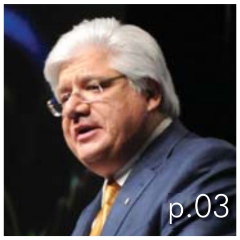
inside the perimeter

spring 2012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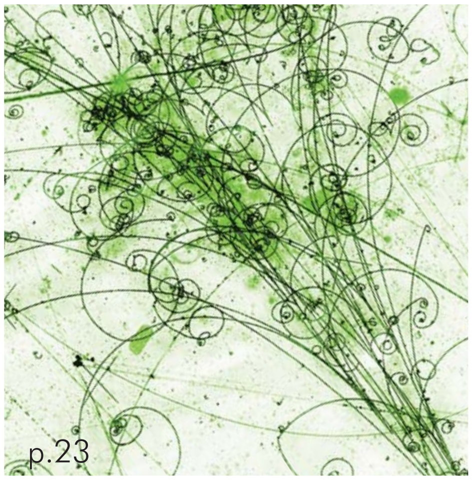
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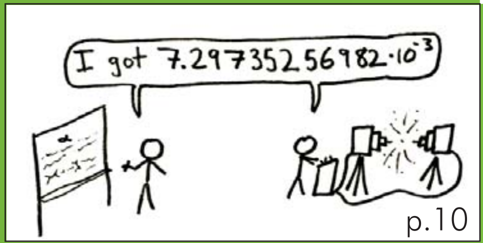

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PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

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Betting on Breakthroughs

The American Association for the Advancement of Science (AAAS) held its annual meeting in Vancouver from February 16 to 20, marking its first foray outside of the United States in 30 years. Perimeter played an active role in several talks, panels, and workshops. Perimeter's Director Neil Turok was one of the meeting's co-chairs and Founder and Board Chair Mike Lazaridis gave the plenary lecture on the importance of science and education. The text below is excerpted from that address.

In business, we understand that risk and reward go hand in hand. We celebrate the risk takers, the ones who stake it all on something nobody else sees. We need to do the same in science.

I have friends who are venture capitalists and they say that only one in ten investments really pay off on average.

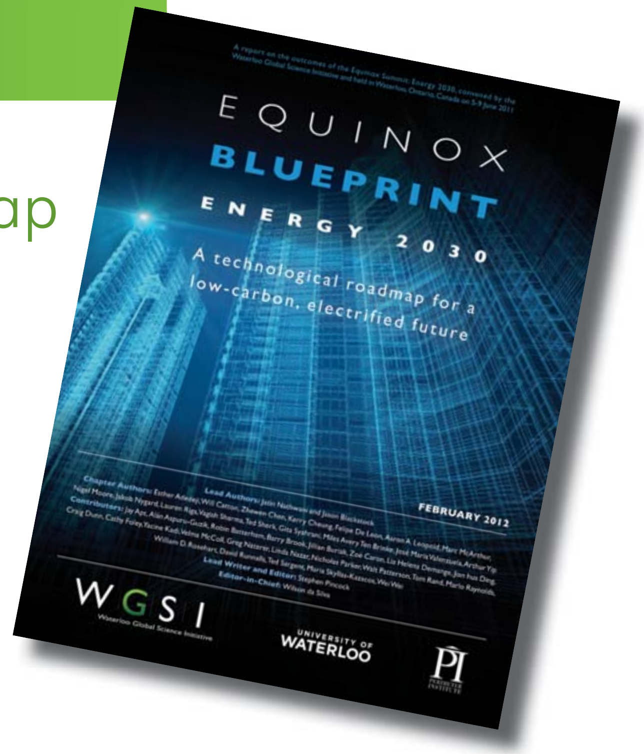
So it is with scientific research. The truly revolutionary stuff – that's being done by trailblazers. What we have to remember is that trailblazers get lost – that's just what happens in unexplored territory. Research hits dead ends. Promising avenues dry up. Models collapse. People are just plain wrong. Over 90 percent of the time, on the venture capitalism model, you'd be losing your bet.

But a few percent of the time, you'd be making breakthroughs. Because that's the other thing trailblazers do: they discover things that are utterly new.

We need a system for scientific research that allows researchers to get lost exploring. Maybe even encourages them to get lost exploring. Because you know what? It's worth it. It's the path to breakthroughs.

– Mike Lazaridis

A Sustainable Energy Roadmap



At the Annual Meeting of the American Association for the Advancement of Science in Vancouver, the Waterloo Global Science Initiative (WGSI) launched the Equinox Blueprint: Energy 2030, which outlines several science-driven pathways to a low carbon energy future.

WGSI is a non-profit partnership between Perimeter Institute and the University of Waterloo. Founded in 2009, these two organizations identified a unique opportunity to combine strengths and examine ways to catalyze the long-range, global thinking that can advance technological ideas and strategies for the future.

The Equinox Summit: Energy 2030, held at Perimeter Institute in June 2011, brought together an international group of pioneering scientists, policy advisors, entrepreneurs, and future leaders to focus on what science and technology can deliver to tackle our global energy challenges. In the months that followed, participants continued to collaborate and share ideas, culminating in the Equinox Blueprint.

The document lays out five potential pathways to providing power for an exploding global population, focusing on specific technologies for the generation, distribution, and storage of electricity. They include:

1. **Energy storage technologies** to enable renewable electricity generation
2. **Enhanced geothermal**, tapping into the Earth's heat using techniques we've already mastered
3. **Advanced nuclear reactors** with enhanced safety, utilizing inexhaustible resources (recycled uranium, thorium, and high level wastes) to close the fuel cycle
4. **Off-grid electrification** using flexible solar cells and self-sustaining micro-grids in developing regions
5. **Smart cities** and **electric transport** for a global future dominated by urban living

Moving forward, WGSI will continue to share the insights outlined in the Blueprint and work to develop implementation strategies with a diverse group of international participants and partners, driven mainly by the young leaders involved in the Equinox Summit. In addition, the WGSI website continues to offer resources to catalyze the global energy dialogue with over 15 hours of archived, high-definition video content from the Equinox Summit and Blueprint launch.

"The Equinox Summit: Energy 2030 was a very different sort of collaboration, emphasizing dialogue between science, policy, industry, and the leaders of 2030," said Professor Jatin Nathwani, the Equinox Summit's Scientific Advisor and Executive Director of the Waterloo Institute for Sustainable Energy (WISE) at the University of Waterloo. "The multinational, multigenerational group arrived at a fresh approach, stepping away from political stalemates towards a science-driven, solutions-based strategy. They offer pragmatic next steps for a global energy transition to take shape."

To find out more, please visit WGSI.org.

– RJ Taylor

Panellists at the Equinox Blueprint release. From left to right: Wilson da Silva, Jason Blackstock, Jatin Nathwani, and Lauren Riga

A New Era for Global Communication

Some of the most sophisticated communications technologies on earth will not be stuck on earth for much longer.

Ultra-secure quantum communications systems will soon likely go into orbit, according to a panel of world-leading experts – including Raymond Laflamme, Associate Faculty member at Perimeter Institute and Executive Director of the Institute for Quantum Computing (IQC) at the University of Waterloo – who explored the topic at the Annual Meeting of the American Association for the Advancement of Science (AAAS) on February 19 in Vancouver.

Laflamme was joined by Thomas Jennewein (IQC), Masahide Sasaki (National Institute of Information and Communications Technology, Japan), and Anton Zeilinger (University of Vienna).

Panellists from left to right: Anton Zeilinger, Thomas Jennewein, Masahide Sasaki, and Raymond Laflamme

In their session, titled "Quantum Information Technologies: A New Era for Global Communication," the researchers explored the various avenues each is investigating to carry out secure quantum communications in space via satellite.

"If we can build these quantum cryptography systems and make them global, we can transfer information in such a way that, if there's a hacker, we will know about it and protect against it," said Laflamme.

Holding a 3D model of a satellite that could create quantum communications links with ground stations on earth, Jennewein said "quantum satellites are the last missing link for the vision of having global quantum networks."

Jennewein envisions satellites used for both practical communications purposes and for fundamental experiments to test the predictions of quantum mechanics. "We could compare our results to theory – for example, does quantum entanglement follow expected behaviour or do we have something unknown going on?" Jennewein said.

Sasaki said quantum cryptography has already "crossed the valley of death" – that is, gone beyond speculation and been established as a viable technology – and said it now "needs to be installed into practical networks."

The security of important data, from medical records to finance, needs to be protected by quantum cryptography in the future, he added.

– Colin Hunter (IQC)

Mathematical Transformations in Africa

Are there reasons to be hopeful that Africa is poised to become a vibrant player in world science? Are there ways scientists and others in the developed world can play a role in making this happen? At a workshop given at the 2012 Annual Meeting for the American Association for the Advancement of Science (AAAS), a curious and enthusiastic audience learned that the answer to both questions is an emphatic yes.

The African Institute for Mathematical Sciences – Next Einstein Initiative (AIMS-NEI) is devoted to creating a pan-African network of centres offering advanced training in mathematics to exceptional African graduates. Workshop attendees learned how AIMS-NEI is working to rapidly and cost-effectively expand Africa's scientific capacity, what distinguishes it from other development efforts, and how they might get involved.

Six presenters, including AIMS-NEI Executive Director Thierry Zomahoun and AIMS Founder Neil Turok, shared their varied experiences and perspectives. "AIMS transformed the way I view teaching," explained Douw Steyn, Professor at the University of British Columbia and a past lecturer at AIMS-South Africa. "You need to be prepared to commit to the students and immerse yourself in the material at all times."

AIMS alumna Dimby Ramarimbahoaka shared her journey from Madagascar to AIMS and now to PhD studies at the University of Calgary. "My mom asked me, 'Why do you want to study math in South Africa?'" she recalled. "I told her that AIMS was a great opportunity. AIMS opened up a whole new world for me. My mom still can't believe I am studying for my PhD!"

AIMS' innovative curriculum emphasizes problem-solving skills and broad training in mathematical sciences, providing an excellent base for advanced, doctoral-level training. Of the 360 graduates to date, 95% have gone onto further studies, the majority in Africa.

As AIMS alumnus Felix Oghenekohw told the audience, beaming, "Watch out – Africa is coming!"

– Morgan Pascal and Natasha Waxman

Editor's Note: For more information on AIMS or to learn about opportunities to get involved, contact the AIMS-NEI Secretariat at info@nexteinstein.org.

Kudos to ...

Director **Neil Turok** has been selected to deliver the 2012 Massey Lectures, joining a list of distinguished thinkers that includes Martin Luther King Jr., John Kenneth Galbraith, and Margaret Atwood. In October, he will present five separate lectures in locations across Canada, which will then air nationally on CBC Radio's *Ideas* program in November.

Romina Abachi of Markham, Ontario received the 2011 Luke Santi Memorial Award, presented annually by Perimeter to a Canadian high school student. Abachi has won numerous academic awards and had the top marks at her high school in the national Fermat and Fryer math contests; co-founded her high school's Nature Studies Club; and won the Identify N Impact Award for her work as co-founder of the Youth Sarcoma Initiative, which raises funds for Toronto's SickKids hospital. Abachi is now studying in the Faculty of Arts and Science at the University of Toronto.

Photo credit: Colin Hunter

Associate Faculty member **Raymond Laflamme** has been named a Fellow of both the American Association for the Advancement of Science (AAAS) and the American Physical Society (APS) for his pioneering contributions to the field of quantum information processing, and for his leadership in founding the Institute for Quantum Computing.

Senior Research Affiliate **John Moffat** has been awarded a John Templeton Foundation (JTF) grant of $222,000 over three years to support his research into promising alternative models in physics.

Photo credit: Scott Norsworthy

Perimeter's media wall, sponsored and created by global visual technologies firm **Christie Digital**, has won a major industry award for innovative use of digital signage. The silver Apex Award in the "Education & Healthcare" category was announced at the annual Digital Signage Expo® in Las Vegas in early March.

