enter cells, and the hunt was on to identify their receptor.

Given that the elusive receptor had been suggested to be made of protein[5], the authors developed two genetic approaches to search for it. One approach was to compare total gene expression in cells that were either resistant or susceptible to infection by an artificial virus bearing the bat flu haemagglutinin at its surface. This led to the identification of messenger RNAs encoding cell-surface proteins that were differentially expressed in resistant and susceptible cells. The second approach was to use the CRISPR gene-editing technique to mutate genes in susceptible cells to prevent these genes from being expressed, and then identify those whose loss of expression prevented the artificial virus from entering. Both approaches led to the same conclusion: the bat flu virus entered host cells by the binding of viral haemagglutinin to a protein complex known as major histocompatibility complex (MHC) class II.

MHC class II proteins are an important component of the immune system. Each complex is composed of one α-chain and one β-chain. The complex displays 'foreign' molecules, such as those from invading bacteria and viruses, at the surface of specialized immune cells — a process called antigen presentation. The foreign molecules are then recognized by other cells that develop an immune response against the infectious agent.

Notably, Karakus *et al*. observed that MHC class II proteins from humans, mice, pigs and chickens all functioned as receptors for bat virus haemagglutinin when expressed in human cells. This finding shows that receptor differences are unlikely to pose a barrier against infection by bat flu viruses between species (Fig. 1). Moreover, it suggests that farm animals might be a possible route by which the newly identified flu virus could pass from bats, with which people have infrequent contact, into the human population. This route is reminiscent of that taken by avian flu viruses when they give rise to human pandemics.

The ability of the bat flu virus to use MHC class II proteins from such a broad range of species is perhaps at first surprising. However, chicken MHC class II α-chains are similar to one type of mammalian α-chain[6], and such similarities might provide clues to which molecular domains of the receptor are directly involved in its interactions with the virus haemagglutinin.

The identity of this viral receptor raises several questions. Does receptor choice confer an evolutionary advantage? Hijacking MHC class II as a receptor might allow the virus to evade immune surveillance in infected bats. Indeed, MHC class II proteins are the means by which the Epstein–Barr virus infects certain human immune cells, and binding of the virus to the receptor impairs the immune system's ability to respond[7]. Many viruses interfere with the expression of, or destroy, their receptors to stop other virus particles from sticking to cells they have just infected and enable their onward spread. Other flu viruses use another spike protein, called neuraminidase, to remove sialic acid receptors from infected cells. Neuraminidase is present in bat flu viruses, but its function is unclear.

Receptor use often determines which cells and tissues a virus can infect. MHC class II proteins are usually thought of as occurring on immune cells, but Karakus *et al.* show that bat flu viruses infect mice through MHC class II molecules expressed on epithelial cells that line the upper airways. Whether epithelial cells are the target for infection in the natural host is difficult to establish but relevant to address, because infection of particular tissues in bats might affect the likelihood of animal-to-human transmission.

Interestingly, viruses that spread readily between bat species are also more likely to spread to humans[8]. Virus excretion in saliva, urine or faeces might make transmission to humans easier than an airborne route. Of note, the expression levels of MHC class II proteins in the respiratory epithelium are usually low, but they increase under certain circumstances, such as during viral infections[9]. Infection with other viruses could thus affect the susceptibility to flu of people or animals exposed to infected bats.

The likelihood of bat viruses spilling over to other species is also influenced by factors such as the bats' geographical distribution and the exposure of the recipient hosts to the animals[1]. We lack surveillance data to tell us how widely distributed bat flu viruses are, and whether they are carried by bat species with which humans or domestic animals have close contact. Given that receptor use does not seem to be host-restricted[4], and that the enzyme responsible for replicating the bat flu virus seems to function well in human cells[2], the lack of human infections by bat flu so far might be due solely to lack of opportunity. ■

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QUANTUM PHYSICS

Quantum-information scrambling validated

The delocalization of information in interacting quantum systems seems to play a key part in their evolution. A method has been developed that could enable the dynamics of this process to be directly probed in experiments. **SEE LETTER P.61**

JONATHAN HOME

Quantum correlations that spread between parts of a many-body system are intrinsically linked to the system's evolution towards thermal equilibrium, in a process called thermalization. Measuring these correlations is challenging, because of the need to filter relevant information from the huge amount that is present, without the measurement being mimicked or corrupted by the presence of noise. On page 61, Landsman *et al.*[1] demonstrate that quantum teleportation of a single quantum bit (qubit) can provide direct evidence of dynamics that lead to correlations between all the components of a three-body system. This approach could be a powerful tool for characterizing future many-body quantum simulators — controllable quantum systems that can be used to model other quantum systems.

When physical systems interact, information is distributed between them. In general, this process leads to correlations between the systems. In the case of quantum-mechanical interactions, the correlated systems are said to be entangled; the information cannot subsequently be retrieved from any single system, but is shared across the whole composite array. As a result, if we were to look at only a local region (such as a single system), we would conclude that the interactions have caused any initial information to be lost. This effect is connected to the progression

