thickness, and directly compared the results with their data set of where fractures are observed to occur.

The researchers find that the stress pulling apart most water-free surface crevasses is currently too small to allow the crevasses to penetrate the entire ice-shelf thickness. Similarly, the stress in the few parts of the ice shelf at which water regularly accumulates on the surface is often compressive, and therefore prevents the water from squeezing its way through hydrofractures to the bottom of the ice shelf. Under present conditions, these regions of the ice shelf are stable and unlikely to collapse rapidly.

However, as atmospheric temperatures continue to rise, larger portions of the ice shelves are expected to undergo surface melting than at present. Lai *et al.* find that up to 60% of the area of ice shelves that buttress (block the flow of) the ice sheet could be destabilized if they become inundated with meltwater, as a result of crevasses being filled by the water. Taken together, the authors' findings pinpoint the portions of ice shelves that are most vulnerable to atmospheric warming, and show that large sections that are currently stable could collapse as atmospheric temperatures continue to rise.

Lai *et al.* focus on atmospheric warming as suspect number one, but it remains unclear how tightly the fate of ice shelves is tied to suspect number two: oceanic warming. At present, atmospheric temperatures remain too cold over much of the Antarctic ice sheet to promote substantial surface melting[6]. By contrast, a warming ocean has been linked[8,9] to the thinning and retreat of ice shelves in the Amundsen Sea Embayment in West Antarctica. This is especially true for the ice shelves fed by the Pine Island and Thwaites glaciers — warm ocean water is rapidly thinning these shelves and sculpting deep basal channels into their undersides. These channels have been linked to increased fracturing of the ice shelf[10], but surface melt can also drain into surface depressions associated with the channels, forming rivers that efficiently remove water from the surface of the ice shelf and thereby prevent widespread inundation of the ice shelf[11]. What happens on the top of an ice shelf is thus tightly linked to what happens at the bottom.

Increasingly sophisticated models have been used to simulate (or re-enact) the retreat and disintegration of ice shelves in response to atmospheric warming (see refs 2 and 3, for example). However, a deeper understanding of the effects of both the ocean and the atmosphere is needed to accurately predict the fate of ice shelves in a warming climate, because ice shelves are vulnerable to attack from above and below. In other words, the chief suspects in the destabilization of ice shelves do not act in isolation — they are co-conspirators.

Jeremy N. Bassis is in the Department of Climate and Space Sciences, University of Michigan, Ann Arbor, Michigan 48109, USA.
e-mail: jbassis@umich.edu

1. Scambos, T. A., Bohlander, J. A., Shuman, C. A. & Skvarca, P. *Geophys. Res. Lett.* **31**, L18402 (2004).
2. Banwell, A. F., MacAyeal, D. R. & Sergienko, O. V. *Geophys. Res. Lett.* **40**, 5872–5876 (2013).
3. MacAyeal, D. R., Scambos, T. A., Hulbe, C. L. & Fahnestock, M. A. *J. Glaciol.* **49**, 22–36 (2003).
4. Lai, C.-Y. *et al. Nature* **584**, 574–578 (2020).
5. Weertman, J. *J. Glaciol.* **13**, 3–11 (1974).
6. Scambos, T., Hulbe, C. & Fahnestock, M. in *Antarctic Peninsula Climate Variability: Historical and Paleoenvironmental Perspectives* Vol. 79 (eds Domack, E. *et al.*) 79–92 (Am. Geophys. Un., 2003).
7. Weertman, J. *Acta Metall.* **26**, 1731–1738 (1978).
8. Dutrieux, P. *et al. Cryosphere* **7**, 1543–1555 (2013).
9. Jenkins, A. *et al. Nature Geosci.* **11**, 733–738 (2018).
10. Dow, C. F. *et al. Sci. Adv.* **4**, eaao7212 (2018).
11. Bell, R. E. *et al. Nature* **544**, 344–348 (2017).

