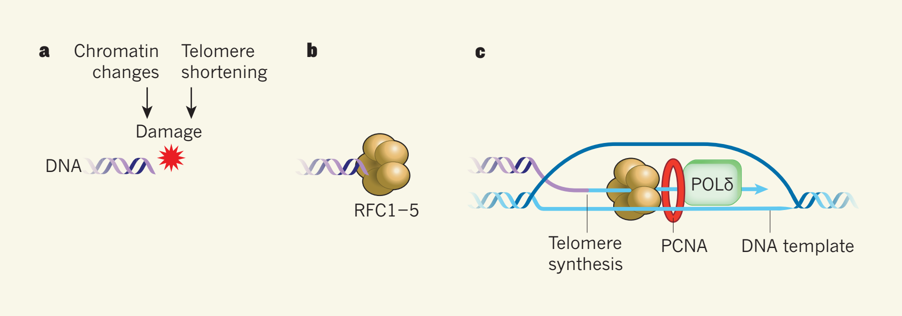

Figure 1 | Break-induced telomere synthesis. Some cancer cells maintain the telomeric DNA sequences that cap the ends of their chromosomes through a mechanism dubbed alternative lengthening of telomeres (ALT). Dilley *et al.*[1] outline a process called break-induced telomere synthesis, which underlies ALT. **a**, Double-stranded DNA breaks can arise in telomeres for several reasons, including telomeric shortening during cell division or changes to the way in which telomeric DNA is packaged as chromatin. **b**, In ALT cells, the protein complex RFC1–5 rapidly binds to double-strand breaks in telomeres. **c**, RCF1–5 recruits the protein PCNA and the DNA polymerase enzyme POLδ to the break. This protein complex synthesizes long tracts of DNA using a complementary strand of DNA as a template from which to replicate the telomere.

cause large fluctuations in telomere length, as is seen in ALT cells[8].

The characteristics and kinetics of this DNA synthesis match those of a phenomenon called break-induced replication, which is a telomere-maintenance mechanism in yeast strains that lack telomerase[9]. Break-induced replication is a form of homologous recombination that initiates DNA replication when only one end of a double-strand break shares sequence similarity with a template. Dilley *et al.* term this process in mammalian ALT cells break-induced telomere synthesis.

The authors next set out to characterize the proteins responsible for break-induced telomere synthesis. The protein Rad51 has a key role in homologous recombination, and is required for break-induced replication in yeast[9]. But, surprisingly, Dilley and colleagues found that Rad51 was dispensable for break-induced telomere synthesis in ALT cells. Rather, a complex that consists of the polymerase POLδ and the proteins PCNA and RFC1-5 is found at sites of DNA damage in ALT cells and is required for break-induced telomere synthesis (Fig. 1). The authors theorize that this atypical complex is responsible for the dominant pathway of telomere synthesis in ALT cells.

Although Dilley *et al.* shed light on the mechanisms underlying ALT in cancer cells, their findings also open up new questions. For instance, the authors demonstrated that they could trigger break-induced telomere synthesis in both ALT and telomerase-producing cells, so why is this method of telomere replication not operative in most cancer cells? It is unclear what induces the ALT mechanism and how that mechanism is specifically sustained in the 10–15% of cancer cell types that use ALT. The authors provide one possible explanation — that ALT cells have higher rates of persistent telomere damage than other cancer cells.

Alternatively, it might be that there is a change in the way in which telomeric DNA is packaged around histone proteins to form chromatin. Disruption of histone function has been shown[10] to induce ALT-like characteristics in cells, suggesting a mechanistic link between altered telomere histones and the ALT mechanism. Moreover, mutations in a chromatin-remodelling protein complex, ATRX–DAXX, are highly recurrent in human ALT tumours[11–14]. The current work does not address how mutations in the ATRX–DAXX complex lead to ALT, but this will be an interesting avenue for further investigation.

