2018 ANNUAL REPORT

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

VISION

To create the world's foremost centre for foundational theoretical physics, uniting public and private partners, and the world's best scientific minds, in a shared enterprise to achieve breakthroughs that will transform our future

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This report covers the activities and finances of Perimeter Institute for Theoretical Physics from August 1, 2017, to July 31, 2018.

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WELCOME

Just one breakthrough in theoretical physics can change the world.

Founded in 1999, Perimeter Institute is an independent research centre located in Waterloo, Ontario, Canada, that seeks to make breakthroughs in our understanding of the universe.

Here, scientists seek to discover how the universe works at all scales – from the smallest particle to the entire cosmos.

Their ideas are unveiling our remote past, explaining the world we see around us, and enabling the technologies that will shape our future, just as past discoveries in physics led to electricity, computers, lasers, and a nearly infinite array of modern electronics.

Perimeter is training the next generation of physics pioneers, and sharing the power and importance of scientific discovery with the world.

The science is complex, but the basic Perimeter equation is simple: Bright minds. Illuminating ideas. Brilliant future.

Step inside the Perimeter.

AN ACCELERATOR OF DISCOVERY

RESEARCH

180+ SCIENTISTS IN RESIDENCE conducting research

13 MAJOR PRIZES AND HONOURS awarded to Perimeter scientists in 2017/18

1,000+ VISITING INTERNATIONAL SCIENTISTS annually

5,200+ PAPERS appearing in 170+ journals with 240,000+ citations since 2001

11,000+ ONLINE TALKS and lectures accessed by viewers in 190 COUNTRIES

19 YEARS after its creation, Perimeter is now ranked among the TOP THEORETICAL PHYSICS INSTITUTES in the world

OUTREACH

40 MILLION STUDENT INTERACTIONS since 2001

26,000+ EDUCATORS trained through Perimeter workshops since 2005

785 TOP HIGH SCHOOL STUDENTS from 58 COUNTRIES have attended the International Summer School for Young Physicists since 2003

80 COUNTRIES have used Perimeter's educational resources

TRAINING

In 2017/18, Perimeter was home to

61 POSTDOCTORAL RESEARCHERS

53 PHD STUDENTS and

30 PSI MASTER'S STUDENTS from 22 COUNTRIES

MESSAGE FROM THE BOARD CHAIR

My fundamental motivation for helping to establish Perimeter (PI) was my belief in the power of science to transform society in unimaginable and prosperous ways. My goal was to help Canada play a leadership role in the advancement of our understanding of physics and in the development of new transformative technologies that will benefit both Canada and the world.

Every day there is new evidence that our plan is working and that our goals for Canada are being realized. Our progress over the past year, both at Perimeter and across the Quantum Valley, is nothing short of thrilling, and the opportunities over the next year are truly exciting. It gives me great pleasure to share with you a few highlights, and to acknowledge a few of the many people at Perimeter that make this possible.

We set out to establish Perimeter as a unique environment that would help Canada attract the very best researchers, and enable them to help solve the really difficult problems in physics. When I talk to researchers, industry, and government, both here and around the world, it's increasingly obvious that Perimeter has achieved a very strong brand and reputation in the global physics community.

Since the beginning, PI has always had a strong focus on recruiting the best young researchers. Over the years, we have attracted a long list of brilliant people that came to Perimeter as young researchers and have since had major impact in their areas of science at PI. This year has been no exception. I want to acknowledge the outstanding young researchers that recently joined PI's Quantum Matter group. They came here from different and diverse institutions because they recognized Perimeter as a unique environment where they could come together to collaborate with each other and have major impact. This is just one example of the many exceptional research faculty and associate faculty that joined us over the past year.

Important advances were made this year at Perimeter, which you'll read about in the pages ahead. Its unique research environment actively encourages daring, cross-field collaborations, and there are many examples of how this pays off. When theory and experiment get together, amazing things happen. On this front, new work by PI researchers and collaborators have established a framework that will be crucial to evaluating new quantum theories. At the forefront of the new and rapidly developing field of gravitational wave detection, PI researchers are developing a blueprint for the next generation of more sensitive detectors that will enable new probes of the physics of neutron star mergers, such as the one seen by LIGO last fall. Finally, over the coming months, you will hear about the critical role played by Perimeter researchers toward a major breakthrough in cosmology that will dramatically advance the field.

The past century of solid-state electronics, computers, networks, smartphones, internet, and so much more that has come from our discovery of quantum mechanics clearly demonstrates the power of science. Our understanding of the unique attributes of the quantum laws of reality gives researchers, industry, and entrepreneurs exciting and prosperous opportunities to develop fundamentally impactful new materials and technologies that simply are not possible under classical physics rules.

Almost across the board, our Quantum Valley ecosystem partners have made great progress over the past year in advancing Canada's position as a global leader in the Second Quantum Revolution – the new large-scale global industry based on quantum technologies. This progress includes the recruitment of a large number of world-leading researchers, the advancement of our basic knowledge of

quantum mechanics, and the development of new technologies and new products. We have also seen the growth of new businesses that have built quantum-based technologies and products for global markets, and that have attracted increasing customer interest and venture capital investment. The Quantum Valley's growing recognition as a global leader has also shown itself in terms of a number of different industry partnerships, collaboration with foreign government entities, and increasing success in driving global standards in several areas of quantum science and technology.

PI plays a critical role in the Quantum Valley. Its researchers contribute to the advancement of our basic knowledge of physics and ensure Canada's industry stays abreast of new discoveries and breakthroughs. This is the critical first step in the technology development cycle. More importantly, the continued success and growing international brand that Perimeter has established over the past 19 years has helped make the Quantum Valley possible and continues to fuel its success.

This could only happen in Waterloo. And it is only possible because of the vision, focus, investment, and hard work of a large, and growing, number of contributors and partners. Of course, the Government of Canada and the Province of Ontario have been fundamental partners since Perimeter's beginning, and I would like to thank them for their continued leadership and support.

Perimeter's private partners are a crucial and growing part of the equation as well. We have raised more than $30 million towards an ambitious campaign goal of $100 million. I would like to personally thank all the donors that have recognized the importance of PI to our future. In particular, I'd like to recognize the very generous support of Ron Mannix, Coril Holdings, the Daniel Family Foundation, and Power Corporation of Canada.

I note too with sadness the passing of our great friend and supporter, Clay Riddell, whose foundation funds the Clay Riddell Paul Dirac Chair at Perimeter. Clay was a leader among forward-looking Canadian philanthropists.

I also want to recognize the Perimeter Board and Leadership Council whose genuine affection for PI and extensive skills and experience help ensure that it has the resources, the governance, and the people that make it unique, nimble, and successful. I want to thank Amit Chakma, Patrice Merrin, and Jane Kinney for agreeing to join PI's Board and to help us with our mission. Above all, I'd like to acknowledge the visionary leadership of Perimeter's Director, Neil Turok, who has given a decade of extraordinary service to Perimeter. His leadership, passion, and limitless enthusiasm motivates us all.

We were all saddened by the passing of Stephen Hawking earlier this year. Stephen was a global leader in physics and an inspiration to all of us. He was also a close friend and a major supporter of Perimeter. His passing was a great loss to all of us.

It's easy to believe that the hard work is behind us, but that would be a big mistake. Our efforts to date have definitely made Canada a global leader in physics and in the Second Quantum Revolution, but these are early days and competition from the largest global companies and leading countries is increasing. If we want to realize the long-term benefits of our investment in physics, we must continue to drive forward our collective effort. I believe that we are already starting to see returns. I also believe that the long-term benefits for Canada will be huge and will be realized for decades to come. For these reasons, I want to encourage all of our contributors, supporters, and partners to continue your efforts and I want to thank you in advance for your continued investment and support.

– Mike Lazaridis, O.C., O.Ont., FRS, FRSC
Chair, Board of Directors

MESSAGE FROM THE INSTITUTE DIRECTOR

One of my favourite moments of the past year was when Imogen Wright, one of the first graduates of our master's program in theoretical physics, spoke at a careers day we hosted for our young researchers in order to highlight the many ways our alumni put their physics training to use.

Imogen told a packed auditorium how, after leaving Perimeter, she'd been drawn to the study of medical diagnosis as a means of helping her country, South Africa, face HIV/AIDS. The curiosity, confidence, and research skills she'd acquired at Perimeter helped her to create an efficient computational method to track mutations in the HIV genome. With these techniques, she co-founded a company called Hyrax Biosciences, providing a genetic test capable of predicting HIV drug resistance. This helps doctors to optimize treatment and combat the rise of drug-resistant strains. Hyrax is on track to test 250,000 people next year, and to save many thousands of lives.

Imogen's is truly a Perimeter story. We, too, started out with a desire to change the world. Perimeter was founded 19 years ago, and I have been here for the past 10. Compared to Cambridge, where I moved here from, we are very young. Yet we have very quickly become a model institute attracting people from around the world not just to study here, but to study us – to learn how to build such a place. Successful institutes like Perimeter are rare, hard to achieve, and have a big impact on a country's long-term prospects. Why? Because technology is the foundation of the modern economy, and any country's prospects are intrinsically linked to science.

Imogen's story – just one of many we heard that day – illustrates how broadly applicable the ideas and skills we develop as physicists are. Consider artificial intelligence and machine learning, one of today's hottest areas of innovation. Many of the most effective algorithms exploit principles developed by statistical physicists. And more and more physicists are becoming involved in pushing the field forward.

One of the most exciting physics-related developments is the use of machine learning to identify interesting quantum materials. These are likely to be the key to future technologies like quantum computers, quantum sensors, ultra-secure communication devices, and more. Quantum materials can have extraordinary properties, but we need better tools to understand and control them – and machine learning is becoming one of those tools. It's an exploding field, which Perimeter scientists are leading. We have recently hired an exciting group of young condensed matter theorists, expanding our computational and predictive capabilities to foresee which materials are most likely to be fruitful for the future. You can read more about this research, and our new Quantum Matter Initiative, in the pages ahead.

Equally exciting developments are taking place in cosmology, where advanced data analysis techniques pioneered at Perimeter are enabling progress that would have been unthinkable even a decade ago. The field of radio astronomy, in particular, is being revolutionized by "software telescopes." Instead of using expensive dishes and mechanical pointing, they use fixed arrays of inexpensive receivers with powerful supercomputers which allow the telescope to focus on all points on the sky simultaneously. The data they yield are revealing fundamental new insights into gravity, nuclear, and particle physics, data which supersede that which is available from traditional particle colliders. We are literally using the universe as a giant physics experiment of extraordinary power.

Canada's new CHIME telescope is pioneering this field, shedding light on some of the most mysterious objects in the cosmos.

Perimeter, and Waterloo Region as a whole, are taking off as centres of advanced data processing and nascent quantum enterprise. The creation of "Quantum Valley" here is an achievement for Ontario and for Canada, the importance of which can't be overstated. Centres of excellence like this raise a country's and a region's reputation and profile, attracting top global talent which drives future growth.

Here at Perimeter, this has been a banner year. We were joined by four new faculty members: Neal Dalal and William East in cosmology and gravity, and Yin-Chen He and Timothy Hsieh in quantum materials. Several more exceptional young researchers in these fields have been recruited and will join us next year. Perimeter's Associate Faculty program, which hires faculty cross-appointed with Canadian universities, has likewise been successful, attracting mathematician Matilde Marcolli, cosmologist Will Percival, and gravity theorist Huan Yang as joint faculty with the Universities of Toronto, Waterloo, and Guelph respectively.

Physics opens the doors to new methods and so amplifies the work of other sciences and industries. That is also why, through our outreach programs, we reach out to students, teachers, and the general public. Across Canada and around the world, we are helping to educate and inspire hundreds of thousands of students every year. In a world beset by anxiety and short-term thinking, we are empowering people to think critically, and to discover the power of scientific understanding.

The payoffs can be huge. Imogen's company, founded to help fight HIV, is now ready to take on tuberculosis, and estimates it may be 10 years ahead of the curve in developing a blood test for cancer.

"Every single person in this room," Imogen told her audience of young researchers, "is well-resourced and well-educated enough that world-changing ideas are within our reach. Every single one of us is a very powerful instrument."

Imogen's words recalled to me our dear friend and ally Stephen Hawking, who we sadly lost last spring. When I first told him about Perimeter, his eyes lit up. He became one of our greatest supporters and the first of our many Distinguished Visiting Research Chairs. During Stephen's first visit, he emphasized the great value of bringing brilliant people together within an inspiring intellectual environment. "The importance of special places and special times, where magical progress can happen, cannot be overstated. It seems to me the same ingredients are being assembled here, at the Perimeter Institute in Waterloo. I am hoping, and expecting, great things will happen here."

They already are.

– Neil Turok, Director
and Mike and Ophelia Lazaridis Niels Bohr Chair

RESEARCH

This year, Perimeter scientists produced **495 papers**.[1] Since its inception, Perimeter Institute's scientists have produced over **5,200 papers**, which have appeared in over **170 journals**, attracting well over **240,000 citations**.[2]

[1] This reflects the one-year period from August 1, 2017 to July 31, 2018. Each publication has been counted only once, regardless of how many Perimeter researchers collaborated on it.

[2] This data comes from the Google Scholar and Spires databases.

Perimeter Institute is a world-leading centre of scientific research. Our field is the lowest-cost, highest-impact area of science: fundamental physics.

Our strategy is to bring the best minds in the world together under one roof, and support them in doing their most ambitious work.

Our goal is nothing less than breakthroughs. There are about 150 researchers in our building on any given day, each working to unlock the mysteries of the universe, in fields ranging from quantum mechanics to cosmology. We tackle the big questions: How did the universe begin? What is it made of? How does information work at its most fundamental level? What is the nature of dark matter and dark energy? How can we understand and harness the quantum world?

In the pages ahead, you'll read about researchers putting quantum mechanics to the test, investigating neutron star mergers, applying artificial intelligence to quantum condensed matter, unfolding the young universe, pushing holography further, and more.

We cannot predict the outcome of these investigations. But history has shown that the benefits of breakthroughs in theoretical physics will surpass anything we can predict, or even imagine. Consider: Einstein's work on the nature of light gave us lasers. Curie's work on the nature of radiation gave us X-ray technology. Maxwell's work on the nature of electromagnetism gave us smartphones. These were theoretical physicists, not inventors. They worked

without applications in mind. And yet the technologies built on the foundations they laid have changed the world.

The discoveries of Einstein, Curie, and Maxwell are a hundred years or more in the past. Today's discoveries, made by today's theoretical physicists, will make possible the next wave of transformative technologies that will shape our century.

"Perimeter Institute for Theoretical Physics, the Institute for Quantum Computing, and the Waterloo Institute for Nanotechnology … have attracted prominent physicists … and made Canada an outsize force in the field, which the US and China typically dominate."

– Bloomberg Businessweek

THE MYRIAD USES OF A PHYSICS EDUCATION

What can you do with a physics degree besides becoming a professor of physics?

Quite a lot, it turns out. At Perimeter Institute's inaugural "Career Trajectories Day" in May 2018, more than 150 graduate students and postdoctoral researchers from Perimeter and eight Ontario universities heard from an array of physics graduates who had experienced extraordinary success outside academia.

There were data scientists from Shopify and the Royal Bank of Canada, a leading propulsion development engineer from SpaceX, and several entrepreneurs, including one whose company develops low-cost genetic tests to combat HIV and other diseases. There was even an acclaimed novelist. Their collective message was clear: the skills physics instills have value far beyond academia.

"Physics is an awesome basis for solving all kinds of problems in business," noted entrepreneur Michael Serbinis, best known as the founder of Kobo, and now founder and CEO of League. "People that have a background in physics and engineering – they just go to first principles, versus fear or confusion."

THE POWERFUL UNION OF AI AND QUANTUM MATTER

Humanity is on the threshold of understanding and controlling matter at its most basic and powerful level. Thanks to advances in two fields – artificial intelligence (AI) and condensed matter – barriers that once seemed impassable are crumbling. Perimeter researchers are at the forefront of this effort.

On one side of the equation is artificial intelligence. AI algorithms can now solve problems that are too big, too complex, too multi-layered for classical computers to tackle.

On the other side are exotic materials called "quantum matter," in which minuscule building blocks combine in novel ways that lead to the emergence of new and powerful behaviours.

We've already seen the impact such research can have: the discovery of semiconducting materials led to the Silicon Revolution. Now, using AI techniques, physicists are not only identifying quantum matter that may exist in nature; they are also working out how we can build such materials from scratch.

This is a union of two fields that are each coming into their own, and it is creating a unique moment in science, one Perimeter is uniquely positioned to lead. The Institute is deeply embedded in Quantum Valley, where the quantum innovation chain runs from theory to new commercial ventures. By providing a collaborative, cross-disciplinary environment that encourages links to experiment, Perimeter is laying the foundation for innovation.

ARTIFICIAL INTELLIGENCE TEACHES ITSELF TO SOLVE QUANTUM CHALLENGES

In popular culture, quantum computing is often painted as an ultra-powerful technology that will first outrace, and then replace, its classical counterpart. In reality, though, the two are inextricably linked.

This relationship took one more step thanks to a paper published in *Nature Physics* by researchers at Perimeter Institute and the University of Waterloo, with collaborators at ETH Zurich, Microsoft Research Station Q, D-Wave Systems, and the Vector Institute for Artificial Intelligence.

The team applied an industry-standard AI to a quantum computing problem: working out the state of a quantum device using only snapshots of data gleaned from experimental measurements.

Currently, we do this through a process called "quantum state tomography." Using imperfect snapshots of the system as a starting point, researchers use complex algorithms to mathematically backtrack until they can ascertain the full quantum state at the moment the measurements were taken.

In the paper, "Neural-network quantum state tomography," Perimeter Associate graduate student **Giacomo Torlai**, Perimeter Associate Faculty member **Roger Melko**, and collaborators had a cutting-edge AI neural network do the heavy mathematical lifting.

The AI learned how to combine the measurements of the quantum hardware to create its complete quantum mechanical description. Unlike most approaches designed to understand quantum hardware – which are tailored to the specific regime – the team's AI is platform-agnostic. The neural network is general enough to be applied to a variety of quantum devices.

This effort is part of the broader "quantum intelligence" program in which theorists and experimentalists are using machine learning to design and analyze quantum systems.

A SYSTEMATIC WAY TO BUILD NONTRIVIAL QUANTUM STATES

There is a rapidly growing field of research called "quantum simulation," in which a small quantum system – say, a handful of trapped ions – is manipulated to create exotic quantum behaviours, either in the form of quantum states or dynamics. This is currently done on small quantum systems that can be highly controlled, but it is often not straightforward to prepare highly entangled states.

Recent work by Perimeter Faculty member **Timothy Hsieh** and collaborator Wen Wei Ho (Harvard University) greatly simplifies the process. They offer a general approach to efficiently generate protocols for all sorts of quantum states with nontrivial long-range correlations.

The approach, called Quantum Approximate Optimization Algorithm (QAOA), comes from quantum information. It was initially proposed to solve classical optimization problems using quantum computers. Hsieh and Ho, however, realized it could also be used to solve a quantum problem: how to build nontrivial quantum states of great interest in condensed matter physics, such as topological order or quantum critical points.

With QAOA, experimentalists would start with a certain set of interactions and, after a variable amount of time, switch to a second set of interactions. The system then switches back and forth between the interactions at specific intervals, almost like an all-purpose fine-tuning mechanism. The end result: a nontrivial quantum state made from scratch.

The idea has already gained the attention of experimentalists, including researchers at the Institute for Quantum Computing at the University of Waterloo.

"There's this growing crosstalk between condensed matter and quantum information, which I think is very valuable," Hsieh says. "The advantage of our approach is that it's a pretty simple protocol. We have experimental platforms now that can actually carry this out on their systems."

Perhaps most exciting, this new approach is general, rather than tailored to specific target states, and can be extended to many different classes of states, making it extremely useful to an emerging field with enormous potential.

References:

G. Torlai (University of Waterloo and Perimeter Institute), G. Mazzola (ETH Zurich), J. Carrasquilla (Vector Institute and D-Wave Systems), M. Troyer (ETH Zurich and Microsoft Research Station Q), R. Melko (University of Waterloo and Perimeter Institute), and G. Carleo (ETH Zurich and Flatiron Institute), "Neural-network quantum state tomography," *Nature Phys.* 14, 447-450 (2018), arXiv: 1703.05334.

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QUANTUM MATTER INITIATIVE

Physics is witnessing the emergence of a fast-growing field called "quantum matter." It sits at the nexus of condensed matter physics, quantum information, quantum gravity, and string theory, and pulls ideas from across this spectrum to create powerful new discoveries.

The Quantum Matter Initiative at Perimeter Institute aims to bring together leading scientists in these areas for collaborative research into major open questions.

In the past year, Perimeter has made three significant hires as part of the Quantum Matter Initiative. Emerging leaders **Timothy Hsieh**, **Chong Wang**, and **Yin-Chen He** have all joined Perimeter Institute's faculty, adding to a strong interdisciplinary team that includes **Robert Myers**, Krembil Galileo Galilei Chair **Davide Gaiotto**, **Roger Melko**, **Subir Sachdev** – the Cenovus Energy James Clerk Maxwell Chair (Visiting) – and a growing roster of postdoctoral researchers.

Quantum matter embraces a creative and cohesive approach as researchers seek synergies through interdisciplinary collaboration, just like Perimeter Institute itself.

ADVANCING QUANTUM FIELD THEORY

What are we made of? It's one of the oldest questions in physics, and perhaps the most important.

For centuries, physicists pursued the quest to understand the most fundamental constituents of the universe. In the past century, this quest lead to the discovery of first molecules, then atoms, and then subatomic particles. But it turns out that the fundamental building blocks of nature are not particles at all. The fundamental building blocks of nature are called fields. Fields spread continuously, like fluids, through the universe, bunching and rippling in interesting ways that we experience as particles or forces.

