inside the Perimeter

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PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Inside the Perimeter

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IN THIS ISSUE

04/ We are innovators, *Neil Turok*

06/ Young women encouraged to follow curiosity to success in STEM, *Tenille Bonoguore*

08/ A quantum spin on passing a law, *Colin Hunter*

09/ Creating clean 'quantum light', *Tenille Bonoguore*

12/ How to make magic, *Colin Hunter and Tenille Bonoguore*

14/ Innovation tour delivers – and discovers – inspiration across Canada, *Tenille Bonoguore*

15/ Teacher training goes to Iqaluit, *Stephanie Keating*

16/ The (surprisingly) complex science of trapping muskrats, *Roger Melko*

18/ Fundamental science success deep underground, *Arthur B. McDonald*

20/ Hearing the universe's briefest notes, *Stephanie Keating*

22/ Our home and innovative land, *Colin Hunter*

24/ Ingenious Canada

26/ Fostering the untapped curiosity of youth, *Percy Paul*

27/ "How do we change the future? We reinvent it.", *Colin Hunter*

28/ Power to the people

30/ The story behind the PI hockey stick, *Robert Myers*

31/ String theory solution is tailor-made, *Tenille Bonoguore*

33/ The power of place

35/ Counterfactual, *Tenille Bonoguore*

37/ Finding hope in a darkening world, *Tenille Bonoguore*

38/ Thanks to our supporters

40/ Upcoming conferences

41/ Turning challenges into opportunities, *Stephanie Keating*

42/ From the Black Hole Bistro: Chef Ben's Maple cider brined pork loin

43/ Particles

46/ PI kids are asking: What causes the seasons to change?, *Stephanie Keating*

WE ARE INNOVATORS

As a cosmologist, I'm often asked whether studying the universe is at all relevant to our everyday lives and concerns. My answer: completely!

Our knowledge of the laws of motion, electricity, and light made airplanes, computers, and wireless communication all possible. We learned all these things from trying to make sense of the universe. Solving today's great mysteries in physics, like what banged at the big bang, what the dark energy or dark matter is made of, and how quantum theory governs space and time, will, I believe, open doors to unimaginable new technologies.

Our ability to comprehend the workings of nature, and to apply that knowledge with ingenuity to improve our world, makes us who we are. We contemplate and imagine, experiment and observe. When we understand, we design, and we make. In doing so, we continually reshape the world. We are innovators.

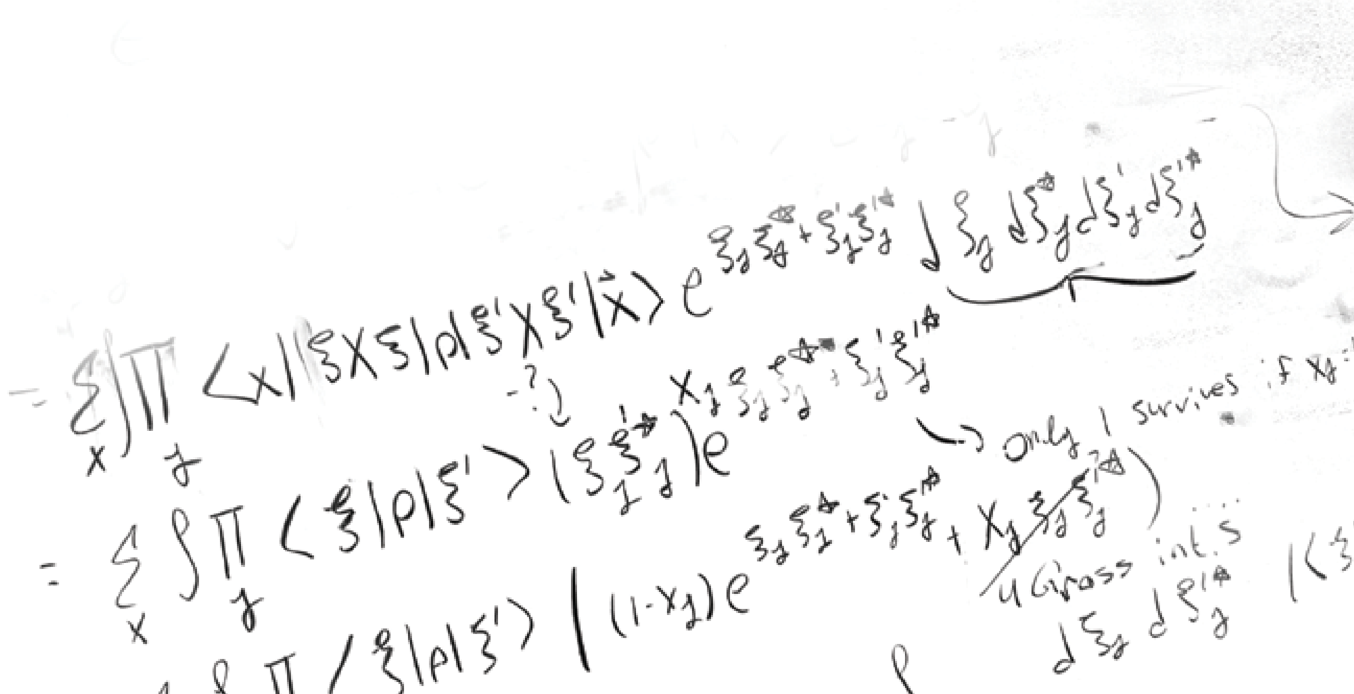
Innovation is a buzzword these days – but it's much more than that. It's an essential aspect of our existence, and a tool we need more than ever. Consider the many challenges we face, from the lack of resources and opportunities, to environmental damage and the marginalization of communities, to increasing nationalism and prejudice, "fake news" and a loss of confidence in expert opinion. Our best hope in tackling all of these problems lies, I believe, in encouraging young people to become self-confident and knowledgeable critical thinkers and capable innovators.

That's why Innovation150 is one of the themes of Canada 150, the sesquicentennial celebration. Perimeter is playing a big part, as you'll read in the pages ahead. For my part, I am in the midst of a six-city cross-Canada tour, delivering a talk called "We Are Innovators." By shining a spotlight on Canada's potential to foster innovation, I hope to encourage all Canadians, especially Canadian youth, to better understand the world and to effect positive change both at home and abroad.

What does it take to be an innovator? As a handy mnemonic, I use four Cs: curiosity, courage, creativity, and collaboration. Everyone sees these traits differently; as a physicist, I am inspired by the pioneers of our field.

The playful curiosity of a young Michael Faraday, an apprentice tinkering in his mentor's lab, led to the first electric motors and generators – and, eventually, to Maxwell's understanding of electromagnetism, which allowed radio, radar, and the mobile-communication revolution.

The courage of Marie Skłodowska Curie, a young Polish woman who overcame extreme prejudice to pursue Nobel-winning research in both physics and chemistry, and whose discoveries helped launch the quantum revolution that shaped 20th-century physics, as well as many techniques for medical diagnosis.



More recently, the creativity and collaboration of Art McDonald and his SNOLAB team enabled them to transform a nickel mine two kilometres underneath Sudbury into a world-leading neutrino observatory. It allowed us to see processes deep in the heart of the sun, giving us a new window onto physics at very high energies, and earning Art a share of the 2015 Nobel Prize. (Art, who is also on Perimeter's Board of Directors, shares his thoughts about innovation and science with us on page 18 of this issue.)

What all of these innovators share are traits we are all born with – curiosity, courage, creativity, and a collaborative spirit – combined with an intense focus on discovering the truth.

But discovery is only part of the equation. Equally important is using innovations wisely, for the betterment of everyone. Social innovators who overcome divisions and improve the way we live together are every bit as important as scientists, technologists, and entrepreneurs.

Here in Canada, I see a special opportunity. Canada's diversity and tolerant culture – of peoples and of ideas – is a source of strength; it is often at the intersection or collision of alternative viewpoints that innovation takes place. It is vital that we reinforce Canada's strength as a place where diversity is cherished and understood as a driver of progress – a place where talent is valued, wherever it arises, and where every person is empowered.

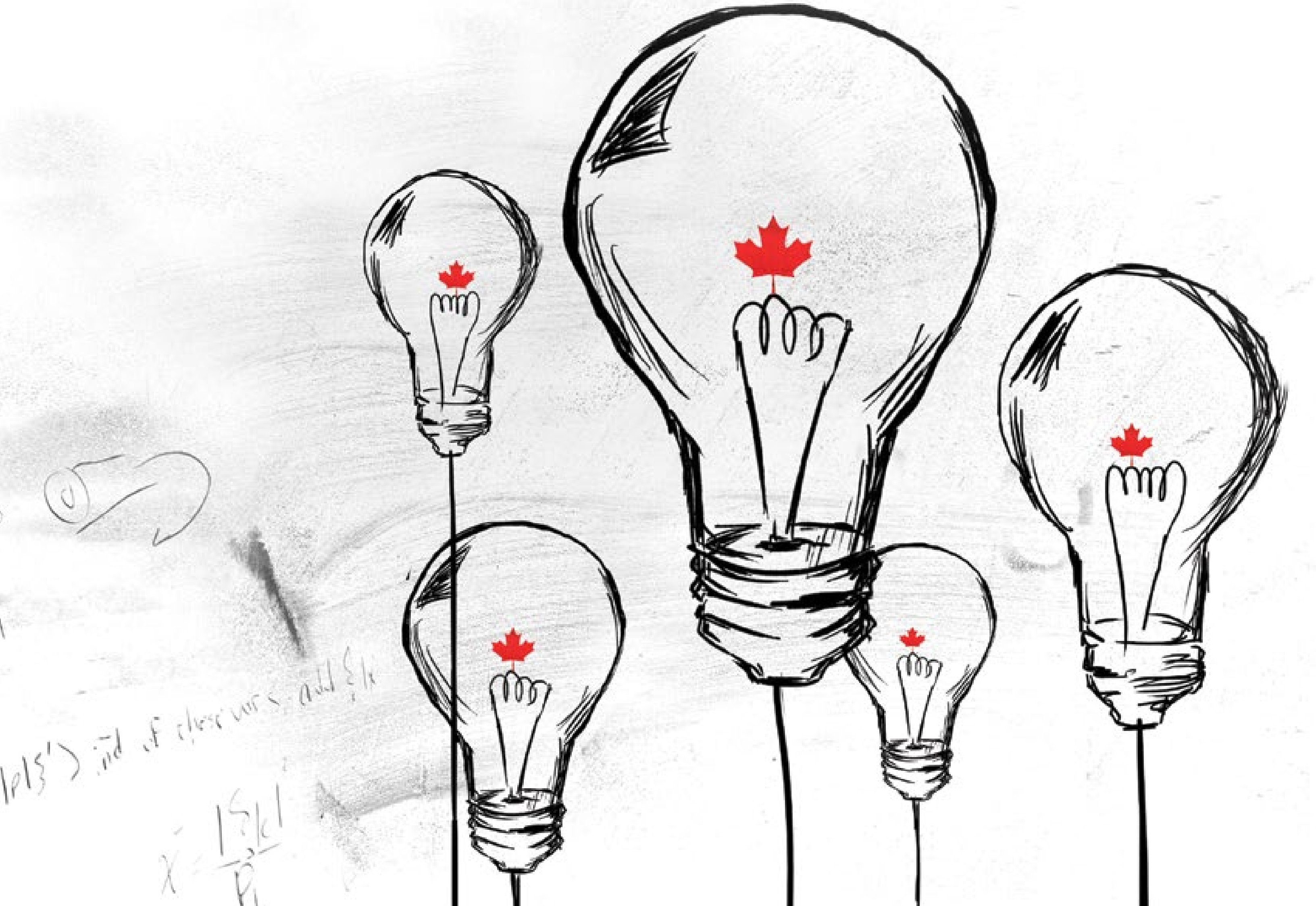
I believe the world's current crises provide Canada with an opportunity to attract the best and brightest minds and to become a global knowledge leader. This happened in 17th-century Holland, where the invention of the telescope and microscope fuelled the scientific renaissance; it happened in 18th-century Scotland, with the emergence of luminaries like Adam Smith and David Hume. Likewise, in the 21st century, I believe the world may come to look at Canada as the place where our collective future is imagined.

This will not come without effort and commitment, and there is much to be done. The whole of society needs to lend its energy to supporting innovation. This spans schools, communities, universities, companies, unions, government – everyone.

Perimeter is proud to be a part of this. We connect students and teachers to modern science. We connect visionary philanthropists with cutting-edge research. And of course, as scientists, we work to open up new paths on which we can all journey toward a deeper understanding of the universe.

Every day, Perimeter reminds me of why I love physics. It rewards curiosity, creativity, courage, and collaboration with the most precious of all things: the capacity to shape our destiny.

– Neil Turok



YOUNG WOMEN ENCOURAGED TO FOLLOW CURIOSITY TO SUCCESS IN STEM

Curiosity, ambition, and a willingness to embrace uncertainty are rewarded in STEM careers, speakers tell teens at Inspiring Future Women in Science day.

If Linda Hasenfratz could eliminate one stereotype about women in science and tech, it would be that there are no women in science and tech.

As the CEO of Linamar Corporation, the world's second-largest automotive-parts manufacturer, Hasenfratz is proof not only that women can make strong careers in science and technology, but that they already are doing just that. She is recognized as one of the most successful entrepreneurs in the country, is the current Chair of the Business Council of Canada, and was a prominent attendee when Canadian Prime Minister Justin Trudeau and U.S. President Donald Trump held a roundtable discussion about women in the workforce.

When Hasenfratz spoke to 200 high-school students at the annual Inspiring Future Women in Science event, held at Perimeter in March, she was clear: not only is there great potential in studying STEM, there's room for everyone.

"I think the momentum is building in terms of women in science and technology. There's probably 20 times the women studying science than 25 years ago, when I started," she said.

"Science and tech are great choices for anyone who's naturally curious about the world around you, and about how the world works. And the earnings potential is great."

Many of the students came from high schools across southern Ontario hoping to find out what they should pursue after graduation. Instead, they were advised to stop looking for answers: indecision is their ideal state right now.

"It's great to have lots of things you're interested in at this point," said forensic anthropologist Tracy Rogers. "Once you're [at university], that's when you're going to see what else exists."

Quantum physicist Shohini Ghose likened it to living out Heisenberg's uncertainty principle. "You don't have to be one thing or another," she said. "Explore what you know and what you don't know. Be a shapeshifter and adapt. That will make you much more able to explore and experience the world."

For Jenna Brown, a Grade 12 student at École Secondaire Catholique Notre-Dame in Woodstock, the overwhelming message from the speakers, panellists, and mentors was that there are no wrong choices when carving out your own life path.

"Right now, a lot of us are under pressure to choose an undergrad. [The speakers] kind of stressed that, whatever you pick, it's not going to be a mistake because you're still learning something, and you can always change your mind after. I think that just makes everybody feel a bit better," she said.

One after another, the speakers also tore apart the common stereotype that STEM is unwelcoming to women. Yes, sometimes the numbers of women are low. It can be strange to be the only woman in a class, or at a meeting, but that doesn't mean your work won't be respected, said Dawn Tattle, an engineer and president of Anchor Shoring and Caissons.

"There are some people who test you a little more," Tattle said. "When you're starting a career, people are always going to test you, whether you're male or female. Don't take that as because you're in a non-traditional field."

And there's a bonus: "There's never a line-up for the women's washroom."

As the daughter of a Perimeter Institute physicist, 17-year-old Ninon Freidel already has a better idea than many of what a science career can look like, but she was surprised by the vast range of job opportunities in STEM.

"I knew you could go into physics, math, or engineering, but I didn't know the specifics," said the Grade 11 international baccalaureate student at Cameron Heights Collegiate.

"I found out all these jobs I didn't even know existed. It was eye-opening. It put in perspective the opportunities that are out there."

The main benefit of pursuing STEM is that it can change with you as your career progresses, or as unexpected opportunities arise. Melissa Sariffodeen got into programming on her home computer as a teen, but pursued a varied career through accounting, sales, and business development before launching Ladies Learning Code.

It was a winding path, she said, but what she learned on the way has proved invaluable in her current projects. "STEM is every career," she said. "It's going to be invaluable to everything you do. Having that skillset, regardless of what you do, is so critical and so invaluable."

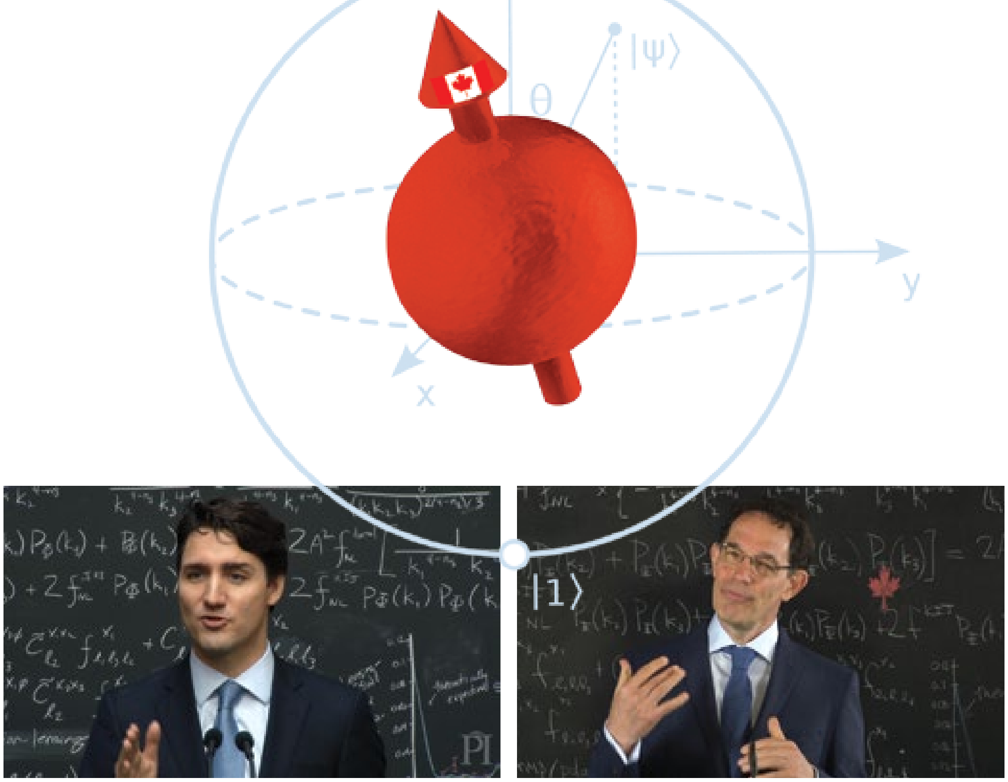
– Tenille Bonoguore

Further exploration: To watch all of the talks from this year's Inspiring Future Women in Science event, go to YouTube.com/PIOutreach and click "Playlists".

