

so that they are more likely to get the NIH grant later.” Sceptics have questioned whether the couple’s money might be better spent by public institutions such as the NIH and the World Health Organization. But Quake says that the biohub seeks to complement those agencies.

Indeed, neither the biohub nor its parent initiative could replace government funding even if it wanted to. The initiative’s \$3-billion commitment — to science that aims to cure, manage or prevent all diseases — pales in

comparison with the roughly \$30 billion that the NIH spends annually on medical research.

The biohub’s leaders hope to accelerate the rate at which its grantees’ discoveries prove useful by requiring investigators to meet a dozen times each year. Recipients must also post their manuscripts on open-access preprint servers, such as arXiv, as soon as they submit the paper to a peer-reviewed journal. But researchers are permitted to file for patents, which would be owned jointly by the biohub and

the scientists’ home institutions.

Marc Kastner, president of the Science Philanthropy Alliance in Palo Alto, California, has advised Chan and Zuckerberg, among others. He applauds the biohub for selecting researchers who want to pursue non-traditional projects.

“If you’re going to take a century-long view on curing disease,” he says, “you need to emphasize basic research because you can’t tell where breakthroughs come from.” ■

## GEOMETRY

# Long-sought maths proof could shake up seismology

*Solution to puzzle might allow Earth’s structure to be determined from wave speeds.*

BY DAVIDE CASTELVECCHI

Mathematicians say that they have solved a major, decades-old problem in geometry: how to reconstruct the inner structure of a mystery object ‘X’ while knowing only how fast waves travel between any two points on its boundary.

The work has implications in real-world situations; for example, it could help geophysicists who use seismic waves to analyse the structure of Earth’s interior.

“Without destroying X, can we figure out what’s inside?” asked mathematician András Vasy of Stanford University in California, when he presented the work in a talk at University College London (UCL) earlier this month. “One way to do it is to send waves through it,” he said, and measure their properties. Now, Vasy

and two of his collaborators say that they have proved<sup>1</sup> that this information alone is sufficient to reveal an object’s internal structure.

## LOOKING INWARDS

The problem is called the boundary-rigidity conjecture. It belongs to the field of Riemannian geometry, the modern theory of curved spaces with any number of dimensions. Albert Einstein built his general theory of relativity, in which mass warps the geometry of space-time, on this branch of mathematics.

Mathematicians already knew that the way in which curvature varies from place to place inside a ‘Riemannian manifold’ — the mathematical jargon for curved space — determines the shortest paths between any two points. The conjecture flips things around: it says that knowing the lengths of the shortest paths

between points on a boundary essentially determines the curvature throughout. The geometry is therefore said to be ‘rigid’. So by measuring how fast waves travel inside a space, one could work out the shortest paths, and, theoretically, the overall structure.

The conjecture dates back to at least 1981, when the mathematician René Michel<sup>2</sup> formulated certain technical assumptions about the spaces for which it should be true. (It is not true for Riemannian manifolds in general.)

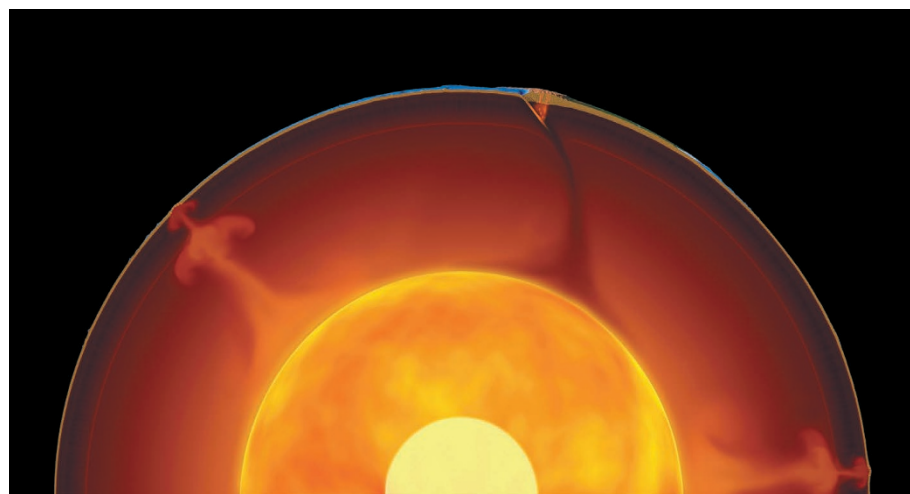
Vasy’s co-author Gunther Uhlmann, a mathematician at the University of Washington in Seattle, had already solved it for two-dimensional manifolds — that is, curved surfaces<sup>3</sup>. Now, Vasy, Uhlmann and Plamen Stefanov, who is at Purdue University in West Lafayette, Indiana, have solved it for spaces that have three or more dimensions, as well.

