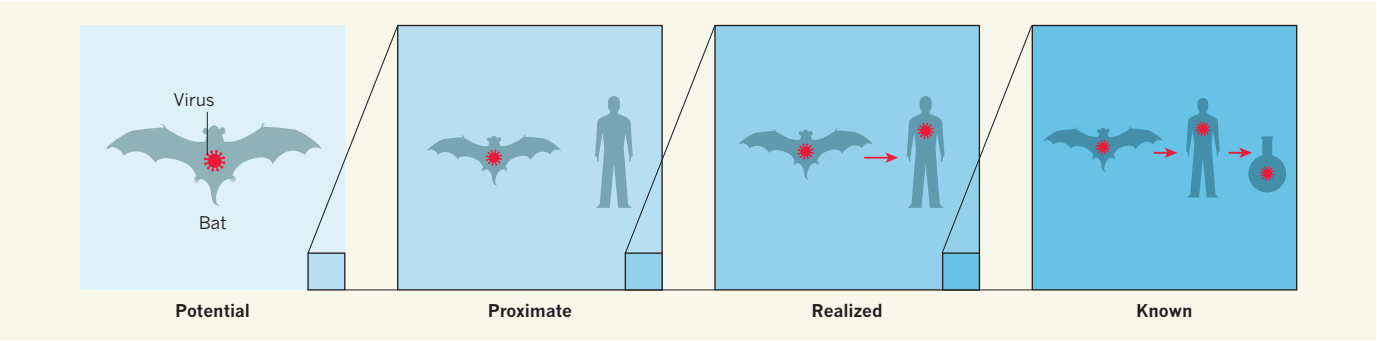

Figure 1 | Grouping viruses that have zoonotic potential. Zoonotic viruses are those that can be transmitted from animals to humans. They can be divided into nested groups on the basis of their success in infecting humans, and our success in detecting them. Potential zoonotic viruses are all animal-borne viruses that are biologically able to infect humans. A subset of these, proximate zoonotic viruses, have the ecological opportunity to infect humans (for instance, because they are carried by animals in close proximity to humans). A further subset, realized zoonotic viruses, actually have infected humans. A final subset, known zoonotic viruses, have been detected in humans and reported in the scientific literature. Olival *et al.*[1] have conducted a comprehensive analysis of virus sharing between humans and other mammals, detecting patterns in known zoonotic viruses and predicting patterns in the wider groups.

models. But none of the key outcomes can be predicted with better than 30% accuracy. We are therefore far from a predictive era in zoonotic disease epidemiology. As the authors state, their predictions are best used to prioritize research and viral-surveillance efforts, not to drive specific policy decisions.

Second, zoonotic. Imagine dividing viruses into nested groups on the basis of their potential — realized or not, and observed or not — to infect humans (Fig. 1). When we say zoonotic, which group do we mean? The authors' analysis of zoonotic potential addresses viruses that may never have encountered humans. Their missing zoonoses include viruses that have infected humans, or may imminently do so, but are not yet recognized. Meanwhile, existing data on zoonotic viruses cover only those known to have infected humans. How well can we project patterns from known zoonoses onto broader groups, given that host and viral traits can differ systematically between them? For instance, viruses that cause more-severe disease are more likely than others to be known, all else being equal. Olival and colleagues' predictions are, necessarily, based on current knowledge. They provide a benchmark against which future data can be compared to chart possible biases arising from projecting trends across these (perhaps dissimilar) groups.

Finally, spillover. The paper addresses whether a given virus is zoonotic and so can spill over from animals to humans, but this is quite different from the quantitative risk of spillover. For example, Olival and colleagues' analysis would not distinguish between Lassa virus (which spills over tens of thousands of times annually[6]) and Lujo virus (which has only ever spilt over once, to our knowledge[6]). Systematic study of quantitative spillover risks will require approaches that integrate the relevant mechanisms, which occur at scales of molecules to landscapes[7].

