of Xu and colleagues[1] are unlikely to be able to provide the distinction, because they probe the magnetism at elevated energies, where it is conceivable that there is no qualitative difference between the two pictures. Some researchers believe that it would be possible to find a distinction by determining the Fermi volume (the momentum-space volume enclosed by the Fermi surface), which counts the number of effectively mobile carriers in the system, in the absence of superconductivity or magnetism[3,5].

Turning to the question of what this has to do with superconductivity, there is a partial consensus that antiferromagnetic fluctuations are responsible for pairing in copper oxide superconductors. Is the hourglass spectrum crucial to this explanation? Is the hourglass spectrum related to so-called stripes[6,7] — that is, the tendency of electrons to self-organize in rivers of charge that have been observed in some of the copper oxide superconductors? Stripes might in fact be one way (the phase-separation way) to reconcile the coexistence of local moments and charge carriers. However, at present the indications of true stripe order in BSCCO are weak, and more experiments are called for. Proposals linking stripes to the superconducting pairing mechanism have been put forward, but none has been developed into a testable theory of superconductivity.

These questions are central to the intriguing puzzle of superconducting copper oxides. We still have some way to go to solve it, but with key experiments such as the present one and state-of-the-art numerical simulations, both guiding phenomenological work, we are making steady progress. ❒

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DROPLET DYNAMICS

Raindrops large and small

Rain hits the ground in drops of different sizes, but the mechanism that produces this distribution is unclear. Could it be that all we need to know is contained in the death of a single drop?

Alexander B. Kostinski and Raymond A. Shaw

Einstein's son Hans Albert was once asked by his father, "How does rain fall?" "In drops", was the young boy's reply[1]. "That is very important as you will see", his father advised. The discrete nature of rainfall may have inspired Einstein to introduce the idea of wave–particle duality to explain blackbody radiation as a particle noise added to the wave noise. Indeed, just as distribution of photon wavelengths in a blackbody spectrum follows the Planck formula, the size of droplets in rain often follows a size distribution described by the Marshall–Palmer formula[2]. However, although the microscopic origin of thermal radiation is now well known, for over 60 years our understanding of rain has remained largely empirical. On page 697 of this issue[3], Villermaux and Bossa breathe new life into this old topic by drawing a physical link between the observed dependence of the average droplet diameter, d_0, and the rainfall rate, R. They ask not what our appreciation of rain can do for physics but what physics can do for our appreciation of rain.

The most commonly quoted property of rain is its fall rate, R, in millimetres per hour (notably in units of speed rather than volume). So why should we care about raindrop size distribution? There are many reasons. The radar echo from a single raindrop is proportional to the sixth power of its diameter, d, but the rainfall rate at ground level depends on both volume (d^3) and terminal velocity ($u(d) \approx d^{1/2}$ under turbulent conditions), and so scales approximately in proportion to $d^{7/2}$. Consequently, to correctly interpret radar data — the principal means of measuring rain remotely — it is essential to know something about the size of the raindrops from which it was obtained[2].

According to the Marshall–Palmer formula, the number of raindrops of diameter between d and $d + \mathrm{d}d$ is $n(d) = n_0 e^{d/d_0}$, where n_0 is a constant fitting parameter with units of (length)$^{-4}$ (per volume and per size bin). Although Villermaux and Bossa[3] provide a general argument to derive the rainfall–size scaling exponent, it is possible to reach their answer by considering raindrops of a single size. Rainfall rate (in units of speed) is given by the product of raindrop concentration, c, volume (d^3) and terminal speed ($d^{1/2}$). The concentration is found by integrating $n(d)$ over all drop diameters, which for droplets of uniform size yields $c = n_0 d_0$. This leads to $R \approx n_0 d_0^{9/2}$, or $d_0 \approx (R/n_0)^{2/9}$, which is in remarkably close agreement with observations of $d \propto R^{0.21}$ for typical rainfall conditions.

Ironically, such agreement raises more questions than it answers. For instance, in the extreme case of drizzle, in which droplets are much smaller than in typical rainfall, the terminal velocity scales in proportion to d, which gives an average diameter of $d_0 \approx (R/n_0)^{2/10}$, slightly changing the scaling exponent. The $d \propto R^{0.20}$ scaling is also often observed[2]. Perhaps more importantly, it remains unclear what physical mechanisms determine the value of n_0, which has been observed to vary by an order of magnitude at a given rainfall rate[4]. This implies that, at times, the average size and concentration change so as to produce more numerous but smaller droplets and to maintain the same rainfall rate.

Returning to earlier heuristic ideas[2,5] with modern tools and a fresh perspective, Villermaux and Bossa[3] provide a compelling argument to explain the origin of the exponential size distribution of natural rain. They use high-speed photography to capture the break-up of large water drops in free fall, and to show that the entire distribution of sizes seen in rain can be reproduced in the break-up fragments of a single parent drop. This suggests that the size distribution of raindrops is caused by simple fragmentation that occurs immediately beneath the base of a raincloud — in contrast to the more conventional expectation that it arises as a consequence of more complex interactions between descending droplets. This will undoubtedly cause many to wonder to what extent the conditions leading to fragmentation in the authors' experiments are relevant to the real world.

