CONSERVATION

Parrot patrol

Understanding the movements of animals can help to focus conservation efforts on key regions of habitat. A standard approach to tracking small animals is to tag them with a tiny radio transmitter and monitor the emitted signals using a hand-held device. But this can prove challenging when following highly mobile animals across difficult terrain.

Writing in *Science Robotics*, Cliff *et al.* report their analysis of the use of autonomous aerial vehicles to track tagged birds (O. M. Cliff *et al. Sci. Robot.* **3**, eaat8409; 2018). They monitored wild swift parrots (*Lathamus discolor*, pictured), an endangered Australian species. The authors report that these drones can estimate birds' positions as rapidly as can humans experienced at using the standard manual-tracking method. **Mary Abraham**

SIMON BENNETT/BIA/MINDEN/GETTY

OPTICAL PHYSICS

Precise control of infrared polarization

A natural material has been discovered that exhibits an extreme optical property known as in-plane hyperbolicity. The finding could lead to infrared optical components that are much smaller than those now available. SEE LETTER P.557

THOMAS G. FOLLAND & JOSHUA D. CALDWELL

Hyperbolic materials are highly reflective to light along a certain axis and reflective to light along a perpendicular axis. Typically, one of these axes is in the plane of the material and the other is out of the plane. A material in which both of these axes are in the plane would enable, for example, the manufacture of ultrathin waveplates — optical components that alter the polarization of incident light. Moreover, the reflective behaviour of this material would allow light to be confined and manipulated at extremely small scales (less than one-hundredth the wavelength of the light). On page 557, Ma *et al.*[1] report the existence of such in-plane hyperbolicity in the natural material molybdenum trioxide.

Many crystals exhibit birefringence, in which their refractive index — a measure of the speed of light in a material — is different along different axes. This property can be used to manipulate the polarization of incident light. The crystal size that is required to achieve sufficient polarization control for practical applications is directly proportional to the wavelength of the incident light and to the strength of the birefringence. Consequently, for light in the mid- to far-infrared regions of the electromagnetic spectrum (with wavelengths of 3–300 micrometres), the crystals typically need to be a few millimetres thick[2]. To overcome this requirement, a potential solution is to consider materials that exhibit hyperbolicity, which is an extreme form of birefringence.

Hyperbolicity was originally thought to exist only in artificial materials consisting of integrated reflective and transparent domains[3]. But in 2014, it was observed in the natural material hexagonal boron nitride[4,5]. The reflective behaviour of both this material and molybdenum trioxide is derived from crystal-lattice vibrations, known as optical phonons, that oscillate in a highly anisotropic (direction-dependent) way. These phonons have relatively long lifetimes (in excess of a picosecond; 1 ps is 10^{-12} s), which strongly suppresses the absorption of light by the material[6]. Since the discovery of hyperbolicity in hexagonal boron nitride, a broad array of natural hyperbolic materials has been identified[7].

Preliminary investigations of molybdenum trioxide were reported earlier this year[8] and showed the existence of hyperbolicity for long-wave infrared light (with wavelengths of 8–14 μm). Ma and colleagues have now demonstrated and characterized in-plane hyperbolicity for the same spectral range. They used this property to confine light to dimensions substantially smaller than its wavelength, through the formation of hybrid light–matter excitations called hyperbolic phonon polaritons. The authors report lifetimes for such polaritons of up to 20 ps, which is about ten times longer than the best values reported for hexagonal boron nitride[9].

Because the crystal structure of molybdenum trioxide is highly anisotropic, all three crystal axes, which define the edges of the crystal's unit cell, have different lengths. Consequently, there is a large difference in the phonon energies associated with these axes and therefore in the corresponding refractive indices — resulting in a birefringence of about 0.31. It should be noted that, earlier this year, a similarly large in-plane birefringence of 0.76 was reported in the natural material barium titanium sulfide for mid-infrared to long-wave infrared light[10]. However, hyperbolicity was not observed for this material.

The in-plane hyperbolicity of molybdenum trioxide offers opportunities to replace conventional optical components with ones that are much smaller. In particular, using the large in-plane birefringence of this material (or of barium titanium sulfide), infrared waveplates could be constructed from thin slabs that have

50 Years Ago

Clearance by Carp
Britain spends about £2.5 million a year on removing water weeds from inland waterways, and in 1964 the British River Authorities spent on average £69 per mile on weed clearance. In an attempt to cut these costs the Ministry of Agriculture, since 1964, has been experimenting with the grass carp, a fish native to China, but widely cultivated … as a means of biological control of water weed. Although the experiments are still at a very early stage, no major snags have occurred so far and the ministry's Salmon and Fresh Water Fisheries Laboratory is still optimistic that the method may work.
From *Nature* 26 October 1968