"If you're looking for someone to be critical of you because you're a woman or you're young, you're going to find them. Don't dial into that frequency."

– Linda Hasenfratz, CEO, Linamar

A QUANTUM SPIN ON PASSING A LAW



At an event honouring exceptional Canadians in public service, Canada's Prime Minister and an audience of 1,500 got an unexpected primer on legislation – from Perimeter Director Neil Turok.

"So that's what's exciting about quantum computing." As Prime Minister Justin Trudeau wound up an impromptu explanation of quantum processing last year, the Perimeter audience leapt to its feet, and a viral internet sensation was launched.

A year later, Perimeter Director Neil Turok returned the favour.

In a heartfelt spoof video watched by Trudeau and the other 1,500 attendees of the annual Public Policy Forum Testimonial Dinner in Toronto, the noted cosmologist explained the intricate process by which a bill is passed into law in Canada.

Turok charted the course of a bill through the House of Commons and Senate – "Canada's binary system of legislative bodies," through its second reading by Senate Committee, during which "the uncertainty principle means the bill is in a state of both 'passed' and 'not passed' at the same time." Finally, he said, the bill enters a "higher dimension known as Royal Assent," at which point it moves from a theoretical bill to a practical law.

The playful parody was a moment of levity during an often-emotional evening that honoured the achievements of six extraordinary Canadians in public service.

Recipients of this year's award were Former Supreme Court Justice Louise Arbour, Calgary Mayor Naheed Nenshi, historian Margaret MacMillan, Indigenous Health Alliance leader Alika Lafontaine, Treasury Board of Canada Secretary Yaprak Baltacıoğlu, McKinsey & Company Global Managing Partner Dominic Barton, and Right To Play International Founder Johann Koss.

"It's always worth remembering: the quality of life we enjoy as Canadians didn't happen by accident, and won't continue without effort," said the Prime Minister, who hosted the awards.

"With smart policy and smart leadership, we'll create a better country for Canadians, and we'll create a legacy that we can all be proud of."

– Colin Hunter

Learn more: www.ppforum.ca

Researchers use technique from classical optics to create clean

'QUANTUM LIGHT'

By blocking one half of an entangled photon pair, team shows how to block 'noise' in quantum light experiments.

It is widely suspected that harnessing the quantum properties of photons could provide one of the best pathways towards building quantum technologies on an industrial scale, but there are a few significant hurdles in the way.

First, we need a way to reliably generate photons with specific characteristics. Second, we need to be able to generate these photons in a material that can be miniaturized and embedded on computer chips. And third, we need a way to eliminate experimental 'noise' from the process, such as unwanted photons.

Now, Perimeter researcher Agata Brańczyk and collaborators Luke Helt and Michael Steel in Australia and Marco Liscidini in Italy have put forward a powerful suggestion of how to do just that, using techniques from conventional glass optics.

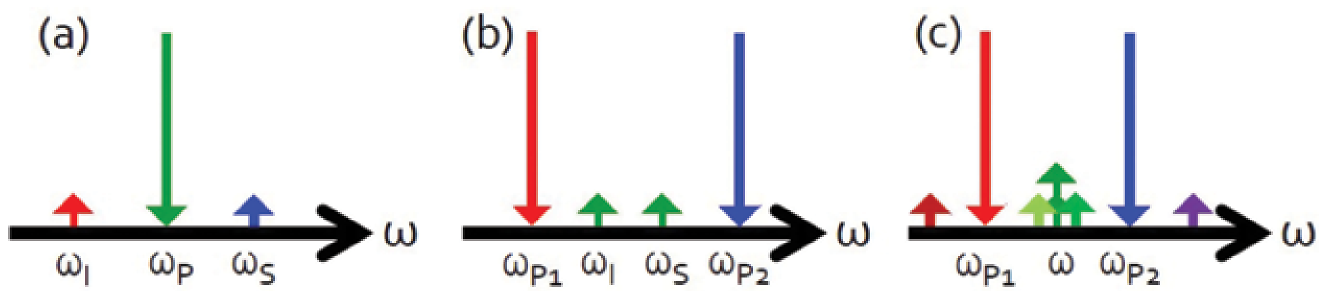
In a recent paper, "Parasitic photon-pair suppression via photonic stop-band engineering," published in *Physical Review Letters*, the team proposes a way to craft a silicon medium that dramatically improves the quality of the generated photons.

Their technique takes a silicon medium and builds into it a periodic variation of the refractive index, called a 'Bragg grating'. Bragg gratings are often used to filter out unwanted light that already exists, but this proposal adds a novel twist: it uses a Bragg grating to prevent the generation of unwanted photons before they are even created.

And the idea could soon be put to the test: the proposal is achievable using today's technology.

How to make quantum light

There are a few methods of generating quantum light. One method, which has been used in single-photon experiments for decades, is spontaneous parametric down conversion (SPDC). In SPDC, a high-powered laser is fired at a specially designed medium (a crystal), inside which a photon splits to create two different, often spectrally entangled, photons. SPDC is popular because it is relatively easy to implement, but it is bulky and extremely challenging to integrate with computer chips.



Various SFWM processes with down and up arrows representing pump and generated frequencies, respectively: (a) single-pump, (b) idealized dual-pump, and (c) dual-pump with undesired noise from parasitic single-pump processes.

Another option, which has gained a lot of researcher attention in recent years, is spontaneous four-wave mixing (SFWM). In SFWM, a high-powered laser is fired at a different type of medium, such as silicon. Inside the silicon, two photons combine into a pair. That pair then splits to create two different photons, which are also typically entangled. Such sources are attractive because they could be made in silicon fabrication facilities, just as we do for computer chips.

Through SFWM, a laser pump of one specific frequency, or energy level, will produce a photon pair of split frequencies: one photon in the final pair will be at a higher frequency than the original beam, and one will be lower. That's because the law of conservation of energy dictates that the final total energy must equal the initial energy. (See 'a' in the diagram.)

More useful for many experimentalists are photon pairs of the same frequency, because those types of photons can interact with each other. To create these, one can start with two lasers set at different frequencies. A photon from each laser will combine to make a pair, and that spectrally entangled pair will emerge at a frequency between the origin beams, at the same frequency as each other. Again, this is thanks to the conservation of energy. One laser pump will have higher energy than the other: a photon from each will combine, then come out at the frequency between the original pumps. (See 'b' in the diagram.)

However, this two-pump system also generates 'noisy' photons; sometimes photons from each laser pump will break up in a different way, creating unwanted pairs. Much like in the first example, one photon will be higher energy and one will be lower than its origin pump beam. In the case of a two-pump system, one photon in the unwanted, or 'parasitic,' pair will inevitably be close to the spectrum of desired photon-pairs. (See 'c' in the diagram.)

These parasitic photons have been a headache for theorists and experimentalists alike, because they contaminate experimental efforts.

Brańczyk and her co-authors had an insight. Trying to block both of those parasitic photons is problematic, because it risks blocking the photon pairs you actually do want.

Instead, they wondered if you could just suppress the 'outer' photon of the parasitic pair – that is, the one that lies furthest away, in energy, from the desired photon pairs. Because the photon pairs are spectrally entangled, perhaps just blocking one half would prevent the other from emerging.

Inspired by Bragg gratings in classical glass optics, they designed a structure with photonic stop-bands that does just that: it creates desired photon pairs, suppresses undesired pairs, and could be made from glass or fibre optics.

"It's a pretty simple idea. We were surprised no one has done it yet," said Brańczyk, who is also a PSI Fellow at Perimeter and an Adjunct Assistant Professor at the University of Waterloo.

"Sometimes that happens. Sometimes you just get lucky, and no one has checked a really simple thing. Usually, the problems you're trying to solve have complicated solutions. Here, the hard work went into checking how well it works, and under what circumstances, but the idea is quite straightforward."

Nothing easy about simple solutions

While the solution might have been simple, getting there was not easy, said Krister Shalm, a quantum physicist and experimentalist who works at the U.S. National Institute of Standards and Technologies, and who knows Brańczyk from his previous position as a postdoctoral researcher at the Institute for Quantum Computing at the University of Waterloo.

"What I've discovered is sometimes the best ideas are the obvious ones. But those types of insights are very difficult and take a long time to get to. If it had been obvious, someone else would have figured it out," he said.

Currently, a lot of effort is expended in labs trying to filter out unwanted photons. The new proposal holds great potential to improve experiments involving quantum light by efficiently reducing, or removing, contamination, he said.

"They've imposed a larger structure [on the glass], so that certain regions behave one way and other regions behave another way," Shalm said. "That creates interference that cancels things out."

Brańczyk is energized by the experimental pathways this idea might open up, but what really drives her is the satisfaction of solving a perplexing puzzle.

"The combination of a quantum light source with a periodic structure was a natural system to look at from a theoretical point of view, but we didn't expect that this combination in its simplest form could be so effective at improving today's photon sources," she said. "These kind of surprise benefits are what makes curiosity-driven research so exciting and worthwhile."

– Tenille Bonoguore

WE SEE THEE RISE

CANADA 150

For more than 150 years, Canada has been a land of inquiry, innovation, and opportunity. That is just the beginning...

How to make magic

You can't predict when you'll hit upon brilliance, but Innovation150 shows how you can prepare for it.

Great breakthroughs are often sparked by a lightning bolt of inspiration. Sadly, you can't bottle lightning, but you can build a lightning rod.

Through preparation and dedication, people from any walk of life – from scientists and artists to students and the elderly – can equip themselves to be transformational innovators. And when they do, they'll continue a proud, if somewhat overlooked, tradition of Canadian innovation stretching back millennia.

Innovation150 is bringing these stories of ingenuity to life as part of the country's sesquicentennial celebrations. Featuring a cross-country tour, exhibits, presentations, stories, and contests, the Perimeter-led celebration aims to inspire Canadians.

The goal? To create a nation of lightning rods ready to seize inspiration when it strikes.

"Innovation150 is an excellent way to celebrate the achievements of Canadian science and encourage our young people to engage with science and technology subjects," said the Honourable Kirsty Duncan, Minister of Science, as she launched the tour at Vancouver's Science World in January.

While the impact of innovation can be broad, the process leading to it is intensely personal. But there are commonalities, says Perimeter Director Neil Turok in the presentation "We Are Innovators," which is touring as part of Innovation150.

Sharing stories from his childhood in apartheid South Africa to his career in cosmology, and exploring examples from science, Turok's talk delves into the traits that helped people seize inspiration when it hits.

He boils it down to a handful of essential traits he calls the "Four Cs": curiosity, creativity, courage, and collaboration. Contrary to popular opinion, innovation isn't innate. It is a state of preparedness anyone can adopt and hone.

"Our country can be a place where young people see beyond national boundaries, and beyond the paradigms that have put our planet in peril," said Turok in his presentation.

"Canada can become a haven for innovation, where the world's points of tension are turned into points of light."

For years, Perimeter has had a kind of unofficial motto: "It's a big universe. Fortunately, we have big ideas." The thrust of Innovation150 is that the same can be said for Perimeter's home and native land: "Canada's a big country. Fortunately, Canadians have big ideas."

It's a message that, thanks to the travelling celebration that brings together five leading science and outreach organizations, will reach hundreds of thousands of people throughout 2017.

"Ingenuity has always been one of our country's greatest resources," said Michael Duschenes, Perimeter's Managing Director and Chief Operating Officer. "Innovation150 will proudly celebrate this legacy, and envision an even brighter future."

Follow the tour, read stories of Canadian innovation, and enter contests at innovation150.ca.

– Colin Hunter and Tenille Bonoguore

Supported by the federal government through Canadian Heritage, Innovation150 is delivered through a partnership between Perimeter Institute for Theoretical Physics, Actua, the Institute for Quantum Computing at the University of Waterloo, the Canadian Association of Science Centres, along with its members, the Canada Science and Technology Museums Corporation, and through collaborations with other leading organizations in every province and territory.

INNOVATION150

PERIMETER INSTITUTE | actua Youth · STEM · Innovation | UNIVERSITY OF WATERLOO | IQC Institute for Quantum Computing | Canadian Association of Science Centres / Association canadienne des centres de sciences | CANADA SCIENCE AND TECHNOLOGY MUSEUMS CORPORATION / SOCIÉTÉ DES MUSÉES DE SCIENCES ET TECHNOLOGIES DU CANADA

CANADA 150 | Canada

INNOVATION TOUR DELIVERS – AND DISCOVERS – INSPIRATION ACROSS CANADA

The Power of Ideas tour is winding its way across Canada to inspire the next generation of hackers, makers, doers, and thinkers – no matter where they live.

Sarah Hart knows the price of isolation. For years, her family has regularly made the long trip to Edmonton so that Hart's sister, who has cystic fibrosis, can get the advanced medical treatment she needs.

With such personal exposure to the importance of modern medical technology, it's no wonder Hart wants to pursue biomedical engineering after she graduates high school this year. What might surprise people is that she wants to do it at home, in Yellowknife.

"My goal is to become a biomedical engineer, and then take those MRI machines and find a way to make them smaller or more portable, so our government can afford them," she said. "The people here deserve to get that treatment at home."

▲ *Students experiment with electrons in Yellowknife.*

Hart has big ambitions, but they're not out of place up here among the frozen lakes and fluttering ptarmigans. Spend any time exploring Canada, and you'll quickly realize that innovation is a survival skill in the Great White North. When the Power of Ideas tour mapped out its path for the country's 150th anniversary, there was no doubt it would venture well above the 49th parallel.

The Inuit created the world's first sunglasses to prevent snow blindness. Today, block-mounted heaters ensure your car engine starts at 40-below. The asphalt ends, so an ice road begins. You see a problem, and you find a way fix it, whether it's keeping your toes warm or solving complex issues of medical access. Innovation isn't a buzzword; it's an essential part of the human character.

The trouble is, most innovation stories focus on the end result – the disruptive new technology, the social breakthrough, the billion-dollar success – when the driving force of innovation is the process that leads to that point. Innovation isn't a destination: it's a process, one that can be learned and honed, and which anyone can be a part of.

The Power of Ideas travelling exhibit is sharing this message with thousands of students through 2017. The tour is visiting 60 communities, most of them in underserved regional and remote areas. Travelling with Perimeter as part of the tour, educational outreach organization Actua is running a Maker Mobile so students can grapple with challenges in science, technology, engineering, and math.

The goal is to inspire Canada's next generation of hackers, makers, doers, and thinkers – no matter where they live.

As the students at Yellowknife's École St. Patrick High School will tell you, it's not just kids in big urban centres who hold the potential to change the future. "It's pretty cool to have this come here, because usually we have to go places to see stuff," said Grade 12 student Sebastian Toner. "To have this cool tour come to Yellowknife is pretty sweet. It's a good opportunity for everyone here."

The tour focuses on middle- and high-school students, but some stops, such as the visit to Yellowknife in early March, also include a public event open to all ages. Four presenters – a physicist, a geophysicist, a marine biologist, and a neuroscientist – are travelling across the country, delivering the Power of Ideas talk and leading demonstrations in the science exhibit.

The experience has prompted them to redefine their own understanding of what innovation means to them, and to Canada.

For presenter Cat Lau, whose background is in psychology and neuroscience, innovation is making a positive difference in the world. "Science is definitely an avenue, a way you can actually go about and make a difference," she said. "Seeing people being so engaged with science gives me so much hope."

The tour is quickly making it clear to her that the impact of science can reach well beyond the field itself. Students have approached her after the presentation, inspired to use ideas from science in their novels or short stories. "It's interesting how science can become a muse for people who might not be interested in it. They could be our next innovators. Who knows?"

Yellowknife students try to solve the mystery tube.

École St. Patrick senior Bishal Yadav didn't need any more incentive to study science – he hopes to pursue aerospace engineering or astronomy after he graduates this year – but having the Power of Ideas visit his hometown made his dream feel a bit closer.

"Usually there's not much science or exhibits in Yellowknife," he said. "Innovation and science go hand in hand. That's how we keep moving forward with technology, and that's how the world keeps on advancing."

Leading that charge will be the Canadian teens and tweens who will get their chance this year to play with the Event Horizon Telescope and Large Hadron Collider demonstrations in the Power of Ideas exhibit, to formulate scientific models with Perimeter Institute's mystery tube, to learn about electrons as they play with the plasma ball, and to make their own weather stations in the Maker Mobile.