Insect behaviour

Catching plague locusts with their own scent

Leslie B. Vosshall

A pheromone molecule that makes crop-damaging locusts swarm has been identified. Could this pheromone, which is sensed by odorant receptors, be used to trap these insects and prevent the agricultural devastation that they cause? **See p.584**

This year is a plague year. The COVID-19 pandemic, caused by the coronavirus SARS-CoV-2, is burning across the globe as we anxiously await an effective vaccine or drug to control it. Another plague, of a much older kind — one that is not curable with vaccines or medicine — is currently raging in Africa (Fig. 1) and the Middle East. Seasons of unusually heavy rains, driven by climate change (see go.nature.com/3fchnrm), have created population explosions of swarming desert locusts (*Schistocerca gregaria*). Swarms can contain billions of insects and cover hundreds of square kilometres. These insects strip vegetation and crops, threatening the precarious existence of subsistence farmers and contributing to food insecurity in vulnerable regions. The only effective weapon for fighting such locust plagues is the aerial spraying of pesticides, but the swarms are fast-moving and unpredictable, and spraying devastates beneficial insects.

How do these vast swarms of voracious insects form, and what can be done to stop them? On page 584, Guo *et al.*[1] identify a pheromone molecule of the migratory locust (*Locusta migratoria*) that might hold the key to swarming behaviour, and the authors' discovery raises the possibility of using locusts' own pheromone to combat this threat.

L. migratoria is a species of grasshopper that begins its life as a benign individual leading a solitary existence. But solitary locusts can attract each other to create ever-larger groups of gregarious locusts. During the process of joining a group, the pigmentation of solitary locusts changes from green to black, in an alteration regulated by a neuropeptide molecule[2]. The gregarious insects also begin to produce the molecule phenylacetonitrile, which is metabolized into cyanide and used as a type of chemical warfare against predators[3].

Researchers have long assumed that an aggregation pheromone was the trigger for swarms, but no molecule had yet satisfied the conditions of being a candidate pheromone. For this, it would need to be a single type of molecule isolated from a natural source that, by itself, has the biological activity of interest — and that, when chemically synthesized in the laboratory, has the same activity as the biological substance[4,5].

From a collection of 35 compounds emitted by locusts[6], the authors identified 6 that are highly enriched in gregarious but not in solitary insects. Guo and colleagues tested each compound for its ability to entice locusts. Only the molecule 4-vinylanisole proved to be highly potent, and it attracted male and female locusts at both juvenile and adult developmental stages. Crucially, 4-vinylanisole was equally attractive to both solitary and gregarious locusts. This suggests that the ability to sense this proposed aggregation pheromone is innate.

The concentration of 4-vinylanisole in the air increased markedly when the population density of locusts rose. This is consistent with the molecule having a role in triggering the positive-feedback loop that gathers gregarious locusts as a swarm grows. The authors carried out a clever experiment to determine how many solitary locusts need to be crowded together to induce the production of this aggregation pheromone. The answer

PATRICK NGUGI/AP/SHUTTERSTOCK

Figure 1 | A child swats locusts in Kenya. One of the worst outbreaks of swarming desert locusts (*Schistocerca gregaria*) in decades has spread across eastern Africa during 2020.

is remarkable: just four or five suffice.

How do locusts sense 4-vinylanisole? This molecule is a volatile odorant — classified as smelling sweet to humans — and the authors hypothesized that olfactory neurons in the insects' antennae would detect it. Indeed, recordings from individual sensory hairs on an antenna allowed the authors to pinpoint one type that selectively responded to 4-vinylanisole. Consistent with the discovery that solitary locusts are as behaviourally sensitive to 4-vinylanisole as are gregarious locusts, the researchers found that the olfactory neurons of both types of locust were extremely sensitive to this pheromone.

The authors next set out to see whether they could identify an odorant receptor protein that could detect the molecule. They profiled 31 of the 141 known locust odorant receptors and identified a single one, called OR35, that was strongly and selectively activated by 4-vinylanisole. To prove that the *Or35* gene encodes the receptor that mediates detection of this molecule, Guo and colleagues used the genome-editing technique CRISPR–Cas9 to generate mutant locusts that lacked this gene, and then tested the behavioural responses of the insects. These mutant locusts did not have antennal responses to 4-vinylanisole and were unable to detect the pheromone and respond behaviourally. This finding is exciting, because it indicates that a locust can be engineered to be immune to the effects of the pheromone. In principle, such an insect would not be expected to convert into the gregarious form.

In a final series of experiments, the authors put the aggregation pheromone to the test. In outdoor trap experiments on artificial turf, sticky traps baited with 4-vinylanisole were highly successful at trapping dozens of locusts released from the laboratory. Sticky traps of the same type, deployed in the field in a wetland reserve near Tianjin, China, successfully caught a modest number of wild locusts.

