News & views

L: MATEUS MORBECK/AFP/GETTY; R: EYE OF SCIENCE/SPL

Figure 1 | The universal dynamics of interface growth. The Kardar–Parisi–Zhang (KPZ) equation describes the dynamics of interfaces in a range of diverse systems, from wildfire fronts to bacterial-colony expansion. Fontaine *et al.*[2] established experimentally that the properties of excitations known as exciton–polaritons can be described by the same equation, offering a means of probing the physics of KPZ systems using an experimental platform that can be precisely controlled.

Statistical physics

A new phase for universal growth of interfaces

Sebastian Diehl

Precise optical experiments reveal that quantum excitations in semiconductors share similarities with a host of growing interfaces. The parallels inspire a fresh approach to studying the dynamics of diverse systems in a controllable way. **See p.687**

What links the spread of a forest fire and the condensed state of quasiparticles called exciton–polaritons — tiny hybrid objects made of light and matter that are found in semiconductors[1]? Fontaine *et al.*[2] answer this question on page 687 with experiments showing that a property of the wave-like nature of the quasiparticles in the condensate behaves just like an interface: it is governed by a mathematical expression, known as the Kardar–Parisi–Zhang (KPZ) equation[3], that describes interfaces ranging from wildfire fronts to the growth of a bacterial colony (Fig. 1). The results suggest that a versatile quantum-optical platform could be used to explore this far-reaching model of non-equilibrium statistical mechanics in a controlled way.

Exciton–polaritons (or simply polaritons) arise in semiconductor structures when light is confined by high-quality mirrors, allowing the trapped photons to become coupled to electronic excitations in the material. The resulting quasiparticles are bosons — the term for particles that can occupy the same quantum state — and if enough of these quasiparticles are in the same state, their microscopic quantum behaviour starts to become apparent on a macroscopic scale, in a phenomenon known as Bose–Einstein condensation[4].

Polariton condensates have a close cousin in ensembles of atoms, but only when the atoms have been cooled to temperatures in the range of 100 nanokelvin — whereas polaritons condense in the cryogenic regime of a few kelvin. Aside from this 10-million-fold quantitative difference in temperature, there is a subtler qualitative distinction between these two condensation scenarios: ultracold atoms are in thermodynamic equilibrium, whereas polaritons are out-of-equilibrium systems. This means that creating a system of polaritons that is dense enough to form a condensate requires an experiment that balances fluxes in and out of the system. Any light lost through the system of mirrors must be replenished by injecting quasiparticles into the system, through a suitable pumping scheme.

So condensation can take place in both systems, and relies only on the atoms or quasiparticles behaving like bosons. But does this mean that these systems will display identical phenomena? In other words, does the fact that the polaritons are out of equilibrium on a microscopic scale mean that their behaviour will differ from that of the ultracold atoms on a macroscopic scale, where experimental observations are made? The answer is yes, and this is where the KPZ equation kicks in: the long-distance properties of polariton condensates are governed by a measure of the wave-like nature of the quasiparticles called phase. And the stochastic dynamics of this phase map to the KPZ equation[5,6].

Originally, the KPZ equation was derived to describe the dynamics of driven interfaces, such as the edge of an expanding bacterial colony[6–8]. Such systems are markedly different from interfaces that are not driven, and the two

types of system fall into different universality classes. This is the term used in statistical physics to describe groups of systems that share the same macroscopic properties despite having differences in their microscopic details. The KPZ equation captures the non-equilibrium nature of a driven system in a single nonlinear term. By contrast, in an undriven system at equilibrium, this term becomes zero – in effect, putting the two types of system into different universality classes.

The idea that polariton condensates belong to the KPZ universality class was proposed some time ago[5,6], but experimental evidence for this has proved elusive – until now. Fontaine *et al.* constructed a one-dimensional lattice made of etched micropillars in a semiconductor material that they set up in a system of mirrors. By using an interferometric device that detects photons, they mapped out the way in which the behaviour of single polaritons was correlated in space and time. A careful study of these correlations revealed behaviour characteristic of the KPZ universality class.

The authors also compared their experimental data with extensive numerical simulations using a model for both the pumping reservoir and the polaritons, with parameters determined through their experiments. The model produces another feature characteristic of the KPZ universality class: fluctuations in the phase are governed by a probability function known as the Tracy–Widom distribution. This behaviour suggests that the system would remain in the KPZ universality class even if topological defects in the phase of the polaritons were introduced, at least in the range of parameters studied by Fontaine and colleagues. However, it remains a challenge for the future to explore this feature experimentally.