"We all have the same basic questions," said Hart, the bio-med hopeful. "What is out there? What are we living in? Everyone has the same questions, no matter what language. [With science] we get past those barriers, to find out the answers together."

– Tenille Bonoguore

FURTHER EXPLORATION:

Follow the Power of Ideas crew on Tumblr as they make their way across Canada at powerofideas.tumblr.com

Go to Innovation150.ca for stories, contests, tour dates, and more!

TEACHER TRAINING GOES TO IQALUIT

When Iqaluit teachers organized a conference last February to strengthen student engagement in STEM topics, they invited Perimeter's Educational Outreach team to join in. Parkas packed, the team eagerly headed north.

They met more than 30 teachers from the city and surrounding communities. They presented a number of workshops on hands-on classroom activities, from math and gardening to incorporating Inuit traditions into teaching. One educator demonstrated the traditional children's game of fishing seal-flipper bones out of a bag using a piece of string: in her class, the students reassemble the structure of the flipper and then compare it to the bones in a polar bear's paw.

Outreach Scientist Kelly Foyle led a workshop exploring Perimeter's free educational resources for high school and elementary grades on topics ranging from space and black holes to the process of science, and then brought out the "mystery tube": a person-sized black cylinder with four ropes dangling from its sides. Pull on one of the cylinder's ropes and another will retract – but it's rarely the one you'd expect. Coming up with testable models of the tube's inner workings provides a great example of the scientific method; teachers constructed their own mystery tubes to share with students.

The unique challenges of teaching in isolated areas can catalyze ingenuity, Foyle said. "The school was amazing. They had live chickens in the class that they had incubated from eggs. It was inspiring to see the creativity of the teachers and the kinds of things that they're doing."

– Stephanie Keating

Perimeter's Educational Outreach team has a host of resources and programs for science teachers. Find out more at perimeterinstitute.ca/outreach/teachers.

The (surprisingly) complex science of trapping muskrats

*Move over, Schrödinger's cat. Perimeter Associate Faculty member **Roger Melko** has a new, and entirely Canadian, way to explore quantum physics.*

Although I didn't realize it at the time, I first started thinking about quantum mechanics while trapping muskrats when I was 10 years old.

I grew up in The Pas, Manitoba. Every Saturday when I was young, my father would fuel up his old snowmobile, attach a rickety red sleigh full of snares, traps, and supplies, and pile us kids aboard for a ride into the frozen swamps in search of muskrats.

As many Northerners know, muskrat homes are reedy domes jutting out of the frozen swampland, like tiny beaver lodges. Muskrats enter and leave their homes through a hole into the water below the lodge, safe from predators like mink and foxes.

Trapping muskrats requires skill and patience. As my father taught us, you must carefully cut a hole out of the side of the lodge with an axe, set the trap (a non-trivial feat with bare hands in minus-30 conditions), and plug the newly cut hole, packing it tightly with snow and grass so that the muskrat's access hole from the water doesn't freeze. Hopefully, when the muskrat comes back, it senses no disturbance in the home that it built, and steps into the trap.

Upon returning to the traps the next morning, I'd keenly watch, barely able to contain my excitement, as my father cut into a reed lodge. From the outside, it was impossible to know. No internal disturbance around the trap would be detectable through the thick reed walls. They were usually empty, but my father would occasionally reach into the house and retrieve a frozen muskrat, sending us kids into wild celebration as we anticipated a cozy afternoon of skinning and stretching pelts around the wood stove, while regaling our mother with the story over hot chocolate.

I sometimes thought, if I wished hard enough, right then and there, the universe would decide that we deserved a successful catch. Indeed, since no one or thing (except maybe the lucky or unlucky rat) knew the outcome before the house was cut, when exactly did the universe make that decision? If I wished hard enough, could I change the outcome, right up until the moment my father stuck his hand into the house?

Herein lies the paradox of "Melko's muskrat": until the moment we cut into the lodge, the muskrat could be either alive or dead. And that meant it was, in some hazy way, both.

As I grew up, I came to understand that the muskrat was caught by the trap (or not) sometime in the middle of the night. Or so I thought, until I learned about quantum superposition during an undergraduate physics class, which opened my mind to a different way of thinking about the possibilities.

It turns out that the basic laws of quantum physics, governing tiny objects like atoms and electrons, can allow these objects to live in the superposition of two different states simultaneously. I wondered if muskrats could be the same, both trapped and free at the same time in the middle of the night. An electron only chooses its state when a "measurement" is made. Perhaps, I wondered, the act of cutting into the reed lodge is a "measurement" that decides the muskrat's fate?

As I found out, this alive/dead paradox even had a name, "Schrödinger's cat," which suggests a cat that is both alive and dead in a box. (I still find the circumstances behind the cat's predicament much less plausible than the muskrat's.)

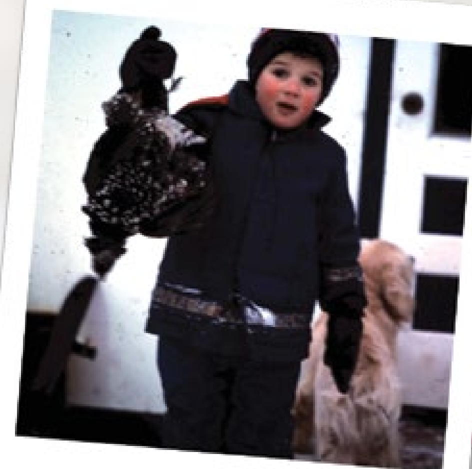
I now research quantum mechanics, computer simulation, and information theory. The paradox of the muskrat is just one of many counterintuitive ideas that I struggle with every day in the mind-bending world of quantum mechanics.

As a theoretical physicist working at Perimeter Institute and the University of Waterloo, I travel the world to work with other researchers, on solving puzzles such as superconductivity, black holes, artificial intelligence, and quantum computers. As a professor, I get to teach a younger generation of physicists all the things that, on my journeys, I found to be curious, hoping that they will see the same big, fascinating universe that I do.

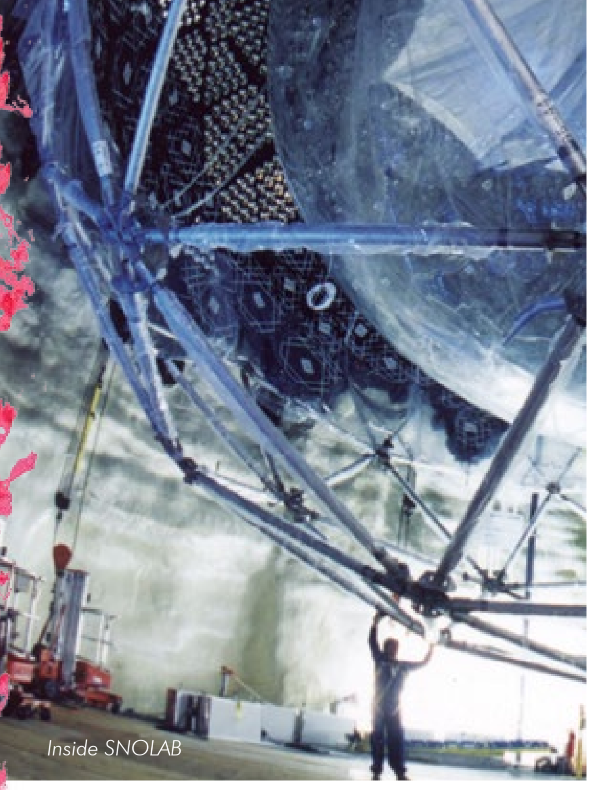
Yes, the path to success is lined with hard work and repeated failure, but curiosity is a powerful force. Don't be afraid to explore, ask questions, read difficult books, and think crazy ideas. Growing up in the North taught me that you can come from anywhere, and go anywhere, with science.

Just remember to make it home for some of mom's muskrat stew every once in a while.

Roger Melko is a Perimeter Associate Faculty member. A version of this piece was originally published in the Winnipeg Free Press *in April 2017.*



A portrait of the author as a young trapper


Inside SNOLAB

Canada's SNO and SNOLAB: FUNDAMENTAL SCIENCE SUCCESS DEEP UNDERGROUND

SNOLAB has developed pioneering experiments at the frontier of particle physics and astrophysics. Nobel Laureate ***Arthur B. McDonald*** *explains how it all unfolded in quintessentially Canadian style, with lots of collaboration, a commitment to recycling, and friendly loans of a whole lot of heavy water.*

It was called "the solar neutrino problem": starting in the 1960s, too few neutrinos had been observed coming from the sun compared to calculations of the nuclear fusion processes powering the sun.

Created to address this conundrum, the Sudbury Neutrino Observatory (SNO) collaboration started with design work in 1984 and used 1,000 tonnes of heavy water from Canada's reserves. With strong collaboration between industry and academia, Canada established a world-leading scientific laboratory two kilometres underground near Sudbury, Ontario.

Eventually, this international collaboration, with members from Canada, the US, the UK, and Portugal showed clearly that two-thirds of the electron neutrinos emitted from the core of the sun changed into mu or tau neutrinos before reaching the Earth.

The findings confirmed that solar model calculations are very accurate. It also determined new neutrino properties that required extensions to the Standard Model of elementary particles, which has been so successful in all other areas in which it has been tested. These measurements were recognized with the 2015 Nobel Prize in Physics and the 2016 Breakthrough Prize in Fundamental Physics.

The success of the SNO project arose from many factors that show clearly how Canada can make a mark internationally in science and technology. Cooperation was the first key factor. The project required strong cooperation from Canadian industry: INCO, now VALE, provided the deep underground location in one of its most productive mines; AECL and Ontario Power Generation cooperated in the loan of $300 million worth of heavy water from Canada's reserves.

It required strong cooperation for the science between nine Canadian and 12 international academic and research institutions. In addition to custom-built electronics, data acquisition, and water purification systems, there were engineering challenges requiring innovation driven by the stringent scientific requirements.

The detector was the size of a 10-storey building, requiring the excavation of a stable cavity larger than had ever been created at such a depth. The geotechnical information obtained has informed mining excavation at much greater depths and the creation of other international underground laboratories.

A 12-metre diameter, 5-centimetre thick transparent acrylic vessel to house the heavy water was constructed in place from 120 pieces small enough to fit in the mine elevator. The lessons learned are enabling enormous aquaria to be constructed around the world.

Most importantly, the 273 member SNO author list included more than 200 graduate students and postdoctoral fellows who experienced a real scientific "eureka" moment together and are now carrying their experience to jobs in academic research, teaching, industrial and medical research, business, and finance.

In 2003, a further collaboration of Canadian scientists, under the leadership of David Sinclair of Carleton University, responded to a call from the Canada Foundation for Innovation for the development of Canadian laboratories that would attract international scientists to work on frontier science and technology. Using the lessons learned from SNO, including the geotechnical experience, the laboratory area was expanded by a factor of three, providing space for many new experiments studying further properties of neutrinos and seeking direct detection of dark matter particles thought to make up about 25 percent of our universe. This laboratory has resulted in many Canadian-international collaborative experiments.

They include the PICO dark matter detection experiment, which has just published a world-leading limit on the interaction of dark matter particles via a spin-dependent interaction. It uses the formation of bubbles in super-heated liquid to indicate the presence of dark matter particles scattering from fluorine nuclei, while suppressing the interaction of other forms of radioactivity.

The DEAP collaboration, another dark matter detection experiment, involves over 65 researchers from 10 institutions in Canada, the UK, and Mexico, and has been running since November 2016. Using more than three tonnes of liquid argon, it employs a different technique than PICO for background suppression to achieve a sensitivity that will be superior to the presently published limits for the spin-independent interaction. It uses the fact that dark-matter-induced nuclear recoils will produce much shorter bursts of light than other forms of radioactivity to discriminate against such background.

These experiments, seeking direct detection of dark matter particles produced in the early universe, are addressing regions of sensitivity that are also being probed at the Large Hadron Collider, where an attempt is being made to produce massive dark matter particles for the first time on Earth.

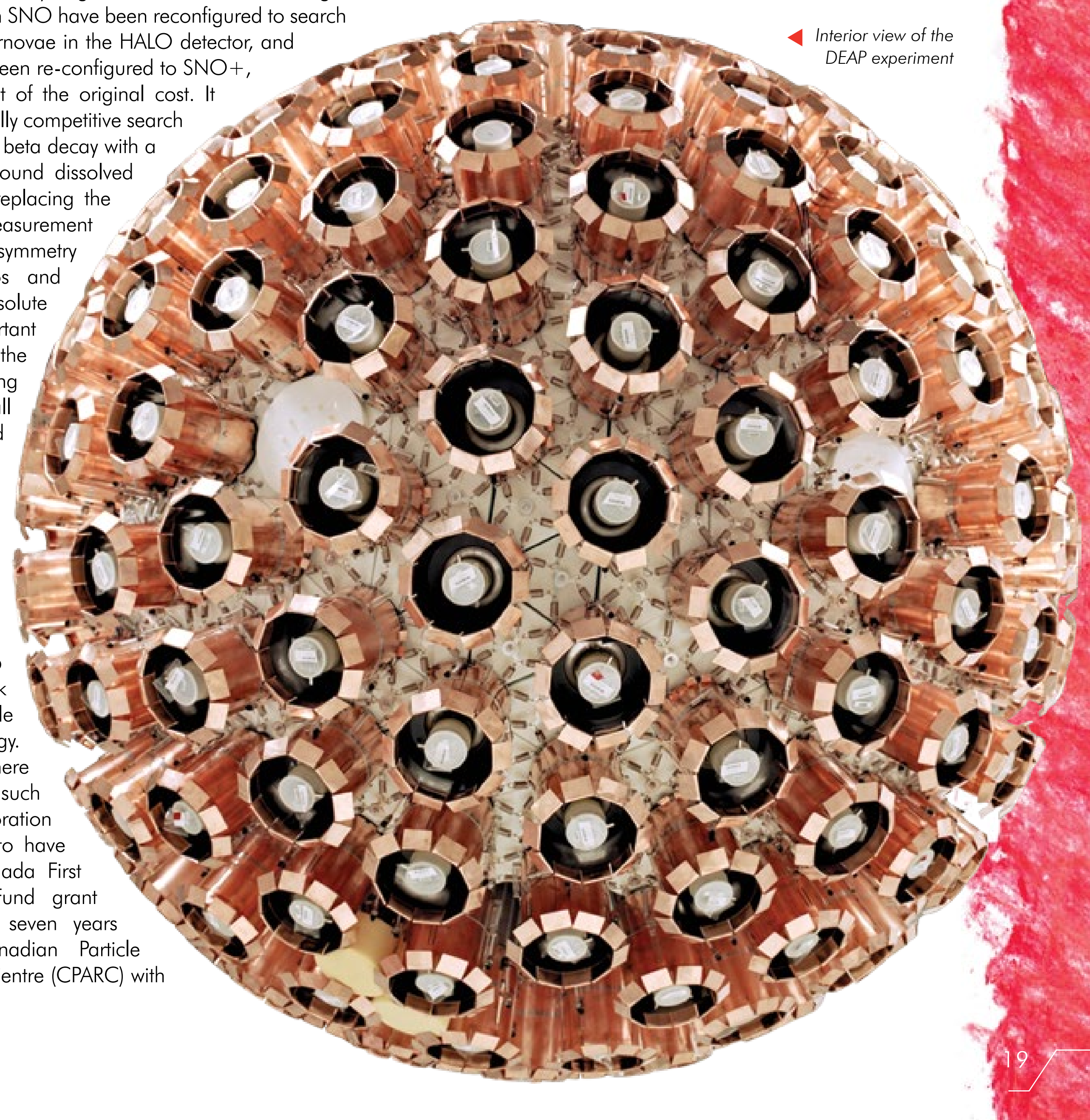
The SuperCDMS, NEWS, and DAMIC experiments use other techniques for background discrimination and will provide leading sensitivity for a lower mass range for dark matter particles within the next few years.

In two great examples of recycling – another Canadian strength – neutron detectors from SNO have been reconfigured to search for neutrinos from supernovae in the HALO detector, and the SNO detector has been re-configured to SNO+, at less than 20 percent of the original cost. It provides an internationally competitive search for neutrino-less double beta decay with a tellurium-organic compound dissolved in a liquid scintillator replacing the heavy water. This measurement is sensitive to the symmetry properties of neutrinos and potentially to their absolute mass value. This important research area influences the theoretical understanding of what happened to all the anti-matter produced in the early universe, as well as the effects of neutrinos on structure formation as the universe evolved.

Our experimental work in these areas has significant overlap with theoretical work at Perimeter in particle physics and cosmology. We are very fortunate here in Canada to have such opportunities for collaboration and are very pleased to have received a recent Canada First Research Excellence Fund grant for $63 million over seven years to establish the Canadian Particle Astrophysics Research Centre (CPARC) with 13 partners, including Perimeter Institute. CPARC includes a Tier 1 Canadian Research Chair in Theoretical Particle Astrophysics and an Assistant Professor, both of whom will be based at Queen's University and will be Associates at Perimeter. We are also very pleased to partner with Perimeter in outreach activities, including participation by SNOLAB in the ISSYP summer program and in the Innovation150 initiative led by Perimeter.

It is our hope that the success of SNO and SNOLAB, along with Perimeter Institute, will be an inspiration for young Canadians in this sesquicentennial year. World-leading research at the frontiers of physics can continue to occur in Canada, and will grow through their active participation in future.

Arthur B. McDonald is Professor Emeritus at Queen's University and a member of Perimeter's Board of Directors. He has been Director of the Sudbury Neutrino Observatory Scientific Collaboration since 1989.