A description involving fields – quantum field theory, or QFT – is the modern paradigm with which we understand particle physics, condensed matter systems, and many aspects of early-universe cosmology. It is used to describe the interactions of elementary particles, the dynamics of many-body systems, and critical phenomena, all with exquisite accuracy.

But despite its power, QFT can be difficult to understand and computationally impossible to use. Perimeter has built one of the world's leading group of researchers developing new approaches to QFT, simplifying its application and extending its reach.

THE STARS ALIGN FOR QUANTUM CHROMODYNAMICS

Perimeter Faculty member **Jaume Gomis** rolls a pen across his desktop. The pen rolls as our intuition tells us it should, skittering a little as its cap catches, slowing as it goes along. Any physicist could use the mass of the pen and the vector of the force and roughly calculate this motion from first principles.

A more exact calculation – that skittering – is much harder, but one can get close by making small corrections and refinements to the first calculation. These refinements are called perturbations, and this realm of physics – where we can predict the behaviour of a system from first principles, refining as needed – is the perturbative realm.

But many things in nature are nonperturbative. For example, we know that protons and neutrons are made of quarks and gluons. We know that these interact through the strong nuclear force. So as with the pen, we can describe the basic objects and the forces at work. The theory of these objects and forces is called quantum chromodynamics, or QCD.

QCD works at very short distances and at very high energies, but at the lower energies and larger scales we can observe on Earth, strong quantum effects reorganize the quarks and gluons into systems whose dynamics are unpredictable, and calculations from first principles fail us. Instead of sliding across the table with a bit of skittering, Gomis says, "they fly off and get married and have children. It's crazy." In other words: QCD at low energies is non-perturbative.

Gomis – with Visiting Fellow **Zohar Komargodski** and Distinguished Visiting Research Chair **Nathan Seiberg** – is working to change that. Working within a simplified version of QCD known as QCD3, they deployed a variety of recent developments from condensed matter physics and pure mathematics to develop a new mathematical formulation which can be used to predict the dynamics of systems at low energies.

It's a major step forward for the subfield. But how can it be validated? It turns out that QCD produces a handful of results that are the same at all length scales – the same in the previously known high-energy version as in the brand-new low-energy theory. These results, known technically as "anomalies," can act as fixed stars, making sure the theory is on the right course.

So, what happened when Gomis et al. calculated the anomalies for his new gauge theory? "It was the most beautiful thing, the most astonishing thing," he says. "They matched so perfectly."

MAKING EXACT SOLUTIONS A MORE EXACT SCIENCE

Here's something every physicist knows: even if you understand a theory well, using it to make exact predictions can be impossible.

For example, consider the break in a game of pool. The result of hitting a single ball with a pool cue is easily calculable. But as one ball hits another, which hits another, which hits another, the equations pile up. The problem quickly becomes too big to compute.

And that's just a pool table with some billiard balls. Now, imagine a quantum system with many interacting particles. The probability of any given particle ending up in any given quantum state after an interaction is known as its scattering amplitude. When it comes to scattering amplitudes, exact solutions – that is, solutions where you write down equations and solve them algebraically, without guess-work or approximation – have long seemed out of reach.

That is where Krembil William Rowan Hamilton Chair **Kevin Costello**'s work on integrable systems comes in. Integrability is a mathematical way of simplifying calculations and yet getting exact solutions. In 2017, Costello's ongoing work in the field took a step forward when he co-wrote a paper with Edward Witten and Masahito Yamazaki, titled "Gauge Theory and Integrability."

The paper offers a new approach to the Yang-Baxter model, a powerful set of equations based on the observation that in some scattering situations, particles may preserve their momentum while changing their internal quantum states.

Because it made it possible to exactly solve some scattering amplitudes, Yang-Baxter has become an important tool in the 40 years since it was first introduced. It has applications across fields of physics from condensed matter to string theory, and from quantum computation to understanding quantum entanglement.

But there is a difficulty: the Yang-Baxter model lacks a systematic construction, and so finding the right solvable equations for a particular problem is hard. It depends on some luck and good guesswork.

That's what Costello has been tackling. His new work provides a procedure for constructing the equations without guesswork – making the quest for exact solutions a bit more of an exact science.

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PERIMETER FACULTY

Asimina Arvanitaki, Stavros Niarchos Foundation Aristarchus Chair in Theoretical Physics

Latham Boyle

Freddy Cachazo, Gluskin Sheff Freeman Dyson Chair in Theoretical Physics

Kevin Costello, Krembil William Rowan Hamilton Chair in Theoretical Physics

Neal Dalal

Savas Dimopoulos, Coril Holdings Archimedes Chair in Theoretical Physics (Visiting)

Bianca Dittrich

William East

Laurent Freidel

Davide Gaiotto, Krembil Galileo Galilei Chair in Theoretical Physics

Jaume Gomis

Daniel Gottesman

Lucien Hardy

Yin-Chen He

Timothy Hsieh

Luis Lehner

Robert Myers

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

Kendrick Smith, Daniel Family P. James E. Peebles Chair in Theoretical Physics

Lee Smolin

Robert Spekkens

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

Guifre Vidal

Pedro Vieira, Clay Riddell Paul Dirac Chair in Theoretical Physics

Beni Yoshida

PROGRESS IN QUANTUM FUNDAMENTALS

Quantum foundations and quantum gravity were the fields on which Perimeter was first founded.

The questions they tackle could hardly be bigger – or more difficult. Quantum foundations seeks to better understand the deep mathematics and concepts that underpin quantum mechanics, our most accurate, widely applicable, and far-reaching theory.

Researchers in quantum gravity are seeking ways to unite quantum mechanics with Einstein's theory of gravity, general relativity. The two great theories are extremely successful in their respective domains, but in situations where both theories must be used at once, our understanding breaks down.

Both quantum foundations and quantum gravity seek to extend the reach of quantum mechanics. They cross-pollinate with each other and, in recent years, have developed surprising and powerful connections to fields such as quantum information, condensed matter physics, and the quest for quantum technologies. Perimeter's choice of founding fields, thought unusual at the time, is starting to look visionary.

TURNING HOLOGRAPHY INSIDE OUT

Perimeter Faculty member **Bianca Dittrich**, postdoctoral researcher **Aldo Riello**, Visiting Fellow **Etera Livine**, and Visiting Graduate Fellow **Christophe Goeller** are experts in quantum gravity. One of the important tools in their field is known as holography, which shows that in some cases, a theory of gravity permeating a space is equivalent to a theory of quantum fields on the boundary of that space. Holography is often used to turn tough problems about gravity into more tractable ones about particles and fields, or vice versa.

Holography normally applies to a special kind of spacetime known as anti-de Sitter (AdS) space, and normally the surface which contains the quantum field theory is infinitely far away. Previous research by Dittrich and former Perimeter postdoctoral researcher Valentin Bonzom had pushed the theory further, showing that holography could also be used in more generic three-dimensional spacetimes with finite boundaries. This new research turning the holograph inside out builds on that discovery.

Dittrich and her collaborators took an established theory of quantum gravity in 3D (that is, in three dimensions: two dimensions of space and one dimension of time) and chose different finite boundaries. For example, they studied hollow spheres, hollow toruses, hollow toruses with twists, and the like. They found a whole class of different (or at least different-looking) 2D statistical models, depending on the surface chosen. It's the first study to find many different 2D dual models for a single 3D theory of gravity.

The research gave a fresh look to the established 3D gravity theory and opened a new path of research for mathematicians who might be interested in comparing the various 2D statistical models, looking for equivalences. In the future, the team wants to learn more about the relationship between their choice of boundary wave functions and the 2D statistical models generated.

But the real payoff was that by learning to embed different 2D quantum surfaces in 3D space, the team learned about holography itself. It's a bit like teaching yourself sewing by turning a dress inside out to learn about how sewing patterns work. It's knowledge that may well come in handy as the researchers attempt to stitch up a theory of quantum gravity fit for our 4D universe.

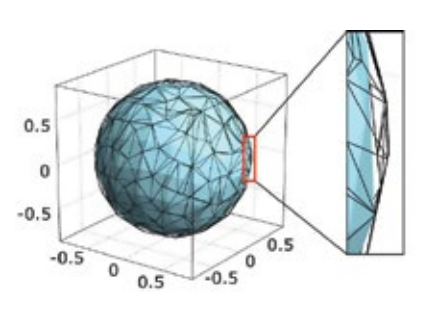
PUTTING QUANTUM MECHANICS TO THE TEST

How do you put a theory like quantum mechanics to the test? One important way is to develop competing theories and pit them against each other in a cage match.

There are, in fact, several theories that compete with quantum mechanics; describing them is a field that's been thriving at Perimeter for years. This year, there was a major development: a team put together by Perimeter Faculty member **Robert Spekkens** built the cage and staged the match. It's the first time such an experiment – long discussed – has actually been run, and the new results are already shaping up as an important advance in the field.

The collaboration consisted of Spekkens and then-Perimeter postdoc **Matthew Pusey** (now at the University of Oxford), together with experimentalists Kevin Resch and Michael Mazurek from the Institute for Quantum Computing at the University of Waterloo. The experiment they designed was deliberately simple. One device prepared a single photon (a particle of light) in a variety of ways. Downstream, another device measured the photon in a variety of ways. Each combination of preparation and measurement was run multiple times, until the data built up to show the frequency at which each outcome of the measurement occurred.

The researchers used some mathematical tools to turn their table of measured probabilities into an easy-to-visualize shape – something even the layperson's eye can evaluate. To zero in on just one set of predictions and results: quantum mechanics predicts that the shape described by the collection of all states should be a sphere. The competing "boxworld" theory predicts that it should be a cube. The shapes returned by the experiment, however, look significantly more quantum than boxy:



Any theory that describes the world would have to fit between the blue soccer-ball-like object and the wire frame around it. Quantum mechanics does, but there's not a lot of space left for its competitors. Or to say it technically, the result puts experimental bounds on the space of competing probabilistic theories.

In physics, there is no such thing as an undisputed champion, and there are important caveats here regarding whether this measurement is "tomographically complete." But for the moment, quantum mechanics has emerged from its first-ever cage match very much on top.

References:

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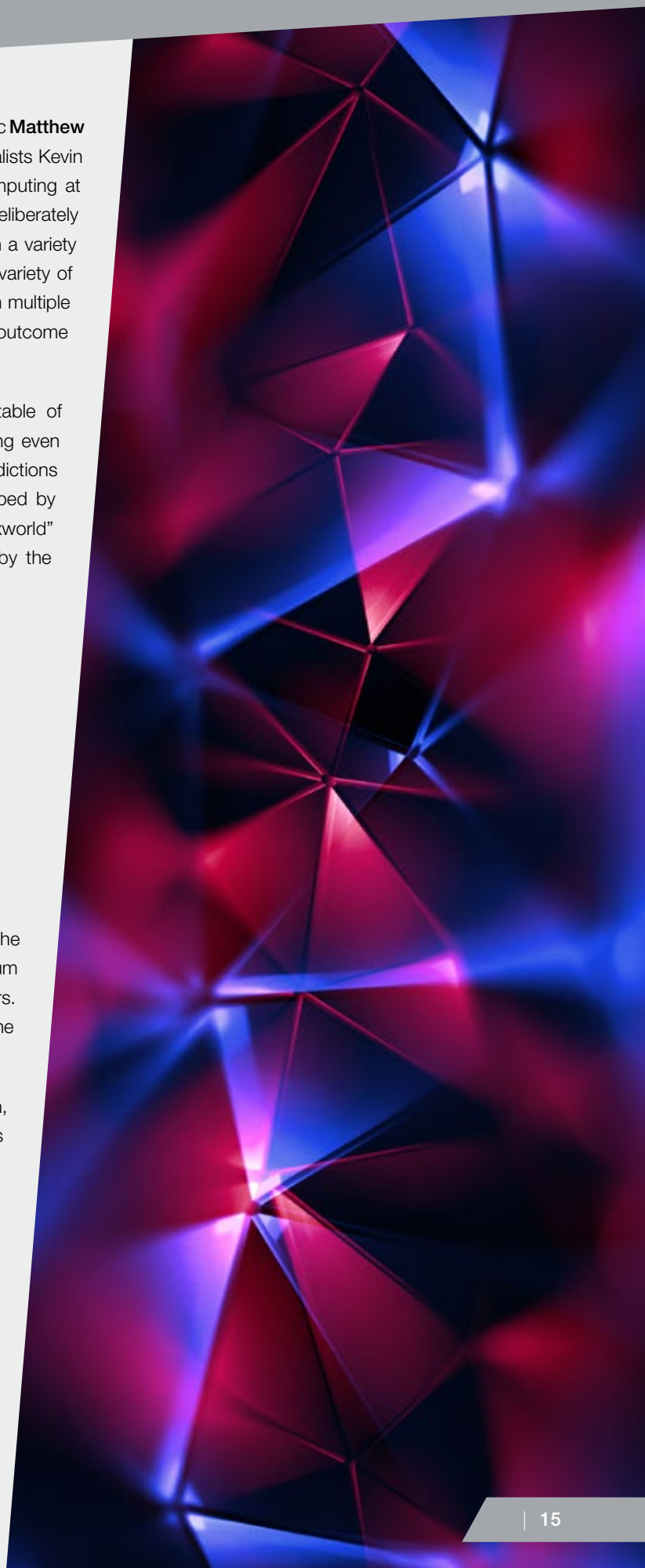
M.D. Mazurek (Institute for Quantum Computing/University of Waterloo), M.F. Pusey (University of Oxford and Perimeter Institute), K.J. Resch (Institute for Quantum Computing/University of Waterloo), and R.W. Spekkens (Perimeter Institute), "Experimentally bounding deviations from quantum theory in the landscape of generalized probabilistic theories," arXiv:1710.05948.



FROM THE DAWN OF THE UNIVERSE TO THE DAWN OF MULTIMESSENGER ASTRONOMY

1.3 billion years ago, two black holes collided. The waves caused by the cataclysm travelled outward at light-speed, minutely rippling the fabric of spacetime before being recorded as they passed the ultra-sensitive detectors of LIGO, the Laser Interferometer Gravitational-Wave Observatory, in 2015.

The detection confirmed the existence of gravitational waves, first predicted by Einstein, and earned LIGO's pioneers the 2017 Nobel Prize in Physics. The ability to detect gravitational waves has opened new eyes on the universe and is driving rapid progress in our understanding of some of its most massive, energetic, and enigmatic events.

Just one year after the initial detection, LIGO joined forces with the Virgo experiment to try to pinpoint the location of a gravitational wave source on the sky. This allowed them to tell conventional telescopes to look in the direction of an event and combine the different types of signals – a new approach called "multimessenger astronomy."

In August 2017, LIGO-Virgo detected a gravitational wave with a telltale signature. They sent an urgent alert to 70 telescopes around the world to focus on a patch of sky 130 million light years away in the Hydra constellation. In real time, astronomers turned their telescopes to the area. The collaboration recorded electromagnetic signals, from gamma-ray bursts right down the spectrum to radio waves, offering unprecedented detail and the precise location of the collision of two neutron stars.

Multimessenger astronomy is already reshaping how we explore the universe, allowing researchers to probe fundamental questions about the nature of gravity and the most energetic events in the universe.

The neutron star merger detection came at a fortuitous time for Perimeter Associate Faculty member **Huan Yang**. Working with collaborators at the University of Birmingham, Yang has been developing the design for a new gravitational wave detector that can probe neutron star physics with much higher precision.

Current gravitational wave detectors are primarily sensitive to low frequencies, corresponding to the "inspiral" stage of a binary neutron star merger for most distant sources. The actual merger processes, however, contain rich information about the physics of nuclear matters in extreme conditions. To exploit this information, detectors with good sensitivity in the high-frequency regime (above 1 KHz) are needed.

The high-frequency detectors will also be better positioned to understand the post-merger emission for binary neutron stars. Before the neutron stars collide, their gravitational wave signature is very similar to that of two black holes colliding. After the merger, however, the waveforms are completely different depending on the kind of object that remains (either a very massive neutron star or a black hole with between two and three solar masses).

The idea has already gained momentum in the community. In June, Yang co-organized the workshop "Path to Kilohertz Gravitational-Wave Astronomy" at Perimeter Institute, bringing together experts from around the world to discuss key issues including the technical challenges of building the new detectors.

With the recent recruitment of researchers such as **William East** and **Daniel Siegel**, Perimeter is poised to become a world leader in the study of strong gravity events. East, who joined Perimeter's faculty in January 2018, uses numerical tools to explore the dynamics of spacetime and gravitational wave radiation. Siegel, who will join Perimeter as an associate faculty member in the spring of 2019, is a leading expert on the electromagnetic observable components of these cataclysmic events. Both avenues of exploration dovetail well with Yang's research. Watch for new physics from big collisions ahead.

NO SMOOTH BEGINNING FOR THE UNIVERSE

Gravitational waves may also one day be used to weigh in on some of the longest-standing questions in cosmology – including just what, exactly, happened at the start of it all. In the meantime, researchers including Perimeter Institute Director **Neil Turok**, who also holds the Mike and Ophelia Lazaridis Niels Bohr Chair, are approaching that question from a more theoretical angle.

A classical description of the big bang implies a singularity: a point of infinite smallness at which Einstein's theory of general relativity

breaks down. To tackle this failure, two proposals were put forward (the "no-boundary proposal" and a theory known as "tunneling from nothing") that attempted to describe a smoother beginning to spacetime using quantum theory. Rather than the infinitely pointed needle of the classical big bang, the proposals described something closer to the rounded tip of a well-used pencil.

Work by Turok with Perimeter PhD student **Job Feldbrugge** and Jean-Luc Lehners of the Albert Einstein Institute in Germany identified crucial mathematical inconsistencies in the "no-boundary" and "tunneling" proposals.

They conclusively showed that a universe emerging smoothly from nothing would be "wild and fluctuating," strongly contradicting observations showing the universe to be extremely uniform across space.

To reach this result, Turok, Lehners, and Feldbrugge had to revisit the foundations of the field. They found a new way to bring in powerful mathematics developed over the past century to study the quantum interference of different geometries for space and time. The work builds on a previous study Turok conducted with **Steffen Gielen**, a joint postdoc at the Canadian Institute for Theoretical Astrophysics and Perimeter and now a Royal Society Fellow in the UK, in which they replaced the concept of the "classical big bang" with a "quantum big bounce."

The team are now trying to determine what mechanism could have kept large quantum fluctuations in check while allowing our large universe to unfold. Their new research implies that "we either should look for another picture to understand the very early universe, or that we have to rethink the most elementary models of quantum gravity," says Feldbrugge.

"Uncovering this problem gives us a powerful hint," says Turok. "It is leading us closer to a new picture of the big bang."

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J. Feldbrugge (Perimeter Institute), J-L. Lehners (Max Planck Institute for Gravitational Physics (Albert Einstein Institute)), and N. Turok (Perimeter Institute), "No rescue for the no-boundary proposal: Pointers to the future of quantum cosmology," *Phys. Rev. D* 97, 023509 (2018), arXiv:1708.05104.

J. Feldbrugge (Perimeter Institute), J-L. Lehners (Max Planck Institute for Gravitational Physics (Albert Einstein Institute)), and N. Turok (Perimeter Institute), "Inconsistencies of the New No-Boundary Proposal," arXiv:1805.01609, *Universe* 4 (2018) no.10, 100.

PERIMETER ASSOCIATE FACULTY

(cross-appointed with partner institutions)

Niayesh Afshordi (University of Waterloo)

Alexander Braverman (University of Toronto)

Avery Broderick, Delaney Family John Archibald Wheeler Chair in Theoretical Physics (University of Waterloo)

Alex Buchel (Western University)

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

Cliff Burgess (McMaster University)

David Cory (IQC/University of Waterloo)

Matthew Johnson (York University)

Raymond Laflamme (IQC/University of Waterloo)

Sung-Sik Lee (McMaster University)

Matilde Marcolli (University of Toronto)

Roger Melko (University of Waterloo)

Michele Mosca (IQC/University of Waterloo)

Ue-Li Pen (Canadian Institute for Theoretical Astrophysics/ University of Toronto)

Will Percival (University of Waterloo)

Maxim Pospelov (University of Victoria)

Ben Webster (University of Waterloo)

Huan Yang (University of Guelph)

Jon Yard (University of Waterloo)

HONOURS, AWARDS, AND MAJOR GRANTS

- **Kendrick Smith**, the Daniel Family P. James E. Peebles Chair in Theoretical Physics, was co-awarded the 2018 Breakthrough Prize in Fundamental Physics as part of the 27-member Wilkinson Microwave Anistropy Probe (WMAP) experiment.
- Associate Faculty member **Raymond Laflamme** was named an Officer of the Order of Canada, one of the nation's highest civilian honours.
- **Neil Turok**, Perimeter Director and Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics, was named an Officer of the Order of Canada (Honorary).
- **Subir Sachdev**, the Cenovus Energy James Clerk Maxwell Chair in Theoretical Physics (Visiting), was awarded the 2018 Lars Onsager Prize of the American Physical Society.
- **Pedro Vieira**, the Clay Riddell Paul Dirac Chair in Theoretical Physics, and Visiting Fellow **Zohar Komargodski** were awarded the 2018 Raymond and Beverly Sackler International Prize in Physics by Tel Aviv University.
- **Kevin Costello**, the Krembil William Rowan Hamilton Chair in Theoretical Physics, was elected as a Fellow of the Royal Society (UK).
- Distinguished Visiting Research Chairs **Charles Bennett** and **Peter Shor** were awarded the 2017 Dirac Medal and Prize of the International Centre for Theoretical Physics.
- Distinguished Visiting Research Chair **Charles Bennett** was awarded the 2018 Wolf Prize in Physics.
- Distinguished Visiting Research Chair **Xiao-Gang Wen** was elected to the National Academy of Sciences (US).
- For the fourth consecutive year, Faculty member **Robert Myers** was recognized as one of the world's most influential scientists on the "2017 Highly Cited Researchers" list compiled by Clairvate Analytics. Distinguished Visiting Research Chairs **Juan Ignacio Cirac** and **Ashvin Vishwanath** also appeared on the list.
- **Neil Turok** and former postdoctoral researcher **Steffen Gielen** were awarded second prize in the 2017 Buchalter Cosmology Prize competition of the American Astronomical Society, while Associate Faculty member **Cliff Burgess** and Associate PhD student **Peter Hayman** shared third prize with their collaborators. Perimeter researchers have been honoured in each year the prize has been awarded.

