FIG. 1: Star-shaped oscillation patterns of Leidenfrost drops on a curved, aluminum surface ($T = 350$ °C). Oscillation modes with $n = 2$ to $n = 13$ are shown when the lobes are at their maximum displacement. The scale bar (2 cm) applies to all images. Source: APS-DFD (http://dx.doi.org/10.1103/APS.DFD.2014.GFM.P0034).

The many faces of a Leidenfrost drop

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When deposited on a hot surface well above its boiling point, a liquid drop can survive for minutes by levitating on an insulating cushion of evaporated vapor. This phenomenon, known as the Leidenfrost effect [1], can be easily observed on a hot pan over a cook stove. The vapor layer is maintained by a sustained evaporation of the liquid beneath the drop [2, 3], resulting in near-frictionless motion on the surface. These properties can lead to a variety of interesting dynamics [4, 5], such as self-propulsion on textured surfaces [6] and self-organized "star-shaped" oscillations of liquid puddles [7]. The latter depends on a sensitive coupling between deformations of the liquid/vapor interface and lubrication flow in the thin ($\approx 100\ \mu$m) vapor layer.

We investigated star-shaped oscillation modes of water drops on a hot aluminum surface with mode numbers from

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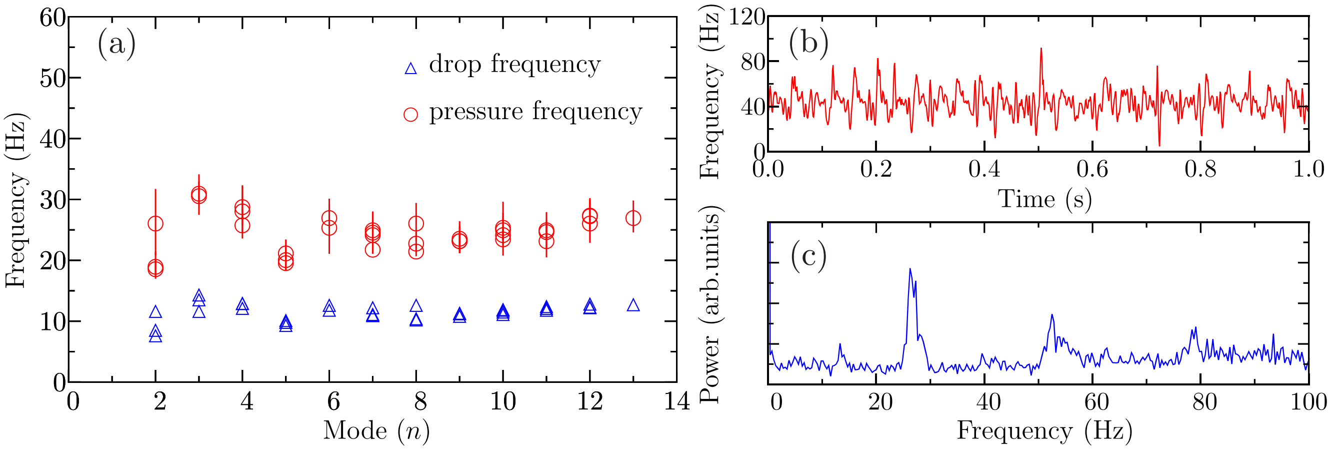

FIG. 2: Pressure variations (a) and corresponding Fast Fourier Transform (b) in the vapor layer beneath a Leidenfrost drop during an $n = 8$ oscillation. The FFT was constructed with 20 s of data. (c) Star-shaped oscillation frequency and peak pressure frequency for different mode numbers. Each data point corresponds to a different drop. The error bar is defined as the half width of the highest peak in the FFT.

$n = 2$ to $n = 13$. We used a high-speed camera (Phantom V7.11) to image the drops from above, as shown in Fig. 1. The aluminum surface was curved in order to keep drops stationary and suppress the buoyancy-driven Rayleigh-Taylor instability in the vapor layer [4, 8]. Surprisingly, we found that all of the oscillation modes in Fig. 1 share the same azimuthal wavelength ($\lambda \approx 1.2$ cm). The frequency of the oscillations is nearly constant ($f \approx 13$ Hz) as can be seen in Fig. 2(a) and is consistent with a quasi-2D dispersion relation [9].

In order to gain insight into the nature of the star-shaped oscillations, we used a pressure sensor (GEMS Sensors) connected to a small, 1 mm hole at the center of the curved aluminum surface to detect pressure variations in the vapor layer directly beneath the drop. Figure 2(b) shows the measured pressure during a 1 s interval of an $n = 8$ mode, which contains multiple frequency components. Figure 2(c) shows the Fast Fourier Transform (FFT) of the pressure data over a 20 s interval, indicating that the highest peak is located at approximately 26 Hz, which is twice the oscillation frequency of the drop. This relationship holds true for all the modes we probed as shown in Fig. 2(a). Note that higher harmonics are also visible, suggesting a nonlinear mechanism for generating the star-shaped oscillations.

Similar star-shaped oscillations have also been observed in driven systems, which is due to a parametric coupling mechanism between the azimuthal oscillations of drops and vertical external forces [7]. Our results exhibit the same characteristics of the parametric coupling in the absence of external forcing fields. However, the origin of the pressure oscillations observed in our experiment remains unclear. We hypothesize that capillary waves excited underneath the drop lead to the pressure variations thereby generating the star-shaped oscillations. Although we do not currently have a model for these capillary waves, they may be related to "brim waves" which exist in viscous drops levitated by an air flow through a porous mold [10].

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