100 Years Ago

There is a general belief that it is a relatively easy problem to estimate a person's intelligence by looking at him; and teachers, physicians, and employers are often compelled to make judgments as to the intelligence of a given person with no more data than can be obtained from a rapid survey of his appearance … In the *Psychological Review* … Mr. R. Pinter gives the results of an investigation he made for the purpose of testing the trustworthiness of these judgments. The author chose twelve photographs of children varying in intelligence from proved feeble-mindedness to unusually great ability and asked groups of people to arrange the photographs in order of merit for intelligence. His groups consisted of physicians, psychologists, teachers, and miscellaneous people. He found that … on the judgment of no one group or of no one person could any reliance be placed … The author concludes that … these haphazard judgments are too untrustworthy to be of practical value.
From Nature 24 October 1918

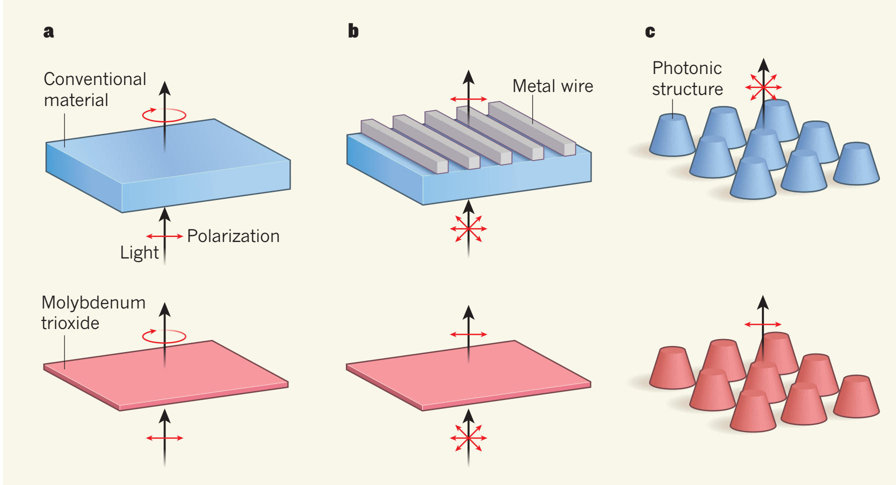

Figure 1 | Manipulating infrared polarization. Ma *et al.*[1] show that the material molybdenum trioxide can be used to precisely control the polarization of infrared light. **a**, Optical components known as waveplates can convert linearly polarized light into circularly polarized light. In the infrared, a waveplate made of a conventional material requires a thickness in excess of 1 millimetre. This material could be replaced with a thin slab of molybdenum trioxide, with a thickness on the order of tens of micrometres. **b**, Components called polarizers can convert unpolarized light (in which the polarization points in all directions) into linearly polarized light. In the infrared, polarizers made from conventional materials typically need to be thick and use a large grid of metal wires. Such a structure could be replaced with a thin film of molybdenum trioxide that requires essentially no fabrication. **c**, Nanoscale photonic structures made from conventional materials can emit unpolarized infrared light. But if molybdenum trioxide were used, linearly polarized emission could be achieved.

thicknesses on the order of tens of micrometres (Fig. 1a). Such waveplates could operate in the long-wave infrared, for which commercial waveplates are not widely available and have thicknesses in excess of 1 mm.

Furthermore, using the material's in-plane hyperbolicity, polarizers — components that extinguish undesired polarizations of incident light — could be made from simple 1-μm-thick films (Fig. 1b). Previously, polarizers needed to be thicker and typically required a large grid of metal wires to be patterned on their surface. The remarkable properties of molybdenum trioxide could therefore greatly reduce both the size and the cost of optical components, offering broad applicability in thin, compact infrared devices.

Beyond conventional optics, the properties of molybdenum trioxide could lead to advances in the realm of nanophotonics, which focuses on confining light to nanoscale dimensions. In the long-wave infrared, where the hyperbolicity of this material is observed, nanoscale light confinement necessarily implies defeating the diffraction limit — the usual restriction that light cannot be squeezed into dimensions much smaller than its wavelength. Molybdenum trioxide can beat this limit and, as a result, presents opportunities for producing improved infrared-emitting devices.

For instance, heating nanoscale photonic structures made from materials that can support polaritons can produce light of one or more specific frequencies — rather than light of a broad range of frequencies that that emitted by, for example, conventional light bulbs. Such structures provide an optical source that is akin to light-emitting diodes, but that can be designed to operate anywhere in the infrared. The emitted light from these photonic structures is usually unpolarized (Fig. 1c). It is only through the use of materials that exhibit in-plane hyperbolicity that light of a single, pure polarization can be generated.

