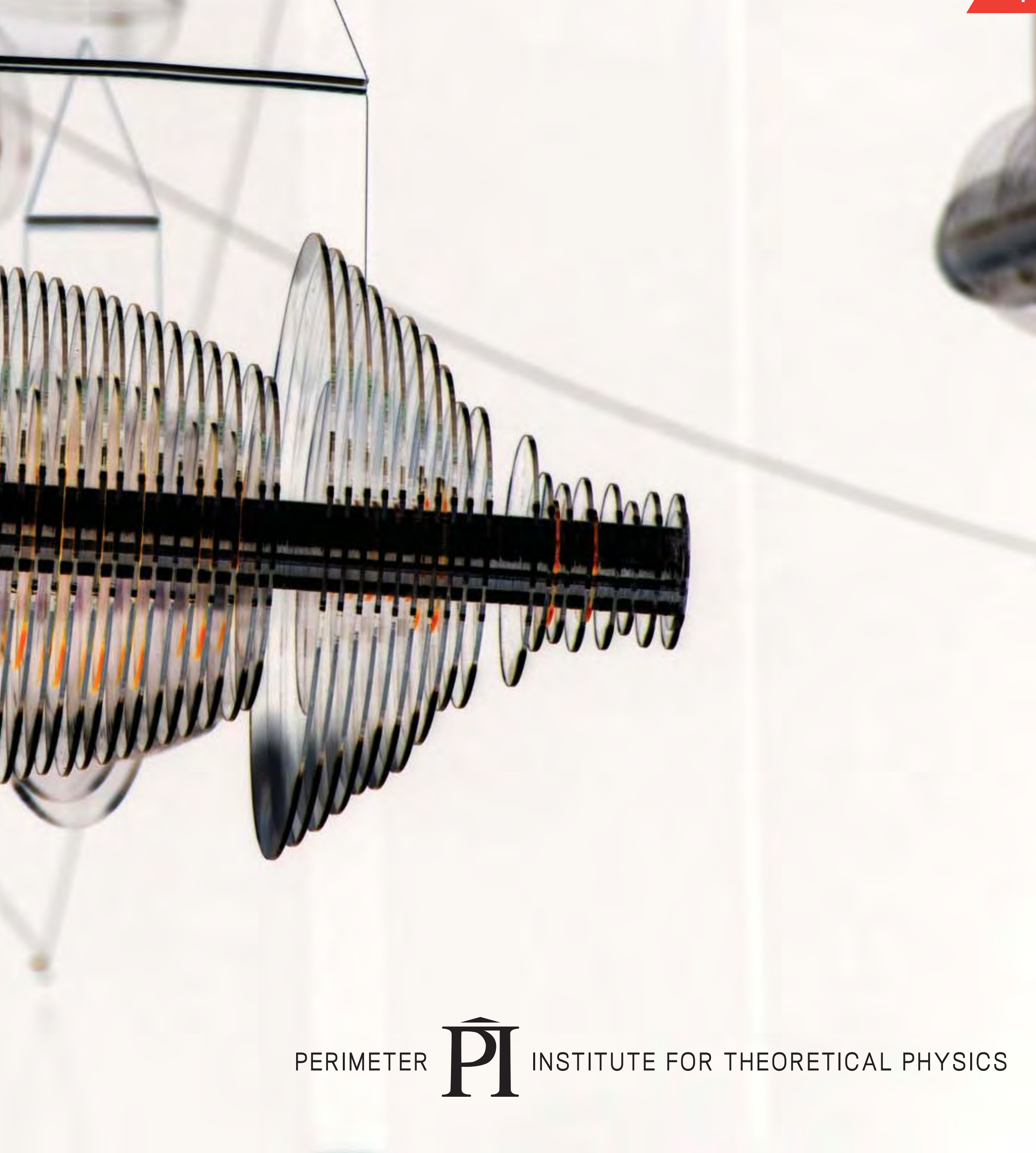
inside the Perimeter

fall 2012



Particle Physics
What's next for the Higgs?

Outreach
BrainSTEM unconference

Lee Smolin
35 King Street & The Spirit of PI

Culture
Orbitals in Space

and more ...

PERIMETER PI INSTITUTE FOR THEORETICAL PHYSICS

The Compact Muon Solenoid, or CMS, detector at CERN undergoing testing. In August, Perimeter brought theorists from around the world together with particle experimentalists from the CMS experiment to help chart the future course of research. See article on page 14.

Photo: CERN

Front cover: Atomic Orbitals by artist Reinhard Reitzenstein. *Read about it on page 39.*

inside the Perimeter

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www.perimeterinstitute.ca

To subscribe for free, send us an email at newsletter@pitp.ca.

31 Caroline Street North,
Waterloo, Ontario, Canada
p: 519.569.7600
f: 519.569.7611

Contact us at newsletter@pitp.ca.

IN THIS ISSUE

When Opportunity Drops From the Sky

Four years ago, when I was invited to serve as director of Perimeter, it was clearly a unique opportunity to help build a new centre for the field that I love. But it was also a daunting challenge, to move to a place I'd hardly heard of and work with people I hardly knew. I talked it over with my friend and colleague Stephen Hawking who, even as he was trying to talk me out of it, offered these words: "Whenever I've had to choose between doing something important or not doing it, it was always the right choice to try." So I took the plunge and never looked back.

It was in that same spirit of adventure that, when I was invited to deliver the 2012 CBC Massey Lectures, I accepted without thinking. It was enough to know some of the names of past lecturers – from Martin Luther King to Doris Lessing and John Kenneth Galbraith – to see that this was an opportunity not to be missed. I completely – yet knowingly – underestimated the scale of what I was getting myself into.

The mandate of the Masseys is to speak on some subject "of importance to contemporary society at large." What could be more important than science?

Yet in the 50-year history of the Masseys – a span of time in which science has become more and more important – hardly any scientists had spoken. And those few had mainly spoken about science's limits and dangers.

Fifty years without a scientific optimist! I figured it was time for a change. I also believe strongly in the importance of scientists explaining what they do and why to the public, and this was a chance to try.

We spend almost every moment of our lives using technologies, from plumbing to computers, but by and large we take them for granted. In facing the future with its many challenges, however, it seems to me the best thing we can do is to properly understand our major assets. And by far and away the greatest of these is our amazing capacity to understand the universe around us and to use its basic properties in intelligent ways. This is the topic I chose for my lectures: how it was that we created explanatory knowledge – of which physics is the prime example – and where it might take us in the future.

When I started, though, I was only dimly aware of all the connections. Like most physicists, I have never taken a history course. So, it was a surprise to find how well it actually connects. For example, Pythagoras's theorem lay at the root of mathematics, but re-emerged as a foundation for quantum theory and general relativity. As I sought ways to explain basic physics without pictures (the lectures are broadcast on radio), I tried to reduce it to its bare bone ideas. And there, at the centre of it all, was the imaginary number *i* — the mysterious chameleon who's been turning up to save the day ever since the Italian renaissance – and whose story is still unfolding!

It was also fascinating to learn just how essential special communities, places, and times were to breakthroughs. Whether Anaximander among the pre-Socratics or Galileo in the Renaissance, Maxwell and his Scots friends or the gypsy-like characters at the heart of modern physics in the 20th century, the great individuals flourished because of those all around them.

Today, physics is even more of a collective effort because of the incredible reach of the problems we are tackling – from less than a billionth the size of an atom to more than ten trillion times the size of the solar system – and their vast complexity, like the macroscopic states of entangled quantum matter.

Many of the questions we're trying to solve are so far removed from experience or even experimental test that, more than ever, it's vital to have people around you on whom you can road test your ideas. Long before I started writing the Massey Lectures, I felt that Perimeter was unique, as a strategic attempt to push forward this most abstract but foundational, ideas-based field. Writing the lectures made me see even more clearly why places like Perimeter are so essential to the world. Ultimately, the big breakthroughs will be made by individuals, but they will only be able to do it with an awful lot of support and interaction.

Towards the end of the lectures, I took a bit of a walk on the wild side. Today, the digital revolution is a huge force in society, shaping jobs, lives, opportunities. But as we physicists know, the world is not digital at all – it is quantum. And on the horizon are quantum computers which are not just vastly more powerful than today's classical ones, they are qualitatively different. It is fascinating to speculate on how life itself may change through the interaction of classical, analogue beings like ourselves, with quantum technologies.

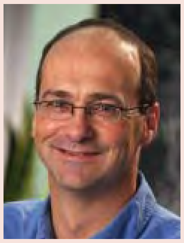
People, especially young people, feel overwhelmed by all the problems they see around them today. Yet in looking at the history of physics and seeing how much was achieved, one can't help but feel enormous optimism. The great lesson, for me, is that we are capable of so much more than we know.

Physics is such a wonderful, human story – one that's essential to understanding who we are and where we are going. The capacity to question and, most amazingly, to explain the universe is a huge part of us. It's a means not only to understand the world, but to determine our destiny. Knowing that we are part of something far bigger than any of us is both humbling and energizing. It helps to give our lives meaning. It puts our problems in perspective and makes progress more likely.

Stephen was right: when you see opportunities, don't hesitate to jump – even when you aren't sure of the landing.

- Neil Turok

Myers awarded Vogt Medal



Faculty member Robert Myers won the CAP-TRIUMF Vogt Medal for Contributions to Subatomic Physics, recognizing his "outstanding contributions to advancing the frontiers of string theory and its applications to theories of gravitation, black holes, and QCD." The honour is co-sponsored by the Canadian Association of Physicists (CAP) and TRIUMF, Canada's national laboratory of nuclear and particle physics. It is named for TRIUMF's founder, Erich Vogt. Myers received the medal at the 2012 CAP Congress in June.

Cachazo wins Herzberg Medal

Faculty member Freddy Cachazo won the CAP Herzberg Medal, which honours outstanding achievement by a physicist early in their career. Cachazo was chosen for his "deep new insights into the structure of quantum field theory, and the development of elegant mathematical techniques to simplify the analysis of high-energy particle scattering experiments." The Herzberg Medal is named for Gerhard Herzberg, long-time director of the pure physics department at Canada's National Research Council and winner of the 1971 Nobel Prize. Cachazo received the medal at the 2012 CAP Congress in June.

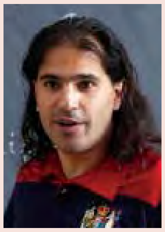
Turok joins Higgs Centre's IAC

Director Neil Turok recently accepted an invitation to join the International Advisory Committee of the newly established Higgs Centre for Theoretical Physics at the University of Edinburgh. The Centre is being established on the heels of the July discovery of the Higgs boson and seeks to deepen our theoretical understanding of the underlying structure of the physical world. It is being named for Professor Peter Higgs, an emeritus professor at the University of Edinburgh, who, along with Turok, will serve as one of eight inaugural members of the committee.

New recruit co-recipient of Gruber Cosmology Prize

The Wilkinson Microwave Anisotropy Probe (WMAP) team, which includes new Faculty member Kendrick Smith, won the 2012 Gruber Cosmology Prize. The observations and analyses of the WMAP team and its lead scientist, Charles Bennett, have provided rigorous, unprecedented measurements of the age, content, geometry, and primordial structure of the universe, which have helped transform cosmology itself from "appealing scenario into precise science," according to the Gruber Prize citation. Read about Smith on page 17.

Arkani-Hamed wins Fundamental Physics Prize



Distinguished Research Chair Nima Arkani-Hamed was named one of nine inaugural winners of the newly established Fundamental Physics Prize, which was created by Russian billionaire Yuri Milner to recognize transformative advances in the field. Arkani-Hamed was honoured "for original approaches to outstanding problems in particle physics, including the proposal of large extra dimensions, new theories for the Higgs boson, novel realizations of supersymmetry, theories for dark matter, and the exploration of mathematical structures in gauge theory scattering amplitudes." Each winner received $3 million, making this the most lucrative academic prize in the world.

Cory and Mosca receive CREATE training grants

The Natural Sciences and Engineering Research Council of Canada recently awarded Collaborative Research and Training Experience (CREATE) grants worth $1.65 million each to Associate Faculty members David Cory and

Photo credit: Peter Kovacs

Michele Mosca. The grants are intended to help launch cutting-edge training and mentorship programs for young Canadian scientists. Cory's project will focus on training these young scientists in the use and development of quantum information processing and neutron methods, while Mosca's will bring together research teams, organizations, and industry from across Canada to prepare a new generation of researchers to pioneer a new global infrastructure for ultra-secure cryptography in the quantum era.

Vieira receives Early Researcher Award

In May, Faculty member Pedro Vieira received an Early Researcher Award (ERA) from Ontario's Ministry of Economic Development and Innovation. ERAs are $140,000 grants given to recently-appointed faculty members across the province with the intent of helping them to build their research teams. Vieira was selected for his proposal, "Quantum Field Theory at Finite Coupling," research that largely concerns strongly coupled gauge theories, including quantum chromodynamics. Vieira and his team will use the grant to develop new mathematical tools to better understand these strongly coupled gauge theories.

10 Perimeter researchers receive NSERC Discovery Grants

Faculty member Philip Schuster received a Discovery Accelerator Supplement of $120,000 over three years from the Natural Sciences and Engineering Research Council of Canada, in addition to a Discovery Grant and an Early Career Supplement. Discovery Grants aim to support ongoing research programs with long-term goals, while Discovery Accelerator Supplements provide substantial and timely additional resources to accelerate progress and maximize the impact of superior research programs. In total, 10 Perimeter researchers received funding from the Discovery Grant program, amounting to $1,668,000 over three- to five-year terms. The recipients included Faculty members Guifre Vidal, Bianca Dittrich, Lucien Hardy, and Pedro Vieira; Senior Researcher Rafael Sorkin; and Research Technologies Group Lead Erik Schnetter. Faculty member Latham Boyle and Associate Faculty members Avery Broderick and Itay Yavin received both grants and Early Career Supplements.

Bianchi awarded Banting Fellowship

Postdoctoral Researcher Eugenio Bianchi has been awarded a Banting Postdoctoral Fellowship, one of 70 new fellowships granted by the Government of Canada in 2012. Banting Fellowships are valued at $70,000 annually, for up to two years. For more on Bianchi's work, see the feature article on page 30.

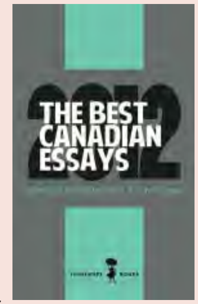
Vieira and Sever among Best Paper Prize recipients

Faculty member Pedro Vieira and Senior Postdoctoral Fellow Amit Sever, along with collaborators Luis Alday and Juan Maldacena of the Institute for Advanced Study, were recognized by the *Journal of Physics A*'s Best Paper Prize for 2012, for their paper on "Y-system for scattering amplitudes". The particle physics paper, which computes N=4 super Yang-Mills planar amplitudes at strong coupling by considering minimal surfaces in AdS_5 space, was initially published in late 2010 and has since received more than 75 citations.

Gurau wins Weyl Prize

Senior Postdoctoral Fellow Razvan Gurau has been awarded the 2012 Hermann Weyl Prize for his breakthrough work in quantum gravity, which showed how two-dimensional models for quantum gravity could be generalized to produce models of three dimensions or more. Gurau received his prize in a ceremony at the International Colloquium on Group Theoretical Methods in Physics in China this summer.

Smolin featured in *Best Canadian Essays 2012*



A book featuring the best Canadian essays of 2012 will include a piece by Perimeter Faculty member Lee Smolin. Smolin's essay on "third-culture" intellectuals who build bridges between the sciences and humanities originally appeared in *Brick: A Literary Journal*.

Bardeen and Fisher named to NAS

Distinguished Research Chair James Bardeen and Scientific Advisory Committee member Matthew Fisher were among the 84 new members elected to the (American) National Academy of Sciences (NAS) in May. The NAS recognizes scientists and engineers for their "distinguished and continuing achievements in original research."