- **Asimina Arvanitaki**, the Stavros Niarchos Foundation Aristarchus Chair in Theoretical Physics, won the 2017 Giuseppe Sciacca International Science Prize.
- Associate Faculty member **Michele Mosca** was appointed as a Knight in the Order of Merit by the Government of Italy for his contributions to quantum information science.
- Perimeter scientists were awarded more than **$3.2 million** in research grants from agencies including the Natural Sciences and Engineering Research Council of Canada and the Simons Foundation.

PERIMETER RECOGNIZED AS TALENT MAGNET

Alumni of Perimeter's scientific training programs feed many fields beyond physics – including technology, finance, government, healthcare, and beyond.

In 2018, this wide-ranging impact was recognized with the "Labour" award from Creative Destruction Lab (CDL), a program of the Rotman School of Management at the University of Toronto that helps new science-based companies scale up. CDL cited the positive impact of Perimeter's training programs on the high-skills labour market that is critical to economic growth.

Perimeter Director of Academic Programs James Forrest accepted the award. "They recognized that being useful does not always mean you can make a product with it now, or even in the near future, and that recruiting and training young minds from all over the world has a huge benefit," Forrest explains. "We were recognized for being an effective talent magnet."

RECRUITMENT

PI BY THE NUMBERS

Perimeter is the world's largest theoretical physics community:

25 faculty, including nine Perimeter Research Chairs

19 associate faculty cross-appointed with partner universities, including one Perimeter Research Chair

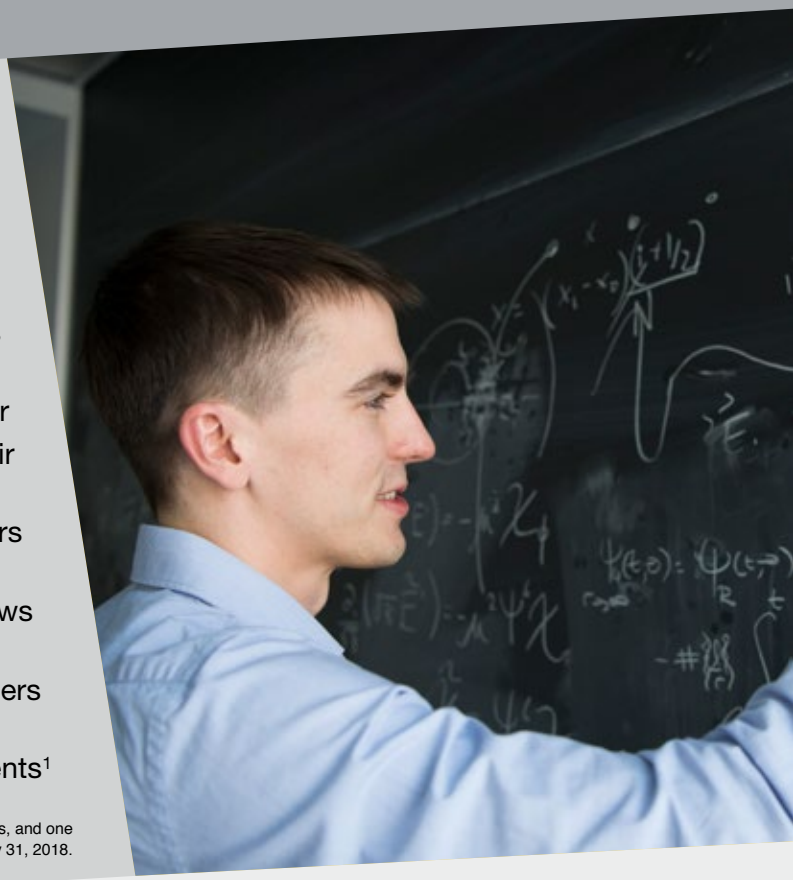
51 Distinguished Visiting Research Chairs

46 Visiting Fellows

61 postdoctoral researchers

84 graduate students[1]

[1] This includes 53 PhD students, 30 Perimeter Scholars International (PSI) master's students, and one additional master's student. All numbers reflect the Perimeter community as of July 31, 2018.



Master's students from Ecuador, Ireland, and New Zealand find common ground over French fries and quantum field theory. One table over, a newly arrived postdoctoral researcher pitches his latest idea on string theory to one of the founders of the field. In other words, it's an ordinary day in the Black Hole Bistro, the beating heart of Perimeter Institute, where nearly 200 resident researchers and students mingle with more than 1,000 visiting scientists per year. Less than 20 years since its creation, Perimeter has become the world's largest independent centre for theoretical physics, attracting many of the planet's best scientific minds.

PERIMETER RESEARCH CHAIRS

Named for legendary scientists whose insights helped define physics, Perimeter Research Chairs are scientific trailblazers. This year, the Institute appointed cosmologist **Kendrick Smith** as the Daniel Family P. James E. Peebles Chair in Theoretical Physics, supported by the Daniel Family Foundation, making him the 10th chairholder at Perimeter.

Smith is a brilliant scientist with a unique background. He holds PhDs in both mathematics and physics, and spent time as a software developer, a combination that has positioned him extremely well for the current explosion of data in cosmology. Prior to joining Perimeter from Princeton University in 2012, Smith had already achieved landmark results, including the first detection of gravitational lensing in the cosmic microwave background (CMB) radiation, and made a name for himself as part of several experimental teams. He recently shared in the $3 million 2018 Breakthrough Prize in Fundamental Physics as part of the Wilkinson Microwave Anistropy Probe (WMAP) collaboration.

Now, Smith is working with the Canadian Hydrogen Intensity Mapping Experiment (CHIME), a British Columbia-based radio telescope seeking to answer fundamental questions in astrophysics and cosmology. Smith has played a major role in coding the software that makes the telescope work, adapting it to help detect mysterious events known as "fast radio bursts." Results aren't out yet, but excitement is building in the community, and the innovative, cost-effective telescope has already positioned Canada as a leader in cosmology. Smith is also playing a key role in developing the new **Centre for the Universe at Perimeter Institute**.

FACULTY

This year, Perimeter welcomed four new faculty members. **Neal Dalal** and **William East** are the first faculty hires tied to the new Centre for the Universe, while **Yin-Chen He** and **Timothy Hsieh** are leaders in the new **Quantum Matter Initiative at Perimeter Institute** (refer to page 11).

Dalal arrived in October 2017 from the University of Illinois at Urbana-Champaign, where he had been an Assistant Professor since 2011. His research probes the fundamental physics of cosmology, the structure of the universe, and the formation of galaxies – often at the interface of theory and experiment – and he has pioneered several tests of the nature of dark matter using cosmological data.

DISTINGUISHED VISITING RESEARCH CHAIRS

Scott Aaronson, University of Texas at Austin
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
Charles H. Bennett, IBM Thomas J. Watson Research Center
Edo Berger, Harvard University
Patrick Brady, University of Wisconsin-Milwaukee
Alessandra Buonanno, Max Planck Institute for Gravitational Physics (Albert Einstein Institute) and University of Maryland, College Park
John Cardy, University of California, Berkeley, and University of Oxford
Juan Ignacio Cirac, Max Planck Institute of Quantum Optics
Lance Dixon, Stanford University
Matthew Fisher, University of California, Santa Barbara
Dan Freed, University of Texas at Austin
Katherine Freese, University of Michigan
S. James Gates Jr., Brown University
Gabriela González, Louisiana State University
Duncan Haldane, Princeton University
Patrick Hayden, Stanford University
Joseph Incandela, University of California, Santa Barbara
Ted Jacobson, University of Maryland, College Park
Shamit Kachru, Stanford University
Anton Kapustin, California Institute of Technology
Adrian Kent, University of Cambridge
Renate Loll, Radboud University, Nijmegen
John March-Russell, University of Oxford
Ramesh Narayan, Harvard University
Sandu Popescu, University of Bristol
Frans Pretorius, Princeton University
Nathan Seiberg, Institute for Advanced Study
Peter Shor, Massachusetts Institute of Technology
Iakov (Yan) Soibelman, Kansas State University
Dam Thanh Son, University of Chicago
Paul Steinhardt, Princeton University
Andrew Strominger, Harvard University
Raman Sundrum, University of Maryland, College Park
Leonard Susskind, Stanford University
Gerard 't Hooft, Utrecht University
Barbara Terhal, Delft University of Technology
Senthil Todadri, Massachusetts Institute of Technology
William Unruh, University of British Columbia
Frank Verstraete, University of Vienna and University of Ghent
Ashvin Vishwanath, Harvard University
Zhenghan Wang, Microsoft Research Station Q
Xiao-Gang Wen, Massachusetts Institute of Technology
Steven White, University of California, Irvine
Mark Wise, California Institute of Technology
Matias Zaldarriaga, Institute for Advanced Study
Alexander Zamolodchikov, Stony Brook University

East uses numerical methods and high-performance computing to study violent astrophysical phenomena – such as black hole mergers and the collision of dense stars – to test existing models of the universe. He joined the faculty in January 2018.

Hsieh joined Perimeter in March 2018 from the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara. His interdisciplinary research explores quantum materials, entanglement, and dynamics.

He arrived in July 2018 from Harvard University, where he was a Gordon and Betty Moore Fellow. He is a condensed matter researcher interested in spin liquids, topological phases, and numerical simulations.

Perimeter's faculty now includes 25 scientists spanning the spectrum of theoretical physics. Next year, the Institute expects to welcome at least one more recruit: condensed matter researcher **Chong Wang** from Harvard University, who will strengthen the growing Quantum Matter Initiative.

ASSOCIATE FACULTY

"To complement a good observational group, you need a good theoretical group. Having the association between the new group at UW and the expertise available at Perimeter will be awesome."

– Will Percival, Perimeter Associate Faculty member and Distinguished Research Chair in Astrophysics at the University of Waterloo

Perimeter works with academic partners to create joint associate faculty positions. Together, we strengthen recruitment efforts, attract top international talent, and help position Canada as an international leader in fundamental physics.

This year, Perimeter welcomed three new associate faculty from the United States and United Kingdom. The Institute now has 19 associate faculty cross-appointed with seven Canadian universities.

Huan Yang arrived from Princeton University in September 2017, jointly appointed with the University of Guelph. He is an expert in black holes and gravitational waves, among other areas, and is a member of the Centre for the Universe at Perimeter Institute.

In March 2018, the Institute welcomed eminent astrophysicist **Will Percival**, previously of the University of Portsmouth, in a joint appointment with the University of Waterloo. Percival works at the interface of observational and theoretical astrophysics and cosmology, with a particular interest in galaxy surveys. He is a senior member of the Dark Energy Spectroscopic Instrument (DESI), Extended Baryon Oscillation Spectroscopic Survey (eBOSS), and Euclid experiment.

Matilde Marcolli began a joint appointment with the University of Toronto in January 2018, after a decade as a Professor of Mathematics at the California Institute of Technology. In addition to bolstering Perimeter's growing strength in mathematics, Marcolli conducts research spanning computational linguistics, particle physics, quantum gravity, and cosmology.

DISTINGUISHED VISITING RESEARCH CHAIRS

Perimeter is the second research home of more than 50 of the world's top physicists. Distinguished Visiting Research Chairs (DVRCs) are appointed to renewable three-year terms and make extended research visits to Perimeter, while retaining permanent positions at their home institutions.

This unique program widens Perimeter's scientific community to include an outsized percentage of the field's pioneers. While here, DVRCs energize the Institute's research community by participating in all facets of life at Perimeter, including organizing conferences, presenting seminars, and collaborating with resident scientists. Freed from their usual teaching and administrative duties, DVRCs report that time spent at Perimeter is highly productive; some, such as recent recruit Matilde Marcolli, even decide to move to Perimeter permanently.

This year, Perimeter appointed one new DVRC and renewed 16 more, bringing the total to 51 DVRCs spanning every branch of theoretical physics – including luminaries such as **Abhay Ashtekar**, **Charles H. Bennett**, **Katherine Freese**, and **S. James Gates Jr**.

The Distinguished Visiting Research Chairs program is supported by Cenovus Energy.

VISITING FELLOWS

The Visiting Fellows program is another means by which Perimeter engages with the wider scientific community while diversifying its own, bringing accomplished researchers to the Institute for regular visits. Like DVRCs, Visiting Fellows are appointed to renewable terms, retain their positions at home institutions, and enrich Perimeter's research environment during extended stays.

This year, Perimeter appointed 17 new Visiting Fellows and renewed seven more, bringing the total to 46 Visiting Fellows spanning a wide range of expertise.

POSTDOCTORAL RESEARCHERS

Tackling some of the most challenging problems in physics requires creativity and fresh perspectives, which makes early-career scientists uniquely equipped to help push the field forward. That's why Perimeter hosts the world's largest community of independent postdoctoral researchers in theoretical physics – and it's getting bigger.

This year, tied to the new Centre for the Universe, the Institute launched the S.W. Hawking, P.J.E. Peebles, and Ya B. Zel'dovich Fellowships. They will be held by exceptional young scientists, who, it is hoped, will become a new generation of pioneers.

In 2017/18, 23 new postdocs joined Perimeter, with 17 more recruited for next year – including five who were jointly recruited with either the University of Toronto or the Institute for Quantum Computing at the University of Waterloo.

As full members of the research community, postdocs have unique opportunities: complete research freedom, encouragement to do ambitious, career-defining work, and mentorship from senior scientists. They have resources to invite collaborators, organize conferences, and present their work internationally. This autonomy pays off: in an extremely competitive international academic market, five departing postdoctoral researchers obtained tenure-track faculty positions in 2017/18.

NEAL DALAL: DIGGING THROUGH COSMIC DATA

As a child, **Neal Dalal** imagined he might grow up to become a paleontologist – sifting through bones and fossils, he would help map out the history of life on Earth.

Instead, Dalal wound up studying history on a grander scale. As a cosmologist, he digs into distant, ancient galaxies and relic radiation leftover from the big bang to understand the origins and evolution of the universe.

Dalal came to Perimeter as a faculty member in October 2017, where he joined the Centre for the Universe, an interdisciplinary research cluster designed to tackle the toughest questions in cosmology.

Here, Dalal hopes to strengthen Perimeter's connections to several major experimental efforts, including large-scale surveys of galaxies that will be used to study dark energy and map the geometry of space.

In addition to tangling with cosmic questions, Dalal hopes to tackle the very human challenge of bridging the communication gap that can exist between specialists.

"It can be hard to communicate because people use different words for the same things," he explains. "Oftentimes, progress is made just by being able to translate one area to another, and vice versa."

TRAINING THE NEXT GENERATION

PSI FACULTY, 2017/18

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

Tibra Ali, Perimeter Institute

Cliff Burgess, Perimeter Institute and McMaster University

Freddy Cachazo (Gluskin Sheff Freeman Dyson Chair), Perimeter Institute

Kevin Costello (Krembil William Rowan Hamilton Chair), Perimeter Institute

François David, Institute of Theoretical Physics/CEA-Saclay

Maité Dupuis, Perimeter Institute

Joseph Emerson, Institute for Quantum Computing (IQC)/University of Waterloo

Davide Gaiotto (Krembil Galileo Galilei Chair), Perimeter Institute

Daniel Gottesman, Perimeter Institute

Ruth Gregory, Durham University

Alioscia Hamma, University of Massachusetts, Boston

Lauren Hayward Sierens, Perimeter Institute

David Kubiznak, Perimeter Institute

Eduardo Martin-Martinez, IQC/University of Waterloo

Kendrick Smith (Daniel Family P. James E. Peebles Chair), Perimeter Institute

Robert Spekkens, Perimeter Institute

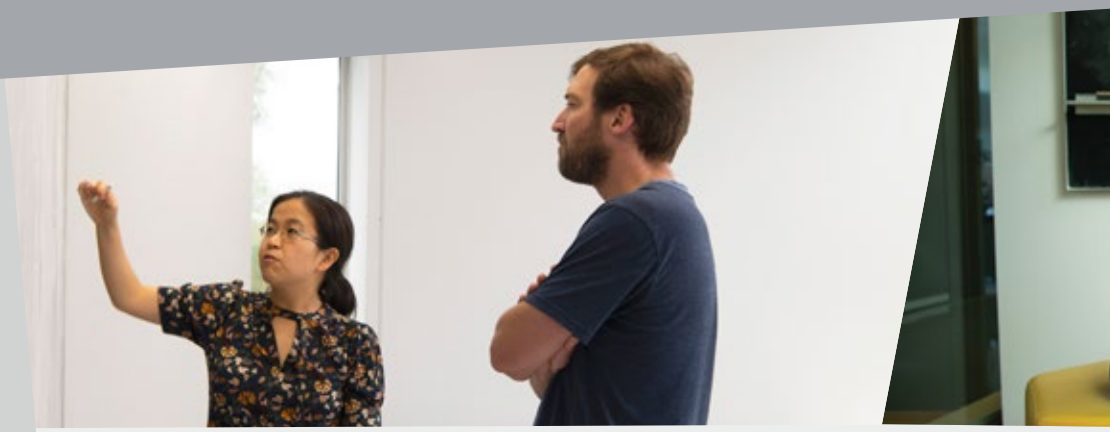
Rakesh Tiwari, McGill University

Sean Tulin, York University

Neil Turok (Mike and Ophelia Lazaridis Niels Bohr Chair), Perimeter Institute

Dan Wohns, Perimeter Institute

Gang Xu, Perimeter Institute



PERIMETER SCHOLARS INTERNATIONAL

"I was no longer the woman in the class. I was a woman in the class."

– Katarina Martinovic, valedictorian of the 2017/18 PSI class

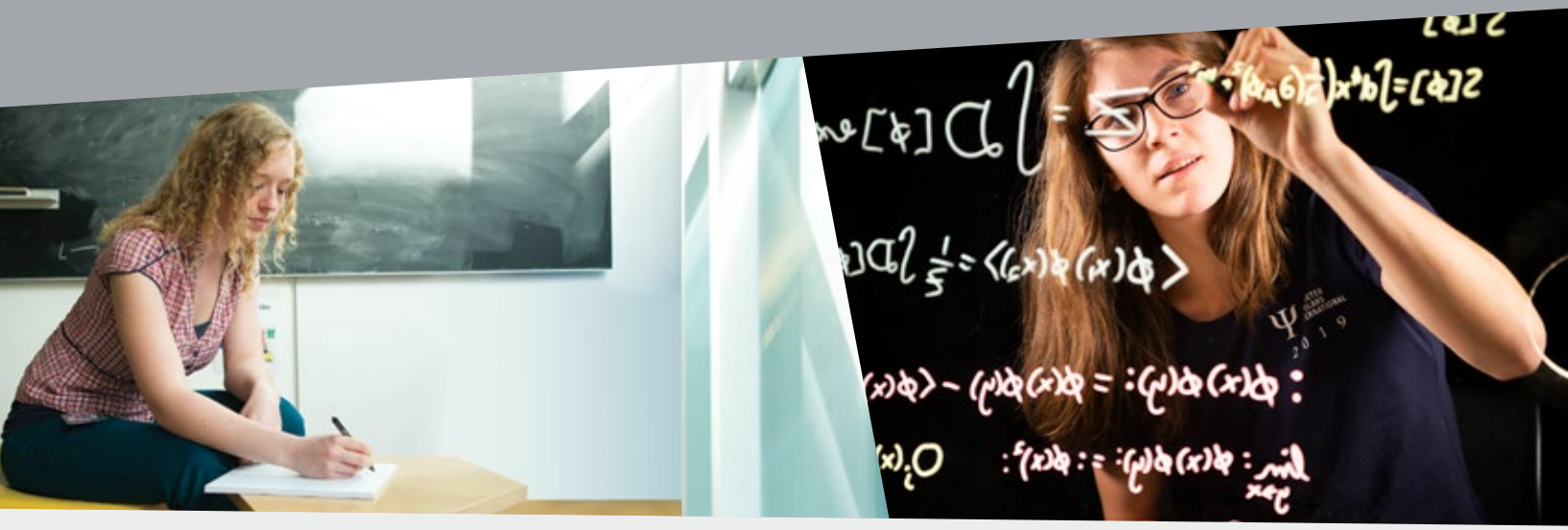
Brilliant young minds are the lifeblood of science. Perimeter Scholars International (PSI) has become one of the most sought-after master's programs in theoretical physics worldwide, with over 500 applicants vying annually for approximately 30 spots. Those accepted spend 10 intense months exploring the full spectrum of cutting-edge theoretical physics, from quantum theory to early-universe cosmology.

The breadth of PSI's curriculum is unique, but so is its emphasis on collaboration over competition and problem solving over rote learning. Students emerge with skills such as critical thinking and computer-based model development that serve them well in academia and beyond. Run in partnership with the University of Waterloo, graduating students receive a master's degree from Waterloo and a PSI certificate from Perimeter.

In 2017/18, PSI trained 30 students, including 13 women, from 22 countries. Five graduates have remained in Canada for their doctoral studies, four of them at Perimeter. Others went on to top international institutions, including the California Institute of Technology, Stanford University, and the University of California, Santa Barbara.

The program continues to be very popular: only seven percent of the 500-plus applicants for PSI's 2018/19 class received an offer, and more than 94 percent of them accepted, a rate higher than virtually all top international institutions. The incoming class comprises 34 students from 23 countries, including 10 women.

The PSI program was generously supported in 2017/18 by: Joanne Cuthbertson and Charlie Fischer, The Hellenic Heritage Foundation, Maplesoft, Brad and Kathy Marsland, Margaret and Larry Marsland, The Savvas Chamberlain Family Foundation, and members of the Emmy Noether Circle.



