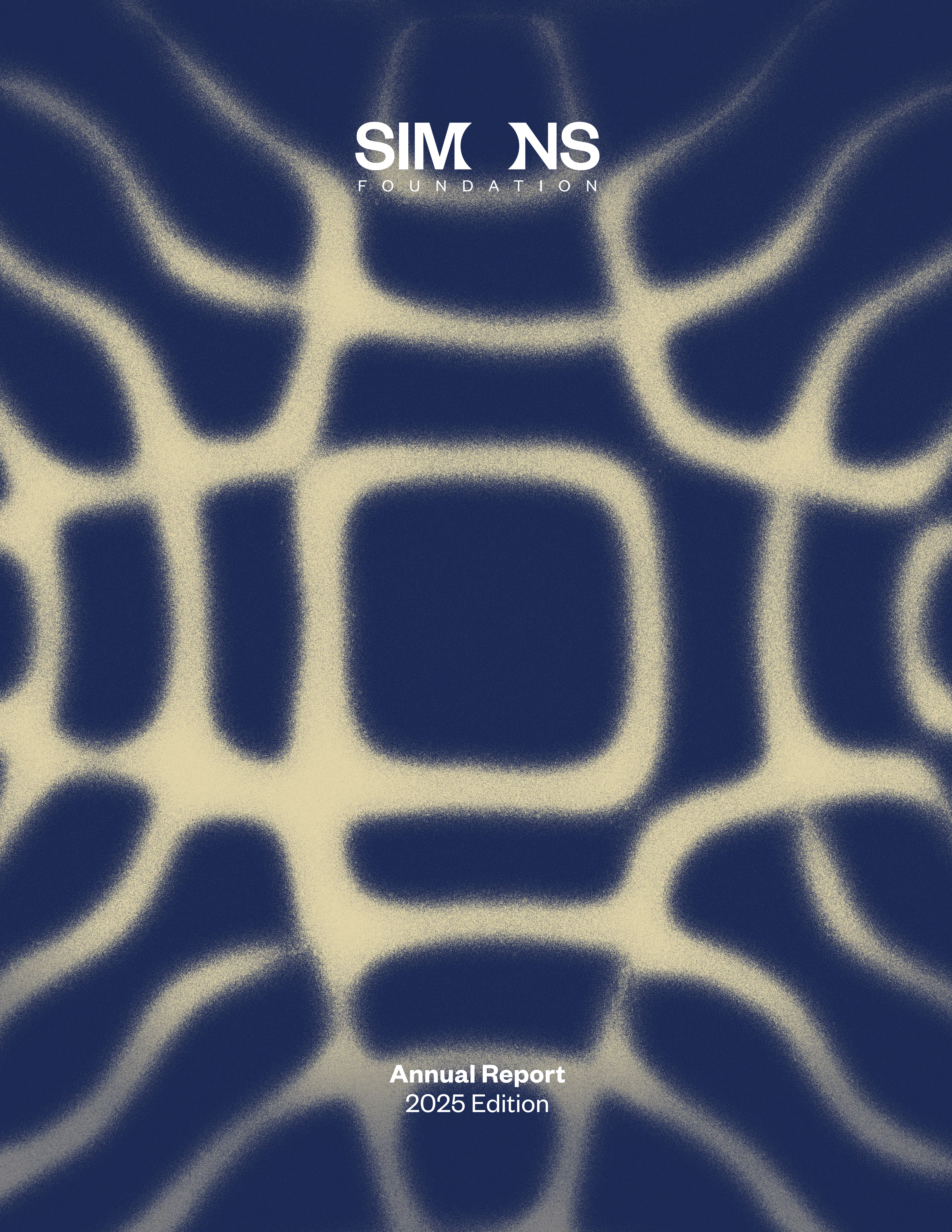

SIMONS
FOUNDATION

Annual Report
2025 Edition

Galileo Galilei famously wrote that the universe is a book “written in the language of mathematics,” and that without it, “one wanders about in vain through a dark labyrinth.”

At the Simons Foundation, this enduring truth — that mathematics is the means by which we understand our world — shapes how we approach discovery across disciplines, from evolutionary ecology to theoretical physics.

We’re pleased to present this special edition of our annual report, which explores the centrality of mathematics in our work through stories on Möbius strips, string theory, machine learning, autism and more.

David N. Spergel, Ph.D.
President

You can view additional media related to these stories on our website.

Cover:

Mathematics underpins the natural world, yet it often remains invisible. The cover of this report is based on the work of physicist and musician Ernst Chladni (1756–1827).

Chladni explored the mathematics underlying the vibration of metal plates — from flat sheets to cymbals and church bells. As sound waves travel through a plate, multiple waves can meet up and cancel each other out. (A similar principle powers active noise-canceling headphones.) This destructive interference creates regions where no vibration occurs. When we coat the plate with sand or salt and adjust the vibrational frequency, geometric patterns emerge as the particles settle in these “calmer” regions.

To watch a video of Chladni plates in action, visit **simonsfdn.org/ChladniPlates**.

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Letter From the President

Galileo Galilei declared that the “book of nature is written in the language of mathematics.” Mathematics provides both the language for science and a description of possible universes and structures beyond what we see in nature.

Jim Simons would tell me that our investments in science enable the technologies that will improve human lives in the future. By investing in deepening our knowledge of mathematics, we not only provide new tools for understanding nature but also enrich our lives through exploring the elegance of mathematical possibilities.

The year 2026 is a particularly appropriate time to celebrate math, as mathematicians from throughout the world gather in Philadelphia for the International Congress of Mathematicians, a quadrennial gathering last held in the United States in 1986. This is a moment that reminds us that mathematics — and science — is a human endeavor that builds on work from all over the world.

This report celebrates math’s role in supporting science and in shaping our understanding of everything from string theory and black holes to ocean microbes and autism.

Many of the articles in this report highlight foundation-supported research enabled by AI methods. Advances in AI are already transforming science and our broader society. Just as the world before electricity was radically different from the world after, the next decade may be radically different from the last.

AI is already changing the way that mathematicians develop their ideas and proofs. Quanta Books’ first book, *The Proof in the Code*, explores Lean, a proof assistant that brings rigorous machine-verified structure for testing theorems.

AI will also change the way that we study the universe. Polymathic AI, which emerged from work at the Flatiron Institute, is developing large learning models built not on words but on data and simulations. At the same time, AI tools are playing a vital role in improving our understanding of autism.

We are truly living through a pivotal time for mathematics and science. Advancements such as AI are only possible because of prior investments in basic research. Now is the time to reaffirm support for basic research.

I am proud of the role the Simons Foundation has played and will continue to play in advancing the frontiers of math and science to improve lives.

David N. Spergel, Ph.D.
President

Letter From the Chair

Pasted inside our home copy of *Webster’s Third New International Dictionary* is a note: “To Jim, with thanks from I.T.P. April 1975.” C.N. “Frank” Yang and his colleagues at Stony Brook University’s Institute for Theoretical Physics (ITP) gifted the dictionary to my husband, Jim Simons, to thank him for giving six mathematical talks on parallel transport at the institute.

Those talks arose from a conversation Frank and Jim had the year before, when Frank told Jim about the Aharonov–Bohm experiment. Physicists were puzzled by how a charged particle could be affected by an electromagnetic potential despite being in a region where the electric and magnetic fields are zero. Jim wondered if the particle was reacting not to a local force, but rather to the underlying geometry of the space it was moving through. He was thinking about a parallel translation of a vector bundle, something mathematicians had figured out 40 years earlier.

Jim and Frank’s conversation on the Aharonov–Bohm experiment laid the foundation for many fruitful discussions to follow and helped cement a decades-long friendship.

Over the centuries, many such exchanges between mathematicians and scientists have spurred their fields forward. A famous example is the competitive collaboration between David Hilbert and Albert Einstein. The two researchers exchanged letters as they raced to derive the set of field equations that explained general relativity. Ultimately, Hilbert’s rigorous mathematical approach, based on the calculus of variations, formalized Einstein’s intuitive understanding of the curvature of space.

But whether it’s a race to the finish or a more collaborative tête-à-tête approach, mathematicians and scientists can inspire and complement each other’s approaches. Today, there are many areas of active collaboration around the world, ranging from one-on-one dialogues to small-group collaborations to institutional efforts.

Over the years, the Simons Foundation has sought to foster such interdisciplinary endeavors to catalyze discoveries both within and across fields. Some examples of these efforts include the Simons Collaboration on the Localization of Waves, the Simons Collaboration on Probabilistic Paths to Quantum Field Theory, and Stony Brook University’s Simons Center for Geometry and Physics. At the foundation’s Flatiron Institute, the Center for Computational Mathematics serves as the glue that unites researchers across the institute’s diverse fields of astrophysics, biology, neuroscience and quantum physics.

By nurturing the flow of ideas across fields and among mathematicians and scientists, we know that basic research will yield unexpected results and lead to impactful insights. It was clear to Jim back in the 1970s that the relationship between math and science was no longer a one-way street. Mathematics provided scientists with the tools to explain their observations, and science pointed the way to new mathematical theorems. Jim eagerly shared all he had learned from the physicists at ITP with his friend and mentor, Isadore Singer, who further passed the word to Michael Atiyah, and so on.

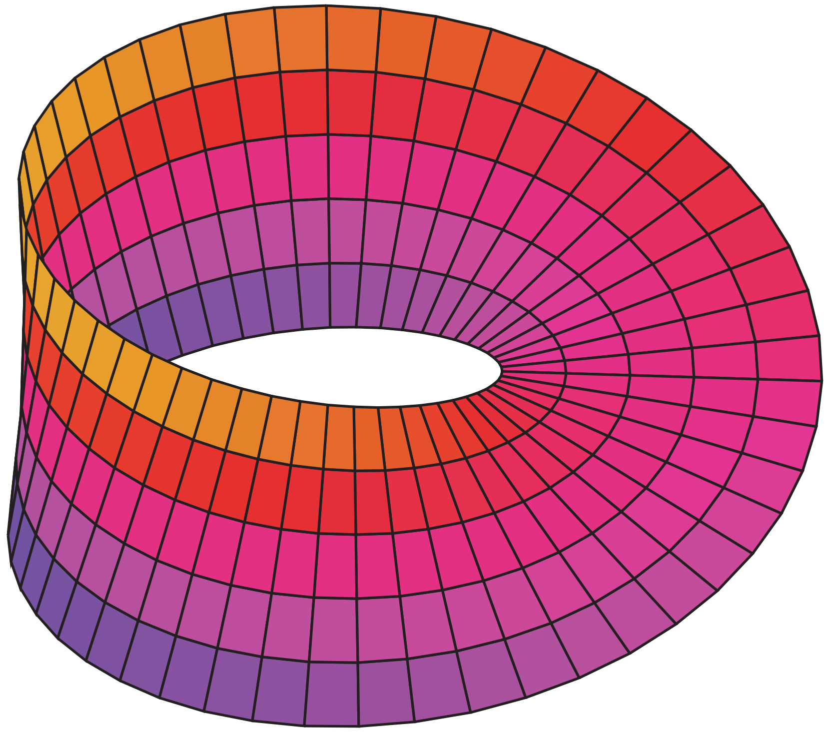
As for the dictionary, the ITP physicists chose it for a specific reason. Weeks of watching Jim write theorems and equations on the blackboard revealed that while Jim was an outstanding mathematician, he was an atrocious speller! It was such a comical, unexpected insight from the collaboration. Jim was quite amused.

Marilyn Hawrys Simons, Ph.D.
Chair

The Twisted Mathematics of Richard Schwartz and Möbius Bands

Take a rectangular strip of paper, give it a half twist and connect its short ends to each other. You have made a Möbius band, also known as a Möbius strip or loop. It is a familiar staple of recreational mathematics and a simple illustration of the mathematical concept of non-orientability. (That is, it has no universal 'up' or 'down' direction.) Plus, it's just fun to play with.

If you start with a long, skinny strip of paper, it's easy to make a Möbius band. With shorter strips, it gets harder to twist and connect the ends. You'll eventually hit the point where you physically can't make a Möbius band because the ratio between the length and width is too low. There is a clever folding pattern that produces a Möbius band from a strip of paper with an aspect ratio of the square root of 3 (around 1.73) to 1. Even though this construction has been described in papers since as early as 1930, no one was able to prove that it was impossible to twist a strip with a smaller aspect ratio into a Möbius band.



A Möbius strip is a surface that connects to itself with a half twist. Mathematician Richard Schwartz recently proved the minimum aspect ratio possible for such a band. Credit: Krishnavedala/Wikimedia

When Richard Schwartz heard about the conundrum, he asked himself, "What's so hard about this problem? I could do this." Schwartz is a math professor at Brown University and four-time Simons Fellow in Mathematics with broad interests, from geometry and topology to writing colorful, mind-bending children's books about math.

His first instinct when faced with the Möbius strip question was to model it on the computer. That exploration gave him some immediate gratification, an improvement on what were then the best-known bounds of the problem based on an argument that involved cutting the Möbius band along a particular set of lines. When he first programmed it into the computer, he erroneously assumed those cuts left him with a parallelogram. "There followed three years where I was trying to push this argument further using the parallelogram idea," he says. His chain of reasoning kept getting more complicated, but the bound never budged. Finally, he started playing with a paper model. "I cut one open, and oh my God, you get a trapezoid." The entire parallelogram argument evaporated, taking with it his original improvement.

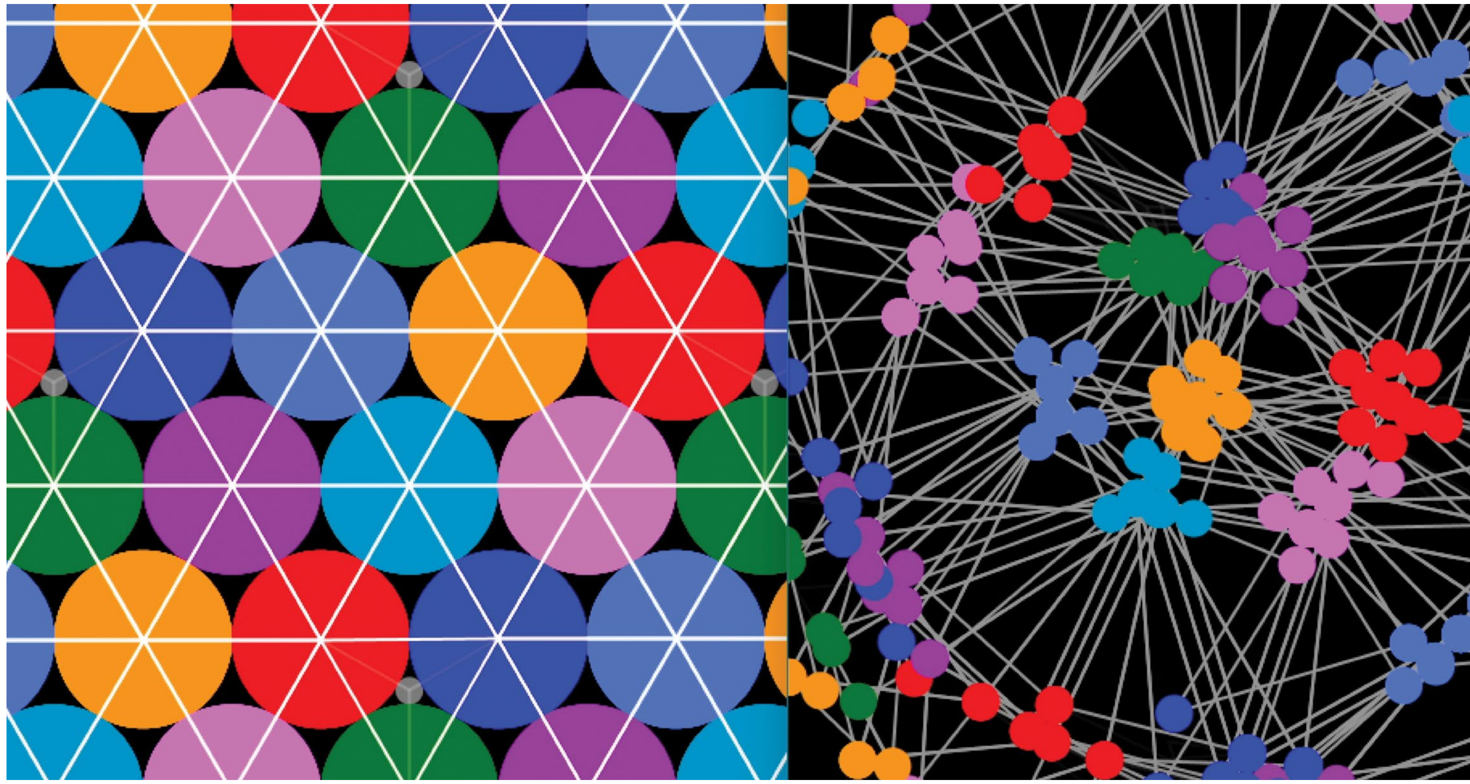
While he was trying to correct his earlier erroneous paper, he realized, "When I did the calculation right, it solved the whole conjecture." In just a few days, he was able to prove that the square root of 3 to 1 is indeed the lower limit of aspect ratios for a Möbius band. He circulated his proof among some other interested mathematicians and, with their feedback and improvements, "it got to be a razor-sharp argument," he says. "I'm thrilled with it."

The optimal Möbius band is the answer to a problem of geometric optimization. Such problems ask, given certain geometric constraints, what the limits are of the shapes that fit those constraints — for instance, the smallest or the largest. The questions are often natural and intuitive (such as identifying the widest Möbius strip), but actually proving that a particular shape is optimal can be fiendishly difficult. Schwartz's misadventure among the specious parallelograms illustrates the combination of playfulness and tenacity that allows him to latch on to these curiosity-driven questions and see them through to the end.