Third PSI class graduates

Perimeter Scholars International (PSI), the Institute's master's program, graduated 37 students in June, the largest class in PSI's three-year history. Six graduates have remained at Perimeter for further graduate studies, while an additional four are working with Perimeter's global outreach partners at various centres for the African Institute for Mathematical Sciences. The majority of the remaining grads have gone on to PhD programs at top international institutions, including Oxford, Princeton, and Caltech.

Photo credit: Jim McDonnell

Two new collaborative agreements

Perimeter has signed memoranda of understanding to encourage scientific exchange with a pair of international partners: the International Centre for Theoretical Physics – South American Institute for Fundamental Research in São Paulo, Brazil, and the Institute of Mathematical Sciences in Chennai, India. Both are one-year agreements with an expectation of renewal.

Seven DRCs renewed

Perimeter has recently renewed the appointments of seven leading physicists in the Institute's Distinguished Research Chairs (DRC) program, each for an additional three years. Stephen Hawking, Ignacio Cirac, Subir Sachdev, Yakir Aharonov, Leonard Susskind, Nima Arkani-Hamed, and Renate Loll will all continue to make Perimeter their second research home, enriching all facets of life at the Institute while spending approximately one to two months a year in Waterloo. In addition, Adrian Kent of the University of Cambridge has become a DRC, bringing the total number to 26.

Marvian wins John Brodie Prize

PhD student Iman Marvian received the 2011 John Brodie Memorial Prize, recognizing his work in quantum foundations. The prize is dedicated to the research creativity and independence shown by Brodie, one of Perimeter's first postdoctoral researchers. Nominations for the 2012 prize are expected to open at the close of the calendar year.

Building receives acclaim

The Stephen Hawking Centre at Perimeter Institute (SHC) was honoured with a design excellence designation at the Ontario Association of Architects' 2012 Awards ceremony. Designed by Teeple Architects, the SHC was one of 15 international structures recognized. In addition, at the City of Waterloo's 2012 Urban Design Awards, Perimeter Institute was selected for the William G. Dailey Award of Excellence as "the best overall project in the city."

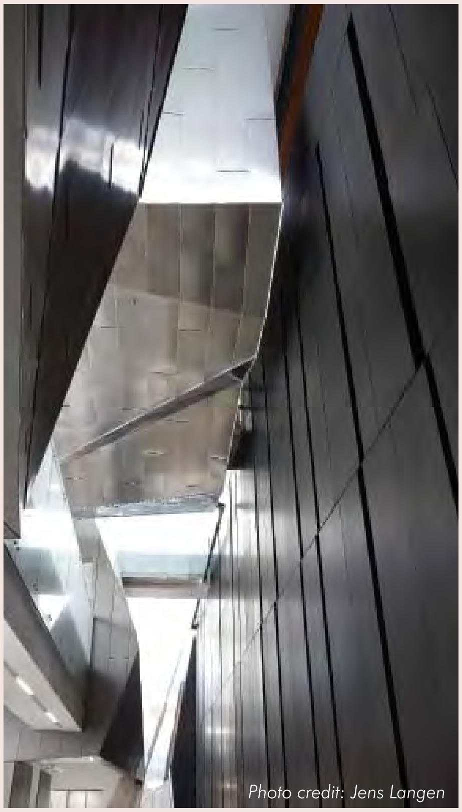


Photo credit: Jens Langen

Check perimeterinstitute.ca for conference updates

Upcoming conferences

Experimental Search for Quantum Gravity: the hard facts
October 22-25, 2012

Emergence and Entanglement II
May 6-10, 2013

Loops 13
July 22-26, 2013

Recent Conferences

Recent Progress in Quantum Algorithms
April 11-13, 2012

This joint workshop – co-sponsored by the Institute for Quantum Computing at the University of Waterloo – discussed the state of the art in quantum algorithms and complexity, and aimed to identify new areas in which quantum computers could play a significant role. With over 50 worldwide participants and 12 plenary lectures, the workshop served as a meeting place for experts, postdocs, and students to present their recent results and discuss major open problems.

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

This workshop brought together a high-powered group of leading experimentalists (mostly from the ATLAS experiment) and theorists, with the aim of understanding the most recent Higgs boson results, confronting current challenges, and paving the way for more precise future measurement. *Editor's Note:* A second workshop with similar focus, but centred around the CMS experiment, was held at Perimeter in August. Read a feature article on that workshop on page 14.

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

This fifth annual one-day symposium gathered condensed matter researchers in southwest Ontario to discuss their most recent research.

Geometry and Physics (GAP 2012)
May 5-7, 2012

GAP 2012 was the fourth annual Geometry and Physics conference – a unique event first launched at Perimeter in 2009, with the goal of highlighting exciting new developments at the intersection of

Participants at the Higgs: Now and in the Future workshop.

geometry and physics, and exposing local graduate students and postdocs to these ideas. Each year, the conference explores three related themes; this year, they were special holonomy, generalized geometry, and integrable systems.

Conformal Nature of the Universe
May 9-12, 2012

This conference brought together some of the world's leading experts to discuss the links between conformal symmetry, cosmology, and gravitational physics. The most widely known such link is the AdS/CFT correspondence, but there are many others. Participants had a variety of expertise, which lead to a lively exchange across different fields in theoretical physics.

Background and Methods of Highly Frustrated Magnetism
June 3, 2012

Highly frustrated magnetism is an active area of research in condensed matter physics, with connections to the quantum computing community. This year, the leading conference on highly frustrated magnetism was held at McMaster University in nearby Hamilton. Before that conference began, Perimeter hosted this one-day tutorial for about 75 graduate students, postdocs, and other researchers, giving an overview of recent developments in the field and providing key background to help these young researchers participate more broadly in the main conference.

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

AdS/CFT correspondence is a framework for addressing questions in strongly interactive systems from a variety of sub-fields of theoretical physics, including condensed matter, high-energy physics, statistical mechanics, and dynamical systems. Over the last decade, most of the field's breakthroughs have concerned static systems. New research attempts to extend the approach to dynamic systems. This workshop brought together researchers from around the world to discuss and explore these new opportunities.

Back to the Bootstrap II
June 11-15, 2012

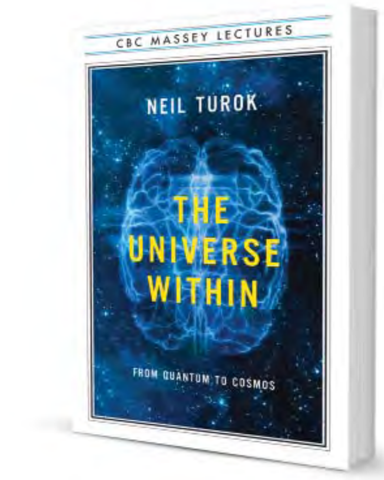
A second installment of a very successful forum with the same name held last year at Perimeter, the "Back to the Bootstrap" workshop was devoted to conformal field theories (CFT) and, in particular, to the circle of ideas surrounding the conformal bootstrap program in three and four dimensions. The bootstrap has been fully successful for two-dimensional CFTs and, in view of recent advances, the time was ripe to reconsider the higher-dimensional bootstrap. This workshop gathered researchers taking a variety of approaches to do just that.

Relativistic Quantum Information
June 25-28, 2012

Relativistic quantum information, or RQI, is a new field that has seen intense activity in the last few years. RQI is concerned with the relationship between special and general relativity and quantum information. Deep questions about the relationship between informational processing and the structure of spacetime are arising. The first experimental tests of the phenomena of RQI seem close. This timely conference brought together some of the most prominent researchers to exchange the latest ideas.

52 teachers from Canada and around the world participated in this year's EinsteinPlus National Teacher's Workshop.

In Good Company



Few among us can claim to have much in common with literary theorist Northrop Frye, economist John Kenneth Galbraith, and civil rights activist Martin Luther King, Jr. But that is the company in which Neil Turok, Director of Perimeter Institute, now finds himself. As the 2012 CBC Massey Lecturer, Turok joins a distinguished list of thinkers in realms ranging from science to literature and philosophy.

Named for former Governor General Vincent Massey, the lectures are sponsored by CBC Radio, House of Anansi Press, and Massey College at the University of Toronto. They were created in 1961 to provide a forum for major contemporary thinkers to address important issues of our time and have been an annual highlight of Canada's intellectual life ever since.

Turok's lectures, *The Universe Within: From Quantum to Cosmos*, seek to share his perspective on the transformative scientific discoveries of the last 300 years and what the coming quantum revolution will mean for the future of science and society.

The Masseys are true multimedia creations, designed to connect with Canadians through three different mass communications media. They are delivered as live lectures in five cities across Canada in October, broadcast on CBC Radio's *Ideas* from November 12 to 16, and published as a physical and e-book by House of Anansi Press.

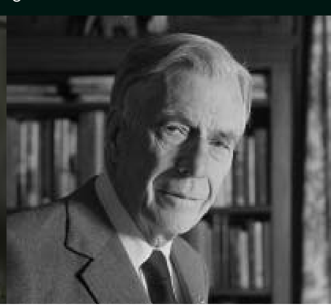
In advance of each lecture, Perimeter's outreach team will visit the host cities to give *GoPhysics!* and *Physica Phantastica* presentations to students illustrating the connections between Turok's lectures and current modern physics understanding, from the ultra-small quantum world to the expansive cosmos.

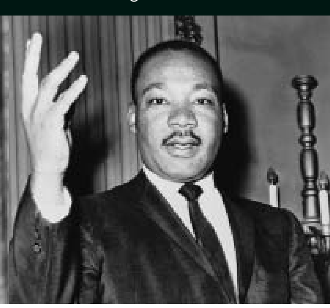
It all began a couple of years ago when Turok addressed a group of journalism fellows at Massey College.

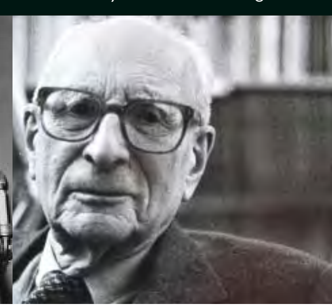
"Everyone was completely blown away by his talk," says Janie Yoon, Senior Editor with House of Anansi Press, who worked with Turok to prepare the book manuscript. "He's such an eloquent and elegant speaker and he's able to relate science and his humanist ideas in such a captivating and accessible way."

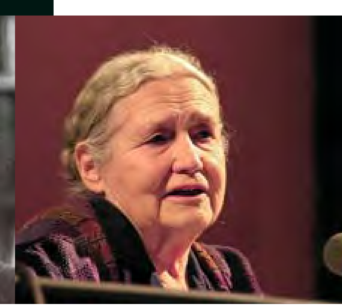
The Massey Lectures began in 1961 and have featured some of the greatest thinkers of the last 50 years, including:


Northrop Frye
The Educated Imagination
1962


John Kenneth Galbraith
The Underdeveloped Country
1965


Martin Luther King
Conscience for Change
1967


Claude Lévi Strauss
Myth and Meaning
1977


Doris Lessing
Prisons We Choose to Live Inside
1985

"My goal is to celebrate our ability to understand the universe, to recognize it as something that can draw us together, and to contemplate what it might mean for our future.… Our science and our humanity are two sides of the same coin. Together, they are the means for us to live up to the opportunity of our existence."

\- Neil Turok, *The Universe Within: From Quantum to Cosmos*

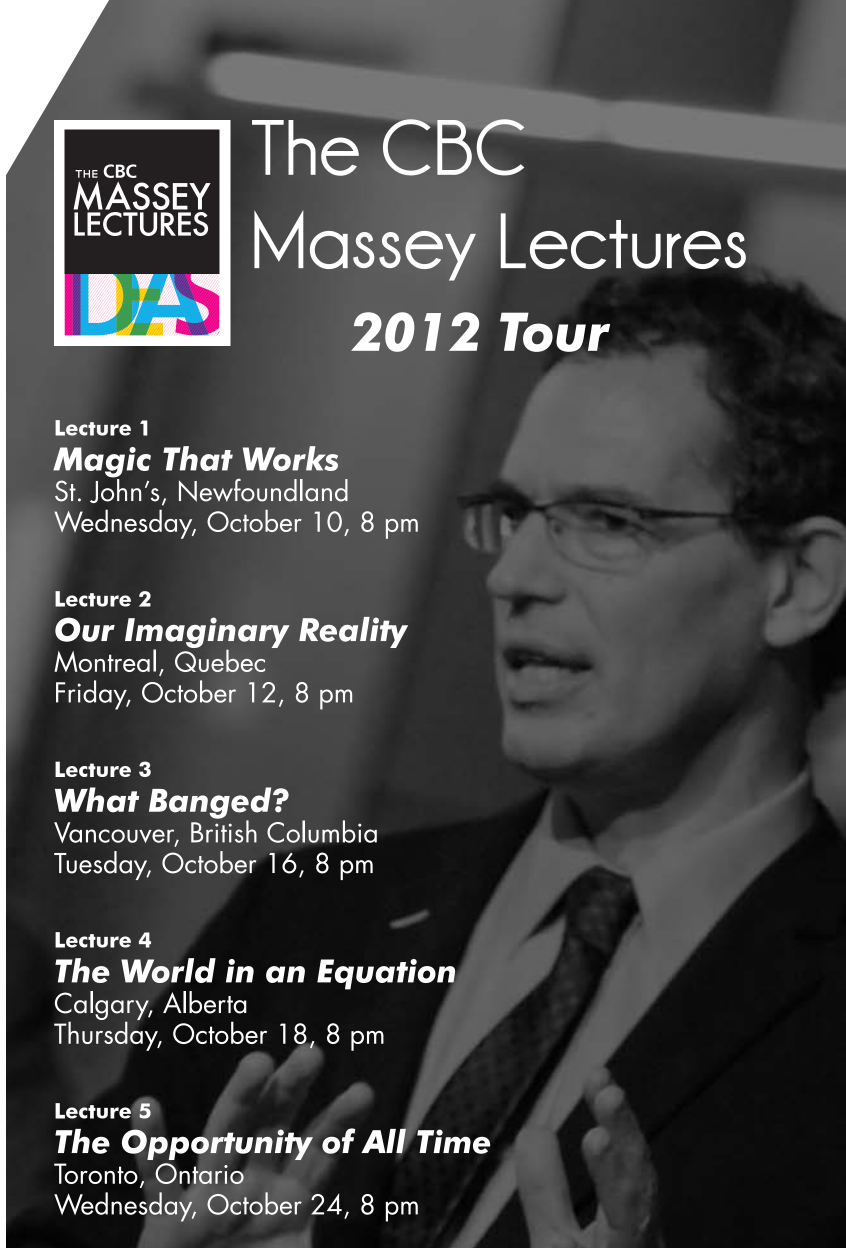
Yoon is part of a group that gets together once a year to brainstorm about possible future Massey Lecturers, often floating several names before coming to a consensus. After hearing him speak to the journalism fellows, John Fraser, Master and Chair of Massey College, suggested Turok. "I remember clearly that when Neil's name was mentioned, there was a second of silence and everyone said, 'Yes, absolutely,'" says Yoon.

Turok is the first scientist to give the Massey Lectures in over two decades, since Richard Lewontin's *Biology as Ideology: The Doctrine of DNA* in 1990. With the recent discovery of the Higgs boson thrusting physics into the limelight, the timing couldn't have been better, says Yoon.

Having previously worked on Massey Lectures by Douglas Coupland and Adam Gopnik, Yoon admits that she found this go-around the most daunting. She felt the need to confess to Turok that she'd dropped out of high school physics after only one day and recalls marvelling that she could even share the same room with a man who understands the universe on such a different level. In a way, though, this made her the perfect test audience. One of Turok's major themes is bridging the gap between science and society, so making the lectures accessible was very important to him.