Dilley and colleagues' link between break-induced telomere synthesis and ALT provides insights that might help us to further understand how ALT is initiated and maintained in human cancer cells. In the future, a more in-depth understanding of these processes might lead to the development of therapies targeting human cancers that depend on ALT. ■

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FLUID DYNAMICS

Turbulence in a quantum gas

The discovery of a cascade of sound waves across many wavelengths in an ultracold atomic gas advances our understanding of turbulence in fluids governed by quantum mechanics. See Letter p.72

BRIAN P. ANDERSON

Microscopic droplets of ultracold atomic gases known as Bose–Einstein condensates might seem among the least-useful substances for studies of turbulence. These droplets typically contain about a billion times fewer atoms than are found in a single human cell, and exist at temperatures of a few billionths of a degree above absolute zero[1]. At these temperatures, the motion of the atoms is incredibly slow. Can turbulence really be induced, sustained and probed in these ultracold atomic gases? Indeed they can, and such turbulence studies are gaining traction, linking atomic and quantum physics with classical fluid dynamics[2]. On page 72, Navon *et al.*[3] report observations of a Bose–Einstein condensate as it is driven into a turbulent state and find evidence for a cascade of wave-like excitations, opening up new possibilities for exploring the universality of turbulence.

Chief among the features that are shared by turbulent fluids is a characteristic distribution of kinetic energy between the components of the fluid that have different momenta. To picture such a distribution, imagine slowly adding cream to coffee and stirring so that the cream is quickly mixed in. The stirring drives energy into low-momentum (long-wavelength) flows, which might be temporarily visible as the cream traces large eddies in the coffee. The liquids are soon mixed and these flows are no longer easily identifiable.

With continued stirring, more energy is injected into low-momentum flows, and the energy initially in these flows is transferred to higher-momentum flows because of the nonlinear dynamics of the fluid. Eventually, energy from high-momentum flows is dissipated as heat because of the viscosity of the coffee. By continuously stirring the coffee, a cascade of excitations can be achieved: energy is injected into the system, transferred through the different momentum components, and finally dissipated (Fig. 1).

Identifying cascades of excitations is a central goal of turbulence studies. These cascades correspond to a power-law dependence of a dynamic quantity such as energy on the wavenumber, a quantity that is proportional to the magnitude of the momentum. Such signatures of turbulence have been experimentally confirmed in countless systems, including superfluid helium[4,5] (liquid helium held at temperatures so low that it has zero viscosity). Navon and colleagues are the first to identify turbulent cascades of wave-like excitations in an ultracold atomic gas.

The authors' experiment uses a Bose–Einstein condensate (BEC) that consists of about 10^5 rubidium atoms. The atoms are trapped in a 3D cylindrical 'box' about 30 micrometres long, with walls formed by laser light. This trap gives the BEC a uniform density, which ensures that the characteristics of the turbulent cascade are the same throughout the condensate.

Navon *et al.* use a time-dependent magnetic field to shake the cloud of atoms, injecting energy into the low-momentum modes of the BEC. Rather than directly measuring the kinetic-energy spectrum, the authors determine the momentum distribution: the fraction of atoms that have a value of the momentum within any given range. They find that, for short shaking times, the majority of the atoms are in low-momentum modes and few atoms are in high-momentum modes.

After further shaking, interactions between the atoms, which lead to nonlinear dynamics of the BEC, push the atomic population into higher-momentum modes. Continued shaking then replenishes the source of low-momentum excitations, and any atoms that populate high-momentum modes are lost from the trap. Finally, after a total shaking time of about 2 seconds, the authors find that a steady cascade of excitations has been established. This is revealed by the power-law dependence of the momentum distribution on the wavenumber, and represents the primary result of the authors' study.