"PSI brought me to Canada. My current supervisor, Roger Melko, and Perimeter Institute made me choose to stay in Canada."

– Anna Golubeva, Perimeter PhD student and 2017 PSI graduate

PHD STUDENTS

When top international students come to Canada for PSI, they often stay. Nearly two-thirds of the Institute's resident PhD students completed the PSI program, meaning top students are finding supervisors they want to work with and staying put. This is good news not just for Perimeter, but also for the Canadian partner universities where they receive their degrees and the Canadian companies where Perimeter graduates have ultimately settled.

PhD students at Perimeter are trained in a world-class research environment, with unparalleled opportunities to interact with scientific leaders. They are encouraged to do original research, while developing advanced analytical, problem-solving, and quantitative skills that are widely applicable and highly sought-after. Graduates have gone on to successful careers in academia, finance, technology, government, and beyond.

Ten PhD students supervised by Perimeter faculty graduated from partner universities in 2017/18. The majority went on to postdoctoral fellowships at leading institutions, including the Massachusetts Institute of Technology, Stony Brook University, and the Institute for Quantum Computing at the University of Waterloo. Others go on to industry positions with companies like BMO Capital Markets.

At year's end, Perimeter had 53 PhD students in residence, with an additional 12 PhD students supervised by Perimeter faculty and associate faculty while in residence at partner universities.

In 2017/18, two PhD students were the recipients of the Peter and Shelagh Godsoe Family Foundation Exceptional Emerging Talent Awards.

VISITING GRADUATE FELLOWS

Perimeter's Visiting Graduate Fellows program provides an avenue for advanced PhD students from around the world to make extended visits to the Institute, interacting with leading researchers at a pivotal time in their training. These young researchers both benefit from – and contribute to – the Institute's dynamic research environment, and the collaborations that form typically extend beyond the length of the students' stays.

In 2017/18, the program continued to grow, as Perimeter hosted 44 Visiting Graduate Fellows for a total of 47 visits. These are not generally brief visits: on average, Visiting Graduate Fellows stayed for more than four months.

"I came to Canada because I believe Canada is especially supportive of foundational research in physics."

– David Schmid, Perimeter PhD student and 2018 Vanier Scholar

CATALYZING RAPID PROGRESS

Participants at "Open Research" conference

BY THE NUMBERS

In **2017/18**, Perimeter …

Held **20** conferences and workshops, attended by **713** scientists from around the world

Presented **290** scientific talks (**261** seminars and **29** colloquia)

Partnered on **eight** joint workshops and conferences held at Perimeter, and sponsored an additional **11** off-site workshops and conferences (**10** in Canada)

CONFERENCES AND WORKSHOPS

Advances in physics are happening fast, as large-scale efforts like the Large Hadron Collider at CERN, Event Horizon Telescope (EHT), and Canadian Hydrogen Intensity Mapping Experiment (CHIME) provide unprecedented amounts of data to analyze. These are massive operations involving hundreds or thousands of scientists. With so many involved, collaboration and communication are paramount.

Perimeter's renowned conference program has been facilitating those crucial conversations for years. The Institute brings together hundreds of researchers annually – theorists and experimentalists alike from diverse research areas – to tackle tough problems and make rapid progress. Conferences focus on leading-edge topics with the potential for significant outcomes, and the program's reputation allows the Institute to attract top thinkers in these areas. Due to its agility, Perimeter often hosts workshops on topics that have yet to be addressed anywhere else.

In 2017/18, 713 scientists from around the world attended 20 conferences and workshops at Perimeter, with talks recorded and made available to a wider audience online.

SEMINARS AND COLLOQUIA

Throughout the year, both resident and visiting scientists give seminars and colloquia that enrich the Institute's intellectual life, sharing pioneering research as it happens, challenging established modes of thought, and fostering collaboration across disciplines.

In the past year, Perimeter hosted 290 scientific talks (261 seminars and 29 colloquia). Talks were given by luminaries from across the Institute's areas of research focus, including Distinguished Visiting Research Chairs **Scott Aaronson**, **Edo Berger**, **Ted Jacobson**, and **Mark Wise**.

PHYSICS TALKS ONLINE

Every time the Perimeter Institute Recorded Seminar Archive (PIRSA) is down for server maintenance, Perimeter's IT staff hears about it. Whether it's a professor in New York or a self-taught student in Bangladesh, there always seems to be somebody who urgently needs to see the latest talks. And no wonder: these seminars present the newest ideas and are particularly invaluable to those who are not located at major research centres.

That's why all scientific talks at Perimeter are recorded and made freely available, both in the Video Library section of Perimeter's website and via PIRSA (pirsa.org). This searchable and citeable archive of over 11,000 seminars, conferences, workshops, and courses was developed by the Institute to share knowledge with the international scientific community, and it has become the leading online institutional video archive in theoretical physics.

In 2017/18, the archive was accessed by 115,402 unique visitors from more than 190 countries, accounting for 867,038 page views.

CAN OPEN-SOURCE SOFTWARE BE A MODEL FOR SCIENCE?

Science is becoming more complex and so are the global networks and collaborations required to pursue big breakthroughs. A growing number of scientists argue that changing not just how we do science, but how we share it as well, could unlock vast new opportunities.

In March 2018, a gathering of scientists, designers, and entrepreneurs assembled at Perimeter to explore how some of the best principles of the open-source movement could be applied to research. Some efforts to pursue "open-source science" are already underway; conference participants discussed lessons learned and potential pitfalls, identifying avenues worth exploring to establish open-source science tools.

"The acceleration of scientific progress is strongly dependent on our ability to create cooperative networks," says conference co-organizer Bapu Vaitla of Harvard University's T.H. Chan School of Public Health. "By democratizing the awareness of the problem and inviting everyone to come help solve it, we find that problems are solved quicker, errors are remedied quickly, and science moves forward at a faster rate."

A GLOBAL LEADER

Physics is a global pursuit. For this reason, Perimeter aims to be a hub not just for Canadian physics, but on an international scale.

The Institute's lively visitor and affiliate programs encourage collaboration, while Perimeter's institutional partnerships and global outreach efforts allow the Institute to reach out to the scientific community and benefit from the diversity of thought required to make major progress. By strengthening international ties, Perimeter is not only raising its own stature in the field, but also hastening the breakthroughs of the future.

VISITOR PROGRAM

A steady flux of new people and new ideas keep Perimeter's research environment vibrant. With over 400 scientific visitors annually, presenting talks or just working in the Black Hole Bistro, the possibilities for fresh perspectives and collaborations multiplies exponentially.

Visitors benefit from the same math: leading scientists from around the world come to Perimeter because they know they will be exposed to new ideas – and, crucially, will have the time and space necessary to pursue them. The resulting cross-pollination of ideas often leads to new collaborations. Experiencing the Institute's unique environment and administrative support first-hand often helps "clinch the deal" in recruitment efforts.

In 2017/18, Perimeter hosted 424 visiting scientists for a total of 465 visits, including 14 Distinguished Visiting Research Chairs, 22 Visiting Fellows, and 9 Simons Emmy Noether Fellows. The rest were short-term visitors, including affiliates, collaborators, seminar and colloquia speakers, and potential recruits. In the past year, visits to Perimeter ultimately led to new appointments at all levels – including Faculty members **Yin-Chen He**, **Timothy Hsieh**, and **Chong Wang**.

AFFILIATES

Perimeter's Affiliate program unites the Canadian physics community by providing select researchers from institutions across the country with the opportunity for regular collaboration visits. The program deepens Perimeter's connections to more than 25 Canadian research centres, while affiliates benefit from access to the Institute's vibrant research community.

In 2017/18, Perimeter appointed 10 new affiliates and renewed 53 more through 2020, bringing the total affiliate community to 116. (Refer to page 63 for a complete list.)

COLLABORATIONS AND PARTNERSHIPS

By partnering with leading centres in Canada and abroad, Perimeter provides collaboration opportunities to its scientists while strengthening its position as a global research hub. The Institute now has more than a dozen such partnerships.

In 2017/18, Perimeter signed a new partnership to promote scientific exchanges and joint workshops with the Institute for Quantum Studies at Chapman University in California, where Perimeter Distinguished Visiting Research Chair Yakir Aharonov acts as co-director. Perimeter also renewed a similar partnership with the International School for Advanced Studies (SISSA) in Italy through 2021.

In May 2018, the Arthur B. McDonald Canadian Astroparticle Physics Research Institute was officially launched at Queen's University, with Perimeter as one of 13 affiliated institutions. Named for the 2015 Nobel laureate in physics (and outgoing Perimeter Board member), the McDonald Institute will act as a national hub of astroparticle physics, with Perimeter researchers making collaboration visits.

Through the new Centre for the Universe, launched in November 2017 with a founding gift from an anonymous philanthropist, Perimeter is bolstering ties with several experimental and observational facilities – including the Event Horizon Telescope (EHT), Square Kilometre Array (SKA), Laser Interferometer Gravitational-Wave Observatory (LIGO), and Canadian Hydrogen Intensity Mapping Experiment (CHIME).

Finally, the Waterloo Global Science Initiative, a partnership between Perimeter and the University of Waterloo, held the Generation SDG Summit to chart a course towards implementation of the United Nations' Sustainable Development Goals in Canada and abroad.

GLOBAL OUTREACH

Talent knows no national boundaries, so Perimeter works collaboratively to help support emerging centres of excellence in developing countries. The Institute encourages scientific exchanges and promotes the rise of new voices in physics and mathematics.

In 2017/18, Perimeter continued to provide support to its two primary global outreach partners: AIMS-NEI, a pan-African network of centres providing mathematical and scientific education to exceptional African graduates, and the South American Institute for Fundamental Research (SAIFR), an emerging centre of excellence in theoretical physics located at São Paulo State University (UNESP) in Brazil. Perimeter researchers continue to be involved with teaching at both the AIMS and SAIFR centres.

Perimeter also shares its expertise in educational outreach internationally. This effort intensified in the past year: in addition to presenting several workshops in Brazil, Perimeter has started to translate its educational resources into Portuguese and is helping SAIFR build a Teacher Network that can vastly extend their reach in South America. Perimeter staff have also initiated discussions on conducting Teacher Network training in Rwanda, where AIMS-NEI is headquartered.

FAREWELL, STEPHEN HAWKING

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

– Stephen Hawking

When **Stephen Hawking** passed away on March 14, 2018, the world lost an icon. Perimeter lost a colleague, friend, and champion.

Hawking was Perimeter's first Distinguished Visiting Research Chair and he made two extended research visits to the Institute, collaborating with resident scientists and delivering a televised public lecture.

In 2011, Perimeter opened the Stephen Hawking Centre – the only building in the world to which Hawking lent his name. And in late 2017, he lent his name again to create the S.W. Hawking Postdoctoral Fellowship at Perimeter Institute, to be held by an outstanding young theoretical cosmologist.

"Stephen's life was heroic, in so many ways. He was a brilliant visionary in theoretical physics, setting an incredibly bold agenda for the field," says Perimeter Director Neil Turok, a friend and former colleague of Hawking's at the University of Cambridge. "His spirit will live on in all of us who knew him, as we aspire, with all our hearts, to perpetuate the many wonderful human qualities he embodied."

EDUCATIONAL OUTREACH AND PUBLIC ENGAGEMENT

"Obviously, we're learning a lot of really cool physics. But on top of that, these sessions have taught me new ways of thinking critically about ideas, and how to pursue the creation of a model for an idea."

– Marin Schultz, Catholic Central High School, Lethbridge, AB, ISSYP 2018 participant

BY THE NUMBERS

Facilitated over **10 million** student interactions through educational programs and resources

Delivered **161** workshops to over **4,600** educators across Canada and abroad

Gave **15** Physica Phantastica presentations to over **3,600** Canadian students

Attracted over **1.4 million** YouTube video views

THE INTERNATIONAL SUMMER SCHOOL FOR YOUNG PHYSICISTS (ISSYP)

Each summer, Perimeter's International Summer School for Young Physicists plunges future scientists from across Canada and around the world into the Institute's vibrant research community. Interestingly, recent faculty recruit **Timothy Hsieh** first came to Perimeter in 2006 as an ISSYP student!

For the exceptional high school students who attend, it's no wonder ISSYP often crystallizes a career path. Surrounded by kids who share their passion for physics, attendees take a deep dive into modern physics, exploring quantum mechanics, special relativity, and current research problems, taught by some of the leading researchers trying to solve them.

The challenging, packed schedule includes talks from top scientists, mentoring sessions, late nights spent debating amongst themselves, and field trips to cutting-edge experimental facilities like SNOLAB (a neutrino laboratory located deep in a Sudbury mine) and the Institute for Quantum Computing at the University of Waterloo. After two weeks, attendees leave saturated with new ideas, and new friends from all over the world.

This year, Perimeter hosted the 16th edition of ISSYP, with 18 Canadians (spanning nine provinces and territories) and 22 international students from 14 other countries, evenly split between young women and men.

The 2017/18 edition of ISSYP was made possible by the continued generous support of the RBC Foundation, ISSYP's Presenting Partner. Additional support was received from Maplesoft.

EINSTEINPLUS

"If we can make more teachers feel like this, and they can share that feeling with their students, it can be contagious and help change education."

– Ana Serio, Escola Vera Cruz, São Paulo, Brazil, EinsteinPlus 2018 participant

Each summer, Perimeter's EinsteinPlus Teacher Camp turns teachers from across Canada and around the globe into students for one week. They explore creative ways of reigniting their passion for physics – using beach balls to understand time dilation, buckets of water to grasp force and momentum, and teamwork and tenacity to puzzle through a host of other vexing problems – so that they can, in turn, elicit the same excitement in their students.

For teachers, it is a valued professional development opportunity that introduces them to Perimeter's educational resources and effective methods for teaching modern physics. In 2018, Perimeter hosted 44 teachers: 17 Canadians and 27 international teachers from 11 countries. For the first time, the EinsteinPlus experience was also available in French through a partnership with Cégep de Trois-Rivières, reaching several teachers from Alberta and Quebec.

Support for EinsteinPlus was provided by Maplesoft.

"We can connect somewhat with super-complex subject matter, but the summer workshop has shown us that it's possible to make it accessible, and I found that very inspiring."

– Roxanne Lemay, École secondaire Chavigny, Trois-Rivières, QC, CERCLE scientifique EinsteinPlus 2018 participant

INSPIRING FUTURE WOMEN IN SCIENCE

"More women in science today means more women in science tomorrow. That's not only good for women – it's good for society."

– Dr. Mona Nemer, Chief Science Advisor for the Government of Canada, at the 2018 "Inspiring Future Women in Science" event

Science encompasses a vast breadth of possibilities and there are many paths to success if you're resilient. That message came as a relief and an inspiration to many of the nearly 200 young women attending this year's edition of the "Inspiring Future Women in Science" conference, which brought high school students to Perimeter to connect with successful women at various stages of their careers in science, technology, engineering, and mathematics (STEM). As part of Perimeter's Emmy Noether Initiatives, which seek to attract and retain more women in physics, the half-day event featured keynote talks, a Q&A panel, and mentoring sessions.

Linamar Corporation was the Presenting Sponsor of the 2018 "Inspiring Future Women in Science" conference.

NEW EDUCATIONAL RESOURCES

Perimeter's free digital resources are designed to help teachers explain a range of important topics in physics – and science more broadly. Each resource includes a set of lesson plans, hands-on activities and demos, background information for teachers, and original Perimeter videos.

This year, with support from the Ontario Ministry of Education, Perimeter released three new educational resources – in English and French – exploring different aspects of the universe.

In "Evidence for Climate Change," Grade 10 students explore the essential science behind climate change through activities focused on heat, carbon dioxide, and thermal expansion.

Through a series of hands-on experiments, "A Deeper Understanding of Energy" teaches Grade 11 students about energy transformations, the power of conservation laws, and the process of how scientific models evolve.

"Wave Model Applications," also for Grade 11 students, introduces the basic properties of waves and illustrates tangible uses of wave phenomena to reduce noise, image shipwrecks, study earthquakes, and detect gravitational waves, among other applications.

"Forces of Nature: Great women who changed science" series of free, downloadable posters won Gold at the CCAE Awards this year.

SHARING THE POWER OF IDEAS ACROSS ONTARIO

Perimeter's Power of Ideas Exhibition racked up a lot of kilometres in 2017, travelling from coast to coast to coast in Canada's sesquicentennial year as part of the successful Innovation150 Tour. Designed and developed by Perimeter in collaboration with the Ontario Science Centre, the hands-on exhibition brings powerful ideas and cutting-edge experiments to life, helping us to understand the natural world.

With support from the Ontario Ministry of Education, the Power of Ideas Tour ramped up anew in the spring of 2018, covering even more ground in Canada's most-populous province, with a focus on remote communities. The tour reached more than 18,000 students in 82 communities across the province – most of them in underserved parts of Northern Ontario – including 19 First Nations communities. Along the way, staff distributed the Institute's sought-after educational resources, which will continue to impact students for years to come.

PERIMETER HONOURED AT CCAE AWARDS

Perimeter Institute won big at the Canadian Council for the Advancement of Education (CCAE) awards, winning two golds, a silver, and a bronze for outstanding achievements in communications, publications, and fundraising.

The Council's annual Prix d'Excellence awards are the benchmark for achievements in educational advancement in Canada. Competing against universities and educational institutes across the country, Perimeter's four awards put it among the top winners nationally in 2018.

PUBLIC LECTURE SERIES

With compelling talks on everything from Canadian innovation and the ingenuity that led to CERN's Large Hadron Collider to creating exotic new materials, Perimeter's Public Lecture Series continues to be one of the Institute's most popular public outreach programs.

This year, Perimeter presented seven engaging talks to full-house crowds in the Mike Lazaridis Theatre of Ideas and to online audiences around the world. Highlights of the 2017/18 season included Emily Levesque discussing "The Weirdest Stars in the Universe"; Perimeter's own Roger Melko on rapid advances in artificial intelligence and machine learning; and Erik Verlinde presenting a new theory about gravity, dark energy, and dark matter.

All lectures are professionally recorded. They are webcast live and available for on-demand playback via Perimeter's website, YouTube, and media partners such as *Scientific American*, *Maclean's*, *COSMOS*, and *Forbes*. The 2017/18 season has already amassed over 580,000 online views.

CULTURAL EVENTS

Tackling deep questions about the universe requires creative minds, and Perimeter complements research activities with cultural events aimed at fostering creativity and sparking inspiration.

In 2017/18, efforts to ensure the Institute is a vibrant place where new ideas can flourish have included art installations by Laura De Decker and Lucy Pullen, a colloquium from writer Cory Doctorow, a performance from a Balinese Orchestra, and watercolour paintings of scientific talks at the "Asymptotic Safety in a Dark Universe" conference.

Perimeter also reaches out to the community with the long-running Classical World Artists Series. This year, captivating performances in the Mike Lazaridis Theatre of Ideas included Vox Luminis, Juho Pohjonen, Xuefei Yang, and the Benedetti Elschenbroich Grynyuk Trio.

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

SCIENCE COMMUNICATION AND SOCIAL MEDIA OUTREACH

Sharing the joy and power of science with the masses is a core element of Perimeter's mission. Through its websites, *Inside the Perimeter* magazine, social media channels, and many partnerships, Perimeter shares news and big ideas from the forefront of science, aiming to be the leading source of accurate, fascinating, and shareable physics content online.

With 215,529 unique visitors accounting for 411,319 page views in 2017/18, insidetheperimeter.ca, the Institute's new public-facing website, is showing that there's a big appetite for accessible, engaging science content. The site aims to contribute to a more scientifically engaged society with deep dives into cutting-edge science; award-winning "Slices of PI" that showcase the fun of science with quizzes and shareable memes; and the new "People of PI" series, telling the human stories behind the science.

Social media engagement continues to grow: Perimeter's Facebook fans increased by 13 percent in 2017/18, while Twitter followers jumped by more than 20 percent. YouTube subscribers increased by 48 percent, and Perimeter's videos were viewed 1,416,827 times, bringing the channel's total views to date to more than 4.5 million.

MEDIA COVERAGE

Influential media look to Perimeter as a reliable source of high-quality theoretical physics news, commentary, and insight. This year, Perimeter research, people, and events received major coverage in national and international media, including in-depth articles in outlets including *The Canadian Press*, *The Globe and Mail*, CBC's *The National*, *CTV National News*, Al Jazeera, *The Economist*, *Forbes*, and many more.

ADVANCING PERIMETER'S MISSION

"I am pleased with the Institute's efforts in helping to advance Canada's prominence in theoretical physics, an area with broad transformative potential to benefit our economy and improve the quality of life of Canadians."

– The Hon. Kirsty Duncan, Minister of Science and Sport

Perimeter is supported by the Government of Canada and the Government of Ontario, and an ever-growing group of international private sector donors. Together with our supporters, we aim to build the world's best theoretical physics institute.

Our government and private partners understand that theoretical physics is the lowest-cost, highest-impact investment they can make to advance all of science and technology – that one breakthrough in theoretical physics can revolutionize society.

In 2017/18, Perimeter entered into the first year of new five-year $50 million funding agreements with both the Province of Ontario and the Government of Canada. These renewed investments continue a partnership that has been essential to the Institute's success since its early days. Perimeter also continues to support their government partners as appropriate. For example, the Institute hosted high-level delegations from seven countries as they planned for the 2018 G7 Summit in Quebec, as well as senior provincial public servants visiting to learn about its unique approach to skills building for next-generation talent and industries. In addition, Perimeter promoted Ontario and Canada to influential audiences – including keynote addresses at the Canada Science Policy Conference, the Public Policy Forum Testimonial Dinner, and the OECD Global Forum on Productivity.