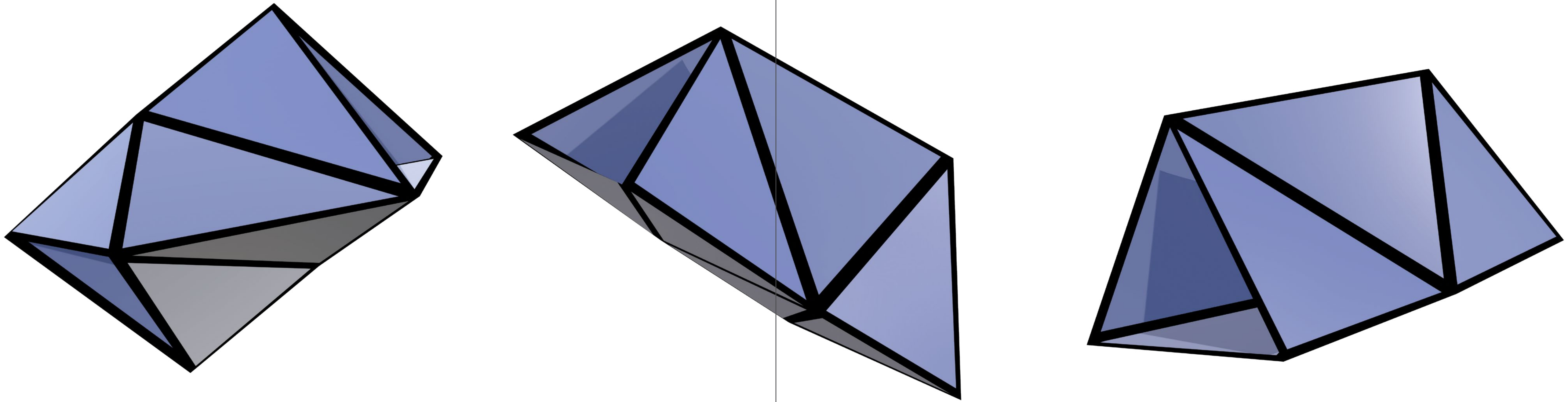
During a trip to the Institut des Hautes Études Scientifiques (IHES) outside Paris during his 2024–2025 Simons Fellowship, Schwartz turned his attention to another geometric optimization problem involving a well-known shape: an origami-like folding of a flat surface into a torus. A torus is the mathematical name for the shape of an inner tube or the layer of glaze covering a doughnut. The term refers to the shape topologically: That is, the shape can be stretched, twisted and deformed and, so long as it isn't torn or glued, still be called a torus.

A flat torus is a representation of the torus as a square, or any parallelogram, with opposite sides 'identified.' That is, the sides behave like the sides in the classic arcade game *Asteroids*. When the user-controlled spaceship travels off the right side of the screen, it reappears on the left side, continuing in the same direction. Just as in the game, the sides of the flat torus are linked.

If you actually sat at your desk, took a square of paper and taped the edges together to realize that flat torus in three-dimensional space, it wouldn't be smooth and pretty like an inner tube — it would be folded or crumpled in some places. The smooth surface of an inner tube requires the stretching of rubber. A flat torus



A still image from an animation of hill climbing, a mathematical optimization technique used by mathematician Richard Schwartz when he was researching how to make a torus shape with the smallest number of vertices. The algorithm starts with an arbitrary solution to a problem and then makes incremental changes to the solution to find a more optimized outcome. Credit: Image courtesy of Richard Schwartz



3D models of 'pup tents,' a family of eight-vertex tori invented by mathematician Richard Schwartz while he was researching how to create a torus with a minimum number of vertices. Credit: Thomas Sumner/Simons Foundation

can't fit in three-dimensional space in a smooth way without distortion, but if you allow some folding, you can do it.

Your first attempt at making a flat torus out of paper will probably look randomly crumpled. A natural mathematical question is whether there is a flat torus that is 'best' in some way. Schwartz was specifically interested in origami flat tori, which are formed by fitting flat triangles together in three-dimensional space so that the total angle around every point — including the vertices where the triangles intersect — is 360 degrees, the same as in a full circle.

Schwartz sought to find origami tori with the fewest vertices possible, a challenge known as the minimum-vertex problem. He had heard about the problem years ago from colleagues, and conversations he had during his fellowship visit to IHES rekindled his interest in the problem. Previous research had established that any such torus must have at least seven vertices and had produced examples with nine. Schwartz set to work proving that nine vertices was the smallest number possible. First, he demonstrated that no seven-vertex triangulation could work, using computer modeling to explore the space of possible configurations of seven points and employing arguments from projective geometry and combinatorics to reduce the total number of cases to be examined.

> "I don't know how to solve it. But if I don't try to solve it, then it's 100 percent guaranteed I'm not going to solve it."
>
> — **Richard Schwartz**

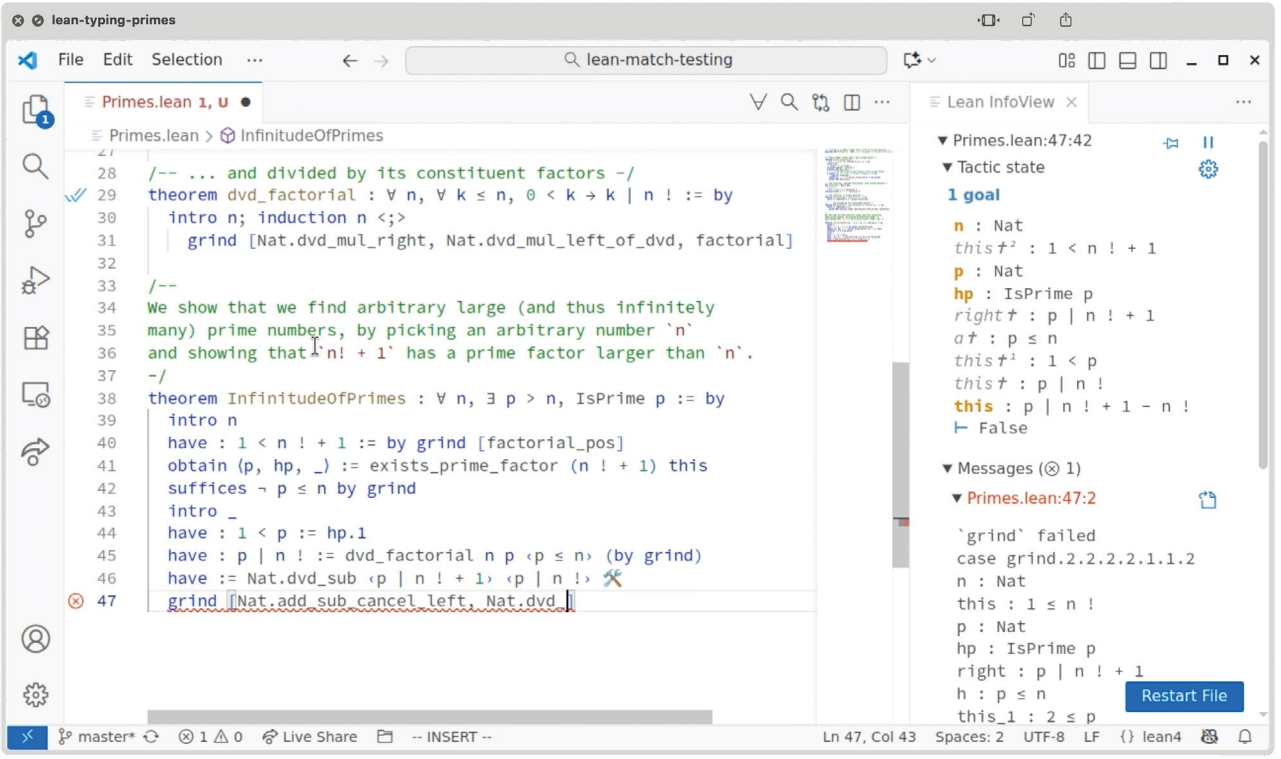
When he tried to extend his arguments to eight vertices, though, he kept failing. He reduced millions of cases to thousands but couldn't narrow them down further. "It just wasn't quite working," he says. "At some point, my brain switched." He began to wonder whether an eight-vertex torus might be possible after all. He ran some experiments and eventually settled on a supervised machine learning approach to find triangulations that could work. After that, it took more work to show that the potential triangulations, which involved numerical approximation, actually yielded honest-to-goodness flat tori. When all the numbers worked out, he ended up with a family of eight-vertex tori he calls 'pup tents' because of their squat shape.

These pup tents are not intended for the shelves of camping goods stores, nor are they likely to have any other practical use. "I just like to play around," Schwartz says. But behind that play are serious questions about the limits of human imagination and understanding. Mathematics is riddled with problems that are simple to state and nearly impossible to solve. When he runs up against one of these questions, he thinks, "We humans ought to be able to answer this question, and we can't. That means that there's some idea that we're missing."

The quest for the proof of one of these deceptively difficult problems continues to drive Schwartz, whether it's a twisted piece of paper, an origami doughnut or something else.

For many years, he has had his sights set on the square peg problem, "like Ahab looking for the whale," he says. That problem asks whether every curve that reconnects with itself in a closed loop without crossing over itself has four points that form the corners of a square. "I don't know how to solve it," he says. No human has yet looked at the question in quite the right way. An elegant solution could be right around the corner or never found in a thousand years. "But if I don't try to solve it, then it's 100 percent guaranteed I'm not going to solve it."

From Trust to Verification: Lean's Impact on Mathematics



```lean
/-- ... and divided by its constituent factors -/
theorem dvd_factorial : ∀ n, ∀ k ≤ n, 0 < k → k ∣ n ! := by
  intro n; induction n <;>
    grind [Nat.dvd_mul_right, Nat.dvd_mul_left_of_dvd, factorial]

/--
We show that we find arbitrary large (and thus infinitely
many) prime numbers, by picking an arbitrary number `n`
and showing that `n! + 1` has a prime factor larger than `n`.
-/
theorem InfinitudeOfPrimes : ∀ n, ∃ p > n, IsPrime p := by
  intro n
  have : 1 < n ! + 1 := by grind [factorial_pos]
  obtain ⟨p, hp, _⟩ := exists_prime_factor (n ! + 1) this
  suffices ¬ p ≤ n by grind
  intro _
  have : 1 < p := hp.1
  have : p ∣ n ! := dvd_factorial n p ‹p ≤ n› (by grind)
  have := Nat.dvd_sub ‹p ∣ n ! + 1› ‹p ∣ n !›
  grind [Nat.add_sub_cancel_left, Nat.dvd_]
```

```
▼ Primes.lean:47:42
▼ Tactic state
1 goal
n : Nat
this✝² : 1 < n ! + 1
p : Nat
hp : IsPrime p
right✝ : p ∣ n ! + 1
a✝ : p ≤ n
this✝¹ : 1 < p
this✝ : p ∣ n !
this : p ∣ n ! + 1 - n !
⊢ False

▼ Messages (⊗ 1)
▼ Primes.lean:47:2
`grind` failed
case grind.2.2.2.2.1.1.2
n : Nat
this : 1 ≤ n !
p : Nat
hp : IsPrime p
right : p ∣ n ! + 1
h : p ≤ n
this_1 : 2 ≤ p
```

An example of what it's like to work on a proof using Lean. This proof demonstrates that an infinite number of prime numbers exists. Credit: Lean FRO

For thousands of years, mathematicians have experienced the emotional roller coaster of checking and rechecking their work: Just when they think a proof is complete, the ground can drop out from under them because of a tiny error. They rebuild their theorems, only to uncover more errors that need fixing.

A new software tool could transform mathematical research, turning that roller coaster into a reassuringly steady climb to a proof. Introduced in 2013, the proof assistant Lean reduces the need for repeated manual checking, allowing researchers to focus on the thrills of mathematical research. When mathematicians formalize their work, or rewrite proofs into code that Lean can verify, they catalyze new ways of collaborating. No other proof assistant has ever been as widely embraced and evangelized as Lean, which boasts an impressive library of formalized work that future mathematicians can easily build upon.

"I think the math community loves most that Lean enables them to work together, even with people that they never met before," says Leonardo de Moura, Lean's creator. "It's almost like the mathematician is a program manager who sets the architecture of the project, and then people all around the world contribute to it and fill the holes."

Lean addresses a fundamental 'trust bottleneck' in mathematics: No researcher can personally verify every result needed to advance new work. As a consequence, mathematicians tend to rely on papers published by people they know or journals they trust. When papers include formalization, mathematicians can confidently build on those results regardless of where they were published. That shift is transforming how mathematicians work.

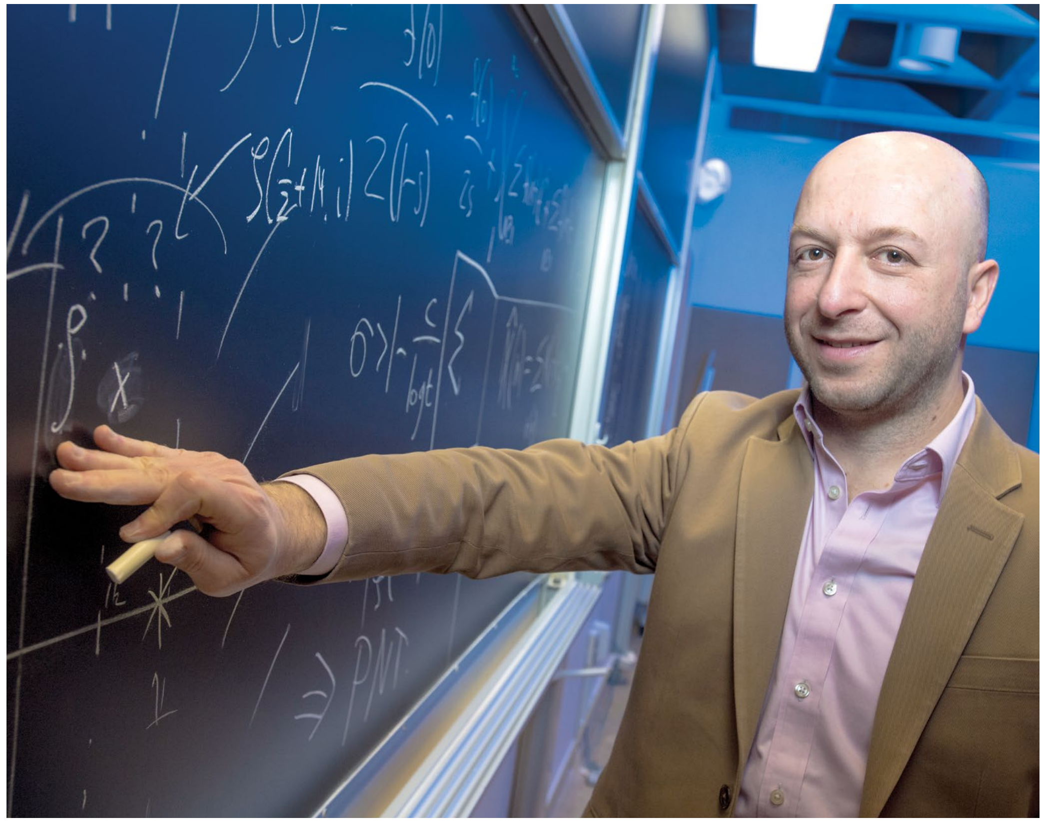
Lean's Beginnings

Although several other proof assistants such as Coq, Isabelle and Mizar can check the logic of a proof, none are as widely used or scalable as Lean. In 2013, when de Moura realized the enormous potential of the debugging program he had written, he released Lean as open-source code and began working on what would become an unprecedented level of scalability and usability.

By 2015, Lean had a small community of users, including Jeremy Avigad, a professor at Carnegie Mellon University who had just taken on a master's student, Sebastian Ullrich, who was visiting from the Karlsruhe Institute of Technology in Germany. For the next several years, Ullrich was the only person besides de Moura adding code to Lean.

2021 was a big year for the proof assistant. In the summer, renowned mathematician Peter Scholze asked the community to validate and clarify a complicated new proof using Lean. The freshly confirmed results were written up in *Nature*. That fall, billionaire Charles Hoskinson donated $20 million to Carnegie Mellon to establish a center focused on Lean under Avigad's direction. A week later, the nonprofit incubator Convergent Research reached out to de Moura and Ullrich asking if they'd be interested in turning Lean into a new type of nonprofit organization.

In 2023, when Ullrich defended his Ph.D. thesis documenting the current version of Lean, the pair established the nonprofit Lean Focused Research Organization (FRO) with guidance from Convergent Research and generous



Rutgers University mathematician Alex Kontorovich, one of the leaders of a 2025 workshop for Lean at the Simons Foundation. Credit: Nick Romanenko/Rutgers University

Mathematicians Antoine Chambert-Loir of the University of Paris and Heather MacBeth of Fordham University — together with Alex Kontorovich — co-led a 2025 Lean workshop at the Simons Foundation. Credit: Ivonne Vetter/MFO; Petra Lein/MFO

philanthropy, including a $5 million gift from Simons Foundation International and related support from the Simons Foundation.

Like a cross between a startup and a university lab, an FRO incubates new research with philanthropic grants. After the five years are up, the Lean FRO will disband and transition into a nonprofit foundation, in the footsteps of foundations related to the Rust programming language and the Linux operating system.

“Before the FRO, it was a research project: Sebastian was a grad student, we were writing papers and our focus was the research,” de Moura says. “Once the community grew a lot, people started expecting a product of better quality. Without this money, it would be impossible to run.”

A Global Shift

To encourage the adoption of Lean, the Simons Foundation hosted a two-week workshop in June 2025. Led by mathematicians Alex Kontorovich, Antoine Chambert-Loir and Heather MacBeth, the workshop brought together 57 postdocs, graduate students and early-career researchers from around the world at the Simons Foundation’s New York City headquarters.

> “I think the math community loves most that Lean enables them to work together, even with people that they never met before.”
>
> **— Leonardo de Moura**

During the workshop, participants formalized solutions to undergraduate-level exercises and more advanced mathematics, including the prime number theorem. That theorem, which quantifies how prime numbers become rarer as they get larger, already had a ‘blueprint,’ or a map of the proof showing every formalized statement and how those statements depend on one another.

“We had had this large-scale formalization project where software engineers who had a few hours on the weekend would volunteer to solve one of these goals; we were slowly but surely making progress through this,” says workshop leader and blueprint designer Kontorovich, who is also a member of the Lean FRO strategic advisory board. During the second week of the workshop, “we worked for five days, eight hours a day, knocking off those [goals]. Once those things were done, I just put in the last step. So that proof formalization is thanks to the Simons Foundation.”

The formalization of the prime number theorem is exciting, even though the theorem itself is nearly a century old. That’s because the mathematical objects and subproofs — called lemmas — that workshop attendees coded into the math library of Lean can be used perpetually by future researchers, which means that Lean becomes easier and faster the more researchers use it. Lean’s verification powers mean that researchers can create and trust AI-generated proofs of lemmas without worrying about AI hallucinations or ‘slop.’

The Promise of Lean

Lean augurs a new future for mathematics. Kontorovich compares Lean to the typesetting program LaTeX, which was unpopular when it was developed in 1978 but is now standard throughout mathematics and science; he predicts that Lean will similarly become ubiquitous in a few generations. Lean is particularly useful in education, providing instantaneous feedback.