The first insect pheromone to be identified was bombykol, from the silkmoth *Bombyx mori*[4]. It took more than 55 years from the report of that discovery for scientists to reach the milestone of generating a mutant insect lacking the bombykol receptor[7]. New tools now enable much swifter progress. This research by Guo and colleagues covers remarkable ground in moving from the identification of the pheromone, to pinpointing the sensory neurons and odorant receptor that detect it, to generating a mutant insect that loses sensitivity to the pheromone, and to providing initial evidence that the molecule functions in the field to lure locusts.

> **"The authors show that 4-vinylanisole can trap locusts."**

Several important questions remain. It is not clear whether 4-vinylanisole is responsible solely for the initial aggregation of locusts, or whether it also triggers the pigmentation change and subsequent aggressive swarming behaviour seen after locusts gather. It is possible that the aggregation pheromone merely brings locusts together and that other, secondary mechanisms, and perhaps extra volatile signals, then induce further changes to the morphology and behaviour of the insect. Further investigation is needed to determine whether desert locusts also respond to 4-vinylanisole.

How might the production of 4-vinylanisole be triggered in a manner that is dependent on insect population density? One possibility is that locusts self-monitor their own production of the pheromone and that, as the density and concentration of the pheromone increase, the insects' olfactory systems begin to adapt. This might lead to an upregulation of pheromone, similar to that seen in the Colorado potato beetle (*Leptinotarsa decemlineata*), which upregulates pheromone production when its antennae are removed[8]. The neural circuits that mediate this pheromone detection, production and pheromone-sensing behaviour in locusts remain completely uncharted.

Finally, how might this discovery be applied to the practical problem of locust plagues? The authors show that 4-vinylanisole can trap locusts. The efficiency was modest, however, and to scale up the trapping capacity, a more potent version of the pheromone would need to be developed, as well as more-powerful trapping technology. Most exciting is the possibility of using OR35 as a tool to identify compounds that block the activity of this receptor. The discovery of such a molecule might provide a chemical antidote to insect aggregation and cause locusts to 'stand down' and return to their peaceful, solitary way of life.

Leslie B. Vosshall is at the Kavli Neural Systems Institute and the Howard Hughes Medical Institute at the Rockefeller University, New York, New York 10065, USA.
e-mail: leslie.vosshall@rockefeller.edu

1. Guo, X. *et al. Nature* **584**, 584–588 (2020).
2. Tawfik, A. I. *et al. Proc. Natl Acad. Sci. USA* **96**, 7083–7087 (1999).
3. Wei, J. *et al. Sci. Adv.* **5**, eaav5495 (2019).
4. Butenandt, A., Beckmann, R., Stamm, D. & Hecker, E. *Z. Naturforsch.* **14b**, 283–284 (1959).
5. Wyatt, T. D. *Nature* **457**, 262–263 (2009).
6. Wei, J. *et al. Insect Sci.* **24**, 60–72 (2017).
7. Sakurai, T. *et al. Sci. Rep.* **5**, 11001 (2015).
8. Dickens, J. C., Oliver, J. E., Hollister, B., Davis, J. C. & Klun, J. A. *J. Exp. Biol.* **205**, 1925–1933 (2002).

Nanotechnology

A conceptual advance that gives microrobots legs

Allan M. Brooks & Michael S. Strano

Tiny devices have been developed that can act as the legs of laser-controlled microrobots. The compatibility of these devices with microelectronics systems suggests a path to the mass manufacture of autonomous microrobots. **See p.557**

In 1959, Nobel laureate and nanotechnology visionary Richard Feynman suggested that it would be interesting to "swallow the surgeon" – that is, to make a tiny robot that could travel through blood vessels to carry out surgery where needed. This iconic imagining of the future underscored modern hopes for the field of micrometre-scale robotics: to deploy autonomous devices in environments that their macroscopic counterparts cannot reach. However, the construction of such robots presents several challenges, including the obvious difficulty of how to assemble a microscopic locomotive device. On page 557, Miskin *et al.*[1] report electrochemically driven devices that propel laser-controlled microrobots through a liquid, and which could be easily integrated with microelectronics components to construct fully autonomous microrobots.