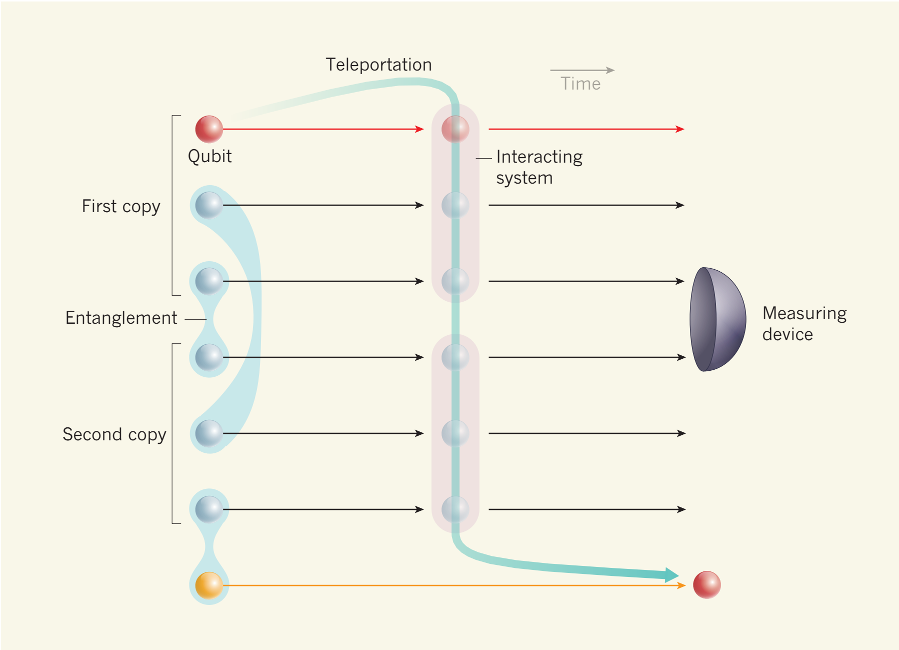

Figure 1 | Verified quantum-information scrambling. Landsman *et al.*[1] report an experiment involving two copies of a system of three quantum bits (qubits). Two qubits in the first copy are entangled (correlated in a non-classical way) with two qubits in the second copy. The remaining qubit in the first copy is called the input (red). The remaining qubit in the second copy is entangled with an external qubit called the target (yellow). The authors allow the qubits in each copy to interact. They then take a measurement of two qubits to check for the existence of a particular entangled state. They also check to see whether the quantum state of the input has been transferred through the two interacting systems to the target by the phenomenon of quantum teleportation. The combination of these checks provides an unambiguous test for whether an effect called quantum-information scrambling has occurred.

of the interacting systems towards thermal equilibrium — a highly disordered state. Delocalization of information in this manner has become known as information scrambling, and its consequences for thermalization make it a useful feature to understand and measure in interacting quantum systems.

An established method for studying scrambling involves looking at measurements, taken at different times, of different parts of a many-body system. When interactions have had enough time to spread correlations between two spatially separated systems, A and B, a measurement of A will influence a subsequent measurement of B. This effect can be tested by comparing whether the sequence of measuring A, allowing the systems to evolve over time, and measuring B produces the same results as the sequence of measuring B, evolving the systems in reverse and measuring A. These measurements are then used to compute mathematical functions called out-of-time-ordered correlation functions[2].

Under ideal conditions, when this method is applied to all pairs of systems, it provides evidence of information scrambling. However, scrambling is indicated by a failure to obtain the same result every time the measurements are repeated. This type of signal is often inconclusive, because it is mimicked by the effects of noise or other imperfections, which cause similar reductions in repeatability. Therefore, it is important to devise techniques that verify that a correct measurement of information scrambling was carried out.

The approach used by Landsman and co-workers accomplishes just such a verification, based on a previous proposal[3]. Rather than using a single copy of an interacting system, the scheme involves implementing similar time evolution on two copies of an interacting system of qubits in parallel (Fig. 1). The copies are initially highly correlated — all but one qubit in the first copy is entangled with an equivalent qubit in the second copy. The remaining qubit in the first copy is called the input, and is encoded with some quantum information. The remaining qubit in the second copy is entangled with an external qubit called the target, which is prepared in its lowest-energy state. This external qubit does not take part in the interactions, but has a crucial role in the verification.

"It is important to devise techniques that verify that a correct measurement of information scrambling was carried out."

After allowing the qubits to interact, the experimenters determine whether information scrambling has occurred. The first step consists of checking whether a specific entangled state exists between two equivalent qubits in the two copies. The probability of the answer 'yes' is equivalent to the result obtained by computing out-of-time-ordered correlation functions. However, in the current approach, the scrambling that is suggested by the presence of the entangled state is verified using a second step. This step involves seeing whether the arbitrary state of the input has been transferred to the target through the two linked systems by quantum teleportation, which happens only if true scrambling occurs. To show this feature, Landsman *et al.* use different quantum circuits to introduce various amounts of scrambling, and neatly illustrate the advantages of the two-step scheme.

The ability of the researchers to carry out these experiments results from the exquisite level of control that they attain over the qubits — in this case, trapped atomic ions. Aside from implementing a new protocol, this work extends such control to a larger system than one for which the same authors had demonstrated it previously[4]. Nevertheless, the delocalization in the current work occurs in systems of three qubits, which are not strictly systems of 'many' bodies, and the method relies on there being a direct correspondence between the dynamics in the two copies. Whether this approach can be extended to larger systems remains an open question. Crucially, however, the main effect of noise or other imperfections might be to take the probability of observing a successful correlation to zero, rather than to produce a false indication of scrambling.

The measurement implemented in this work is chiefly applicable to many-body physics in the laboratory, but, intriguingly, it arose from considerations of information flow in simplified models of purely quantum-mechanical black holes, which rapidly scramble information. In a previous study[5], it was shown that information falling into an aged black hole is almost immediately recoverable from Hawking radiation — light that is released by the black hole. The current experimental protocol mimics this theoretical scenario, with the input quantum state to be teleported playing the part of the infalling information, and the output being viewed as the Hawking radiation. Although we are unlikely to operate a trapped-ion quantum computer in the vicinity of a black hole, the use of these concepts in an experimental technique illustrates the value of pursuing and connecting diverse avenues of research to stimulate the advancement of science. ■

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