“It’s completely different from school when you submit your exercise sheet once a week and you hear back maybe a week later,” Ullrich says. “Just getting that feedback immediately about whether that proof makes sense or not, it’s a complete game changer.”

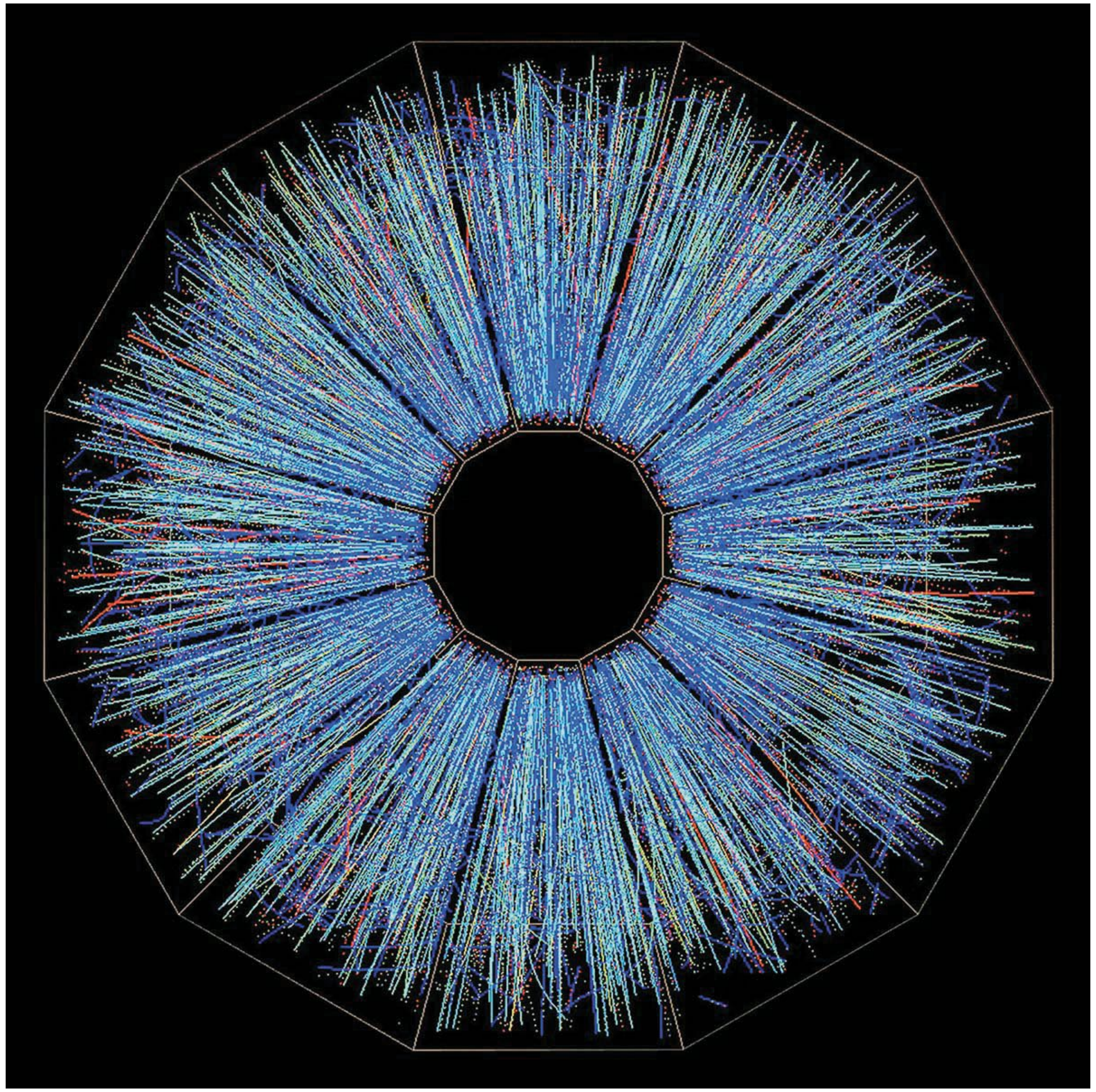
Lean will transform other realms as well. De Moura says, laughing, that “it feels like every week now some startup founder contacts us.”

Lean was created to aid mathematicians and build trust in the field, but researchers are also finding it a powerful tool for AI-assisted mathematics. One AI startup that relies on Lean, Harmonic, won a gold medal at the International Mathematical Olympiad in 2025 after a Google AI chatbot that uses Lean was one point shy of gold in 2024. In early 2026, a 23-year-old used ChatGPT and Lean to solve Erdős Problem 1196, which had remained unsolved for 60 years, in just over 80 minutes of compute time.

As AI improves, it will undoubtedly formalize more math. In 2023, while serving as editor of the journal Experimental Mathematics, Kontorovich ran a special issue on proof assistants, including Lean. The experience convinced him that AI will not be replacing mathematicians anytime soon.

“There are two very separate things that a journal evaluates when it receives a paper: One, is the mathematics correct, and two, is the mathematics interesting,” Kontorovich says. “Lean does not evaluate two at all. Lean will prove that 17 plus 18 equals 35, and it will certify that the theorem is correct, which is not interesting. So, it’s still up to mathematicians to determine what our taste is [and] what our values are.”

Mathematicians and String Theorists Push Each Other's Fields Forward



Debris from a collision between gold nuclei that formed a quark–gluon plasma in the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. Experiments such as this one provide tests of string theory models. Credit: Brookhaven National Laboratory

When asked why he wanted to climb Mount Everest, legendary British mountaineer George Mallory purportedly said, "Because it's there."

Mathematicians, says Lev Rozansky, are drawn to certain mathematical problems for the same reason. "Many mathematicians think there are no practical applications to some problems, but people attempt them anyway, because they're there," says Rozansky, a theoretical physicist and mathematician at the University of North Carolina at Chapel Hill and an investigator with the Simons Collaboration on New Structures in Low-Dimensional Topology. "But it turns out there are many places where there is, in fact, overlap with practical applications."

One of the areas with the largest overlap is a branch of theoretical physics known as string theory. String theorists posit that if you break down matter to its smallest scales, you will eventually find that everything is composed of one-dimensional bits of vibrating energy called strings. The fundamental framework for how these strings move and interact is string theory. This realm of physics requires both an understanding of some of the furthest frontiers of fundamental physics and specialized knowledge of the mathematics at play. That's a combination that's largely out of reach for any one person.

"It's a huge challenge to master several different subjects, and therefore most people tend to stay in one area," says Sergei Gukov, a professor of theoretical physics and mathematics at the California Institute of Technology. The solution, he says, is a greater collaboration between physicists and mathematicians.

Driving that cooperation are initiatives supported by the Simons Foundation that bring together top mathematicians and physicists from around the world. For much of history, math and physics grew together thanks to polymaths such as Isaac Newton and Galileo Galilei. These days, researchers are often siloed in their respective fields, with physicists typically learning only the math necessary for their disciplines and mathematicians largely forgoing the study of physics. At some universities, math and physics departments aren't even located in the same part of campus.

"The cultural gap between mathematicians and physicists is a problem," Rozansky says. "But on the other hand, for those who can understand both sides, there is a great opportunity."

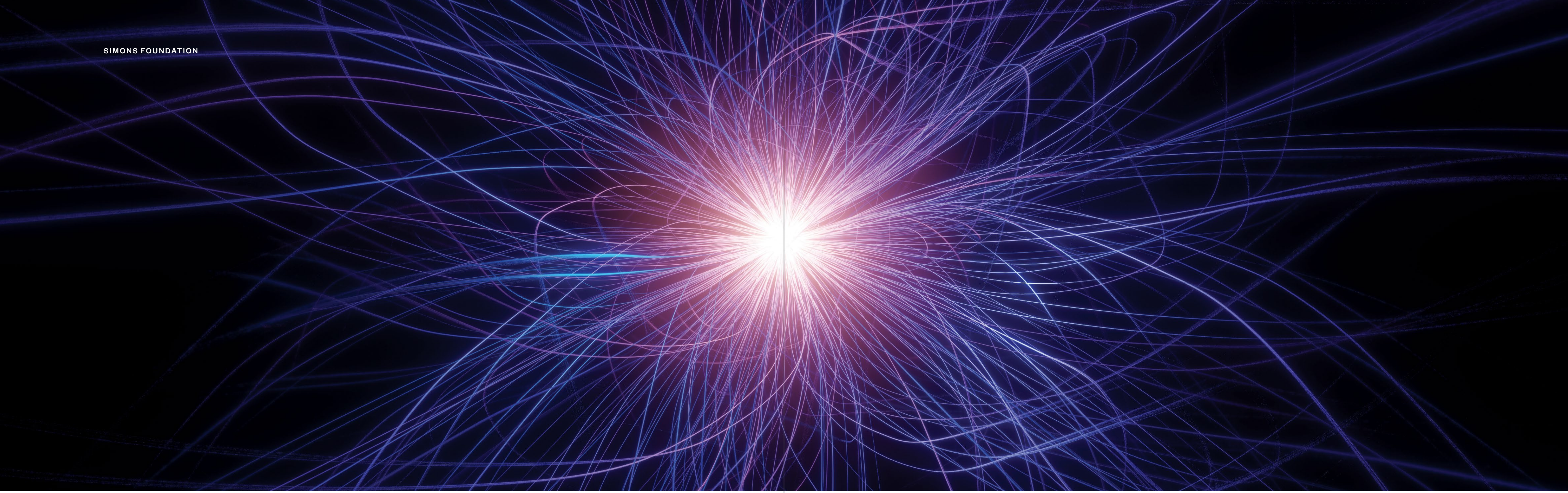
That opportunity includes solving one of the greatest unsolved problems looming over the fields of mathematics and physics. Called the Yang–Mills existence and mass gap problem, this mystery is one of seven with a $1 million bounty for its solution offered by the Clay Mathematics Institute.

The famous Yang–Mills problem is one that the Simons Collaboration on Confinement and QCD Strings was established to tackle. Since 2023, members of the collaboration, comprising a mix of physicists and mathematicians, have been working together to study aspects of string theory and the strong nuclear force (one of the four fundamental forces along with gravity, electromagnetism and the weak force).

> "Cutting-edge developments in mathematics are essential for getting a better grip on confining strings and string theory."
>
> **— Ross Dempsey**

The strong force holds together strongly interacting particles such as protons and neutrons and describes the subatomic particles they're made of, called quarks and gluons. The fundamental description of the strong force is known as quantum chromodynamics, or QCD. Physicists believe that QCD predicts that quarks never travel alone and are instead always 'confined' by stringlike tubes of energy into larger particles like protons and neutrons.

Princeton University's Igor Klebanov, director of the QCD collaboration, is working on understanding quark confinement using ideas at the intersection of string theory and mathematics. Using simplified models and



String theory posits that the universe's fundamental components are not pointlike particles, but rather one-dimensional vibrating strands of energy called strings. Credit: MikeCS Images

mathematical symmetries, Klebanov aims to explain why a single quark can never be found in isolation. This work led Klebanov, along with three other scientists in the QCD collaboration, to a serendipitous finding that a special kind of mathematical symmetry can be applied in a simplified version of Yang–Mills theory. The findings are helping theoretical physicists perform numerical calculations with greater accuracy than before.

"Cutting-edge developments in mathematics are essential for getting a better grip on confining strings and string theory," says Ross Dempsey, a postdoctoral fellow at the Massachusetts Institute of Technology who is affiliated with the QCD collaboration and who worked on the finding with Klebanov and fellow collaboration members Silviu Pufu and Bernardo Zan. "But you also see it going the other way, where advances in string theory inspire new conjectures and new directions in mathematics."

For example, string theory is helping expand the study of multidimensional geometry. Unlike the world we live in, with its three dimensions plus the dimension of time, string theory operates in 10 dimensions. Findings from string theory have led to new discoveries about complex geometries that operate in high dimensions. That means that even if string theory is someday ruled out as a description of physical reality, it will still have played a key role in advancing mathematics.

In another area of mathematics, a connection to string theory led to the proof of the monstrous moonshine theory (its actual name), which involved connecting wildly different areas of mathematics to understand a high-dimensional mathematical structure. The mathematician Richard Borcherds was inspired by the way string theory uses dimensions rolled up on strings into tiny spheres and doughnuts. Borcherds' proof in the 1990s has served as a steppingstone for other researchers who have since uncovered further connections between string theory and this branch of mathematics.

"There's enormous mutual influence between string theory and mathematics," Dempsey says. "Any individual example would be shocking and amazing, but then there are so many of these examples that they become commonplace."

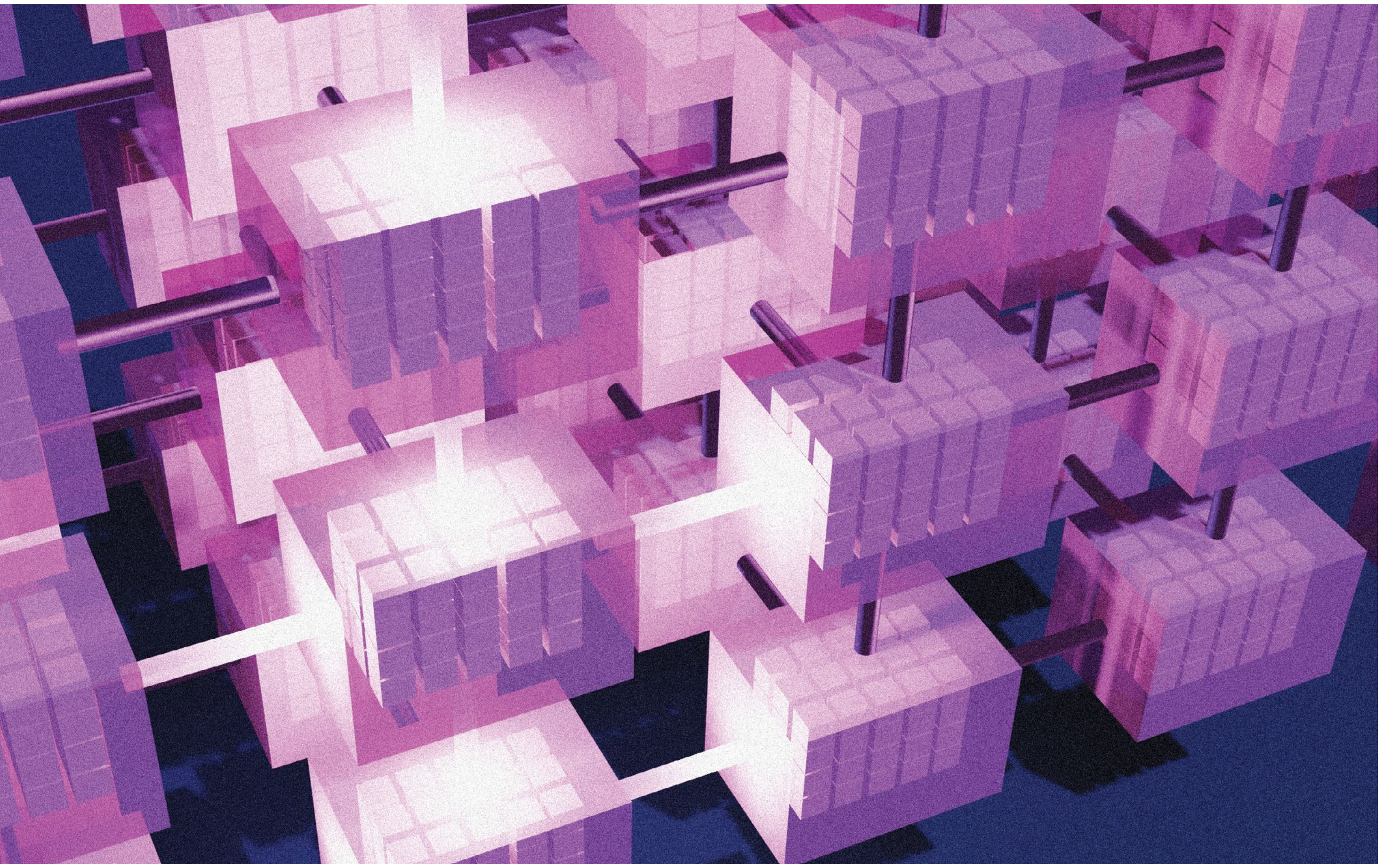
Furthering the study of the mathematical components underlying many aspects of string theory is the Simons Collaboration on New Structures in Low-Dimensional Topology. Low-dimensional topology is the study of three- and four-dimensional manifolds, which are mathematical spaces or surfaces that appear flat on small scales but reveal complex structures, such as knots and chains, when viewed from a distance. These types of spaces are important to fields of physics including relativity, quantum mechanics and string theory. With a diverse group of researchers, the New Structures collaboration aims to bring together new perspectives that can help overcome the barriers that have long thwarted progress in the field.

"Our collaboration could not exist without mathematicians and physicists coming together," says Gukov, a co-director of the New Structures collaboration. "I hope this collaboration will allow us to solve long-standing questions, some that have stood the test of time for many decades."

Besides furthering discoveries at the interface of mathematics and string theory, the collaboration's work is also advancing other areas of physics. The mathematics of manifolds, a type of modern algebra, is also relevant to the quantum realm. Last August, the collaboration discovered that a new class of mathematical theories could be used to make notoriously fragile quantum computers more stable.

"The subjects of mathematics and theoretical physics are getting more interwoven in a meaningful way," Gukov says. "As this connection becomes more meaningful, the bridges between the subjects become more solid and interesting, and it helps bring more people from one community to the other. It's a scenario where one plus one is actually bigger than two."

The Mathematical Tools Trailblazing the Quantum Future



An artistic interpretation of a tensor network, an important tool for studying quantum systems. Credit: Lucy Reading-Ikkanda/Simons Foundation

Quantum physicists are constantly running up against comically large numbers. Just storing the mathematical description of a simple quantum system of only 100 atoms would require far more storage space than that available on every computer hard drive on Earth combined.

This exponentially daunting challenge has led some to think that the only way to solve some of the thorniest quantum problems is with quantum computers. But a team at the Flatiron Institute's Center for Computational Quantum Physics (CCQ) is using mathematics to show otherwise.