Ashvin Vishwanath Named Distinguished Research Chair

Perimeter is pleased to announce the appointment of Ashvin Vishwanath as a Distinguished Research Chair (DRC). DRCs come to Perimeter for extended periods each year to do research; the program enables them to be part of the Institute's scientific community while retaining permanent positions at their home institutions. Vishwanath's appointment brings the total number of DRCs to 28.

Vishwanath is an Associate Professor in the Department of Physics at the University of California, Berkeley. His primary field of research is condensed matter theory, with a focus on magnetism, superconductivity, and other correlated quantum phenomena in solids and cold atomic gases. He is particularly interested in novel phenomena, such as topological phases of matter, non-fermi liquids, and quantum spin liquids. Vishwanath and collaborators showed that a novel phase transition can appear in a quantum magnet, which was long believed to be impossible. He has recently been interested in realizing Majorana and Weyl fermions in solids and in using concepts from quantum information, such as entanglement entropy, to characterize novel phases of matter.

Perimeter's newest DRC already has many ties to the Institute's researchers. His long-time collaborators include fellow DRCs Subir Sachdev and Senthil Todadri, with whom he's excited to renew collaborations. He has also worked with DRC Ganapathy Baskaran and Xiao-Gang Wen, the inaugural BMO Financial Group Isaac Newton Chair, during his years as a student and postdoctoral researcher.

On joining Perimeter's scientific community, Vishwanath said, "I am honoured and also very pleased to have the opportunity to visit Perimeter on a regular basis and interact with its many excellent faculty, postdocs, and other DRCs. Perimeter's focus on high impact research that cuts across traditional boundaries strongly resonates with me. In addition to leading researchers in condensed matter theory, having the opportunity to interact with researchers in other related areas is a strong draw."

Among his honours, Vishwanath has received a Sloan Research Fellowship (2004), the CAREER Award of the National Science Foundation (2007), the Outstanding Young Scientist Award of the American Chapter of Indian Physicists (2010), and the Simons Foundation Sabbatical Fellowship (2012).

– Mike Brown

Arthur B. McDonald Joins Board of Directors

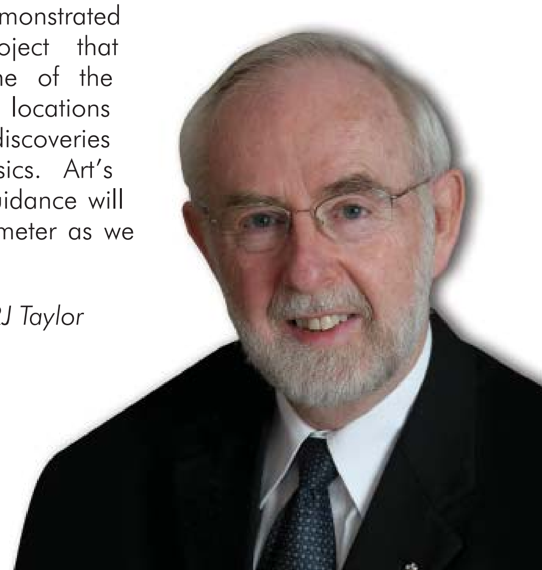
For over 20 years, Arthur B. McDonald has been the Director of the Sudbury Neutrino Observatory (SNO), one of Canada's most ambitious physics experiments. Working in the observatory, located two kilometres below the earth's surface in the Creighton nickel mine, he led a team of international collaborators in discovering that elementary sub-atomic particles, called neutrinos, change from one type to another while traveling from the sun to the earth. The SNO experiment also confirmed that neutrinos have a tiny but nonzero mass. Now, Perimeter is pleased to welcome McDonald to its Board of Directors.

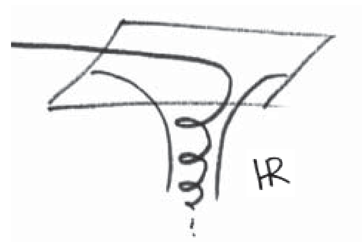
McDonald holds the Gordon and Patricia Gray Chair in Particle Astrophysics at Queen's University. He has received numerous awards for his research, including the 2011 Henry Marshall Tory Medal from the Royal Society of Canada and the 2007 Benjamin Franklin Medal in Physics, alongside researcher Yoji Totsuka. He was named an Officer of the Order of Canada in 2007.

McDonald currently works on the SNO+ experiment at the international SNOLAB, researching an accurate measurement of neutrino mass and helping to explain the processes that generate matter in the early universe. He is also involved with DEAP-3600, a new international experiment searching for dark matter particles.

"We are deeply honoured to have Art McDonald joining Perimeter's Board of Directors," said Neil Turok, Perimeter's Director. "He is both a world-renowned scientist and a true Canadian pioneer, having demonstrated with the SNO project that Canada can be one of the world's pre-eminent locations for groundbreaking discoveries in particle astrophysics. Art's expertise and wise guidance will be invaluable to Perimeter as we continue to grow."

– RJ Taylor





A Chat with Avery Broderick

Avery Broderick joined Perimeter in September 2011 as a faculty member in theoretical astrophysics with a joint appointment at the University of Waterloo. Here, he tells us a little about himself and one of his current research projects – taking the first image of the event horizon of a black hole.

Inside The Perimeter: How are you finding Perimeter?

Avery: Good – except that my family has been sick since we got here!

Inside: Waterloo, land of plague?

Avery: No, it's just that I have little kids – two sets of twins; two nine-year-olds and two four-year-olds. And they all just started new schools – jumped into new germ pools.

Inside: Well, apart from having been ill for four months, are you settling in?

Avery: Oh, yes – Perimeter is fantastic! There's unparalleled support and research freedom. But for me the most attractive part is that Perimeter's the best – or one of the best – places to talk to people about theories beyond general relativity. There are fantastic string theory and quantum gravity groups – and to have both groups is very rare. I'm an astrophysicist, but I really do think of myself as a physicist, not an astronomer. What really motivates me is the opportunity to test general relativity.

Inside: And testing general relativity got you to black holes?

Avery: Absolutely. In black holes, we have a great natural experiment – it's almost as if they're designed to put general relativity to the test. They have these twin virtues, of being extraordinarily simple solutions to Einstein's equations and of being the place where Einstein's predictions about gravity differ most sharply from Newtonian ideas about gravity.

Inside: I understand you're involved in taking the first-ever picture of the event horizon of a black hole.

Avery: Yes, I'm working with the Event Horizon Telescope, coordinated by Shep Doeleman at MIT Haystack. We're working on an image of the super-massive black hole Sagittarius A*, which is the hole at the hub of the Milky Way galaxy.

It is now possible to make a picture of black holes on scales where you can resolve the event horizon. It's extraordinary – the horizon of Sagittarius A* has an apparent size of about 55 microarcseconds: a microarcsecond is a third of a billionth of a degree. That's 450 times smaller than anything that can be resolved by the Keck telescope. That's 2300 times smaller than can be resolved by the Hubble. That's the size of a poppy seed seen from across the nation.

Inside: That *is* extraordinary. What do you hope to learn from such an image?

Avery: For starters, whether black holes exist. I say this to reporters and they're always shocked. They say, "What do you mean 'do black holes exist?'!"

Inside: They say, "You people have been telling us for years that these things exist! We took it on faith!"

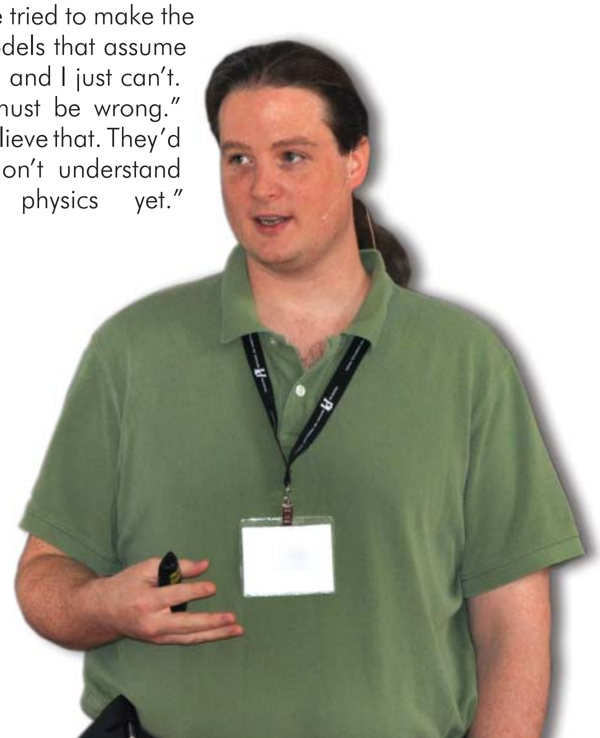
Avery: Exactly. It's an article of faith – it had to be, because event horizons are the defining feature of black holes and there was no way to detect them directly. But we're now at a point where we can, and so we can ask the question afresh.

So, I define a black hole as anything that has a horizon. I don't care if it's a GR [general relativity] black hole. Are there things with compact horizons? I don't mean the cosmological horizon out there, but rather something that's small, that you fall through, and then find yourself disconnected from the outer universe. If we can image that horizon, we'll be able to answer that question: do black holes exist?

Inside: Are we to the point where we can begin to test whether it's a GR black hole or some other kind of black hole? Where we can really use black holes, as you want to, as a test of general relativity?

Avery: We're getting close. This is very difficult. Black holes are, of course, black – nothing comes out of them – but they are also the brightest objects in the universe, because the stuff falling into them shines, and it shines a lot. By the time an object crosses the event horizon, it's given up a good fraction of its rest mass as radiation. So what we've actually studied is not the black part, but the shining part.

We don't understand the physics of the falling stuff, of the accretion disks. We have some good stories and we make some physically motivated models, but there are still many, many questions. Suppose I came out and I said, "I've tried and I've tried and I've tried to make the data fit these models that assume general relativity, and I just can't. Therefore, GR must be wrong." No one would believe that. They'd say, "You just don't understand the accretion physics yet."



But we have begun to show that there are some robust signatures that distinguish a GR black hole from other kinds of black holes. This is where I come in. I take various models, make pictures of them, and predict what we ought to see. And we look for robust signatures of the interesting physics we're after.

One of these signatures is the very clear shadow or silhouette cast by the event horizon on the surface of the accretion disk. That silhouette's shape is indicative of the gravitational lensing around the black hole. If GR is wrong, then the way the lensing works would be different and so that shape will be very different. We'll get to the point in the very near future where we could say, "There's something very wrong here."

Inside: You say that as if that were the outcome you were expecting.

Avery: No, no, no … we're coming to the point where we'd be able to detect differences between the data and the model. Finding out that general relativity is wrong is not the outcome we're expecting – but secretly it is the outcome we're hoping for.

Inside: Well, of course it is. All physicists want to be wrong. Better yet, it would be good if Einstein were wrong.

Avery: That's right! I had a correspondence with my uncle, who is not a scientist but follows this in the popular press, and he asked me if I was open to the possibility that some of these tried and true theories, like general relativity, are wrong. I couldn't stop laughing. Uncle, that's my dream!

– Interview by Erin Bow

Hunting for New Forces

Electromagnetism, strong, weak, and gravity: these are the four forces. But are they the only ones? If there were other forces – forces that interacted with us only weakly, if at all – how would we know?

"There easily could be other forces in nature, and we wouldn't have found them," says Philip Schuster, a new Perimeter faculty member who specializes in particle physics. "They might act on other kinds of matter, like dark matter, but they'd have a tough time coupling to us."

Nonetheless, there are few particular ways in which these forces could be detected. Schuster and fellow Perimeter Faculty member Natalia Toro envisioned a particle physics experiment in which the carrier of such a new force – it would be something like a photon, but with mass – could be spotted in the lab. An article on their research was recently published in *Physical Review Letters*.

The key is that the new force carrier could mix with the photon. "Quantum mechanically, the new boson could convert to a photon – or vice versa," Toro explains. "Then, the new force could couple to electric charge, at some small fraction of the [electromagnetic] strength." This would allow the new force to affect ordinary matter and this effect could be detected with particle physics techniques.