The Institute is currently in the midst of a $100-million private sector campaign, and last year secured new commitments to surpass $30 million. These included major gifts from Coril Holdings, in support of the Coril Holdings Archimedes Chair in Theoretical Physics (Visiting), held by Savas Dimopolous; the Daniel Family Foundation, in support of the Daniel Family P. James E. Peebles Chair in Theoretical Physics, held by Kendrick Smith; and Power Corporation of Canada, proud supporter of EinsteinPlus and the Perimeter Teacher Network.

In 2017/18, Perimeter received $6.42 million in revenues from individuals, corporations, and foundations. With the Institute's US-based 501(c)(3) charity now a public foundation, Perimeter expects to welcome many more private donors in the coming years.

These far-sighted investments of Perimeter Institute's partners give the Institute an edge in the global race for talent in fundamental physics at a time of rapid progress and high discovery potential.

LIGHTING THE WAY

Perimeter recognizes and thanks the following donors, who have made cumulative gifts totalling $100,000 or more since 2014, following the lead of Perimeter's Founding Donor, Mike Lazaridis.

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PERIMETER INSTITUTE LEADERSHIP COUNCIL

The Leadership Council is comprised of prominent individuals who act as ambassadors for Perimeter in the business and philanthropic communities, helping the Institute grow strategically.

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President and CEO, Compugen Inc.

** Term ended in 2018*

FROM ABSTRACT MATHEMATICS TO TANGIBLE PHYSICS

Like many physicists, **Stavros Efthymiou**'s first love was mathematics. His affinity for physics developed later, as he got more exposure to the subject in his school courses.

"I liked mathematics, and physics made it somehow real," says Efthymiou, who grew up on the Greek island of Rhodes and came to Perimeter as part of the 2017/18 Perimeter Scholars International (PSI) master's program.

He was inspired by the challenges, and by the emphasis at PSI on collaboration. "Everyone knows something different about physics," he says. "We learn from each other."

For his PSI research project, Efthymiou worked with Perimeter Associate Faculty member **Roger Melko** on applications of machine learning to condensed matter physics – a field he enjoyed for its freshness and novelty.

In the future, Efthymiou hopes to tackle problems in the quantum realm. Whichever direction he chooses, he is confident that theoretical physics is the best path. "We have knowledge that is very valuable, even if it is not applied," he says.

Stavros Efthymiou was a member of the 2017/18 PSI class and the recipient of the Anaximandros Fellowship, supported by the Hellenic Heritage Foundation and the Savvas Chamberlain Family Foundation.

SUPPORTING – AND CELEBRATING – WOMEN IN PHYSICS

THE EMMY NOETHER COUNCIL

Council volunteers provide expertise, donations, and other support, helping the Emmy Noether Circle bring more women into physics.

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Vicki Saunders
Founder, SheEO

Suzan Snaggs-Wilson*
District Vice President, Scotiabank (West New Brunswick)

** Term ended in 2018*

Gender equality – or the lack thereof – was a major topic of conversation over the last year, both in science and society writ large. It was a welcome development at Perimeter, where efforts to effect real change in the underrepresentation of women in physics have coalesced in recent years to form the Institute's Emmy Noether Initiatives, backed by a committed group of funders and champions of women in science called the Emmy Noether Circle.

Named for the trailblazing scientist whose work underpins much of modern physics, the **Emmy Noether Initiatives** support women at all stages of their career, from high school students through to Perimeter faculty.

Over the past year, highlights included Perimeter's annual "Inspiring Future Women in Science" conference for high school students, as well as sponsorship of the "Canadian Conference for Undergraduate Women in Physics 2018" at Queen's University and the "Women in Physics Canada 2018" conference at the University of Sherbrooke. Perimeter researchers, staff, and

Leadership Council members also met with Lieutenant Governor of Ontario Elizabeth Dowdeswell at Queen's Park to discuss the advancement of women in science, and the Institute released its award-winning poster series, "Forces of Nature: Great women who changed science," shining a spotlight on some of women's historical contributions to the field.

2017/18 also saw an expansion of Perimeter's flagship program to support and promote women physicists thanks to a $600,000 USD grant from the Simons Foundation. Simons Emmy Noether Fellowships will allow early- and mid-career researchers to spend up to a year in Perimeter's vibrant, interdisciplinary community at a critical stage of their career. Over the past year, Perimeter welcomed nine Simons Emmy Noether Fellows for a total of 11 visits.

Thanks to the new funding, the Simons Emmy Noether Fellows program is expanding in size and depth, with conferences, a researcher network, and intensified recruitment of new Fellows in developing countries.

Emmy Noether Initiatives are supported by donors from the Emmy Noether Circle. For a full list, refer to page 41.

"The Simons Emmy Noether Fellows' Network will be unique in connecting highly qualified women researchers in theoretical physics across the globe and to Perimeter Institute."

– Bianca Dittrich, Perimeter faculty member

THANKS TO OUR SUPPORTERS

An ever-growing group of both public and private donors has helped make Perimeter what it is today: a world-leading centre for fundamental research, scientific training, and educational outreach. We are deeply grateful to all our supporters.

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FOUNDER ($150M+)
Mike Lazaridis

$25M+
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BMO Financial Group Isaac Newton Chair in Theoretical Physics ($4 million)
Stavros Niarchos Foundation Aristarchus Chair in Theoretical Physics ($4 million)
The Peter and Shelagh Godsoe Family Foundation Award for Exceptional Emerging Talent ($1 million)

PERIMETER RESEARCH MAJOR GIFTS

Centre for the Universe at Perimeter Institute ($5 million)*
Mike and Ophelia Lazaridis Niels Bohr Chair in Theoretical Physics ($4 million)
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Krembil Galileo Galilei Chair in Theoretical Physics ($2 million)
Krembil William Rowan Hamilton Chair in Theoretical Physics ($2 million)
Coril Holdings Archimedes Chair in Theoretical Physics (Visiting) ($1 million)
Clay Riddell Paul Dirac Chair in Theoretical Physics ($1 million)
Daniel Family P. James E. Peebles Chair in Theoretical Physics ($1 million)
Delaney Family John Archibald Wheeler Chair in Theoretical Physics ($500,000)
Cenovus Energy James Clerk Maxwell Chair in Theoretical Physics (Visiting)

*Anonymous Donor

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Cenovus Energy, in support of the Distinguished Visiting Research Chair program at Perimeter Institute
Maplesoft, Perimeter Educational Outreach Champion
Power Corporation of Canada, proud supporter of EinsteinPlus and Perimeter's Teacher Network
RBC Financial Group, Presenting Partner, International Summer School for Young Physicists
Mike Serbinis and Laura Adams in support of the Theoretical Physics Summer Undergraduate Program at Perimeter Institute

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The Savvas Chamberlain Family Foundation Anaximandros Fellowship
The Joanne Cuthbertson and Charlie Fischer Graduate Student Award
The Hellenic Heritage Foundation Anaximandros Fellowship
Brad and Kathy Marsland Honorary PSI Scholarship Award
Margaret and Larry Marsland Honorary PSI Scholarship Award

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$25,000+

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Stephen Lister and Dr. Molly Rundle

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$2,500+

Michael Horgan

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$1,000+

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EMMY NOETHER CIRCLE

Emmy Noether was a brilliant scientist whose work underpins much of modern physics. Perimeter's Emmy Noether Initiatives – funded by Emmy Noether Circle donors – support and encourage women in science.

FOUNDING DONOR

The Bluma Appel Community Trust

MAJOR GIFTS

The Simons Emmy Noether Fellows Program at Perimeter Institute ($600,000 USD)

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** Supporter of Friends of Perimeter Institute Inc., a 501(c)(3) public charity in the United States dedicated to promoting and supporting education, research, and programs that expand the public knowledge and understanding of theoretical physics.

This list reflects gifts received between August 1, 2017 and July 31, 2018, and multi-year commitments of $50,000 and more.

Charitable registration number: 88981 4323 RR0001

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 Managing Director and Chief Operating Officer reports to the Director and oversees day-to-day operations, supported by a team of administrative staff.

Perimeter'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 Faculty Chair, who assists the Institute's Director with matters such as program reviews, recruitment, and the granting of tenure.

The Scientific Advisory Committee, comprised of eminent international scientists, offers independent scrutiny and advice, providing key support in achieving the Institute's strategic objectives, particularly around recruitment.

BOARD OF DIRECTORS

Mike Lazaridis, O.C., O.Ont., FRS, FRSC, Chair, is Managing Partner and Co-Founder of Quantum Valley Investments (QVI), which he and Doug Fregin established in Waterloo. In 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 nearly two decades of 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 founded Research In Motion (now BlackBerry), where he invented the BlackBerry, created the smartphone industry, and built Canada's largest global tech business. Mr. Lazaridis served in various positions including Co-CEO and Co-Chairman (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. He also founded the Institute for Quantum Computing (IQC), where he serves as Chair of the Board, and the Quantum-Nano Centre, both at the University of Waterloo. He has donated more than $170 million to Perimeter and more than $120 million to IQC. In addition, his generous support for a new technology-focused management institute at Wilfrid Laurier University resulted in the business school being renamed in his honour as the Lazaridis School of Business and Economics.

Among his many honours, Mr. Lazaridis is a Fellow of both the Royal Societies of London and Canada, and he 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 Doctor of Laws degrees from Laval University, McMaster University, Western University, and the University of Windsor. 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. In 2017, Mr. Lazaridis was inducted into the Consumer Technology Hall of Fame, recognizing him as a visionary and pioneer of the consumer technology industry.

Cosimo Fiorenza, Vice-Chair, has played a major role in the development of the Quantum Valley in Waterloo Region. He is a founding member of the Perimeter Institute Board of Directors.

In addition to his role as Vice-Chair of the Board, Mr. Fiorenza is a member of both the Finance Committee and the Investment Committee, and previously served as Co-Chair of the Perimeter Institute Leadership Council. He is also the Chair of the Board of Directors of Friends of Perimeter Institute and a member of the Board of Directors of AIMS-NEI Canada, one of Perimeter's global outreach partners.

Mr. Fiorenza is the Vice-President and General Counsel of Quantum Valley Investments, where he has helped to establish numerous quantum technology start-up companies. He serves as a director and officer of several of these start-ups, actively supporting them in a broad spectrum of matters including recruitment, financial matters, intellectual property, fundraising, and government relations.

Mr. Fiorenza also helped to establish the Institute for Quantum Computing at the University of Waterloo and remains an active member of the IQC Board of Directors and Finance Committee. In 2016, he helped establish Quantum Valley Ideas Lab, a charitable organization focused on applied quantum research and specifically the development of new quantum technologies that will be the basis for new products and new businesses in Canada. Mr. Fiorenza serves as Vice-Chair of Ideas Lab and is also a member of its Finance Committee and Investment Committee. Previously, he spent approximately 20 years with major Toronto law firms, advising some of Canada's leading corporations and entrepreneurs on income tax and commercial matters, with a focus on technology and international structure. Mr. Fiorenza 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.

Amit Chakma has been the President and Vice-Chancellor of Western University since 2009. After completing a PhD in chemical engineering at the University of British Columbia, he became a professor at the University of Calgary before serving in Vice-President roles at the University of Regina and University of Waterloo. The author of more than 100 articles, Dr. Chakma is an expert in areas related to petroleum research and energy management. He serves as Chair of the Council of the Association of Commonwealth Universities and as a member of the Science, Technology, and Innovation Council of Canada. Dr. Chakma is a Fellow of the Canadian Academy of Engineering and a recipient of many honours, including the Queen's Diamond Jubilee Medal and a Lifetime Achievement in Engineering award from the University of British Columbia.

Joanne Cuthbertson, LL.D., was the first elected Chair of EducationMatters, Calgary's unique public education trust, and the founder of SPEAK (Support Public Education – Act for Kids). She is Chancellor Emerita of the University of Calgary and Co-Chair of the Scholars' Academy she established upon retirement. Her long connection to the Glenbow Museum continues as a Fellow. Ms. Cuthbertson is the recipient of the Calgary Award (Education) and a Queen Elizabeth II Diamond Jubilee Medal. She is also a Co-Chair of Perimeter's Leadership Council.

Michael Horgan is a Senior Advisor at Bennett Jones LLP, one of Canada's premier business law firms. Prior to his work in the private sector, he led a distinguished 36-year career as a federal public servant, culminating with five years as Canada's Deputy Minister of Finance. Mr. Horgan has been awarded the Prime Minister's Outstanding Achievement Award for Public Service and a Queen Elizabeth II Diamond Jubilee Medal. He holds a BA in economics from Concordia University and master's degrees in economics from Queen's University and Princeton University.

Art McDonald, C.C., O.Ont., O.N.S., FRS, FRSC, P. Eng., was the Director of the Sudbury Neutrino Observatory (SNO) experiment for over 20 years, and is Professor Emeritus at Queen's University. He shared the 2015 Nobel Prize in Physics and the 2016 Breakthrough Prize in Fundamental Physics for the SNO experiment that showed neutrinos change flavour, implying they have a finite mass. Professor McDonald has received numerous other awards for his research, including the Henry Marshall Tory Medal from the Royal Society of Canada, and was co-recipient of the Benjamin Franklin Medal in Physics. He is a Fellow of both the Royal Societies of London and Canada, and is still active in research on neutrinos and dark matter at the SNOLAB underground research laboratory.

Jeff Moody is the President and Chief Executive Officer of Gluskin Sheff + Associates Inc., a member of the Board of Directors, Chair of the Firm's Asset Mix Committee, and a resigned Portfolio Manager. Mr. Moody received a BA in economics from Western University. Prior to joining Gluskin Sheff in 2001, he was a Managing Partner with Gryphon Investment Counsel, where he was involved in the management of $2.6 billion of pension and endowment assets. Mr. Moody has held many senior investment industry positions in both Canada and London, England, including Co-Head of Global Fixed Income at BMO Nesbitt Burns. He serves as a Trustee for the Jeremy and Judith Freedman Family Foundation and is Chair of the Investment Committee of Perimeter Institute.

John Reid retired from KPMG in 2014, having served as Audit Leader in the Greater Toronto area since 2008. During his 40-year career, he assisted both private- and public-sector organizations through various stages of strategic planning, 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 is a founding member of Perimeter's Board of Directors and a member of its Finance Committee, and he has served on many hospital and college boards throughout Canada. He received a BA in commerce from the University of Alberta and is a Fellow of the Chartered Professional Accountants of Ontario.

Michael Serbinis is the Founder and CEO of LEAGUE, a digital employee health benefits start-up that launched 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, becoming the only global competitor to Amazon's Kindle. He is the CEO of Three Angels Capital, a G7/ML7 Fellow of the Creative Destruction Lab, and a Board member for the MaRS Discovery District and the Vector Institute. 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

Gabriela González, Louisiana State University, Chair (2017-Present)

Professor González is a Professor of Physics and Astronomy at Louisiana State University, focusing on the detection of gravitational waves. From 2011 to 2017, she was the spokesperson for the Laser Interferometer Gravitational-Wave Observatory (LIGO) Scientific Collaboration, a worldwide endeavour that announced the first direct gravitational wave observation in 2016. Before joining LSU in 2001, she worked as a staff scientist with the MIT-LIGO group and was a faculty member at Pennsylvania State University. In 2007, she was awarded the Edward A. Bouchet Award by the American Physical Society.

Steve Carlip, University of California, Davis (2017-Present)

Professor Carlip has been a member of the faculty at the University of California, Davis, since 1990. He works on one of the fundamental unsolved problems in modern theoretical physics, the effort to combine general relativity and quantum mechanics into a consistent quantum theory of gravity. His current interests include (2+1)-dimensional quantum gravity, the quantum gravitational basis of black hole thermodynamics, discrete approaches to gravity, and short-distance dimensional reduction. Carlip is a Fellow of the American Physical Society and the Institute of Physics (UK).

Katherine Freese, University of Michigan (2017-Present)

Professor Freese is the George E. Uhlenbeck Professor of Physics at the University of Michigan, as well as a Guest Professor at Stockholm University. Her research covers a wide range of topics in theoretical cosmology and astroparticle physics; she has been working to identify the dark matter and dark energy that permeate the universe, as well as to build a successful model for the early universe immediately after the big bang. Freese has been a Sloan Foundation Fellow and a Simons Foundation Fellow in Theoretical Physics, and she has been a Fellow of the American Physical Society since 2009. In 2014, she published her first popular science book, *The Cosmic Cocktail: Three Parts Dark Matter*.

Shamit Kachru, Stanford University (2015-Present)

Professor Kachru has been a Professor of Physics at Stanford University since 1999. He is an expert in string theory and quantum field theory, and their applications in cosmology, condensed matter, particle physics, mathematical physics, and quantum gravity. He has made central contributions to areas including string compactification, string theory duality, the AdS/CFT correspondence, and the construction of models of cosmic inflation. Kachru's many honours include a Department of Energy Outstanding Junior Investigator Award, Sloan Foundation and Packard Foundation Fellowships, Bergmann Memorial Award, ACIPA Outstanding Young Physicist Prize, and a Simons Investigator Award.

David B. Kaplan, University of Washington (2017-Present)

Professor Kaplan is a Senior Fellow at the Institute for Nuclear Theory at the University of Washington, where he has also been a Professor of Physics since 1998. He previously served as Director of the Institute for Nuclear Theory from 2006 to 2016. Kaplan's research interests include the application of quantum field theory to the strong interactions, lattice field theory, quantum computing, cosmology, and physics beyond the Standard Model. He has been elected to the American Physical Society, Washington State Academy of Sciences, National Academy of Sciences, and American Academy of Arts and Sciences.

Ramesh Narayan, Harvard University (2017-Present)

Professor Narayan is the Thomas Dudley Cabot Professor of the Natural Sciences at Harvard University. He is an astrophysicist who has won international renown for his research on black holes. Narayan has also carried out research in several other areas of theoretical astrophysics, including accretion disks, gravitational lensing, gamma-ray bursts, and neutron stars. He is a Fellow of the Royal Society of London, American Association for the Advancement of Science, and The World Academy of Sciences, and a member of the US National Academy of Sciences, International Astronomical Union, and American Astronomical Society.

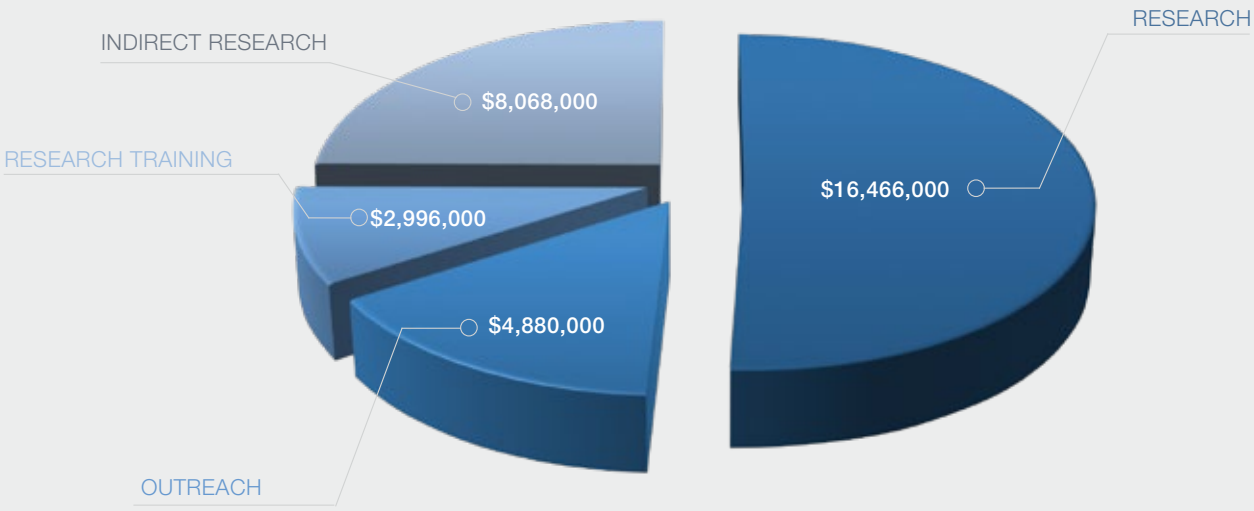
Barbara Terhal, Delft University of Technology (2015-Present)

Professor Terhal is a Professor at the Delft University of Technology (TU Delft) and a staff member at QuTech, a collaborative research centre founded by TU Delft and TNO, the Netherlands Organization for Applied Scientific Research. She is also a part-time staff member at the Institute for Nanoelectronics of the Juelich Research Center in Germany. Her research interests lie in quantum information theory – including quantum algorithms, quantum error correction and its realization in solid-state qubits, and quantum complexity theory. Terhal is a Fellow of the American Physical Society and an Associate Member of the Quantum Information Processing program of the Canadian Institute for Advanced Research.

FINANCIALS

SUMMARY OF OPERATING COSTS (REFER TO PAGE 50)

For the year ended July 31, 2018



Research

Perimeter's mission is to advance our understanding of the universe at the most fundamental level. To that end, the Institute continued to invest in creating a research environment that fosters breakthroughs, growing Perimeter's resident researcher base and providing an influx of visiting researchers through various programs. In 2017/18, Perimeter increased its investment in research by more than five percent over the prior year, in line with growth objectives.

Research Training

Over the last year, Perimeter continued to offer innovative research training programs such as Perimeter Scholars International (PSI), the PhD program, and the Institute's Visiting Graduate Fellows program, each of which help emerging scientists refine their ideas and interests through lively academic and research interactions. Planned increases to PSI participation and additional support to attract promising PhD students contributed to an increase over the prior year's spending of more than 17 percent.

Outreach and Science Communications

Perimeter's world-class educational outreach programs convey the wonder and mystery of the universe and the importance of scientific breakthroughs to audiences across Canada and beyond. Due to the conclusion of Innovation150, the successful Perimeter-led signature initiative of the Government of Canada's sesquicentennial celebrations, Perimeter's spend in this area was reduced compared to the prior year. Nonetheless, the Institute continued to deliver major impact for students, teachers, and the public at large through its core suite of inspirational programs and products.

