analytical studies¹ have described the rate at which circular cross-sections collapse, neglecting any small asymmetric perturbations. Using linear stability analysis, Schmidt and co-workers show that, expanded as Fourier series, the individual contributions of such influences oscillate in time and maintain nearly constant amplitudes². Because the average radius of the neck decreases steadily, the relative sizes of these perturbation modes grow. The oscillatory evolution of the different modes makes the cross-sectional shapes vibrate and distort as they collapse. Ultimately, pinch-off will be initiated when a perturbed cross-section comes into self-contact. This will occur slightly earlier than would be predicted by the circular collapse, and, more importantly, the form of the dynamics, which can resemble a tearing in some cases⁸, will bear the distinct imprints

of the properties of the nozzle that shaped the bubble. These fine-scale dynamics are observed to be highly reproducible and suggest that this insight into the underlying physics of bubble pinch-off could be developed into technologies requiring precise control and timing of gas release in connection with the production of sprays or mixing processes.

At a broader level, this work should stimulate more careful examination of the formation of singularities in other physical systems, to determine the degree to which they faithfully display universal behaviour or have more intricate dynamics precisely controlled by earlier stages of development. As is observed by Schmidt and co-workers, discovering the differences between these scenarios sometimes requires revisions of theory and advances in experimental methods. □

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References

1. Eggers, J. & Villermaux, E. *Rep. Prog. Phys.* **71**, 036601 (2008).
2. Schmidt, L. E., Keim, N. C., Zhang, W. W. & Nagel, S. R. *Nature Phys.* **5**, 343–346 (2009).
3. Eggers, J. *Rev. Mod. Phys.* **69**, 865–930 (1997).
4. Shi, X. D., Brenner, M. P. & Nagel, S. R. *Science* **265**, 219–222 (1994).
5. Thoroddsen, S. T., Etoh, T. G. & Takehara, K. *Phys. Fluids* **19**, 042101 (2007).
6. Eggers, J. & Fontelos, M. A. *Nonlinearity* **22**, R1–R44 (2009).
7. Doshi, P. *et al. Science* **302**, 1185–1188 (2003).
8. Keim, N. C., Moller, P., Zhang, W. W. & Nagel, S. R. *Phys. Rev. Lett.* **97**, 144503 (2006).
9. Burton, J. C., Waldrep, R. & Taborek, P. *Phys. Rev. Lett.* **94**, 184502 (2005).
10. Burton, J. C. & Taborek, P. *Phys. Rev. Lett.* **101**, 214502 (2008).

IMAGING

Singularly fast

Despite improvements in the performance of cameras based on CCD (charge-coupled device) arrays, the rate at which they can capture multiple images is typically limited to around a thousand frames per second. This makes them incapable of imaging any process that occurs over a timescale shorter than a millisecond, such as the firing of neurons in living tissues or the propagation of shockwaves through a solid. But, by getting rid of the millions of light-sensing elements of conventional CCD arrays and replacing them with a single, high-sensitivity, high-speed photodetector, Keisuke Goda and colleagues have shown that they can overcome such limitations, to demonstrate a technique that is capable of collecting more than six million image frames per second — with a single-frame shutter speed of just half a nanosecond (*Nature* **458**, 1145–1149; 2009).

Although the two-dimensional array of a conventional CCD camera enables it to capture many millions of individual pixels simultaneously, it also creates a fundamental trade-off between speed and image resolution. This is because to increase the number of pixels in an array, the size of each pixel must necessarily decrease (or otherwise increase the size of the

array, which is often impractical). This decreases the amount of light each pixel collects, which in turn increases the amount of time needed to collect enough light to generate a clean, noise-free image. Moreover, although all the pixels capture this light at the same time, the information from each row of a CCD array is read sequentially, one pixel at a time, slowing still further the rate at which each image can be captured.

Goda and colleagues beat this trade-off by first converting the spatial

information of an image to the frequency domain. They do this by illuminating different parts of an object with laser light of different frequencies, so that each pixel of an image corresponds to a different frequency. This frequency-encoded information is then converted to a signal that is encoded serially in time (in much the same way that images are encoded and projected with a single scanned electron beam across the phosphor screen of a cathode-ray television — but in reverse) and collected using a single photodetector. Capturing an image in time rather than space relaxes the constraint on the size of the photodetector, so that it can be much larger and therefore operate much more quickly than the elements of a conventional CCD array. This also makes it easier to optically amplify the image signal before it reaches the photodetector, shortening the necessary collection time still further.

The researchers demonstrate the potential of their technique by using it to capture a movie of the ablation of a thin film by a high-power laser (pictured), a process that takes place over the course of a microsecond, with a temporal resolution of 163 nanoseconds.

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