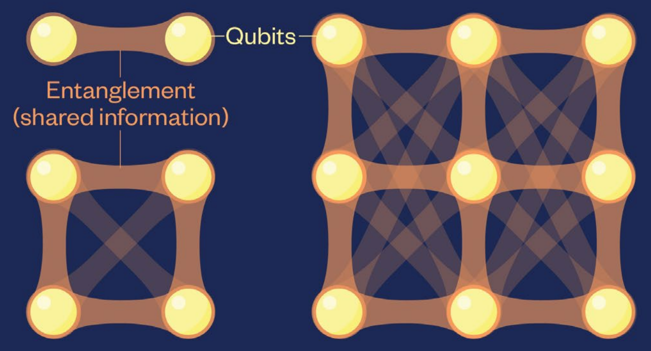
A key test for the CCQ's method came in March 2025, when a group of quantum computing researchers reported that they had used a quantum computer to complete a task that they claimed would take a classical computer tens of thousands of years to figure out.

Classical Compressions

Using mathematical structures called tensor networks, quantum physicists have simulated models on a standard laptop that were once thought to be beyond the reach of classical computation. The achievement offers new insights into the behavior of quantum systems.

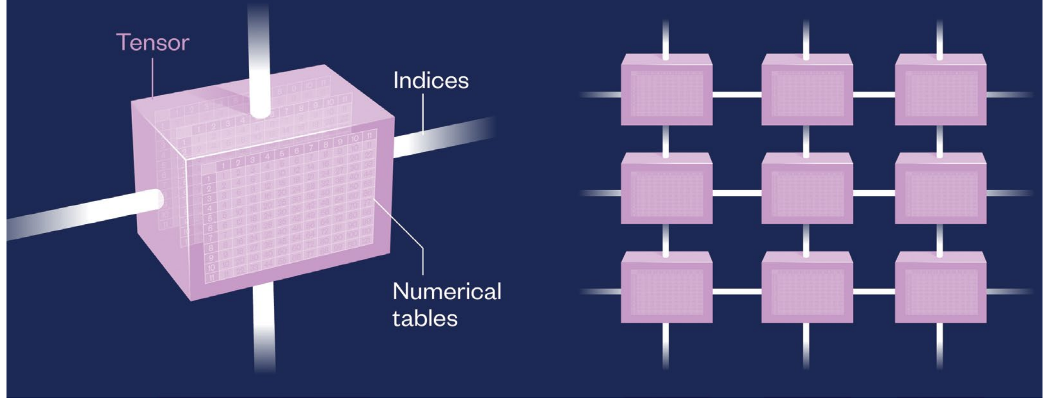
Quantum Power

The evolution of an entangled-qubit system over time is often deemed too difficult to simulate on a classical computer, since its complexity grows exponentially with each additional qubit.



Interconnected Tables

Each tensor in a tensor network condenses a large amount of information into a set of numerical tables. The tables each represent a single entangled qubit along with the data it shares with its neighbors. The tensors are linked by indices — channels that transmit these data, which encode the influence of adjacent qubits on one another.



Credit: Lucy Reading-Ikkanda/Simons Foundation

"I'm always a bit skeptical of these types of claims," says Joseph Tindall, an associate research fellow at the CCQ. "But this one in particular, I realized there were some approaches they had overlooked."

Tindall and his colleagues at the CCQ are experts at solving complex problems in quantum physics using conventional computers and cutting-edge techniques. He and his collaborators set out to complete the task without a quantum computer and, within a few months, had refined a method to solve the problem. Their approach was so efficient that they could solve one of the tasks at hand on a consumer desktop computer in just 30 minutes.

The secret to the team's success was a mathematical object known as a tensor network. Tensor networks use mathematical tricks to simplify systems that can be represented by immense numerical tables of numbers. This allows them to compress huge amounts of data, such as those in quantum systems, into manageable, interconnected tables known as tensors.

Beyond testing claims of quantum supremacy, tensor networks are enabling scientists to tackle many other difficult problems in areas ranging from computer science and mathematics to condensed matter and quantum physics. Foundational work being

Miles Stoudenmire, a research scientist and tensor networks project lead at the Flatiron Institute's Center for Computational Quantum Physics. Credit: Simons Foundation

done at the CCQ is helping lay the groundwork for future breakthroughs, from understanding high-temperature superconductors to developing leaner machine learning approaches.

Research into tensor networks began in the 1970s, led by physicist and mathematician Roger Penrose, who later shared a Nobel Prize in physics for his mathematical description of black holes. Penrose's notation for tensor networks is still used, but the applications of these mathematical systems have expanded far beyond the problems for which he introduced them.

In 1992, Steven R. White devised a powerful algorithm for understanding quantum systems — the density matrix renormalization group — which is now understood (thanks in part to the work of Ulrich Schöllwock) to inherit its efficiency from an underlying tensor network structure. Over the last 15 years, the use of tensor networks has exploded, and they are now found in fields from mathematics to chemistry.

"There are a lot of problems in math and science where you have huge amounts of data — data so big it can't fit on your computer," Tindall says. "A tensor network offers a way of compressing that data, kind of like a zip file."

These techniques come from a branch of mathematics called linear algebra that deals with tables of numbers known as matrices. Linear algebra is typically used to describe systems in low dimensions such as those involving a single matrix. But by linking matrices together, researchers realized that linear algebra could be used to describe problems with more dimensions.

Using networks of these linked matrices — that is, tensor networks — researchers can take very complex systems found in quantum dynamics and simplify them enough that they can be handled by classical computers. Some of the mathematical methods used in this simplification were developed recently, while others are hundreds of years old. Some of those techniques, though known to mathematicians, are new to quantum dynamics research.

"One of our mathematicians recently introduced us to this ancient technique widespread in mathematics, which is new to us as physicists," says Miles Stoudenmire, a research scientist at the CCQ. "It's blowing our minds because it lets us solve certain problems exponentially faster."

These problems include challenges in quantum physics in which a system might change

Joseph Tindall, an associate research scientist at the Flatiron Institute's Center for Computational Quantum Physics, uses tensor networks to study quantum systems. Credit: Simons Foundation

quickly early on but settle down over time. The ancient mathematical method — which the researchers are keeping under wraps for now — enables the system to be simulated more quickly over time so the entire simulation can be completed much faster.

Today, tensor networks are used to study a range of problems from chemistry to disease transmission. However, their primary application remains studying quantum systems. Some of this research is allowing scientists, including those at the CCQ, to better understand superconductors — materials through which electricity flows without resistance. Superconductors are important in many technologies, from magnetic resonance imaging (MRI) to quantum computing. The work could ultimately lead to the development of better superconductor technologies.

To help expand the use of tensor networks, a group at the CCQ headed by Matthew Fishman is developing ITensor, an open-access software library that helps researchers around the world develop better and more efficient tensor network software. By providing a standardized way to record system information, ITensor simplifies running complex simulations such as those involving quantum systems.

"ITensor has been very popular with physics professors all around the world," Stoudenmire says. "It's a tool that lets their students really quickly and reliably describe a quantum system in a lab."

An additional software library built on top of ITensor, the Tensor Network Quantum Simulator, is also being used by quantum computing companies to help benchmark their quantum claims. Researchers at the CCQ are continually working to improve their tensor network libraries to better handle complex systems and incorporate new techniques under development.

"Tensor networks are a very nascent field still, and it's important to have state-of-the-art codes available so that people can use them to solve new problems," Tindall says. "The aim of what we're doing with ITensor and other projects at the CCQ is to really make things more accessible so we can push the boundaries of what's possible with tensor networks."

Delving Into the Mathematical Absurdities of Black Holes

In 1783, more than 200 years before the first direct image of a black hole was obtained in 2019, the British scientist John Michell worked out a series of calculations describing hypothetical stars so massive and dense that light couldn't escape their gravity, rendering them invisible. This concept was bold, yet so alien in its day that it made few waves among Michell's colleagues.

It wasn't until more than a century later, in 1916, that famous names like Karl Schwarzschild and Albert Einstein reintroduced the idea through the theory of general relativity. This describes how massive objects like stars warp the fabric of space-time, creating distortions we experience as gravity. Like Michell, Einstein and Schwarzschild posited that if gravitational pull is strong enough, it becomes inescapable. Further calculations expanded this idea, reinforcing the premise that black holes are at least mathematically feasible. Now, we know that black holes do exist and are surprisingly simple systems whose properties can be described by just a few variables, while also being some of the universe's most enigmatic objects.

Indeed, black holes remain a source of mystery and fascination for modern astronomers. They're places where our mathematical understanding of the universe breaks down, seemingly housing a singularity akin to dividing by zero. Researchers at the Flatiron Institute's Center for Computational Astrophysics (CCA) posit that there's much to learn in these strange spaces, and that black holes can reveal just as much about the universe overall as they can about themselves. Today, CCA researchers continue to build on the foundation of Einstein's work as they push black hole research toward new horizons.

"Black holes are interesting in their own right but also are extremely connected to several different areas that researchers here at CCA care about," says Will Farr, a senior research scientist in the Gravitational Wave Astronomy group at the Flatiron Institute. "Whether you're studying the entire universe or the formation and evolution of galaxies or stars, black holes have links that are quite important and profound."

Researchers at the CCA largely focus on two types of black holes, distinguished by their mass relative to that of our own sun. Stellar mass black holes form when stars collapse, creating black holes of up to several hundred solar masses, while supermassive black holes — which form the center of many galaxies, including our own — can top more than 1 billion solar masses as they consume surrounding gases or merge with other black holes.

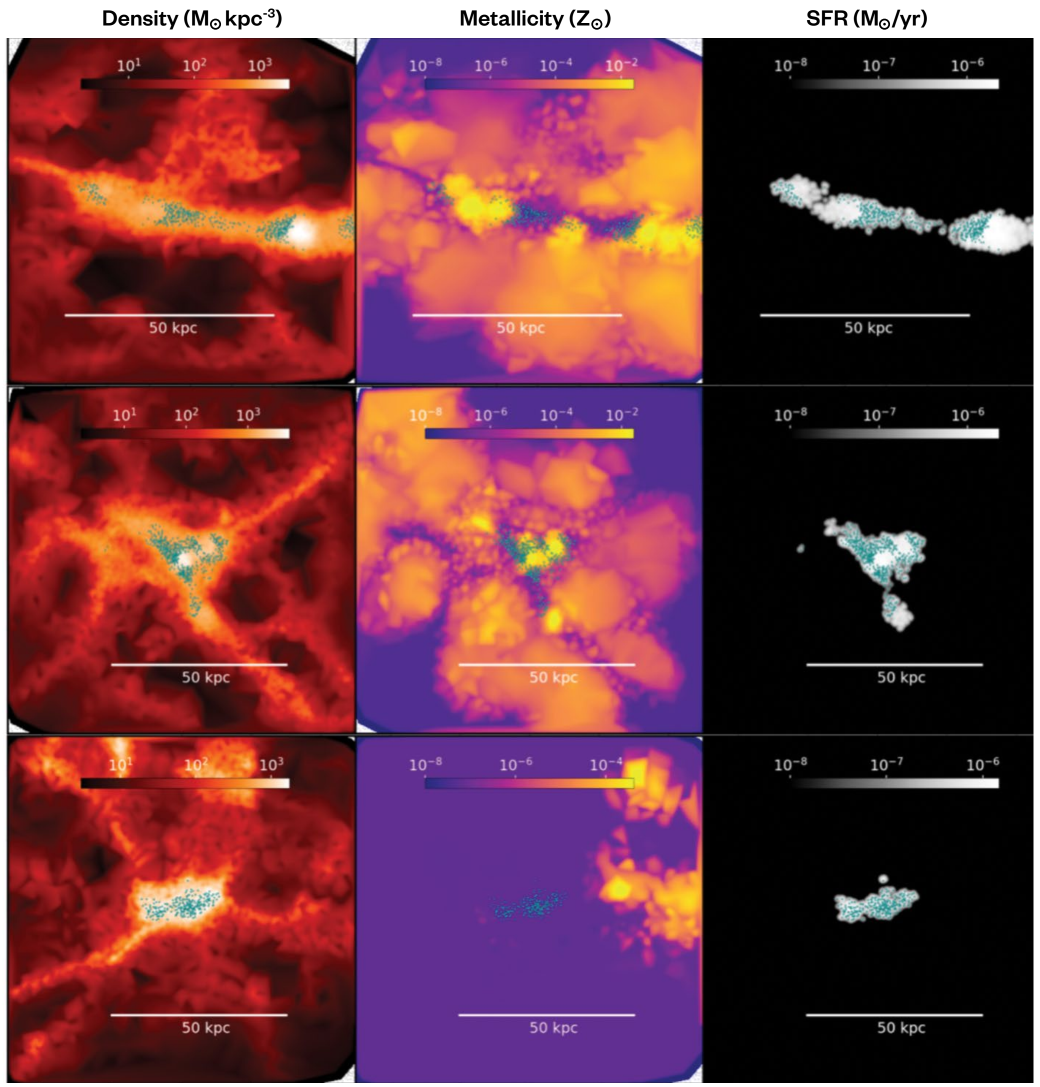
Farr and Maximiliano Isi, an astrophysicist at the CCA, use gravitational waves to investigate aspects of black hole behavior. Black holes are detectable only when they interact with something else, often a star or another black hole, and produce waves in space-time similar to the sound waves made by striking a bell. Just as the sound can tell you something about the bell, such as whether it's a church bell or a handbell, these gravitational waves hold information too. If black holes follow Einstein's predictions, it should be possible to explain patterns in this ringing by analyzing a few foundational properties, including a black hole's mass and spin.

In a recent study, a massive team, including CCA researchers, analyzed such gravitational 'ringing' captured by global observatories, which together provided the clearest measurements ever produced. The group found that the waves originated from a suspected merger between two black holes that produced a new one with a mass equivalent to 63 solar masses and a spin rate of 100 revolutions per second. This system is similar to the first merger ever detected, in 2015, allowing researchers to compare observations taken then and now.

"Our tools and instruments are much more precise and powerful, and because of that, we were able to see details we simply couldn't before," Isi says, adding that these enhanced capabilities stem in part from painstaking statistical work to increase the quality of information pulled from such distant signals. "By comparing these systems and the overlap in tones, we found that, indeed, these black holes do appear to be simple objects."

In 2025, Isi and Farr also analyzed gravitational waves from the largest black hole merger ever detected, which created a new, monstrous black hole of 225 solar masses.

This finding was unexpected because the parent black holes were estimated to have masses 137 and 103 times that of our sun. Such black holes should be exceedingly rare, as those masses fall within a theorized black hole mass gap created by nuclear processes inside massive stars. Using mathematical simulations, a team of CCA researchers led by former



Flatiron Institute scientists and their collaborators are simulating some of the universe's earliest galaxies, enabling them to create maps of gas density, heavy-element abundance and star-formation rates, as shown here for three galaxies. Leading theories of supermassive black hole formation suggest that the first black holes emerged in star-forming regions that lacked heavy elements. Credit: Aklant Kumar Bhowmick

When black holes merge, they emit gravitational waves that can be measured by sensitive instruments on Earth. LIGO recorded the clearest black hole merger signal yet — GW250114 — in January 2025. Credit: Maggie Chiang for Simons Foundation

Flatiron Research Fellow Orr Gottlieb found a possible solution: Magnetic fields generated during black hole formation can sometimes eject enough stellar material to produce a lower-mass black hole that falls within the mass gap range.

CCA Senior Research Scientist Rachel Somerville of the center's Galaxy Formation group is similarly interested in this question of why black holes sometimes grow to sizes we don't expect. Supermassive black holes, for example, can grow to be billions of times heavier than our sun, but it takes them billions of years. Yet observations from the James Webb Space Telescope have revealed that supermassive black holes up to 300 million times the mass of our sun existed just 500 million years after the Big Bang.

This is surprising, because if the first 'seed' black holes had masses similar to those of the stellar black holes detected through gravitational waves, it would have been difficult for them to grow that large so quickly. That's because radiation from the superheated gas around the growing black hole tends to slow down or even shut off further growth.

Several hypotheses exist to explain how this might have happened, and Somerville is now using simulations to explore different ideas. According to her work, the way the first black holes formed can make a big difference. Today, the distances between stars are large enough that stars rarely collide, but in the early days of the universe, it was a more cluttered place.

"The early galaxies we observe with James Webb are very dense, and there is evidence that many stars may have formed in dense star clusters. In those super-dense environments, there may have been collisions between stars, and if this happens a bunch of times, you can end up with pretty chunky black holes," Somerville says. These larger 'seed' black holes could have gotten an additional boost if they also grew by merging within their host galaxy.

Amy Secunda, an astrophysicist at the CCA, uses simulations to study how black holes control the growth of galaxies. Most have a supermassive black hole at their center, which is constantly pulling in gas from an accretion disk around its core. "These areas are really energetic and very influential, to the point of changing the way the universe looks," she says. For example, the gas supermassive black holes accrete fuels powerful outflows that stop new stars from forming.

> "Whether you're studying the entire universe or the formation and evolution of galaxies or stars, black holes have links that are quite important and profound."
>
> **— Will Farr**

It's possible to generate light curves from accretion disks, which emit energy detectable as ultraviolet and visible light. Between advancements in measurement techniques and the ability to simulate light curves mathematically, Secunda says that we're now swimming in data that need to be analyzed as efficiently as possible. Recently, Secunda has been developing machine learning algorithms capable of sorting through millions of these light curves and teasing out patterns faster than a single person could analyze just one.

Secunda says that while she's new to machine learning approaches, she's keen to learn more from her Flatiron Institute colleagues. Researchers studying black holes there now meet monthly to discuss ongoing research and potential new collaborations.

For Isi, the many unanswered questions about black hole observations only add to the excitement, "because it's such a clear indication that there's much yet to discover."

Building an AI That Understands the Universe

Imagine if ChatGPT were trained not on text and images, but on scientific and mathematical reality. That's the vision behind Polymathic AI, an initiative launched in 2023 and supported by the Simons Foundation and its Flatiron Institute.

Generative artificial intelligence — the powerful form of AI that also underlies large language models such as ChatGPT — has ushered in many scientific advances. But most scientific models are built for specific, singular problems and can't be broadly applied. The Polymathic AI team is building large foundational models that can tackle a wide range of scientific problems, from astrophysics to molecular biology.

The idea for the initiative came about at a physics conference attended by Shirley Ho, now project lead for Polymathic AI, where there was a lot of buzz about how generative AI chatbots such as ChatGPT and Google Gemini were going to solve major scientific problems. "I thought, 'How would that work?'" says Ho, who is also a senior research scientist at the Flatiron Institute. "Those models are only trained on large amounts of text, web images and YouTube videos; they're not grounded in physical reality. What if we built large generative AI models for science instead?"

