TURNING POINTS:

27 Ways Perimeter Institute has Changed the Course of Physics
A Twenty-Fifth Anniversary Celebration

2025

TURNING POINTS

Cosmology

Solving an Astronomical Mystery: Fast Radio Bursts (2017-2025)

In 2007, a new phenomenon was discovered called fast radio bursts – powerful, distant, and fast jets of energy with no clear origin. Perimeter, as part of the CHIME and CHORD radio telescope collaborations, has helped discover thousands of such bursts and revealed their likely origin: neutron stars.

kSZ Cosmology (2015-2025)

Was the early universe truly a simple place? Perimeter researchers developed brand-new methods of statistical analysis to find out, making a new type of astronomical measurement feasible for the first time: kSZ cosmology. With it, they aim to test for hidden complexity amid the first light to escape after the big bang, cosmic microwave background radiation.

Gravity Modified (2011)

Einstein’s theory of relativity is incredibly powerful, but using it to explain astronomical observations of our universe requires two mysterious components: dark energy and dark matter. Perimeter researchers have proposed a potential modification to gravity, known as ‘massive gravity,’ which does away with the need for dark energy altogether. Future observational evidence might either refine our understanding of gravity, or better explain dark energy and vindicate relativity.

Mathematical Physics

Twisted Holography Meets Celestial Holography (2019-2025)

Is the universe a hologram? Some models of the universe suggest that a 3D description of gravity and a 2D description of quantum field theory are mathematically equivalent. Perimeter researchers are working to define this unique duality more rigorously, building on "twistors," a mathematical concept invented by Nobel laureate Roger Penrose. Twistors may play a key role in finding a version of holography that works in the real universe: a project known as "celestial holography."

Revealing the Secrets of the Coulomb Branch (2016)

To study particles like quarks and electrons, physicists use approximations of reality known as "gauge theories." The lowest level of energy or "ground state" of a gauge theory is described by two mathematical branches: the well-understood Higgs branch, and the mysterious Coulomb branch. Perimeter mathematicians made great strides in exploring the Coulomb branch, breaking new ground in a difficult field.

Uniting Topological Modular Forms and Elliptic Genus (2019)

Many of the biggest breakthroughs in science involve colliding ideas from unrelated fields. Perimeter researchers broke an impasse in a longstanding mathematical conjecture by combining a mathematical idea (topological modular forms) with an element of quantum field theory (elliptic genus) in an untried way, with important implications for supersymmetric field theories.

Particle Physics

Secluded WIMP Dark Matter (2008)

Perimeter researchers showed how some types of dark matter could be 'secluded' from ordinary particles, hiding them from traditional experiments. Indirect evidence of these particles, though, should still be observable. This insight fundamentally reshaped the worldwide hunt for dark matter.

Beam-dump Experiments (2013)

A new type of detector, known as a beam-dump experiment, can search low energy ranges for unusual particles, including dark matter, using existing technologies. Perimeter researchers developed this concept, which spurred ongoing cutting-edge experiments including the Jefferson Laboratory's APEX and heavy photon experiments.

Small Scale Particle Detectors (2018-2022)

What if you could find dark matter and other new particles using inexpensive tabletop experiments as well as with multibillion-dollar supercolliders? Perimeter has designed several such detectors – like ARIADNE and LAMPOST – that complement the work done at CERN's Large Hadron Collider and other huge detectors. These tabletop experiments expand physicists' observations into different energy levels and unexplored parameter spaces.

Quantum Foundations

The Axioms of Quantum Theory (2001-2011)

The mathematical formulation of quantum theory can be complex and abstract. Perimeter researchers, though, have led the field in working up from simple statements of truth – axioms — to provide clearer understanding of the properties and limits of quantum theory, and what they might tell us about the world we live in.

Indefinite Causality (2005-2010)

What would it mean to live in a universe where the order of cause-and-effect is no longer clear? This unusual situation is one potential outcome of reconciling quantum mechanics and Einstein's theory of relativity. Perimeter scientists grappling with this problem have proposed explanations for why we might not experience these effects – causality remains definite locally, but is indefinite on a grand scale.

Quantum Causal Inference (2014-2025)

Causal inference is a subfield of machine learning that is used to determine cause-and-effect relationships from statistical data. Perimeter researchers have pioneered a quantum- informed version of causal inference that helps decision makers in fields as diverse as medical diagnostics and environmental policy. Their work is now the gold standard in testing quantum effects in causal structures.

Quantum Information

Quantum Key Distribution (2005)

Quantum cryptography enables you to send a message privately and catch eavesdroppers – but what if quantum mechanics turns out to be incorrect? Could an advanced, post-quantum eavesdropper listen in? Perimeter researchers developed a protocol that keeps security keys safe, even from advanced eavesdroppers, as long as the adversary is incapable of sending a signal faster than light, breaking causality itself.

QIP=PSPACE (2011)

To develop practical quantum computers, researchers need to understand when quantum computers have an advantage over their classical counterparts, and when they don't. In one type of computation known as an interactive proof, one computer pitches a solution, while a second checks its work. Perimeter researchers proved that in these scenarios, classical and quantum computers are evenly matched. This was a surprise result, given that in many other scenarios, quantum computing shows an advantage, and it has become a seminal, textbook standard result in the field.