Designing propulsion strategies for microrobots that move through liquid environments is challenging because strong drag forces prevent microscale objects from maintaining momentum[2]. To overcome this challenge, Miskin and co-workers designed tiny actuators – devices that convert energy into motion – that fold and unfold when minuscule amounts of electric current are applied (Fig. 1). The current causes ions from a surrounding solution to adsorb to the actuator's surface, modifying the stress in the leg and thereby causing it to bend. The authors construct these actuators using the same nanofabrication techniques as those used to make computer chips.

But Miskin and co-workers went beyond designing and testing individual micro-actuators – they have also developed a prototype microrobot that uses four of these actuators as legs on which to move slowly over bumpy surfaces submerged in water. The legs are wired to several photovoltaic patches (solar cells) on the robot's central chassis. When an operator shines a laser on these patches, the actuators bend and unbend. The operator can alternate between bending the front and back legs by shining the laser on different patches, thus propelling the robot.

Researchers have been developing onboard propulsion mechanisms for microparticles submerged in liquid for more than a decade. By adding functional patches and other features to such particles, machines that are smaller and faster than Miskin and colleagues' robots have been developed[3,4]. So what makes this new work so special? One key improvement is the efficiency of the propulsion mechanism. The other advance is that the authors' actuators have great potential to be integrated with microelectronic circuits. This is important, because future applications will require microrobots not only to swim on demand, but also to follow more-advanced instructions using inputs from onboard sensors and logic circuits.

An interesting aspect of Miskin and colleagues' work is that they have used a fresh design concept for their microrobots. Rather than adding a propulsion mechanism to a static particle, they have miniaturized an archetypal robot: a walking machine that has mechanical legs controlled by electronics. Because the actuators are constructed using the same techniques as those used to make circuit boards, the 'brains' (logic circuits) and the legs of future robots could, in principle, be printed simultaneously. And because the actuators can be operated by the low-power

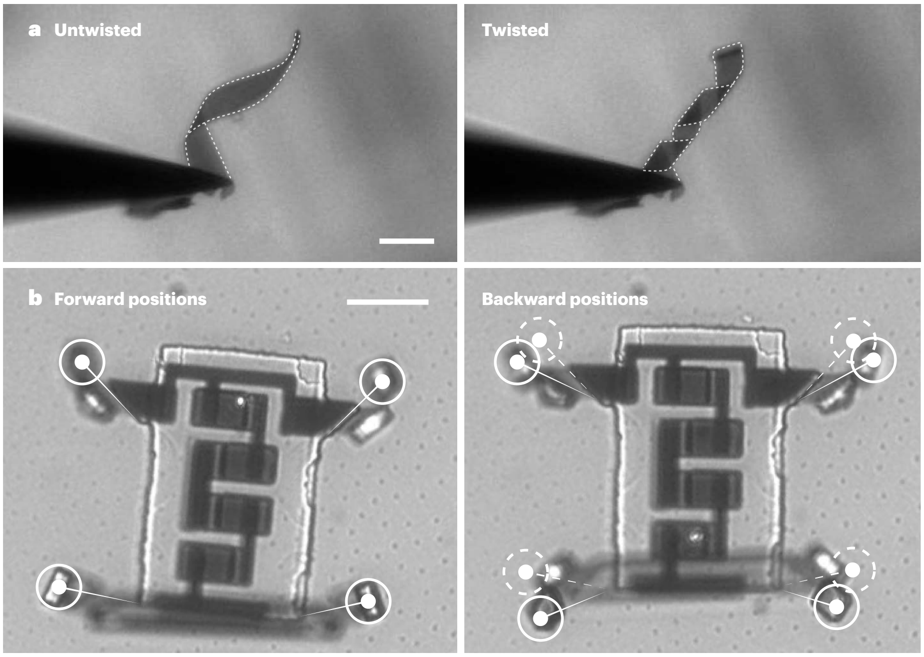

Figure 1 | Walking microrobots. a, Miskin *et al.*[1] report actuator devices that reversibly twist in response to ultralow electric currents. Dashed lines have been added to aid visualization. Scale bar, 20 micrometres. **b**, The authors use the actuators as the 'legs' of microrobots. The legs adopt forward positions when twisted, and backward positions when less twisted. By activating forward and backward positions sequentially using laser beams, the robots walk across bumpy surfaces submerged in water. Current leg positions are highlighted with solid lines and circles; the forward positions are also indicated on the right using broken lines and circles, for reference. Scale bar, 20 µm. (Images from ref. 1.)