The name is a nod to the initiative's wide-ranging potential. Like human polymaths who are well versed in multiple subjects, Polymathic AI's models cut across individual scientific disciplines.

"If you know seven languages, then the eighth is easy to pick up," Ho says. "It's a similar argument here. The physical realities that ground our models are all connected. That transferability makes these models really powerful."

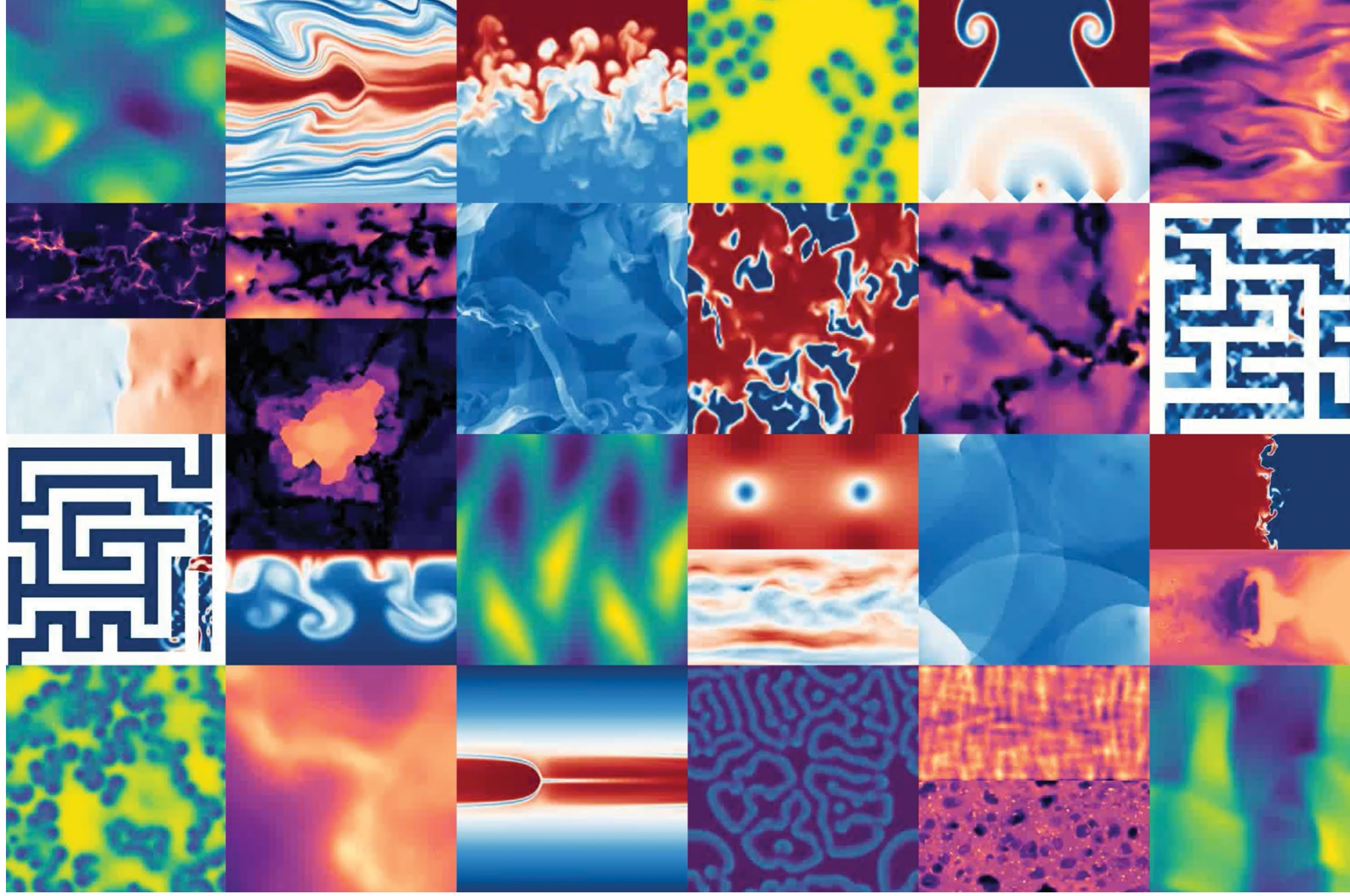
The Polymathic AI team is building several large models that span different areas of science.

In 2025, the Polymathic team released Walrus, a foundational model for physical dynamics spanning multiple disciplines. Walrus can predict the dynamics of fluids and fluidlike systems, ranging from merging stars and acoustic waves to the movement of bacterial colonies. This was made possible by the team's previous data release, the Well, which contains 15 terabytes of high-quality simulation data contributed by computational scientists at the Flatiron Institute and elsewhere. The Well contains 19 different physical scenarios across 63 different fields of science.

"Compared to what existed before, this was a huge step forward for data quality in this space," says Walrus lead developer Michael McCabe, a research scientist at Polymathic AI.

In addition to benefiting from the diversity of data in its training set, Walrus has a design that overcomes some hurdles encountered by previous fluid mechanics models. Namely, it's better able to make long-term predictions and is more efficient, which is important in a field with such huge datasets whose analysis requires complex computations.

Also in 2025, Polymathic AI released the first iteration of its large foundational model for astronomy, AION-1. The astronomy model is trained on images taken by powerful telescopes, as well as on measurements such as the spectral fingerprints of stars. In collaboration with many other astronomers, the team first built and released a 100-terabyte dataset called Multimodal Universe, consisting of hundreds of millions of data points in a format ready for use in AI training.



A mosaic of simulations included in the Well collection of datasets used to train AI models. Credit: Alex Meng, Aaron Watters and the Well Collaboration

The AION-1 model has broad applications. It can estimate the physical parameters of galaxies, such as their distances from Earth, their masses and their rates of new star formation. It can classify galaxies by their shapes, a process that normally must be done manually. It can also infer conclusions from small amounts of data, which is particularly important when data gathering requires powerful and expensive machinery such as space-based telescopes.

Others in the field are now trying to build something similar, says AION co-leader François Lanusse.

"Nobody else has yet been able to do the same kind of exercise at this scale. It's to the credit of the Simons Foundation that we were able to do this when we did," he says. "When we began, this was really prospective. We knew that if we gathered good people and thought hard about it, we were going to find interesting applications. But this would not have been possible through conventional funding agencies."

That's because of the broad reach of Polymathic AI's models — most other generative AI models in science are built to tackle singular problems. The Polymathic team is building models that could apply across disciplines, an area in which conventional government funding is sparse.

Another model takes aim at a closer celestial entity: our sun. Polymathic AI researchers are modeling the dynamics of active regions on the surface of the sun with data from NASA's Solar Dynamics Observatory. Solar flares — electromagnetic radiation eruptions on the sun — can disrupt telecommunications here on Earth and even cause electrical blackouts. The ability to predict and prepare for these flares could help governments and businesses protect satellites and other equipment from expensive damage. Other groups have built AI models for predicting the evolution of active regions, but their accuracy drops off quickly over time, whereas the Polymathic AI model remains accurate for orders of magnitude longer, says project leader Rudy Morel. The model could have broader applications across physics for anyone who wants to make predictions on very long timescales.

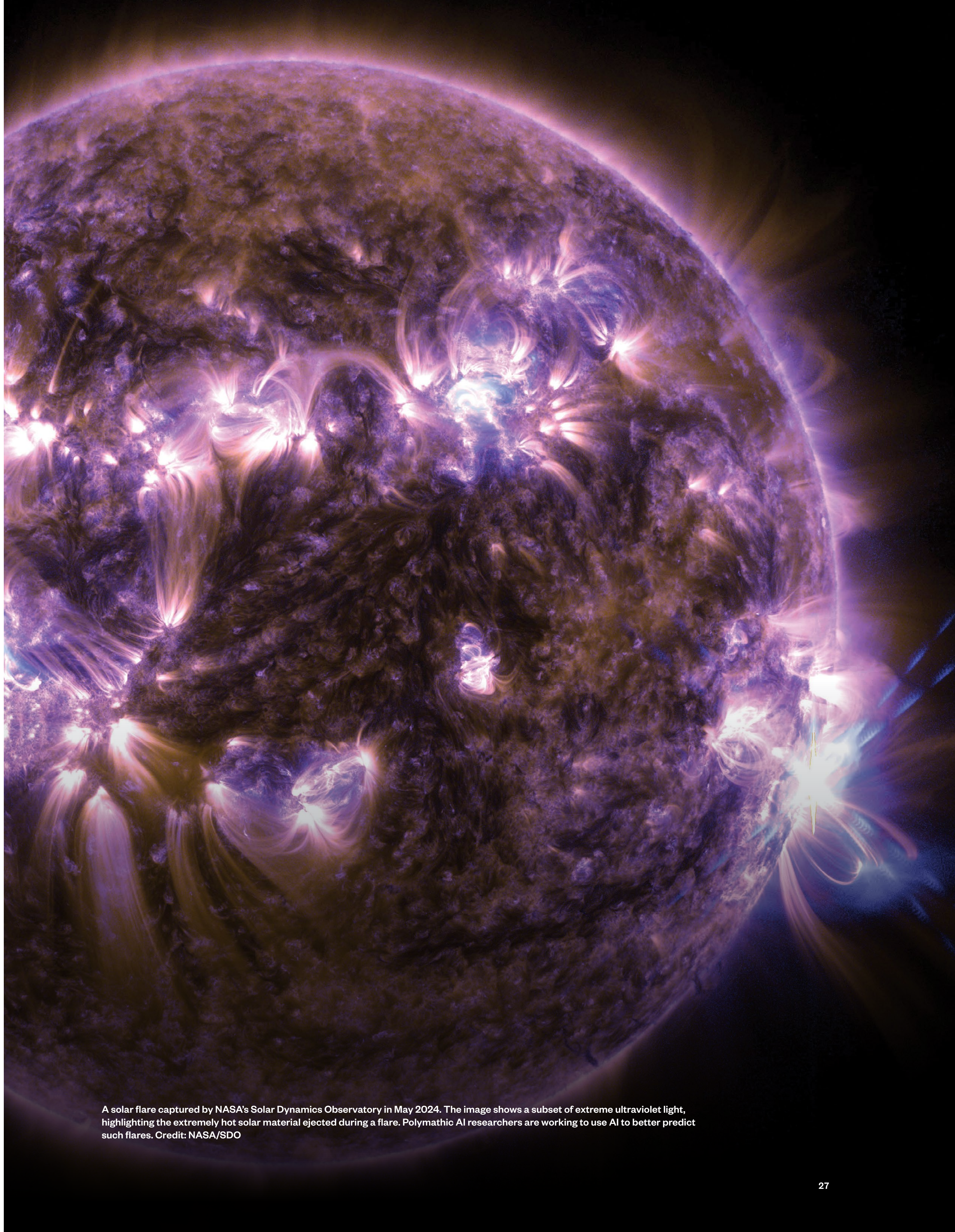
The Polymathic AI team is also working on complex scientific problems at a much smaller physical scale: biological molecules. Since

Shirley Ho, a senior research scientist at the Flatiron Institute, serves as project lead for Polymathic AI. Credit: Simons Foundation

the Human Genome Project was completed more than 20 years ago, biologists have amassed huge datasets, broadly categorized as "-omics." These datasets may comprise the full collection of DNA sequences, RNA levels or protein levels in a given cell or organism, among other measurements. But predicting how one type of molecule affects another (say, how a single DNA mutation could have ripple effects throughout the body) remains out of reach for many models. The first iteration of the Polymathic AI model can predict the downstream effects of any mutation and takes meaningful steps toward predicting the structures of RNA molecules, an even thornier problem than the protein structures predicted by DeepMind's AlphaFold, says project leader Siavash Golkar.

Another group at Polymathic AI wants to understand how AI does what it does. The beauty of, and frustration about, large foundational models such as ChatGPT is that nobody understands how they work — the models' inner reasoning is not accessible to their developers. The models are built on the backbone of linear algebra and statistical likelihood, but how they arrive at their conclusions remains mysterious. The answers to those mysteries will likely be in the language of math, Ho says.

"Can we turn these models into insight? That insight will probably be in the form of some mathematical equations," she says. "Math is the basis of all machine learning, and ultimately of everything we're doing. We are no longer just teaching machines to speak our language; we are teaching them to speak the language of the universe."



A solar flare captured by NASA's Solar Dynamics Observatory in May 2024. The image shows a subset of extreme ultraviolet light, highlighting the extremely hot solar material ejected during a flare. Polymathic AI researchers are working to use AI to better predict such flares. Credit: NASA/SDO

Beyond the Cryo-EM Resolution Revolution

A researcher works on a cryo-electron microscope at the New York Structural Biology Center. Credit: NYSBC

In the early 2010s, science entered a new era known as the resolution revolution, powered in large part by advances in a powerful imaging technique called cryo-electron microscopy, or cryo-EM. By bombarding flash-frozen molecules with electrons and analyzing the resulting images, researchers were suddenly able to create atomic-level renderings of everything from enzymes and ribosomes to viruses and antibodies. Cryo-EM turned out new discoveries at such a clip that in 2017, three of its key developers were awarded a Nobel Prize.

Today, the Simons Foundation continues to advance cryo-EM and related technologies in disciplines such as structural biology, biochemistry and medical science. In 2015, the foundation funded the establishment of the Simons Electron Microscopy Center (SEMC) at the New York Structural Biology Center (NYSBC) in Harlem. SEMC is dedicated to training a new generation of scientists, advancing cryo-EM capabilities, and using microscopy to solve pressing scientific questions.

Flatiron Institute Research Scientist Sonya Hanson's research focuses on modeling and analyzing experimental data and simulations to understand the molecular mechanisms underlying biological processes. Credit: Simons Foundation

At its core, cryo-EM is a tool powered by math. Researchers start by embedding thousands or millions of molecules they're interested in imaging into a grid, which they then expose to a beam of accelerated electrons. As the electrons bombard the sample, they produce millions of randomized 2D images that have no consistent angle or orientation. To create a 3D model from that chaotic data, scientists need algorithms capable of reorienting and reorganizing the many slices of the whole, like pieces of bread that, layered together, make a loaf. To do this, mathematical models describe an image by its patterns and details rather than by its pixel locations and match slices with similar properties.

The underlying math is complicated, but the resulting capabilities are unparalleled, and from its first day, the center has helped bring cryo-EM tools to more people, including researchers working in distant fields. The team at SEMC oversees 19 microscopes and a variety of companion machines that would be prohibitively expensive for many labs. Yet the center makes them available — and trains scientists in their use and how to analyze the resulting data — through collaborations with the National Institutes of Health and other groups within the NYSBC and the Simons Foundation's Flatiron Institute.

"We offer training from the ground up, sometimes spending weeks with a single person or group to help design a protocol for their particular experiment," says Alex de Marco, SEMC's director. In 2025, the center supported roughly 1,000 users and was acknowledged in more than 50 scientific publications. "I often think this is where we make the most difference, because this offering just doesn't exist anywhere else."

At the same time, researchers continue to refine electron microscopy–based methods, which in turn open new areas of research. Yong Hyun Song, a biophysicist at NYSBC who is also affiliated with the Flatiron Institute, consistently ran into the same problem during his early work studying neurons: High-resolution microscopy provides fine detail within a tiny area, yet neurons have sensory projections that can extend to a meter in length. Song bridged detail and scale by stitching together mosaics of images to create a single, larger picture. Electron beams are typically circular, however, and the picture window is a rectangle, creating a mismatch between the two components. "What that means is that when you want to go right next to the area you just imaged with your rectangular camera, your circular beam will have burned a significant portion of it away," he says. De Marco and his colleagues solved the

Flatiron Institute Senior Research Scientist Pilar Cossio develops mathematical and computational methods to characterize the structures and dynamics of biomolecules based on experimental data and simulations. Credit: Nicky Quamina-Woo/Simons Foundation

problem by creating the first square electron beam, allowing Song to produce beautiful renderings of neurons and reveal how motor proteins help shuttle resources along their length.

As these tools become more powerful, it means that scientists suddenly have a glut of high-quality data to analyze. Increasingly, researchers are realizing that to draw as much information as possible from these resources, we need correspondingly powerful analytical tools.

Debanjana Maji, a postdoctoral researcher affiliated with the NYSBC, the Flatiron Institute and Rockefeller University, is currently utilizing algorithms developed by Flatiron researchers to study RNA — the intermediate molecule that facilitates the translation of DNA instructions into functional proteins. RNA is a complex molecule that changes shape, and that shape, in turn, determines its behavior. Tools like X-ray crystallography image RNA by first trapping it in a single state within a crystal lattice; however, this process obscures the molecule's dynamic nature.

"Cryo-EM does a better job of capturing all the different shapes, but we still need a good analysis tool to make sense of what we're seeing," she says. The algorithm Maji uses, developed by statistical biophysicist Pilar Cossio, operates on a principle called Bayesian inference. A model first predicts all the different shapes an RNA might take based on its composition and chemistry and then gauges the relative importance of each shape based on how frequently it appears experimentally. Common shapes are probably biologically important, Maji says, "but sometimes the rare ones are too, and other structural biology methods often average out that rare fraction."