"It is an incredibly ambitious book. To make it succinct and economical and to ensure that there was a narrative arc that tied all of it together – that alone was so hugely challenging," says Yoon. "And that's besides the idea of being able to explain in concrete terms something as abstruse as mathematics. But I think he's succeeded. I've said this to him, but when I look back, this will definitely be one of the best books I've worked on. I can feel that."

- Mike Brown



THE CBC MASSEY LECTURES

The CBC Massey Lectures

2012 Tour

Lecture 1
Magic That Works
St. John's, Newfoundland
Wednesday, October 10, 8 pm

Lecture 2
Our Imaginary Reality
Montreal, Quebec
Friday, October 12, 8 pm

Lecture 3
What Banged?
Vancouver, British Columbia
Tuesday, October 16, 8 pm

Lecture 4
The World in an Equation
Calgary, Alberta
Thursday, October 18, 8 pm

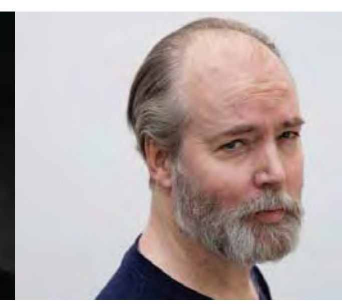
Lecture 5
The Opportunity of All Time
Toronto, Ontario
Wednesday, October 24, 8 pm

Noam Chomsky
Necessary Illusions
1988

Michael Ignatieff
The Rights Revolution
2000

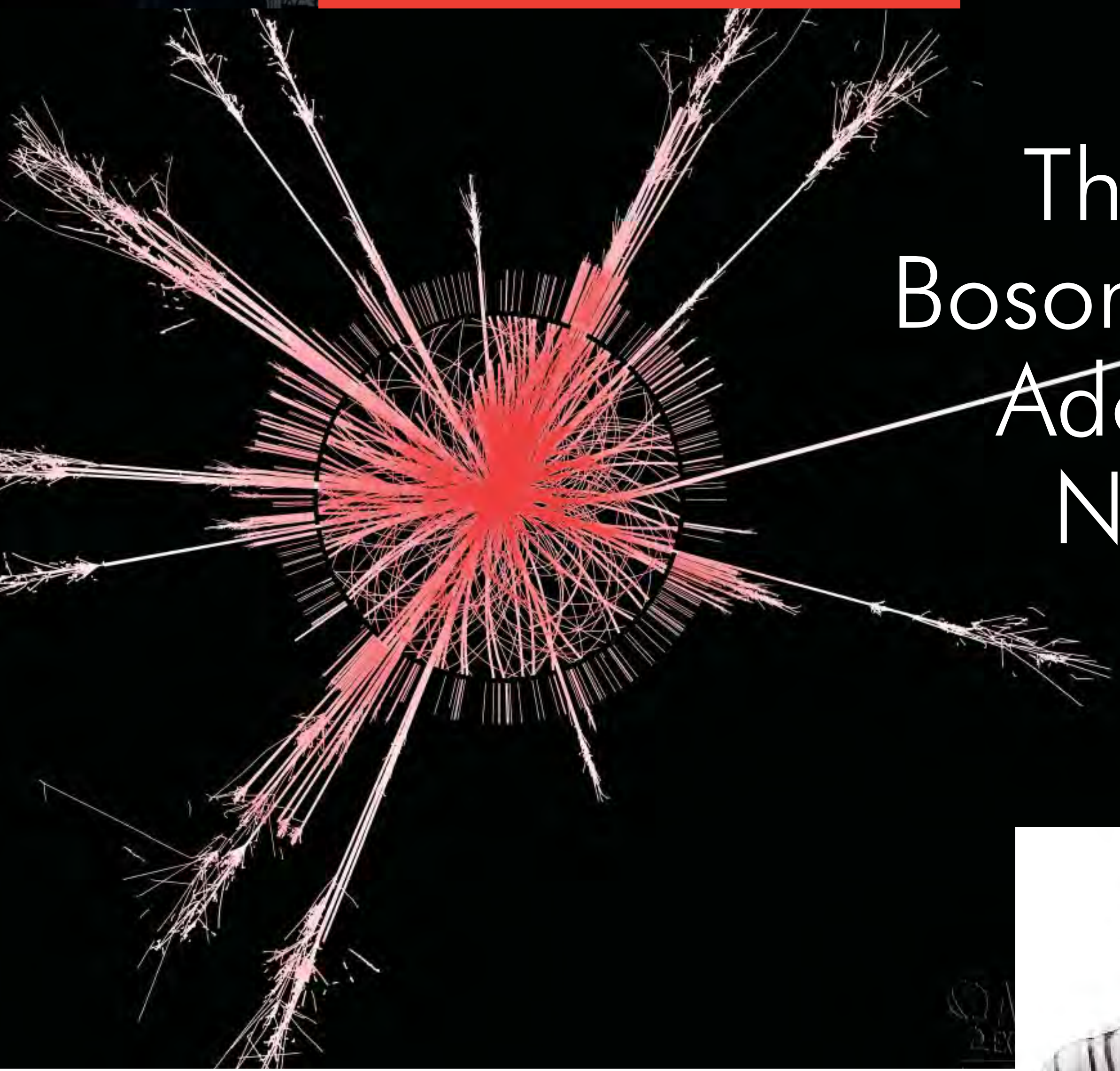
Stephen Lewis
Race Against Time
2005

Margaret Atwood
Payback: Debt and the Shadow Side of Wealth
2008



Douglas Coupland
Player One: What is to Become of Us
2010

The 2012 Massey Lectures will be broadcast from November 12 to 16, 2012 on CBC's *Ideas*, weekdays at 9 pm.



The Higgs Boson: Much Ado About Nothing?

It took 40 years, and cost billions of dollars, but the Higgs boson has finally been found. In the excitement that followed, it was clear to the general public that discovering the Higgs is a Nobel-worthy Big Deal. But is it much ado about nothing?

It is all about nothing – but not quite in the way you might think. The Higgs boson is significant because of what it says about the vacuum.

Colloquially, a vacuum is a space entirely devoid of matter, but to physicists the vacuum is the physical state having the lowest energy. Until the 1960s, these two notions of vacuum were thought to be synonymous. Since matter carries energy, when you remove it all, what is left should have the least possible energy. But then, over 40 years ago, Peter Higgs and others realized that the state with least energy needn't be empty. It can instead be filled with a physical quantity called the Higgs field.

A field is something that can mediate a force, much like the gravitational field mediates the attraction felt by a ball falling to the earth or a magnetic field mediates the force between the earth and a navigational compass. The hypothetical Higgs field would similarly mediate a new force between particles.

What is unusual about the Higgs field is that it costs less energy to have it than not to have it. This means that although gravitational and magnetic fields vanish if there isn't a mass or a magnet around, the Higgs field should be present even in the vacuum, without any particles.

The Higgs field is to particles as the ocean is to fish. The ocean isn't created by fish and the Higgs field is not created by the particles. But, if you want to understand fish, you'd better understand water – and if you want to understand the properties of particles, you'd better understand the Higgs field.

The idea that the vacuum is pervaded by a physical field seems bizarre. Its proposal in the 1960s was provoked to reconcile some new-found properties of the weak interactions – those interactions that mediate radioactive decays – with familiar properties of elementary particles. In particular, the weak interactions appeared to require elementary particles like the electron to move at the speed of light, which they clearly don't. But the puzzle could be resolved if the vacuum were filled with a field that could slow the electrons down.

Is the vacuum really filled with a field? How could such a radical speculation be tested? What better way than to excite a wave in the vacuum? This is just what CERN physicists did. By colliding particles with sufficient violence in the LHC, they caused a wave to move through the vacuum. In the same way that electromagnetic waves (including light, radio, and UV waves) are known to consist of swarms of particles called photons, the newly discovered Higgs particles make up waves in the Higgs field: that is, waves in the properties of the vacuum itself.

Confirming the existence of the Higgs field has been an epic journey. After being out on a theoretical limb for more than 40 years, a pillar of experimental evidence now supports a radical view of the vacuum. And now that waves in the vacuum can be produced at will, studying them can test whether the vacuum is better described by the Standard Model or by one of the alternatives that wait to replace it.

Enough about that, says the man in the street. Is the Higgs boson going to change my life?

In some ways, it already has: the ability to reach the world at the click of a mouse is partially due to the invention at CERN of the World Wide Web in the early days of LHC development. In the long run, its long-term impact is difficult to predict. But if revolutions in computer miniaturization can be traced to our ability to manipulate atoms, imagine what an ability to manipulate the vacuum might bring. Much ado about nothing indeed.

- Cliff Burgess

Cliff Burgess is a particle physicist and Associate Faculty member at PI, who is jointly appointed at McMaster University.

An earlier version of this article appeared in the July 7, 2012, edition of the Toronto Star.

MINUTE PHYSICS

The following is an excerpt from the first of three videos on the Higgs boson from MinutePhysics, produced by Perimeter's Film & Media Artist-in-Residence Henry Reich. A spiralling YouTube success, MinutePhysics has a half-million subscribers and more than 35 million views.

The Higgs boson is a particle that's an excitation of the Higgs field, which was needed in the Standard Model to (1) explain the weak nuclear force and (2) explain why any of the other particles have mass at all. The boson is the only part of the Higgs field that is independently verifiable, precisely because the other parts are so tangled up in the weak nuclear force and in giving particles mass.

The fact that the Higgs boson is so independent from the rest of the Standard Model is why it's the last piece of the puzzle to be discovered. And if it turns out to be exactly what was predicted, then the Standard Model would be complete.

The only problem is that we know the Standard Model isn't a complete description of the universe. It entirely misses out on gravity, for example. To physicists, it would be much more interesting and helpful if the Higgs boson turns out to be not quite what we expect. Then, we might get a clue as to how to reach a deeper understanding of the universe.

It's Postdoc recruiting season!

Applications are now being accepted for postdoctoral research positions to begin in the fall of 2013. New and recent PhDs working in fundamental theoretical physics are encouraged to apply by November 16, 2012. Most postdoctoral positions are three-year terms, though outstanding candidates may be considered for five-year senior fellowships. For more information, visit www.perimeterinstitute.ca.

What's Next for the Higgs?

After the work, the party. After the party – more work.

In July, the physics world celebrated when the elusive Higgs boson – the subject of a decades-long intensive search – was found at last. After the celebration, though, physicists went right back to work. Finding the Higgs does not simply mean an old theory was proven right. It means new theories can be tested more sharply than ever.

"Discussions at PI have contributed to an ongoing strategic shift in the management and intellectual direction taken by the collaboration. Within my group, the PI workshop is seen as a turning point in our strategic development, and the discussions we enjoyed there should seed changes which will have a large impact on our future work."

- Steve Worm, CMS Group, Experimental Division B

An early stop on the road to the next phase of Higgs research came in August, when physicists from around the world gathered here at Perimeter. The conference brought theorists from around the world together with particle experimentalists from the CMS experiment. (Physicists from the other general-purpose CERN experiment, ATLAS, gathered for a conference at Perimeter in April.)

According to CMS spokesperson Joseph Incandela, "My own view was that it was the most useful workshop I have ever attended. I wish all workshops could be like this. Nobody was pushing anything. It was really great. We all had a common goal of trying to figure out where the new physics might appear and I think we came away with a lot more ideas than I had anticipated."

The conference was organized by Perimeter Faculty members Natalia Toro and Philip Schuster, along with Incandela, and CMS physics coordinator Greg Landsberg. Other participants included many of the experiment's current "conveners" – senior physicists who supervise segments of the research program – and a few dozen particle physics theorists.

Though technically on "LHC Search Strategies" broadly, the conference naturally focused on questions raised by the newly discovered Higgs. For three days, the 50 participants discussed what the new data about the Higgs boson means, which theories would explain all aspects of the results, what the next important measurements are, and what we are likely to learn from them.

These questions start with the Higgs, but their answers will come largely from searches for other new particles. There may be additional Higgs-like particles that might be harder to find than this first one. There may be partner particles: the Higgs boson just discovered is spin zero and everything we know about spin-zero particles from theory and past experiments suggests that it should generically – the technical term physicists use is "naturally" – be accompanied by new particles that we haven't yet found. The best-known beyond-the-Standard-Model

The CMS Detector at CERN.

Higgs: Charting the Channels

The Higgs discovery was made via analysis of decay particles. Scientists study decay products because the Higgs boson is very unstable. It is created by very high energy collisions, such as those in the Large Hadron Collider, but lasts for only a tiny fraction of a second – less time than it would take a beam of light to cross the width of an atom – before it decays into a handful of secondary particles. It is these secondary particles that are measured by the ATLAS and CMS detectors. There are several special combinations of particles that the Higgs can decay into and each of those combinations is called a "channel."

The next step will be to measure each channel more carefully and map out exactly how the particle decays: into what channels with what frequencies. This will not only confirm that this particle is the Higgs, but will also tell us what kind of Higgs it is.

Theorists have a number of competing ideas about the framework underpinning both the Standard Model and the Higgs mechanism. Each of these competing ideas gives slightly different predictions about the properties of the Higgs boson. By mapping the decay channels – and doing other things like measuring the spin – physicists can determine what the properties of the newly discovered Higgs are and thereby begin to zero in on the right framework.

The Higgs could then become a tool to probe physics beyond the Standard Model.

theory with partner particles is supersymmetry, but extra-dimensional theories, technicolour theories, composite-Higgs theories, little-Higgs theories, and others have them also. Finally, there may be exotic particles – such as partner particles for the lighter quarks – hiding somewhere in the vast amounts of data the LHC produces.

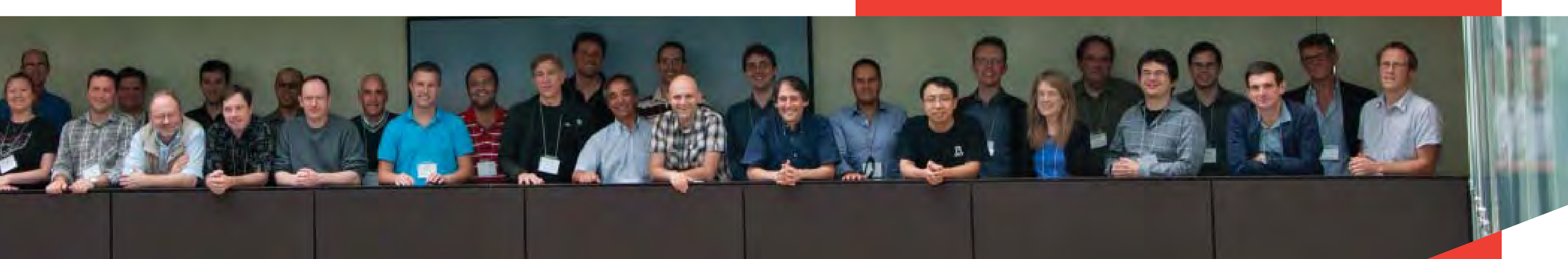
"We shouldn't assume we've seen everything that's there," says Toro. "Some things may be hard to tease out."

"The Higgs itself is a case in point," notes Schuster. "The mass we just measured means humans have been producing this Higgs particle for about 20 years, since the Tevatron came online at Fermilab. It can take a lot of data and a lot of work to find these things."

"What's required to learn more is a very broad, very systematic search program," Schuster continues. "The big question driving this workshop was, 'What are the key pieces of that program, and how will it teach us about the origin of the Standard Model itself?'"

"It's an exciting time," Toro adds. "Now that the Higgs has been found, we're past the realm of speculation. We can ask very focused questions about what to look for in our data to solve the big puzzles in particle physics. This workshop helped us decide what to ask, and how."

- Erin Bow



Participants at the "LHC Search Strategies" conference.

Matt Johnson: Figuring out the Beginning of the Story

Matt Johnson first thought he wanted to be a fiction writer, but the fantastical true story of the universe proved more alluring. Today, his research centres on cosmology – how the universe began, how it evolved, its ultimate size, and where it's headed.