## LAYER BY LAYER

In Einstein’s space-time, curvature produces gravitational lensing, in which the path of light bends around massive objects such as stars. Similar mathematics apply to conventional lensing, or refraction: light rays or sound waves shift direction when the medium through which they are travelling changes.

In the case of seismic waves — generated by events such as earthquakes — the differing properties of Earth at varying depths mean that the shortest path for such waves is usually not a straight line, but a curved one. Since the early twentieth century, geophysicists have used this fact to map the planet’s internal structure, and this is how they discovered the mantle and the inner and outer cores.

Those discoveries were rooted in mathematical treatments that had some simplifying ▶



Earth’s inner structure could be revealed by the speed at which waves travel from one edge to another.

► assumptions. Until now, it was not clear that one could fully determine Earth's structure using only wave travel times.

But that is what Vasy and his team's proof shows — and the geophysical problem was a key motivation for solving the conjecture. Their assumption, which differed from Michel's, was that the curved space, or manifold, is structured with concentric layers. This allowed them to construct a solution in stages. "You go layer by layer, like peeling an onion," says Uhlmann. For practical applications, this means that researchers will not only know that there is a unique solution to the problem; they will also have a procedure to calculate that solution explicitly.

The three mathematicians circulated their 50-page paper among a small pool of experts and then posted it in the arXiv repository. Depending on the feedback they get, the authors hope to submit it to a journal in the coming weeks.

#### FROM THEORY TO REALITY

But applying the theory to real geophysical data will not happen immediately, says Maarten de Hoop, a computational seismologist at Rice University in Houston, Texas. One difficulty is that the theory assumes that there is information at every point. In reality, however, data are collected only at relatively sparse locations.

The theory could lead to a better understanding of known features, such as the mantle plumes underneath Iceland or Hawaii, and, perhaps, to the discovery of new ones, adds de Hoop.

As with every meaty mathematical result, it will take time to get to grips with the proof and vet it thoroughly, says Gabriel Paternain, a mathematician at the University of Cambridge, UK. Experts are taking the claim seriously, in part because it builds on a technical step from a linear form of the problem that the community has accepted as a breakthrough<sup>4</sup>, adds UCL mathematician Yaroslav Kurylev. So far, says Paternain, the impression is "excellent". ■

1. Stefanov, P., Uhlmann, G. & Vasy, A. Preprint at <https://arxiv.org/abs/1702.03638> (2017).
2. Michel, R. *Invent. Math.* **65**, 71–83 (1981).
3. Pestov, L. & Uhlmann, G. *Ann. Math.* **161**, 1093–1110 (2005).
4. Uhlmann, G. & Vasy, A. *Invent. Math.* **205**, 83–120 (2016).



Technicians install sensors for the Perdigão wind-mapping project.

#### ATMOSPHERIC SCIENCE

# Huge wind-flow study spins up

*International team in Portugal seeks to improve models of wind patterns over rugged terrain.*

BY ALEXANDRA WITZE

**M**achines have invaded a windswept rural valley in eastern Portugal. Squat white containers stare at the hillsides, sweeping lasers across the eucalyptus-studded slopes, and towers bristling with scientific instruments soar 100 metres into the air.

Their international team of minders will spend the next five months measuring nearly everything it can about the wind that blows through the site. An unprecedented arsenal of meteorological equipment will study speed, direction and other characteristics for the world's most detailed wind-mapping

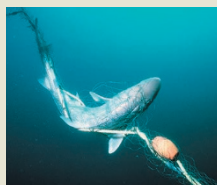
project. The aim is to illuminate fundamental properties of wind flow over complex terrain, to help researchers improve atmospheric computer models and enable engineers to decide where to put wind turbines to get the most energy from them.

The results of the project, called Perdigão, should also improve models of how air pollution sinks into valleys and help drones and aircraft to navigate gusty mountain terrain.

"This will be utterly transformative in both understanding the physics of the atmosphere and also how to optimally use wind energy," says Sara Pryor, an atmospheric scientist at Cornell University in Ithaca, New York, who



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