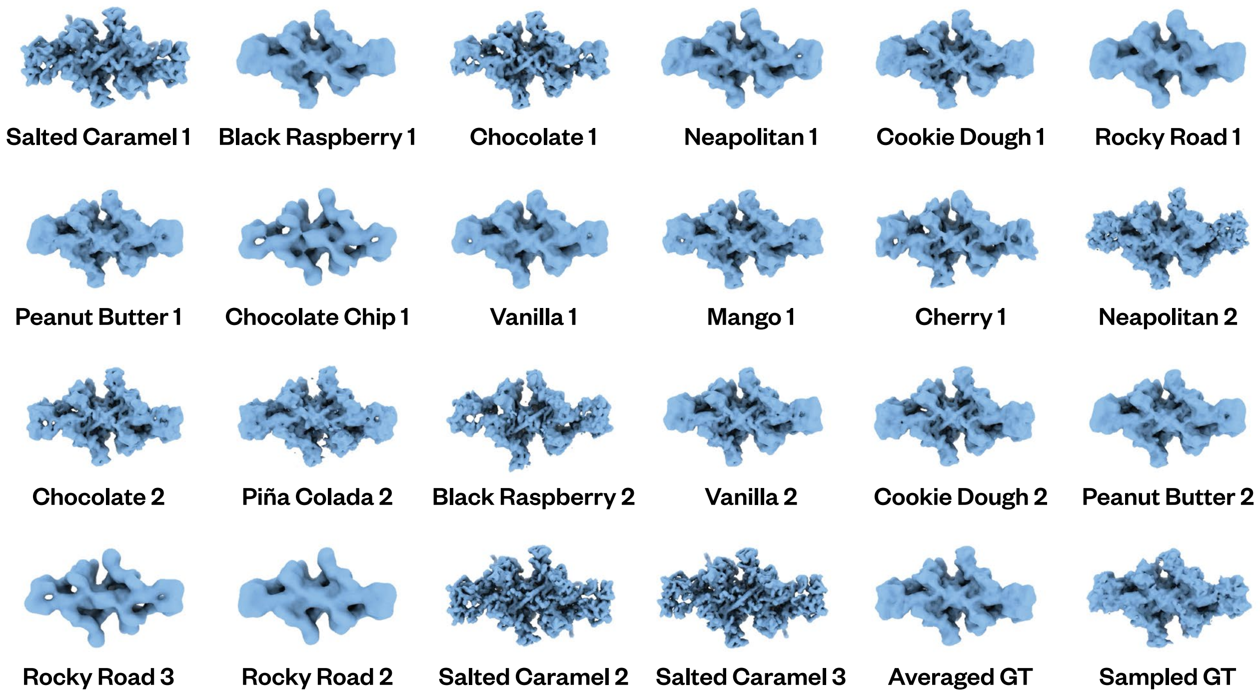
Cossio, a joint member of the Flatiron Institute's Center for Computational Mathematics (CCM) and Center for Computational Biology (CCB), adds that her algorithm is just one of many statistical frameworks that exist to process cryo-EM data. To create the most useful tools, Flatiron researchers brought together an interdisciplinary cohort of investigators to provide input.

Cossio and computational biophysicist Sonya Hanson, who is also a joint member of the CCB and CCM, co-launched a competition in 2023 that invited participants to analyze the same dataset using their own custom pipelines. The dataset included 33,742 cryo-EM images of a protein called thyroglobulin that resembles a dove, complete with "flapping wings" that assume different shapes. Groups were asked to analyze the images and identify all the different shapes, as well as how frequently they appear.

Nine groups participated, contributing a total of 41 submissions, and Cossio says the variety of approaches people used amounted to "a whole zoology of methods." Some people leveraged Bayesian approaches similar to Cossio's, but others created machine learning algorithms that differentiate the structure and volume of different thyroglobulin conformations, or conducted principal components analyses that pull out the variables most likely to influence the protein's shape.

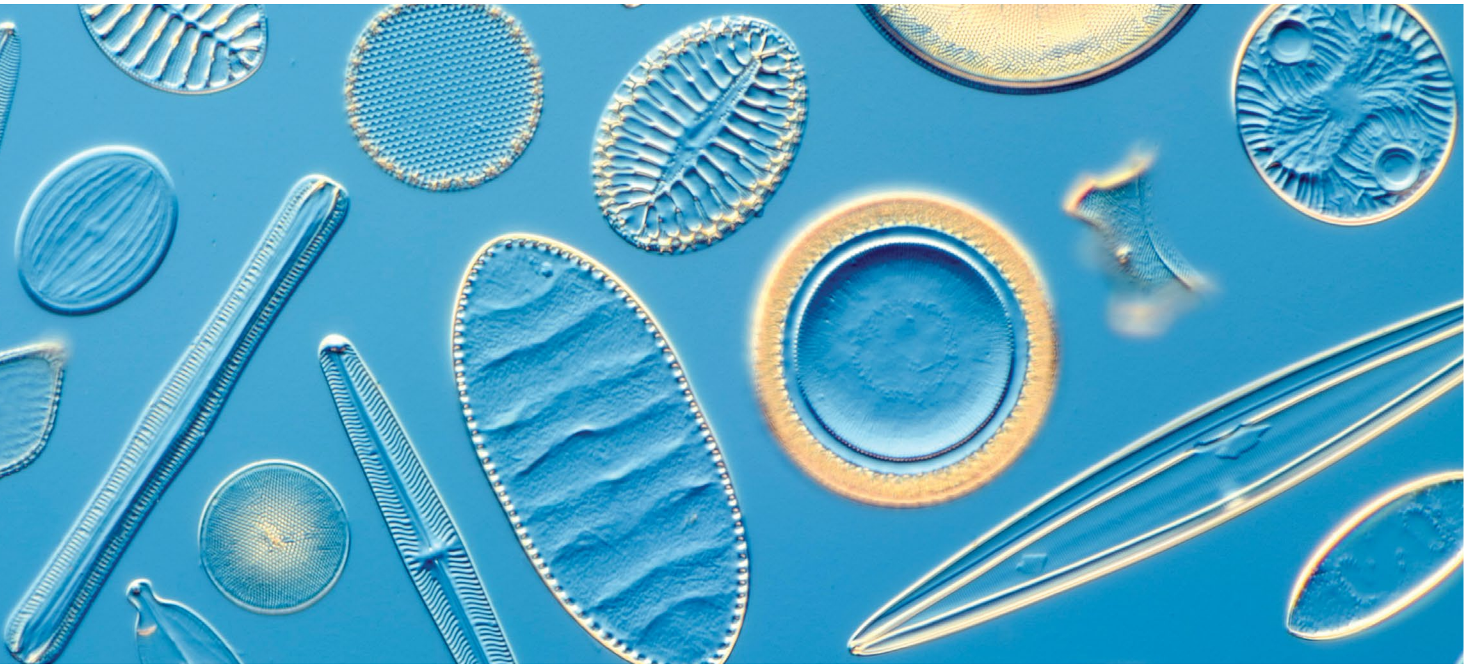
The goal, Hanson says, is to establish a new gold standard for validating the increasingly complex yet meaningful results by comparing the output of each pipeline. That nearly every group currently developing methods in this space participated is a sign of just how invested the field is in moving these tools forward, she says.

"In my experience, methods development has always been a very collaborative space, but it's rare to see it happen so publicly," Hanson says. "The fact that we continue to see cryo-EM applied to new problems in new areas all the time really gives you a sense of how much there still is to learn."



A comparison of the performance of different methods for determining molecular ensembles from single-particle cryo-electron microscopy datasets. In this case, the models were tasked with reconstructing thyroglobulin, a large protein produced by the thyroid gland. The names of the participating research groups were kept anonymous and replaced with ice cream flavors.
Credit: M. A. Astore *et al.* 2025

Pivot Fellow Natasha Blitvić Brings Math to Marine Microbiology



A microscopic view of single-celled algae called diatoms. Diatoms have unique cell walls made of silica and form an important foundation of the marine and freshwater food chains. Credit: Wim-Van-Egmond/Science Photo Library

Peer into a single drop of seawater and you'll find millions of individual bacteria, algae and plankton. Each microbe leads a busy life. Collectively, their behavior exerts an influence far larger than their microscopic size would suggest. Marine plankton account for roughly half of all photosynthesis on Earth, and by breaking down organic materials, microbes help drive the global cycling of nutrients such as carbon, nitrogen and phosphorus.

Teasing apart just how small-scale interactions between microbes influence large-scale processes is a massive question, and it's one that cannot be answered by any one lab or even a single scientific discipline. Rather, it's a problem that requires scientists from across fields to bring their knowledge to the task, pivoting from one field to inform another.

Mathematician Natasha Blitvić of Queen Mary University of London recently did just that, completing a 12-month term as a Simons Foundation Pivot Fellow investigating marine microbial systems. First launched in 2022, the fellowship supports researchers embarking on work in a new discipline. Shifting from one field to another can enable surprising breakthroughs, as seen in the work of famous cross-disciplinary pioneers such as physicist-turned-chemist Marie Curie and Louis Pasteur, a microbiologist who began his career in chemistry.

Still, it can be an uphill battle to learn a new field, build a community and convince funders to support your work. The Pivot Fellowship addresses these issues by having each fellow work with a mentor and by providing financial support. After a year of mentoring, fellows may have the option to apply for an additional five-year research award in their new field.

"I'm impressed with this fellowship because it's one of the rare schemes that really understands what it means to pivot," Blitvić says. "They've thought about the challenges and tried to alleviate them so you can really focus on your best work."

Blitvić understands those challenges well. Despite a lifelong interest in math and philosophy, Blitvić initially felt she needed to pursue a degree in something with stronger job prospects. She therefore majored in engineering instead of mathematics, taking math classes on the side "for fun," she says. Ultimately, she committed to math, earning a Ph.D. from the Massachusetts Institute of Technology in 2012 with a thesis in pure mathematics.

Today, Blitvić describes herself as a probabilist — someone who specializes in probability theory and searches for unexpected probabilistic intuition in other areas of mathematics. At its core, her work attempts to pull order from chaos based on the premise that even the most random systems have underlying drivers that mathematicians can measure and model. As an example, you can think of a coin: On any given flip, it's impossible to know which side the coin will land on. But if you flip 100 coins, roughly half will land heads and half tails. "Randomness becomes predictable if you look at it on the right scale," Blitvić says.

Making a Pivot

After many years as a pure mathematician, Blitvić began to feel siloed and wanted to apply her work in new ways. She started thinking about systems that could benefit from her expertise and landed on marine microbes. Around 98 percent of the ocean's biomass is made up of microbes, yet there's much that scientists still don't know about their influence on ecosystems and climate. One of the challenges lies in being able to predict large-scale patterns from inherently random microscale behaviors.

For her fellowship, Blitvić partnered with Roman Stocker, a pioneering microbial ecologist at the Swiss Federal Institute of Technology

Pivot Fellow Natasha Blitvić and her mentor, Roman Stocker. Credit: Michael Lisnet/Simons Foundation

(ETH) in Zürich and co-director of the Simons Collaboration on Principles of Microbial Ecosystems (PriME). Stocker and his team use experimentation to inform their modeling and bridge microscale and macroscale processing in the ocean, including the roles that microbes play in nutrient cycling, harmful algal blooms and coral disease. Having worn a few hats himself — including those of engineer, fluid dynamicist and mathematician — Stocker appreciates the value of inter-disciplinary collaboration.

"This idea of pivoting has really defined my career, and I greatly enjoyed and benefited from committing myself to different ways of thinking," he says. "Natasha and I share this understanding, and simply having her available for others in my group to learn from has broadened everyone's perspective and helped us design better experiments."

The Random Factor

Blitvić's primary focus has been on improving the incorporation of randomness into ecological modeling. Such randomness — also called stochasticity — means that a system's behavior is explained in part by chance, rather than being entirely predictable. Often, this randomness isn't accounted for in models, or it's included superficially in ways that don't mirror the reality of microbial communities. "You can't just brush it away," she says. "My goal has been to introduce stochasticity into our analyses at an intrinsic level, where it's likely to make an important difference."

She began by developing a tailored modeling and analysis framework for analyzing the results of a field study to quantify chemotaxis, or the ability of a microbe to sense and follow chemical gradients, that Stocker's group had collaborated on. With her probabilistic prowess, Blitvić was able to develop a stochastic model for the experiment that enabled the researchers to pull as much information out of the measurements as possible.

Later, as other members of the team came to understand the power of tailored mathematics, Blitvić was brought on to other projects, including an experiment to study how fluid dynamics can create hot spots for bacterial cells to exchange DNA when they touch, a process known as bacterial conjugation. This exchange of genetic material is one of the ways bacteria evolve — by acquiring new genes from their neighbors.

Blitvić co-led a project resulting in a model describing the foraging habits of bacteria that break down marine particles. Many bacteria specialize in feeding on these particles near the coast, where they are common. The assumption is that such bacteria should be less numerous in the open sea, where particles are scarcer. Yet the team's research suggests that such specialists can still be found even in nutrient-poor environments because the payoff of randomly encountering a particle remains so high. The team dubbed the phenomenon "stochastic resilience" in reference to the idea that so long as some bacteria encounter a particle, the population as a whole survives.

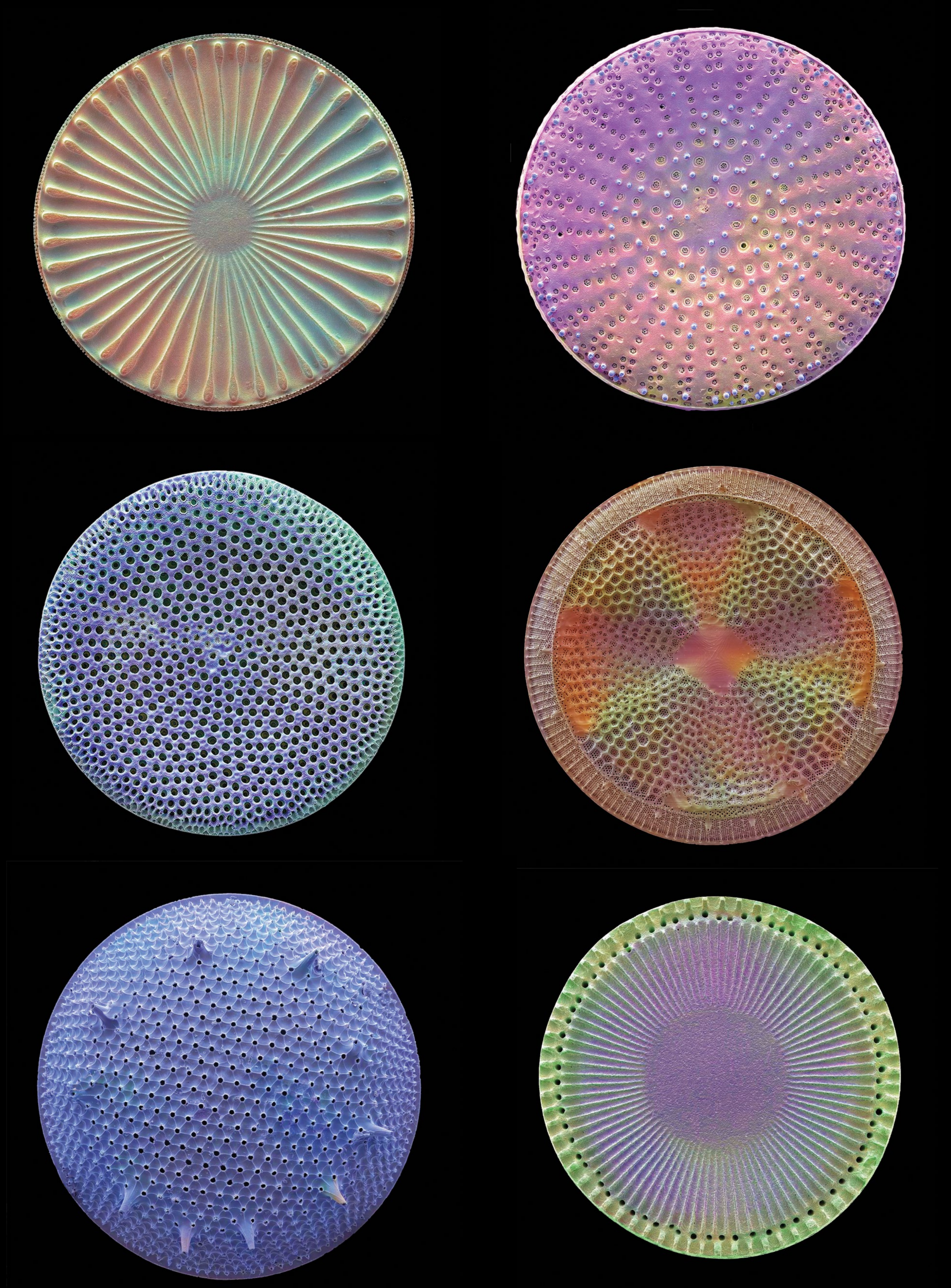
"One of the implications we're now able to defend is that these bacteria that forage on marine particles are significant enough that we should take them into account in global models of carbon sequestration," Stocker says. "This is exactly the type of insight I was hoping Natasha would bring to our work."

Scaling Up

Blitvić finished her fellowship in August 2025 and is now writing up papers and continuing to nurture the relationships she made. Blitvić has since applied to lead a Simons Collaboration — another foundation initiative that funds investigators from different disciplines to work together on a timely problem — to further her work in partnership with other notable researchers in her new field.

"What we're proposing is really a scaling up of the pivot philosophy from an individual to a group," she says. "We want to do science differently — as a small team, in a more integrative way, developing both mathematics and experiments in tandem based on a common language."

Regardless of whether the collaboration becomes a reality, Blitvić says that her time as a Pivot Fellow has been a tremendous success. "I've been very pleased with the results this kind of approach can yield," she says.