Interior view of the DEAP experiment

HEARING THE UNIVERSE'S

CHIME, a radio telescope under construction in British Columbia, expects to find hundreds of "fast radio bursts" and generate a trove of data that may help us understand these mysterious signals in space.

Astronomical events, like the birth of a star or formation of a galaxy, typically take place on vast scales: millions or even billions of years. But some can occur in a relative blink of an eye.

These "transients" come in many forms, from supernovae to planetary transits, and can occur over years, weeks, days, or even milliseconds. In the past 10 years, astronomers have identified a mysterious new population of transients: brief, bright, and rare flickers known as fast radio bursts (FRBs).

In 2007, astronomers noticed a spectacularly bright but incredibly short signal in archival data collected by the Parkes Observatory, a radio telescope in New South Wales, Australia. The whole event lasted less than five milliseconds. Blink and you'll miss it? Actually, blink and you would miss up to 40 FRBs; the average human blink lasts about 200 milliseconds.

Their fleeting nature means they are also rarely seen. In the decade since that first discovery, only 25 more bursts have been observed.

With so few recorded events, there are more theories about the origin and nature of FRBs than there are detections. Part of the problem is simply the lack of data. It is incredibly difficult to pin down exactly where in the universe the bursts are coming from.

Now, a group of Canadian researchers has proposed a way to hunt for these rare flickers using a new telescope. When they turn it on, they expect to see not just one or two FRBs, but hundreds.

CHIME, which stands for Canadian Hydrogen Intensity Mapping Experiment, is an innovative new radio telescope under construction near Penticton, British Columbia, that could solve the mystery of the FRBs when it comes online later this year.

The telescope is expected to see almost as many bursts in the first few days of its operation as have been detected in the past 10 years. "In two and a half days, we'll have found more FRBs than the rest of the world," says Perimeter Faculty member Kendrick Smith. "It's going to be a game-changing experiment."

The full project is a collaboration between researchers at the University of Toronto, the University of British Columbia, McGill University, and the Dominion Radio Astrophysical Observatory. Several Perimeter researchers, including Smith, are lending their theoretical expertise to the project.

The search for ultrafast blips is actually something of a bonus mission: CHIME's primary task is to probe a lesser-studied stretch of time in the universe's history known as the "adolescent universe," which lies between the aftermath of the big bang (now thought to be well understood, thanks to high-precision measurements of the cosmic microwave background radiation) and the more recent universe that can be studied via conventional telescopes.

To do this, CHIME will measure how neutral hydrogen clumps together in distant galaxies. The hydrogen acts as a tracer of density and large-scale structure in the universe. By understanding how the universe grew in its teenager phase, the CHIME team hopes to gain insight into one of the most puzzling problems in cosmology: the nature of "dark energy," the mysterious force responsible for the acceleration of the universe's expansion.

At a Canadian Institute for Advanced Research meeting in 2014 – which brought together theorists, experimentalists, and observational astronomers from a number of different subfields, including transient astronomy – researchers realized CHIME's exceptional capabilities could be broadened with relatively little effort.

BRIEFEST NOTES

The CHIME radio telescope, near Penticton, BC

Radio transient expert Victoria Kaspi, a physics professor at McGill University, pitched a proposal to the Canada Foundation for Innovation to add an additional computing cluster to CHIME's antennas dedicated to combing the data for elusive FRB signals.

The setup is ideal because CHIME can survey the sky faster than any other radio telescope on the planet. Think of a digital camera: the more pixels there are in the sensor, the higher the resolution of the photograph. Radio telescopes have far fewer "pixels," because the wavelengths they are detecting are huge compared to visible light, but the principle is the same: the more pixels you have, the greater detail you can see in a given time.

"Currently, the biggest coherent receiver on any radio telescope is the Parkes Observatory, which has a 13-pixel receiver," explains Ue-Li Pen, a Perimeter associate faculty member and Interim Director of the Canadian Institute for Theoretical Astrophysics.

"Almost all other radio telescopes have one pixel. In comparison, CHIME has a thousand pixels. So whatever Parkes can do, CHIME is going to do another factor of 100 times better and faster."

The increase in sensitivity brings with it another set of challenges, says Smith. "We're going to generate an avalanche of data."

CHIME will churn out a petabyte of data every single day. That's 1,024 terabytes, or a million gigabytes – equivalent to more than 38 years of continuously binge-watching Netflix in HD, or more than 990 years of streaming high-quality music.

The CHIME team has to search that data as it arrives, in real time. "It's too much to save to disk, so you only get to look at it during a little window of time when it's in memory," explains Smith. "You need big supercomputers on site, doing real-time processing for every analysis we want to do – including FRBs."

The team originally assumed that it would be impossible to process that magnitude of data so quickly. "We thought we would have 10 people working on it. We'd buy this gigantic farm of machines, with a huge power bill, and only search a subset of the data," says Pen. Then they discovered some promising but little-used algorithms that could help speed up their search.

"Kendrick got excited," says Pen with a chuckle. "If it's a nifty algorithm problem, that's right up his alley."

The code that Smith, his students Masoud Rafiei-Ravandi and Utkarsh Giri, and research assistant Maya Burhanpurkar helped develop and optimize is "a hundred times faster than anybody expected," says Pen. "It's going to be better than ever thought possible, at a tenth the power cost. This is a case where just the right person going in can change the game."

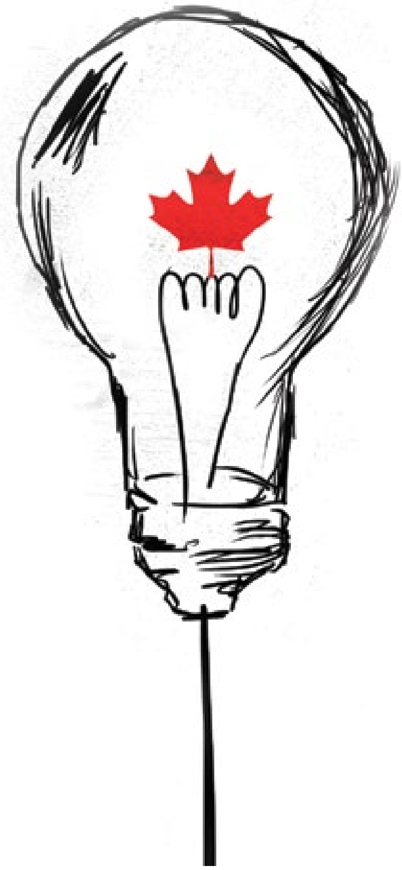
As the code sifts through the signals, it also has to contend with potential false positives. "Every time someone uses, say, a keyless entry to a car in the parking lot – that can look like an FRB in our data," says Smith. "And there are lots of little computers in cars. A car going by on a nearby road can interfere with the data." To minimize the human-made disruptions, visitors to the CHIME site have to power off their cell phones and turn off the Wi-Fi capabilities on their laptops.

One question CHIME should be able to answer is whether or not fast radio bursts are one-off occurrences – perhaps produced by cataclysmic events like supernovae or the collision of dense objects such as neutron stars or black holes – or if they repeat themselves. Of the 26 FRB detections to date, only one of the bursts has repeated itself, but it's possible, according to Pen, that all FRBs repeat eventually.

"It's an open question," he says, "but CHIME will solve that problem. If they repeat, CHIME will see it." It will also be able to detect whether the bursts repeat in a predictable, periodic fashion – a result that would line up with one hypothesis suggesting they are somehow associated with neutron stars.

Once CHIME is turned on, Smith expects the telescope will see events almost immediately: "In the optimistic scenario, where all of the software and hardware works smoothly and there are no problems – which never happens – then I think we would see events basically right away, on the first day."

– Stephanie Keating



OUR HOME AND INNOVATIVE LAND

Canada's Governor General explores how Canadian innovation has shaped the world – and how we're just getting started.

A few letters differ between the words "invention" and "innovation," but the difference in meaning is profound.

When Canada's Governor General, His Excellency the Right Honourable David Johnston, set out to write a book about Canadian innovation, that distinction became abundantly clear. Innovation, he came to understand, is much more than creating a new tool or technology – it's a mindset.

That is the fundamental insight behind a new book he co-authored with National Research Council Chair Tom Jenkins, titled *Ingenious: How Canadian Innovators Made the World Smarter, Smaller, Kinder, Safer, Wealthier, and Happier*.

From recycling to nuclear physics, the egg carton to the Declaration of Human Rights, the book chronicles Canadian ideas that have helped shape the world. During a recent visit to Perimeter Institute, the Governor General sat down with *Inside the Perimeter* to discuss the book, the surprising things he learned writing it, and the role fundamental science plays in innovation.

Inside the Perimeter: What was the impetus behind writing *Ingenious*?

Governor General David Johnston: It was a determination by Tom [Jenkins] and myself to reinforce the culture of innovation in the country. My installation speech as Governor General, which was six and a half years ago now, was entitled "A Smart and Caring Nation: A Call to Service." It had three pillars: family and children, learning and innovation, and philanthropy and volunteerism. These themes seem to come all together under the notion of innovation.

Inside: The word "innovation" gets used a lot these days. What does it mean to you?

DJ: Innovation is a very broad term, but at its simplest it's doing things better. Usually it means taking an existing idea and crafting it in a certain way that improves a process, an institution, a technology. Innovation comes from the Latin *innovare* which means to refresh or to alter. It's very interesting, that notion of a refresh – of looking at things from a fresh view or angle, and doing it a little bit differently. Very often innovation is a series of steps, not a light bulb going on at a particularly time. It's a series of light bulbs or flashes that are built upon.

Inside: Speaking of light bulbs, they're an interesting part of the book.

DJ: One of my favourite of the 297 stories in the book is the light bulb, because it's such a metaphor for new ideas, but also a classic Canadian story because the light bulb was patented here by two inventors. They didn't have the money to commercialize their inventions, but Thomas Edison was then in the early days of building General Electric. He patented many different things, but was also a great collector or purchaser of patents. He purchased those patents, made the light bulb, and Westinghouse and GE became the great light bulb producers of the world.

Inside: How did your own views on Canadian innovation change in the process of writing the book?

DJ: Dramatically! Tom and I both say we were flabbergasted by the number of innovation stories. We said we'd do a book where we'd collect, say, 50 stories of great Canadian innovations. Well, we found there was no database at the National Research Council or the Museum of Science and Technology, so job one was to create the database, which is now in place with the Museum of Science and Technology. We went from 50, then to 150 stories for Canada's 150th anniversary, but there were more and more. Then we finally had to stop at 297 because the publisher said that's all we can contain within this size of a book – that's it! We now realize that there are many, many that we've left out, [which form part of] an ongoing project with innovationculture.ca.

Inside: What makes Canada particularly fertile soil for innovation?

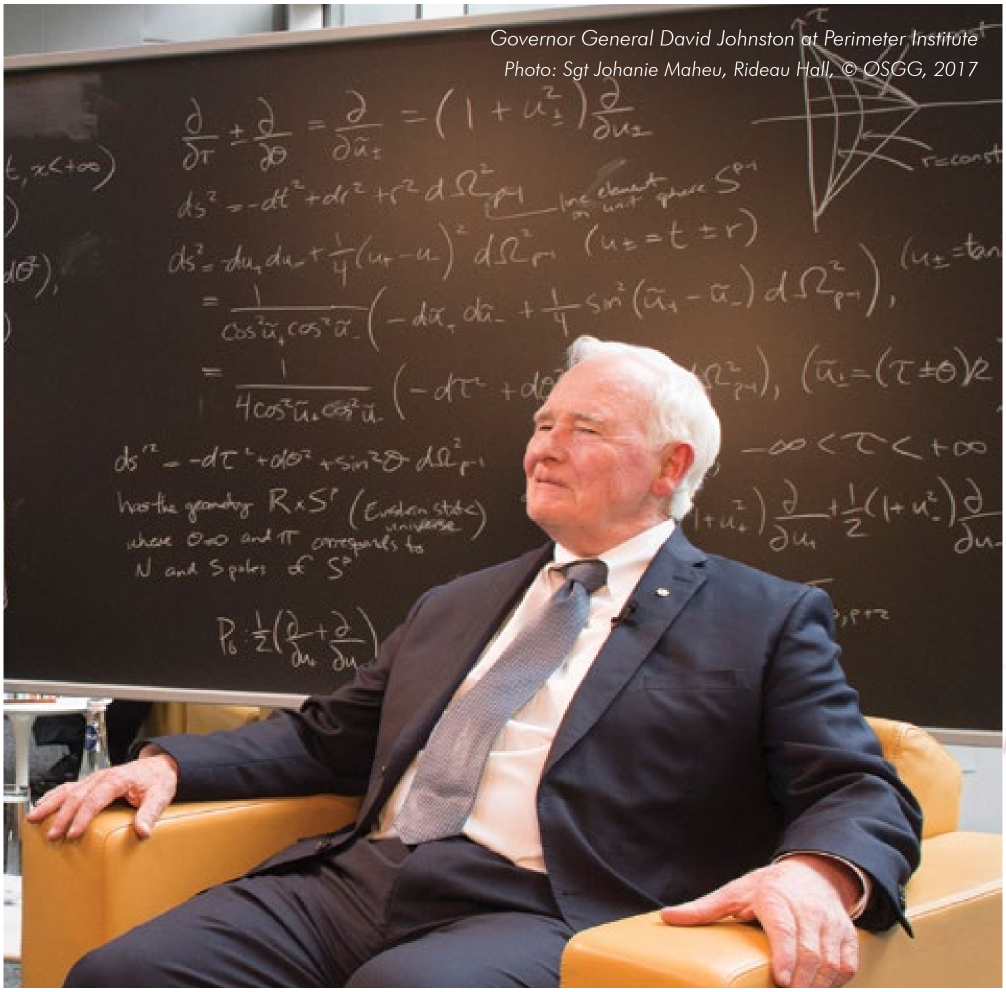
DJ: The country itself is an experiment in innovation, an experiment in diversity. How do you make so many different strains of cultures work in a productive, harmonious way? We are a society that tends to be collective rather than individualistic. So we have been a collective experience, and have had to be so to deal with a harsher climate, with vast distances, and with our smaller population. And we have also realized that immigration, which has made the country work, has added new waves of enthusiasm and energy, generation after generation.

Inside: What role do you see Canada playing on the world stage in troubled times?

DJ: We, in a sense, should be the Athens to the new Romes – to be the place that is not going to have the largest armada, or the biggest gross domestic product, but we'll be a place where learning is cherished, and learning is something we share very generously with the rest of the world.

Inside: What role does fundamental research, like the kind that happens here at Perimeter, play in innovation?

DJ: Curiosity is what underlies learning. If you can pique minds to be asking the right "whys", good things happen. Basic research enhances our curiosity. I think the role that Perimeter will play is to … ensure that every one of our citizens, especially our younger citizens, can expand to the limits of their talent and beyond. This happens not simply because you've increased the critical mass of thinking people, but because you've established higher targets for achievement, reinforced curiosity, and that you must use innovation to improve the lives of other people.



Governor General David Johnston at Perimeter Institute
Photo: Sgt Johanie Maheu, Rideau Hall, © OSGG, 2017

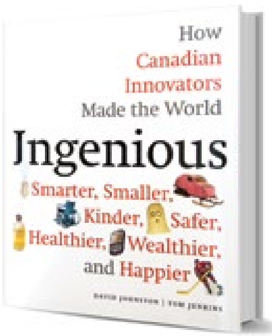
Inside: You've been closely involved with Perimeter Institute since the very beginning. Finish this thought: I am part of the Perimeter equation because…

DJ: Because it's so important to Canada, and so important to the world of innovation – of doing things better. This place is a pinnacle, a beacon of light that illuminates so much. When Mike [Lazaridis, Perimeter's Founder] first began talking about a place where the best thinkers in fundamental physics would come together, it was music to my ears. What's really impressed me is how far Perimeter has come in a relatively short period of time. It usually takes decades and decades and decades to build a great institution. This one, in just over one decade, established itself as a world leader, and that's quite remarkable.

– Interview by Colin Hunter

This interview has been edited for clarity and length.

INGENIOUS



Canadians are an ingenious – but famously humble – lot, with the result that many Canadian innovations aren't well known. To remedy that situation a little, Governor General David Johnston and National Research Council Chair Tom Jenkins have released a new book called Ingenious.

Here are a few of the science-related highlights from the book's 297 innovations that Canada has given to the world.

1. ATOMIC RECOIL

Largely overlooked by history, Harriet Brooks was a post-graduate student of nuclear physics pioneer Ernest Rutherford at McGill University. Brooks determined the nature of radioactive emissions from thorium, discovered radon and its atomic mass, and discovered atomic recoil – experiments that laid the groundwork for future nuclear science.

2. NEUTRON SCATTERING

Working at the Chalk River Nuclear Laboratory in Ontario in the 1950s, physicist Bertram Brockhouse developed neutron scattering, a powerful method of analyzing the properties of matter. He earned the 1994 Nobel Prize in physics for his techniques, which revolutionized condensed matter physics and are still used today.

3. ELECTRON TRANSFER THEORY

In 1951, Rudolph Marcus was the first person to record mathematically how the overall energy in a system of interacting molecules changes to induce an electron to jump from one molecule to another. The discovery was a breakthrough in the theory of chemical reactions, and paved the way to discoveries in corrosion, photosynthesis, polymers, and more.