Looking forward, Olival *et al.* call for investment in viral surveillance, which would expand our knowledge of potential zoonoses — particularly if it involves epidemiological metadata and rigorous data-sharing. But although most pandemics are zoonoses, most zoonoses do not cause pandemics, so it is essential not to invest in broad, shallow surveys at the expense of understanding what determines pandemic potential. The crucial factor for a pandemic is human-to-human transmission, which is governed by viral traits[8] and population susceptibility[9] and mobility[10]. Gaining insights into transmissibility will require in-depth field and laboratory studies, combined with the development of quantitative methods to integrate the diverse data streams involved. In this endeavour, data-driven mechanistic models might end up being the new animal entrails. ■

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MATERIALS SCIENCE

A light-fuelled wave machine

A polymer that incorporates liquid-crystal components generates continuous mechanical waves when lit by ultraviolet light, with potential applications for energy harvesting and self-cleaning surfaces. **SEE LETTER P.632**

YANLEI YU

Polymers formed from liquid-crystal molecules are known as liquid-crystal networks (LCNs). They exhibit remarkable properties that allow them to undergo controllable and reversible shape changes in response to external stimuli. When combined with light-sensitive molecules, LCNs can directly convert light energy into 3D motions such as bending, twisting, rotating and oscillating, making them a promising type of material for building actuators (devices that move or control a mechanism or system)[1]. On page 632, Gelebart *et al.*[2] report the first strategy for using an LCN to generate

continuous mechanical waves driven by a fixed light source.

Azobenzene groups are the most frequently used molecular motifs in photodeformable LCNs. These groups have two configurations: a rod-like '*trans*' form and a bent '*cis*' form. When the *trans* azobenzene absorbs ultraviolet light, it isomerizes into the *cis* form. This reduces molecular order in the LCN, alters conformations of polymer chains and ultimately causes macroscopic deformation[3–5]. Subsequent heating or irradiation of the LCN with visible light causes the reverse isomerization, undoing the deformation.

In the past few years, remarkable progress has been made in the fabrication of azobenzene-containing LCNs and soft actuators. For example, films consisting of a bilayer of an LCN and polythene have been used to make plastic motors to drive rotation[6], 'inchworms' that creep along a surface[7] and robots that manipulate objects[8], all driven by light energy, without the aid of batteries, electric wires, gears or contact-based driving systems. Spring-like, photodeformable ribbons[9] have also been made by adding small quantities of 'dopant' molecules to LCNs. The ribbons undergo complex motion under UV irradiation, including winding, unwinding and helix inversion, all of which depend on the orientation of the LCN molecules.

Dynamic surface corrugations with micrometre-scale heights have been generated in LCN coatings under light irradiation[10,11]. The corrugations form when light-induced azobenzene isomerization generates molecular voids that lower the overall density of the LCN. Laser-driven oscillations at frequencies of up to 270 hertz have also been generated using cantilevers made from an LCN film; the oscillations were induced by the *trans–cis–trans* reorientation of azobenzene groups[12]. And artery-inspired microactuators have been assembled from linear liquid-crystal polymers[13]. The light-induced deformation of these microtubes generates a localized cone-like geometry, producing an adjustable capillary force that propels liquids towards the narrow ends of the cones — a new approach to manipulating liquids using light.

Gelebart *et al.* add another form of dynamic motion to the roster of LCN deformations. The authors realized that azobenzene derivatives that undergo fast thermal relaxation (*cis*-to-*trans* isomerization without light irradiation) provide an opportunity to develop continuous light-fuelled wave motion in LCN films. Two strategies can be used to enhance the thermal relaxation of azobenzenes[14]: attaching a group that both pushes and pulls electrons on and off the azobenzene; or forming a tautomerizable azohydrazone, a compound that readily isomerizes to form an azobenzene. High temperatures also accelerate the *cis*-to-*trans* isomerization of azobenzenes[15].

"The authors realized a light-fuelled, self-propelled walking device."

The authors incorporated azobenzenes that undergo fast thermal relaxation into LCN films and controlled the orientation of the rod-like liquid-crystal molecules so that they were homeotropic (perpendicular to the surface) at one face, but planar (parallel to the surface) at the other. They observed that constant UV irradiation drove continuous millimetre-scale movement of the films. The motion is the result of both UV-induced *trans*-to-*cis* isomerization and of the reverse *cis*-to-*trans* process owing to fast thermal relaxation. The back process is also accelerated because the polymer's temperature increases as it absorbs UV irradiation.