Examples of the incredible diversity of diatoms, microscopic single-celled algae that form a significant portion of the world's biomass and produce much of Earth's oxygen. Credit: Steve Gschmeissner/Science Photo Library

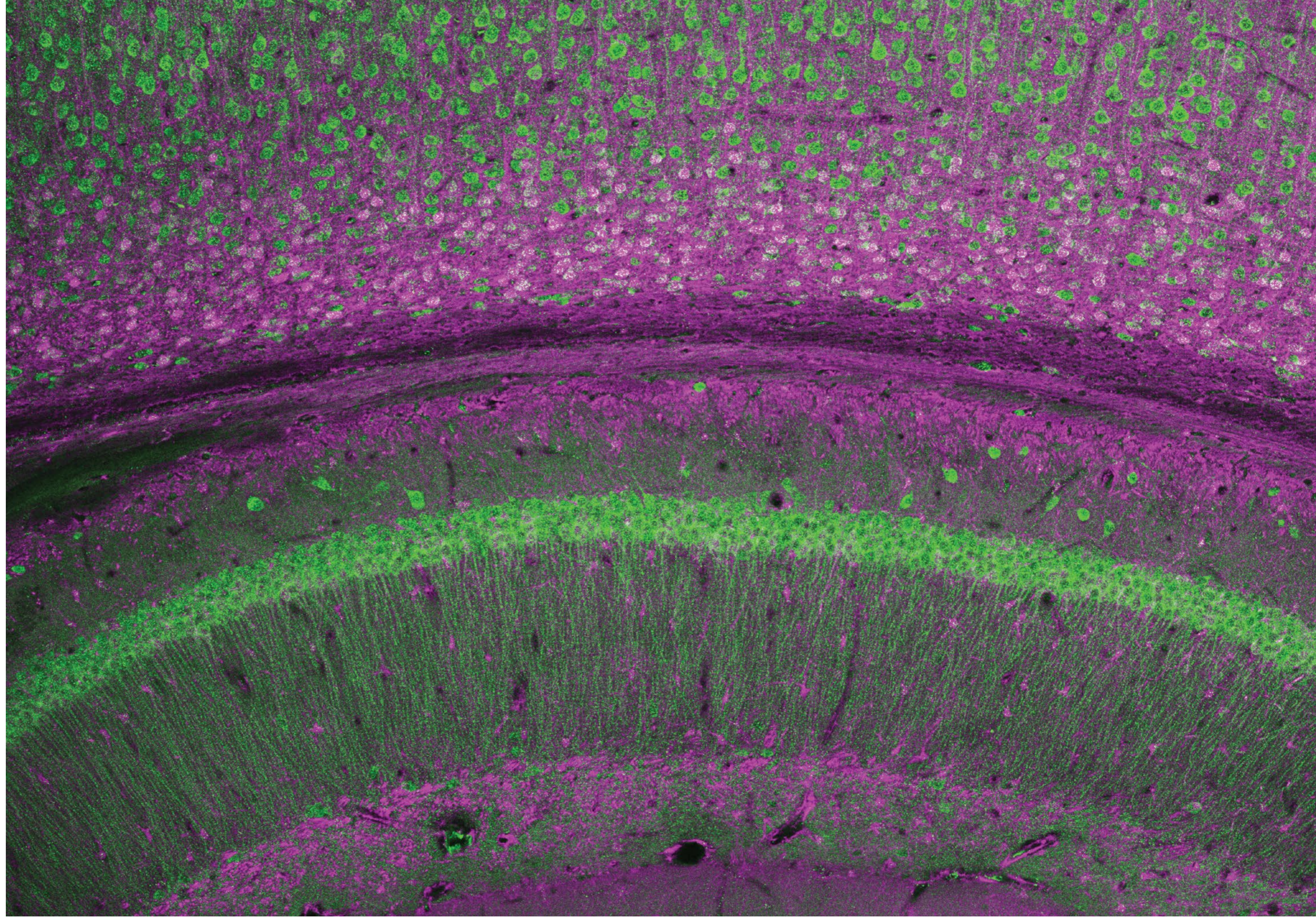
Why We Need Computation to Understand the Brain

Nearly 15 years ago, a handful of neuroscientists had a radical idea: to combine mathematical theory, computation and experimentation in the quest to understand the brain. They presented their concept to Jim and Marilyn Simons at the Buttermilk Falls Inn in Milton, New York, where the couple had gathered 18 researchers in 2012 to discuss potential new scientific projects. Jim Simons was immediately intrigued. He had always wanted to better understand the underpinnings of the brain — what was literally happening in his own brain when he was pondering a math problem? What neural activity made that kind of cognition possible?

The scientists' proposal was based on an idea championed by Bill Newsome, a professor of neuroscience at Stanford University School of Medicine, to move beyond the traditional one-neuron-at-a-time method of studying neural activity and instead study collections of neurons together. The field is called 'systems neuroscience,' but at the time, Jim Simons proposed a different term to describe this project: the global brain.

In 2014, the Simons Collaboration on the Global Brain (SCGB) launched as the Simons Foundation's first collaborative neuroscience research effort. 2025 was the collaboration's last year of funding. Over the years, the SCGB brought together more than 100 investigators and many more students and fellows funded through the program, all striving to understand how different neurons and parts of the brain work together to enable complex cognition. SCGB scientists study the brains of a variety of animals, from fruit flies to mice to nonhuman primates.

Simons Collaboration on the Global Brain Investigator Byron Yu. Credit: Carnegie Mellon University College of Engineering



An immunofluorescence image of a mouse cerebral cortex and hippocampus. Credit: Alexandros Lavdas

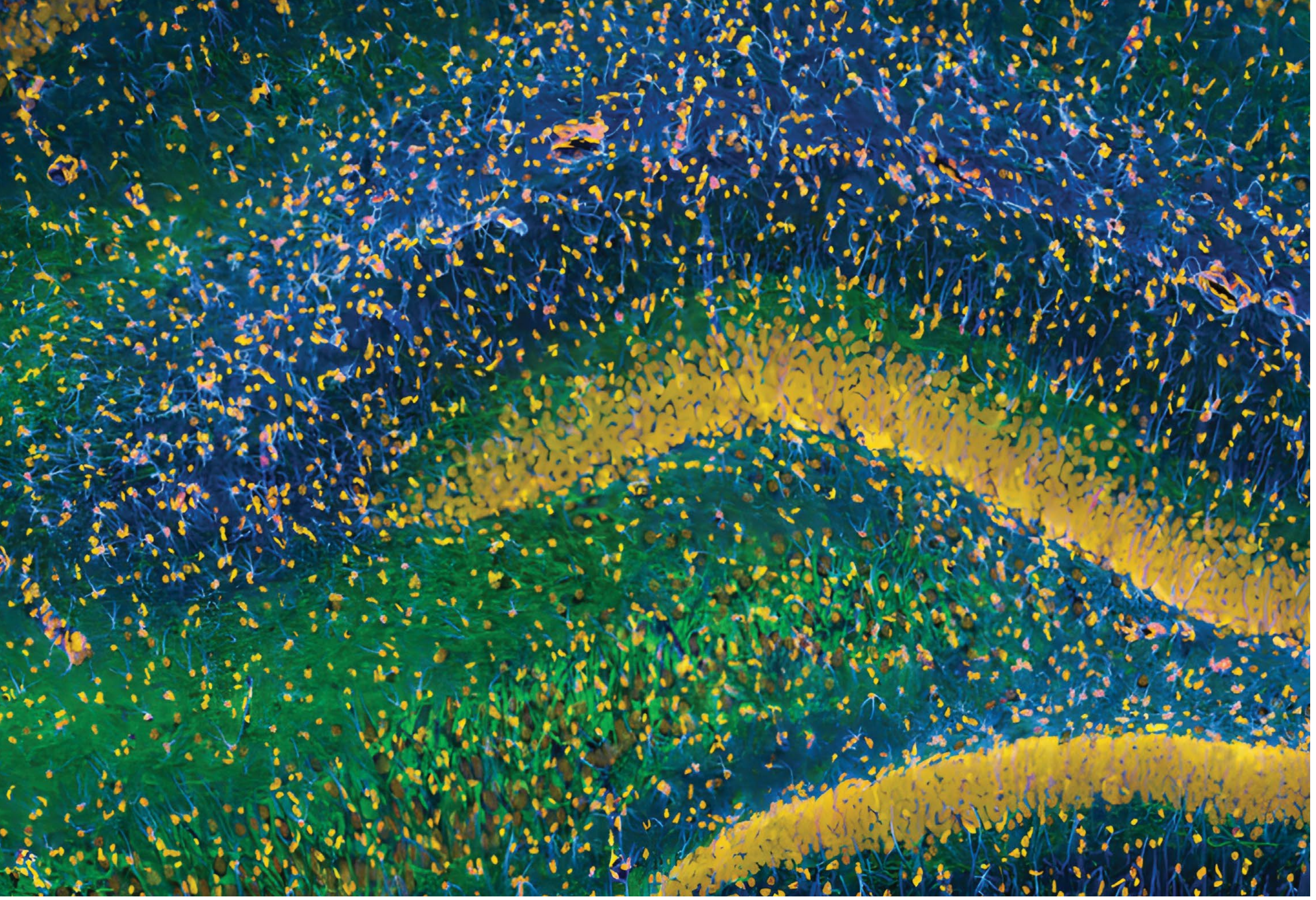
"This was part of the transition from studies of single neurons to studies of populations of neurons," says Larry Abbott, a theoretical neuroscientist at Columbia University and an SCGB investigator who has been involved with the collaboration since its inception. "Things have changed so quickly that this sounds like ancient history, but partly that's because of the SCGB. It really fostered this change."

The shift from studying one cell at a time to studying multiple neurons in concert necessitated the development of improved computational and mathematical tools to analyze neuroscience data. New technologies on the scene — such as Neuropixels, thin silicon probes that measure activity from hundreds of neurons at once — were suddenly generating hundreds or thousands of times more data than previous neural activity studies ever had. Experimental scientists needed mathematicians to help them sift through it all and theorists to help them make sense of it.

"At the time, there were only a handful of initiatives focusing on computational neuroscience work," says Alyssa Picchini Schaffer, vice president and senior scientific officer of the Simons Foundation's neuroscience collaborations. "There was this realization that deeply grounding the theory in biology and, on the flip side, having experimental neuroscientists really dig in and understand the computational approaches, that was the special sauce."

It was quickly apparent that uncovering the patterns of neural activity that underlie cognition requires studying many regions of the brain at once, and that meant large-scale science, in terms of both the amount of data generated and the number of investigators with different areas of expertise involved. Perhaps most emblematic of the SCGB's big, collaborative science ethos is the International Brain Laboratory (IBL), an SCGB-funded consortium of 22 neuroscience labs that came together in 2017 to map neural activity across the entire mouse brain as animals engaged in a single task.

Their brainwide map of neural activity from 300,000 neurons, finished in 2023, required new computational tools for storage and analysis, developed by a dedicated team of



An image of the brain's hippocampus. The tissue is stained to reveal the organization of glial cells (cyan), neurons (green) and DNA (yellow). Credit: NIH/Image Point FR/BSIP

12 engineers who support the IBL. This large dataset of neural activity, a first of its kind, has been made openly available for exploration and insight generation to the broader neuroscience community. Computational neuroscientists working in the IBL have also developed approaches based on their data that could have broad applications across systems neuroscience.

The thorny problem of big data analysis has reached many corners of neuroscience. Byron Yu, a neuroscience and engineering professor at Carnegie Mellon University and an SCGB investigator, has been working for more than 10 years on a collaborative effort to understand how different parts of the brain interact to enable vision and interpretation of what we see. That effort requires tracking neural activity from hundreds of neurons across those different parts of the brain in one experiment. In traditional neuroscience studies that measured the activity of only a few neurons at a time, scientists typically studied the activity of each neuron individually or that of pairs of neurons. But for these large, more complex datasets, Yu and his colleagues needed to apply multivariate statistical methods (a process known as 'dimensionality reduction'), which make it possible to study how larger numbers of neurons coordinate their activity together. As datasets get larger across systems neuroscience, this statistical approach is becoming more and more common.

Yu specializes in data analysis and statistics, while his collaborators — Adam Kohn, chair of neuroscience at Albert Einstein College of Medicine, and Christian Machens, a neuroscientist at the Champalimaud Foundation — lead the project's laboratory experiments and modeling efforts, respectively.

"Experimentation, modeling and analysis are like three corners of a triangle. Each one has its own value, but when you put the three together, that's where the power comes from," Yu says. "The meeting point is really interesting, where the data meet the model and we can compare and contrast."

The SCGB has also invested in training the next generation of neuroscientists. The collaboration funds fellowships for postdoctoral fellows and those transitioning to academic independence. Laura Driscoll, now a scientist at the Allen Institute for Neural Dynamics, received one of those fellowships to support her research and transition, building on her postdoctoral work with David Sussillo and the late Krishna Shenoy at Stanford University.

One clear problem in machine learning is the difference between our brains and artificial neural networks in how they adapt to variations. Our brains are very good at learning new skills by making inferences from skills we already know, but computers are less readily adaptable in this way. Driscoll's project studied how an artificial neural network trained to complete multiple tasks used sections of its activity patterns repetitively to accomplish those tasks, the way a dancer might use the same basic dance moves in different choreographed routines. Understanding how an artificial network is able to complete multiple tasks that it has been trained on is the first step toward building networks that can flexibly learn new skills.

"The work I was doing wouldn't have been possible if it weren't for the Simons Foundation, because there weren't many other funding mechanisms for people who are doing simulations in artificial neural networks," Driscoll says. "I feel a lot of gratitude toward the SCGB for being able to have the career that I've had so far."

The SCGB brought together all its investigators and fellows for a regular annual meeting, and several SCGB scientists say that meeting was the highlight of their year — and even helped change the course of their careers.

"I don't think I've ever been in a group of such distinguished scientists as at the yearly meeting," says Sussillo. "In terms of what they set out to do, it worked. Those ways of thinking have now become mainstream, thanks to the Simons Foundation. What an honor to be a part of it."

Stanford Medicine neuroscientist Bill Newsome championed the idea of moving beyond traditional one-neuron-at-a-time studies of neural activity to study collections of neurons together. This idea led to the Simons Collaboration on the Global Brain.
Credit: Ian Terpin/Stanford University

How Mathematical Modeling Identified Subclasses of Autism

The Li family poses for a photo in 2025. Important research into understanding autism is made possible by the generosity of SPARK participants, such as the Li family, whose de-identified data are made available to researchers. Credit: Scott DeFillippo, DeFillippo Photo and Video

Two people who have been diagnosed with autism can have very little in common. That gap — between a shared label and vastly different experiences — has long been one of the field's biggest unsolved challenges. Factor in a wide range of potential genetic contributors, and the puzzle becomes even more complicated.

In their July *Nature Genetics* study, researchers at the Flatiron Institute's Center for Computational Biology (CCB) used advanced mathematical models to analyze data from more than 5,000 research participants with autism. The work revealed four distinct groups that link autism-related traits with underlying genetics. This work could open the door for more precise diagnoses and personalized support in autism interventions.

"This study shows how computational approaches can help connect what we observe clinically to underlying genetics and molecular biology," says Olga Troyanskaya, a senior research scientist and deputy director for genomics at the CCB who served as the study's senior author. "Because autism and many other complex human conditions are so heterogeneous, methods that enable more comprehensive, data-driven stratification can reveal biologically distinct subtypes — an important step toward clearer mechanisms and, ultimately, more precise paths to diagnosis and care."

A Person-Centered Approach

Neither of the study's two first authors, Natalie Sauerwald and Aviya Litman, got their start in genetics or neuroscience. They both began their academic journeys in mathematics, completing undergraduate degrees in the subject before embarking on graduate work in genomics.

"Genomics is especially well suited to a mathematical and computational background — it's a field defined by vast amounts of data that require complex algorithms and analytical frameworks to understand," says Sauerwald, a CCB associate research scientist.

This is especially true for autism, which presents a unique challenge from a genomics perspective due to its high variability. There isn't a single "autism gene" — there are many genetic variations (called genotypes) that could play a role. There is also a wide range of observable traits (called phenotypes) associated with autism such as sensory issues or impaired language. Understanding why autism can manifest so differently among individuals is a big focus for the field, and matching genotypes with phenotypes is no easy feat.

"A lot of studies will take a trait-centered approach in which they examine everyone who shares one particular trait, but that doesn't capture an individual's complexity," says Litman, who is a graduate student in Troyanskaya's lab.

Instead, the team wanted to try a more comprehensive, "person-centered" strategy that accounted for all of an individual's traits rather than grouping people by just one. Their data, collected from SPARK — a landmark study supported by the Simons Foundation Autism Research Initiative (SFARI) — included genotypic and phenotypic information from more than 5,000 individuals with autism.

"Our goal from the start was to include everything — to preserve the complexity and nuance of the data, revealing what matters and how the pieces fit together," says Sauerwald. "When you account for that level of complexity all at once, you naturally arrive at a person-centered approach."

The team built a type of model called a 'mixture model' that could integrate many data types collected in many ways. This was critical, as the study's data took several forms. Some measures were binary — simply asking whether someone had a certain trait or not. Others were grouped into categories, such as levels of language ability. Some were even measured on a continuum, for example the timing of key developmental milestones. The scientists stressed that compiling and analyzing all these data in a meaningful way was only possible thanks to mathematics.

"Mathematics provides a language that allows us to structure that information and extract insight," says Litman. "Without it, making sense of hundreds of phenotypes and millions of genetic variants would be impossible."

Senior Research Scientist and Deputy Director for Genomics Olga Troyanskaya of the Flatiron Institute's Center for Computational Biology. Credit: Princeton University, Sameer A. Khan/ Fotobuddy (2020)

The Four Groups

Based on their person-centered approach, the team identified four major categories of SPARK participants.

The largest group, Social and Behavioral Challenges, shows co-occurring traits such as ADHD, anxiety, depression, mood dysregulation, and communication and repetitive behavior challenges, but little to no developmental delay. This accounts for about 37 percent of participants.

The Mixed ASD with Developmental Delay group, which made up 19 percent of participants, shows the opposite pattern: notable developmental delays but fewer emotional or behavioral difficulties.

The Moderate Challenges group (34 percent of participants) includes individuals with milder or fewer social and behavioral challenges and no developmental delays.

The smallest group, Broadly Affected (10 percent), experiences widespread challenges across social communication, repetitive behaviors, development and mental health.

Importantly, the scientists say that these are not set-in-stone groupings, but rather a starting point for further research.

“This doesn’t mean that there’s necessarily only four classes,” says Troyanskaya. “I think what this demonstrates is that there are at least four classes.”

Autism Under the Hood

These four groups were established based on phenotype, and when the scientists started to dig into each group’s underlying biology, they were intrigued to see shared genetic characteristics.

The team started by looking at different genetic variants carried within each group and then traced these variants to the biological processes they affect in the body (such as how neurons fire or how a cell packages its DNA). Whether and how a biological process was affected varied significantly between groups, the team found.

“There was very little overlap,” says Litman. “While we looked at many biological processes previously implicated in autism, each one was largely associated with a different group.”

And it wasn’t just that individuals in each group shared certain genetic variants: The timing of gene activation also aligned.

For instance, in the Social and Behavioral Challenges group, the affected genes were largely active after birth, and individuals in this class showed minimal developmental delays and were diagnosed, on average, at a later age. In contrast, the ASD with Developmental Delays category was associated with genes that were primarily active before birth.

“It’s exciting — and surprising — to see that these biological signatures lined up so precisely,” says Sauerwald. “We didn’t expect they would be quite so distinct, but it speaks to the potential validity of the groups.”

Toward a More Personalized Understanding of Autism

In future work, the team will continue to refine the subtypes, and they hope that their study will encourage researchers and clinicians to think of autism in a more personalized way.

“The main takeaway is that autism should not be treated as a single, uniform condition,” says Sauerwald. “Our results support the idea that different forms of autism may arise from fundamentally different biological mechanisms — an idea we hope will guide future research.”

All of this research will require significant contributions from mathematical and computational tools, and the scientists note that this need will only become more prevalent as the field and the available data grow.

“As scientific data continues to grow in scale and complexity, computation becomes essential. It’s no longer possible to understand even a single genome — let alone thousands — without a mathematical framework to make the data interpretable,” says Sauerwald. “Computational approaches are becoming central across scientific fields, and institutions like the Flatiron Institute play a key role in enabling that work.”