Indirect Research and Operations

Indirect research and operating expenditures cover the costs of core support areas, including administration, advancement, information technology, and facilities. Perimeter continues to maximize efficiencies where possible, maintaining a world-class research institute by investing the majority of its funds into its core mandate of research, training, and educational outreach. In 2017/18, indirect research and operations comprised 25 percent of the Institute's overall expenditure, in line with historical averages.

INCOME

Perimeter's private sector fundraising campaign remained very strong, generating over $6 million to support the operations of the Institute, while research grant revenue from private foundations exceeded $1 million. Meanwhile, federal and provincial governments continued to provide revenues in accordance with the terms of their grant agreements. Early receipt of certain federal contributions in advance of the 2018/19 fiscal year resulted in additional income recognition in 2017/18. Ongoing major investments from both the Governments of Canada and Ontario demonstrate recognition of Perimeter's value for money and strong return on investment among its public funders.

FINANCIAL POSITION (REFER TO PAGE 49)

Many years of prudent investing have resulted in a robust endowment fund that is helping to secure the future of the Institute.

Perimeter's endowment 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. It allows for the accumulation of private funds to address the Institute's future needs and provides the near-term flexibility to react to targeted research opportunities that may present themselves. The investment of marketable securities earned a return of almost nine percent over the past year.

THE LONG-TERM PLAN

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

As of July 31, 2018, Perimeter has completed the first year of five-year commitments of $50 million from both the federal and provincial governments, providing combined funding of $100 million over the coming years. The multi-year government commitments Perimeter has received since inception demonstrate the Institute's strong collaboration with public partners and that Perimeter is viewed as an excellent and strategic government investment.

In addition to government support, Perimeter Institute consistently seeks innovative ways to expand its sources of funds from the private sector. Private sector donations, in accordance with donor requests, are either utilized as contributions toward operational expenditures or protected in an endowment fund designed to maximize growth and minimize risk. However, investment returns can be 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.

Zeifmans

REPORT OF THE INDEPENDENT AUDITORS ON THE SUMMARIZED FINANCIAL STATEMENTS

To the Directors of
Perimeter Institute

The accompanying summarized financial statements, which comprise the summarized statement of financial position as at July 31, 2018 and the summarized 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, 2018. We expressed an unmodified audit opinion on those financial statements in our report dated December 6, 2018. Those financial statements, and the summarized financial statements, do not reflect the effects of events that occurred subsequent to the date of our report on those financial statements.

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

Management's Responsibility for the Summarized Financial Statements

Management is responsible for the preparation of a summary of the audited financial statements on a basis developed by management, which includes removing the statement of cash flows, retaining major subtotals, totals and comparative information, and retaining the information from the audited financial statements dealing with matters having pervasive or otherwise significant effect on the summarized financial statements.

Auditor's Responsibility

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

Opinion

In our opinion, the summarized financial statements derived from the audited financial statements of the Institute for the year ended July 31, 2018 are a fair summary of those financial statements, in accordance with the basis developed by management, which includes removing the statement of cash flows, retaining major subtotals, totals and comparative information, and retaining the information from the audited financial statements dealing with matters having a pervasive or otherwise significant effect on the summarized financial statements.

Other Matter

The audited financial statements of the Institute are available on request by contacting the Institute.

Zeifmans LLP

Toronto, Ontario
December 6, 2018

Chartered Professional Accountants
Licensed Public Accountants

201 Bridgeland Avenue | Toronto
Ontario | M6A 1Y7 | Canada

zeifmans.ca
T: 416.256.4000

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PERIMETER INSTITUTE

Summarized Statement of Financial Position

as at July 31, 2018

	2018	2017
ASSETS		
Current Assets:		
Cash and cash equivalents	$ 16,881,000	$ 6,771,000
Investments	342,928,000	324,504,000
Grants receivable	3,442,000	38,000
Other current assets	679,000	1,282,000
	363,930,000	332,595,000
Property and equipment	42,046,000	42,786,000
TOTAL ASSETS	$ 405,976,000	$ 375,381,000
LIABILITIES AND FUND BALANCE		
Current liabilities:		
Accounts payable and other current liabilities	$ 1,294,000	$ 1,043,000
TOTAL LIABILITIES	1,294,000	1,043,000
Fund balances:		
Invested in capital assets	41,948,000	42,772,000
Externally restricted	56,567,000	122,077,000
Internally restricted	305,441,000	203,440,000
Unrestricted	726,000	6,049,000
TOTAL FUND BALANCES	404,682,000	374,338,000
	$ 405,976,000	$ 375,381,000

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PERIMETER INSTITUTE

Summarized Statement of Operations and Changes in Fund Balances

For the Year Ended July 31, 2018

	2018	2017
Revenue		
Government grants	$ 29,383,000	$ 19,078,000
Research grants	1,086,000	1,726,000
Donations	6,424,000	6,913,000
	36,893,000	27,717,000
Expenses		
Research	16,466,000	15,681,000
Research training	2,996,000	2,566,000
Outreach and science communications	4,880,000	8,470,000
Indirect research and operations	8,068,000	7,197,000
	32,410,000	33,914,000
Excess of revenue over expenses (expenses over revenue) before investment and amortization impacts	4,483,000	(6,197,000)
Amortization	(2,747,000)	(2,437,000)
Investment income	28,608,000	20,183,000
Excess of revenue over expenses	30,344,000	11,549,000
Fund balances, beginning of year	374,338,000	362,789,000
Fund balances, end of year	$ 404,682,000	$ 374,338,000

Zeifmans

LOOKING AHEAD: PRIORITIES AND OBJECTIVES FOR THE FUTURE

Perimeter Institute is on track to achieve its overriding goal: to create and sustain the world's leading centre for foundational theoretical physics research, training, and educational outreach. To build on the Institute's momentum, Perimeter has established a set of strategic objectives to guide its continued development. The advancement of the Institute's core mission will continue to inform every facet of its research, training, and outreach efforts.

Achieve breakthroughs in our understanding of the universe, drawing insights from and contributing to the whole spectrum of theoretical physics, focusing strategically on research areas that offer the greatest opportunity for major discoveries.

Create the world's strongest community of theoretical physics researchers by continuing to attract and retain top international talent and providing them with unparalleled infrastructure and support to help maximize productivity.

Attract and develop the next generation of brilliant minds by providing exceptional graduate students and postdoctoral researchers with the training and support to develop the powerful, widely applicable skills that will fuel successful individual careers and the knowledge economy more broadly.

Attract outstanding visiting scientists by holding timely, focused conferences, workshops, and seminars on cutting-edge topics and facilitating a constant flow of eminent and emerging physicists for both short-term and extended collaboration visits.

Act as Canada's hub for foundational physics research, strengthening connections with institutions across the country and enabling frontier research, high-quality training, and public engagement.

Catalyze the emergence of top centres for math and physics globally, providing access to excellence for vast new pools of scientific talent, and sharing knowledge and expertise, with a focus on developing countries.

Share the transformative power of theoretical physics across Canada and around the world, inspiring a new generation of scientific explorers through high-impact educational outreach, while engaging the general public with the wonder and excitement of basic physics research.

Continue to strengthen Perimeter's visionary public-private partnership by demonstrating excellent return on investment, securing sustained funding from government partners, and expanding the Institute's private sector support base.

APPENDICES

FACULTY

Neil Turok (PhD Imperial College London, 1983) is the Director of Perimeter Institute. He was Professor of Physics at Princeton University and Chair of Mathematical Physics at the University of Cambridge before assuming his current position in 2008. In 2013, he was also appointed to the Mike and Ophelia Lazaridis Niels Bohr Chair at Perimeter. 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 have been confirmed. He developed the single bubble open inflationary universe model with Stephen Hawking, among others. He also developed the cyclic universe model with Paul Steinhardt. Currently, he is working on a new approach to quantum cosmology which resolves the big bang singularity and explains the emergence of time. With Ue-Li Pen, he has recently shown how gravitational waves may be used to constrain and observe physical phenomena in the primordial universe. 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 Fellow in Cosmology and Gravity and a Senior Fellow of Massey College at the University of Toronto. In 2012, Turok was selected to deliver the CBC Massey Lectures, broadcast across Canada. 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 six centres – in South Africa, Senegal, Ghana, Cameroon, Tanzania, and Rwanda – and has become Africa's leading institution for postgraduate training in mathematical science. For his scientific discoveries and his work building AIMS, Turok was awarded a TED Prize in 2008, as well as awards from the World Summit on Innovation and Entrepreneurship and the World Innovation Summit on Education. In 2016, he was awarded the John Torrence Tate Medal for International Leadership in Physics by the American Institute of Physics. He was made an Honorary Fellow of the Institute of Physics in the UK and named as winner of the John Wheatley Award of the American Physical Society. He was also chosen as the Gerald Whitrow Lecturer of the Royal Astronomical Society. In 2018, he was named an Honorary Officer of the Order of Canada.

Asimina Arvanitaki (PhD Stanford University, 2008) is the Stavros Niarchos Foundation Aristarchus Chair in Theoretical Physics at Perimeter Institute, where she has been a faculty member since 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. These experiments rely on the latest developments in metrology, such as atomic clocks, and the optical trapping and cooling of macroscopic objects. She recently pioneered a new experiment that can look for new spin-dependent forces in nature at an unprecedented level of precision. Arvanitaki also works on theoretical challenges raised by experimental results, such as a model of particle physics influenced by string theory called "split SUSY." She was co-awarded the 2017 New Horizons in Physics Prize by the Breakthrough Prize Foundation.

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 Postdoctoral Fellowship; he was also a Junior Fellow of the Canadian Institute for Advanced Research. 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 constructed the theory of "porcupines": networks of low-frequency gravitational wave detectors that function together as gravitational wave telescopes. With Shane Farnsworth, Boyle discovered a reformulation of Connes' non-commutative geometry that greatly simplifies and unifies its axioms, and elucidates its connection to the

Standard Model of particle physics. With Kendrick Smith, he developed the idea of "choreographic crystals" in which the basic elements perform a choreographed dance that can have a much higher symmetry than any instantaneous snapshot reveals. Most recently, with Steinhardt, he has been developing a new approach to Penrose-like tilings and exploring new applications of these structures to physics.

Freddy Cachazo (PhD Harvard University, 2002) is the Gluskin Sheff Freeman Dyson Chair in Theoretical Physics at Perimeter Institute, where he has been a faculty member since 2005. Cachazo is one of the world's leading experts in the study and computation of scattering amplitudes in gauge theories, such as quantum chromodynamics and N=4 super Yang-Mills (MSYM), and in Einstein's gravity theory. His many honours include 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 from the Canadian Association of Physicists (2012), a New Horizons in Physics Prize from the Fundamental Physics Prize Foundation (2014), and the CAP-CRM Prize in Theoretical and Mathematical Physics from the Canadian Association of Physicists and the Centre de recherches mathématiques (2016).

Kevin Costello (PhD University of Cambridge, 2003) joined Perimeter in 2014 from Northwestern University, where he had been a faculty member since 2006. He is the Krembil William Rowan Hamilton Chair in Theoretical Physics. Costello works on the mathematical aspects of quantum field theory and string theory. He is the author of *Renormalization and Effective Field Theory*, a path-breaking monograph introducing powerful new mathematical tools into the theory of quantum fields, and co-author of *Factorization Algebras in Quantum Field Theory*. Costello's previous honours include an Alfred P. Sloan Research Fellowship, the Berwick Prize of the London Mathematical Society, and several prestigious grants from the National Science Foundation in the United States. In 2018, he was elected as a Fellow of the Royal Society (UK).

Neal Dalal (PhD University of California, San Diego, 2002) joined Perimeter in October 2017 from the University of Illinois at Urbana-Champaign, where he had been an Assistant Professor since 2011. Prior to that, he was a postdoctoral researcher at the Institute for Advanced Study and a Senior Research Associate at the Canadian Institute for Theoretical Astrophysics. His research probes the fundamental physics of cosmology, the structure of the universe, and the formation of galaxies, and he has pioneered several tests of the nature of dark matter using cosmological data.

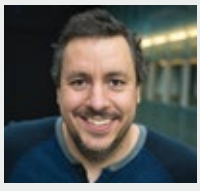
Savas Dimopoulos (PhD University of Chicago, 1978) is the Coril Holdings Archimedes Chair in Theoretical Physics (Visiting) at Perimeter Institute. He joined Perimeter in 2016, while retaining his position as the Hamamoto Family Professor in the School of Humanities and Sciences at Stanford University, where he has been on the faculty since 1979. In that span, he has also taught at Boston University, Harvard University, and the University of California, Santa Barbara, and he was a staff member at CERN from 1994 to 1997. Dimopoulos is a leading particle physicist, well known for his work on constructing theories beyond the Standard Model. With collaborators, he has done foundational work on the Minimal Supersymmetric Standard Model (MSSM) and proposed the "ADD" model of large extra dimensions. Among his many honours, Dimopoulos has received the Tommassoni Prize in Physics, the J.J. Sakurai Prize in Theoretical Physics from the American Physical Society, and a Distinguished Alumnus Award from the University of Houston. He was an Alfred P. Sloan Foundation Fellow and is currently a Fellow of both the Japanese Society for the Promotion of Science and the American Academy of Arts and Sciences.

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, constructed new realizations of quantum geometry, and identified holographic properties of background independent gravity. Dittrich has received the Otto Hahn Medal of the Max Planck Society, which recognizes outstanding young scientists, and an Early Researcher Award from the Ontario Ministry of Research and Innovation.

William East (PhD Princeton University, 2013) joined Perimeter as a Director's Fellow in 2016 and became a member of the faculty in January 2018. Prior to that, he was a postdoctoral fellow at the Kavli Institute for Particle Astrophysics and Cosmology at Stanford University (2013-16). East uses numerical methods and high-performance computing to study violent astrophysical phenomena – such as black hole mergers and the collision of dense stars – as a test of existing models of the universe. For his thesis, he was awarded the Nicholas Metropolis Award of the American Physical Society (2015) and the Jürgen Ehlers Prize of the International Society on General Relativity and Gravitation (2016).

Laurent Freidel (PhD L'École Normale Supérieure de Lyon, 1994) joined Perimeter Institute first as a visitor in 2002 and then as faculty in 2006. Freidel is a mathematical physicist who has made many notable contributions in the field of quantum gravity, developing spin foam models, among other things. He has also introduced several new concepts in this field, such as group field theory, relative locality, and metastring theory and modular spacetime. He possesses outstanding knowledge of a wide range of areas including gravitational physics, integrable systems, topological field theories, 2D conformal field theory, string 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 since 1995. He is also the recipient of several awards.

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 major conceptual advances. 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. Gomis was awarded an Early Researcher Award from the Ontario Ministry of Research and Innovation for a project aimed at developing new techniques for describing quantum phenomena in nuclear and particle physics.

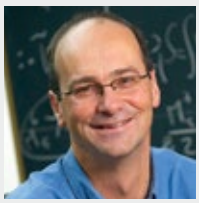
Daniel Gottesman (PhD California Institute of Technology, 1997) joined Perimeter's faculty in 2002. From 1997 to 2002, he held postdoctoral positions at the Los Alamos National Laboratory, Microsoft Research, and the University of California, Berkeley (as a long-term CMI Prize Fellow for the Clay Mathematics 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 50 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 and a Fellow of the American Physical Society.

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, University of Durham, University of Innsbruck, and 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 has worked on characterizing quantum theory in terms of operational postulates and providing an operational reformulation of quantum theory. He has recently shown how to reformulate general relativity in operational terms. This is seen as a stepping stone en route to finding a theory of quantum gravity.

Yin-Chen He (PhD Fudan University, 2014) joined Perimeter in July 2018 from Harvard University, where he'd been a Moore Postdoctoral Fellow since 2016. Prior to that, he spent two years as a postdoctoral researcher at the Max Planck Institute for the Physics of Complex Systems. He is a condensed matter researcher interested in strongly correlated systems, particularly quantum spin liquids, quantum criticality, conformal field theory, topological phases of matter, quantum field theory, and numerical simulations.

Timothy Hsieh (PhD Massachusetts Institute of Technology, 2015) joined Perimeter in March 2018 from the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara, where he'd been a Moore Postdoctoral Fellow since 2015. Hsieh works in condensed matter, specializing in exotic states of matter whose physical behaviours are dictated by the mathematical structures found in topology. His research interests also include quantum materials, entanglement, and applications of synthetic quantum systems for quantum simulation.

Luis Lehner (PhD University of Pittsburgh, 1998) began a joint appointment with Perimeter and the University of Guelph in 2009, joined Perimeter as a full-time faculty member in 2012, served as Deputy Faculty Chair from 2014 to 2017, and has been Faculty Chair since March 2018. He was previously 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 in the Cosmology and Gravity program. Lehner also serves on the Scientific Council of the International Centre for Theoretical Physics – South American Institute for Fundamental Research and the Advisory Board of the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara.



Robert Myers (PhD Princeton University, 1986) is one of the leading theoretical physicists working on string theory and quantum gravity 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 joining Perimeter as one of the founding faculty members in 2001. He served as Perimeter's Faculty Chair from 2010 to 2018. Myers has made seminal contributions to our understanding of black hole microphysics, D-branes, and the application of entanglement entropy to holography and renormalization group flows. Among his many honours, he has received the Canadian Association of Physicists' 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. Myers was named on the Thomson Reuters/Clarivate Analytics list of "Highly Cited Researchers" in 2014, 2015, 2016, and 2017.

Subir Sachdev (PhD Harvard University, 1985) joined Perimeter in 2014 and holds the Cenovus Energy James Clerk Maxwell Chair in Theoretical Physics (Visiting). 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 was awarded the 2018 Lars Onsager Prize of the American Physical Society.

Kendrick Smith (PhD University of Chicago, 2007) is the Daniel Family P. James E. Peebles Chair in Theoretical Physics at Perimeter Institute, where he has been a faculty member since 2012. He previously held postdoctoral positions at Princeton University (2009-12) and the University of Cambridge (2007-09). 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 and the 2018 Breakthrough Prize in Fundamental Physics – as well as CHIME and the Planck collaboration. Smith has achieved several landmark results, including the first detection of gravitational lensing in the cosmic microwave background (CMB) radiation. He 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 faculty positions at Yale University, Syracuse University, and Pennsylvania State University. Smolin's research is centred on the problem of quantum gravity, where he helped to found loop quantum gravity, though his contributions span many areas, including quantum foundations, cosmology, particle physics, the philosophy of physics, and economics. His nearly 200 papers have generated over 19,000 citations to date. He has written four non-technical books and co-written a book on the philosophy of time. Smolin's honours include the Majorana Prize (2007), the Klopsteg Memorial Award (2009), the Buchalter Cosmology Prize (2014), 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 an International Royal Society Fellowship at the University of Cambridge. His field of research is the foundations of quantum theory, where he is known for his work on the interpretation of the quantum state, the principle of noncontextuality, the nature of causality in a quantum world, and the characterization of the symmetry-breaking and thermodynamic properties of quantum states as resources. Spekkens co-edited the book *Quantum Theory: Informational Foundations and Foils*, and he is a Project Leader of the "Quantum Causal Structures" collaboration. He was awarded the Birkhoff-von Neumann Prize of the International Quantum Structures Association in 2008, and won first prize in the 2012 Foundational Questions Institute (FQXi) essay contest, "Questioning the Foundations: Which of Our Assumptions are Wrong?"

Guifre Vidal (PhD University of Barcelona, 1999) joined Perimeter's faculty in 2011 from the University of Queensland in Brisbane, where he was a Professor in the School of Mathematics and Physics. Vidal works at the interface of quantum information, condensed matter physics, and quantum field theory. He develops tensor network algorithms to compute ground states of quantum many-body systems, and has proposed a modern formulation of the renormalization group, based on quantum circuits and entanglement. He is currently developing non-perturbative tools for strongly interacting quantum fields, and exploring the use of tensor networks in holography. His past honours include a European Union Marie Curie Fellowship, a Sherman Fairchild Foundation Fellowship, and an Australian Research Council Federation Fellowship.

Pedro Vieira (PhD École Normale Supérieure de Paris and the Theoretical Physics Center at the University of Porto, 2008) is the Clay Riddell Paul Dirac Chair in Theoretical Physics at Perimeter Institute, where he has been a faculty member since 2009. Prior to that, he was a Junior Scientist at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) 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 AdS/CFT correspondence, theoretical calculations of scattering amplitudes, and correlation functions in interacting quantum field theories. He is a Principal Investigator on the Simons Collaboration on the Nonperturbative Bootstrap. His many honours include a Sloan Research Fellowship, the Gribov Medal of the European Physical Society, and the Raymond and Beverly Sackler International Prize in Physics from Tel Aviv University.

Beni Yoshida (PhD Massachusetts Institute of Technology, 2012) joined Perimeter's faculty in July 2017, having initially arrived at the Institute as a Senior Postdoctoral Fellow in 2015. Prior to that, he was a Burke Fellow at the Institute for Theoretical Physics at the California Institute of Technology (2012-15), where he worked in John Preskill's group. Yoshida's research focuses on applications of quantum information theory to problems of quantum many-body physics. In particular, he has used the techniques of quantum coding theory to find novel topological phases of matter and developed a framework of classifying fault-tolerant logical gates by using topological gauge theories. He has also recently developed an interest in black hole physics.

ASSOCIATE FACULTY

Niayesh Afshordi (PhD Princeton University, 2004) is jointly appointed with the University of Waterloo. Previously, he was the Institute for Theory and Computation Fellow at the Harvard-Smithsonian Center for Astrophysics (2004-07) and a Distinguished Research Fellow at Perimeter Institute (2008-09). Afshordi began his appointment as an associate faculty member in 2009. He specializes in interdisciplinary problems in fundamental physics, astrophysics, and cosmology. Among his honours, Afshordi has received a Discovery Accelerator Supplement from the Natural Sciences and Engineering Research Council of Canada, an Early Researcher Award from the Ontario Ministry of Research and Innovation, and the Vainu Bappu Gold Medal from the Astronomical Society of India. He also won third prize in the 2015 Buchalter Cosmology Prize of the American Astronomical Society.

