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Memory encoding vibrations in a disconnecting air bubble

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The implosion that disconnects a submerged air bubble into several bubbles provides a simple example of energy focusing. The most efficient disconnection is an entirely symmetric one terminating in a finite-time singularity. At the final moment, the potential energy at the start of the disconnection is entirely condensed into the kinetic energy of a vanishingly small amount of liquid rushing inwards to disconnect the bubble. In reality, however, the initial shape always possesses slight imperfections. We show that a memory of the imperfection remains and controls the final fate of the focusing. Linear stability reveals that even an infinitesimal perturbation is remembered. A slight initial asymmetry excites vibrations in the cross-section shape of the bubble neck. The vibrations persist over time. Near the singularity, their amplitudes freeze, locking onto constant values, while their frequencies chirp, increasing more and more rapidly. The net effect is that the singularity remembers exactly half of the information about the initial imperfection, the half encoded by the vibration amplitudes. We check this scenario in an experiment by releasing an air bubble from a nozzle with an oblong cross-section. This excites an elongation-compression vibrational mode. We measure the vibration excited and find quantitative agreement with linear stability. When the initial distortion has a small, but finite, size, the saturation of the vibration amplitude causes the symmetric singularity to be pre-empted by an asymmetric contact between two distant points on the interface. Numerics reveal that the contact is typically smooth, corresponding to two inward-curving portions of the bubble surface colliding at finite speed. Both the contact speed and curvature vary non-monotonically with the initial distortion size, with abrupt jumps at specific values. This is because the vibration causes contact to occur at different values of the phase. A contact produced when the shape distortion is pronounced requires a smaller initial amplitude than a contact produced when the vibration is out of phase. (Joint work with Nathan C. Keim, Lipeng Lai, Laura E. Schmidt, Konstantin Turitsyn and Sidney R. Nagel.)