4. SMARTPHONES

There's a ton of physics in a smartphone: from the electromagnetics in its radio and antenna, to the quantum mechanics in its onboard computer and electronics, to the condensed matter physics behind its flatscreen. When Mike Lazaridis pulled all of these together and launched the BlackBerry in 1997, he started a worldwide smartphone revolution that continues unabated today.

5. NEUTRINO MASS

Down a mine shaft two kilometres underground, the Sudbury Neutrino Observatory solved a mystery of the universe: where were all the sun's neutrinos going? Only a third of the expected number seemed to be reaching Earth. Led by Arthur B. McDonald, the SNO team worked out that neutrinos oscillate between three varieties – electron, muon, and tau – and that neutrinos have mass, earning the team the 2015 Nobel Prize in Physics.

CANADA

6. 'ZOMBIE' STARS

When stars die, some explode in supernova and then collapse to form black holes. But not all. McGill University's Victoria Kaspi is a world-leader in studying "zombie" stars: bizarre, dense regions of space that exhibit exotic physics. Kaspi's pioneering observational studies of pulsars, magnetars, and binary systems garnered her the prestigious Herzberg Gold Medal in 2016.

7. RADIOTHERAPY

In the 1950s, Canada was a leader in the production of powerful nuclear reactors. At the University of Saskatchewan, Sylvia Fedoruk and Harold Johns took nuclear technology in an entirely different direction, using gamma radiation from cobalt-60 to target malignant tumours. Radiotherapy, as it came to be called, was a breakthrough in nuclear medicine that remains a mainline cancer treatment today.

8. MOLECULAR SPECTROSCOPY

In some chemical reactions, molecules break down and release "free radicals" that quickly combine to form new molecules. The process lasts a few millionths of a second, but in the 1950s and 1960s, Ottawa physicist and chemist Gerhard Herzberg found a way to study it. Using quantum mechanical calculations and spectroscopy, he mapped out the chemical structure of many free radicals and earned a Nobel Prize.

9. SAFER NUCLEAR POWER

With the CANDU reactor, Atomic Energy of Canada created a power generator that prioritized safety and efficiency. The hundreds of fuel channels that make up the reactor core are set in a grid that passes horizontally through a tank of heavy water. If the reactor is damaged, this setup provides two independent methods of shutting down fission immediately.

10. SYNTHESIZER

After helping develop the first radar systems, physicist Hugh Le Caine turned his focus to "beautiful sounds." Using technologies from radar, radio, and atomic physics, he created the world's first voltage-controlled synthesizer, the electronic sackbut, which he named after the Renaissance-era trombone.

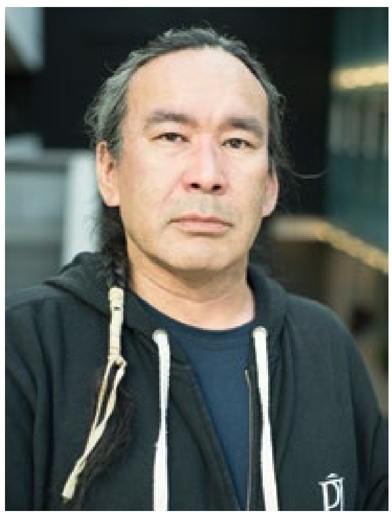
FOSTERING THE UNTAPPED CURIOSITY OF YOUTH

Kids growing up in remote Canada are full of curiosity. It just needs an opportunity to flourish, writes Perimeter research assistant ***Percy Paul****.*

I remember the feeling of the grass on the back of my neck as I lay gazing at the night sky. The Northern Lights were a common sight for those of us who lived on the English River First Nation reserve in northwest Saskatchewan, but the frequency of their appearance never diminished their beauty.

When I was around 10, my friends and I would lie on the newly sodded grass of the local school at night and watch the shapeshifting colours, exchanging theories about what they were.

Were they spirits of departed loved ones that dance if you whistle, growing more colourful as they become happier, as our Dene elders told in their stories? Or were they something else? Something fantastical, like in the strange alien worlds Isaac Asimov described in the novels I found at the local library?



I didn't know it at the time, but I was becoming a scientist. I was looking at the world, wondering how it all worked, coming up with hypotheses, and seeking evidence. Now, decades later, I am officially a scientist.

As I write this, I am sitting in the Perimeter Institute for Theoretical Physics in Waterloo, Ontario, where I am working on a particularly tricky computational problem involving string theory in higher dimensions. I'll spare you the details.

Such advanced physics may seem a world away from my childhood fascination with the Northern Lights, but it's fundamentally the same activity. I am examining how the universe seems to work, posing questions, and doing my best to find answers. And I'm driven by the same underlying motivation we are all born with: curiosity.

Asking questions is the most innately human thing we can do. For millennia, people have gathered around campfires, looked up at stars, and wondered why things are the way they are. I'll be doing it this summer, and I bet you will too.

Such curiosity drove my 10-year-old self to seek answers in books. The local library was a wonderland, a buffet of food for a hungry mind. *The Encyclopedia Britannica* fascinated me, especially the section on mathematics. I didn't understand what all the strange symbols meant, but I was intrigued because they looked a bit like the written word in the Dënesųłiné (ᑌᓀᓱᒼᕄᓀ) language.

I spent practically an entire year in that library, until I was old enough to go to high school. I fed my curiosity with every kind of book, but was particularly drawn to ones that could explain what all those weird mathematical symbols meant.

I still recall the rush of adrenaline when I solved my first mathematical problem. Using only my brain and some pencil-drawn symbols, I had demonstrated some inalienable truth about nature. That sense of satisfaction is what keeps me going as a scientist, even now that the problems have become significantly more difficult.

And that process – being curious, asking questions, seeking answers – is one I believe more young people should experience for themselves. There is so much untapped curiosity and talent among young people, particularly in remote areas like where I'm from, that just need opportunities to flourish.

The world needs innovative young people more than ever. Humans have created big problems for our planet and ourselves, and I believe curious, creative, and courageous young people need to work together to find solutions.

That doesn't mean I envision a generation of nothing but scientists. It means I hope young people will employ a scientific mindset and tenacity to whatever problems they tackle. I didn't spend all my younger days with my nose in books. I made things with my hands. My cousin and I built a fanboat with a propeller made of wood we chopped and carved.

Every activity required problem-solving, creative thinking, and an unwillingness to give up. I've never been afraid to fail, because failure is just another learning experience. I think more young people need to embrace that idea.

My path to science was not easy. String theory is difficult enough, but I have also struggled with bipolar disorder for much of my adult life. It has caused me some big setbacks, but perseverance in my quest to learn has kept me going forward.

My hope is that more young people – perhaps gazing up at the Northern Lights – will understand the joy of seeking answers, and apply their energy to seeking solutions for a better world.

Percy Paul was born and raised in Saskatchewan. He is a research assistant at the Perimeter Institute for Theoretical Physics. This piece was originally published in the Saskatoon Star-Phoenix, *March 29, 2017.*

“HOW DO WE CHANGE THE FUTURE? WE REINVENT IT.”

Cryptographer Sherry Shannon-Vanstone says the status quo isn’t working for women entering STEM fields. She’s hoping to help Perimeter change that.

It takes a strong mind to create uncrackable codes for digital security; it takes just as strong a spirit to crack the stereotypes that can greet women in STEM fields. Sherry Shannon-Vanstone has plenty of both.

The successful cryptographer worked for the US government and in Silicon Valley before moving to Waterloo to co-lead Certicom, a cutting-edge cybersecurity company, with her husband Scott Vanstone. Achieving that success required tenacity and drive. It was also hugely rewarding.

As the co-chair of Perimeter Institute’s Emmy Noether Council, which aims to help correct the long-standing gender imbalance in physics, Shannon-Vanstone gets to combine her love of science and her passion for supporting women in STEM careers.

Inside the Perimeter caught up with Shannon-Vanstone this past March, just before she delivered a keynote address to 200 high-school girls at Perimeter’s Inspiring Future Women in Science conference for 2017.

Inside the Perimeter: How did you first get involved with Perimeter?

Sherry Shannon-Vanstone: About five years ago, my husband Scott and I were approached to become donors. We had philanthropic activities that we were involved with, but we were looking to do something with a farther-reaching effect, especially in science. We understand the roots of Perimeter. Perimeter is a local entity with a global impact and that is what we wanted. I became further involved with Perimeter about three years ago, when I was asked to speak as part of the International Women’s Day event at Perimeter. Later, I was invited to be part of the Emmy Noether Council.

Inside: Had you heard of Emmy Noether before?

SSV: I hadn’t heard her name before, and that was one of the things that caught my attention. I have a degree in mathematics and I have a vision and personal goal to help anyone that wants to go into the STEM subjects – in particular, young women. And here we have a woman in mathematics with a great story, and the opportunity to bring her story to life.

Inside: Why do you feel a responsibility to inspire young women today?

SSV: Of 100 women who are getting a bachelor’s degree today in STEM, only three or four of them will be working in this area in 10 years. That is today’s stats – we’ve got to change that. How do we change the future? We reinvent it. I spent years as a mathematician and working as a businesswoman and I have been happy to use this experience to encourage young women. But my story is just one of the many stories that could be a role model for these young women. We need to find these interesting individuals, like Emmy Noether, shine the spotlight on them, and bring them to life. And there are many other stories like hers that we can highlight. Let’s get the momentum going.

Inside: You support Perimeter in many ways, from philanthropy to guidance to attending events. Why do you want to be such a big part of the equation?

SSV: I am part of the equation because I believe in the fundamental scientific research that is being conducted here at the Perimeter Institute. I also believe in the outreach programs, from the concert series to the public lectures, to the Emmy Noether Circle. I believe in inspiring young women in STEM and I believe in Perimeter.

– Interview by Colin Hunter

Perimeter’s Emmy Noether Initiatives aim to support women scientists at all levels of their careers. Guided by strategic expertise from members of the Emmy Noether Council, these initiatives help create fertile ground for all future leaders of science. Find out more at perimeterinstitute.ca/research/emmy-noether-initiatives.

Power to the people

Canada is not immune to global issues of energy equality, explains this excerpt from the OpenAccess Energy Blueprint, issued this year by the Waterloo Global Science Initiative.

We are living in times of great economic and social opportunity. Emerging technological, social, and business innovations mean that it is now possible for more than 1 billion people to, for the first time, gain access to the modern electricity services that will radically transform their well-being.

Canada is linked to the global energy access challenge through its remote off-grid communities. Despite being what the UN considers an Annex 1 industrialized country, pockets of population that are distant from the grid do not have an adequate level of energy services.

Across the country – particularly in the North – there are 279 active remote communities that are not connected to the North American electric grid, 239 of which rely on diesel fuel for electricity and oil for heating requirements that is flown, barged, or trucked in. Nearly two-thirds of these remote communities are Indigenous. [1] [2]

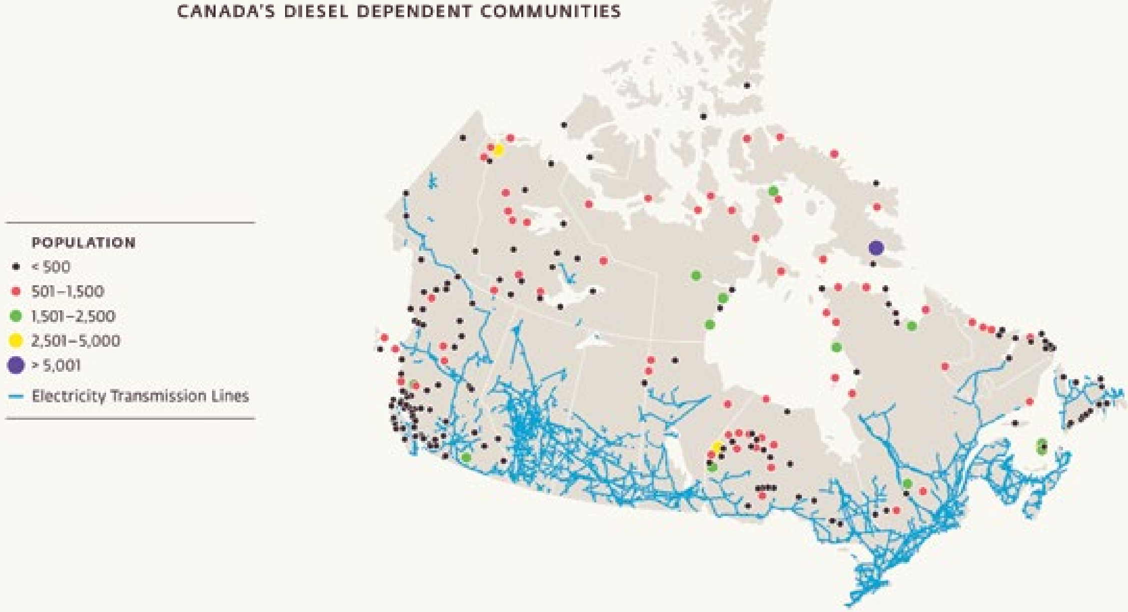
The cost of diesel is much higher than simply the fuel – transportation, storage, and, ultimately, generation and storage site clean-up and remediation must also be accounted for. Climate change is set to make things worse, both by worsening the extremes of the weather, and by making some transport options even more uneconomic.

Many communities only have ground transportation access via winter ice roads and warming trends in recent years have seen some communities' road access diminish to the point where they have to fly in their fuel. Air transportation can double the cost of electricity.

CANADA'S DIESEL DEPENDENT COMMUNITIES

Remote communities

Canada has 279 active remote communities that are not connected to the North American electric grid, 239 of which rely on diesel fuel for electricity and oil for heating requirements that is flown, barged, or trucked in. Nearly two-thirds of these remote communities are Indigenous.



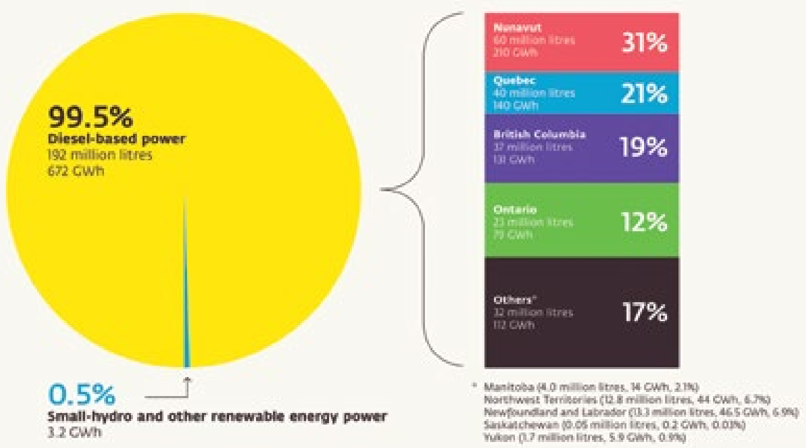
[1] Natural Resources Canada, 2012, Remote Communities Database
[2] Knowles, J., 2016, "Power shift: Electricity for Canada's remote communities," Conference Board of Canada

School closures because of power outages swallow a fifth of the education time in communities like Pikangikum First Nation, where power surges due to unreliable generators regularly destroy education infrastructure, such as Wi-Fi routers, internet servers, and laptop computers.[3] In the same community, lack of electrical power for sewage and drinking water systems has exacerbated existing problems like the rates of gastrointestinal, skin, and urinary tract infections which occur at a much higher rate than in grid-connected communities.[4]

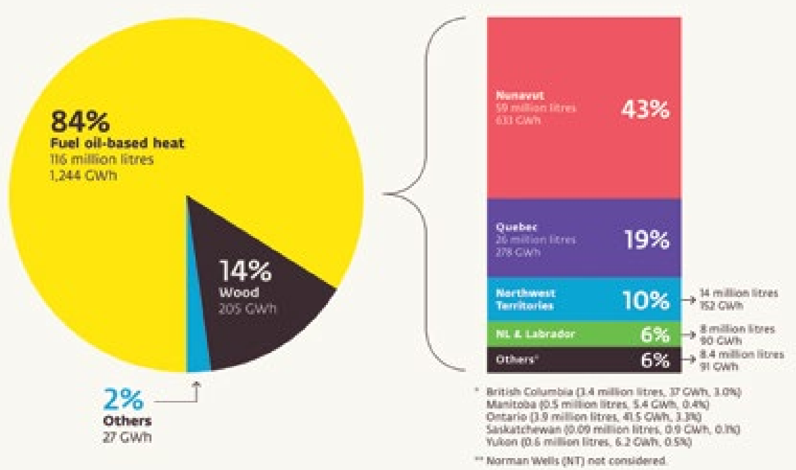
We know that education, health, economic opportunity, and social inclusion are all radically improved by reliable access to energy. Today, there is an incredible opportunity to invest in Canada's fastest growing population and one of Canada's fastest growing industries – Indigenous-led renewable energy projects to both power and empower communities.

Founded in 2009, the Waterloo Global Science Initiative (WGSI) is a non-profit partnership between Perimeter Institute and the University of Waterloo. The OpenAccess Energy summit was held at Perimeter in April 2016. Read the full Blueprint at wgsi.org.

ELECTRIC ENERGY SOURCE AND DIESEL CONSUMPTION ESTIMATE IN FUEL DEPENDENT COMMUNITIES



HEATING ENERGY SOURCE AND DIESEL CONSUMPTION ESTIMATE IN FUEL DEPENDENT COMMUNITIES



OPEN ACCESS ENERGY

The OpenAccess Energy Blueprint outlined four key recommendations to meet energy needs in remote Canadian communities:

1. Commit to an order-of-magnitude increase in funding for sustainable energy solutions in remote Indigenous communities.