He recently became Perimeter's newest Associate Faculty member, jointly appointed with York University.

"Perimeter is the most exciting place around to do research in early universe cosmology. We've got Neil Turok as the Director, we've got Stephen Hawking visiting regularly, great faculty, very bright postdocs and students. People here are doing excellent research," says Johnson, who has reason to know. Before being appointed as a faculty member, he was a postdoc at Perimeter. Prior to that, from 2007 to 2010, he was the Moore Postdoctoral Scholar at Caltech.

Johnson's hiring is Perimeter's first joint appointment with Toronto's York University, which offers complementary strengths to Perimeter's. "York is really strong in astronomy, high energy theory, and experimentally – their group performed the first spectroscopic measurements of antihydrogen atoms a few months ago," says Johnson.

Right now, says Johnson, he is working on how a radical sounding prediction of string theory could be tested observationally.

"The current standard model of cosmology proposes two periods of accelerated expansion: inflation in the first instants after the Big Bang and the present era of dark energy domination. My research on how these epochs begin and end could have big implications for the age-old question, 'How big is the universe?'"

A staple of many modern physics theories is the idea that accelerated expansion takes place within small regions of the infant universe called "bubbles." One implication of this is the eternal inflation scenario: in some regions, expansion never ends! In this picture, our observable universe is just one corner of a patchwork multiverse with diverse, spacetime-dependent, physical properties. If this is the case, there could be many universes – each in its own bubble.

Could these bubble universes ever touch or collide, and what would happen if they did?

Recently, Johnson showed that this radical picture of the universe, contrary to previous thought, can in fact be tested by looking for the signature of collisions between bubbles. With collaborators in fields ranging from observational cosmology to numerical relativity (including Perimeter's Luis Lehner), he proposed and investigated the potential signatures of bubble collisions, and performed the first observational tests of eternal inflation using observations of the Cosmic Microwave Background (CMB) radiation from the WMAP satellite.

Now, he intends to take the work a step further with upcoming data from the Planck satellite, expected in early 2013 and 2015.

"This data will tell us if there's any evidence for bubble collisions. It may also shed light on the question of how the four-dimensional universe we experience could result from theories with extra spatial dimensions, such as string theory. With fundamental theory guiding observational searches, perhaps we will find that the universe is larger and more diverse than we ever have imagined."

- Natasha Waxman

Kendrick Smith: Looking Back in Time

Kendrick Smith studies the infant universe – and like anyone with an infant in their life, he's juggling several roles.

For instance, Smith, a new Perimeter faculty member, describes himself as part observational cosmologist, part theorist. "I definitely live with one foot in each world," he says. "I write pure theoretical papers, playing with different possibilities for Big Bang physics, predicting what their statistical imprints would be. I also write data analysis papers and I'm a member of collaborations like WMAP and Planck."

The space-based telescope WMAP – or Wilkinson Microwave Anisotropy Probe – was one of the first experiments to map the small variations in the oldest light in the universe, the cosmic microwave background radiation (or CMB). This ancient light comes from the first moment in which the universe became transparent, just 378,000 years after the Big Bang itself. It was a landmark experiment in cosmology: it confirmed our basic picture of the universe and added unprecedented precision. It's thanks to WMAP, for example, that we know the age of the universe. Recently, the WMAP team and its lead scientist, Charles Bennett, won the Gruber Prize in Cosmology. The prize citation noted that their results helped transform cosmology itself from "appealing scenario into precise science."

WMAP is no longer taking data. The Planck experiment is a new space-based telescope that aims to expand and improve on WMAP's work. Smith is also involved with the QUIET experiment, an earth-based telescope that seeks to measure the polarization of the cosmic microwave background.

"What we're trying to do with experiments like this is use the entire universe as a giant particle accelerator," Smith explains. Particle accelerators, like the Large Hadron Collider at CERN, are often described as recreating the hot, dense conditions of the early universe in miniature. Smith's approach simply skips the middle man. "We can treat the data we have from the early universe as if it were data from a particle accelerator experiment," he says.

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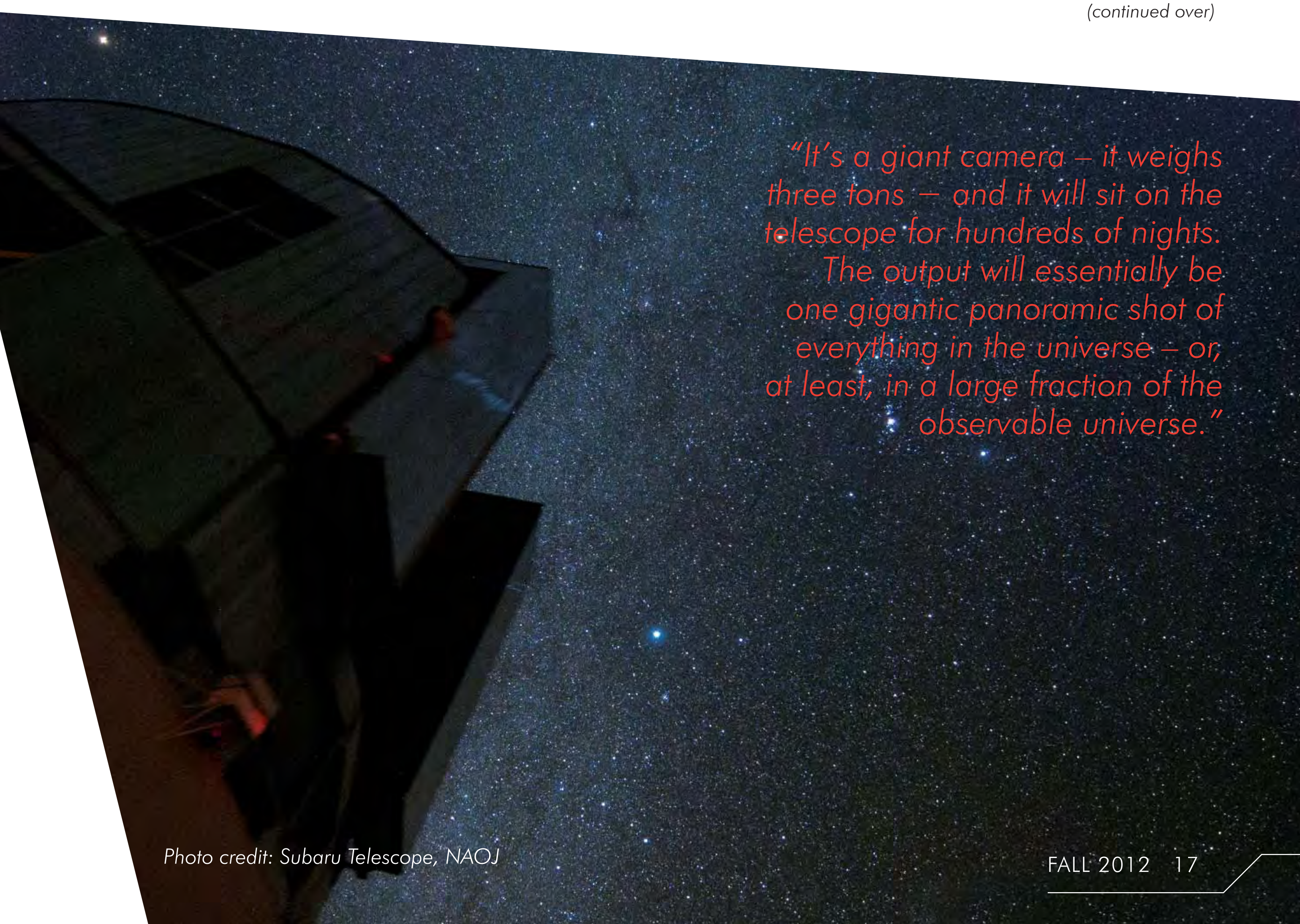

"It's a giant camera – it weighs three tons – and it will sit on the telescope for hundreds of nights. The output will essentially be one gigantic panoramic shot of everything in the universe – or, at least, in a large fraction of the observable universe."

Photo credit: Subaru Telescope, NAOJ

"By observing the statistical properties of the universe, we can get some insight into what was happening during the Big Bang. We're looking for evidence of the kind of physics that occurs at much higher energies than we will ever be able to access here on earth."

Smith is responsible for several landmark results in cosmic microwave background studies. He was the first to detect gravitational lensing in the CMB. He also improved the way in which CMB data were used to constrain the theories about the physics of the Big Bang and thereby showed that WMAP data was consistent with single-field inflation.

Smith started at Perimeter in September, but we won't see much of him until 2013. This year, he is largely on site with the Hyper Suprime-Cam project. The HSC is a gigantic digital camera being built for the Subaru telescope.

Perched on the summit of Mauna Kea in Hawaii and run by the National Astronomical Observatory of Japan, Subaru is a specialized telescope that has been finding and characterizing some of the most distant – and therefore oldest – objects in the universe. The new camera will vastly expand its reach. "It's a giant camera – it weighs three tons – and it will sit on the telescope for hundreds of nights," Smith explains. "The output will essentially be one gigantic panoramic shot of everything in the universe – or, at least, in a large fraction of the observable universe."

Where the cosmic microwave background is a snapshot of the infant universe, before stars and galaxies formed, the picture from the HSC will tell us about the universe in its toddler years. "It's more powerful for things that only happened in the later universe," says Smith. "For example, we'll be able to look for evidence of dark energy – our name for whatever it is that seems to be pushing the universe apart at ever-growing speeds. We don't know much about it and we need to know more."

Smith comes to Perimeter from Princeton, where he has been the Lyman P. Spitzer Postdoctoral Fellow since 2009. Prior to this, he was the PPARC Postdoctoral Fellow at the University of Cambridge from 2007 to 2009. This is his first faculty position.

- Erin Bow

So you're telling me gravity's not a force pulling down? Outreach scientist Richard Epp completes a demonstration with two teachers that shows the fallacy in Newton's force model of gravity and helps explain why we moved to Einstein's curved spacetime model instead. This was just one of the highlights from the 2012 Ontario Association of Physics Teachers conference, which was held at Perimeter.

Associate Faculty Member Avery Broderick and his son making Crazy Cosmic Creations at a family fun event in June 2012.

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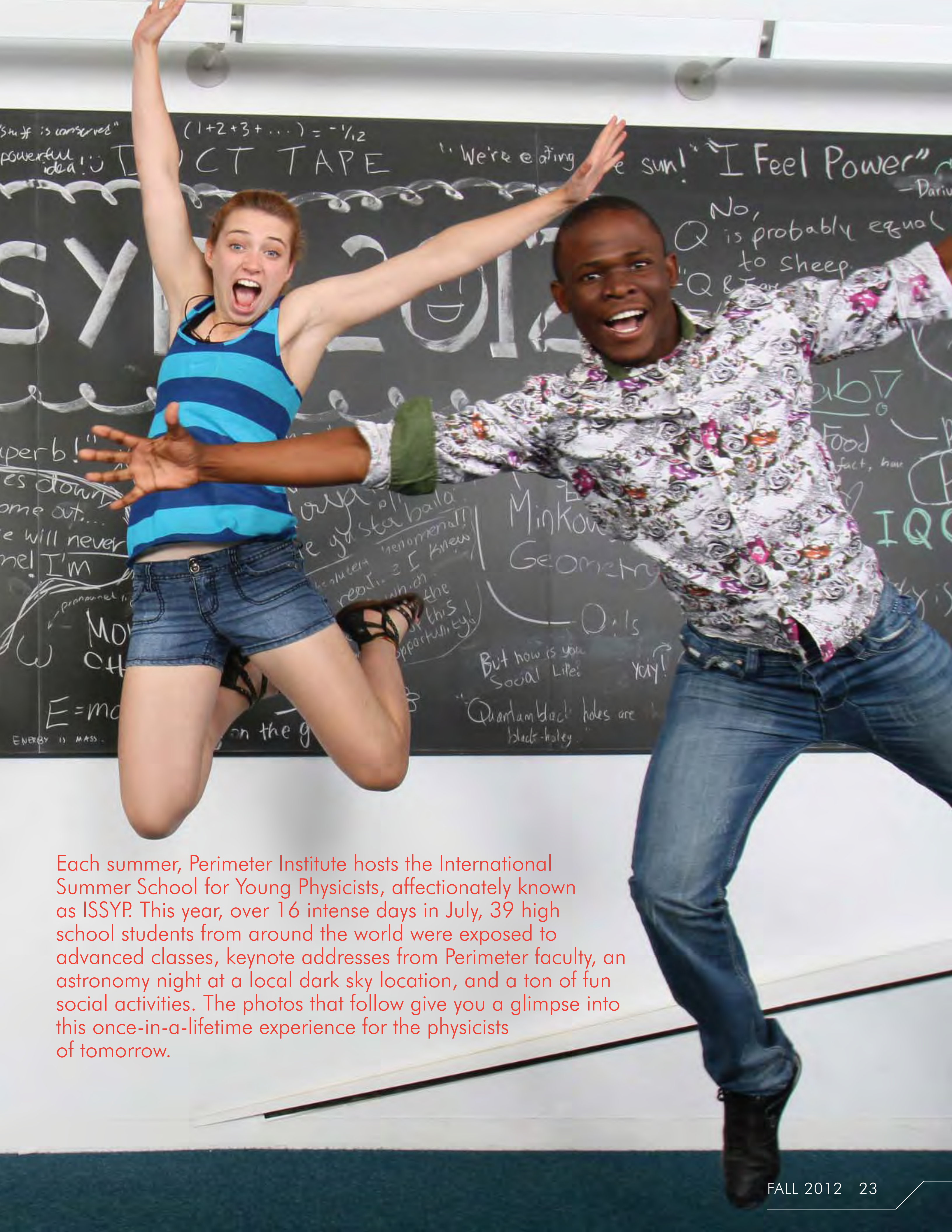

Each summer, Perimeter Institute hosts the International Summer School for Young Physicists, affectionately known as ISSYP. This year, over 16 intense days in July, 39 high school students from around the world were exposed to advanced classes, keynote addresses from Perimeter faculty, an astronomy night at a local dark sky location, and a ton of fun social activities. The photos that follow give you a glimpse into this once-in-a-lifetime experience for the physicists of tomorrow.

With students representing 13 countries, ISSYP 2012 was a truly international program. Above, Boya Zhao of China (left) and Alexander Sidorov from Russia (middle) work on an experiment, as Richard Epp looks on.

Emma Taylor of Alliston, Ontario experiences physics in action at Science North in Sudbury. She said, "I have had my views of the world shaken up completely and I really like that. My drive to learn more has increased exponentially."

Students traversing an underground tunnel at SNOLAB, one of the experimental centres they visited during the two-week summer school. "The visits to IQC and SNOLAB showed me that scientific progress is not slowing down. Actually, it takes place before our very eyes," said Iwona Chalus, a participant from Poland.

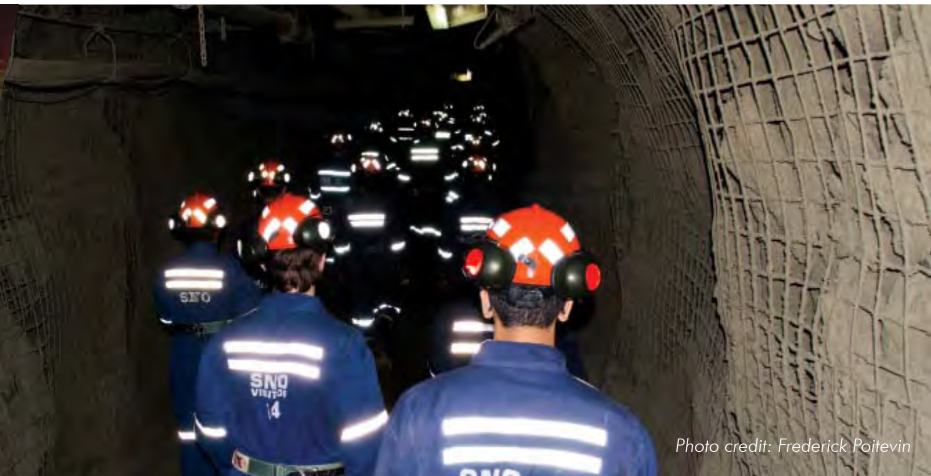

Photo credit: Frederick Poitevin

Students worked in small groups with Perimeter scientists in areas of particular interest to them. "The mentoring sessions were invaluable," said Mathew DeCross of Rochester, New York. "They were providing this really intense level of depth that let us see more directly exactly what's involved in this field we're getting into." The groups presented their findings at a poster session in Perimeter's atrium.