"A few years ago, physicists realized that there could well be new forces at energy ranges we've already explored – and we would have missed them, because the processes are so rare," says Schuster. "But we also realized that we have equipment in laboratories all over the world where one could do a one-month experiment and be orders of magnitude more sensitive to new forces."

Schuster and Toro worked closely with theorists James Bjorken and Rouven Essig of the SLAC National Accelerator Laboratory and experimentalist Bogdan Wojtsekhowski of the Thomas

APEX spokespeople Bogdan Wojtsekhowski, Philip Schuster, Natalia Toro, and Rouven Essig

Jefferson National Accelerator Facility in Virginia to design an experiment to run at Jefferson Lab, which has the highest intensity electron beam in the world. The experiment, dubbed APEX, involves more than 60 scientists and engineers, and has just completed a test run.

Jefferson Lab was chosen not only because of the intensity of the beam, but because the mass range it can explore is both previously unexplored and particularly interesting.

There are places where we've already checked for new forces, explains Toro, sketching in the air a graph that resembles a large hill with a sagging cloud cover above it. The graph shows the coupling strength of the new force carrier on one axis and carrier's mass on the other. The open, unexplored space between the hill and the cloud is the same space that the Jefferson Lab beam – and other beams around the world – can easily reach.

(continued on page 10)

This clear sky space also happens to be the space in which something interesting might well be happening. There's an anomaly in the magnetic moment of the muon – the g-2 anomaly – that could be explained by a new force carrier in this mass range with a very weak coupling. There are astrophysical anomalies that could be explained if dark matter was affected by the new force – and there are some models based on these anomalies that predict that the force carrier was in this mass range. Finally, the coupling strength in this space is about one part per thousand – a region interesting to theorists because it's a loop factor, a radiative correction in quantum field theory.

It's a lucky coincidence. "I definitely remember an afternoon that was full of lots of 'holy cow!' moments, when we realized these things lined up," says Schuster.

APEX's successful test run proved the feasibility of looking for new force carriers using existing accelerators and also explored a piece of the parameter space – taking a narrow swath out of the clear sky. "After the first hour of running, we were into new territory," says Toro. "It's a beautifully sensitive experiment."

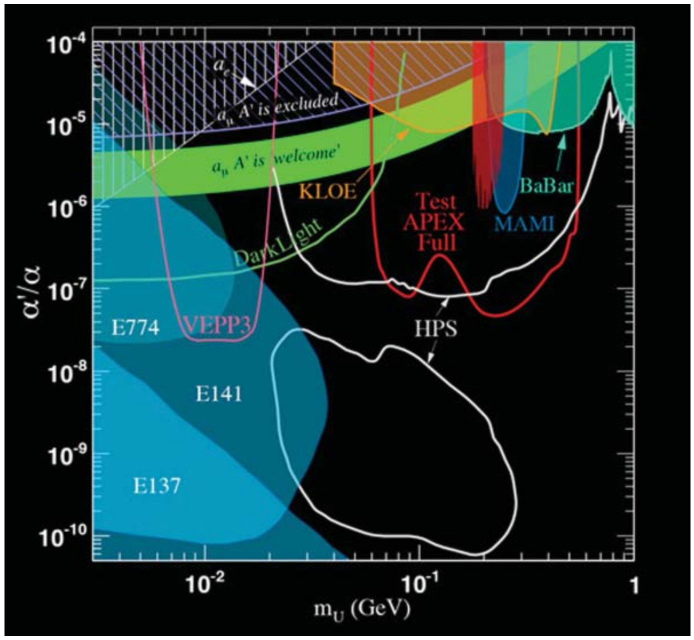
APEX is preparing for a full run.

– Erin Bow

APEX is one of several experiments hunting for the carrier of a new force, a hypothetical boson dubbed A'. This graph shows the range of the parameter space covered by these proposed experiments. The solid red is the slice of parameter space covered by APEX's test run. The full APEX experiment will search the entire area above the red curve.

Further exploration:

- An Electron Fixed Target Experiment to Search for a New Vector Boson A' Decaying to e+e- arxiv:1001.2557
- Search for a new gauge boson in the A' Experiment (APEX) arXiv:1108.2750
- Physicists hunt for dark forces, Eric Hand, Nature 484:7392 03 April 2012



In Conversation: the Theory/Experiment Divide

Inside the Perimeter: How did you two make the leap from looking at data to designing experiments? I think it's rare for theorists to do that.

Philip Schuster: It's rare these days, but it's worth noting that it hasn't always been rare.

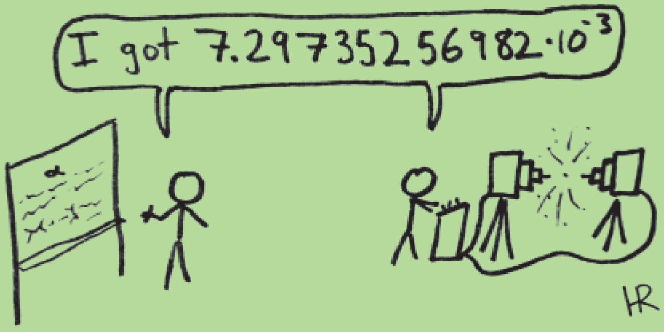
Natalia Toro: Dirac did experiments. One of our colleagues, James Bjorken, who developed some of the theoretical underpinnings for QCD in the late 1960s and '70s, also did experiments. So, historically, it's not unusual.

Philip: There's a reason for the shift. It used to be that the experiments that were sensitive enough to find new physics were not terribly complicated. You could pull together 20 people, make a proposal, have it reviewed in a month or two, get funding, build it in a month or two, and then take the data in a matter of weeks. In total, it might be a six-month to a one-year project. That's how it used to be for many experiments in the 1940s, '50s, and '60s. But at some point, the equipment became sufficiently sophisticated, sufficiently expensive, sufficiently hard to build, that this model didn't work.

Natalia: It now takes highly specialized expertise and many years to pull together a high energy physics experiment. Suddenly, we're talking about experiments that take ten years, start to finish. Some of the LHC experiments are 30-year experiments. That's too big a chunk of time to spend developing experiments, unless developing experiments is your profession.

Philip: So, that's why theory and experiment divided. But there are many areas – and new force carriers are one – where experiments can still be run on the old time scales. And there, theorists can be more intimately involved from start to finish and can contribute something in a finite time.

Natalia: So it's not shocking that theorists should be involved in experiments. We're not matter and antimatter. We don't need to be kept apart.



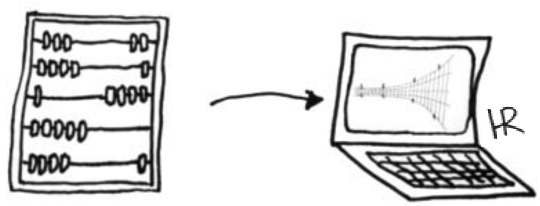
Beyond the Blackboard

Every handyman knows you need the right tools for the job and the maxim holds just as true when the job is solving the Einstein field equations for binary black holes.

As Perimeter's Research Technologies Group Lead, Erik Schnetter is charged with bringing the worlds of IT and research together to develop a research technology program that provides residents with the right tools for scientific computing and collaboration.

He's uniquely qualified to do so, with research experience spanning both computational physics and nuts-and-bolts software development. Before coming to Perimeter, Schnetter was Assistant Research Professor at the Center for Computation & Technology (CCT) at Louisiana State University and a member of the widely respected Albert Einstein Institute-CCT Binary Black Hole collaboration. He has co-developed leading software for solving the Einstein equations and a popular toolkit used with the Cactus computing platform.

"When I came to Perimeter, I wanted to create a uniform environment," says Schnetter. To that end, he has helped create a scientific computing environment (SCE) that launched in late 2011. Researchers can now access virtual or dedicated server resources by simply sending an email. The flexibility and responsiveness of the system are key benefits, since research needs for computational resources can arise quickly.



In addition to making seven high-powered Linux servers available, Schnetter has developed standardized server environments throughout the Institute, which are even available for individual researchers' workstations. By giving everyone access to the same set of tools, it makes collaboration easier.

With the arrival of new faculty engaged in computationally-intensive work – such as Avery Broderick, Guifre Vidal, and Itay Yavin – Schnetter and the IT team are also in the final stages of implementing a high performance computing (HPC) system at Perimeter. It will serve as a bridge for work that doesn't require large external HPC resources, such as SHARCNET, yet is too large for a single workstation – a smaller, more flexible system that they can directly control for quicker feedback.

"If every time you make a mistake, you have to wait a week before you get feedback, you don't make much progress in a month. Therefore, we need a set of systems that are progressively more powerful and progressively less flexible, and this in-house HPC fills that need," explains Schnetter. "If a job runs for two weeks, then it doesn't matter whether it gives the answer 10 minutes later or not, but if you're sitting in front of your computer and waiting for a result, then 10 minutes make all the difference."

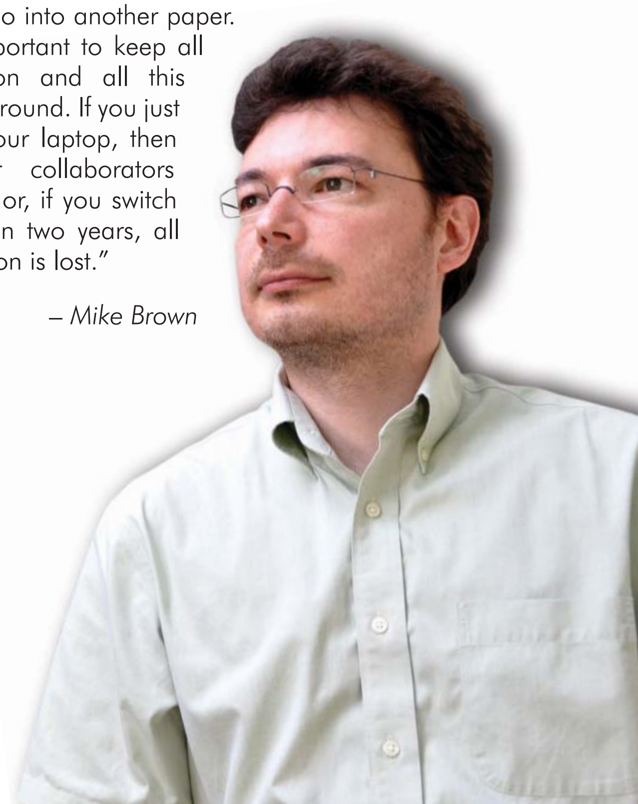
Schnetter recently held a well-attended one-day workshop, Computational Methods at Perimeter, on February 9, to explain some of the new tools and initiate fruitful discussions among those using computational methods in their research. "Even if the physics is very different, the computational methods are often very similar – even between groups that may not usually work together," says Schnetter.

Schnetter is also developing tools for researchers who don't do computational work. "Research technologies are much larger than just computational physics or computational science," he says. "There are also collaboration aspects of it."

As such, Schnetter is working on a project to facilitate long-distance research collaborations, called Spaces, which aims to bring together all the tools researchers already use – such as Dropbox, Google Docs, wikis, mailing lists, subversion repositories, etc. – into one convenient space. It will allow researchers to visit a Perimeter-hosted website (spaces.perimeterinstitute.ca) with reliable system administration and, at the click of a button, create a new space that they can share with collaborators. All of these tools can be accessed through a single sign-on and each individual space is password protected.

Spaces also provides a way of keeping track of ideas and results that could otherwise be lost. "Often, when you write a paper, there is a cut-off of the finished results that get into the paper – but you had many interesting discussions and ideas that didn't quite work out, which are still valuable," says Schnetter. "Maybe they should go into another paper. It's really important to keep all this discussion and all this information around. If you just have it on your laptop, then maybe your collaborators don't have it or, if you switch your laptop in two years, all this information is lost."

– Mike Brown



Reconsidering Spacetime

Look around you. Do you see space?

Lee Smolin answers by quoting Diego Rivera: "I don't see space. I see things."

