University of Waterloo

Amir Masoud Ghezelbash, University of Saskatchewan

Shohini Ghose, Wilfrid Laurier University

Florian Girelli, University of Waterloo

Stephen Godfrey, Carleton University

Thomas Gregoire, Carleton University

John Harnad, Concordia University

Jeremy Heyl, University of British Columbia

Gilbert Patrick Holder, McGill University

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Viqar Husain, University of New Brunswick

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Gabor Kunstatter, University of Winnipeg

Kayll Lake, Queen’s University

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Randy Lewis, York University

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Michael Luke, University of Toronto

Adrian Lupascu, University of Waterloo/IQC

Norbert Lütkenhaus, University of Waterloo/ IQC

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Robert Mann, University of Waterloo

Gerry McKeon, Western University

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Volodya Miransky, Western University

Guy Moore, McGill University

Ruxandra Moraru, University of Waterloo

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Erich Poppitz, University of Toronto
David Poulin, University of Sherbrooke
Robert Raussendorf, University of British Columbia
Ben Reichardt, University of Southern California
Kevin Resch, University of Waterloo/IQC
Adam Ritz, University of Victoria
Moshe Rozali, University of British Columbia
Barry Sanders, University of Calgary
Veronica Sanz-Gonzalez, York University
Kristin Schleich, University of British Columbia
Achim Schwenk, Darmstadt University of Technology
Douglas Scott, University of British Columbia
Sanjeev Seahra, University of New Brunswick
Peter Selinger, Dalhousie University
Gordon Semenoff, University of British Columbia
John Sipe, University of Toronto
Philip Stamp, University of British Columbia
Aephraim Steinberg, University of Toronto
Alain Tapp, University of Montreal
James Taylor, University of Waterloo
André-Marie Tremblay, University of Sherbrooke
Mark Van Raamsdonk, University of British Columbia
Johannes Walcher, McGill University
Mark Walton, University of Lethbridge
John Watrous, University of Waterloo/IQC
Steve Weinstein, University of Waterloo
Lawrence Widrow, Queen's University
Frank Wilhelm-Mauch, University of Waterloo/IQC
Don Witt, University of British Columbia
Bei Zeng, University of Guelph

CONFERENCES AND WORKSHOPS, 2013/14

Newtonian Studies of Black Hole Stars Meet General Relativity Effects
August 19-30, 2013

Cosmology and Strong Gravity
October 11, 2013

Physics Around Mirror Symmetry
October 21-25, 2013

PI-UIUC Joint Workshop on Strongly Correlated Quantum Many-Body Systems
November 7-8, 2013

Waterloo Soft Matter Theory
December 5, 2013

PI Day
January 30, 2014

Emergence in Complex Systems
February 10-14, 2014

Implications of BICEP2
April 4, 2014

Renormalization Group Approaches to Quantum Gravity
April 22-25, 2014

Supersymmetric Quantum Field Theories in Five and Six Dimensions
April 24-26, 2014

4 Corners Southwest Ontario Condensed Matter Physics Symposium 2014
May 1, 2014

Compute Ontario Research Day 2014
May 7, 2014

Quantum Many-Body Dynamics
May 12-16, 2014

Quantum Gravity Day
May 21-22, 2014

Low Energy Challenges for High Energy Physicists
May 26-30, 2014

New Ideas in Low-Energy Tests of Fundamental Physics
June 16-19, 2014

International Workshop on Quantum LDPC Codes
July 14-16, 2014

COURSES, 2013/14

General Relativity for Cosmology
Instructor: Achim Kempf,
University of Waterloo
September 19-November 28, 2013
Viewable at: http://pirsa.org/C13036

Topics in QFT on Flat and Curved Spacetimes
Instructor: Ugo Moschella,
University of Insubria, Como
September 25-October 23, 2013
Viewable at: http://pirsa.org/C13022

Quantum Field Theory for Cosmology
Instructor: Achim Kempf,
University of Waterloo
January 7-April 1, 2014
Viewable at: http://pirsa.org/C14001

Introduction to Effective Field Theories
Instructor: Cliff Burgess,
Perimeter Institute and McMaster University
January 10-March 28, 2014
Viewable at: http://pirsa.org/C14016

Spacetime Approach to Force-Free Magnetospheres
Instructor: Ted Jacobson,
University of Maryland, College Park
February 25-March 5, 2014
Viewable at: http://pirsa.org/C14019

SPONSORSHIPS, 2013/14

"13th International Conference on Unconventional Computation and Natural Computation," Western University

"14th Canadian Summer School on Quantum Information and 11th Canadian Quantum Information Students' Conference," University of Guelph

"15th Canadian Conference on General Relativity and Relativistic Astrophysics," University of Winnipeg

"2013 Canadian Undergraduate Physics Conference (CUPC)," McMaster University

"2014 CAP Congress," Laurentian University/SNOLAB

"Canada-America-Mexico (CAM) Graduate Student Physics Conference," University of Waterloo

"GAP 2014," University of British Columbia/Pacific Institute for the Mathematical Sciences

"Lake Louise Winter Institute 2014," University of Alberta

"QCrypt 2013," University of Waterloo/Institute for Quantum Computing

"Quantum Computing, Algebra, and Combinatorics," University of Waterloo

"String-Math 2014," University of Alberta

"Theory Canada 9," Wilfrid Laurier University

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