2. Recognize Indigenous leadership and support capacity building.

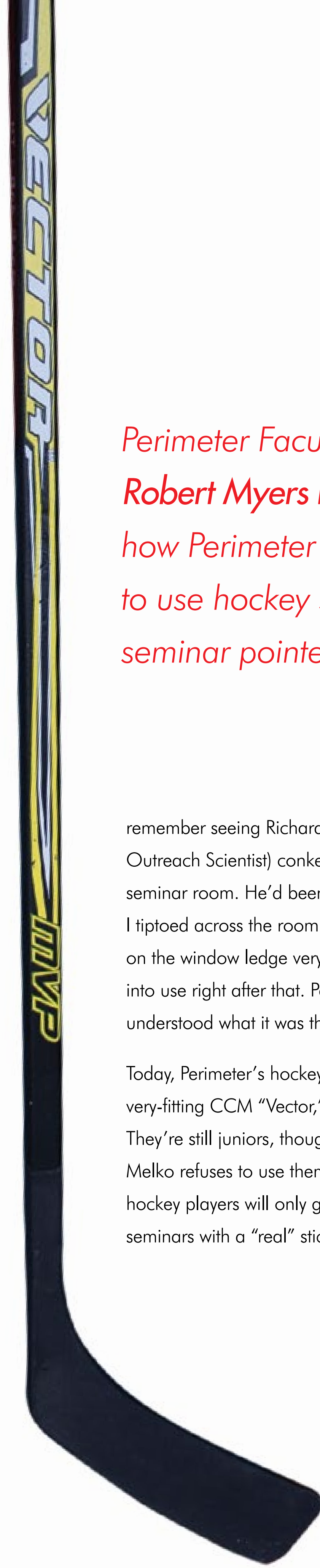
3. Create a single, intergovernmental point of contact to help navigate regulations and funding.

4. Connect people, technologies, and information in order to provide accountability, guide planning, and expose opportunities.

wgsi.org

[3] Bombacino, E., 2016, "How energy poverty devastates Pikangikum First Nation," TVO
[4] Northwestern Health Unit, 2006, Inspection Report on the Pikangikum Water and Sewage Systems

The story behind the PI hockey stick

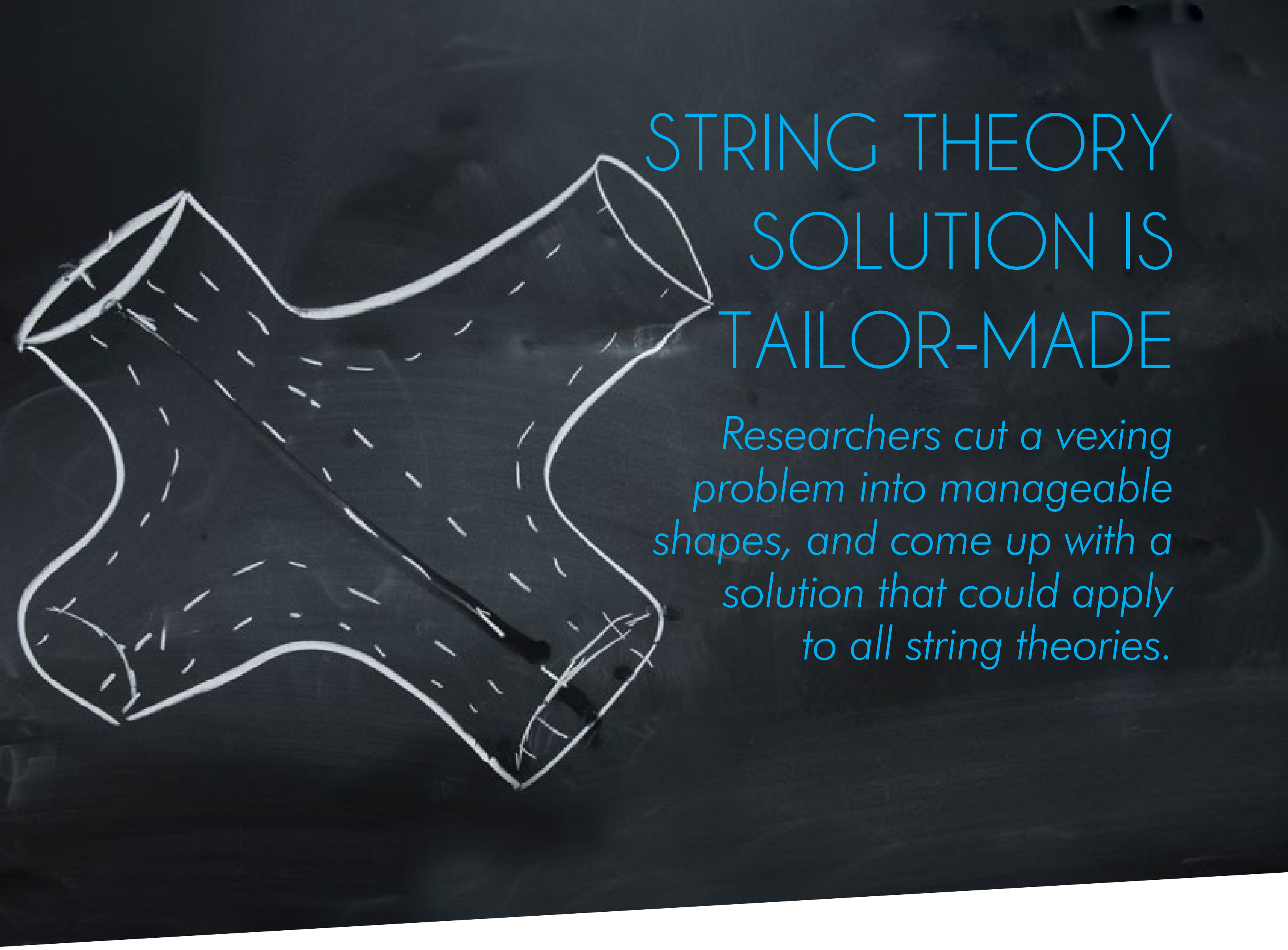


Perimeter Faculty Chair ***Robert Myers*** *recounts how Perimeter came to use hockey sticks as seminar pointers.*

We were in the old building at 35 King Street and we needed a pointer for seminars. I got an idea, went down the street to McPhail's Cycle & Sports, and bought a junior hockey stick. The junior bit was important: they're shorter and lighter than regular hockey sticks, and, you know, we physicists are not all tremendous athletes.

I had been working upstairs in my cubicle all night, and was about to head home when I remembered the stick. It'll give you a sense of what life was like in those days that I distinctly remember seeing Richard Epp (our founding Outreach Scientist) conked out on the couch in the seminar room. He'd been working all night, too. I tiptoed across the room and set the hockey stick on the window ledge very gently. It started coming into use right after that. People just naturally understood what it was there for.

Today, Perimeter's hockey stick pointers are the very-fitting CCM "Vector," which is awesome. They're still juniors, though, which means Roger Melko refuses to use them. Apparently, "real" hockey players will only give condensed matter seminars with a "real" stick.



STRING THEORY SOLUTION IS TAILOR-MADE

Researchers cut a vexing problem into manageable shapes, and come up with a solution that could apply to all string theories.

A few years ago, a Brazilian-Canadian-French collaboration discovered that a particular problem in string theory could be solved if you approached it as a tailoring issue: specifically, how to cut up a pair of pants.

While it sounds like the set-up for a punchline, that sudden insight, published in 2015, has proved to be no joke. By cutting a challenging physics problem down to size, the trio of researchers found a way to simplify and solve it, and created a powerful solution for string interactions that are much too complicated to study in their full state.

Now, the tailors are at it again. In a recent paper published in the *Journal of High Energy Physics*, physicists from Perimeter Institute and Brazil's Instituto de Física Teórica and the South American Institute for Fundamental Research (IFT-SAIFR) turned a string-theory problem into a pants-cutting problem, and applied it to a more complex system.

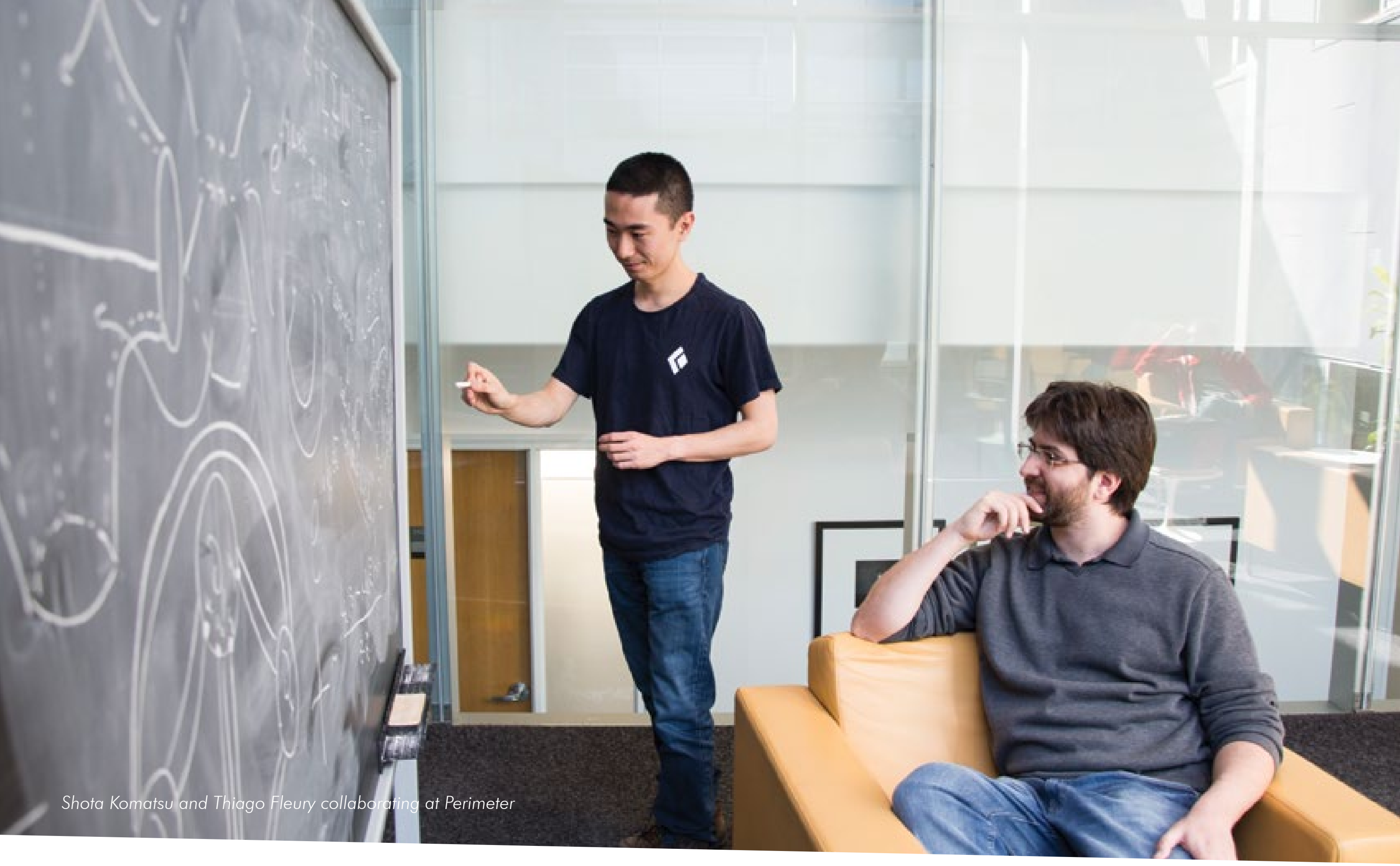
Their results address a long-standing problem in the string theory subfield of integrability, and could prove meaningful for the entire strings community.

How strings make space

Let's set the scene a little. String theory posits that subatomic particles are actually strings vibrating in space. The world that we see and feel arises from how these strings move from one point to another (called propagation) and how they merge or separate (called interaction).

Integrability is the mathematical tool used to understand string propagation and interactions as they occur in a hypothetical, curved space called Anti-de Sitter (AdS) space. Why do theories in a non-realistic universe count? Because they can serve as analogies to other, more complex theories, and vice versa.

Thanks to something called the AdS/CFT duality, string theories in AdS space can be considered equivalent to other theories in a lower dimension. This means theorists are able to translate complex theories up or down to a more manageable dimension – as long as they can also translate and keep track of each theory's unique attributes up and down the chain.



Shota Komatsu and Thiago Fleury collaborating at Perimeter

It was another analogy that finally unlocked the puzzle of string propagation. A landmark 2009 paper showed that the string propagation problem was almost equivalent to a condensed matter problem. This allowed string theorists to import and adapt condensed matter techniques.

However, there were no such analogies for string interactions. These remained a thorny challenge as researchers worked to develop new techniques with which to study them.

A powerful new idea was put forward in 2015 by Perimeter Faculty member Pedro Vieira (who was a co-author on the 2009 propagation paper), Perimeter postdoc Shota Komatsu, and Benjamin Basso, then at the École Normale Supérieure – all working together in Brazil.

In what they called the "pants" approach, explained more fully below, they studied the simplest interaction of a string: when one string splits into two. Cutting the problem in half proved not only mathematically powerful, but visually helpful.

A year later, Komatsu and IFT–SAIFR postdoctoral researcher Thiago Fleury wanted to tackle a more difficult interaction: when two strings merge then split again. It turns out, they ended up finding not just a powerful way to study integrability in string theories[1] and gauge theories[2]; they might have found a new way to study all string theories.

The paper has already gained the attention of the integrability community, and will be a featured paper at the Integrability in Gauge and String Theories conference in Paris this July. It is also expected to make waves when the string theorists gather for their largest annual conference, Strings 2017, this June in Tel Aviv.

Vieira, who now holds the Clay Riddell Paul Dirac Chair at Perimeter Institute, plans to highlight the work when he provides the annual overview of research in integrability. "I think it's really a breakthrough in understanding string interactions," he said. "It's definitely the most important result of the year in this field, by far."

The problem of split strings

The strings-as-pants analogy sounds odd at first, but it makes sense when you see it. Diagram A shows what looks like an empty pair of pants standing in front of you. At the "waist" is a closed string loop. As that string moves through time, it makes the shape of a cylinder. When the interaction occurs, and the string splits in two, it creates two new cylinders that end at the "left cuff" and the "right cuff" of the pants. This is called a three-point function, because there are three "ends."

Now, take some scissors and slice down each of the outside seams, then up the inseams, to leave a "front half" and a "back half." Each half is a hexagon: waist, left-leg seam, cuff, inseam, cuff, right-leg seam. This theoretical tailoring means those closed strings are now sliced open, and that means they can be studied using integrability. After the strings are studied, the hexagons are then "glued" back together, with some mathematics added in to account for the introduction of "seams" where none previously existed.

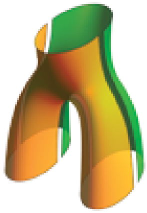


Diagram A: One string splits into two.

The original tailoring reduced an incredibly complex computation into smaller, simpler building blocks, and provided a process through which string interactions could be understood.

This new paper, "Hexagonalization of Correlation Functions," takes a similar approach to a different problem: how two strings interact and then split into two new strings. This is called a four-point function, because there are four "ends" of the strings. This is a much more complex situation, which means its solution can yield much richer information.

That complexity is what drew Komatsu to the problem. "Trying to understand the four-point function was a challenge. It was clear that it's a very interesting object," Komatsu said.

Komatsu and Fleury started by looking at results generated by studies of four-point functions in very weak regimes (where the attraction between particles is very weak, so they fly around and interact very little), and in very strong regimes (in which strong couplings create multiple interactions and make the system difficult to study).

Due to the differing math techniques used to probe each regime, the results were vastly different. But there were commonalities. At the weak end of the spectrum, the math was complicated by many contributions, but those contributions seemed to pool into four different areas. At the strong end, the strings were complicated to describe, but the math seemed to indicate that each string had four special regions.

The math was giving strong hints that the solution lay in somehow dividing the problem into four parts, but how? A number of researchers at Perimeter and SAIFR took up the challenge. Some took the pants idea, joined two "pairs" at the waist, and cut them along the seams.

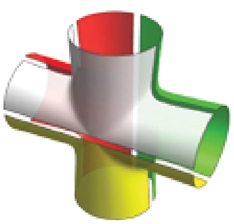


Diagram B: Two string interactions cut into hexagons.

Komatsu and Fleury did something different: they cut one "side" of the interaction vertically, and the other horizontally (see diagram B). This created four hexagons, but in a different way. It also created four split strings that could be calculated and glued back together. "The idea itself, we had it almost from the beginning," said Komatsu, who came to Perimeter in 2014.

Using integrability, they began computing the interaction contribution from each hexagonal patch. This was a formidable effort: when the "pants" are formed, excitations called magnons are divided between the two. The researchers had to sum over all possible divisions, and to move a magnon from one hexagon to another, they had to introduce propagation phases.

Needless to say, the mathematical techniques to do these operators needed to be custom tailored. After a year collaborating from their respective home bases in Waterloo and São Paulo, and getting together during visits facilitated by the Perimeter-SAIFR partnership, Komatsu's and Fleury's idea was vindicated: their results using this new method agreed perfectly with previous results of the four-point function at weak couplings and at strong couplings.

São Paulo

The power of place

To generate new ideas, it helps to mix things up. Getting out from behind your desk can be useful. Getting 8,200 kilometres away and immersing yourself in a different culture can unlock a whole new level.