This is, he says, a step in the right direction. But we know from relativity theory that it's not true either. We've had to give up the common sense notion of space, the one that lets us say, "That bell tower is four blocks east, three blocks south, and 60 feet tall." We've replaced it with spacetime: if we look at the clock in the bell tower, for instance, what we see is not the clock, not an object in space, but the clock as it appeared when the photons now entering our eyes left the clock face five blocks away – the clock as an object in spacetime.

But what – and how – do we see? We don't see spacetime at all; we see momentum, energy. Specifically, we detect photons coming at us, from various directions, with various energies. Einstein has taught us to infer the geometry of spacetime by using those photons to exchange signals, but the measurements we make are fundamentally measurements of momentum and proper time.

So, momentum space is what we see and spacetime is inferred.

This leads to some new questions. Do we all infer the same spacetime? Do we infer the same spacetime when we observe the world using quanta with different energies? In special relativity, the answer is yes: spacetime is energy-independent and invariant, and locality is absolute. The fundamental reason for this is that translations are generated via the laws of conservation of energy and momentum. But what if the conservation laws are non-linear? What if they are distorted by the curvature of momentum space?

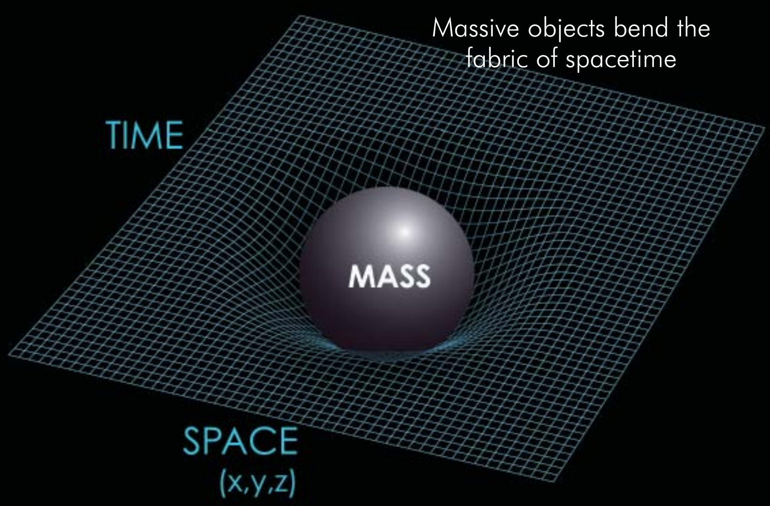
As far back as 1938, the German physicist Max Born postulated that spacetime and momentum space should be interchangeable – this expresses a feature of quantum mechanics that can be taken as a principle and is now known as "Born reciprocity." Taking this principle outside of quantum mechanics leads to a surprise: if it's true, then it should be possible to curve momentum space in the same way spacetime can be curved. That's where Perimeter enters the picture.

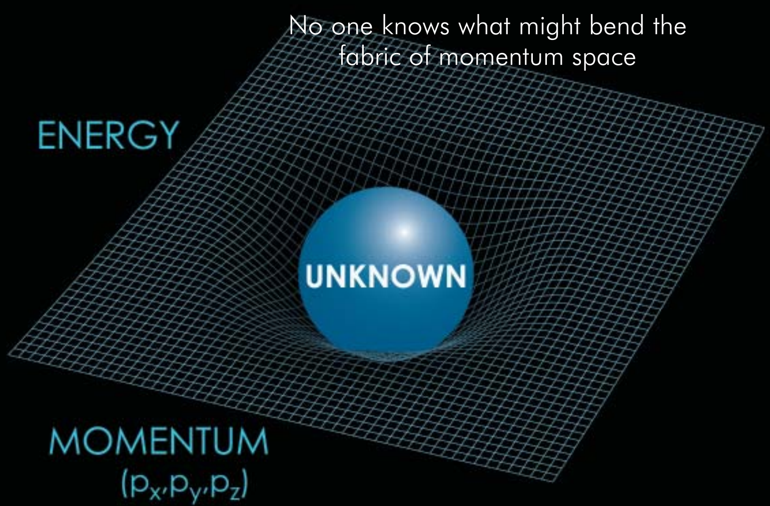
Laurent Freidel and Lee Smolin, both faculty members at the Perimeter Institute, have been collaborating with Giovanni Amelino-Camelia at Sapienza University of Rome in Italy and Jerzy Kowalski-Glikman at the University of Wroclaw in Poland. The quartet has been investigating the effects of a curvature of momentum space.

What they discovered is shocking: the curvature of momentum space would indeed distort the conservation laws. Special relativity would say that any two photons, regardless of their energies, would travel at exactly the speed of light. In a curved momentum space, though, that's no longer true: high-energy photons would move differently than low-energy ones. Spacetime – which is inferred, remember, by measuring such photons – would no longer be absolute. Observers would no longer agree on the location and timing of distant events, only

Fabrics of Reality

People studying general relativity often picture spacetime as a stretchy fabric. It has four dimensions – three spatial dimensions and a single dimension in time. Momentum space is similar, but it has three momentum dimensions and a single energy dimension.





local ones – a new principle called relative locality. Special relativity, then, would be reduced to a low-energy approximation – at high energies, over large distances, anomalies would start to appear.

All approaches to quantum gravity, in their own very different ways, agree that empty space is not so empty after all. Whether it's the foamy froth of particles conjured by string theory or the choppy sea of quantized lengths proposed by loop quantum gravity, physicists are beginning to picture spacetime as anything but the smooth abstraction governed by the universal and implacable speed of light.

By codifying one way in which spacetime might be reconsidered, the new principle of relative locality gives physicists new places to start and new lenses to look through as they sort through and develop competing quantum gravity theories.

– Erin Bow

Relative Locality: The Birth of an Idea

Relative locality describes ways in which special relativity might be modified while keeping the basic principle that there is no absolute meaning to being at rest so that velocity is only meaningful relative to an observer. Keeping this principle of relativity, but allowing modifications in its expression in special relativity, was proposed a bit more than a decade ago by Giovanni Amelino-Camelia, and also independently by Lee Smolin, working in collaboration with Joao Magueijo. These ideas are called doubly or deformed special relativity. The idea was that modifications of special relativity would be consequences of the fact that spacetime is really quantum mechanical – that is, as a consequence of quantum gravity.

However, as these ideas were developed, it became clear that there was an apparent conflict with the principle of locality. Apparent paradoxes were pointed out by Bill Unruh (now a Distinguished Research Chair at PI) and a colleague and by Sabine Hossenfelder (a former PI postdoc now on the faculty of NORDITA in Stockholm.)

In September of 2010, Amelino-Camelia and Jurek Kowalski-Glikman came to PI for several weeks to work with Freidel and Smolin on finding a way out of these paradoxes. Things looked very dark for almost the whole of their visits and it seemed that the ideas of deforming special relativity would have to be given up. Each of the four had an intuition that they had tried hard to express that there was a way to make sense of all this, but nothing they had tried or proposed had completely gelled.

The four had a last lunch together, during which they had a breakthrough insight: the paradoxes were paradoxical only because people were making some unwarranted assumptions. Namely, it had been assumed that all observers see objects live and move in the same spacetime and that objects seen with different wavelengths of light live in the same spacetime. If one drops those assumptions, then a consistent picture of nature emerges immediately. One is free to do this because the picture of events in spacetime is inferred from more fundamental measurements which are in momentum space. Thus, over lunch in the Black Hole Bistro, a new principle was born: the principle of relative locality.

Ignite Waterloo Coming To Perimeter

On June 12, Perimeter Institute will play host to Ignite Waterloo 9, an event that seeks to capture the best of Waterloo Region's geek culture with a series of five-minute speed presentations on a wide range of topics. Since the organization's first event in November 2009, more than 100 speakers have presented on topics they're passionate about.

At Ignite Waterloo 8 on February 28, contributors included two of Perimeter's own, Faculty member Robert Spekkens and Arts & Culture Consultant Peter Hatch.

For more information about Ignite Waterloo, including information on speaking at the upcoming Perimeter-hosted event, visit www.ignitewaterloo.ca or contact Peter Hatch at phatch@perimeterinstitute.ca.

Faculty member Robert Spekkens' talk at Ignite Waterloo 8, "A Green That is Greener Than Any Green You've Ever Seen," addressed the physics and physiology of colour vision.

Tensor Networks for Quantum Field Theories

A tightly-focused two-day workshop entitled "Tensor Networks for Quantum Field Theories" brought some of the world-best practitioners of tensor networks to Perimeter in October 2011.

The purpose of the gathering was to discuss one of the most significant developments in this field: the recent extension of the tensor network formalism to quantum field theories. Many of the leading figures behind this extension – including Jutho Haegeman of the University of Ghent, Tobias Osborne of the University of Hannover, and Frank Verstraete of the University of Vienna – gave invited talks. These were complemented with talks on the use of tensor networks on the lattice by Philippe Corboz of ETH Zurich, Zheng-Cheng Gu of KITP, and Glen Evenbly of Caltech. The public talks were followed by four closed-door, marathon discussion sessions.

One goal of the workshop was to introduce Perimeter residents and other local researchers to a promising non-perturbative approach to quantum field theory and, to that end, Perimeter's own Guifre Vidal gave two introductory lectures to the subject. Interest was broad: condensed matter researchers, quantum information researchers, and string theorists – including students, postdocs, and faculty – attended both the introductory lectures and the talks by distinguished visitors. Most of the talks found the Sky Room filled to capacity and there have been many interesting discussions among PI faculty in the months since the workshop closed, and there is talk of making this an annual event.

– Guifre Vidal and Frank Verstraete

Effective Field Theory and Gravitational Physics

The first observations of gravitational waves will be the first steps towards exploring the cosmos with a completely new set of eyes. Gravitational wave detectors, such as LIGO, VIRGO, or the planned LISA, will observe astrophysical sources whose evolution involves a number of widely separated length scales. As we take this first data, it's vital to build signal templates that encompass the physics accurately. Therefore, we urgently need a self-consistent methodology which accounts for effects at all these different scales. Effective field theory (EFT) has begun to provide us with one such tool in the construction of these templates.

In late November 2011, Perimeter Institute hosted a workshop on applications of EFT techniques to classical general relativity. The organizers included the two co-founders of the field, Walter Goldberger (Yale) and Ira Rothstein (Carnegie-Mellon), as well as Perimeter researchers Rob Myers and Michael Smolkin. The meeting brought together all of the researchers using the EFT approach, as well as renowned scientists using more traditional methods to address the theory of gravity – the first such gathering.

EFT has its roots in quantum field theory and it was a remarkable insight to see that these techniques can be fruitfully applied to a variety of problems in classical gravity. Gravitational wave science provided the original motivation and has so far been the primary focus of these applications. To date, EFT has been used to derive new results for calculating gravitational potentials and multipole moments for binary systems at third order in the post-Newtonian approximation. It has also been utilized to calculate corrections to leading order radiation reaction forces in general relativity, as well as classical electrodynamics. Such higher order results will be used in generating gravitational wave templates to extract parameters such as masses and spins of binary constituents at the rapidly developing detectors.

With these successes has come the realization that EFT can be applied to a much broader variety of classical problems in theoretical physics. In gravity, the EFT approach has also been used to study the thermodynamic properties of Kaluza-Klein black holes and it is now being applied to better understand cosmological inflation. Similar studies have also begun to better understand hydrodynamic behaviour of fluids.

The workshop included talks by both senior and junior researchers shedding light on these new developments, as well as theoretical challenges. The main focus of the meeting was to exchange ideas and try to formulate the right questions within the EFT approach to classical theories of gravity, with particular emphasis on gravitational wave production. The end result was a dynamic, timely, and stimulating meeting that brought to the attention of a select group of theorists a wide spectrum of tools and deep insights of the quantum field theory realm.

– Walter Goldberger, Rob Myers, Ira Rothstein, and Michael Smolkin

Emergence and Effective Field Theory

For generations, physicists have been trying to find the smallest possible elements of nature and understand the rules that govern them. Emergence is a step away from that road: emergent phenomena are the properties of a system that do not belong to the fundamental parts. Phonons – "particles" of sound inside a crystal – are the classic example. The study of emergence has been a fruitful approach to generating new insights and recently there has been tremendous progress in describing emergent phenomena using effective field theories (EFTs).