Alexander Braverman (PhD Tel Aviv University, 1998) joined Perimeter in 2015, jointly appointed with the University of Toronto. He was previously a faculty member at Brown University (2004-15) and held lecturer positions at Harvard University (2000-04) and the Massachusetts Institute of Technology (1997-99). Braverman specializes in several areas with applications to mathematical physics, including algebraic geometry, representation theory, number theory, and the geometric Langlands program. He has been a Clay Mathematics Institute Prize Fellow and a Simons Fellow in Mathematics.

Avery Broderick (PhD California Institute of Technology, 2004) began a joint appointment with Perimeter and the University of Waterloo in 2011, and was named the Delaney Family John Archibald Wheeler Chair in Theoretical Physics in January 2017. 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 is a key member of the Event Horizon Telescope collaboration, 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 the Ontario Ministry of Research and Innovation.

Raffi Budakian (PhD University of California, Los Angeles, 2000) joined Perimeter in 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. Budakian previously held a faculty position at the University of Illinois at Urbana-Champaign and research positions at the University of California, Los Angeles, and the IBM Almaden Research Center in San Jose. He 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 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) joined Perimeter in 2010 and is jointly appointed as a Professor of Chemistry at the University of Waterloo and Deputy Director of Research at the Institute for Quantum Computing. He was previously a Professor of Nuclear Science and Engineering at the Massachusetts Institute of Technology. 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 is the Principal Investigator of the $144 million Transformative Quantum Technologies program, with $76 million in funding from the Canada First Research Excellence Fund. He chairs the advisory committee for the Quantum Information Processing program at the Canadian Institute for Advanced Research, and he is a Fellow of both the American Physical Society and the Royal Society of Canada.

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 theoretical cosmologist, whose interdisciplinary research seeks to understand how the universe began, how it evolved, and where it is headed. Johnson has made contributions to fields ranging from inflationary cosmology and string theory to numerical relativity and cosmic microwave background radiation data analysis. His research has attracted competitive funding from the Natural Sciences and Engineering Research Council of Canada, the Foundational Questions Institute, and the New Frontiers in Astronomy and Cosmology grant program administered by the University of Chicago.

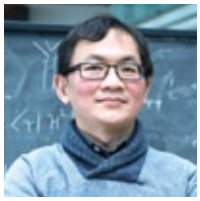
Raymond Laflamme (PhD University of Cambridge, 1988) is a founding faculty member of Perimeter Institute, jointly appointed at the Institute for Quantum Computing at the University of Waterloo, where he served as Executive Director from 2002 to 2017. He is also the Mike and Ophelia Lazaridis John von Neumann Chair in Quantum Information at the University of Waterloo and the Canada Research Chair in Quantum Information. He held research positions at the University of British Columbia and Peterhouse College, University of Cambridge, before moving to the Los Alamos National 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, the Royal Society of Canada, and the American Association for the Advancement of Science, and he was named an Officer of the Order of Canada in 2017. He was awarded the 2017 CAP-CRM Prize in Theoretical and Mathematical Physics by the Canadian Association of Physicists and the Centre de recherches mathématiques. With colleagues, Laflamme 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, quantum field theory, and the AdS/CFT correspondence. His recent work has included low-energy effective field theories for non-Fermi liquids and construction of holographic duals for general quantum field theories based on quantum renormalization group.

Matilde Marcolli (PhD University of Chicago, 1997) began a joint appointment with Perimeter and the University of Toronto in January 2018, after a decade as a Professor of Mathematics at the California Institute of Technology. She is a mathematical physicist whose research interests include computational linguistics, differential and algebraic geometry and topology, and mathematical models for cosmology and neuroscience. Among her many honours, Marcolli has won the Heinz Maier Leibniz Prize and the Sofja Kovalevskaja Award, both in 2001, and held many visiting research positions. She has also written four books, mostly recently *Feynman Motives* in 2009, and edited several others.

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 the Herzberg Medal from the Canadian Association of Physicists, the Young Scientist Prize in Computational Physics from the International Union of Pure and Applied Physics, an Early Researcher Award from the Ontario Ministry of Research and Innovation, and a 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 (IQC) at the University of Waterloo. He is a founding member of Perimeter Institute, as well as co-founder of IQC. He is also a Professor in the Department of Combinatorics and Optimization of the University of Waterloo's Faculty of Mathematics, and the co-founder and Director of CryptoWorks21, an NSERC-funded training program in quantum-safe cryptography. Mosca co-founded the ETSI-IQC workshop series in quantum-safe cryptography, which brings together a broad range of stakeholders working toward globally standardized quantum-safe cryptography, and co-founded evolutionQ Inc. in order to support organizations as they evolve their quantum-vulnerable systems and practices to quantum-safe ones. His research interests include quantum computation and cryptographic tools that will be safe against quantum technologies, and he is globally recognized for his drive to help academia, industry, and government prepare our cyber systems to be safe in an era with quantum computers. Mosca co-authored the respected textbook *An Introduction to Quantum Computing*. He has received numerous academic honours, including the Premier's Research Excellence Award (2000-05), Fellowship of the Canadian Institute for Advanced Research since 2010, Canada Research Chair in Quantum Computation (2002-12), and University Research Chair at the University of Waterloo (2012-present).



Ue-Li Pen (PhD Princeton University, 1995) joined Perimeter in 2014. He is jointly appointed with the Canadian Institute for Theoretical Astrophysics at the University of Toronto, where he has been a professor since 1998 and is currently Interim Director. Pen is a theoretical astrophysicist who studies systems where basic physical effects can be isolated from astronomical complexities. His research projects include the non-linear dynamics of the cosmic neutrino background, 21cm intensity mapping, pulsar VLBI scintillometry, and the Canadian Hydrogen Intensity Mapping Experiment (CHIME). Among his many honours, Pen is a Senior Fellow of the Canadian Institute for Advanced Research in the Cosmology and Gravity program. In 2018, he became just the second researcher at a Canadian institution to receive a Simons Investigator Award from the Simons Foundation since the program's introduction in 2012.

Will Percival (PhD University of Oxford, 1999) joined Perimeter in March 2018 after more than a decade on the faculty of the Institute of Cosmology and Gravitation at the University of Portsmouth. He is jointly appointed at the University of Waterloo, where he holds the Distinguished Research Chair in Astrophysics. Percival is a cosmologist working primarily on galaxy surveys, using the positions of galaxies to measure the cosmological expansion rate and growth of cosmological structure. He is a senior member of the Dark Energy Spectroscopic Instrument (DESI), Extended Baryon Oscillation Spectroscopic Survey (eBOSS), and Euclid experiment. Among his many honours, Percival has received the 2008 Fowler Prize of the Royal Astronomical Society and a Distinguished Scientist fellowship from the Chinese Academy of Sciences in 2016.

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.

Ben Webster (PhD University of California, Berkeley, 2007) joined Perimeter in July 2017, jointly appointed with the Department of Pure Mathematics at the University of Waterloo. He previously held faculty positions at the University of Virginia, Northeastern University, and the University of Oregon. Webster's research centres around connections between representation theory, mathematical physics, geometry, and topology, including knot homology, the geometry of symplectic singularities, and categorification. Among his honours, he has received a Sloan Research Fellowship and a CAREER award from the National Science Foundation in the US.

Huan Yang (PhD California Institute of Technology, 2013) joined Perimeter in September 2017 from Princeton University, where he held a one-year postdoctoral fellowship. He is jointly appointed with the University of Guelph. Yang is a theoretical astrophysicist whose areas of expertise are black holes and gravitational waves, with strong connections to recent observations. In particular, he explores strong-field gravitational astrophysics and fundamental physics with strongly gravitating systems. Yang's recent work aims to understand physics buried within existing data and provide new insights to guide future observational efforts.

Jon Yard (PhD Stanford University, 2005) joined Perimeter in 2016, jointly appointed with the Institute for Quantum Computing and the Department of Combinatorics and Optimization at the University of Waterloo. He previously held research positions at McGill University (2005), the California Institute of Technology (2005-07), Los Alamos National Laboratory (2007-12), and Microsoft Research (2012-16). Yard's research interests include quantum information, mathematical fields, quantum fields, and condensed matter. With Graeme Smith, he received the 2009 Pat Goldberg Memorial Best Paper Award from IBM Research for proving that quantum capacity does not completely characterize the utility of a channel for transmitting quantum information.

SENIOR MANAGEMENT

Managing Director and Chief Operating Officer
Michael Duschenes

Senior Director of Finance and Operations
Stefan Pregelj

Director of Academic Programs
James Forrest

Director of Advancement
Heather Clark

Director of Communications and Media
Colin Hunter

Director of Educational Outreach
Greg Dick

Director of External Relations and Public Affairs
John Matlock

Director of Finance
Sue Scanlan

Director of Information Technology
Ben Davies

Director of People and Culture
Sheri Keffer

Director of Publications
Natasha Waxman

POSTDOCTORAL RESEARCHERS, 2017/18

** Indicates PSI Fellow*

Ben Albert
Alvaro Alhambra
Tibra Ali*
Masha Baryakhtar
Beatrice Bonga
Agata Branczyk*
Sylvain Carrozza
Shira Chapman
Lorenzo Di Pietro
Galyna Dobrovolska
William Donnelly
Maïté Dupuis*
Angelika Fertig
Zachary Fisher
Federico Galli
Martin Ganahl
Marc Geiller
Henrique Gomes
Lauren Hayward Sierens*
Ben Heidenreich
Matthijs Hogervorst
Junwu Huang
Michael Jarret
Theo Johnson-Freyd
Aleksander Kubica
David Kubiznak*
Stefan Kühn
Ravi Kunjwal
Robert Lasenby
Ian Le
Adam Lewis
Ashley Milsted
Moritz Munchmeyer
Elliot Nelson
Tadashi Okazaki
Solomon Owerre
Zhen Pan
Roji Pius
Daniele Pranzetti
Jorge Alejandro Preciado
Hung-Yi Pu
Nicolas Quesada
Louk Rademaker
Djordje Radicevic
C. Jess Riedel
Aldo Riello
Denis Rosset
Ana Belen Sainz
John Selby
Mohamad Shalaby
Jamie Sikora
Sebastian Steinhaus
Dave Touchette
Alex Weekes
Wolfgang Wieland
Daniel Wohns*
Elie Wolfe
Gang Xu*
Junya Yagi
Ziqi Yan
Qiao Zhou

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

Professor Forrest joined the University of Waterloo's faculty in 2000 and became Perimeter's Academic Programs Director in 2014. He was the Director of the Guelph-Waterloo Physics Institute from 2005 to 2010 and has served in several administrative roles at Waterloo. His research focuses on the physics of soft matter on the nanoscale, particularly 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.

PHD STUDENTS, 2017/18 (partner university, supervisor)

Eugene Adjei (University of Waterloo, Agata Branczyk)
Natacha Altamirano (University of Waterloo, Niayesh Afshordi)
Alvaro Ballon Bordo (University of Waterloo, David Kubiznak/Robert Myers)
Chenfeng Bao (University of Waterloo, Neil Turok)
Jacob Barnett (University of Waterloo, Lee Smolin)
Pablo Bosch Gomez (University of Waterloo, Luis Lehner)
Dylan Butson (University of Toronto, Kevin Costello)
Juan Cayuso (University of Waterloo, Matthew Johnson)
Frank Coronado (University of Waterloo, Pedro Vieira)
Clement Delcamp (University of Waterloo, Bianca Dittrich)
Diego Delmastro (University of Waterloo, Jaume Gomis)
Job Feldbrugge (University of Waterloo, Neil Turok)
Adrian Franco Rubio (University of Waterloo, Guifre Vidal)
Utkarsh Giri (University of Waterloo, Kendrick Smith)
Anna Golubeva (University of Waterloo, Roger Melko)
Lucia Gomez Cordova (University of Waterloo, Pedro Vieira)
Tomas Gonda (University of Waterloo, Robert Spekkens)
Alfredo Guevara (University of Waterloo, Freddy Cachazo)
Markus Hauru (University of Waterloo, Guifre Vidal)
Juan Hernandez (University of Waterloo, Robert Myers)
Florian Hopfmueller (University of Waterloo, Laurent Freidel)
Qi Hu (University of Waterloo, Guifre Vidal)
Nafiz Ishtiaque (University of Waterloo, Jaume Gomis)
Mansour Karami (University of Waterloo, Niayesh Afshordi/Avery Broderick)
Seth Kurankyi Asante (University of Waterloo, Bianca Dittrich/Lee Smolin)
Gabriel Magill (McMaster University, Cliff Burgess)
Hugo Marrochio (University of Waterloo, Robert Myers)
Fiona McCarthy (University of Waterloo, David Kubiznak/Robert Mann)
Sebastian Mizera (University of Waterloo, Freddy Cachazo/Bianca Dittrich)
Seyed Faroogh Moosavian (University of Waterloo, Davide Gaiotto)
Heidar Moradi (University of Waterloo, Xiao-Gang Wen)
Soham Mukherjee (University of Waterloo, Erik Schnetter)
Chiamaka Okoli (University of Waterloo, Niayesh Afshordi)
Masoud Rafiei-Ravandi (University of Waterloo, Kendrick Smith)
Surya Raghavendran (University of Toronto, Kevin Costello)
Miroslav Rapcak (University of Waterloo, Davide Gaiotto/Jaume Gomis)
Matthew Robbins (University of Waterloo, Niayesh Afshordi/Robert Mann)
Shan-Ming Ruan (University of Waterloo, Robert Myers)
Nitica Sakharwade (University of Waterloo, Lucien Hardy)
Laura Sberna (University of Waterloo, Neil Turok)
Andres Schlief (McMaster University, Sung-Sik Lee)
David Schmid (University of Waterloo, Robert Spekkens)
Andrei Shieber (University of Waterloo, Lucien Hardy)
Barak Shoshany (University of Waterloo, Laurent Freidel)
Vasudev Shyam (University of Waterloo, Lee Smolin)
David Svoboda (University of Waterloo, Laurent Freidel/Ruxandra Moraru)
Paul Tiede (University of Waterloo, Avery Broderick)
Qingwen Wang (University of Waterloo, Niayesh Afshordi)
Ryan Westernacher-Schneider (University of Waterloo, Luis Lehner)
Jingxiang Wu (University of Waterloo, Davide Gaiotto)
Yigit Yargic (University of Waterloo, Lee Smolin)
Yehao Zhou (University of Waterloo, Kevin Costello)
Yijian Zou (University of Waterloo, Guifre Vidal)

MASTER'S STUDENTS, 2017/18 (country of origin)

Nanna Havn Aamand (Denmark)
Ahmed Abouelkomsan (Egypt)
Mohammed Montadhar Al-Hakim (Germany)
Gwyneth Allwright (South Africa)
Julia Alsina Oriol (Spain)
Francisco Vladimir Calvera Ciguenas (Peru)
Lila Chergui (Canada)
Kfir Dolev (USA)
Matthew Duschenes (Canada)
Stavros Efthymiou (Greece)
Jeremie Francfort (Switzerland)
Thomas Fraser (Canada)
Lucia Maria Garozzo (Italy)
Finnian Gray (New Zealand)
Alexandre Homrich (Brazil)
Aurora Ireland (USA)
Puttarak Jai-akson (Thailand)
Cheryne Jonay (Switzerland)
Jeremy Kelly-Massicotte (Canada)
Niamh Maher (Ireland)
Katarina Martinovic (Montenegro)
Avirukt Mittal (India)
Michael Morales Curi (Peru)
Felipe Ortega Gama (Mexico)
Qiaoyin Pan (China)
Victor Py (France)
Leonel Quinta Queimada (Portugal)
Carlos Rodriguez Fernandez (Ecuador)
Barbara Skrzypek (USA)
Jessica Weitbrecht (Ireland)
Lei Yang (New Zealand)

RESIDENT RESEARCHERS

Resident Research Affiliate
John Moffat

Senior Research Affiliate
Steve MacLean

Senior Researcher
Rafael Sorkin

AFFILIATES, 2017/18

Arif Babul, University of Victoria
Sonia Bacca, TRIUMF
Jonathan Bagger, TRIUMF
Jonathan Baugh, University of Waterloo/Institute for Quantum Computing (IQC)
Richard Bond, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)
Ivan Booth, Memorial University
Vincent Bouchard, University of Alberta
Robert Brandenberger, McGill University
Gilles Brassard, University of Montreal
Anne Broadbent, University of Ottawa
Jim Bryan, University of British Columbia
Anton Burkov, University of Waterloo
Simon Caron-Huot, McGill University
Benoit Charbonneau, University of Waterloo
Jeffrey Chen, University of Waterloo
Kyung Soo Choi, University of Waterloo/IQC
Matthew Choptuik, University of British Columbia
Dan Christensen, Western University
Richard Cleve, University of Waterloo/IQC
Alan Coley, Dalhousie University
Andrzej Czarnecki, University of Alberta
Saurya Das, University of Lethbridge
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
Rodrigo Fernandez, University of Alberta
Marcel Franz, University of British Columbia
Doreen Fraser, University of Waterloo
Andrew Frey, University of Winnipeg
Valeri Frolov, University of Alberta
Ion Garate, University of Sherbrooke
Jack Gegenberg, University of New Brunswick
Ghazal Geshnizjani, University of Waterloo
Shohini Ghose, Wilfrid Laurier University
Florian Girelli, University of Waterloo
Gilad Gour, University of Calgary
Marco Gualtieri, University of Toronto
John Harnad, Concordia University
Igor Herbut, Simon Fraser University
Jeremy Heyl, University of British Columbia
Bob Holdom, University of Toronto
Michael Hudson, University of Waterloo
Viqar Husain, University of New Brunswick
Kazi Rajibul Islam, University of Waterloo/IQC
Thomas Jennewein, University of Waterloo/IQC
Joel Kamnitzer, University of Toronto
Joanna Karczmarek, University of British Columbia
Spiro Karigiannis, University of Waterloo
Achim Kempf, University of Waterloo
Yong-Baek Kim, University of Toronto
Pavel Kovtun, University of Victoria
David Kribs, University of Guelph
Hari Kunduri, Memorial University
Gabor Kunstatter, University of Winnipeg
Kayll Lake, Queen's University
Debbie Leung, University of Waterloo
Randy Lewis, York University
Hoi-Kwong Lo, University of Toronto
Norbert Lütkenhaus, University of Waterloo/IQC
Joseph Maciejko, University of Alberta
Richard MacKenzie, University of Montreal
A. Hamed Majedi, University of Waterloo/IQC
Alexander Maloney, McGill University
Robert Mann, University of Waterloo
Eduardo Martin-Martinez, University of Waterloo/IQC
Gerry McKeon, Western University
Guo-Xing Miao, University of Waterloo/IQC
Volodya Miransky, Western University
Ruxandra Moraru, University of Waterloo
David Morrissey, TRIUMF
Norman Murray, University of Toronto/CITA
Christine Muschik, University of Waterloo
Wayne Myrvold, Western University
Julio Navarro, University of Victoria
Ashwin Nayak, University of Waterloo
Elisabeth Nicol, University of Guelph
Duncan O'Dell, McMaster University
Don Page, University of Alberta
Prakash Panangaden, McGill University
Manu Paranjape, University of Montreal
Vern Paulsen, University of Waterloo/IQC
A.W. Peet, University of Toronto
Alexander Penin, University of Alberta
Harald Pfeiffer, University of Toronto/CITA
Levon Pogosian, Simon Fraser University
Dmitri Pogosyan, University of Alberta
Eric Poisson, University of Guelph
David Poulin, University of Sherbrooke
Steven Rayan, University of Saskatchewan
Michael Reimer, University of Waterloo/IQC
Kevin Resch, University of Waterloo/IQC
Adam Ritz, University of Victoria
Pierre-Nicholas Roy, University of Waterloo
Moshe Rozali, University of British Columbia
Barry Sanders, University of Calgary
Kristin Schleich, University of British Columbia
Douglas Scott, University of British Columbia
Sanjeev Seahra, University of New Brunswick
Peter Selinger, Dalhousie University
John Sipe, University of Toronto
Aephraim Steinberg, University of Toronto
James Taylor, University of Waterloo
André-Marie Tremblay, University of Sherbrooke
Adam Tsen, University of Waterloo
Mark Walton, University of Lethbridge
John Watrous, University of Waterloo
Steve Weinstein, University of Waterloo
Lawrence Widrow, Queen's University
Christopher Wilson, University of Waterloo/IQC
Edward Wilson-Ewing, University of New Brunswick
Don Witt, University of British Columbia
Peter Wittek, University of Toronto
Karen Yeats, University of Waterloo
Bei Zeng, University of Guelph

SCIENTIFIC VISITORS, 2017/18

** Indicates Distinguished Visiting Research Chair*
*** Indicates Visiting Fellow*
**** Indicates Simons Emmy Noether Fellow*

Scott Aaronson*, University of Texas at Austin

David Aasen, California Institute of Technology

Jahed Abedi, Institute for Research in Fundamental Sciences (IPM)

Michalis Agathos, University of Cambridge

Prateek Agrawal, Harvard University

Syed Ahmed, Raman Research Institute

Vincenzo Alba, International School for Advanced Studies (SISSA)

Emanuele Alesci, Pennsylvania State University

Olalla Alvaredo***, University of London – Royal Holloway

Haipeng An**, Tsinghua University

Xinliang An, University of Toronto

Anders Andreassen, Harvard University

Lorenzo Annulli, University of Lisbon/Higher Technical Institute (IST)