Quantum Information Meets Black Holes (2007-2017)

Can you retrieve information thrown into a black hole, and if so, how long would it take? Perimeter researchers exploring this question uncovered new insights into how information scrambling occurs inside black holes. By bringing quantum information theory in contact with black holes, the most extreme gravitational objects in the universe, this research program sparked new experimental tests, and may soon influence the design of next-generation quantum technologies and materials.

Quantum Gravity

Deformed Special Relativity (2002-2010)

In one of Perimeter Institute's most influential papers, theorists proposed a new way to unite gravity with quantum mechanics by imposing a new invariant (something that does not change, like the speed of light). This invariant is a fundamental scale – the smallest possible length or energy level – that would grant gravity and quantum mechanics a shared property. The idea spurred enormously productive new area of research, and redefined the field of quantum gravity.

Effective Spin Foams (2019)

The holy grail of physics – uniting Einstein's theory of relativity with quantum mechanics – might be solved by 'quantizing gravity' – breaking spacetime down into a mesh of tiny building blocks. One promising version of this, called spin foams, are very difficult to simulate. Perimeter researchers developed the first practical method to do so, enabling them to probe the idea rigorously for the first time ever.

Local Holography and Corner Symmetry (2016-2025)

Most approaches to quantizing gravity are top-down: they start with a theory, and work toward reality. Some Perimeter researchers are now seeking a bottom-up approach, that breaks down the boundaries between top-down theories like holography, string theory, and loop quantum gravity. They place the fundamental concept of symmetry (long excluded from theories of gravity, but vital to quantum physics) at the heart of the problem. That work has led to exciting new breakthroughs and unexpected collaborations across disciplines.

Quantum Fields and Strings

Entanglement Entropy Meets Holography (2010)

Entanglement is a core concept in quantum mechanics: it enables quantum computing and communications, and is key to exotic material behaviours in condensed matter research. Perimeter scientists have developed a new conceptual bridge connecting entanglement with the longstanding problem of quantum gravity. This research launched a flourishing new field and sparked breakthroughs both in quantum information and the unification of general relativity with quantum mechanics.

Reviving the S-Matrix Bootstrap (2011-2025)

Quantum field theories are the frameworks physicists use to describe the behaviour of elementary particles like electrons and photons. Perimeter scientists revived a once-abandoned technique – the S-matrix bootstrap – that allowed them to test not just a single quantum field theory, but to map out the space of all possible field theories consistent with the laws of physics.

The CHY Formalism (2014)

Sometimes, breakthroughs come from finding alternative descriptions of existing physics. Perimeter researchers developed the highly influential 'CHY formalism,' which does the same work as Feynman diagrams (a longstanding technique for describing particle interactions), but also makes certain intractable problems and calculations trivial. The CHY formalism has given scientists new insights into particle behaviour that Feynman diagrams couldn't have provided on their own.

Quantum Matter

Machine Learning in Quantum Matter (2016-2025)

Are quantum computing and artificial intelligence compatible? Perimeter scientists discovered certain problems in quantum physics, which get more difficult as the number of electrons in a device grows, are closely related to problems in machine learning, where image recognition, for example, becomes more difficult as the number of pixels grows. From this initial insight, Perimeter's work at the intersection of AI and quantum has grown, and recently led to the integration of a neural network with a Rydberg atom quantum computer at Harvard University.

Many-Body Localization (2013)

Some quantum states of matter do not obey expected laws of physics, such as the tendency of a group of particles to flow toward thermal equilibrium. Perimeter researchers uncovered the mechanism behind these materials' absence of "thermalization," and showed how they can become platforms for many types of novel and exotic materials, including recently discovered 'time crystals.'

The 'Fuzzy Sphere' Technique (2023)

Understanding phase transitions is a core requirement for understanding quantum materials. The 'fuzzy sphere' technique, developed at Perimeter, enables researchers to simulate phase transitions with orders of magnitude fewer data points than traditional 'lattice' methods, using less computing power while still giving accurate results as well as new results that weren't possible with traditional methods.

Strong Gravity

The First image of a Black Hole (2019)

The Event Horizon Telescope released the first ever picture of a black hole in 2019. It was achieved by connecting multiple radio telescopes together into a single Earth-sized telescope. The telescope is a global collaboration, with Perimeter researchers providing the telescope with its vital analytical brain.

Violations of Cosmic Censorship (2010)

Einstein's theory of gravity predicts that a singularity at the heart of a black hole will always be hidden from observation behind an event horizon. The first ever violation of this prediction was found by Perimeter scientists in higher dimensions, suggesting that this rule must be a special property of our four-dimensional universe.

Where Does Gold Come From? (2019)

For a long time, it was unclear how heavy elements like gold, uranium, and platinum form. Using data from multiple types of astronomy, including gravitational wave detectors, researchers at Perimeter revealed these elements are created in the energetic collisions between neutron stars.

Learn more

To learn more about these breakthroughs and the cutting-edge research being done at Perimeter Institute, join us at perimeterinstitute.ca/turning-points

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