Still, the effort to extend recent successes into new fields has led to conceptual challenges. The "Emergence and Effective Field Theory" workshop brought together physicists from a wide variety of fields, along with philosophers of physics – about 60 researchers in all – to respond to these challenges. The conference was co-sponsored by the Rotman Institute of Philosophy at the University of Western Ontario, which supports philosophical work that is engaged with science.

Leo Kadanoff, whose work has shaped the modern study of emergence, kicked off the conference by describing stable synchronization between two pendulum clocks, noted by Christiaan Huygens in the 1660s, as an example of an emergent phenomenon. Several of the talks discussed condensed matter theory, the original context in which EFTs were developed. Other talks covered topics as diverse as thermal behaviour in quantum systems, decoherence, and emergence of spacetime symmetries.

On the experimental side, Bill Unruh and Silke Weinfurtner discussed using surface waves in laminar flow designed to study Hawking radiation, treated as a universal phenomena manifest in a variety of situations. One of the highlights of the conference was Yves Couder's fascinating experimental studies of an oil droplet bouncing across a surface. The motion of the oil droplet, which depends on the surface waves produced by previous bounces, displays surprising quantum behaviours.

Many of the philosophical talks focused on developing accounts of laws, explanations, and representations that make room for emergence and EFT. We've long thought that phenomenon can only be "explained" if they can be deduced from a description of the system at a fundamental level – a conception of explanation that is challenged by emergent phenomena. Bob Batterman, in particular, emphasized that giving an account of emergent phenomena forces one to rethink basic questions regarding how scientific theories represent the world.

– Bob Batterman, Leo Kadanoff, Chris Smeenk, and Lee Smolin

TO VIEW RECORDINGS OF ALL CONFERENCE TALKS, VISIT WWW.PIRSA.ORG.

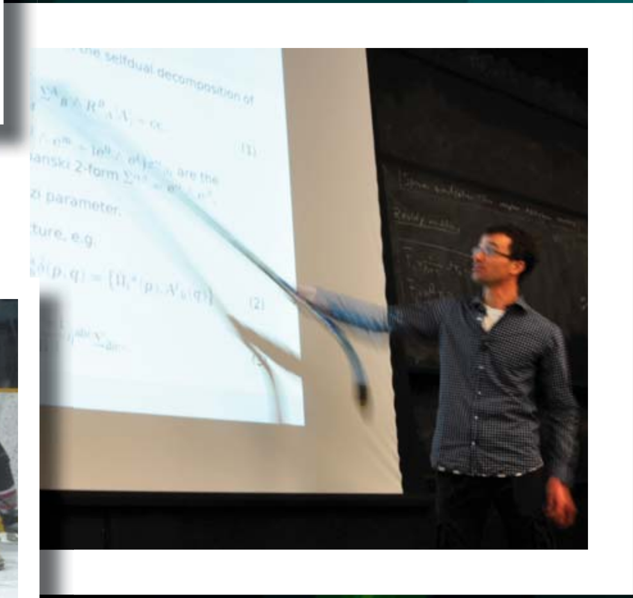
Colleen Brickman (right), PI's longest-serving employee, bid a fond farewell to her colleagues. The Bistro, as is their wont, commemorated the occasion with an impossibly delicious dessert.

Jordi Savall, master of the viola da gamba, in concert

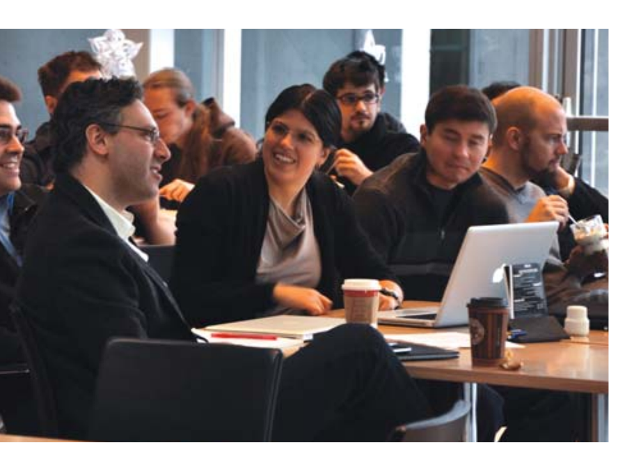
What better way to celebrate Pi Day than a pie-baking contest? Here the judges are hard at work picking a winner.

The Outreach team provided high school teachers an excuse to play with marbles during this activity as part of its Particle Physics Day.

Physics in action: PI staff do some experimental tests of their notions of force and motion at their Monday morning hockey game.



Off the ice, Wolfgang Wieland demonstrates the versatility of the hockey stick in his seminar, "Spinor Quantisation for Complex Ashtekar Variables"



PI researchers during the announcement of CERN's latest findings

There must be something in the coffee! The last few months have seen a number of additions to the PI family, including:

Rafael Ben-Dayan

Mason Michael Leddy

Addison Marie Schnurr

Dorothy and Elizabeth Uniac

Dominik Pregelj

Juyah Afshordi

William Edward Baltrusaitis

Alice Elizabeth Fraser

DRC Subir Sachdev gives a talk during a recent visit

This year's PSI class contains students from six continents. Briefly, S. Man, who draws his ancestral lineage to the seventh, Antarctica, joined their ranks. He left during the spring term.

3D Tensor Field Theory: Renormalization and One-loop $ß$-functions, J. Ben Geloun, D. O. Samary, arXiv:1201.0176

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Constraining Extra Neutral Gauge Bosons with Atomic Parity Violation Measurements, R. Diener, arXiv:1111.4566

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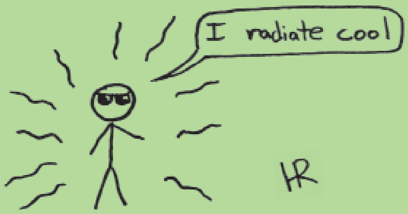

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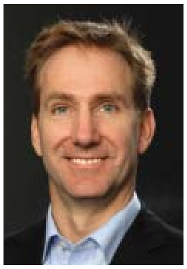
Can Studying Science Make Me A Better Entrepreneur?



A bright red stack of boxes caught my eye as I combed through the massive exhibit at this year's Calgary City Teachers' Convention. In that moment, an idea that has been swimming in my head found form: studying science can make you a better entrepreneur.

Let me explain. The bright red boxes contained a board game called Mathoply. A take-off of the classic board game Monopoly, this version is designed to teach math in the classroom.

Now, sharing the power, the mystery, and the wonder of science and math is what gets me up and into work each day. But it's not Mathopoly's approach to teaching math that I am celebrating here – wonderful as it may be – but rather the story of the game's creation. Willi Penner, Mathopoly's inventor, is a grade five math and junior high science teacher who turned the math curriculum into a game to engage students and keep them motivated. He got shot down at CBC's *Dragons' Den*, but he persevered, improved the game, took some strategic risks – and landed it in Chapters, Canada's biggest bookstore chain.

There are plenty of non-science lovers in the world and too often we pitch the study of science to them solely in terms of its ability to describe the world: take science and you will be better able to appreciate the world around you.

But science is more than that. Science is a strategic workout for your brain. It develops creativity. It gives you strategies for pulling apart problems, spotting assumptions, looking at things from new angles. It gives you skills to help you succeed in whatever it is that you do, including the art of entrepreneurship.

As I write this, I am over the Rockies en route to a keynote address by Canadian innovator Mike Lazaridis, which prompts me to ask the question, "What great new idea can change the world?" Pose this to creative youth from around the globe and they will have a torrent of ideas, most of which will not be scientific in nature. But the mental skill set of problem solving, questioning, and having the confidence to take calculated risks in search of answers is exactly what those idea-rich kids need to give their vision flight. And it is exactly those skills and habits of mind that scientific thinking can develop.

Perhaps this is an old idea with only a subtle shift in focus, but it is one I'd like to pursue. Do you have more living examples of how scientific thinking has helped non-scientific ideas take flight? I will happily receive them via email (gdick@perimeterinstitute.ca) or Twitter (@Greg_Dick).

– Greg Dick

Henry Reich and the Spiralling Success of MINUTE PHYSICS


Photo credit: David Montgomery

On June 26, 2011, Henry Reich uploaded a video to YouTube entitled, "What is Gravity?" It was 85 seconds long and featured his simple, humorous sketches and voice-over narration, explaining one of physics' central concepts simply and accessibly. It now has over 400,000 views.

Since then, Reich has uploaded, on average, one new video a week – more than 40 in total – on topics ranging from the Hairy Ball Theorem to how the sun shines. Together, they comprise his *MinutePhysics* YouTube channel (www.youtube.com/minutephysics), which has amassed nearly 19 million views and been featured on *New Scientist*, *Gizmodo*, and YouTube's front page, as well as garnering shout-outs in blogs on *Wired* and *Scientific American*. With over 250,000 subscribers, *MinutePhysics* has cracked the 500 most popular channels on the world's largest video-sharing website. Not bad for something Reich describes as "just a fun thing to do for the two months before school started."

"School" was film school at the University of Southern California in Los Angeles, which he entered in August 2011. It was his second post-graduate program. Previously, Reich was a student in the inaugural class of the Perimeter Scholars International (PSI) Masters program in 2009-10.

(continued on page 22)

After graduating from PSI, Reich did freelance work with film crews and visual effects work for one of YouTube's 10 most popular channels. With a few months to go before immersing himself in another program, he decided to give *MinutePhysics* a shot.

"I didn't have any idea of how well received it would be or how successful it would be, but the goal was basically to put in a full effort to do the best I could and then see what happened," Reich says.

Things didn't ignite immediately. Reich remembers being quite happy to have 3,000 subscribers and 40,000 views, and figured he might as well just keep doing it. So, between school and continued visual effects work, he made time – about 12-14 hours per video between scripting, production, and promotion – to keep the videos coming, often at the expense of sleep. And then?

"It kind of just went bonkers," Reich recalls, grinning.

Still, the success of *MinutePhysics* was making it increasingly difficult to balance all his pursuits and it became clear that something had to give. In early December, during a visit to Waterloo, Perimeter's Director, Neil Turok, offered Reich an opportunity to return. "It didn't take that long for me to say yes," he says.

And so, after taking a one-year leave from film school and driving across the United States, Reich arrived back at Perimeter in early February to begin a year-long contract as the Institute's first Film & Media Digital Artist-in-Residence.

There's a lot of symmetry in the move.

"PSI was fundamental in facilitating *MinutePhysics*," Reich says, citing the program's spirit of creativity and risk-taking, as well as the breadth of its teaching. "How much you learn over the course of a year in the PSI program is pretty astounding."

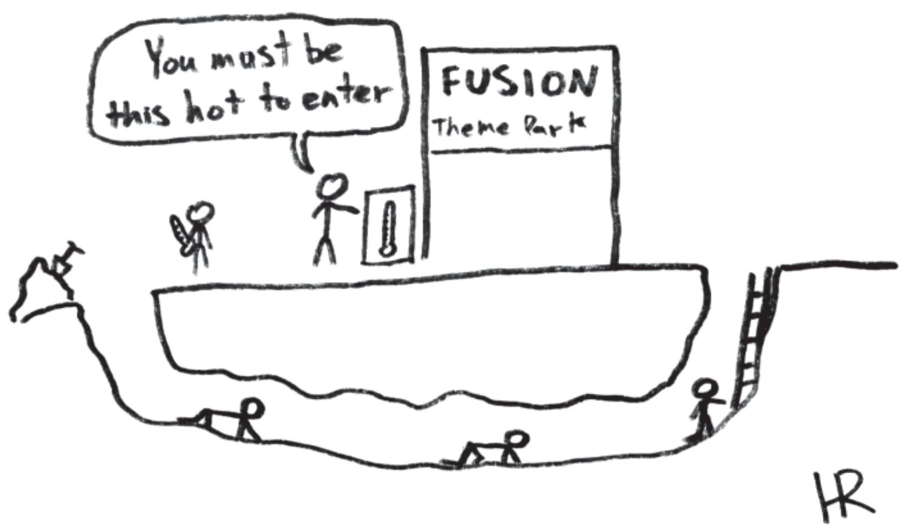
PSI also introduced Reich to Nima Doroud, Bruno Le Floch, and Alex Yale, colleagues in the program who he now relies on to vet scripts for scientific accuracy. "My goal is not to dumb things down," Reich explains. "If they really want the real deal, but made accessible, that's, I think, what having done PSI and done film puts me in this interesting position to be able to do. I could never have done it without having done the PSI program."

