

early 2013, the system vastly overestimated flu cases for two weeks⁷. By relying wholly on associations rather than also incorporating epidemiological risk factors, the algorithm had few checks and balances against over- or underestimation, and offered few insights into the factors driving short-term patterns in flu incidence.

In summary, although big-data analyses cannot replace careful epidemiological studies, they can give broad insight into the potential benefits of public-health policies. In this case, Heft-Neal and colleagues' work highlights the benefits of aspiring to reduce air pollution to the lowest levels observed in their data set, and provides assessments of the effects of more-modest changes in pollution levels. This type of analysis certainly has a place in the modern public-health toolbox. As noted by

Kofi Annan²: "Without good data, we're flying blind. If you can't see it, you can't solve it." ■

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1. Dowell, S. F., Blazes, D. & Desmond-Hellmann, S. *Nature* **540**, 189–191 (2016).
2. Annan, K. *Nature* **555**, 7 (2018).
3. Heft-Neal, S., Burney, J., Bendavid, E. & Burke, M. *Nature* **559**, 254–258 (2018).
4. GBD 2016 Mortality Collaborators. *Lancet* **390**, 1084–1150 (2017).
5. Cohen, A. J. *et al.* *Lancet* **389**, 1907–1918 (2017).
6. Burnett, R. T. *et al.* *Environ. Health Perspect.* **122**, 397–403 (2014).
7. Lazer, D., Kennedy, R., King, G. & Vespignani, A. *Science* **343**, 1203–1205 (2014).

This article was published online on 27 June 2018.

CONDENSED-MATTER PHYSICS

The heat is on for Majorana fermions

Exotic particles called Majorana fermions have potential applications in quantum computing, but their existence has yet to be definitively confirmed. Two groups have now glimpsed these particles. [SEE ARTICLE P.205](#) & [LETTER P.227](#)

KIRILL SHTENDEL

The building-blocks of matter — protons, neutrons and electrons — are examples of particles called fermions. Eight decades ago, the Italian physicist Ettore Majorana predicted the existence of fermions that are their own antiparticles¹. These particles, now known as Majorana fermions, would be of great fundamental interest, and could revolutionize quantum computing. Evidence for Majorana fermions among elementary particles remains elusive; however, in the past few years, there has been striking progress in this hunt in the realm of condensed-matter physics². On pages 205 and 227, respectively, Banerjee *et al.*³ and Kasahara *et al.*⁴ report signatures of Majorana fermions in heat-transport experiments in two very different condensed-matter settings.

Condensed-matter systems contain excitations that behave like ordinary particles, but that need not resemble the actual elementary particles that the systems are made of. For example, the phenomenon of superconductivity (more specifically, topological superconductivity) provides a setting in which an electron can effectively 'forget' its electric charge. As a result, the electron becomes indistinguishable from its antiparticle, which in this context is an electron vacancy called a hole. Whether topological superconductivity

is an intrinsic feature of solid-state materials remains an open question. However, the key aspects of the phenomenon can be mimicked in certain condensed-matter systems, providing the right conditions for the emergence of Majorana fermions. The two systems investigated in the current papers seem to be of just this kind.

Banerjee and colleagues looked for evidence of Majorana fermions on the edge of a condensed-matter system that exhibits the quantum Hall effect — whereby, at low temperature and in the presence of a strong magnetic field, the material's transverse electrical conductance becomes quantized (it can have only specific values). The authors focused on a particular state for which this conductance is 5/2 times the fundamental unit. The exact nature of this state has been a subject of debate, but all of the strong contenders can be thought of as superconducting states of composite fermions⁵.