Finally, hyperbolic materials such as molybdenum trioxide could serve as the basis for hyperlenses — lenses that produce magnified images of objects smaller than the wavelength of the imaging light. They could also be used in heterostructures (structures in which layers of different materials are combined) to make nanophotonic components that have controllable properties[11,12].

Ma and colleagues have demonstrated that, once again, nature has more in store for us than we thought. The future of nanophotonics was once considered to be in the realization of artificial materials, but this study and others in the past few years have demonstrated that, in many cases, the best approach for finding advanced materials is to look among the vast array of natural materials. The results of these studies offer substantial advances in the fields of infrared optics and nanophotonics that could enable infrared imaging and detection to become as ubiquitous as its visible counterpart — a vision that would enable imaging through smoke for first responders, near-instant medical diagnostics and enhanced chemical spectroscopy. ■

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SUSTAINABILITY

Transforming the global food system

Can the predicted rise in global food demand by 2050 be met sustainably? A modelling study suggests that a combination of interventions will be needed to tackle the associated environmental challenges. SEE ARTICLE P. 519

GÜNTHER FISCHER

The global population in 2010 was estimated to be 6.9 billion people, and by 2050 is predicted to reach between 8.5 billion and 10 billion people[1]. This increase would bring a corresponding rise in food demand that would affect the environmental toll that food production exerts on the planet. On page 519, Springmann *et al.*[2] report their analysis of the environmental pressures that would arise in a projected scenario for the global food system in 2050. They also modelled the effects of implementing approaches to lessen the environmental consequences of food production.

Food security has long been a challenge for human societies, and is a pressing global issue. Indeed, many targets related to this area are part of the United Nations' Sustainable Development Goals[3], which include eradicating hunger, ending poverty and combating climate change. Achieving a sustainable global food system clearly requires progress on social, economic and environmental fronts.

Springmann and colleagues built a model to assess the projected global demand for agricultural products by 2050 on a country-by-country basis, given the expected changes in population, income levels and dietary preferences by that time. It has been predicted[4] that global income in 2050 will be 3–4 times higher than it was in 2010. The authors' projections of future food consumption were based on established statistical associations between food demands and changes in income or population. These predict that, by 2050, there will be less undernutrition, a shift towards greater global consumption of livestock-based products and a fairly constant intake of staple crops per person.

The authors assessed predicted global environmental impacts for the projected food production by mid-century. They focused on five environmental pressures: the greenhouse-gas emissions associated with agricultural production; the use of land for crop production, given the associated consequences (such as carbon or biodiversity losses) that might accompany land-use changes; the demand for water to irrigate crops; and the application of either nitrogen- or phosphorus-based fertilizers, respectively. It is important to consider fertilizers because of the greenhouse-gas emissions that are linked to their use, and the possibility that they might contaminate soils or aquatic ecosystems.

Springmann *et al.* compared the projected environmental impacts in 2050 to a proposed set of planetary boundaries thought to represent safe operating limits for human activities[5]. For example, the boundary set by the authors for agricultural greenhouse-gas emissions was established in relation to the threshold necessary to keep global warming at a level of 2 °C above pre-industrial levels. However, their limit for emission levels is less stringent than the limit needed to achieve the 1.5 °C target set in the United Nations Framework Convention on Climate Change Paris Agreement of 2015, which was analysed in a recent report[6] by the Intergovernmental Panel on Climate Change. This report details how limiting warming to 1.5 °C rather than to 2 °C above pre-industrial levels would reduce the climate-related risks to health, livelihoods, food security and water supply. On the basis of current food yields and agricultural practices, Springmann and colleagues estimate that, between 2010 and 2050, the environmental impacts of the food system could increase by between 50% and 92% and reach levels that exceed the proposed boundaries[5] for planetary stability.

The researchers went on to assess the effect of possible interventions that could reduce these environmental pressures. These measures relate to managing food demand and raising food-production efficiency in terms of three broad intervention categories.

One intervention category concerns improvements in agricultural technologies and resource management. These could enhance production efficiency and increase crop yields per unit of land, given a particular water and nutrient input. Another category was dietary changes, whereby individuals might limit their meat consumption and move towards plant-based foods. Meat production usually requires a more intensive and environmentally damaging mode of production than that needed for plant-based food[7]. Moreover, limiting meat and sugar consumption and eating fruit and vegetables is aligned with nutrition guidelines for a healthy diet[8]. The third category the authors considered was

BEN NELMES/REUTERS

Figure 1 | Discarded food waste in British Columbia, Canada. This food did not reach consumers.