At ISSYP's closing ceremony, Richard Epp, Senior Manager of Scientific Outreach and one of the program's guiding hands, knighted each participant in the summer school, saying, "I dub thee, International Young Physicist."

At ISSYP, students from all over the world have the chance to meet and bond over their shared passion for physics. "I'll definitely stay in touch with the people I've met at ISSYP," grinned Kalina Slavkova of DeLand, Florida.

Photo credit: Frederick Poir

Generous support for ISSYP is provided by

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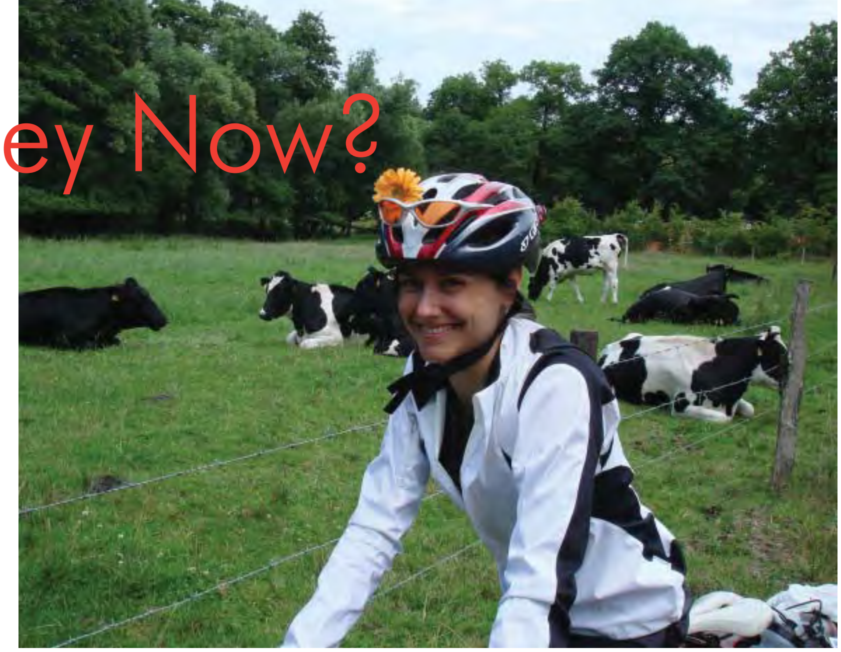
Where Are They Now?



A different kind of cycle: Levasseur splits her time between early universe cosmology and epic bike rides. She's already biked from Montreal to Jacksonville, Florida, and is planning to pedal from Paris to Beijing.

Laurence Perreault Levasseur is a rising star in theoretical physics. At 24, she's working on her PhD at Cambridge, has three peer-reviewed publications, and owns an enviable conference presentation record. She was recently selected as one of this year's "30 under 30" by *Scientific American*, and attended this year's prestigious Lindau Meeting, an invitation-only conference that gives promising young scientists a chance to rub elbows with Nobel laureates.

Her career got a jump start when she was a high school student selected to attend the International Summer School for Young Physicists (ISSYP), Perimeter's annual summer camp for gifted high school students from across Canada and around the world. Participants learn intensively, meet Perimeter scientists, visit science laboratories, and bond over a shared love of physics. It's an enrichment opportunity like no other and often helps talented students like Levasseur make the decision to pursue physics at the university level.

Levasseur attended ISSYP in 2004 and says it "profoundly modelled" her view of science. Since her time at Perimeter, the program has expanded its international scope, increased the number of students to 40 per year, and graduated 160 more kids with star potential.

Levasseur, who recently returned from teaching physics to undergraduate students in China, wrote to *Inside the Perimeter* to tell us about her doctoral research:

"It fits in the bigger picture of inflationary cosmology," she says. "During the first moments after the Big Bang, when the universe was expanding exponentially, it's believed that the seeds for the formation of all large-scale structures of the universe – like galaxies – were produced from quantum fluctuations in a scalar field. One of the key parts of the story of any inflationary model is how to end inflation. This process is called reheating and it's one of my main interests.

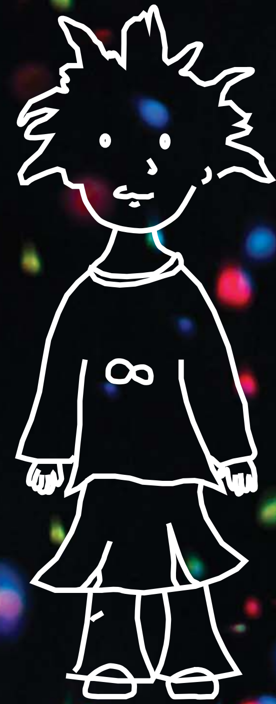
I am also interested in alternatives to inflation – theories that preserve the success of inflation, but get around some of its problems. Along this line, I have been studying theories of modified gravity, particularly Galileon theories."

Levasseur credits ISSYP as her "first contact with advanced physics," where she met first-class scientists and had the chance to share her passion for science. This, of course, is exactly what it was designed to do. At less than a decade old, ISSYP is still evolving. But Levasseur's success shows that it is already bearing fruit. As more ISSYP graduates continue to distinguish themselves, more promising scientists are expected to point to Perimeter as the place where their life in science began.

- Phil Froklage

"Rowdy" Rob Spekkens squaring off against "Lethal" Latham Boyle in Perimeter's second Annual Sumo Tournament, which raised money for a local charity.

PI KIDS ARE ASKING



Nora, who is four, loves to mix paint to get new colours. She wants to know: "How come I can't mix white?"

Well, it's all about light. White light – like sunlight or the light from most light bulbs – is actually a mix of all the different colours. You can see this for yourself: sometimes, if you shoot a beam of white light through something clear, you'll see a rainbow. All the different colours of the rainbow, when mixed together, make light white.

If you were mixing light instead of paint – if you had coloured flashlights, for example – then you could mix white. You could just add all the colours of the rainbow back together. But mixing paint is different than mixing light.

Paint isn't like a flashlight. It doesn't give off light. It's like a mirror. It bounces light back to you. If something looks white, it's bouncing all the light back at you. If something looks blue, it's bouncing only the blue light back at you. All the other colours are being absorbed – sucked up by the paint and turned into heat. If something looks black, it's actually absorbing all the different kinds of light and turning them into heat. That's why, for example, a black shirt gets hotter in the sunshine than a white one.

So why can't you mix your paints together to get white? It's because every colour of paint takes away some light. Keep mixing all the colours and you'll take away all the light: you'll get black.*

Or, to put it another way: Remember that white light is a mix of all the colours? You'll never get all the colours by taking colours away.

Try this: Put pieces of coloured cellophane over flashlights with rubber bands and try mixing light instead of paint. Shine coloured light on coloured objects and watch how things change. Make the beams from two flashlights overlap on a white piece of paper. What happens if you mix red and yellow light together? You won't get orange – but you might get curious.

*If you really mix all your paints, you'll probably get a grey-brown. The reason is that there are colours you can't get by mixing the usual assortments of red, yellow, and blue paints – magenta, for example – and those left-over slips of colour lighten up the black a little. See physics.info/color/ for more about colour mixing.

- Erin Bow

Got a question for PI Kids? Send it to newsletter@pitp.ca

Photo credit: JohnKyo, red-letterimaging.com

A Chat With Bianca Dittrich

Bianca Dittrich is one of Perimeter's first home-grown faculty members.

Bianca grew up in Berlin and completed her undergraduate degree at the nearby University of Potsdam. She did her diploma thesis with Renate Loll, who is now a Perimeter Distinguished Research Chair. In 2002, just a year after Perimeter began scientific operations, she came here briefly with her (then) PhD thesis advisor, Thomas Thiemann. Later, she spent three years here as a postdoctoral fellow. More recently, she led the Max Planck Research Group "Canonical and Covariant Dynamics of Quantum Gravity" at the Albert Einstein Institute in Potsdam, Germany.

Bianca's particular research interest is the dynamics of quantum gravity.

Inside the Perimeter: I've heard Perimeter's Director, Neil Turok, call quantum gravity the most challenging problem in physics today. What made you pick the hardest thing out there?

Bianca: I didn't make a conscious decision to pick the hardest thing. The gravity theory which we have – Einstein's general relativity – is a very beautiful theory. The maths do become difficult, but at its heart, it's so simple – it just describes gravity as a property of spacetime. To unite it with another very beautiful theory, quantum field theory… Let's just say it's an interesting challenge.

Inside: Can you give us some feeling for how you spend your working days? What's the big question that preoccupies you?

Bianca: Mostly, my work is to do with making a quantum theory of spacetime, because by describing spacetime we inherently describe gravity. So I spend my time asking what quantum spacetime looks like. Can spacetime really be divided into atoms?

Inside: I think you don't mean "atoms" in the sense of "hydrogen atoms," but rather in the sense of the Greek word "a-tomos" – that which can't be cut?

Bianca: Exactly. The idea is that spacetime is made up of small grains, like grains of sand, which can't be divided further – that there's some minimum volume that acts as a quanta of spacetime and a volume smaller than that doesn't make physical sense. We call these atoms of spacetime, even though it doesn't have anything to do with the kind of atoms that make up molecules.

The main problem is to make sense of the statement, "What does it mean for spacetime to be made of atoms?"

Inside: I admit, I don't instantly see the challenge …

Bianca: It's that everything has to be described relationally. Say there is such a thing as a minimal volume and it's x by y by z 10 to the minus 35 metres, or Planck lengths, or what have you.

Inside: Very small.

Bianca: Yes, but my point isn't that it's very small, it's, "What are you holding the ruler against?" If what you are describing are atoms of spacetime, you can't describe them as atoms in spacetime. In such a situation, what does the phrase "minimum volume" even mean? In such a situation, it doesn't make sense to speak about movement. It doesn't make sense to talk about position.

Inside: Okay, now I begin to see the problem.

Bianca: It's a big one.

Inside: And which part of this big problem has grabbed you? What are you working on?

Bianca: At the moment, I'm working on the problem of how to get from the little grains, or atoms, of spacetime, back to a smooth structure. We can create a theory of quantized spacetime that works for a few atoms, but that theory needs to be able to deduce what spacetime looks like macroscopically, if you have many atoms.

We do know what spacetime looks like on a large scale. We know it looks smooth – it is called the fabric of spacetime for a reason. We know, for instance, that it exhibits diffeomorphism symmetry, which is the symmetry of general relativity. That means that gravity is invariant under a change of coordinates.

Inside: That is to say, gravity works the same here as it does over there. If I tip the solar system this way, the gravity is the same as if same as if I tip it that way. The coordinate system and the position don't matter.

Bianca: Right. And again, this is deeply related to the problem that atoms of spacetime don't have a position in spacetime, because they are spacetime.

Inside: Now my head is starting to hurt. Let's switch gears. Can you remember how you first got into physics, into science? Were you one of the stargazing kids?

Bianca: Yes! I took an astronomy course in school – I think I was 18 – and my primary reason for doing that was to finally get to look through a telescope. And I did. But unfortunately I got to look through it in the daytime. Inside.

Inside: Well, that's disappointing!

Bianca: In defense of my teachers, it was Berlin. With the light pollution, it's not the best place for stargazing.

Inside: Still, you can see more if you take the telescope outside. But despite this crushing disappointment, you ended up in physics.

Bianca: It wasn't obvious to me that I wanted to study physics. I was interested in things like geo-ecology and chaos theory. I did some chemistry at school. But it turned out that what I liked about those subjects was always the physics. If you keep asking question after question after question about something, if you really run it to ground – someone will say, "Well, that's physics."

Inside: I can imagine that if you keep asking the "why is that?", "why is that?", "why is that?" questions, you eventually end up at the very bottom, with atoms of spacetime.

Bianca: Well, I did.

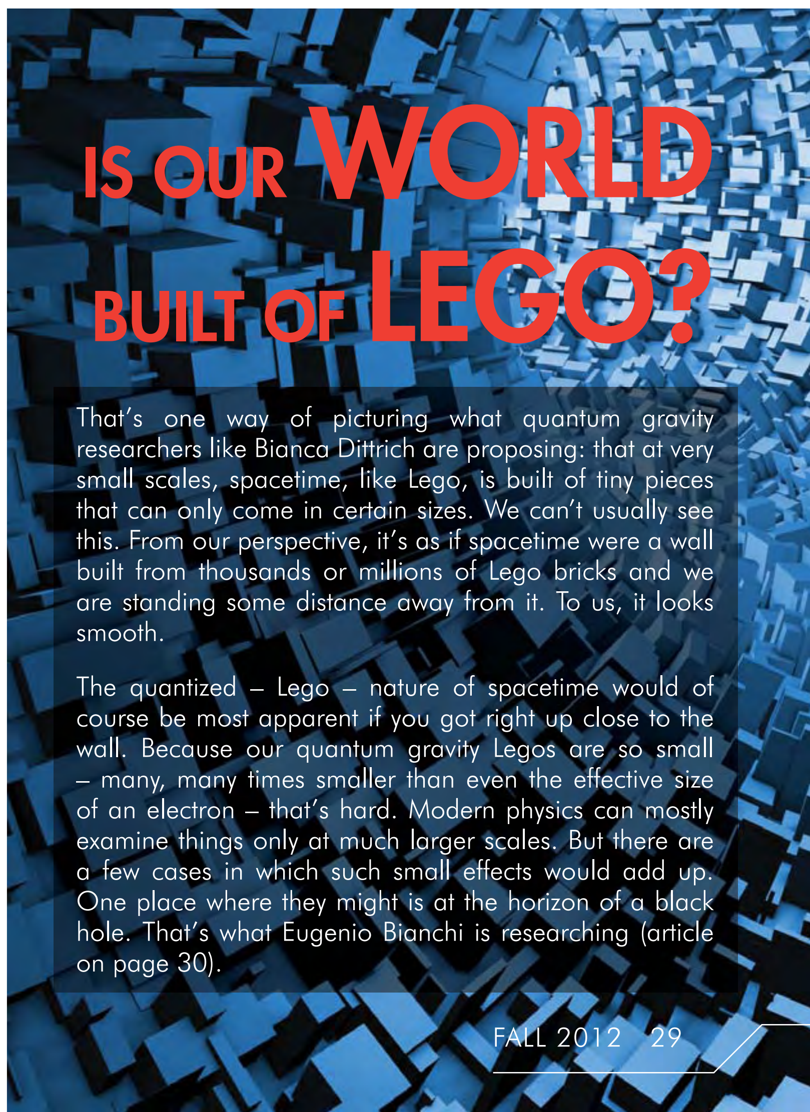
Inside: And having got to the bottom, you have to get back up the ladder again.

Bianca: Yes, and that's the difficult part. It's easy enough to come up with models of atomic spacetime, but we always have to prove that these models make sense and are consistent with what we actually observe.

The atomic hypothesis is more than 2,000 years old. But to prove that it was really so – that ordinary matter was really divided into atoms – took a very long time.

When it comes to figuring out if there are atoms of spacetime itself and what that means – well, I'm hoping this next step will be shorter.

- Interview by Erin Bow



IS OUR WORLD BUILT OF LEGO?

