concentrated in a limited number of genes.

BHR has several notable advantages over existing approaches to assessing heritability, functional partitioning and genetic correlation. First, it is computationally much more tractable and efficient than are existing methods. Second, it uses only summary statistics, not individual-level genetic data. Summary-based analyses have been transformative in complex-trait genetics[7], in part because they avoid privacy concerns for study participants and so can be shared more easily by researchers.

The method also seems to be largely robust against issues commonly seen in rare-variant genetic analyses, such as population stratification (in which some genetic variants are more common in some groups than in others, and thereby are erroneously found to be associated with a trait) and confounding environmental factors. As such, BHR seems to be a practical and robust method that can produce relatively unbiased estimates of the degree to which rare variation affects complex traits.

Weiner and colleagues' findings also come with caveats. For instance, the authors analysed only individuals of European ancestry, owing to sample-size limitations. Given that rare variants can be ancestry-specific[8], analysis of other ancestry groups is warranted. BHR assesses only protein-coding variants, but mutations in non-coding regions can have functional consequences, too[9]. BHR assumes that each gene acts independently, but interactions between genes carrying rare variants might also affect biological processes[10]. And the role of rare and common variation surely differs between different traits. What factors or evolutionary processes determine the contribution of rare or common variants to different traits, and why?

One more factor that could complicate the interpretation of the results is assortative mating — when individuals mate with others who have similar trait measurements, human height being a classic example[11]. Assortative mating is known to bias estimates of heritability and genetic correlation[12], and its impact on BHR-based estimates has yet to be fully evaluated.

Weiner and colleagues' study indicates that rare variants will contribute relatively little to heritability of disease at the population level. But these rare variants might still be valuable to consider when it comes to developing treatments. In support of this idea, the evolutionarily conserved genes in which rare-variant effects tend to cluster often encode proteins that can be targeted by drugs.

Although exciting, the potential of Weiner and colleagues' findings to translate to the clinic remains speculative for now. But there is no need to speculate over the importance of their work to basic biology — the authors have clarified some fundamental aspects of complex-trait genetics.

Luke M. Evans and **Pamela N. Romero Villela** are at the Institute for Behavioral Genetics, University of Colorado Boulder, Boulder, Colorado 80303, USA. **L.M.E.** is also in the Department of Ecology and Evolutionary Biology, University of Colorado Boulder. and **P.N.R.V.** is also in the Department of Psychology and Neuroscience, University of Colorado Boulder.
e-mails: luke.m.evans@colorado.edu; pamela.romerovillela@colorado.edu

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Quantum physics

Quantum avalanches wipe out the effects of disorder

Lea F. Santos

Experiments on ultracold atoms reveal that disorder doesn't stop a quantum system of interacting particles from reaching thermal equilibrium. Instead, small thermalized regions ripple like an avalanche through the whole system.

When electrons move through a disordered material, they zigzag between imperfections. If there is enough disorder, the electrons can become trapped, inhibiting the material's ability to conduct electricity. This phenomenon is known as Anderson localization, and it was proved to be true for any strength of disorder in a one-dimensional system of wave-like particles, such as electrons[1], as long as they don't interact with one another. The picture changes when they do interact — a case known as many-body localization, which is still a subject of debate. Many-body localization arises only when the strength of the disorder is greater than that of the interactions. Even then, it has been proposed that small regions of weak disorder can accidentally appear and avalanche through the system to destroy the localization[2–7]. Writing in *Nature Physics*, Léonard *et al.*[8] demonstrate that this is indeed the case in a system in which ultracold rubidium atoms mimic particles moving through a disordered solid.

The experiment was performed in an optical lattice, which is a system that resembles a solid crystal. It is engineered by using intersecting laser beams to create a spatially periodic pattern of peaks and valleys in energy — the lattice potential — that traps ultracold atoms or molecules. This approach offers an ideal way of investigating complex phenomena, such as many-body localization, because interactions and disordered potentials can be introduced in a controlled manner.

Interactions are the main cause of complexity in many-body quantum systems. They drive such systems towards thermal equilibrium even if the systems are completely isolated from their surroundings[9,10]. But many-body localization offers a way of avoiding thermalization, because if the motion of the components of a system is restricted, then the system can't thermalize. Adding enough disorder to a system could therefore prevent thermalization by inhibiting the effectiveness of the interactions and ensuring localization. There is broad theoretical support for the idea that this holds in 1D systems, at least when the interactions act over short distances. But this general view is challenged by the results of Léonard and colleagues' experiments.

The disorder in such experiments is introduced by engineering a random potential at each lattice site. But this can result in the accidental appearance of small regions in which neighbouring lattice sites have nearly the same potential. In these regions, the interactions are not inhibited, so thermalization can occur. A thermal region of this kind serves as a 'thermalizing bath' to a neighbouring site, which, in turn, equilibrates with the thermal region and gets incorporated into it. The process is then repeated, and at each step the thermal region becomes larger and therefore more efficient at thermalizing its surroundings. This accelerated mechanism of delocalization is