That was part of the impetus behind the UNESP-SAIFR-Perimeter partnership that now links Perimeter Institute with the South American Institute for Fundamental Research (SAIFR), at the São Paulo State University (UNESP) in Brazil.

The partnership aims to train young scientists, support collaborations, and strengthen international research ties. In practice, it is opening new channels of discovery, says Perimeter postdoctoral fellow Shota Komatsu.

"You never realize, but I think you are very much influenced by the surrounding environment, indirectly. Even the way you do physics and the way you think may be a little bit affected by the environment," says Komatsu, whose latest research is a perfect example of what can come from the partnership.

Spearheading the project is Pedro Vieira, the Clay Riddell Paul Dirac Chair at Perimeter. He says Komatsu's and Fleury's collaboration is an excellent example of the ongoing exchange between the institutes.

"I think it's going perfectly," he said. "The people going there are working very well, and vice versa. I'm very happy with the way this is going. The partnership is only growing more and more."

Waterloo

‘More beautiful cutting’

Vieira says it was a powerful insight. “It’s a different way of cutting this object. You cut it into the same kind of hexagon, but the way you cut is different. It is more beautiful,” he said.

For Komatsu and Fleury, this is just the beginning. The mathematics of hexagonalization are complicated, and as the coupling strength increases, the math becomes harder to control. Both researchers are working to iron out as many issues as they can before presenting the paper at the subfield’s big conference in July.

“There are many things to understand, and to do. I’m going to work exclusively on this [until the conference],” Fleury said.

This paper provides a basic framework they look forward to expanding on, Komatsu said. “So far, we only checked that the hexagonalization can reproduce the results computed by other means,” he said. “We should in principle be able to compute many more results than are computable by other methods. To make it really work, or in order to get some real predictions, there are still some details that we need to work out.”

Because weak and strong regimes are so different, physicists use different techniques to study them. If theorists could find a single method that worked in the strong and weak regimes, they might also finally have a way to probe the regions in between, which, today, are basically impenetrable.

Vieira suspects that hexagonalization might just provide such an avenue. “I think it’s really a breakthrough in understanding string interactions,” he said.

“Because it applies to any N-point function in a very elegant way, it’s very likely that it extends beyond the gauge/gravity dualities we are studying. Shota’s and Thiago’s idea can, I suspect, be applied to all string theories.”

– Tenille Bonoguore

Read the papers:

N. Gromov, V. Kazakov, and P. Vieira, “Integrability for the full spectrum of planar AdS/CFT,” Physical Review Letters *103 (2009) 131601*

B. Basso, S. Komatsu, and P. Vieira, “Structure constants and integral bootstrap in planar N=4 SYM theory,” arXiv:1505.06745

T. Fleury and S. Komatsu, “Hexagonalization of correlation functions,” Journal of High Energy Physics *01 (2017) 130*

[1] String theory attempts to merge quantum mechanics with general relativity. String theories replace the particles in particle physics with one-dimensional strings.

[2] Gauge theory is a class of quantum field theory. Gauge theories constrain the laws of physics in a way that leaves the basic physics of the quantum field unchanged, making it possible to reveal underlying structures.

COUNTERFACTUAL

Any scientist can tell you that truth is a tricky proposition. Evidence is much more straightforward – or is it? When James Weatherall, a mathematician and philosopher of science, visited Perimeter to deliver his public lecture, Inside the Perimeter *took the opportunity to ask about the role, and fate, of evidence-based thinking in an age of alternative facts.*

Inside the Perimeter: This is an age of doubt and disbelief of facts. Can you talk to me about the connections between philosophy and science in the age of science denialism and alternative facts?

James Weatherall: There's an interesting question here, which is: why should we believe true things? Why should we care about evidence? One of the most striking things about the current political climate in the West … is how little the evidence seems to matter. There are clearly many people who simply deny the things that are best supported by all of the evidence available. In part, it's being unaware of that evidence, but in part it's simply discounting it, or saying, "No, that's not relevant to how I form my beliefs, and I am just confident that this other thing, which has much less support, is true."

Inside: Where do you see this in action?

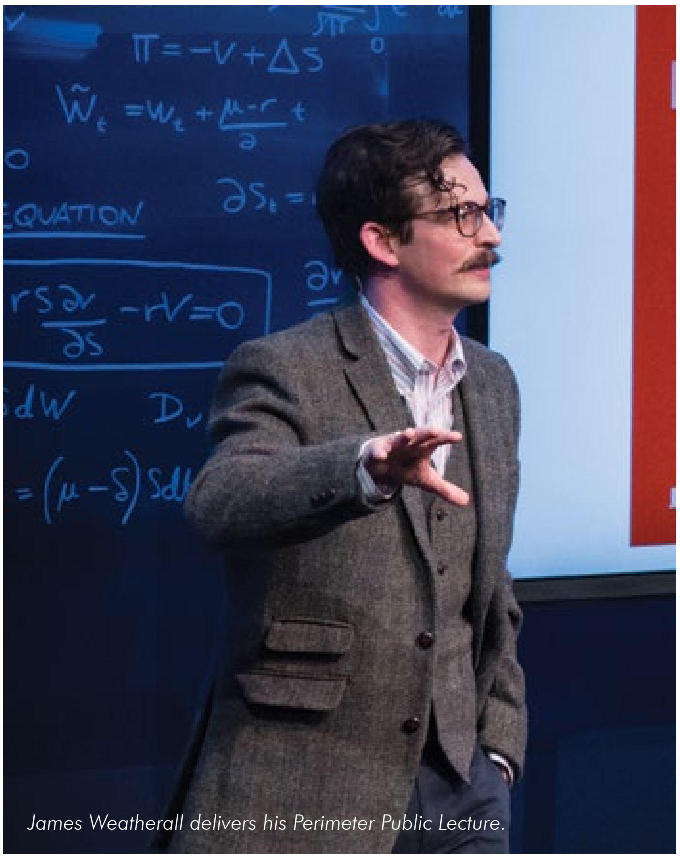
JW: You see this of course in connection with climate change, but you see it elsewhere. There's a raging debate in the US about the value of vaccines. Also, in Europe, where there's a lot more support of climate change, genetically modified foods are very controversial in a way that I think they're less controversial in America.

Inside: This might seem an odd question to ask a scientist, but why does truth matter?

JW: You would expect that not being able to properly account for evidence should hurt you at some point – that it should matter. There should be some point at which the world pushes back. I think this is how many philosophers have thought about beliefs in the world. Why do we care about the truth? Because we care about actions that we could take, in order to yield the outcomes we want. If you're not somehow sensitive of what's true in the world in taking those actions, you're not going to get the outcomes you expect. Yet somehow that connection seems to be getting lost.

Inside: What is causing that connection to break? Why is truth losing ground?

JW: There are different ways in which social factors are influencing how we form beliefs that are distinct from the evidence. In many cases, what seems to matter most is agreeing with the people around you, particularly in an age when many people are interacting through social media. You can get a kind of echo chamber where the only people who you hear from – or the vast majority – are in agreement with you. The immediate feedback you get from the world is all positive when you agree with this group of people. The costs of believing something that's not well supported evidentially, and that perhaps might matter in a bad way down the line, becomes very abstract in comparison to this very immediate feedback.



James Weatherall delivers his Perimeter Public Lecture.

Inside: How is this impacting our broader, shared society?

JW: One of the things we're seeing now is the way in which science and politics interact with one another, and how an even broader set of even stronger social factors seem to enter in there. Of course there's a relationship between economics and policy, [but] there's also a relationship between science and economics, in which science is used to inform policy.

If you can take advantage of social factors to influence people's beliefs in order to enact your policy preferences, there's an economic incentive to do so. This has been understood by certain corporate interests for a very long time. The tobacco industry systematically tried to undermine scientific evidence between tobacco and lung cancer. Very similar methods, and in some cases the same people, have been used to undermine the relationship between greenhouse gases and climate change.

This is something that has been there for a long time. I think we have seen an acceleration of this process enabled in part by the ways in which our social structures have changed, in large part because of the Internet.

Inside: In this kind of environment, should scientists defend science? Or is there a danger in becoming advocates?

JW: On the one hand, it seems to me as if not standing up and insisting on where the evidence really lies, not making that public, not communicating that as clearly as possible, would be a mistake. On the other hand, the more scientists and advocates for science look like political agents, the easier it is to undermine their authority on the grounds that they're just pushing one political view among many.

Inside: Is there still a place in society where evidence rules?

JW: There's an old saying that all politics is local. The one place you can see the connection between evidence-based belief and political action and politics more generally, where the world pushing back in the right ways, is with local politics. It is the case that people are going to tend to care about their own water supply; you're going to tend to care about your own children's schools and things like that, in a way that you perhaps don't, or you're free to care less, about global issues.

The real puzzle is how to make people think about these more abstract, larger-scale issues that require coordinated global action, like climate change, in the way that they think about things closer to home. I don't think anyone has figured out a way to do that.

– Interview by Tenille Bonoguore

Watch James Weatherall's Perimeter Public Lecture – and all of the other lectures – at www.YouTube.com/PIOutreach

FINDING HOPE IN A DARKENING WORLD

Perimeter donors credit the independence of theoretical physics as its greatest strength.

Judith DesBrisay, "Possibilities 8"

In decades of exploration, from the Arctic to Antarctica and many places in between, Mike Cannell and Judith DesBrisay have borne witness to two compounding losses.

The wild places they visit and love are tangibly suffering from the negative impacts of climate change. Meanwhile, public faith in the scientific process that monitors – and could help address – those impacts is quickly eroding.

It would be easy to throw their hands up and retreat to their remote, off-grid second home in BC's interior. Instead, they decided to support theoretical physics by becoming annual Perimeter donors.

The connection they've made isn't quite as odd as it first appears, Cannell explains, particularly given their own relationships with the sciences.

In 1974, Cannell worked on the fabrication of components for the TRIUMF particle beam accelerator. He later spent 18 years as faculty and administration at the British Columbia Institute of Technology. DesBrisay is a retired nurse who sought out many remote postings, and who continues to create works of art exploring the relationship between people, the environment, and science.

In 1997, Cannell was hired to help establish the Centro de Entrenamiento Industrial y Minera, a technical institute in Antofagasta, Chile. While they were there, Cannell and DesBrisay watched the blossoming of the Atacama Desert astronomical telescope industry.

"If you have ever worked in or around such a facility, or hung out in the control room of either an accelerator or an astronomical observatory, one realizes that the entire enterprise is in support of theory and exploration," Cannell says. "The distinction [between them] quickly disappears."

Over decades, Cannell and DesBrisay had an inside view of academic administration and environmental change. It left them despondent about how politics can influence both. That, strangely enough, was what drew them to Perimeter. They hope that Perimeter and institutes like it can help bolster the case for science by raising awareness about how essential it is to a healthy society and a healthy planet.

"Theoretical physics is unlikely to be impacted by political or corporate pressure," Cannell says. "I also like the model of PI for the students [and postdocs], that they're working on their own problems and not providing cheap labour or acting as indentured servants for other researchers."

They see a worrying global inclination towards social disintegration and science denialism. Not only is wealth accumulating in fewer hands, but so is power, and the powerful have little incentive to change the system.

"Because we've travelled from pole to pole, from Ellesmere Island and Greenland to the Atacama and the Amazon Basin, we can say with great certainty that the planet's not doing well," Cannell says. "Perimeter won't provide solutions to global problems, but we might learn something interesting for the sake of knowledge."

Perhaps, he adds, a more advanced understanding of scientific concepts can force us to accept the dichotomy facing humankind: ignore nature and we'll destroy ourselves. "The impact of the Anthropocene threatens our survival on planet Earth. Human beings must confront our insignificance in the workings of natural forces and the processes within our universe."

– Tenille Bonoguore

To find out how you can be part of the Perimeter equation, visit perimeterinstitute.ca/support-perimeter

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UPCOMING CONFERENCES

International Workshop on Quantum Spin Ice | June 7-9

This workshop will bring together experimentalists and theorists to discuss the challenges and promises that surround the search for a quantum spin liquid state in QSI candidate models and materials.

Radiative Corrections at the Intensity Frontier of Particle Physics | June 12-14

A convergence of experimental innovation and theoretical ideas has brought the so-called intensity and precision frontiers to the forefront of particle physics. The precision goals of these experiments demand correspondingly precise theory.

Making Quantum Gravity Computable | June 19-23

The school is aimed at junior researchers (PhD students/postdocs) with a quantum gravity background or interest in applying numerical tools to quantum gravity.

Bounce Scenarios in Cosmology | June 26-28

An attractive possibility which has gained popularity in recent years is to replace the big bang by a bounce, in which an expanding universe emerges from a prior period of contraction. This workshop will bring together researchers who have developed different types of bounce scenarios in cosmology.

New Directions in Dark Matter and Neutrino Physics | July 20-22

This workshop on non-traditional ideas and alternative methods of probing new physics, both at underground laboratories and at high-intensity accelerators, aims to complement the international conference, “Topics in Astroparticle and Underground Physics 2017,” to be held in Sudbury from July 24 to 28.

Contexuality: Conceptual Issues, Operational Signature, and Applications | July 24-28

2017 marks 50 years since the seminal 1967 article by Kochen and Specker proving that quantum theory fails to admit of a noncontextual model. This is the first large conference dedicated to the subject.

Women in Physics Canada | July 26-28

This three-day conference at the University of Waterloo/Institute for Quantum Computing will visit Perimeter on July 26 for a panel discussion and poster session.

Hopf Algebras in Kitaev’s Quantum Double Models | July 31-August 4

The physics of Kitaev quantum double models is inherited from topological quantum field theories, while their underlying mathematical structure is based on a class of Hopf algebras. This structure is also seen across diverse fields of physics.

Experimental Techniques in Table-Top Functional Physics | August 21-25

There has been a resurgence of interest in small-scale high-sensitivity experiments that look for new forces and new particles beyond the Standard Model. This workshop explores some common experimental techniques, and aims to fuel new ideas through interdisciplinary interaction.

TURNING **CHALLENGES** into **OPPORTUNITIES**

Math seemed like a roadblock to a dream physics career, until one conversation sparked a new approach.

As a child, Eugene Adjei immersed himself in the fantastical universes created in comic books. He and his friends in Accra, Ghana would even make their own comics, then exchange their hand-drawn efforts.

Now 24 years old, Adjei is thrilled – and a little awestruck – to meet and interact with some of the real-life "superheroes" of theoretical physics as part of Perimeter Scholars International.

"So far my experience has been very enlightening," Adjei says. "I have gotten to meet people that I normally just read about in books, like Lee Smolin. It's a very surreal experience."

In high school, Adjei was intrigued by how physics could explain everyday phenomena in the world around him – like how lightning strikes, or why the sky is blue.

He turned to his grandmother, an educator whose house was full of science textbooks. As he delved deeper into the subject, he realized that a strong mathematical background was necessary to fully understand the theories.

At the time, Adjei did not feel strong enough in math to continue with physics. "In truth, I gave up on it for a while," he admits. "By the end of high school, I was convinced of pursuing a business program."

But once out of high school, a series of conversations with a friend about philosophy and religion reawakened Adjei's passion for understanding the physical world.

Instead of viewing his challenges with math as a limitation, he decided to create an opportunity for self-improvement. He enrolled in an undergraduate degree in mathematics at the University of Ghana, supplementing the math-heavy course load with lessons on quantum mechanics and electromagnetic theory.

Adjei next tackled a Master's in Mathematical Sciences from the African Institute for Mathematical Sciences - Ghana, where he received the F.K.A. Allotey Meritorious Award for exceptional academic performance.

At Perimeter, Adjei is working with postdoctoral researcher Wolfgang Wieland on a project in loop quantum gravity. The field excites him with its potential for developing a new understanding of physics by bringing together two supposedly opposing theories – quantum mechanics and general relativity.

Coming to PSI marks the first time Adjei has lived off-continent, though he has travelled to North American once before: in 2008, he and a partner travelled to Houston, Texas, where they received the silver medal at the inaugural International Sustainable World Energy, Engineering, and Environment Project (I-SWEEEP) competition for their efforts to develop an environmentally friendly pesticide.

Despite the obvious differences in weather (Adjei notes his excitement for snow, which he has only before seen on TV), Waterloo and Accra have at least one thing in common: "The people are very friendly," says Adjei. "It reminds me a lot of home."

Back in Ghana, his parents and grandmother are overjoyed that Adjei is following his dream. "I am humbled and I have a deep appreciation to Perimeter for this opportunity," Adjei says. "It is my hope that in the future, more African students can experience this great institute just as I have had the good fortune to experience."

– Stephanie Keating

Eugene Adjei is the 2015/16 Scott Griffin Foundation Honorary PSI Scholarship Award winner.

Chef Ben's maple cider brined pork loin

black hole bistro

Ontario Pork is some of the most delicious in the world. If you can get heritage-breed pork such as Berkshire or Tamworth from a local butcher or farmers' market, this recipe will really shine.

Maple Cider Brined Pork Loin

INGREDIENTS

½ pork loin (approx. 2.5–3 lbs)

1 cup maple syrup

2 litres + 1 cup apple cider

4 litres ice

1 cup sea salt

1 sprig rosemary

5 juniper berries

Crushed chilies to taste

2 tablespoons sunflower or vegetable oil

2 tablespoons cold butter

In a large saucepan, bring the maple syrup, cider, salt, rosemary, juniper berries, and chilies to a boil.

Transfer the liquid to a very large pot or bowl. Add 4 litres of ice directly to the mixture to cool the brine.

Once the brine is cool, place the liquid and the loin in an extra-large, re-closable freezer bag. Completely submerge the loin in the brine, force all the air out of the bag and seal. Place the bag in the refrigerator for 12-36 hours.