At Perimeter, Reich is continuing to develop *MinutePhysics*, which will feature tie-ins to some of the Institute's more in-depth educational resources. Being a part of Perimeter's vibrant scientific community also allows him access to some of the world's top physicists, as both guest lecturers and content advisors. "If I have a question about string theory, I don't have to look online; I can walk down the hall and ask a string theorist," he says.

Reich will also work with the Outreach department on creating new resource modules and hosting a meet-up to bring together heavy hitters in the world of educational visual media, entrepreneurs, and forward thinkers from formal education. In addition, he will be working with Turok to create video materials tied to the Massey Lectures. And, of course, it is his illustrations that are featured throughout this very magazine.

"We're really fortunate to have Henry here," says Greg Dick, Perimeter's Director of Educational Outreach. "It's an example of PI being nimble enough and smart enough to react when good opportunities arise. He's connected to PI, he's talented, he's a physicist, and he's embarking on really quality outreach in a whole new space – perfect fit."

– Mike Brown



Beyond The Atom

Remodelling Particle Physics

Particle physics has become *the* hot topic in physics, unsurprising given that the discipline lays claim to the biggest scientific experiment in human history, the Large Hadron Collider (LHC) at CERN. December's announcement of the LHC's latest findings in the search for the Higgs boson made headlines around the world, another example of the public thirst to know. Paradoxically, though, particle physics still doesn't get much attention in high school classrooms across the country.

"There just aren't a lot of resources out there on particle physics," explains Damian Pope, Senior Manager of Educational Outreach at Perimeter Institute. "It's this exciting subject that students hear about and it's fascinating, yet it's hard to understand and can be intimidating."

Looking to change that, in October 2010, a team led by Pope began work on a *Perimeter Explorations* module on particle physics. *Explorations* modules are in-class educational resources designed to help teachers explain a range of important topics in physics. They include a 30-minute video, featuring professional animations and high-quality production, and a rich teacher's guide with activities designed to provide hands-on learning opportunities for students. Perimeter has already produced highly acclaimed resources on quantum physics and dark matter, which have been viewed by over 250,000 students to date.

Pope, who holds a PhD in theoretical physics, worked with experienced high school teachers Dave Fish and Roberta Tevlin, both of whom had worked on the two previous *Explorations* projects, and Show Communications, a Canadian film company specializing in scientific videos. Over 18 months, they brought the project from brainstorming, to scriptwriting, to filming, and finally to production.

At every turn, they sought the input of more than a dozen Canadian high school teachers. They interviewed a host of top researchers in particle physics, including Perimeter Faculty members Cliff Burgess, Philip Schuster, and Natalia Toro; former Perimeter postdoctoral researchers Brian Batell and Ghazal Geshnizjani; and McGill professors Andreas Warburton and Brigitte Vachon. Burgess also acted as a science advisor, along with Rolf Landau, the head of educational outreach at CERN, and Professor Eric Mazur, a renowned physics education expert from Harvard University.

"One of the key features of Perimeter's approach to outreach is that we have multiple perspectives at the table," explains Pope. "We have the film and creative people there. We have the high school teachers, with years of experience in the classroom, because it's ultimately for them and their students. And then we have the people with the PhDs in physics, who know the very, very latest results. It's about getting all these people in the room together and creating something that works on all fronts."

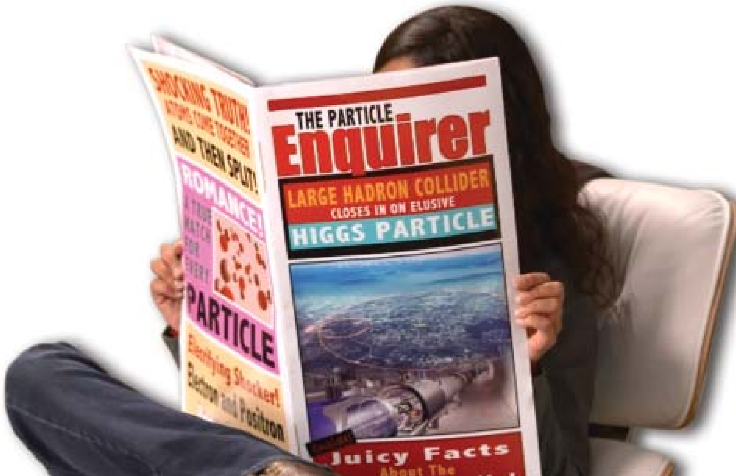
Still, coming up with succinct, accurate ways of explaining notoriously difficult concepts like the Higgs boson is not without its challenges. "For me, the hardest thing is taking what the researchers do at this very high level and then packaging it, distilling it, making it engaging, and making it fit in with the curriculum for high school students," says Pope.

As if this wasn't daunting enough, the aforementioned announcement of the LHC's latest findings loomed large. Pope's team was 16 months in, with an almost complete video, staring down an announcement with the potential to radically change what we know about particle physics.

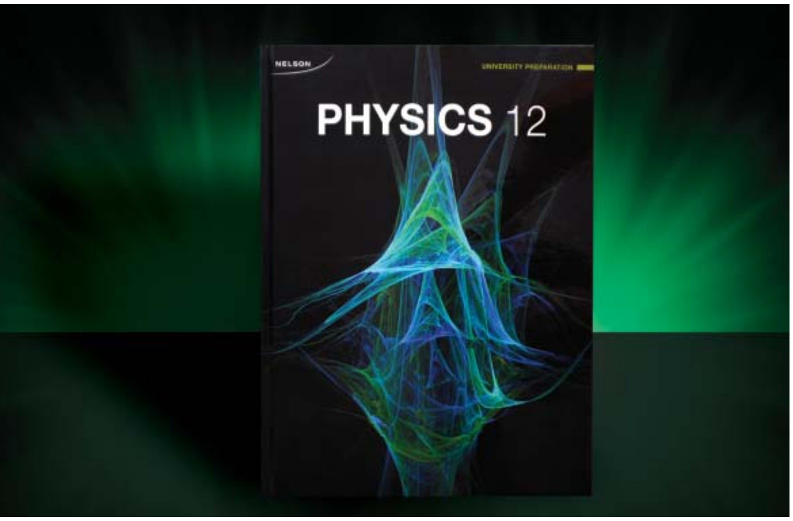
"It could've rendered parts of the video either incomplete or, in the worst-case scenario, outdated," says Pope. "We knew that was the risk with being at the cutting edge, but we decided it was better to be there and take that risk. Ultimately, we try to convey the latest understanding of current models and theories, like the Higgs boson, but just as much, we want to convey the spirit of science as a living enterprise. It's about asking questions, it's about mystery, and it's about trying to solve it all."

– Mike Brown

Canadian teachers can order "Beyond the Atom: Remodelling Particle Physics" at www.pitp.ca.



Classroom Connections



Yeats said that education is not the filling of a pail, but the lighting of a fire. This is the guiding philosophy of Perimeter's Outreach efforts and now it infuses *Physics 12*, Ontario's newest grade 12 physics textbook as well. Released by Nelson in January, the text draws from several Perimeter resources to effectively illustrate key modern science concepts to Ontario students. As the only physics text tied to the new curriculum, it will be widely used throughout the province for years to come.

Educational Outreach Director Greg Dick was one of the textbook's four authors, while Outreach Scientist Richard Epp was an Accuracy Reviewer and Educational Consultant Dave Fish was on the panel of teacher advisors.

Among the inclusions, the new text contains Perimeter's "Measuring Planck's Constant" LED lab in its entirety. The lab provides students with a simple and powerful activity to discover this key to quantum physics, Planck's constant, using only a 6-volt battery, an LED, a resistor, a voltmeter, a few wires, and a potentiometer. According to David Vrolyk, a teacher at Sir John A. MacDonald Secondary School in Waterloo, the fact that the lab requires only inexpensive, readily available equipment helps set it apart.

"They've figured out how to make a real lab that connects with quantum, which a normal high school can do – rather than only one that's got super-advanced equipment," says Vrolyk, who has been teaching grade 11 and 12 physics in Waterloo Region for 14 years. "Until recently, the labs for quantum weren't that simple."

It's not the only area of the text where Perimeter's influence is felt. The chapters on quantum mechanics and special relativity are presented from an authentically scientific perspective that draws heavily on Perimeter's "The Challenge of Quantum Reality" resource and *GoPhysics!* presentations respectively. Vrolyk was particularly impressed with the approach to special relativity.

"Instead of simply presenting Einstein's ideas, they're trying to give kids his perspective and then show the development of the theory," Vrolyk explains. "Einstein was famous for his thought experiments, so it leads kids through one of Einstein's thought experiments."

"They've taken their expertise, their ability, and their key people that do a great job of explaining these concepts, and they've done a phenomenal job of putting it into words."

– Mike Brown

Photo courtesy of CERN

What the Higgs?

On December 13, 2011, the two biggest experiments running at the Large Hadron Collider (LHC) at CERN gave their annual report on their scientific progress. This is not usually the kind of thing that catches the public interest, but this year was different. This year, it seemed, we were going to get a sneak peak at the Higgs boson.

Perimeter scientists gathered in the Black Hole Bistro to view the livestream of the announcement. It was earlier than scientists usually like to get up, but the blow was cushioned by the excitement, the coffee machine, and generous helpings of "Higgs and Bacon" cooked up by the Bistro. By lunch time, news stories were flying around the globe and Perimeter held a live web event of its own discussing the findings, geared towards high school students, teachers, and the general public. More than 6,500 tuned in.

What is the Higgs boson?

Searching for the Higgs boson was what the LHC was built to do. In a way, physicists were looking to fill in the last piece of a puzzle – a puzzle called the Standard Model. This simple and comprehensive theory explains all the hundreds of particles and their complex interactions with only six quarks, six leptons (like the electron), and a handful of force-carrying bosons (like the photon). Though it's not a theory of everything – it leaves gravity out of the mix, for starters – the Standard Model is a well-tested, highly successful theory, one of the great triumphs of modern physics. The model, as we currently understand it, contains 18 particles and we've found 17 of them. The Higgs is the last undiscovered piece.

The Higgs is important because it's thought to give particles mass. Without the Higgs mechanism, all particles would be massless, like the photon. We ourselves would not exist.

What did CERN find?

In short, CERN found tantalizing hints. The two experiments each saw a bump in the data around 124 to 126 GeV – the kind of bump one might expect if a Higgs boson of about that mass were produced in the collider and then decayed into other, more easily detected particles. (A GeV, or giga-electron volt, is a unit of mass used by particle physicists; one GeV is about the mass of a proton.)

It's encouraging that two separate experiments found this bump in roughly the same place. Still, it's too early to say if the bump is just a glitch. Indeed, CERN is being very – and appropriately – careful not to call this a discovery. It's more a place to look carefully as ATLAS and CMS continue to gather data in 2012. Nonetheless, many scientists expect the Higgs to be either found or ruled out by the end of the year.

– Erin Bow

Beaming It Live

Perimeter's webcast featured Philip Schuster and Natalia Toro, two Perimeter faculty members and theorists working with the ATLAS collaboration, and visiting researcher Andy Haus, a faculty member from New York University and an experimental physicist, also with ATLAS. The researchers explained how the LHC worked, discussed the importance of the Higgs boson, and then began taking apart the results of the day.