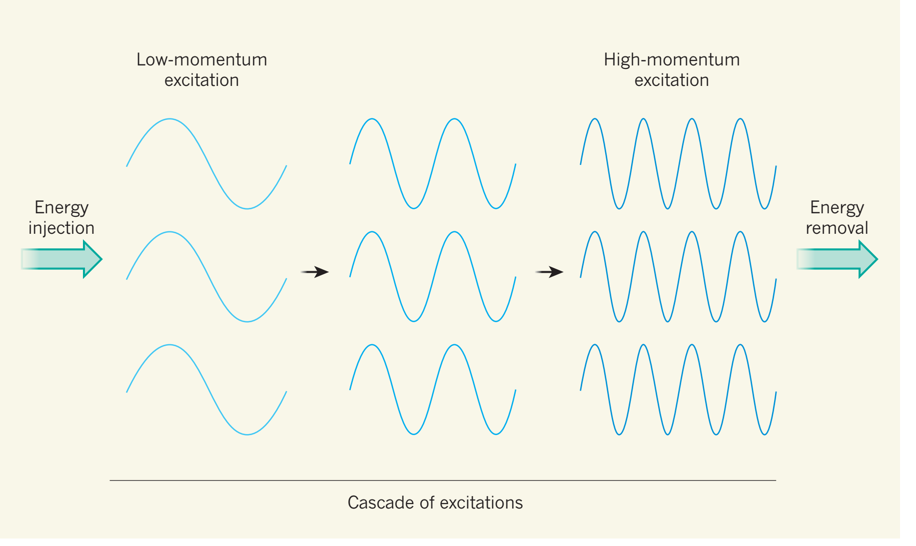

Figure 1 | A turbulent cascade. Navon *et al.*[3] find evidence for a cascade of wave-like excitations in an ultracold atomic gas. This simple schematic illustrates how energy in low-momentum (long-wavelength) excitations cascades to high-momentum (short-wavelength) excitations. First, energy is injected into the system, manifesting as excitations of the low-momentum sound modes of the fluid. Because of the fluid's nonlinear dynamics, energy is transferred to successively higher-momentum modes. Eventually, energy is dissipated as heat from high-momentum excitations (in a typical classical fluid), or high-momentum atoms are lost from the system (in the authors' experiment). Navon and colleagues show that excitations covering a wide range of momenta are present simultaneously in their system — a characteristic feature of turbulence.

Navon and collaborators' measuring technique involves first suddenly removing the box that confines the atoms, then allowing the atom cloud to expand freely and, finally, acquiring a 2D image of the cloud. For turbulent fluids, the atoms have enough kinetic energy that the interactions between them are comparatively weak. The images of the cloud therefore provide scaled representations of the momentum distributions that existed before the box was removed.

The authors have expertly tackled one aspect of measuring turbulence in ultracold atomic gases, yet many problems remain to be solved before turbulence in these systems can be fully understood. For instance, few theoretical studies have considered analytically the power-law dependence of the momentum distribution for a turbulent atomic fluid. The authors obtain a momentum distribution that is proportional to the wavenumber raised to the power of −3.5. This is close to the predicted value of −3 for weakly interacting waves in a turbulent compressible superfluid[6]. But the underlying physical mechanisms that give rise to the difference between these values are not understood.

It will also be helpful to extend the cascade over a range of wavenumbers that is larger than that achieved in this experiment: this would allow more flexibility in probing and understanding the nonlinear dynamics of turbulent cascades. Finally, the presence of vortices (localized regions of circulating fluid about a fluid-free core) in this experiment was inferred only through simulations. In general, the amount of energy involved in vortex excitations compared with sound excitations can greatly affect momentum or energy distributions[7]. Future measurements of vortex dynamics should help researchers to develop a better understanding of turbulence in quantum atomic fluids.

Navon and colleagues' experiment is a crucial step in the further establishment of trapped ultracold atomic gases as systems for studying turbulence. Of broader importance is the contribution of their work to the growing set of techniques for experimentally and theoretically probing turbulence in fluids whose dynamics are governed by quantum mechanics. With substantial theoretical challenges to overcome, the discovery of previously unknown links between turbulence and quantum mechanics is one of the most exciting prospective outcomes of these studies. ■

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