Anurag Anshu, National University of Singapore

Leandro Aolita, Federal University of Rio de Janeiro

Michael Appels, Durham University

Amjad Ashoorioon, National Institute for Nuclear Physics (INFN), Italy

Abhay Ashtekar*, Pennsylvania State University

Alexander Atanasov, Yale University

Gary Au, University of Saskatchewan

Newshaw Bahreyni, Gettysburg College

Yuntao Bai, Princeton University

Ana Balibanu, Harvard University

Mario Ballardini, University of the Western Cape

Jean-Daniel Bancal, University of Basel

Leonardo Banchi, Imperial College London

Ning Bao, University of California, Berkeley

James Bardeen*, University of Washington

Till Bargheer, Leibniz University of Hannover

Dror Bar-Natan, University of Toronto

Glenn Barnich, Free University of Brussels

Jonathan Barrett**, University of Oxford

Ganapathy Baskaran*, Institute of Mathematical Sciences, Chennai

Aron Beekman, Keio University

Gwyn Bellamy, University of Glasgow

Jibril Ben Achour, Fudan University

Joseph Ben Geloun**, University of Paris 13

Yoni BenTov, California Institute of Technology

Marcus Berg, Karlstad University

Eric Bergshoeff, University of Groningen

Asher Berlin, SLAC National Accelerator Laboratory

Laura Bernard, University of Lisbon/Higher Technical Institute (IST)

Clément Berthiere, University of Tours

Swetha Bhagwat, Syracuse University

Amit Bhoonah, Queen's University

Ofek Birnholtz, Rochester Institute of Technology

Marcel Bischoff, Ohio University

Nikita Blinov, SLAC National Accelerator Laboratory

Celine Boehm***, Durham University

Radja Boughezal***, Argonne National Laboratory

Raphael Bousso, University of California, Berkeley

Jo Bovy, University of Toronto

Patrick Brady*, University of Wisconsin-Milwaukee

Suddhasattwa Brahma, Asia Pacific Center for Theoretical Physics

Joseph Bramante**, Queen's University

Sebastian Bramberger, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Robert Brandenberger, McGill University

Jacob Bridgeman, University of Sydney

Torsten Bringmann, University of Oslo

Anne Broadbent, University of Ottawa

Adam Brown, Stanford University

Benjamin Brown, Imperial College London

Časlav Brukner, University of Vienna

Joren Brunekreef, Radboud University, Nijmegen

Phil Bull, University of California, Berkeley

Nick Bultinck, Princeton University

Maya Burhanpurkar, Harvard University

Anton Burkov, University of Waterloo

Miguel Campiglia, University of Montevideo

Raul Carballo-Rubio, International School for Advanced Studies (SISSA)

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

Dean Carmi, Tel Aviv University

Daniel Carney, University of Maryland, College Park

Juan Carrasquilla**, Vector Institute for Artificial Intelligence

Katerina Chatziioannou, University of Toronto/ Canadian Institute for Theoretical Astrophysics (CITA)

Saptarshi Chaudhuri, Stanford University

Chien-Yi Chen, University of Victoria

Natalia Chepiga, University of California, Irvine

Chi-Ting Chiang, Stony Brook University

Goffredo Chirco, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Giulio Chiribella**, University of Oxford

Emily Cliff, University of Illinois at Urbana-Champaign

Jordan Cotler, Stanford University

Antonin Coutant, Laboratory of Acoustics at the University of Le Mans

Sarah Croke, University of Glasgow

Elizabeth Crosson, California Institute of Technology

Will Cunningham, Northeastern University

Leo Cuspinera, Durham University

Mariusz Dabrowski, University of Szczecin

Saurya Das, University of Lethbridge

Shane Davis, University of Virginia

Tommaso De Lorenzo, Aix-Marseille University

Elena De Paoli, Aix-Marseille University

Claudia de Rham**, Imperial College London

Benjamin Dickens, University of California, Berkeley

Emanuela Dimastrogiovanni***, Case Western Reserve University

Tudor Dimofte, University of California, Davis

David DiVincenzo, RWTH Aachen University/ Institute for Quantum Information

Vladimir Dobrosavljevic, National High Magnetic Field Laboratory

Pietro Dona, Pennsylvania State University

Fay Dowker**, Imperial College London

Benjamin Doyon, King's College London

Justin Dressel, Chapman University

Nick Early, University of Minnesota

Astrid Eichhorn**, Heidelberg University

Chris Elliott, Institute of Advanced Scientific Studies (IHES)

Dominic Else, University of California, Santa Barbara

Matthew Evans, Massachusetts Institute of Technology

Glen Evenbly**, University of Sherbrooke

Philippe Faist, California Institute of Technology

Gregory Falkovich, Weizmann Institute of Science

Shane Farnsworth, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Terry Farrelly, Leibniz University of Hannover

Matteo Fasiello, Stanford University

Farzad Fathizadeh, Swansea University

Frank Ferrari, Free University of Brussels

Matthew Fisher*, University of California, Santa Barbara

Simon Foreman, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)

Valentina Forini***, City University of London

Anthony Fradette, University of Victoria

Andrew Frey, University of Winnipeg

Daniel Friedan, Rutgers University

Tobias Fritz**, Max Planck Institute for Mathematics in the Sciences

Ernesto Frodden, Center for Scientific Studies (CEC)

Lena Funcke, Max Planck Institute for Physics

Barak Gabai, Harvard University

Damian Galante, University of Amsterdam

Thomas Galley, University College London

Iordan Ganev, Institute of Science and Technology Austria

Chandrima Ganguly, University of Cambridge

Isabel Garcia Garcia, University of Oxford

Iñaki García-Etxebarria, Max Planck Institute for Physics

Luis Pedro Garcia-Pintos, University of Massachusetts, Boston

Jerome Gauntlett**, Imperial College London

Sachin Gautam, Ohio State University

Snir Gazit, University of California, Berkeley

Dongsheng Ge, École Normale Supérieure de Paris

Jan Gerken, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Flaminia Giacomini, Institute for Quantum Optics and Quantum Information

Natalia Giovenale, National University of Córdoba

Roman Gold, University of Frankfurt

Hart Goldman, University of Illinois at Urbana-Champaign

Vasco Goncalves, International Centre for Theoretical Physics – South American Institute for Fundamental Research (ICTP-SAIFR)

Jose Raul Gonzalez Alonso, Chapman University

Achamveedu Gopakumar, Tata Institute for Fundamental Research

Alison Gopnik, University of California, Berkeley

Victor Gorbenko, Stanford University

David Gosset, IBM Thomas J. Watson Research Center

Kanato Goto, University of Tokyo

Philip Goyal, State University of New York (SUNY) at Albany

Stephen Green, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Sasha Greenfield, Chapman University

Ruth Gregory**, Durham University

Aaron Grisez, Chapman University

Andrey Gromov, University of Chicago

Kevin Grosvenor, University of Copenhagen

Andrea Guerrieri, International Centre for Theoretical Physics – South American Institute for Fundamental Research (ICTP-SAIFR)

Anshu Gupta, Inter-University Centre for Astronomy and Astrophysics

Razvan Gurau**, École Polytechnique de Paris

Roland Haas, University of Illinois at Urbana-Champaign

Hal Haggard, Bard College

Daniel Halpern-Leistner, Cornell University

Shajid Haque, University of Windsor

Edward Hardy, University of Liverpool

Jelle Hartong, University of Edinburgh

Koji Hashimoto, Osaka University

Yin-Chen He, Harvard University

Song He, Chinese Academy of Sciences/Institute of Theoretical Physics

Aaron Held, Heidelberg University

Simeon Hellerman, Kavli Institute for the Physics and Mathematics of the Universe

Reyco Henning, University of North Carolina

Christopher Herzog, Stony Brook University

Eric Hessels, York University

Justin Hilburn, University of Pennsylvania

Colin Hill, Institute for Advanced Study

Ian Hinder, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Kurt Hinterbichler, Case Western Reserve University

Wen Wei Ho, Harvard University

Matt Hogancamp, University of Southern California

Gilbert Holder**, University of Illinois at Urbana-Champaign

Stefan Hollands, Leipzig University

Anson Hook, Stanford University

Sabine Hossenfelder, Frankfurt Institute for Advanced Studies

Onur Hosten, Stanford University

Matheus Hostert, Durham University

Timothy Hsieh, University of California, Santa Barbara/Kavli Institute for Theoretical Physics

Jiangping Hu, Chinese Academy of Sciences/ Institute of Theoretical Physics

Emilie Huffman, Duke University

Nick Hunter-Jones, California Institute of Technology

Viqar Husain, University of New Brunswick

Marios Ilias Galanis, Stanford University

Kent Irwin, Stanford University

Akash Jain, Durham University

Karl Jansen, German Electron Synchotron (DESY)

Casey Jao, University of California, Berkeley

Patrick Jefferson, Harvard University

Michael Johnson, Smithsonian Astronomical Observatory

Nathan Johnson-McDaniel, University of Cambridge

David Jordan, University of Edinburgh

Ian Jubb, Imperial College London

Felix Julie, University of Paris-Sud

Martin Jung, Technical University of Munich

Joel Kamnitzer, University of Toronto

Adrian Kent*, University of Cambridge

Markus Kesselring, Free University of Berlin

Vedika Khemani, Harvard University

Nima Khosravi, Shahid Beheshti University

Isaac Kim, Stanford University

Taro Kimura, Keio University

Naoki Kiryu, University of Tokyo

Matthias Kleinmann, University of Siegen

Nilas Klitgaard, Radboud University, Nijmegen

Dax Koh, Massachusetts Institute of Technology

Zohar Komargodski**, Weizmann Institute of Science

Eleni Kontou, University of York

Ryszard Kostecki, University of Warsaw

Jerzy Kowalski-Glikman, University of Wroclaw

Badri Krishnan, Max Planck Institute for Gravitational Physics (Albert Einstein Institute) and Leibniz

University of Hannover

Pavel Krtouš, Charles University

Brad Lackey, University of Maryland, College Park

Lampros Lamprou, Massachusetts Institute of Technology

Andreas Lauchli, University of Innsbruck

Edoardo Lauria, University of Leuven

James LeBlanc, Memorial University

Ciaran Lee, University College London

Matthew Leifer**, Chapman University

Rob Leigh, University of Illinois at Urbana-Champaign

Martin Lesourd, University of Oxford

Yeong-Cherng Liang, National Cheng Kung University

Eugene Lim, King's College London

Chien-Hung Lin, University of Minnesota

Jennifer Lin, Institute for Advanced Study

Tongyan Lin, University of California, San Diego

Jesse Liu, University of Oxford

Zi-Wen Liu, Massachusetts Institute of Technology

Renate Loll*, Radboud University, Nijmegen

Robin Lorenz, University of Oxford

SCIENTIFIC VISITORS (CONTINUED)

Niccolo Loret, Sapienza University of Rome

Raeez Lorgat, Massachusetts Institute of Technology

Matteo Lostaglio, Institute of Photonic Sciences (ICFO)

Matthew Low, Institute for Advanced Study

Andy Lucas, Stanford University

Peter Lunts, Flatiron Institute

Zhenwei Lyu, Beijing Normal University

Noah MacAulay, University of Toronto

Carlos Mafra, University of Cambridge

Seth Major, Hamilton College

Shotaro Makisumi, Columbia University

John March-Russell*, University of Oxford

Gustavo Marques-Tavares, Stanford University

Kate Marshall, University of Newcastle

Mario Martone, University of Texas at Austin

Lluis Masanes, University College London

Kiyoshi Masui, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)

Dalimil Mazac, Stony Brook University

Edward Mazenc, Stanford University

Benjamin Mazin, University of California, Santa Barbara

Samuel McDermott, Fermi National Accelerator Laboratory (Fermilab)

Jacob McNamara, Harvard University

Marco Meineri, École Polytechnique Fédérale de Lausanne

Paula Mellado***, Adolfo Ibanez University

Raissa Mendes, Fluminense Federal University

James Mertens, Case Western Reserve University

Florent Michel, Durham University

Jonah Miller, Los Alamos National Laboratory

Stephen Morgan, University of Sydney

Ian Moss, University of Newcastle

Pavel Motloch, University of Chicago

Ramis Movassagh, Massachusetts Institute of Technology

Markus Mueller**, Institute for Quantum Optics and Quantum Information

Jessica Muir, University of Michigan

David A. Nichols, Radboud University, Nijmegen

Karim Noui, University of Tours

Masahiro Nozaki, University of Chicago

Zohar Nussinov, Washington University in St. Louis

Niels Obers, University of Copenhagen

Alexei Oblomkov, University of Massachusetts, Amherst

Javier Olmedo, Pennsylvania State University

Prince Osei, Quantum Leap Africa/African Institute for Mathematical Sciences (AIMS)

Naritaka Oshita, University of Tokyo

Claudio Paganini, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Don Page, University of Alberta

Zhen Pan, University of California, Davis

Duccio Pappadopulo, New York University

Natalie Paquette, California Institute of Technology

Sarthak Parikh, California Institute of Technology

Yuchen Pei, KTH Royal Institute of Technology

Riccardo Penco, University of Pennsylvania

Alexander Penin, University of Alberta

Geoffrey Penington, Stanford University

Mark Penney, Max Planck Institute for Mathematics

Paolo Perinotti, University of Pavia

Eric Perlmutter, California Institute of Technology

Frank Petriello, Argonne National Laboratory

Federico Piazza, Aix-Marseille University

Nicolo' Piazzalunga, Stony Brook University

Aaron Pierce, University of Michigan

Joanna Piotrowska, University of Cambridge

Cyril Pitrou, Paris Institute of Astrophysics

Bill Poirier, Texas Tech University

Giuseppe Policastro, École Normale Supérieure de Paris

Swetha Prabhat, Syracuse University

Anirudh Prabhu, Stanford University

Frans Pretorius*, Princeton University

Petr Pushkar, Columbia University

Eugene Rabinovich, University of California, Berkeley

David Radice, Princeton University

Sohrab Rahvar, Sharif University of Technology

Daniel Ranard, Stanford University

Sebastian Rauch, Swiss Federal Institute of Technology (ETH Zurich)

Diego Regalado, European Organization for Nuclear Research (CERN)

Bartosz Regula, University of Nottingham

Hanno Rein, University of Toronto

Michael Reisenberger, University of Montevideo

Marcus Reitz, Radboud University, Nijmegen

Katarzyna Rejzner**, University of York

Jing Ren, University of Toronto

David Rideout, University of California, San Diego

Katja Ried, University of Innsbruck

Massimiliano Rinaldi, University of Trento

Kai Roehrig, University of Cambridge

Alexander Roman, University of Toronto

Anna Romanova, University of Utah

Vladimir Rosenhaus, University of California, Santa Barbara/Kavli Institute for Theoretical Physics

Shan-Ming Ruan, University of Waterloo

Markus Rummel, McMaster University

Mairi Sakellariadou***, King's College London

Grant Salton, Stanford University

Jessica Santiago, Victoria University of Wellington

Edivaldo Santos, University of Chicago

Ryosuke Sato, Weizmann Institute of Science

Claudia Scheimbauer, University of Oxford

Oliver Schlotterer, Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

Marcel Schmittfull, Institute for Advanced Study

Kai Schmitz, Max Planck Institute for Nuclear Physics

Volker Schomerus, German Electron Synchotron (DESY)

Sarah Schon, Queen's University

Andrew Scoins, Durham University

Sanjeev Seahra, University of New Brunswick

Michael Seifert, University of Chicago

Ali Seraj, Institute for Research in Fundamental Sciences (IPM)

Evangelos Sfakianakis, University of Leiden

Henry Shackleton, Massachusetts Institute of Technology

Horng Sheng Chia, University of Amsterdam

Daniel Siegel, Columbia University

Jon Sievers, University of KwaZulu-Natal

Olivier Simon, Stanford University

Kevin Slagle, University of Toronto

Marcelle Soares-Santos, Fermi National Accelerator Laboratory (Fermilab)

Iakov (Yan) Soibelman*, Kansas State University

Adam Solomon, University of Pennsylvania

Antony Speranza, University of Maryland, College Park

Liron Speyer, University of Virginia

Emmanuel Stamou, Weizmann Institute of Science

Bogdan Stefanski, City University of London

Dejan Stojkovic, State University of New York (SUNY) at Buffalo

Miles Stoudenmire, Flatiron Institute

Georgios Styliaris, University of Southern California

James Sully, McGill University

Sherry Suyu, Max Planck Institute for Astrophysics

Volodymyr Takhistov, University of California, Los Angeles

Dan Tamayo, University of Toronto/Canadian Institute for Theoretical Astrophysics (CITA)

Isaac Tamblyn, National Research Council of Canada

Massimo Taronna, Princeton University

James Tener, University of California, Santa Barbara

Mae Hwee Teo, Stanford University

Barbara Terhal*, Delft University of Technology

Eduardo Testé Lino, International Centre for Theoretical Physics – South American Institute for Fundamental Research (ICTP-SAIFR)

Jedidiah Oliver Thompson, Stanford University

Naftali Tishby, Hebrew University of Jerusalem

Jonathan Toledo, École Polytechnique Fédérale de Lausanne

Andrew Tolley**, Imperial College London

Koon Tong Goh, National University of Singapore

Michael Troxel, Ohio State University

Yu-Dai Tsai, Cornell University

Luca Turin, Alexander Fleming Biomedical Sciences Research Center

Hendrik Ulbricht, University of Southampton

Lev Vaidman, Tel Aviv University

Antony Valentini, Clemson University

Rien van de Weijgaert, University of Groningen

Evert van Nieuwenburg, California Institute of Technology

Ken Van Tilburg, Institute for Advanced Study

Jasper van Wezel, University of Amsterdam

Petr Vasko, University of Warsaw

Fleur Versteegen, Heidelberg University

Rodrigo Vicente, University of Lisbon/Higher Technical Institute (IST)

Giovanni Villadoro, Abdus Salam International Centre for Theoretical Physics (ICTP)

Aaron Vincent**, Queen's University

Michael Viscardi, University of California, Berkeley

Manus Visser, University of Amsterdam

Curt von Keyserlingk, University of Birmingham

Amar Vutha, University of Toronto

Mordecai Waegell, Chapman University

Aron Wall, Stanford University

Yidun Wan, Fudan University

Chong Wang, Harvard University

Tian Wang, California Institute of Technology

Yifan Wang, Princeton University

Zhiqiang Wang, McMaster University

David Weir, University of Helsinki

Rainer Weiss, Massachusetts Institute of Technology

Brian Williams, Northwestern University

Mark Wise*, California Institute of Technology

Gabriel Wong, University of Virginia

Imogen Wright, Hyrax Biosciences

Cenke Xu, University of California, Santa Barbara

Masahito Yamazaki, Kavli Institute for the Physics and Mathematics of the Universe

Yaping Yang***, University of Massachusetts, Amherst

Penghui Yao, University of Maryland, College Park

Hossein Yavartanoo, Chinese Academy of Sciences/Institute of Theoretical Physics

Philsang Yoo, Yale University

Yi-Zhuang You, Harvard University

Stav Zalel, Imperial College London

Alexander Zamolodchikov*, Stony Brook University

Jesus Zavala Franco, University of Iceland

Fuchun Zhang, Chinese Academy of Sciences/ Kavli Institute for Theoretical Sciences

Yong Zhang, Chinese Academy of Sciences/ Institute of Theoretical Physics

Gufang Zhao, University of Massachusetts, Amherst

Yue Zhao, University of Michigan

Tianci Zhou, University of Illinois at Urbana-Champaign

Quntao Zhuang, Massachusetts Institute of Technology

Paul Ziegler, University of Oxford

Peter Zimmerman, University of Arizona

Liujun Zou, Massachusetts Institute of Technology

CONFERENCES AND WORKSHOPS, 2017/18

Hopf Algebras in Kitaev's Quantum Double Models: Mathematical Connections from Gauge Theory to Topological Quantum Computing and Categorical Quantum Mechanics
July 31-August 4, 2017

Experimental Techniques in Table-Top Fundamental Physics
August 21-25, 2017

Hands-On Maple Workshop
October 24, 2017

Lights, Sounds, Action in Strong Field Gravity
November 6-7, 2017

Quantum Black Holes in the Sky?
November 8-10, 2017

The Path Integral for Gravity
November 13-17, 2017

Computational Methods for General Relativistic Magnetohydrodynamics: Con2Prim and Friends
February 13-14, 2018

Gauge Theory, Geometric Langlands, and Vertex Operator Algebras
March 22-24, 2018

Open Research: Rethinking Scientific Collaboration
March 26-28, 2018

Observers in Quantum and Foil Theories
April 2-6, 2018

Algorithmic Information, Induction, and Observers in Physics
April 9-13, 2018

New Directions in Conventional and Ambitwistor String Theories
April 16-20, 2018

PI-NRC Meeting
May 7-8, 2018

Searching for New Particles with Black Hole Superradiance
May 9-11, 2018

Career Trajectories Day
May 15, 2018

Open EFTs and Gravity as a Medium
June 4-8, 2018

Asymptotic Safety in a Dark Universe
June 5-7, 2018

Path to Kilohertz Gravitational-Wave Astronomy
June 11-13, 2018

Low Energy Challenges for High Energy Physicists 3
June 18-21, 2018

Tri-Institute Summer School on Elementary Particles (TRISEP) 2018
July 9-20, 2018

ACADEMIC SPONSORSHIPS, 2017/18

Perimeter sponsored the following off-site conferences and workshops:

"15th International Conference on Quantum Physics and Logic (QPL 2018)," Dalhousie University

"2018 CAP Congress," Dalhousie University

"Atlantic General Relativity Workshop and Conference," St. Francis Xavier University

"Canadian Conference for Undergraduate Women in Physics (CCUWiP) 2018," Queen's University

"Cosmological Frontiers in Fundamental Physics 2018," International Solvay Institutes

"Geometry and Physics (GAP) 2017," Fields Institute for Research in Mathematical Sciences/University of Toronto

"Joint Canada-Asia Pacific Conference on General Relativity and Relativistic Astrophysics 2018," University of Alberta

"Lake Louise Winter Institute 2018," University of Alberta

"The Physics of Galaxy Scaling Relations and the Nature of Dark Matter," Queen's University

"Theory Canada 13," St. Francis Xavier University

"Women in Physics Canada 2018," University of Sherbrooke

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