"The interesting thing to me is that the Higgs is running out of places to hide," said Toro. "We now know that it has to be heavier than 100 GeV – we've known that for a while – and today's results show that it has to be lighter than 130 or so GeV. The net is closing in."

"It's been very exciting today," noted Haus. "For months, each experiment has known independently that they saw an excess of events," or a bump. "But it wasn't until today that we got to see each other's cards and found that the two excesses lined up."

"Evidence has come and gone at this level in the past," cautioned Schuster. "This is exciting, but it's preliminary. We absolutely need more data."

"How much would you bet on this being a real effect, not a glitch?" moderator Damian Pope asked the panel. "I'd bet 2.3 sigma," joked Haus – citing the exact measure of how likely the ATLAS "bump" is to be a random fluke.

And what's next in the search for the Higgs? "If this is a real signal, it won't disappear," said Schuster. "You'll see our confidence in it climb past the 5 sigma mark – the gold standard we use to say we've discovered something. And then we can look at the data in more detail. We'll be able to start studying questions like, 'Is this the Standard Model Higgs?' or 'Is this a Higgs, but a little bit different than what we expect?' Depending on what underlying theories we use to generate the Standard Model, we get different predictions for the detailed properties of the Higgs. So now we want to turn the Higgs into a tool, to probe beyond the Standard Model."

Building Something Bigger

Perimeter Chief Operating Officer Michael Duschenes and Ramatoulaye Sall, Manager of Facility & Logistics, AIMS-Sénégal

In September 2012, the African Institute for Mathematical Sciences (AIMS) is slated to open its third independent centre – in Ghana – as part of an ambitious plan, known as the Next Einstein Initiative (AIMS-NEI), to nurture the continent's brightest young scientific minds.

Located in Saltpond, a coastal area two hours east of the capital of Accra, AIMS-Ghana will be patterned on AIMS-South Africa, which was founded by Perimeter's Director Neil Turok in 2003 and has become a globally recognized pan-African centre of excellence for postgraduate education and research. The Next Einstein Initiative has also become the centrepiece of Perimeter's global outreach efforts.

In early December, Perimeter's Facilities Manager Brian Lasher visited Ghana, marking his second trip to West Africa in just over a year, following an October 2010 visit to Sénégal, where the second AIMS centre opened in September 2011.

During a whirlwind eight-day visit, Lasher assisted AIMS staff on several fronts, including hiring a Facilities and Logistics Manager; finalizing the architecture competition for the design of the new centre; evaluating temporary sites for the institute while a permanent building is being built; and brainstorming about the myriad tasks to be executed before the centre's planned opening next September.

"With my experience in construction – whether it be project management or superintendent – I brought that bit of coordination to try to help set it all up on a realistic schedule, and help make everybody aware of all the little hurdles that you have to overcome to move to the next step," said Lasher, who was central in the construction of both Perimeter's award-winning building and the recent Stephen Hawking Centre expansion.

It's just one example of how Perimeter is supporting the development of mathematical sciences in Africa from afar. Perimeter staff have also assisted in developing the AIMS-NEI business plan and helped attract a wide range of supporters, including Google, RIM, numerous Canadian universities, and the Government of Canada.

"We want to see this succeed and grow and be sustainable," explains Stefan Pregelj, Perimeter's Senior Analyst, Financial Operations. "Governance is one of the keys and I think we've done some really good work on that side, in helping to make sure there are the right people in place in the right countries and the right model for transferring money there. I think all of that has helped make donors more comfortable investing in AIMS."

Perimeter has hosted several AIMS staff members to share its best practices and will continue to do so, according to Chief Operating Officer Michael Duschenes. During a January trip to AIMS centres in both South Africa and Sénégal, Duschenes discussed with AIMS-NEI's Executive Director Thierry Zomahoun other ways that PI can assist, including sending Perimeter staff to Africa to run professional development workshops.

And though the challenges are many – from erratic electricity and infrastructure issues to managing the cultural and language obstacles of bringing together students from such a wide swath of countries – both Lasher and Duschenes were impressed by what they saw.

Brian Lasher with former Director of Operations and Programmes at AIMS-NEI Arun Sharma

African Music Academy, one of the possible temporary sites of AIMS-Ghana

"It felt far more mature than it actually is," said Duschenes of the AIMS-Sénégal centre. "That's always a really good sign because I know they've had a million hurdles. If you can give the sense that you've got something pretty firmly established when you are still a very young organization, you're doing a lot of things right. In general, the progress that has been made over a short period of time in building AIMS-NEI is very impressive."

"My visit to AIMS really reinforced why global outreach is such a valuable part of Perimeter's mandate. We're part of a global enterprise, trying to solve some of the toughest problems in science. Success will require contributions of talented people from all over the world," explained Duschenes. "Exporting some of the experience we have gained to help accelerate the creation of these centres is one part of the international role Perimeter can play. And we end up learning as much from them as they do from us. There is a sense of purpose and ambition to the AIMS mission that is inspiring."

Lasher left Ghana equally impressed by the passion of the AIMS staff. "They truly believe in the process and they all go above and beyond to make it happen. It's inspiring and it also drives you to do the best you can for the program," he explains. "It's been a highlight of my career to say I've been involved in something like that, as small a piece as I've been."

– Mike Brown

Answering the Call

Astrid Eichhorn

Before Postdoctoral Researcher Astrid Eichhorn arrived at Perimeter Institute in the fall of 2011, the African Institute for Mathematical Sciences (AIMS) had captured her imagination. Upon reading about AIMS in a June 2011 article in *Nature* by Neil Turok, she wondered if she would ever get the opportunity to teach there. She didn't have to wait long for an answer.

Just five weeks after arriving in Waterloo, Eichhorn got an email Turok had sent to Perimeter's research community, wondering if anyone was available to teach an introductory course in quantum mechanics at the brand new AIMS-Sénégal centre. The scheduled lecturer from China was unable to secure a travel visa and the course was due to start in one week. Could anyone fill in?

Eichhorn answered the call, though she asked for an additional week to prepare. And so, from late November until the week before Christmas, Eichhorn found herself in Africa for the first time, teaching a three-week survey course on the highlights of quantum mechanics to 32 of the continent's brightest young minds. She stayed in a dormitory not far from the students' own, ate three meals a day in their company, and interacted with them from dawn until dusk.

"It was a great experience; it was a very, very rewarding type of teaching because the students were all extremely motivated and enthusiastic," explains Eichhorn. "I really had a great time and I'm thinking about applying to lecture there again."

This time around, she might even have more than a week to prepare.

– Mike Brown

AIMS-Sénégal students

Tales From The Black Hole: The Savoury Science of Risotto

In the grey depths of winter, few dishes on the Black Hole Bistro's menu were so appealing as the daily risotto. This down-home Italian dish – the name simply means "little rice" – comes out of the kitchen in a shallow bowl, grains of tender rice and sauce puddling outward. It is a venerable dish, dating back to the 1500s, and there are hundreds of variations. The basic technique, though, rarely varies and is defined by the slowness with which stock is added. But what's the science behind it? Why couldn't you add all the stock at once, put a lid on it, and simmer?

It's all about the starch. The hot stock slowly pulls the starch from the rice into the liquid. There, the starch begins to break down, forming a three-dimensional cross-linked structure inside the liquid – a gel. The end result is that the rice, without much starch inside it, is tender and the sauce is delectably creamy. That's why the variety of rice – traditionally Arborio or similar – is important. All varieties of rice contain a starch made from two polysaccharides, amylose and amylopectin, but each variety has the two in different ratios. The important distinction is that amylopectin is soluble in water – it will be pulled into the stock and make the creamy sauce – and amylose is not. Arborio rice has low amylose – just enough to give the risotto a bit of tooth.

– Erin Bow

The Black Hole Bistro's Head Chef Brian Abbott walks us through the steps of a classic risotto.

Inside The Perimeter: What's been the favourite risotto you've made here recently?

Brian: We play around with risotto so much. If you can make a basic risotto, the possibilities are endless. You'll need two to three parts stock or other liquid to one part rice. The rest is technique.

Inside: Okay, so tell me about technique. Where do I start?

Brian: I'd start by sautéing some onions – don't brown them – until they're tender and fragrant. You may add a little bit of garlic – don't brown the garlic. Then, add the rice when the onion is very soft. The oil should just barely coat the rice: they'll look as if they are separate pieces of rice, just barely coated in the oil or butter – just a sheen on them. You'll see the centre of the rice: a little white seed inside the pearly part. That's the starch.

You might add a splash of wine just here – something nice and crisp. It's optional.

Then, you add the liquid. Just barely cover the rice with warm stock. A good stock will really show in a risotto. Usually, you'd use a vegetable or mushroom stock, or something else light – chicken or veal. But you can use anything.

Don't boil the risotto. Just let it absorb. Making risotto is like getting into a bath – you just want to soak in the warmth. Let the rice relax. Risotto is meant to have a passion to it. You have to take it slow. Give the pan a stir or a shimmy, so the rice doesn't stick. Add the stock ladle by ladle.

Inside: I think every home cook's question is, "How do I know when it's done?"

Brian: Just taste it. It shouldn't be starchy – you shouldn't taste raw starch. On the other hand, it shouldn't be mushy. You want it to be al dente – just have a little tooth. If you're taking your time, it will be about 30 to 40 minutes.

When it's just about done, you can add some cooked ingredients. You could try roasted mushrooms, already cooked in the oven so that their flavour is intensified – a little bit of caramelization on the mushrooms, a light seasoning. Just fold them in. Risotto suits the season – roasted mushrooms in the winter, asparagus in the spring, tomatoes in the summer. Bacon, of course, is good anytime!

Inside: So, how do I finish it?

Brian: Depending on what you're doing, you might put in a little lemon juice, maybe some fresh herbs. Traditionally, it's finished with butter, though you could use a little olive oil too. Turn off the heat – you just want the butter to melt into it. It's nice when it all stays together. And then some cheese – parmesan cheese is very traditional, but you can play.

Inside: And then eat it right away?

Brian: Yes, you should eat it right away – it doesn't keep well. But anyway, how can you resist?

Spring Risotto

Bring stock to a simmer in a medium pot. Dice the shallots, zest the lemon, and grate the cheese. Prepare the asparagus: chop off the woody bottoms and cut the tender upper stalks and heads into 1 cm pieces.

Heat the olive oil in a large skillet or sauté pan, then add shallot and cook until soft. Add the rice and stir to coat. Then, add the stock a ladle-full at a time. Stir and wait until the stock is completely absorbed before adding more stock. Add the asparagus after about ten minutes. Continue adding stock until the risotto is creamy. Add the peas and stir for one minute.

Remove the risotto from the heat and stir in your lemon juice and zest. Stir in cheese. Eat at once. Serves four.