The Austin family signed up for SPARK after learning that many autism research studies do not include girls of color in their cohorts. De-identified data from SPARK participants have enabled new insights into autism. Credit: Scott DeFillippo, DeFillippo Photo and Video

Quanta Books Opens a New Chapter in Science Publishing

Your typical overworked editor considering an idea for a book about a programming language for mathematicians could be forgiven for relegating it to the bottom of the bin. But for those in the know, the story of Lean is a must-read saga centered on a group of mathematical evangelists bringing about a revolution in the field.

While other publishers might have missed out, a new player in the publishing world, Quanta Books, brings this and other compelling stories in math and science to life for its readers. Its first book, *The Proof in the Code*, will cover the history and future of Lean and is scheduled for release in June 2026.

“All important scientific discoveries have an inherently dramatic story behind them: There’s always a challenge, there’s always people struggling for a long time, and there’s the conflict that the problem has to be solved,” says Thomas Lin, publisher of Quanta Books, an editorially independent subsidiary of the Simons Foundation. “We never try to avoid what’s actually interesting about the science. That’s the key for us.”

That niche of explaining modern science and math research is one that Lin is particularly suited to fill: The book imprint shares DNA with *Quanta Magazine*, for which Lin served as founding editor-in-chief. Leveraging the Quanta Books team’s editorial expertise and *Quanta Magazine*’s dozen years of experience with its science-loving audience, the imprint will craft approachable books that serve as canonical references for their subject matter.

“We want to make things seem more approachable, because these are difficult subjects,” says Lin. “Math is hard for most people, and certainly, areas of theoretical physics can seem inaccessible. We want to be that bridge for people. Ultimately, we want to create the definitive popular book on a subject.”

Lin has led the launch of several publishing initiatives at the Simons Foundation. In 2012, he started an online science news publication, which expanded into *Quanta Magazine* in 2013 under the oversight of foundation co-founder Marilyn Simons. Today, the award-winning magazine reaches millions of readers and employs over a dozen seasoned science writers. In 2022, it won a Pulitzer Prize for staff member Natalie Wolchover’s 10,000-word feature chronicling the James Webb Space Telescope.

Starting a book imprint “made sense from my perspective, building on what I’ve learned at the magazine in terms of telling amazing stories about science and math and which ones might be worth a book-length project,” Lin says. “The audiences that we were able to draw to the magazine gave me a good sense of the opportunity for producing and marketing books about basic fundamental science and mathematics intended for a popular audience.”

Carrying high expectations from his experience at *Quanta Magazine*, Lin began laying the groundwork for Quanta Books in late 2022. He officially left the magazine in April 2024 in the capable hands of its new editor-in-chief, Samir Patel, and made the imprint’s first hire, Senior Editor Tisse Takagi.

Quanta Books employs a secret weapon: unusually hands-on relationships with editors. The imprint will publish three to five books a year. Takagi contrasts that with “most editors at trade houses who have to work on 10 to 12 books a year.” By partnering with the 80-year-old publisher Farrar, Straus and Giroux, the imprint can focus on content, with the larger publishing house handling marketing, distribution and production.

“We can devote a lot of attention to the authors and develop a partnership while the author is writing the book instead of sending them off to draft the entire thing on their own and then engaging in a long editorial process,” says Takagi, who has been in the book business for almost 20 years. “The Simons Foundation’s support allows us to really focus and spend time on the thing that matters, which is making each manuscript and each book as good as it can be.”

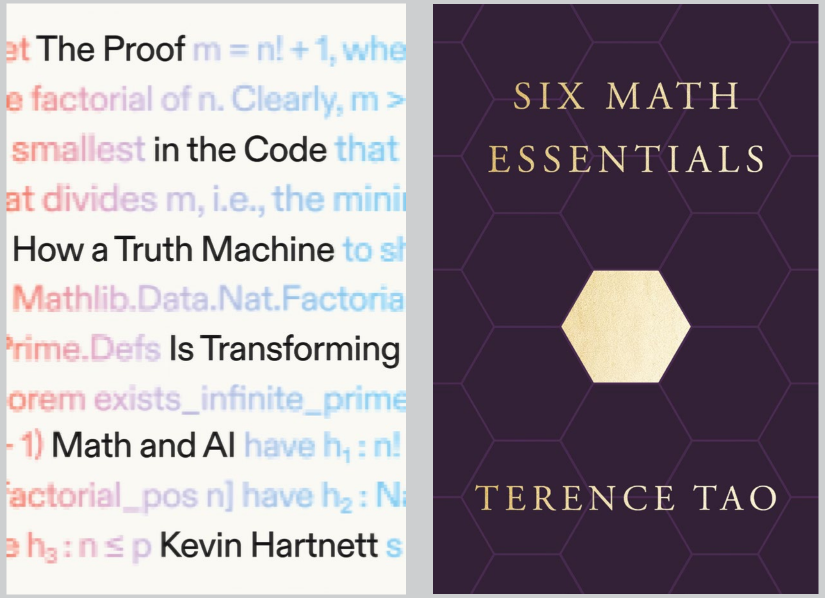
For *The Proof in the Code*, which will be released in June 2026, Lin and Takagi worked closely with author Kevin Hartnett, providing feedback on each successive chapter during biweekly meetings. From concept to final draft, Hartnett, a veteran math journalist, wrote the book in just 18 months, taking it on in his free time.

“The book would not exist without Quanta Books,” says Hartnett, who worked at *Quanta Magazine* as a freelancer, staff writer and then staff editor from 2015 to 2022. “I would remain someone who had aspirations to write a book but hadn't done it. That changed when Tom called me and said, ‘I’m starting Quanta Books. I want you to write the first book, and it should be about Lean.’”

Quanta Books creates unique books by encouraging first-time book authors or assigning niche topics (or, in Hartnett’s case, both). For instance, one day at the foundation, Lin pitched an idea for a short book to prominent mathematician Terence Tao. Lin bills *Six Math Essentials*, coming out in October 2026, as a “very friendly introduction to the main areas of math.”

“It’s the perfect combination of having essentially the world’s foremost mathematician, who’s a genius, writing at a level that anybody can understand,” Lin says about the forthcoming book, whose six chapters focus on numbers, algebra, geometry, probability, analysis and dynamics. “In a way, it’s about him welcoming people [to the math community] and his belief that everybody has some innate math ability, but some people get turned off for various reasons.”

Welcoming possibly reluctant readers to math and science aligns perfectly with the Quanta Books mission. In early 2027, it will publish *Everything Is Fields* by physicist David Tong, on quantum field theory. Lin teases that future years’ book slates include titles on astronomy, geology and biology.



The covers for Kevin Hartnett’s upcoming book, *The Proof in the Code*, and Terence Tao’s book *Six Math Essentials*. Credit: Quanta Books

“You hear a lot of people say, ‘I became a scientist because I read Stephen Hawking’s *A Brief History of Time* when I was a kid’ or ‘I became a scientist because I read [Richard Dawkins’] *The Selfish Gene*,’” says Takagi. “Books capture your imagination in a way that other media can’t. You can tell people a bunch of facts about science and hope they stick, but if you learn those facts through a really engrossing, evocative story, then you’re much more likely to remember it and to be moved by it and for it to change your view of the world.”

Pi Day Festivities Highlight the Beauty in Mathematics

“Mathematicians are fascinated by the same questions that I am: questions of deep patterns, inner landscapes, structures inside truth, and the ecstasy and illumination that come with understanding, all of a sudden, things that have been hidden,” filmmaker Werner Herzog told a crowd of hundreds gathered at the Brooklyn Public Library for its Night in the Library event celebrating mathematics.

The event was produced in partnership with Infinite Sums, a national initiative from the Simons Foundation’s Science, Society & Culture (SSC) division. Infinite Sums aims to broaden the public’s perception of mathematics beyond the practical — not just as a problem in a textbook, but as an ever-evolving source of discovery, inspiration and understanding. Throughout 2026 and beyond, Infinite Sums is partnering with “math ambassadors” at museums, botanical gardens, community centers, libraries and other cultural hubs throughout the country to bring mathematics to life.

During the Brooklyn Public Library’s Pi Day event, saxophonist and mathematician Marcus Garrick Miller performed his show, “Beauty and Logic,” which combines mathematical principles with live music. Credit: Greg Richards/Brooklyn Public Library

“We aren’t trying to change people’s opinion of math — we’re trying to broaden it,” says Simons Foundation Senior Vice President Ivvet Modinou, who leads the SSC division. “We talk about its beauty, how it underpins the universe and all of science. But that is not something you learn in school. You learn equations, and you learn that math is complete. But in fact, a mathematician will tell you that they are still creating new math every day. We are excited to be partnering with so many outstanding organizations to help reveal more of the richness of math.”

Many of these engagement opportunities center around three key dates in 2026: Pi Day (3/14, mirroring the first three digits of the famous irrational number), Infinity Day (8/8, a nod to infinity’s mathematical symbol, ∞) and Fibonacci Day (11/23, in recognition of the Fibonacci sequence, in which each number is the sum of the two preceding it — 0, 1, 1, 2, 3, etc.). The Night in the Library event, held on Pi Day, gave more than 8,000 visitors the opportunity to attend dozens of lectures and activities led by experts across science and the arts (and even ended, fittingly, at 3:14 a.m.).

In one section of the library, mathematician Lucia Perez, one of several speakers from the Simons Foundation’s Flatiron Institute, described how scientists study the universe from Earth by combining careful observation with clever mathematical tools, using “cosmic rulers” such as pulsating stars to measure vast distances. This eventually led to the discovery that the universe is expanding, laying the foundation for the Big Bang theory. More recently, these mathematical tools have helped identify ‘dark energy,’ the mysterious force that propels this expansion.

The San Antonio Botanical Garden’s Pi Day event illustrated how mathematical concepts such as pi show up throughout the natural world. Credit: San Antonio Botanical Garden

“All of the understanding that we have about our universe comes from sitting on Earth and being very observant and thoughtful and clever with our math,” says Perez.

Downstairs in the library’s auditorium, jazz musician and mathematician Marcus Garrick Miller led the audience through a musical exercise. He asked the audience for seven numbers that added up to 12 (with duplicates allowed). Each represented a note in a scale: C was 1, D was 2, etc. Choosing from these seven numbers, he created a musical scale, and from that scale, he and his band improvised a song.

“By using this mathematical thinking of trying to find seven numbers that add up to 12, by setting these constraints and then letting our imaginations run wild, we can generate many different scales, all associated with different feelings,” Miller told the crowd.

A lifelong jazz musician who studied mathematics at Harvard University, Miller is passionate about building a bridge to mathematics through music.

“For people who aren’t math people, seeing something they love — like music — connected to math in a meaningful way opens up a whole new curiosity about the world,” he says.

The Night in the Library was one of hundreds of Pi Day events around the country supported by the Infinite Sums initiative.

The San Antonio Botanical Garden (SABG) in Texas — along with mathematicians from nearby Trinity University, St. Mary’s University and Southwestern University — illuminated the wonder of mathematics in the natural world, showing how counting tree rings can reveal a tree’s age, how pi factors into sound waves and how mathematics informs garden design.

“There was such incredible energy throughout the day — the number of people who showed up and the enthusiasm they brought with them

The Brooklyn Public Library welcomed thousands of visitors to celebrate mathematics and its surprising connections to everything from poetry to dance. Credit: Greg Richards/Brooklyn Public Library

During the Pi Day celebration at the Brooklyn Public Library, filmmaker Werner Herzog spoke about his lifelong interest in mathematics and how it intersects with filmmaking. Credit: Greg Richards/Brooklyn Public Library

was amazing,” recalls SABG Chief Mission Officer Andrew Labay.

“One highlight for us was the pi chalk walk, where guests and staff filled the garden entry with colorful digits of pi. It was such a creative, joyful way to experience mathematics together,” adds SABG Vice President of Learning and Interpretation Katie Erickson.

The Virgin Islands Children’s Museum, on St. Thomas in the U.S. Virgin Islands, hosted a Pi Day event featuring talks on how mathematics shows up in everything from marine science to nutrition. This was followed by a workshop using the power of pi to make dresses for bamboula, a West African–derived dance (as well as an associated rhythm and drum).

“At the Virgin Islands Children’s Museum, we celebrate Caribbean culture whenever possible, and this was the perfect way to show how math is woven into our heritage,” says Amber McCammon, the museum’s CEO. “Bamboula is a symbol of freedom and resistance in the Virgin Islands; linking the mathematical constant of a circle's circumference to the construction of these iconic skirts turned an abstract ratio into a celebration of our ancestors’ ingenuity. It showed that our traditional dance is also a master class in geometry.”

The Pi Day events are just one part of a broader ongoing effort, with Infinite Sums continuing to expand its reach in 2026 and beyond. Whether it’s partnering with filmmakers to tell stories about how mathematics shapes the human experience or connecting artists with scientists to create pieces centered on the theme of symmetry, there will be plenty to explore.

“Math education is often focused on the utility of math, and it’s true that math is practical, but that sells math short,” says SSC Program Director John Tracey. “With Infinite Sums, we really want to surprise people when it comes to what math can be. We want to lean into its elegance and inspire people from there.”

Financials

BALANCE SHEET

(Unaudited, accrual basis, in $)

ASSETS	As of 12/31/25	As of 12/31/24
Cash and Cash Equivalents	176,126,773	156,411,509
Investments	3,972,832,883	3,817,694,643
Property and Equipment, Net	368,249,622	361,165,471
Right-of-Use Lease Assets	116,240,274	121,709,281
Deposits and Other Assets	25,188,916	26,657,716
Total Assets	**4,658,638,468**	**4,483,638,620**

LIABILITIES		
Accounts Payable and Accrued Expenses	45,330,144	27,455,881
Grants Payable, Net	256,026,546	367,777,715
Mortgage and Lease Liabilities	245,345,378	356,837,218
Deferred Excise Tax Liability	15,713,161	15,713,161
Total	**562,415,229**	**767,783,975**

NET ASSETS		
Beginning Net Assets	3,715,854,645	3,666,729,106
Current Year Change in Net Assets	380,368,594	49,125,539
Total	**4,096,223,239**	**3,715,854,645**

Total Liabilities and Net Assets	**4,658,638,468**	**4,483,638,620**

INCOME STATEMENT

(Unaudited, accrual basis, in $)

REVENUE	For the Year Ended 12/31/25	For the Year Ended 12/31/24
Contributions	269,125,000	-
In-Kind Contributions	18,270,000	-
Investment Income	400,805,004	402,134,901
Interest Income	6,555,542	8,981,373
Rental Income	2,896,747	2,746,524
Other Program Income	452,011	(105,782)
Total	**698,104,304**	**413,757,016**

EXPENSES		
Program	249,701,244	302,795,948
Management and General	68,034,466	61,835,529
Total	**317,735,710**	**364,631,477**

Change in Net Assets	**380,368,594**	**49,125,539**

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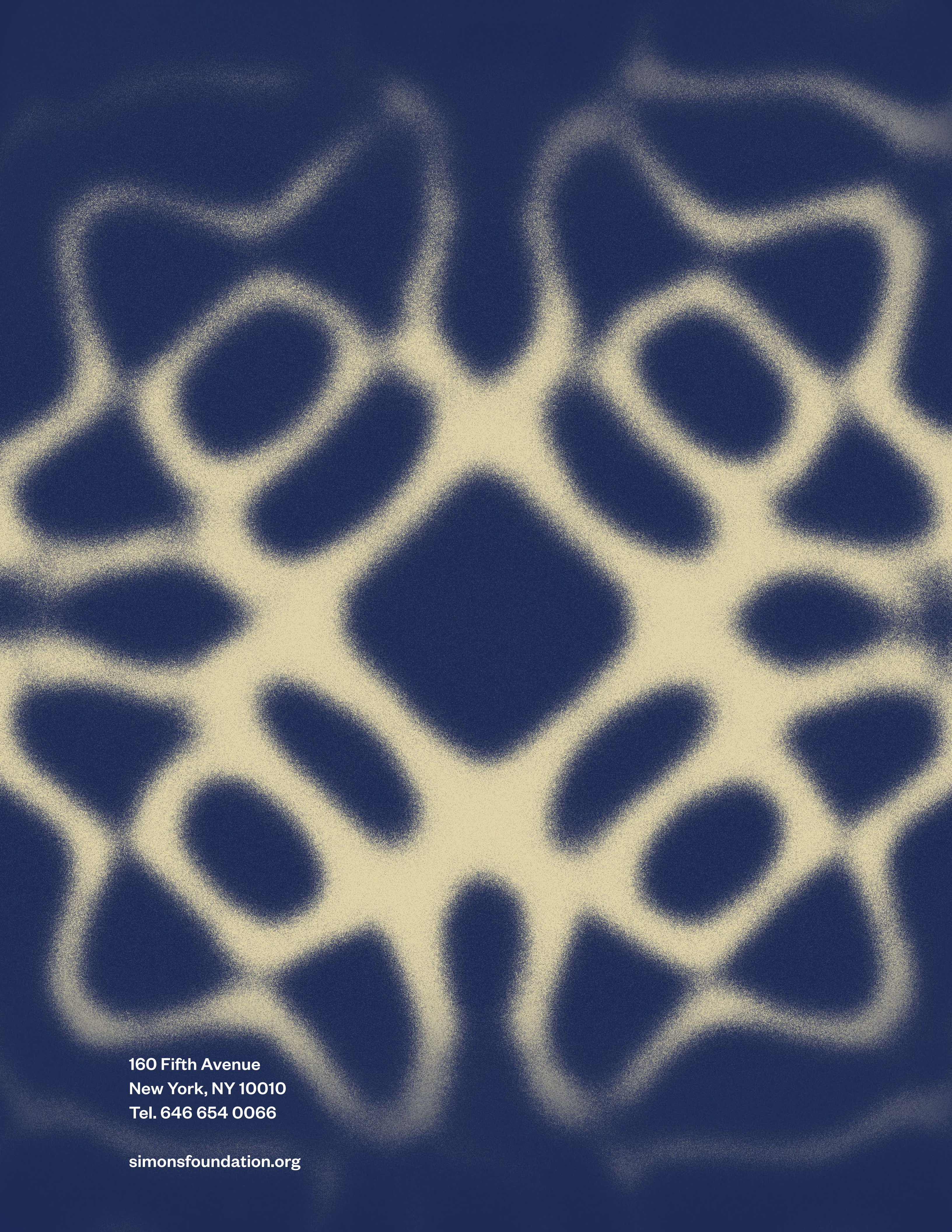

160 Fifth Avenue
New York, NY 10010
Tel. 646 654 0066

simonsfoundation.org