That's one way of picturing what quantum gravity researchers like Bianca Dittrich are proposing: that at very small scales, spacetime, like Lego, is built of tiny pieces that can only come in certain sizes. We can't usually see this. From our perspective, it's as if spacetime were a wall built from thousands or millions of Lego bricks and we are standing some distance away from it. To us, it looks smooth.

The quantized – Lego – nature of spacetime would of course be most apparent if you got right up close to the wall. Because our quantum gravity Legos are so small – many, many times smaller than even the effective size of an electron – that's hard. Modern physics can mostly examine things only at much larger scales. But there are a few cases in which such small effects would add up. One place where they might is at the horizon of a black hole. That's what Eugenio Bianchi is researching (article on page 30).

How to Build a Black Hole

Gravity and quantum mechanics are seemingly at odds. That, in a nutshell, is the biggest open problem in modern physics. We have two highly successful theories – gravity, as defined by Einstein's theory of relativity, and quantum mechanics, as expressed in quantum field theory – and no idea how to use both theories at once.

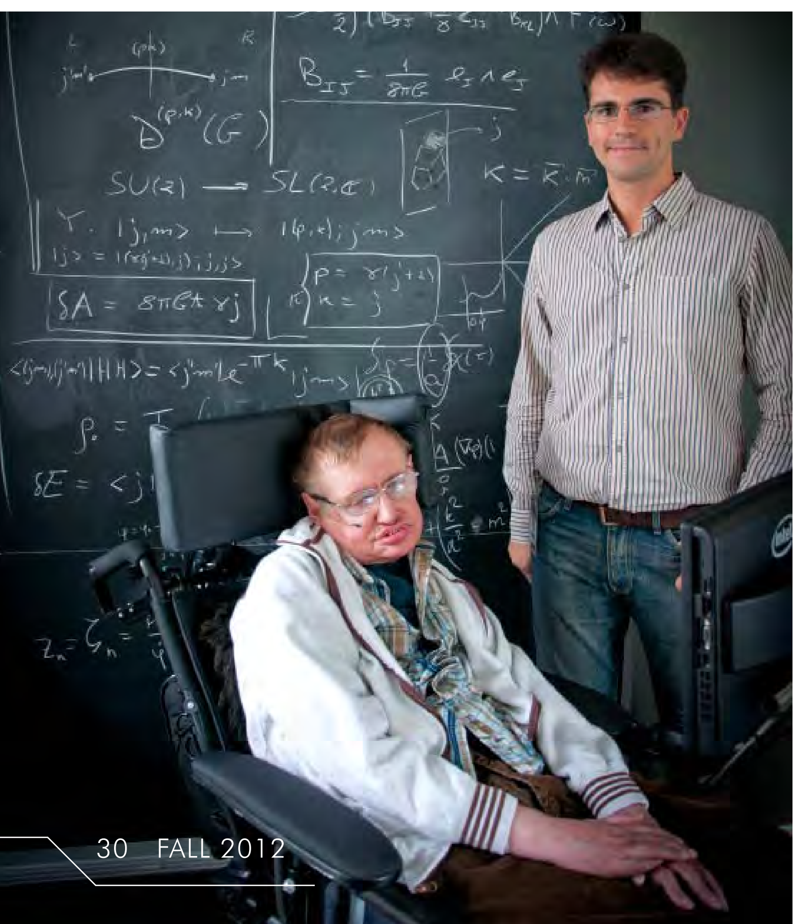
The two theories do, however, have a single, tantalizing intersection: the Bekenstein-Hawking formula for the entropy of black holes:

$$S = \frac{A}{4\hbar G}.$$

As physics formulae go, that's an attractive one. The math is simple. The equation fits on one line. And then there's that intersection: it is one of the few places in physics where G, Newton's constant (which defines the strength of gravity as we know it), meets *h*, Planck's constant (which defines the size of energy quanta in quantum mechanics). Quantum mechanics and gravity, together in one line.

Since this equation often seems the one signpost on the difficult road to quantum gravity, researchers revisit it regularly. Recently, Perimeter Postdoctoral Researcher Eugenio Bianchi made a landmark breakthrough: taking a loop quantum gravity approach, he re-derived the Bekenstein-Hawking formula from first principles.

Bianchi discussed his results with one of the originators of the Bekenstein-Hawking formula during his recent visit.



Loop quantum gravity, or LQG, is one of several competing theories which attempt to reconcile quantum mechanics and gravity. Among other things, LQG predicts that space is "discretized" at very small scales. If this is true, then quantities like area and length can only come in multiples of a fundamental unit of length, in much the same way Lego blocks only come in multiples of the same length.

There are a number of black hole entropy results in LQG, all consisting in a sophisticated counting of configurations. To understand the idea of configurations, consider a three-dimensional shape made out of Lego. If you wanted to build such a shape, you might use only the smallest kind of blocks, or you could replace two of the small blocks by a bigger block, or you could try to use as many big blocks as possible, only filling in the cracks with small blocks, and so on. There are a number of different ways to make the same shape out of different blocks. Taking the logarithm of that number will tell you the entropy of the Lego sphere. Analogously, in LQG, there are a number of different ways to make a black hole's horizon out of the discretized chunks of space, and entropy is a measure of this multiplicity.

One of the triumphs of loop quantum gravity is that calculating the entropy of a black hole by counting configurations gives an entropy that grows as the black hole grows. Indeed, it's directly proportional to the area of the hole's horizon, just as Bekenstein and Hawking predicted.

But until now, the equation showing the entropy of a black hole in loop quantum gravity contained a parameter not present in the Bekenstein-Hawking equation: the so-called Immirzi parameter γ, which defines the quantum of area – the size of a single Lego block. Specifically, that area is $A = 8\pi\gamma\hbar G j$. Since loop quantum gravity is built up from such blocks, the appearance of the Immirzi parameter in any LQG result is not a surprise – but still, it's not a perfect duplication of the famous Bekenstein-Hawking formula.

Another concern is the thermodynamic interpretation of the results. A black hole is a dynamic system with a temperature and energy, and it should be possible to interpret the entropy in terms of these quantities. Unfortunately, the usual "build and count" LQG calculations do not provide much insight into this matter.

Bianchi was determined to change that. On the chalkboard outside his office at Perimeter's Stephen Hawking Centre, he set to work studying the energy and temperature of each of the LQG Lego blocks that make up the one-way surface of a black hole – what physicists call the hole's horizon.

The hallway in the Hawking Centre proved the perfect place for such work, and not just because the building and equations share a namesake. It was also a place where Bianchi could easily share his ideas. For example, he employed a relatively new formalism in LQG called spinfoams, and was able to discuss his work with Perimeter Faculty members Lee Smolin and Laurent Freidel, two of the originators of LQG and spinfoams. Other colleagues would pass by his chalkboard and ask questions about his work, which helped him to further refine his argument. Among them was Carlo Rovelli, who first calculated black hole entropy in LQG and just happened to be visiting Perimeter at the right time to see Bianchi's work in progress.

After many such discussions and months of chalkboard work, Bianchi found that each LQG Lego block in a black hole's horizon contributes an entropy that's a simple multiple of the Immirzi parameter: $2\pi\gamma j$. Since the area of each block is also expressed in terms of the Immirzi parameter, the two γ's neatly cancel each other and the entropy of the black hole is just:

$$S = \frac{A}{4\hbar G}.$$

Bingo – a perfect match for the Bekenstein-Hawking formula. The Immirzi parameter is notably absent. Bianchi's formula even has the correct factor of ¼.

Rediscovering a formula from 30 years ago suggests that LQG might be on the right track. More importantly, it provides a stepping stone for a better understanding of LQG. As Bianchi says, "I think of the result I presented as a first exploratory step and I expect more developments in this direction in the future."

While Bianchi works out what these future results might be, other physicists – including Perimeter Associate Faculty member Avery Broderick – are busy trying to experimentally probe black holes. The hope is that these efforts will converge on the ultimate goal of any theory of quantum gravity: experimentally verified predictions.

- Ross Diener

Further Exploration:

- E. Bianchi, "Entropy of Non-Extremal Black Holes From Loop Quantum Gravity," arXiv: 1204:5122.
- Watch Bianchi's talk, "Black Hole Entropy from Loop Quantum Gravity": PIRSA: 12050053.

BLACK HOLES *and* ENTROPY

Black holes are a fascinating physical phenomenon: regions of space with such strong gravitation that not even light can escape. They are straightforward enough for a high school student to understand, but exotic enough to keep seasoned scientists guessing. And with black holes – as with many things in physics – thinking carefully about simple ideas can lead to deep insights.

For example, you might realize that since we cannot look into black holes, all black holes of the same mass are perfectly identical to an outside observer. (Okay, they can have charges and spin too, but ignore that for now.) Think about what that implies.

To start with, if a signal of light is sent into the black hole, the signal is lost because that light cannot escape back out and all the black hole can tell us is its mass. Furthermore, a black hole of a given mass could have come from the collapse of a number of different types of stars that could have collapsed in a number of different ways – that is, there are a number of different configurations it could have on the inside and still appear the same on the outside.

The lost signal, the unknowable history – to a physicist, these bring to mind entropy. Entropy is more familiar to most people as a measure of the randomness of a system. An alternative way of understanding entropy is to say that it quantifies missing information. For instance, if there are a number of different ways a large system can be made up of its constituents and still have the same macroscopic properties, then we assign that system large entropy. Since we just concluded that identical black holes can be made in different ways and black holes also make information go missing, it might be natural to define a black hole's entropy.

Back in 1972, considerations along these lines led Jacob Bekenstein to suggest that black holes should have a well defined entropy. Stephen Hawking took this proposal seriously and, in 1975, he derived the Bekenstein-Hawking formula. It is a famous equation, admired for its simplicity, syncretism, profundity, and universality. Not surprisingly, these properties are best illustrated by actually writing the equation down, as follows:

$$S = \frac{A}{4\hbar G}.$$

One interesting thing about this equation is that its handful of symbols are borrowed from diverse fields of physics. The S stands for the entropy of the black hole. The A represents the area of the black hole's horizon – that is, a surface on which gravitational pull first becomes so strong that not even light can escape. The G is Newton's constant, the number that governs the strength of gravity as we know it. The other constant, $\hbar$, comes from quantum mechanics.

It is intriguing that all these constants should be found in the same equation. After all, gravity and quantum mechanics are seemingly at odds. The most straightforward approach to 'quantizing' gravity gives rise to an infinite number of infinite quantities that must be arbitrarily removed. But a theory with an infinite number of arbitrary parameters is not predictive, as any new experiment can be described by just adjusting one of the theory's countless parameters. This makes the unification of quantum mechanics and gravity a notoriously difficult problem. Yet here are their respective fundamental constants happily collaborating to determine the entropy of a black hole. This suggests that the Bekenstein-Hawking formula provides a glimpse into the elusive world of quantum gravity.

35 King Street & The Spirit of PI

This past summer, we held a party to celebrate PI's first home at 35 King Street, which was about to pass into other hands. As we celebrated, I was reminded of the old friends who were there with us in the first year, who have moved on to other things during the course of the last decade. I was also reminded of the ideals and principles which animated the launch of PI and was struck that most can still be felt guiding our work a decade later.

PI now is an imposing presence, in terms of our influence scientifically, in terms of our number of scientists and, not the least, architecturally, with two world-class examples of modernist architecture as our home. It may be hard then for those who have arrived at PI recently to appreciate the sheer audacity and élan it took to found a new scientific institute in a small town in Ontario. We had big plans, but we started small, with three faculty members (Rob Myers, Fotini Markopoulou, and I), one director (Howard Burton), four postdocs, a few students, and a small but extremely dedicated staff that included Colleen Brickman, Janet Fesnoux, John McCormick, and Sue Scanlan.

When we arrived in Waterloo that September (in the shadow of 9/11 – but that is another story), there was no institute, but only an admin office for the staff. We began working at home and meeting in cafes and restaurants – one of which was Time Square. One day, Howard noticed that the restaurant at Time Square had been evicted overnight and he immediately put in a bid to lease it for PI. The first task when we moved in a few days later was to clear the dirty dishes off the tables, which had been left when the sheriff had come to impose the eviction. A few days later, telephones arrived, then Internet, then after a week or two of sitting on the floor, desks and chairs arrived. Over the next weeks, PI began to take shape: a seminar room, offices (mostly partitioned), blackboards. We kept the bar, couches, espresso machine, and pool tables on the second floor, adding just blackboards to make the friendliest and funkiest physics lounge any of us had ever enjoyed. Many visitors to what we renamed as Space-Time Square remarked on a resemblance to high tech start-ups in the intensity and ambition that was palpable in every conversation.

The science took off right away. Discussions were intense and focused and, from the beginning, we worked hard. Just one personal story to stand for many: my first visitor was João Magueijo and we hatched our version of doubly special relativity over marathon sessions at Symposium. Only a few months in, we held our first conference – in the movie theatre across the street.

We also had a great deal of fun. There was no bistro, but

Intense discussions, abundant blackboards, and the occasional game of pool characterized Perimeter's early days. (Photo 2002).

the second floor bar — quickly named the hbar — was the scene of many passionate arguments about physics. Very quickly, the tradition of Friday Social became established and in that first year Mike Lazaridis could often be found dropping in for a drink and a chat about where physics was going.

But all the fun framed a most serious purpose. We were out to revolutionize physics – both the subject and how it was done. We were very aware that opportunities to start a new home for a scientific institute come once in a lifetime and we were determined to do it right and to make an ideal place for great science to be done. Here was the chance to remake the idea of what a scientific institute was – even what a career was — freed of the excess baggage carried by universities of a thousand years of evolution from monasteries that were designed to preserve old knowledge, not incubate new discoveries. We were also very mindful of the trust given us by those who had invested so much in the founding of PI. Out of this heady atmosphere, a set of principles and ideals quickly evolved, which fleshed out the vision Howard and Mike had invited us to share. Here is my summary of them:

- Our focus is on the foundations of physics; our purpose is to discover new laws of nature and, by doing so, to deepen our understanding of nature.
- Go for real breakthroughs. This means prioritizing high risk/high payoff attempts to make big discoveries over low risk/low payoff incremental work. This dictates a focus on fundamental questions. Because breakthroughs happen most often at the boundaries of established research programs, hire people who follow their own compasses rather than fads and prioritize people who pioneer new directions over people who make incremental advances to well established directions.
- Hedge our bets: rather than choosing between different approaches to fundamental questions like quantum foundations, unification, or quantum gravity, hire the best people at the leading edge of competing research programs.
- No proxies: we are not interested in artificial measures of success, only in success itself.
- Don't copy any existing model — even the most successful ones — but develop our own strategy and path to success. Learn by making our own mistakes.
- Be neither the institute for support of underfunded foundational approaches nor a bastion of the mainstream, but a centre that spans work from both orthodox and unorthodox approaches, all aimed at making breakthroughs. Develop our own vision of where science is going and apply it confidently.
- Challenge each other with hard questions, but support each other's efforts to solve them. Be intellectually tough within an atmosphere of fun, affection, and respect.
- Empower young people, who history shows us make many of the breakthroughs in physics. This means, among other things, that postdocs are independent scientists who don't work for faculty members and who have resources of their own, and junior faculty members have all the scope and resources they need to follow their dreams.

In 2002, Janet Fesnoux greets Laurent Friedel, one of Perimeter's first scientific visitors and now a faculty member.

- Be dynamic and flexible. Be prepared to act fast when opportunities emerge and don't let structures invented to help us get in our way.
- Bring science to the public. From the beginning, PI had a major focus on outreach and education.
- Treat everyone – scientists and staff alike, residents and visitors – with the warmth and respect that their hard work deserves.

Thus, as I often explained to curious visitors, PI is based on a set of oppositions: orthodox and unorthodox approaches, string theory and quantum gravity, quantum information and quantum foundations. Empower young people and also exploit the wisdom and experience of older scientists.