The authors use the Euler equation of inviscid hydrodynamics, along with several plausible assumptions, to estimate the critical Weber number at which a drop becomes unstable. This is related to the question of why we never see very large raindrops, such as the one shown in Fig. 1a. The answer is that beyond a certain size, fluid flow around a falling drop overwhelms the cohesion of surface tension (Fig. 1b). This can be visualized in terms of a capillary length — about 3 mm for the air–water interface. The Weber number compares inertia with surface cohesion: We = $(\rho_a u^2 d)/\sigma$, where ρ_a and σ are the air density and surface tension, respectively. Thus, We can be viewed as a squared ratio of drop size and capillary length. Villermaux and Bossa[3] arrive at a critical Weber number of six (Fig. 1b), which translates to a critical drop diameter of about 6 mm, consistent with their observations and those of others[6].

In this respect, reports of very large raindrops of up to 1 cm in diameter in Brazilian and Hawaiian clouds are interesting and puzzling[7]. Surfactants, such as those produced by forest fires, complicate the situation and have been detected in raindrops[8], but their presence should lower the surface tension and therefore the Weber number. On the other hand, they are likely to promote coalescence of such 'softer' raindrops on the way down.

Terminal speed is an important parameter when applying Villermaux and Bossa's critical Weber numbers to natural rain, particularly because speed increases with drop size. In that respect, the perspective of Villermaux and Bossa is complemented by the recent findings that not all raindrops fall at their terminal speed[9]. Some break the speed limit by an order of magnitude in the immediate aftermath of fragmentation, by ejected smaller droplets that momentarily maintain the momentum of their parent drops. Such 'superterminal' drops were caught on camera before they had a chance to relax to their terminal speed (which takes only a fraction of a second), and thereby corroborate the break-up mechanism. This may allow for further study and testing of the Villermaux and Bossa perspective. In particular, it could address longstanding questions about whether break-up is predominantly spontaneous, as they suggest, or the result of collisions between drops, which is the common view.

Remote sensing has much to contribute here. For example, perhaps drop oscillations between prolate and oblate asphericity (preceding the break-up) are the source of the surprising depolarization of radar or lidar waves that has been observed at vertical incidence[10]. Also, returning to radar meteorology, the d^6 dependence of the radar echo suggests that the Villermaux and Bossa[3] vision of progressive refinement of the size distribution below the cloud base can be tested by studying radar reflectivity versus height with high spatial resolution. Natural rainfall still has something to teach us, so let it rain. ❐

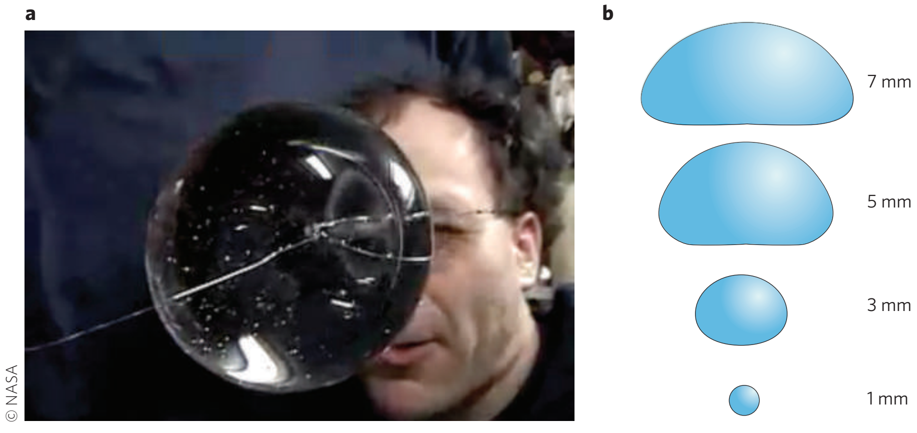

Figure 1 | Raindrops under stress. **a**, Giant raindrops such as the one shown here, held by astronaut Don Pettit on the space shuttle, are not observed in the atmosphere because of the deformation and subsequent instability experienced by a terrestrial raindrop falling through air at its terminal speed, u (reached when the gravitational force is balanced by air resistance). **b**, Deformation of falling drops is determined by competition between surface tension and fluid stresses. As a result, asphericity increases with drop size. The opposition between aerodynamic stress $\rho_a u^2$ and the surface tension σ is captured by the Weber number We = $(\rho_a u^2 d)/\sigma$. The critical We number of six derived by Villermaux and Bossa[3], above which spontaneous drop break-up occurs, can be motivated by equating the spherical-drop surface energy density to inertial energy density as $(\sigma\pi d^2)/(\pi d^3/6) = \rho_a u^2$.

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HEAVY ELECTRONS

The gathering storm of data

The nature of the 'hidden order' in URu_2Si_2 has resisted characterization for the past twenty-five years. Recent photoemission results report the observation of a narrow heavy-fermion band that sharpens below the mysterious transition and provides new clues about its origins.

P. Chandra and P. Coleman

The electronic applications of tomorrow will probably not be direct extensions of what we know today, but will more likely depend on principles of electron organization in matter, which we are only beginning to discover. Physicists are just starting to appreciate the rich fabric of the periodic table and the vast diversity of electronic behaviour that can be shown by different compounds. Although practical applications of emergent phenomena such as superconductivity or magnetism require materials in which these states occur at, or above, room temperature, the unusual electronic correlations and