Preheat the oven to 300 degrees Fahrenheit. Remove the loin from the brine and pat dry. Heat a cast iron pan on medium heat on the stovetop, adding sunflower or vegetable oil. Once the pan is hot, sear the loin on all sides and both ends.

Once the searing is complete, place the loin in a roasting pan and put in the oven until the internal temperature of the loin reaches 145 degrees Fahrenheit.

While the pork is cooking, deglaze the cast iron pan with a wooden spoon and 1 cup of cider. Simmer to reduce the cider by half its original volume. When the liquid is reduced, remove from the heat and whisk in the butter, one tablespoon at a time, to thicken the sauce. Add salt and pepper to taste.

Remove the loin from the oven and cover with foil. Allow it to rest for 20 minutes.

Slice thin and serve with sauce and your favourite sides.

Ben Uniac is the Black Hole Bistro Head Chef at Perimeter Institute.

Arvanitaki wins New Horizons Prize

Asimina Arvanitaki has won the prestigious New Horizons in Physics Prize, making her the fifth Perimeter Institute faculty member to earn the award since it was first presented in 2013. Arvanitaki, who holds the Stavros Niarchos Foundation Aristarchus Chair at Perimeter, shared the prize with two peers, Peter Graham of Stanford and Surjeet Rajendran of the University of California, Berkeley, for pioneering work that bridges theory and experiment to forge novel ways of exploring particle physics.

"My field of research, involving small-scale particle physics experiments, is a relatively new one, so it is rewarding for it to get this kind of recognition from the physics community," said Arvanitaki. "We are seeking novel approaches to probing fundamental physics in ways that would not have been possible even 10 years ago. This award indicates that we are on the right track, with the potential to obtain important results with low-cost experiments on ever-shorter time scales. This recognition gives us even more ambition to live up to that potential."

Raymond Laflamme wins CAP-CRM Prize

Pioneering quantum computing researcher Raymond Laflamme has been awarded this year's CAP-CRM Prize in Theoretical and Mathematical Physics from the Canadian Association of Physicists and the Centre de recherches mathématiques. Laflamme, Executive Director of the Institute for Quantum Computing and a Perimeter associate faculty member, was lauded for his theoretical and experimental work in quantum error correction, fault tolerance, and quantum information processing using linear optics.

New Emmy Noether Visiting Fellows announced

Four outstanding early-career scientists will join Perimeter in the coming academic year as Emmy Noether Visiting Fellows. Named after the pioneering German mathematician, the program has now welcomed 23 researchers to Perimeter in just five years.

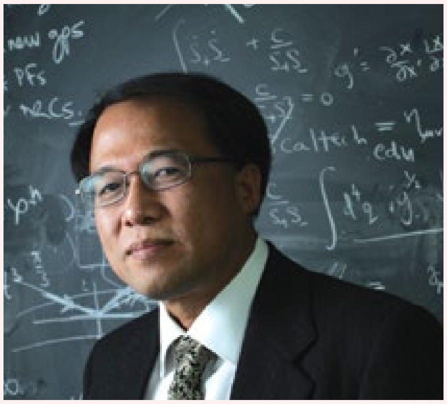
The coming year's fellows are: quantum field theorist Olalla A. Castro Alvaredo (City University of London), cosmologist Emanuela Dimastrogiovanni (Case Western Reserve University), condensed matter physicist Paula Mellado (Adolfo Ibáñez University), and mathematician Yaping Yang (University of Massachusetts, Amherst).

Each researcher will spend up to a year as part of Perimeter's thriving, interdisciplinary community while on leave from their home institutions. Applications for the next group of fellows will open in November. Information about all of Perimeter's activities to support and encourage women scientists can be found at perimeter.ca/research/emmy-noether-initiatives.

Robert Myers named among most influential for third year

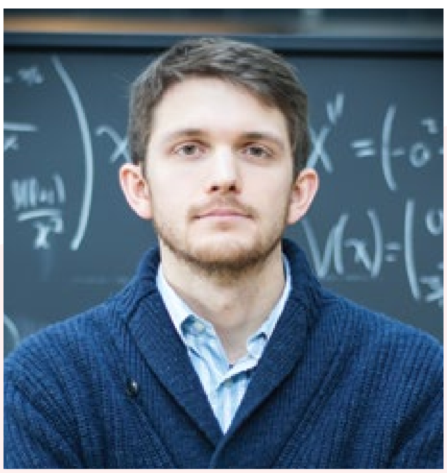
Perimeter Faculty Chair Robert Myers is once again on a list of the world's most influential scientific minds. Myers was recognized on the "2016 Highly Cited Researchers" list by Clarivate Analytics, formerly the Intellectual Property and Science business of Thomson Reuters, marking his third consecutive year on the list. Perimeter Distinguished Visiting Research Chair Juan Ignacio Cirac (Max Planck Institute of Quantum Optics) joined Myers on the list for the second consecutive year.

Wen wins Buckley Prize



Distinguished Visiting Research Chair Xiao-Gang Wen (MIT) has won the 2017 Oliver E. Buckley Condensed Matter Physics Prize of the American Physical Society. The award recognizes Wen's theories of topological order and how such order impacts a broad range of physical systems. He shares this year's prize with Alexei Kitaev (Caltech).

Buchalter Prizes



In something of a cosmology double-hat-trick, Perimeter Institute researchers have won two awards in the Buchalter Cosmology Prize. It's the third time since the prize's launch three years ago that Perimeter has been a double finalist. Perimeter postdoctoral researcher Elliot Nelson, above, won the $5,000 second prize for his paper "Quantum decoherence during inflation from gravitational nonlinearities," and Associate Faculty member Cliff Burgess shared the $2,500 third prize with his co-authors Richard Holman, Gianmassimo Tasinato, and Matthew Williams (a former Perimeter PhD student who is now at the University of Leuven).

Two New DVRCs appointed

The Perimeter research community has welcomed two new Distinguished Visiting Research Chairs (DVRCs): Charles Bennett and John March-Russell. Bennett is an information theorist and computer scientist at IBM's Thomas J. Watson Research Center, who is recognized as one of the founding fathers of modern quantum information theory. March-Russell is a theoretical particle physicist working on the creation of new "Beyond the Standard Model" theories of fundamental forces and matter. Both of these eminent scientists will make Perimeter their second research home, visiting for extended periods while retaining permanent positions at their home institutes. The Institute now has 52 DVRCs.

Giulio Chiribella appointed CIFAR Azrieli scholar

Quantum physicist and Perimeter Institute Visiting Fellow Giulio Chiribella has been named one of 18 inaugural CIFAR Azrieli Global Scholars. The University of Hong Kong professor received $100,000 in research support and was appointed to one of CIFAR's 14 research programs for two years. The new program funds and supports researchers within five years of their first academic appointment, helping them build research networks and develop essential skills needed to become leaders in global research.

Perimeter Board welcomes new member

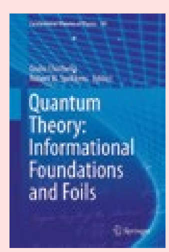
Perimeter is delighted to welcome Jeff Moody to its Board of Directors. Moody, who is Senior Executive Vice-President, Investments and Client Wealth Management at Gluskin Sheff + Associates, is also the Chair of Perimeter's Investment Committee.

ISSYP alum wins Luke Santi Award

Joscelyn van der Veen, a first-year student studying mathematical physics at the University of Waterloo, has won this year's Luke Santi Award for Student Achievement. The award is presented in memory of Luke Santi, a high school student and friend of Perimeter who had a passion for research and discovery, earning top marks while volunteering his time in service of others.

Like Luke, Joscelyn attended Perimeter's International Summer School for Young Physicists (ISSYP). She credits her 2015 ISSYP experience as the defining moment when she knew she wanted to turn her interest in physics into a career. "If I enjoy this," she said of ISSYP, "then I'm pretty sure this is what I can do with my life. It was the most incredible experience I've ever had."

New book explores quantum foundations and foils

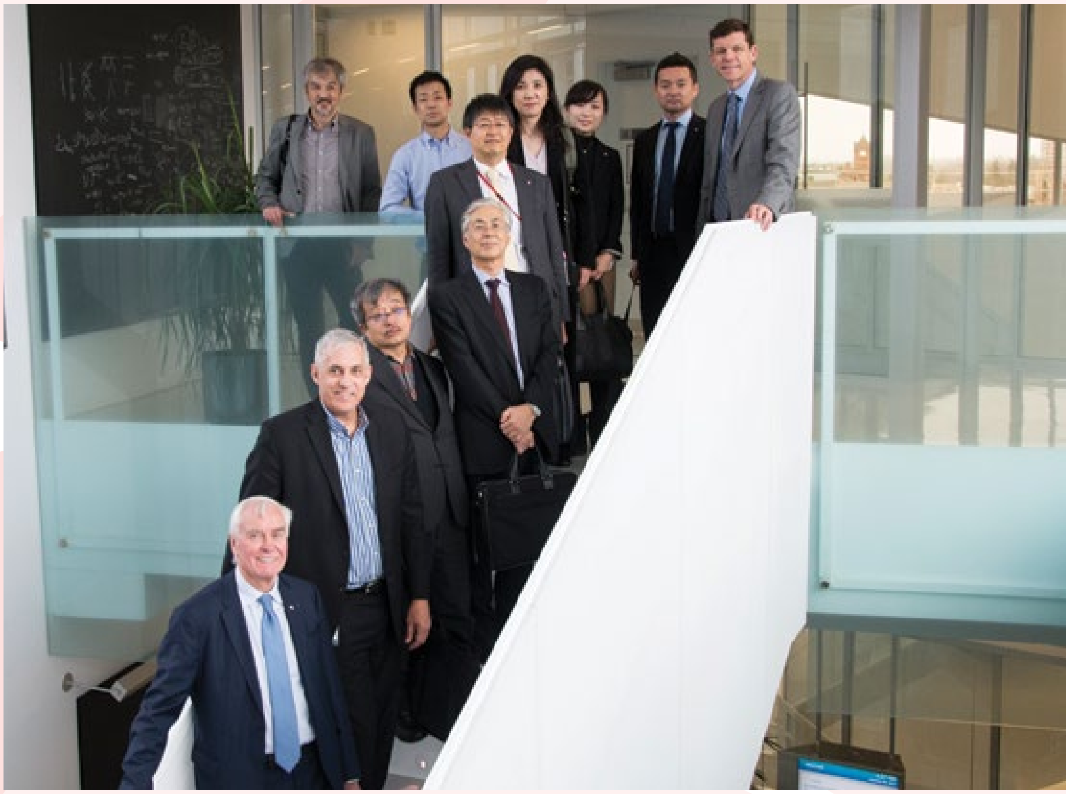


A recent book edited by Perimeter Faculty member Robert Spekkens and Perimeter Visiting Fellow Giulio Chiribella (University of Hong Kong) seeks to showcase the breadth of quantum information and tease out common themes among the various approaches now in use. *Quantum Theory: Informational Foundations and Foils* (Springer) includes 14 original contributions from leading experts in the field, among them Perimeter researchers and alumni including Lucien Hardy, Christopher Fuchs, Markus Mueller, and Roger Colbeck.

New classroom resource embraces the fun of "doing"

There's a big difference between reading a recipe and baking a cake. In the mess of doing, the experience comes alive. It's the same with science education. Four new educational resources from Perimeter Institute are designed to bring STEM subjects to life for students in grades 5 through 8. The result of a four-year grant from Ontario's Ministry of Education, the resources link directly to the Ontario curriculum and aim not only to teach science, but to help build communication, collaboration, creativity, and critical thinking skills along the way. Canadian teachers can access all of Perimeter's classroom resources for free at perimeterinstitute.ca/store.

Showcasing Canada



Perimeter is a destination for international delegations studying the Institute's mission and model. In January 2017, leading representatives from the Japanese Science and Technology Agency learned about Perimeter's research, training, and outreach operations, and the Institute's many linkages abroad.

BLACK HOLE BLUES AND OTHER STORIES FROM SCIENCE

From quantum computing to the music of black holes, the Perimeter Public Lecture Series is a great science-lover's night out (or in).

We're about to wrap up another great year of lectures. In the latest series, we've had an insider's tour of the next big space telescope, learned how to bake pi(e), explored the strange physics of Wall Street finance, and much more.

Held on the first Wednesday of each month from October through June, the series is webcast live on InsideThePerimeter.ca, where audience members can ask questions over social media. And just in case you missed any, they're all viewable on demand at YouTube.com/PIOutreach.

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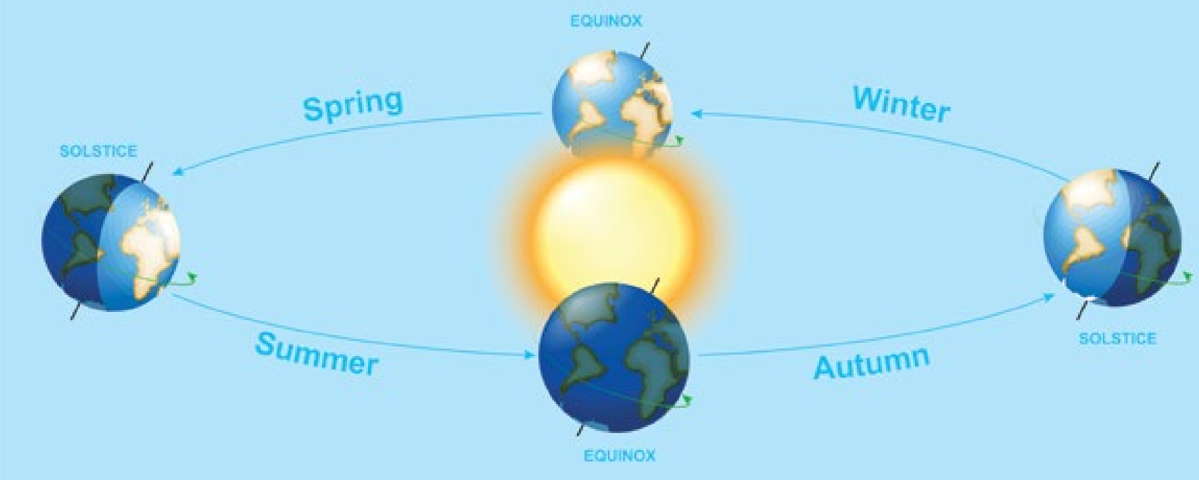
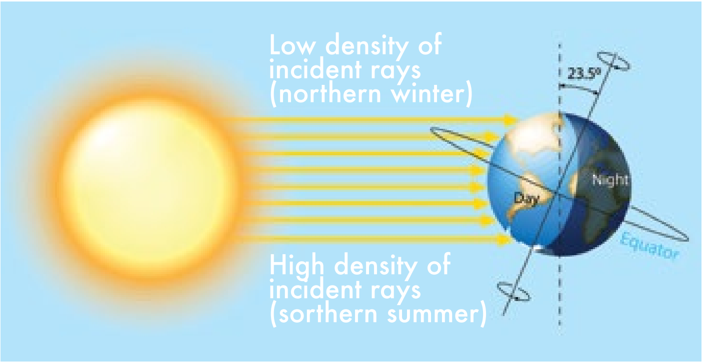


What causes the seasons to change? And why are the seasons the opposite for my friend in Australia?

It might be tempting to think that the seasons are caused by the Earth's changing distance from the sun: that in summertime, the air feels warmer because we're closer to the sun, and that the coldness of winter is because we are farther from the sun's toasty rays.

This seems to make sense at first, but it turns out to be a common misconception. It is true that the Earth's orbit is slightly elliptical – that is, it doesn't go around the sun in a perfect circle. If you're from Canada, it might surprise you to find out that the Earth is closest to the sun (a point called "perihelion") in January and farthest from the sun ("aphelion") in July!



That brings us to the second part of your question, which provides an important clue about why the distance from the sun is not the reason for the seasons. Canada's winter months, December through March, are Australia's warmest ones. If the seasons were caused by the Earth being closer to the sun in the summer, you would expect both hemispheres to share the same seasons.

The key to understanding the seasons lies with one peculiar fact about the way the Earth orbits the sun: the axis that the Earth spins about (one turn equals one day) is actually tilted slightly – about 23.5 degrees. So the north and south poles don't point quite straight up and down. This means that as the Earth moves around the sun, different parts of the planet get different amounts of sunlight.

When the northern hemisphere is tilted toward the sun, it has longer days and receives a higher concentration of the sun's rays, which warms that part of the planet more than the southern hemisphere, which is tilted away, giving it shorter days and a lower intensity of sunlight. This is, as you might guess, summer in the northern hemisphere and winter in the southern hemisphere.

In between these extremes, there are points where the Earth is tilted neither toward nor away from the sun, and both hemispheres receive roughly equal amounts of sunlight and have equally long days and nights, giving us spring and autumn.

Now that you know that the tilt of the Earth causes the seasons, you might be wondering *why* the Earth is tilted at all. Well, we don't really know. Some theories suggest that a giant impact while Earth was still forming could have knocked the axis off-kilter.

What we do know is that the Earth's tilt varies with time. Over a cycle that lasts about 40,000 years, the tilt varies between 22.1 and 24.5 degrees. The tilt is also affected by the movement of large air masses or ice sheets, continental drift, and other things. When the tilt is larger, the seasons get more extreme: winters get colder and summers get hotter for both of the hemispheres. But 40,000 years is a really long time – so we won't notice the difference in our lifetimes!

– Stephanie Keating

Hey kids! Have a question? Send it to magazine@perimeterinstitute.ca.

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