In addition to the isomerization processes, the films underwent heat-induced deformation when they reached a temperature greater than the phase-transition temperature of the LCN films (the temperature at which liquid-crystal materials pass from an ordered state to a disordered state). When Gelebart *et al.* attached both ends of their LCN films to a substrate and exposed the films to UV irradiation, they observed that the combination of isomerization and thermal effects generated travelling waves in the films. Furthermore, the direction of the waves could be controlled by the orientation of the planar and homeotropic sides of the film with respect to the UV irradiation, because each side responds differently to the irradiation (Fig. 1).

The wave propagation and regeneration are caused by self-shadowing of the film — continuous displacement of the wave changes the position of the areas exposed to and hidden from the UV irradiation, and these variations generate feedback that drives the waves. The area exposed to UV light, in turn, depends on the angle of incidence between the light and the film. Gelebart *et al.* found that waves propagate for angles of incidence up to certain critical values. At higher angles, the film becomes fully exposed, cancelling the self-shadowing effect.

The authors went on to demonstrate how the wave propagation could be used to make light-driven devices. First, they showed that sand placed on the side of the film at which the wave originates is continuously transported towards the opposite side; the sand can even be thrown far from the film, if there is a sudden release of energy. The researchers also used the film to carry uphill an object that was much heavier and larger than the film itself. Most notably, they used the waves to realize a light-fuelled, self-propelled walking device.

Before the photodeformable films can be used in the real world, researchers must work out how to integrate the LCN films into complex systems or machines. Effort is also needed to improve the efficiency with which light is converted into work to enable local, precise deformations using low-energy light sources, and to design systems that allow complex motion. The mechanical properties of the LCN films should be improved by combining them with other polymers. And the cost of the films will need to be reduced. Nevertheless, I anticipate (as the authors suggest) that photodeformable LCN films will become candidate materials for use in energy-harvesting devices, self-cleaning mechanisms and miniaturized transport systems for use in poorly accessible places. ■

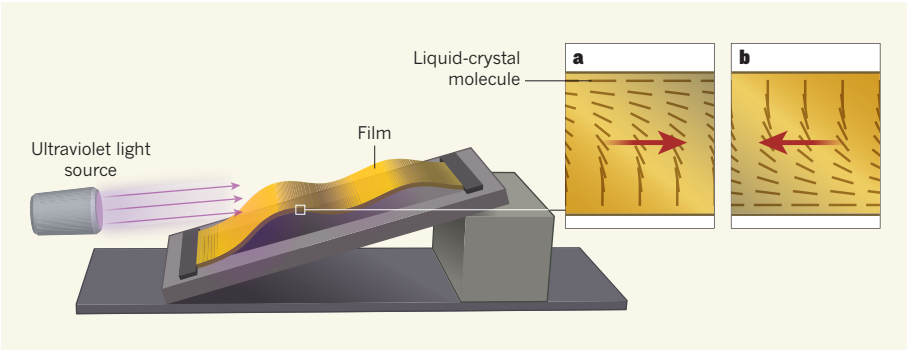

Figure 1 | Continuous waves in a liquid-crystal network. Gelebart *et al.*[2] report films made from a liquid-crystal network (a polymer that incorporates a liquid-crystal motif) that produce continuous mechanical waves when fixed at both ends and illuminated obliquely by ultraviolet light. The rod-like liquid-crystal molecules in the films were homeotropic (perpendicular to the film's surface) at one face of the film, but planar (parallel to the surface) at the other. The direction in which the waves move depends on which way up the film was attached to the surface. **a**, When the planar side of the film is uppermost, the wave propagates away from the light source (red arrow). **b**, When the homeotropic side is uppermost, the wave propagates towards the light source.