By contrast, Kasahara and colleagues investigated a form of ruthenium chloride known as α -RuCl₃. This material is thought to be in a phase known as the Kitaev spin liquid — a peculiar state of matter that lacks long-range magnetic order all the way down to zero kelvin^{6,7}. Although α -RuCl₃ is an electrical insulator, the description of the magnetic properties of a Kitaev spin liquid is mathematically equivalent to that of a topological



50 Years Ago

Motorists in south and central England who cleaned their cars during the last weekend of June regretted their diligence when they rose on Monday, July 1, to find deposits of orange coloured dust over every exposed surface. The explanation was an early morning shower of rain, laden with dust swept up probably from somewhere in North Africa ... this was an unusual event, even for a country which prides itself on the peculiarities of its climate ... it turned out that the last time a dust fall like this happened was in 1903 ... On the same day as the widespread dust fall, Minehead ... Dulverton ... and Burnley ... were bombarded by hailstones the size of golf balls ... The Meteorological Office is keeping an open mind on whether this is a coincidence or whether there was a causal relationship between the dust and the hail.

From *Nature* 13 July 1968

100 Years Ago

During the last twenty years there has been an extraordinary increase in the ... output of books and papers on scientific subjects. In the olden time many a quiet student would be content to spend his life upon one piece of work ... in the hope that it might remain a permanent addition to human knowledge ... [A]nyone wishing to learn the present state of our knowledge ... might well despair of ever discovering all that has recently been written ... A complete catalogue of all scientific publications throughout the world would be, unfortunately, very bulky ... An alternative method is to draw up a list of journals ... and to confine the catalogue to papers published in these journals. When this plan is adopted it is hoped that authors ... will gradually acquire the habit of sending any original paper they wish to publish to one of these periodicals.

From *Nature* 11 July 1918

superconductor. Therefore, Majorana fermions should exist on the edge of α -RuCl₃.

The direct detection of Majorana fermions in condensed-matter systems was never going to be easy. Such particles must be electrically neutral and therefore cannot participate in electrical transport (although they can mediate such transport in superconductors^{8,9}). However, although Majorana fermions are unable to conduct current, they can conduct heat.

Electrons can conduct both electricity and heat. As a result, metals — which contain many free electrons — are typically good heat conductors. This idea is formalized by the Wiedemann–Franz law, which states that electrical conductivity is directly proportional to thermal conductivity divided by temperature. Although the identification of this relationship is often lauded as one of the early successes of solid-state theory, the proportionality constant is not universal for ordinary metals: scattering processes, which limit both electrical and thermal conductivity, affect these properties differently in different metals.

However, if the motion of particles in a material is ballistic (if there is effectively no scattering), both electrical and thermal conductivity are quantized and proportional to the number of propagating modes (conduction channels). Each electron mode contributes a unit of thermal conductance, and, crucially, each Majorana mode contributes only half a unit. Both Banerjee *et al.* and Kasahara *et al.* observed this fraction of thermal conductance on the edges of their condensed-matter systems.

The existence of Majorana edge modes in a condensed-matter system is a strong indicator that the topological order of the system is non-Abelian — which means, for example, that a collection of the system's excitations has a huge number of quantum states with the same energy. The non-Abelian nature of the quantum Hall state studied by Banerjee *et al.* has long been expected (albeit not confirmed beyond reasonable doubt). However, Kasahara and colleagues' findings provide the first experimental evidence of a non-Abelian spin liquid. Although more work is needed to confirm the exact nature of this state, the discovery of such an unconventional phase of matter is truly exciting.

Banerjee and colleagues used their measurements to try to discriminate between different candidate non-Abelian states. This task is harder than obtaining evidence for non-Abelian topological order. It relies on counting both fractional and integer contributions to the system's thermal conductance, which, in turn, requires certain assumptions to be made about the process by which different propagating modes reach thermal equilibrium¹⁰. The issue of equilibration is further complicated by the fact that the edge modes can reach equilibrium not only with each other, but also with lattice vibrations

called phonons, which provide an unwanted contribution to the thermal conductance.

Banerjee *et al.* went to great lengths to minimize this phonon contribution. They carried out their experiments at temperatures of about 20 mK and used a sophisticated design of a source and drains to avoid the coupling of edge modes to phonons. By comparison, Kasahara and colleagues' experiment was much less intricate and required temperatures of only about 5 K. These authors could not detect a signal of half-integer quantization at lower temperatures, which probably suggests that the system transitioned to a different phase. Their results also indicate that a substantial amount of heat was carried by phonons.