As with many scientific advances, the authors' achievement was made possible by an ingenious approach to a technical problem that had prevented previous observation of KPZ physics in a polariton condensate. The difficulty arises from a phenomenon called condensate fragmentation, in which correlations in the phase of the polaritons break down at separations well below the system size, severely limiting the distances over which KPZ behaviour can be observed. This effect is a result of attractive interactions between the polaritons, so one way around it involves engineering a system in which these interactions are repulsive. Instead, Fontaine *et al.* overcame the problem by forcing their condensates into regimes in which their mass was effectively negative. In combination with negative interaction energies, this amounts to a system with positive mass and stable repulsive interactions that evolves backwards in time.

Fontaine and colleagues' experimental developments open up opportunities for exploring non-equilibrium phenomena with polaritons. Two immediate directions for study are intimately connected to the new role for the key variable in the KPZ equation – phase in place of interface. A first major challenge is the observation of KPZ physics in two spatial dimensions, which has not yet been achieved experimentally, owing to the absence of 2D interfaces in nature[9]. Recasting the interface in terms of the polariton phase elegantly circumvents this obstacle, but reaching the relevant system size poses a practical challenge.

The fundamental difference between phase and interface sets another intriguing challenge. Phase is a periodic variable that can develop topological defects, such as vortices, and these defects can drive phase transitions, even in systems comprising a single spatial dimension[10]. This possibility sets polariton condensates apart from other systems exhibiting KPZ physics, and awaits experimental exploration. All in all, there are clear grounds for hope that exciton–polariton systems will offer a versatile platform for addressing key challenges in non-equilibrium statistical mechanics through highly controlled experiments.

Sebastian Diehl is at the Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany.
e-mail: diehl@thp.uni-koeln.de

1. Carusotto, I. & Ciuti, C. *Rev. Mod. Phys.* **85**, 299 (2013).
2. Fontaine, Q. *et al. Nature* **608**, 687–691 (2022).
3. Kardar, M., Parisi, G. & Zhang, Y.-C. *Phys. Rev. Lett.* **56**, 889–892 (1986).
4. Kasprzak, J. *et al. Nature* **443**, 409–414 (2006).
5. Altman, E., Sieberer, L. M., Chen, L., Diehl, S. & Toner, J. *Phys. Rev. X* **5**, 011017 (2015).
6. Ji, K., Gladilin, V. N. & Wouters, M. *Phys. Rev. B* **91**, 045301 (2015).
7. Halpin-Healy, T. & Zhang, Y.-C. *Phys. Rep.* **254**, 215–414 (1995).
8. Krug, J. *Adv. Phys.* **46**, 139–282 (1997).
9. Takeuchi, K. A. *Physica A* **504**, 77–105 (2018).
10. He, L., Sieberer, L. M. & Diehl, S. *Phys. Rev. Lett.* **118**, 085301 (2017).

The author declares no competing interests.

In retrospect

35 years of channelling potassium ions

Crina M. Nimigean

In 1987, two independent groups cloned a gene that encoded the potassium-ion-channel protein Shaker, enabling functional and structural studies that have transformed ion-channel research.

Nerve impulses travel through cells as trains of electrical signals called action potentials, which arise from fast changes in voltage when ions move across the neuronal membrane. The membrane-spanning ion-channel proteins that mediate this process have fascinated scientists for more than half a century, since their existence was first proposed. The channels not only select for their preferred ion type – sodium (Na^+), calcium (Ca^{2+}) or potassium (K^+) – but also sense changes in transmembrane voltage and respond by regulating the flow of ions through their pores. In 1987, a group headed by Mark Tanouye[1], and another led by partners Lily and Yuh-Nung Jan[2,3], took a key step towards understanding voltage-gated ion channels, identifying the first gene that encoded a K^+ channel. Their work opened the door to a tsunami of investigations, eventually leading to the determination of high-resolution structures for a wealth of K^+ channels.

To understand a protein's properties, one needs to determine what it looks like and how it functions. Key to this is a knowledge of the protein's amino-acid sequence, which is determined by the gene that encodes it. First, it is necessary to identify the gene and its location in the genome.

In 1977, it was proposed that a gene named *Shaker* encoded a K^+ channel[4]. Flies harbouring mutations in the gene displayed shaking legs under anaesthesia, and the same phenomenon occurred when wild-type flies were treated with K^+-channel blockers. The Tanouye and Jan groups cloned *Shaker* independently, but they used a similar approach, known as chromosome walking. This technique involves cloning overlapping sections of genomic DNA, starting with a piece of DNA that forms a duplex with a region around the *Shaker* locus. The groups then looked for corresponding sequences in messenger RNA libraries from fruit-fly brains, and discovered one sequence that was similar in predicted architecture to that of a previously cloned Na^+ channel[5].