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50 Years Ago

Professor Rankama has rightly drawn attention to the prevailing disorder in geochronological time-units and the abbreviations used for them, and his advocacy of "megayear" and "gigayear" is worthy of support. But the current international abbreviation for "year" … is not "yr" but "a" and the appropriate abbreviations for megayear and gigayear are thus Ma and Ga. The admittedly incongruous appearance (for English-speaking readers) of the first may perhaps explain why it has not yet been generally adopted.
From *Nature* 1 July 1967

100 Years Ago

One day recently I went to look at a chaffinch's nest which I had known of for some time. I had just begun to climb up the hawthorn-tree in which the nest was placed when I heard the "pink, pink" of an alarmed chaffinch, and immediately about five cock chaffinches and more than half a dozen hens and young ones appeared from what seemed to me nowhere. These chaffinches flew all round the tree in a most agitated manner, and one cock actually got on top of my head and pulled my hair vigorously, while a hen, which … I think was the mate of my assailant, flew on to the nest and pecked at me every time I tried to touch it. Their attack induced me to get down; and not until I was more than fifty paces from the tree did the other chaffinches go away. Not very long after this I was in the garden when I saw two cuckoos which were flying very low, and I could clearly perceive that one of them was carrying an egg in its beak … I know that there has been much dispute as to whether cuckoos do or do not carry their eggs; but in this instance I can personally testify that a cuckoo was carrying what was obviously an egg.
From *Nature* 28 June 1917

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IMMUNOLOGY

Gut sensor halts viral attack

Intestinal infection with rotavirus is a major cause of diarrhoea in infants, and can be fatal. The identification of immune sensor proteins that detect and restrict this viral infection now illuminates the body's defence system. SEE LETTER P.667

PEDRO H. V. SAAVEDRA & MOHAMED LAMKANFI

Intestinal cells can be infected by a type of virus known as a rotavirus, which is one of the leading causes of severe diarrhoea in infants and young children worldwide. Although effective rotavirus vaccines have been available since 2006, routine vaccination has been adopted in only a few developing countries, and it is estimated that the virus causes more than 200,000 childhood deaths annually[1]. There is only limited understanding of how intestinal cells sense rotavirus infection and mount an antiviral response. Now, on page 667, Zhu *et al.*[2] identify host proteins that are key components of this response.

Rotavirus is mainly spread by direct oral ingestion through contact with contaminated objects, or from water or food. Once ingested, the virus tends to infect epithelial cells that line the intestine, and this is where the virus, which contains double-stranded RNA, replicates. Zhu and colleagues investigated the host-defence response to the infection.

A key component of the response is the formation of a multiprotein complex called an inflammasome[3]. This complex contains core proteins, which are present in most inflammasomes, and sensor proteins that respond to specific types of pathogen and are present in only a subset of inflammasome complexes. Inflammasome activation usually promotes protective host defence and repair mechanisms. However, if activated in diseases such as chronic inflammatory disorders, these complexes can contribute to tissue damage and disease development[4].

Inflammasome complexes mainly serve to recruit and engage the enzyme caspase-1. When activated in response to specific pathogen- or host-derived cues, caspase-1 acts as 'molecular scissors', cleaving proteins containing certain sequences of amino acids that include aspartate. This cleavage activates key immune regulators, including signalling proteins known as cytokines, which convert biologically inert precursor proteins such as pro-interleukin-1β (pro-IL-1β) and pro-IL-18 into the pro-inflammatory proteins IL-1β and IL-18, respectively[3]. Caspase-1 can also cleave the gasdermin D protein, releasing its amino-terminal fragment. This fragment can generate pores in cellular membranes and cause a type of cell death called pyroptosis, which occurs through cellular rupture[5–9].

Zhu and colleagues investigated whether inflammasomes might be involved in host defence against the virus. They observed that, compared with wild-type mice, animals lacking a functional copy of the core inflammasome proteins Asc or caspase-1 were more susceptible to rotavirus infection. By contrast, animals lacking known inflammasome sensor proteins were not more susceptible. This prompted the authors to search for other sensor proteins that might detect rotaviral infection and engage a protective inflammasome response.

The authors focused on the evolutionarily conserved family of nucleotide binding domain and leucine-rich (NLR) proteins, which have diverse roles in immunity[10]. They investigated the protein Nlrp9b, a previously uncharacterized member of this family, because it is expressed mainly in intestinal epithelial cells. The authors used genetic engineering to produce mice that either lacked Nlrp9b throughout their bodies or lacked it only in intestinal epithelial cells. They found