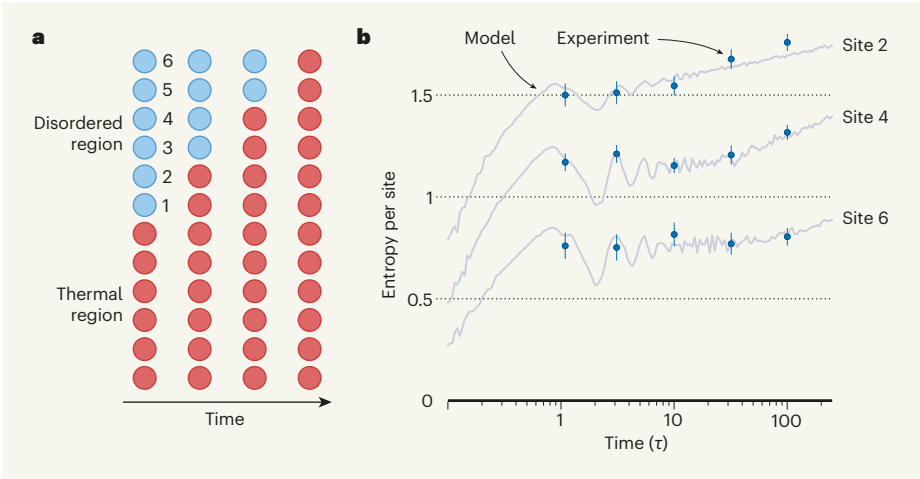

Figure 1 | Increasing entropy signals a 'quantum avalanche'. Interactions drive many-body quantum systems towards thermal equilibrium, but disorder could inhibit this thermalization process. Consensus that this holds in 1D systems with short-range interactions has been challenged by a process called a quantum avalanche, in which a small 'thermal' region can gradually lead to the thermalization of the whole system. **a**, Léonard *et al.*[8] demonstrated this phenomenon in a 1D system of atoms of the isotope rubidium-87, in which the thermal region initially contained six sites. **b**, They found that the entropy per site of the disordered region increased over time, with the sites closest to the interface between thermal and disordered regions increasing first, as shown for sites 2, 4 and 6. Eventually, the whole disordered region became thermalized. Time is measured in units of τ, a characteristic time constant for the system, which is 4.3 milliseconds, and entropy is dimensionless. (Adapted from Fig. 3 of ref. 8.)

referred to as a quantum avalanche.

Léonard and colleagues prepared a 1D system of atoms of the isotope rubidium-87 in a state that had a single atom per site. They then monitored each stage of the ensuing quantum avalanche. The atoms could hop between sites, and when more than one atom was on a site, they experienced repulsive interactions. The authors chose six neighbouring sites to form the disordered 'many-body localized' part of the system and kept either six sites or two sites free from disorder so that they represented the thermal region (Fig. 1a shows the first case). Quasiperiodic disorder in the disordered region was used to prevent nearby sites from accidentally having the same potential.

The authors found that the ensuing dynamics depended on the size of the thermal region. A quantum avalanche occurred when the thermal region contained six sites, but not for systems with a thermal region comprising just two sites. A possible explanation for this difference is that the region with only two disorder-free sites does not develop chaotic features, which are a prerequisite for an effective thermalizing system.

To detect whether one of the atoms moved between any two given sites, the authors measured the correlation between the density of atoms at those sites — a negative correlation indicating motion. For the system with six sites in the thermal region, negative correlations between all sites of the thermal region quickly built up, indicating delocalization, and the region rapidly reached thermal equilibrium. On longer timescales, negative correlations built up across the interface between the thermal and the disordered region, indicating the transport of atoms between the two regions.

The authors' experimental set-up enabled them to image each site in the system, allowing them to measure the probability distribution of the number of atoms at each site. They then used this to compute the entropy per site of the disordered region. For the system with the six-site thermal region, the entropy of the site closest to the interface was the first to increase, followed by that of successive neighbouring sites (Fig. 1b). This process reflects the progressive thermalization of the disordered region. By contrast, there was no increase in entropy for the system with a two-site thermal region.

Léonard and colleagues' results therefore challenge previous assumptions that many-body localization is stable in 1D systems. The findings also improve our understanding of the thermalization mechanism and of how quantum information spreads in many-body quantum systems that have short-range interactions. Future work could consider engineering the disorder in these systems to ensure the stability of the many-body localized phase[11]. A full understanding of this intriguing phenomenon will also require a thorough analysis of the way in which the thermalizing process in the disordered region depends, for example, on the size of the thermal region, the timescales and the initial states.

Lea F. Santos is in the Department of Physics, University of Connecticut, Storrs, Connecticut 06269, USA.
e-mail: lea.santos@uconn.edu

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Climate science

High variability under an Antarctic ice shelf

Craig McConnochie

Fixed moorings and underwater vehicles have uncovered varied patterns of melting and morphology under a West Antarctic glacier, offering insight into the potential for its collapse and highlighting key challenges for modelling. **See p.471 & p.479**

Ice loss from the West Antarctic Ice Sheet is one of the largest contributors to global sea-level rise. Indeed, the Thwaites Glacier in West Antarctica alone is responsible for around 4% of the total annual increase[1] — a contribution that has earned it the name the Doomsday Glacier because of its potential to cause rapid sea-level rise over the coming century. In two papers, Davis *et al.*[2] (page 479) and Schmidt *et al.*[3] (page 471) report observations of the melt rate, ocean conditions and ice shape deep beneath the Thwaites Glacier ice shelf — suggesting that complex interactions between the ice and the ocean will have a key role in the glacier's future.