I am impressed that these ideals remain the core of the spirit of PI. Neil [Turok] has introduced new directions and new emphases in a way that to me deepens our commitment to and broadens our understanding of the original principles. A decade of rapid growth has not diluted the essentials of the spirit of PI. Our task remains the same: to be a home for great discoveries and breakthroughs in science. In the end, PI's success may be judged by a single paper which remakes science — a paper that, if we do things right, is as likely to be written by a student or postdoc as a faculty member. Let us continue to flourish as a community of people, all of whom are trying to write that paper whose revelations we will celebrate together!

- Lee Smolin

Lee Smolin is a founding faculty member of Perimeter Institute. His newest book, Time Reborn, *will be published by Knopf Canada and Houghton Mifflin Harcourt (US) in 2013.*

Double-checking Dark Matter

Dark matter is a hot topic these days. Dozens of experiments are looking for WIMPs in the lab – but only one claims to have found them.

Researchers at the DAMA experiment, located in the Gran Sasso underground Laboratory in Italy, have been claiming for more than a decade that they have detected WIMPs (or weakly-interacting massive particles – see "Wanted: WIMPs" to learn more). The wider dark matter research community has met this claim with skepticism. Recently, Perimeter Faculty member Itay Yavin and Postdoctoral Researcher Josef Pradler stepped forward with an independent analysis, which appears to strengthen DAMA's case.

One can think of the DAMA experiment as an effort to chart what Yavin calls "a wind of WIMPS." The idea is that a huge halo of dark matter, comprised of WIMPs, surrounds our galaxy. Our sun moves at about 220 kilometers per second through that halo as it orbits around the centre of the galaxy. Like driving through still air, this creates a steady "wind."

Now, consider the earth's orbit around the sun. As earth moves in its orbit, it also moves through the WIMP wind. In the winter, the earth's orbit is aligned with the WIMP wind; in the summer, the earth's orbit pushes against the wind. You might expect a bit more splatter on the earth's metaphorical windscreen in the summer, and you'd be right. The geometry of the orbit allows scientists to make a clear-cut prediction: we should observe a small yearly rise and ebb in any signal from dark matter, and the signal's peak should be on June 2. DAMA sees exactly that.

To track the strength of the WIMP wind, DAMA uses a scintillating detector – that is, an array of crystals that emit light when particles interact inside it. With 13 years of data collected, DAMA's claim to have detected an annual rise and fall – a modulation – in the number of scintillations is not in doubt. However, there is something else that could make the DAMA detector scintillate, which also has a period of one year and a peak in the summer: cosmic muons.

Cosmic muons come from cosmic rays – that is, the charged particles (mainly protons) moving at high speeds that are constantly showering down on the earth from space. When these particles hit the earth's atmosphere, they produce a cascade of secondary particles, many of which are unstable and decay into muons. Some of these muons have a high enough energy to penetrate the 1,400 metres of rock and reach the underground chamber where the DAMA detector is located.

The number of high-energy muons produced depends on the temperature. The colder the air, the denser it is and the more likely the secondary particles are to collide before they decay, decreasing the energy available to their decay products, the muons. Therefore, more high-energy, rock-penetrating muons are produced in the summer than the winter, which should result in an annual rise and fall in the number detected by an underground scintillator.

So is DAMA seeing these relatively mundane and well-understood muons, or dark matter?

Yavin and Pradler set out to find out. "DAMA has made a strong claim for seeing dark matter, maintaining that muons cannot be the cause of the signal," says Pradler. "But there is good reason to be skeptical – especially since the collaboration is somewhat secretive about their data. What we did was offer an independent analysis of the muon hypothesis."

The two researchers compared DAMA's published results with cosmic muon data taken with the Large Volume Detector experiment, an apparatus which measures the cosmic ray muon flux and which sits next to DAMA in the Gran Sasso laboratory. Pradler and Yavin looked at the amplitude, phase, and power spectrum of two annual modulations – and found that they were very unlikely to be from the same source. For instance, with regard to the phase, they found that while the DAMA signal peaks in June, the muon flux peaks in July.

Together with Spencer Chang, an Assistant Professor at Oregon University, they performed a correlation analysis and other tests, but all seemed to indicate that the two data sets – the muon set and the DAMA set – were insufficiently correlated. In other words, whatever DAMA is seeing, it is almost certainly not muons.

In the interest of getting a better understanding of dark matter, the researchers have suggested a next step. If DAMA's signal is from dark matter, it should – as a matter of pure mathematics – have higher harmonics. "It's like the vibrations of a guitar string," explains Yavin. "The dark matter signal is a 'note' with a frequency of one year. It should have overtones." Checking for such overtones, they say, would be a good way to distinguish a dark matter signal from the background noise.

These results have appeared in *Physical Review D* and have been presented widely at conferences.

"The reason so many people care about this result is that dark matter is an exploding frontier," says Yavin. "There are many experiments looking for dark matter in the lab – some at the SNOLAB underground facility here in Canada, some at the Soudan mine in Minnesota, more at Gran Sasso – 10 or 20 worldwide experiments looking for dark matter in the lab. We need to get a better handle on what that signal might look like."

- Erin Bow

WANTED

Up to 96 percent of the universe is missing.

We used to think the universe was made up of a few types of particles: electrons and their exotic cousins, quarks and the atomic nuclei they form, photons of light, and the other particles that are so well understood that the theory of them is called the Standard Model.

But over the last several decades, it's become clear to astrophysicists that the parts of the universe we can see are not nearly massive enough to account for the way big things - like galaxies and galactic clusters - are structured. It is now widely thought that the visible parts of the galaxy are surrounded by a "halo" of dark matter, which cannot be seen because it does not give off light. Only its gravitational effects can be observed.

Despite the fact that there should be more than five times the amount of dark matter than ordinary matter all around us, no one has ever managed to definitely detect so much as a particle of it.

That definitely puts WIMPs, as the prime suspects in the dark matter case, on the list of the galaxy's most wanted.

What to look for:

WIMPs are elementary particles, like quarks or electrons, which have only tiny interactions with ordinary matter. Here's what we think we know about their modus operandi.

- They don't interact with the electromagnetic force: that is, they don't attract or repel ordinary particles with charges and they don't emit or absorb photons. There's some chance, however, that whatever force does interact with WIMPs can "mix" with the electromagnetic force at the quantum mechanical level.
- They don't interact with the strong force that binds quarks into protons and neutrons to make atomic nuclei.
- They interact through the weak force, like neutrinos, or through some other force with a similar strength.
- They presumably have the same sort of gravitational interactions as ordinary matter.

So far, WIMPs have dodged all attempts to spot them in the wild or catch them in the lab.

DEAD OR ALIVE

In Person, Virtual Sparks Fly at BrainSTEM unconference

SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS

The revolution in global science education will be televised. On YouTube.

Brady Haran is a former BBC journalist who runs a dozen YouTube channels devoted to exploring the world of science. Destin Sandlin is a self-described "tinker-thinker" who is trying to fund his children's education with the science shows on his YouTube channel, *Smarter Every Day*. Along with a handful of other online science video creators – including Perimeter's own YouTube superstar, Henry Reich, creator of *MinutePhysics* – they have over 300 million views and more than 2.5 million subscribers on the world's largest video-sharing website, representing a massive science niche. Until recently, however, most of them had never met.

That changed in late June, when Haran, Sandlin, and a who's who of the YouTube science community descended on Waterloo for the BrainSTEM unconference at Perimeter Institute, held in collaboration with Waterloo-based Communitech and supported by funding from the Federal Economic Development Agency for Southern Ontario. Reich, Perimeter's Film & Media Digital Artist-in-Residence and one of the main organizers of the unconference, said he was amazed that almost everyone he approached came. In transit between the hotel and a restaurant on the eve of the conference, Derek Muller of *Veritasium* joked, "If this car crashes right now, all of science on YouTube is going down." An avid fan, having learned of the unconference, greeted arriving delegates early one morning with a sign that read, "Will you sign my lab coat?"

BrainSTEM was designed to connect the off-the-wall imaginations that can bring topics like "How to Weigh a Million Dollars with Your Mind" to life in 60 seconds flat together with science outreach experts, digital media professionals, entrepreneurs, and other educational leaders. Recognizing that online science content is an exploding area, BrainSTEM featured a 48-hour build-a-thon running simultaneous to its core discussions. Nine teams of two to four entrepreneurs from local colleges and universities worked feverishly in the Space room to create a game, video, or app related to science education, with nearly $50,000 in prize money on the line.

Greg Dick, Perimeter's Director of Educational Outreach, says the goal was to create an ideas incubator that flipped the traditional conference structure on its head. "Most of the good conversations at any conference happen in between the sessions," says Dick. To catalyze the animated, free-flowing exchanges that generally happen only during the coffee breaks, they built the schedule collaboratively with delegates. The resulting roster of topics – from "Transforming Experiences into Digital Content" to "Scientific Accuracy: How Much Is Good Enough?" – reflected what was on delegates' minds and kick-started two days of intense discussion on the state of science education and how this diverse group could work together to improve it.

"I think the people from the education space had their eyes opened to the quality of science content already on YouTube, including things teachers don't have the resources to do in the classroom. This is another tool for them to engage students in a forum they're already familiar with," explains Dick, noting that the YouTube folks benefitted equally from the chance to speak with the range of experts assembled. "In general, the relationships forged at BrainSTEM hold a lot of exciting possibilities."

For example, following the opening keynote address by Angela Maiers, the passionate educator and social media evangelist behind the "You Matter" campaign, Catherine Fife, then President of the Ontario School Boards' Association, invited her to speak at their annual meeting, which could have a significant trickle-down effect in every school in the province.

Or take John Sobol, the entrepreneur behind The Media League, a creativity league that brings the competitive nature of sports into the media space. The Media League aims to engage students at 2,000 high schools across North America to create media content related to six education themes. Sobol's involvement in BrainSTEM convinced him to extend it into the science realm.

"In the course of one or two weeks, you'll go from 0 to 6,000 pieces of science content on the web, made for students by students," says Dick. "That's a really powerful tool because you're engaging youth in the process of science and you're doing it in the spaces, like YouTube, where they are already interacting."

The list of connections goes on. Writer, blogger, and filmmaker Carin Bondar was hired by Chris Casella to expand the hugely popular Australian *ScienceAlert* website into North America. Marie-Claire Shanahan, an Associate Professor of Science Education and Science Communication at the University of Alberta, is now seeking grant funding to further explore the educational impacts of online science videos, with the likes of Reich, Haran, and Muller as collaborators. And YouTube EDU is holding a summit of their own this fall which will reunite several members of this group to discuss how they should proceed with YouTube educational videos.

By the end of the unconference, the bonds of community were clearly established. Many attendees moved on together from Waterloo to VidCon, an online video conference in southern California. "We got to spend time together, hang out, and talk about future projects," says Reich. "I now feel much more comfortable just calling somebody up and saying, 'Do you want to do this quick little thing for a video?'"

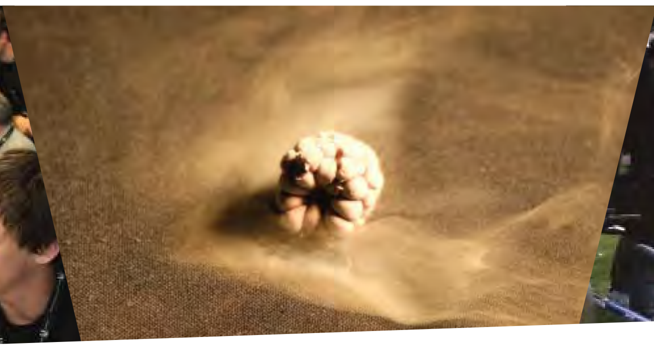
"In order to change the way people think, it's good if all these other science creators on YouTube link to each other," Sandlin reflects. "It's not a competitive thing; we're helping each other because, if people watch *MinutePhysics* or *Smarter Every Day*, they're more likely to change their viewing habits and change the way they think about the world. That's ultimately what we're trying to do."

- Mike Brown

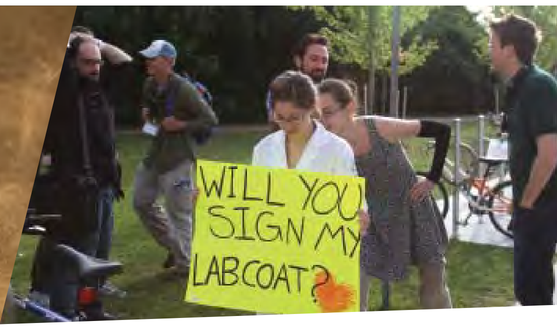
Major support for BrainSTEM was provided by

Federal Economic Development Agency for Southern Ontario
Agence fédérale de développement économique pour le Sud de l'Ontario

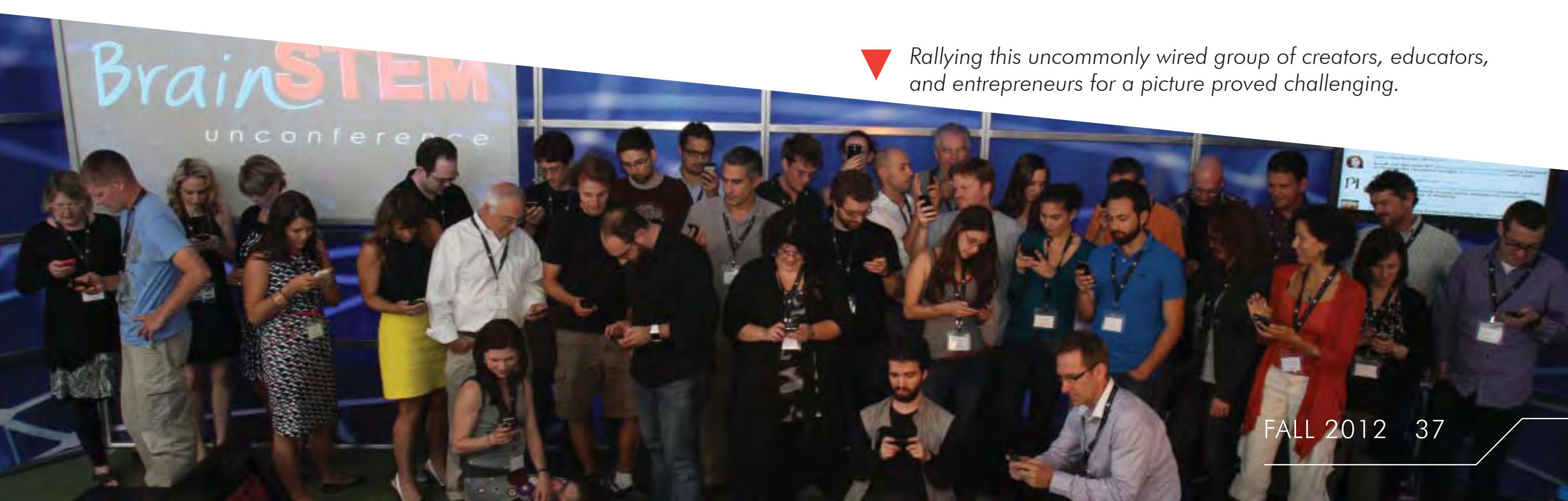
Cara Santa Maria, Science Correspondent for The Huffington Post, *asks questions of one of the teams competing in BrainSTEM's 48-hour build-a-thon.*



Smarter Every Day *filmed part of an episode at Perimeter, using a high speed camera and this raspberry frozen with liquid nitrogen.*



Professional mathemusician Vi Hart of Khan Academy signs the lab coat of a fan.



Rallying this uncommonly wired group of creators, educators, and entrepreneurs for a picture proved challenging.

The Science of Scones

The Black Hole Bistro's sous-chef and master baker Carla Mancuso makes scones that all but melt in your mouth. Here is her recipe, complete with notes on the science behind that perfect texture.