1 tablespoon olive oil
2 small shallots
1 cup arborio rice
4 cups chicken stock
1 bunch asparagus
½ cup frozen spring peas
1 teaspoon lemon zest
2 tablespoons lemon juice
¾ cup grated parmigiano reggiano

PIRSA PICK OF THE ISSUE

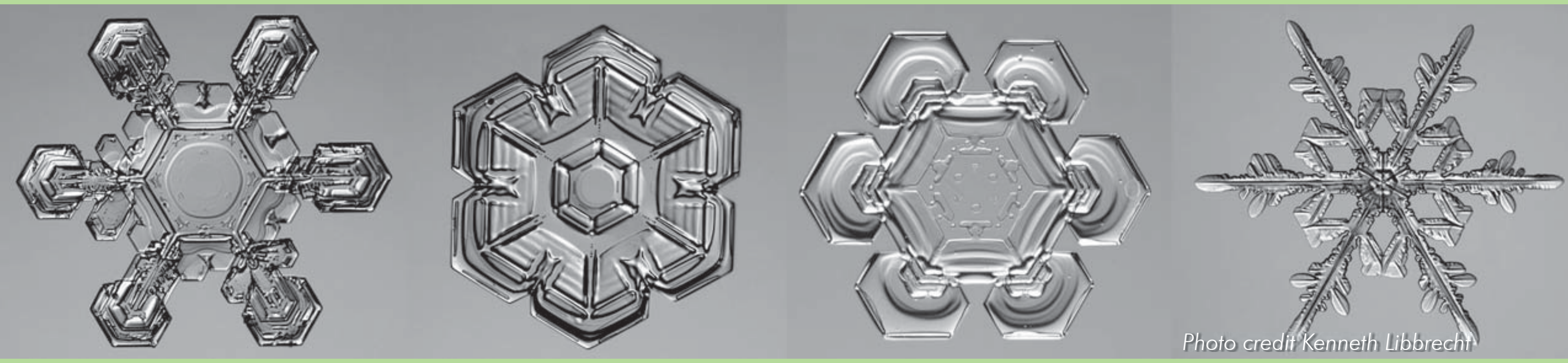


Photo credit Kenneth Libbrecht

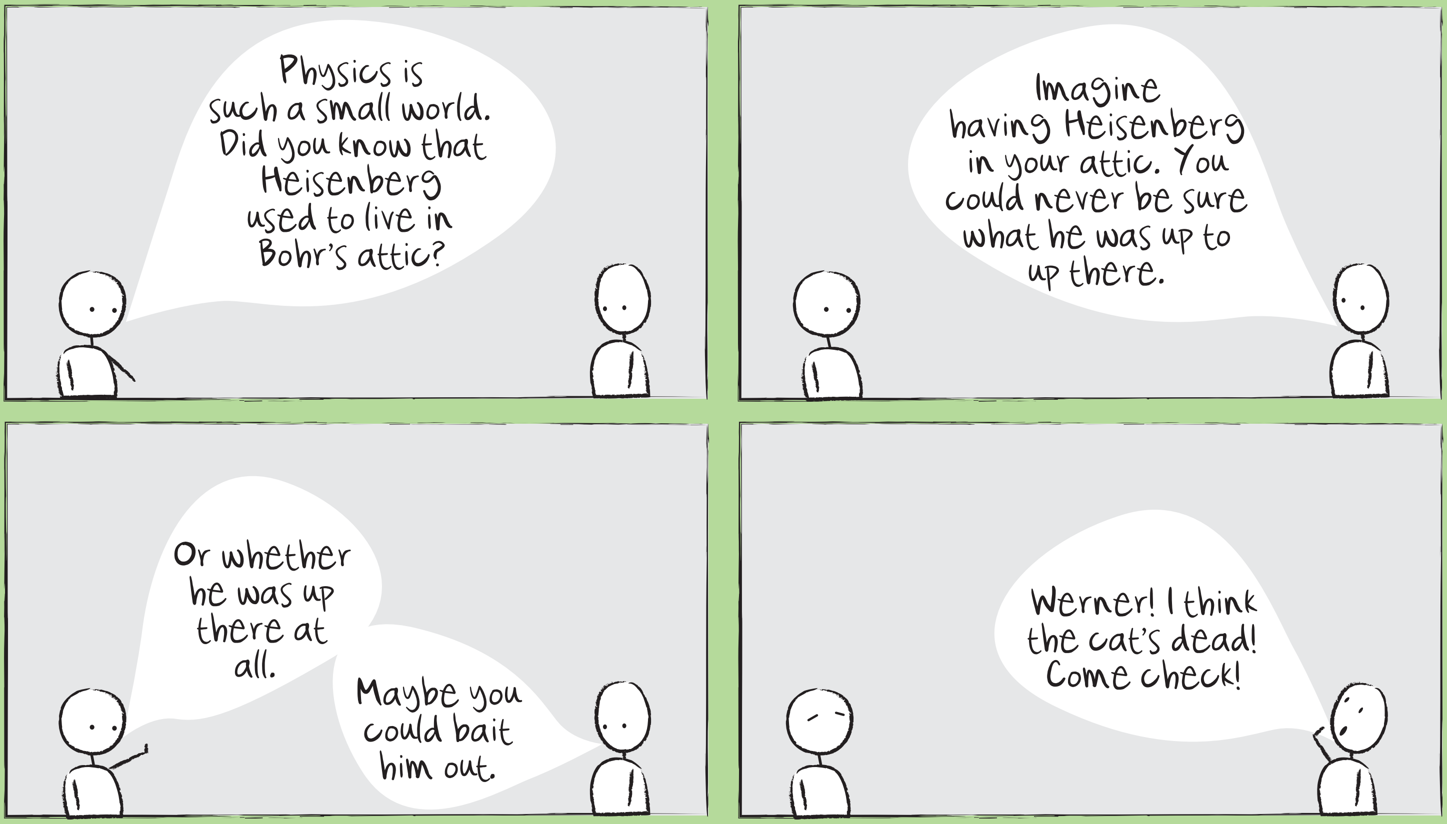
Snow crystal morphology, or the physics of snowflakes, is still an unsolved physics problem. Professor Kenneth Libbrecht has been working hard to better understand the phenomenon – to "crystallize" his understanding, if you will. After all, as he says, "It's just ice and the stuff falls out of the sky. You'd think you'd have a better idea what's going on." In addition to new physics models, Libbrecht has produced some of the most stunning modern pictures of snowflakes and the world's most detailed videos of snowflake growth.

If you didn't experience enough snow this winter, you can learn more by watching Libbrecht's colloquium, "The Secret Life of a Snowflake: An Up-Close Look at the Science and Splendour of Nature's Frozen Art." See for yourself what this California professor has to teach us about snow.

PIRSA: http://pirsa.org/12020090/

Overheard @ PI

Staff members talk while waiting for coffee:



Laurie Anderson Packs Perimeter's Atrium

"You're walking. And you don't always realize it,
but you're always falling.
With each step you fall forward slightly.
And then catch yourself from falling.
Over and over, you're falling.
And then catching yourself from falling.
And this is how you can be walking and falling
at the same time."

– Laurie Anderson
Lyrics from "Walking and Falling" on the album *Big Science*

Laurie Anderson, a ground-breaking performance artist, visited Perimeter in January. Anderson is a pioneer and an iconoclast, who seamlessly integrates cutting-edge technologies into her art. She has presented her visual work in major museums worldwide and even served as NASA's only artist-in-residence.

The sell-out audience packed the atrium floor, while Perimeter staff and researchers lined the surrounding balconies to watch. Her performance was at once thought-provoking, funny, and hauntingly beautiful. It was a singular cultural happening in a season that has also included tremendous performances by Jordi Savall, Matt Haimovitz and Christopher O'Riley, and Colin Stetson.

The next day, Anderson joined researchers and guests for Perimeter's second "inreach" event. While Perimeter's robust outreach program brings great scientific ideas to a broader audience, our inreach program brings great cultural ideas to our scientists. It's a new program but Anderson's visit has helped it take off like a bottle rocket.

– Erin Bow

Faces of Perimeter's Leadership Council:

Alexandra Brown

Alexandra Brown is a senior media executive whose past roles include Director at eBay Canada, Project Director at CanWest, and Senior Vice President at Alliance Atlantis. She's currently a media consultant and the president of Aprilage, creator and producer of the APRIL face-aging software system.

Alex is one of Perimeter's donors and also a member of Perimeter's Leadership Council, a group of prominent individuals who volunteer their time as Perimeter's ambassadors to the business and philanthropic communities. She recently took a few minutes to speak to *Inside the Perimeter* about her work for the Institute.

Inside The Perimeter: How did you get involved with Perimeter? What drew you in?

Alex: The overall vision of the Institute appealed to me. I don't come from the world of science, I come from the world of media – but I know how magic happens. Magic happens when you get great people together. You may have a goal in mind, but you aren't sure how to get there. You never know where the spark is going to come from or where it's going to take you. That's an excitement I know well – and something I feel every time I'm at Perimeter.

Inside: How are you finding your experience on the Leadership Council?

Alex: It's been great. Everyone I've met is top drawer and so devoted to the work at Perimeter. It's been a privilege to meet the scientists and the students. I don't always understand what they're talking about, but I can certainly sense their excitement.

Inside: You open a lot of doors for Perimeter. How do people react when you bring it up?

Alex: People are sometimes a little bit daunted and think you're about to launch into a conversation about string theory. But of course that's not what I do. The scientists can take care of that. What I talk about is the big push for the next big breakthrough. I talk about the people who come from all over the world to do their research and the unmatched atmosphere within the building.

I also talk about the way Perimeter does outreach beyond a traditional scientific sphere, connecting with teachers and students and beyond. It reaches into the world of art and culture, which I think is important. You always learn something when you talk to people who are doing interesting things in different fields and you never know where the spark is going to come from. Or where it's going to go. My daughter is in grade nine and last fall at Perimeter she got to meet Julie Payette, the astronaut. This year she's head of her school's astronomy club – 60 girls, looking at the stars.

Inside: There are a lot of things you could devote your time to. Why do you think Perimeter is important?

Alex: What motivates me is the dream of what's possible. Think about people like Newton and Maxwell and Einstein. Where would the world be without those people, without that physics? When you start thinking about how physics has already changed the world, and when you think about the work physicists are doing right now, then you start dreaming big about the future.

– Interview by Erin Bow

Following Mike Lazaridis' plenary lecture at AAAS, guests gathered for a reception.

From left to right: Glenn Ives, Chairman, Deloitte & Touche LLP; Maria Antonakos, Director of Advancement, Perimeter Institute; Karen Keilty, Partner, Deloitte & Touche LLP; Michael Duschenes, Chief Operating Officer, Perimeter Institute

From left to right: Donald Campbell, former Perimeter Board member and Senior Strategy Advisor, Davis LLP; Philip Lind, Vice Chairman, Rogers Communications Inc.; Carol Lee, member of Perimeter Institute Leadership Council and Co-Founder & CEO, Linacare Cosmetherapy Inc.; Mike Lazaridis, Perimeter Institute Founder and Board Chair; and Catherine Bergman

PI KIDS ARE ASKING

Julie, who is seven, just read a book that said Earth was the only planet with air. She says, "Isn't air everywhere? What's outer space made of?"

To start with, air isn't everywhere. Air is a kind of matter – a scientific word for "stuff" – and it has weight. Gravity holds it close to the Earth's surface, just as it holds you. As you go higher, there's less air. The air doesn't even go up very far; if Earth were the size of a basketball, the layer of air that's stuck to it would be only two millimetres thick. Once you get above that layer, there's no air at all. We call this a vacuum. You can make a vacuum here on Earth by sucking all the air out of a sealed box. What's inside the box when you're done? Just empty space, right?

But here's the tricky part. Empty space isn't nothing; it's something. If matter and light are the art of the universe, then space is the paper on which that art is drawn. If we didn't have the paper, we wouldn't have the art. If space weren't something, we wouldn't have the universe.

Physicists used to think that "paper" of space was sort of like graph paper: a set of ruled lines, never changing, and looking the same no matter where you stood. They used to think that the paper could never change the art and the art could never change the paper.

After Einstein, we learned that all those things are wrong. Space is more like a fabric than a paper. It can stretch, twist, and even tear. Matter bends space – so the art affects the paper. The bending of space changes the way things move – so the paper affects the art.

Physicists today are trying to figure out more about the fabric of space. We don't know if it's a smooth fabric or if it's made of little stitches – which is what some quantum gravity theorists believe – or woven of strings – which is what some string theorists believe. There are other stranger possibilities, too. The nature of space is a great mystery – one of many we're studying here at Perimeter.

- Erin Bow

Upcoming Conferences

Recent Progress in Quantum Algorithms
April 12, 2012

Higgs: Now and in the Future
April 23-24, 2012

4 Corner Southwest Ontario Condensed Matter Physics Symposium 2012
May 3, 2012

GAP 2012: Geometry and Physics
May 5-7, 2012

Conformal Nature of the Universe
May 9-12, 2012

Background and Methods of Highly Frustrated Magnetism
June 3, 2012

Exploring AdS/CFT Dualities in Dynamical Settings
June 4-8, 2012

Back to the Bootstrap II
June 11-15, 2012

Relativistic Quantum Information
June 25-28, 2012

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