Under these circumstances, it should be surprising that the authors saw signs of quantized Hall heat transport — the heat conduction in the direction perpendicular to that of the thermal gradient — by Majorana fermions. However, two recent studies^{11,12} have argued that phonon coupling not only is not detrimental, but also can actually be necessary for

the observation of such an effect. More work, both theoretical and experimental, is required to fully understand the implications of these experiments. Nevertheless, it is undoubtedly exciting that the quest for Majorana fermions is heating up in this manner. ■

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1. Majorana, E. *Nuovo Cimento* **14**, 171–184 (1937).
2. Wilczek, F. *Nature Phys.* **5**, 614–618 (2009).
3. Banerjee, M. *et al. Nature* **559**, 205–210 (2018).
4. Kasahara, Y. *et al. Nature* **559**, 227–231 (2018).
5. Read, N. & Green, D. *Phys. Rev. B* **61**, 10267–10297 (2000).
6. Kitaev, A. *Ann. Phys.* **321**, 2–111 (2006).
7. Jackeli, G. & Khaliullin, G. *Phys. Rev. Lett.* **102**, 017205 (2009).
8. Mourik, V. *et al. Science* **336**, 1003–1007 (2012).
9. He, Q. L. *et al. Science* **357**, 294–299 (2017).
10. Simon, S. H. *Phys. Rev. B* **97**, 121406 (2018).
11. Ye, M., Halász, G. B., Savary, L. & Balents, L. Preprint at <https://arxiv.org/abs/1805.10532> (2018).
12. Vinkler-Aviv, Y. & Rosch, A. Preprint at <https://arxiv.org/abs/1805.11587> (2018).

ECOLOGY

How rats wreak havoc on coral reefs

The introduction of non-native rats can devastate island ecosystems. It now emerges that these rats also harm a complex web of interactions linking seabirds with the algae and fishes of nearby coral reefs. SEE LETTER P250

NANCY KNOWLTON

Non-native rats that invade tropical islands can cause problems for the ecosystems they invade¹. These intruders can decimate the native populations on which they feed, such as plants and terrestrial invertebrates. Bird populations can plummet, too, when rats eat eggs and nestlings. The complex, indirect effects of rodent presence can spread deeply and widely through island food webs². However, little attention has been paid to the indirect impacts of such invasive species on adjacent coral-reef communities. On page 250, Graham *et al.*³ address this for sites on the Chagos Archipelago in the Indian Ocean (Fig. 1), comparing coral reefs surrounding six rat-infested islands with those adjacent to six islands that lacked rats. The authors find that reefs near rat-infested islands have fewer nutrients, fewer fishes and reduced numbers of fishes grazing on the algae that compete with corals.

One of the most marked effects of rats was a 760-fold decline in the number of nesting seabirds per hectare on rat-infested islands compared with rat-free islands. On the

latter islands, the larger populations of birds produced larger deposits of guano — nitrogen-rich bird excrement. This nitrogen is mostly obtained from food that the birds consume during long-distance foraging trips to parts of the ocean that, thanks to their higher levels of nutrients, are 100 to 100,000 times more productive than the waters in the immediate vicinity of an island. The nitrogen deposition rates on the rat-free islands were 251 times greater per hectare than were those on the rat-infested islands. Using a technique to identify different isotopic forms of nitrogen, the authors could distinguish this 'imported' seabird nitrogen from locally derived nitrogen. This enabled Graham and colleagues to track where the seabird-deposited nitrogen ended up.

Some nitrogen was absorbed by plants on the islands, and some entered the ocean through rain or breaking waves. For example, 100 metres from the shore of rat-free islands, both a type of sponge and a type of macroalgae had elevated levels of nitrogen derived from seabird foraging, compared with the levels recorded near rat-infested islands. At 230 metres from the shore of rat-free islands, the concentration of seabird-derived nitrogen