2 cups all-purpose flour
2 ½ Tbsp sugar
1 Tbsp + 1 tsp baking powder
1 ½ tsp salt

1. Mix dry ingredients together.

Baking powder contains both an alkaline component (sodium bicarbonate, or baking soda) and an acid salt (usually tartaric acid), suspended in an inert starch. Get it wet and it reacts both with itself and with the acids in the recipe — in this case, the lactic acid in the yogurt or buttermilk — releasing carbon dioxide. The released gas, like the steam from the butter, makes the scones puff up.

¼ lb. (8 Tbsp) cold butter

2. Grate butter into the dry ingredients and rub with fingers to create a course meal texture. Add any additions at this point, depending on whether you want sweet or savoury scones: chocolate chips, blueberries, lemon zest, poppy seeds, dried cranberries, currants, fresh herbs, grated cheese, or cooked bacon.

The scones are partly leavened by steam. That's why the butter has to be cold and cut into small pieces — here, with the large holes on a cheese grater. The little flour-coated capsules of butter inside the dough flash to steam when they hit the hot oven. Those small pockets of steam give the scones a flaky texture.

1 egg
¾ cup buttermilk or yogurt (a small 175 g container will work)
2 tsp vanilla
(for sweet scones)

3. Mix egg and buttermilk together (plus vanilla if making sweet scones), and add to dry ingredients with a spatula. Mix only until ingredients are all wet.

4. Knead 10 times on a counter. Roll or pat out into a 10-inch circle and cut eight wedges with a knife.

Keeping the kneading to a minimum keeps the dough from getting too elastic, which would make the scones chewy and tough. Kneading creates shearing forces which break the bonds between the randomly aligned strands of gluten protein in the flour. It also stretches the proteins out and aligns them. The whole process is rather like turning wool into yarn. This increased structure would be good if you wanted bread, but it's bad for delicate scones.

5. Place on parchment-lined pan, brush with milk or cream, and sprinkle with sugar or salt depending on whether it is sweet or savoury.

6. Bake @ 375° for seven minutes, rotate pan, and bake approximately seven minutes more or until they are golden brown.

Yields eight pieces.

Orbitals in Space

It started with a boom lift in the atrium.

Researchers and staff passing through Perimeter's main atrium on May 16 were startled to encounter a full-scale boom lift inside the building. It seemed to present a topological puzzle: the lift certainly didn't look as if it could have fit through any of the doors. (In fact, the doors to the Bistro are 100 inches tall and the lift was 99 with the arm lowered: it was a nail-biter for the facilities team.) Soon, steel cables were tracing cantinary arches across the space. By the next day, the boom lift was gone and the atrium was transformed by suspended plexiglass sculptures, catching the eye and bouncing the light.

The sculptures are made of rounded forms – ovals and more complex shapes – stacked in layers along a central axis. They are organic-looking, certainly, but something about them also says "scientific diagram." In fact, they represent atomic orbitals.

Atomic orbitals – which are also called electron clouds – are something many of us initially come across in high school, when we're first told to throw out the "atoms are like tiny solar systems" model and start thinking quantum mechanically. The electron clouds describe the area in the atom where a given electron is most likely to be found: they are clouds not of electrons, but of probability. For the first couple of electrons, that cloud has a simple shape: a sphere. But add more electrons and the shape becomes more complex.

Only recently, with the development of quantum chemistry, has it become possible to completely describe probability clouds for systems of more than one atom – that is, the orbitals of molecules. The data are so complex that they are best presented visually.

Inside the Perimeter sat down with artist Reinhard Reitzenstein, who is director of the sculpture program at SUNY Buffalo, on the first day of the installation.

Inside the Perimeter: Tell me about this project. Why atomic orbitals?

Reinhard: I walked into the atrium and knew right away that I wanted to suspend something. This place is so ripe with thoughts. You can almost taste them. So I wanted to suspend an echo of the kinds of thoughts and ideas that were floating through the space. I thought, "what better than orbitals?" because I'd been entranced by them already.

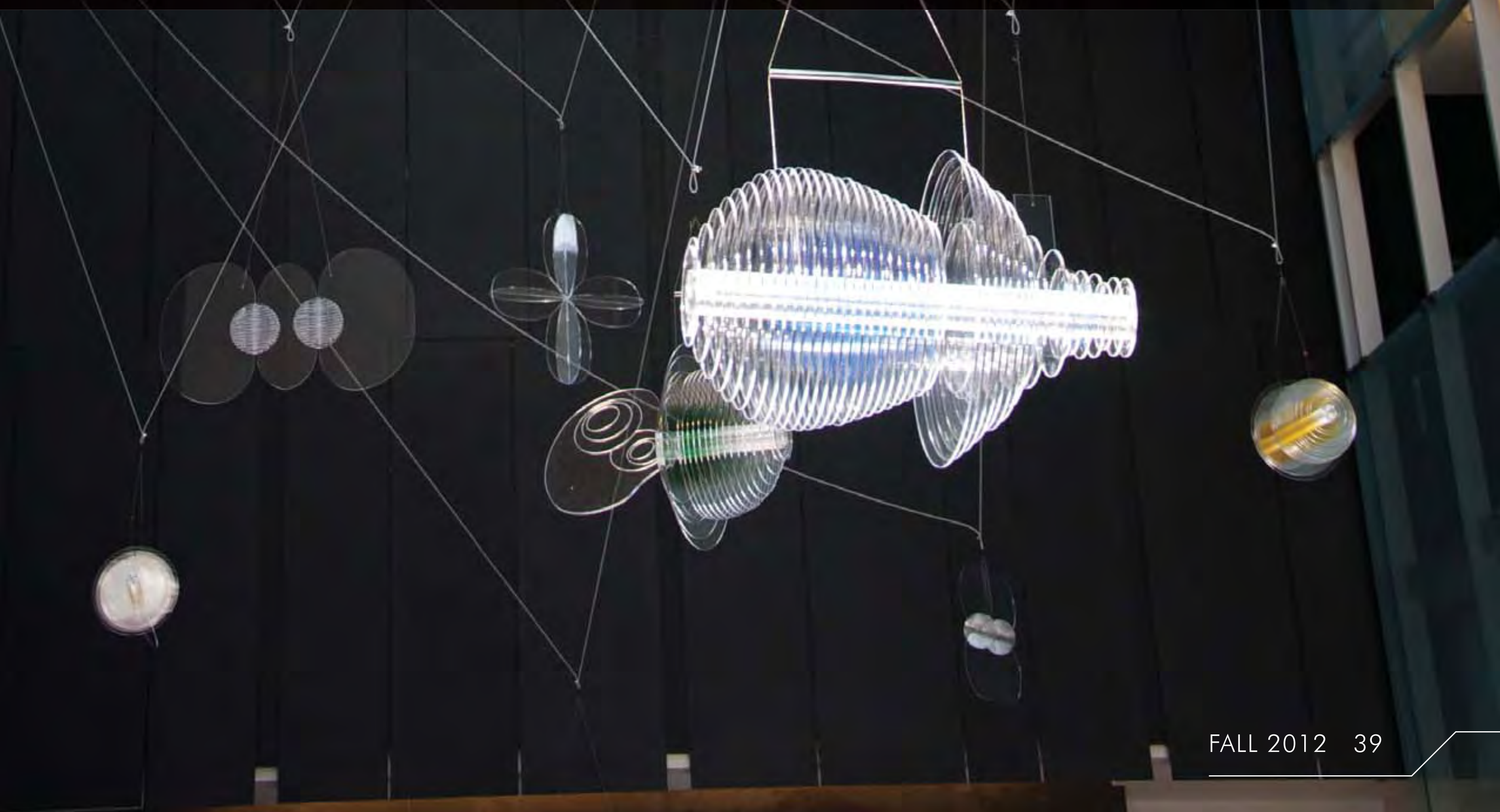
Inside: Really? There's something you don't hear people say every day: "I was entranced by atomic orbitals."

Reinhard: I am, though.

I'm intrigued by the gradual coming together again of science and art. Historically, they've been divided – artificially divided. But as information becomes available to artists, we're starting to see that divide close. I had already done bronze castings of the sombrero form, which supports some of Einstein's equations. They're classical-looking, yet really kind of contemporary in terms of information.

From there, I went to a piece based on an atom corral built on a prepared surface of rubidium. And from there, I went to the tribolite form.

The tribolite form is a giant two-atom rubidium molecule



with an electron cloud that looks a little like a fossil tribolite. I built it. No one had ever built it. I know that because the information was pretty new at the time.

Inside: So you had an idea for sculptures based on atomic orbitals, and then …

Reinhard: I knew I wanted them to be clear, to play with the light. It's one of the key ingredients of the design of the building here, which is one of the most beautifully integrated light-rich buildings I've ever been in.

So we used laser cut acrylic disks to catch the light. We had a very tight timeline to produce them: only six weeks. Fortunately, I had a willing assistant in my graduate student, Anthony Dimezza. He's a sculptor and he wanted to learn more about CAD (computer-assisted design) and laser cutting.

I didn't really know how they'd turn out until I got to see them in the space. One of the things that's really nice about an atrium like Perimeter's is that you have 360-degree access, so the vantage points change as you rise in elevation. I didn't want you to ever meet one directly – I always wanted either a view down or across or up so that you then have to have a relationship to the object, to the architecture, to your body in space. So the viewer is always implicated in this relationship.

Inside: That's very quantum: the observer effect.

Reinhard: Exactly. The viewer makes a difference.

Inside: I'm a little surprised to see these in place today. It did not look yesterday as if it were going to be done today.

Reinhard: Hey, I'm surprised too. We were here until almost 3:00 this morning. I was worried, but when disorder is most evident, you're usually close to finishing. Chaos theory would support that, I think.

Inside: The spontaneous emergence of higher-order structures. You really are inspired by scientific ideas, aren't you?

Reinhard: Oh, it's hard to map out the path inspiration takes. I've talked to a whole bunch of researchers in the last couple of days and usually our conversation centres around where we get our inspiration from. We never quite know, either!

Artists and scientists differ in outcome, but our processing is parallel. We share the energy of research and inspiration and interconnectivities. We share creativity as our source. This makes the exchange between art and science so exciting.

- Interview by Natasha Waxman and Erin Bow

Donor profile:

Carol Lee

Carol Anne Lee, a native of Vancouver, is CEO and President of Linacare Cosmetherapy Inc., a BC-based company which develops and manufactures a line of therapeutic moisturizing creams. Their skincare products have successfully helped countless cancer patients maintain healthy skin through their chemotherapy and radiation treatment. Being a conservationist and passionate advocate for the heritage virtues of Vancouver's historic Chinatown district, she is deeply involved in a foundation dedicated to its revitalization. In addition, Carol contributes to numerous boards and committees involved in business, education, science and trade.

Carol is one of Perimeter's donors and a member of our Leadership Council, a group of prominent individuals who volunteer their time to Perimeter as ambassadors to the business and philanthropic worlds. She recently shared her thoughts on the Institute, and some of her experiences representing Perimeter worldwide.

Inside the Perimeter: What made you decide to get involved with Perimeter?

Carol: I thought that the Institute was a wonderful idea for Canada, and for the world. I was particularly impressed with the ambition of Perimeter's vision, and what Mike [Lazaridis] and Neil [Turok] wanted to achieve. I like to support organizations in Canada that are striving to be among the best in the world; I believe Canada is capable of that. Canada has a great pool of talent, but sometimes I feel we are satisfied with mediocrity. Many organizations could learn from Perimeter. If they believe I can help them in some small way achieve that goal, how could I say no?

Inside: The American Association for the Advancement of Science – the world's largest general scientific society – held its annual meeting in your home town of Vancouver this year. What was the meeting like for you?

Carol: It was very impressive. It was the first time in 31 years that the AAAS meeting was held in Canada. Mike Lazaridis delivered the keynote address and it was so inspiring. I wish he was exposed to a broader audience. I think he could really get people excited and encourage them to support science. After Mike's speech, PI hosted a small reception where I had the opportunity to meet some members of the PI team, including distinguished scientist Raymond Laflamme. Seeing their passion for this work really energized me.

Inside: There are a lot of things you could devote your time to. Why do you support basic scientific research?

Carol: My business partner is a scientist. He's an MD/PhD, and he's shown me that the scientific philosophy is very unique, very focused on collaboration and co-operation. Scientists put the research first, and tend to take less credit than people working in

Photo credit: Jens Langen

other fields. Collectively, their goal is to find the truth. I often hear the scientists I work with say something along the lines of "well if I hadn't discovered it, someone else would have." I don't hear that very often in the business world. Mike said in his keynote speech that science is the world's only real, global democracy. I like that idea, that no matter where you come from or what language you speak, all scientists have the same agenda of sharing ideas and advancing knowledge. I think that's a noble attitude and there's a lot we can learn from it.

Inside: Have you always been interested in science?

Carol: I have always been interested in science. Working with Perimeter lets me use my talents to support science in my own way. It also makes me feel that theoretical physics is relevant and tangible. Most people I come across don't know much about theoretical physics, or why it's important. I don't know very much either, but I do know that many technologies that we enjoy today we owe to advances in theoretical physics. I believe Perimeter will bring physics to the public and make it relevant; much like the Three Tenors brought operatic music to the rest of the world.

If I can help get that message out there, I'm happy to do it. And with the passion of Mike and Neil, and the mission of the Institute, we will be successful. It's a very exciting time.

- Interview by Phil Froklage

Photo credit: Jens Langen

During his recent visit, friends of Perimeter enjoyed an evening with renowned cosmologist Stephen Hawking.

Sun Life Financial Renews Support for Public Lecture Series

The Perimeter Public Lecture Series, presented by Sun Life Financial, is the Institute's longest-running, highest-profile public event.

Since 2003, the series has brought great thinkers from around the world to Waterloo to share big ideas on a variety of subjects: from mathematics to physics, from history to healthcare, from the origin of snowflakes to the possibility of life beyond earth. Past lecturers have included Nobel Prize winners, playwrights, historians, and, of course, many esteemed scientists. Tickets to the lectures are free to the public and the 600-seat theatre consistently sells out – often within minutes of the tickets becoming available.

Sun Life has been the exclusive presenting sponsor of the lectures since 2010 and recently renewed their support through the 2012-13 season.

"Sun Life is thrilled to once again be the presenting sponsor of the Perimeter Institute's very popular and thought-provoking Public Lecture Series," says Mary De Paoli, Executive Vice-President, Chief Marketing Officer and Public & Corporate Affairs. "These lectures enrich Kitchener-Waterloo's reputation as a leader in research and innovation."

Perimeter Institute is grateful for Sun Life's commitment to sharing the joy and fascination of science with everyone.

- Phil Froklage

November's Public Lecture will be:

Discovery of the Higgs Boson: Sweet Dream or Nightmare
Melissa Franklin, Harvard
Wednesday, November 7, 2012 at 7:00 pm
Tickets available Monday, October 22

Watch dozens of past public lectures at pitp.ca/Outreach.

Investing in the Future

The work we do at Perimeter can seem abstract, but really, it's about impact. Theoretical physics, with its low overhead costs and track record of fostering innovation, is the smartest way to build a better future – maybe not tomorrow, but a generation from now.

No one could have imagined GPS when Einstein was talking about general relativity, but a few far-sighted people saw he would one day change the world.

We need those same sorts of people to support us today: visionaries.

Perimeter is an independent, non-profit, charitable organization. We're funded by an innovative private-public partnership, and our agreement with the government commits us to seeking private sector investment to match our public funding.

Perimeter is about more than just research. We develop award-winning outreach programs to engage the public and provide world-class training for the next generation of Einsteins. We're already making Canada a global leader in theoretical physics research. We hope you'll join us.

To learn more about supporting Perimeter Institute, please contact Debbie Adare, Advancement Services Manager, at 519-569-7600 ext. 5101 or dadare@perimeterinstitute.ca.

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An ever-growing group of both public and private supporters have helped make Perimeter what it is today: a world-leading centre for fundamental research, scientific training, and educational outreach. We couldn't do it without their vision and support.

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