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From *The 69th Meeting of The American Physical Society – Division of Fluid Dynamics*

Sparkling Firework Droplets

Mysterious, beautiful "pine-needle" streaks of light created by Japan's Senko-hanabi revealed to be caused by liquid droplets and their trajectory as they fragment

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Washington, D. C., November 21, 2016—In Japan, many adults hold fond childhood memories of fireworks as a symbol of the summer season. *Senko-hanabi*, which translates to "sparkling fireworks," emit a small fireball with streaks of light akin to pine needle structures. As one of the most popular hand-held fireworks since the early Edo period, from 1603 to 1868, they're renown for fragile beauty accompanied by a soothing sound.

Like many others, as a child, Chihiro Inoue, now an associate professor in the Department of Aeronautics and Astronautics at the University of Tokyo, wondered how and why sparkling fireworks emit their unique light streaks. The answers to these questions remained elusive for several centuries.

During the 69th Annual Meeting of the American Physical Society's Division of Fluid Dynamics (DFD), being held November 20-22, in Portland, Oregon, Inoue will describe his work uncovering the liquid dynamics at play behind *Senko-hanabi's* beauty.

What are sparkling fireworks composed of exactly? "It's black powder, which is a mixture of potassium nitrate, soot, and or charcoal, and sulfur, simply wrapped inside an end of twisted paper," explained Inoue. "It doesn't contain metal powders at all—unlike other sparklers."

"When we enjoy the fireworks on a summer night, we hold onto the top end of the paper string and ignite the lower end that contains the powder," Inoue said.

To explore the light pattern being emitted, Inoue used a high-speed camera to see the sparkling fireworks in action. "The first-ever time-resolved images were amazing," he said.

What did he find? The light streaks, surprisingly, consist of "liquid" droplets and their ensuing fragmentation phenomenon. "These droplets are high-temperature (1,000 K) melted molten salts," Inoue said. "Trajectories of the droplets are seen as light streaks by our eyes. It's interesting that the essential phenomenon in 'fireworks' is actually liquid dynamics, which involves a chemical reaction with the oxygen of air, thermal decomposition of metastable compounds within the melt, gas bubble nucleation, and bursting liquid ligaments and droplets formulation—all occurring in a sequential manner."

Intriguingly, the main discovery of Inoue's work centers on the fragmentation phenomenon. For example, when droplets break apart within your shower, fountains, or rain, its fragments are quickly stabilized or it fragments to become stable.

“In general, a liquid droplet or a solid material will fragment only once or twice. ‘Sprays’ that we encounter on a daily basis are produced by such fragmentation occurring everywhere around the initial injected bulk liquid,” Inoue said.

For sparkling fireworks, however, Inoue and colleagues discovered that an initial single droplet successively fragments up to eight times and directly produces a cascade of daughter droplets. “We found a new fragmentation pattern, ‘successive fragmentation,’ and also successfully formulated the original phenomenon, which we’ll present at DFD 2016,” he said.

“Through our findings, we now understand the principle of beauty behind the traditional firework—uncovering the mysteries hidden for centuries, and answering my questions from childhood,” Inoue said.

This study was conducted with Dr. Y. Izato and Professor A. Miyake of Yokohama National University, Professor E. Villermaux of Aix-Marseille University, and Dr. J. Kuwabara of Photron.

Now that Inoue and colleagues have discovered that a droplet potentially fragments many times, not just once or twice, if they can apply the unique event to particle generation technology—which is widely important within mechanical, chemical, and medical fields—it may be possible to develop an even more efficient method in the future.

Inoue is also collaborating with Mr. and Mrs. Tsutsui (http://tsutsuitokimasa.jp), masters of sparkling fireworks, to “explore adding a different ‘taste’ to sparkling fireworks, now that we understand the essence of their beauty,” he said.

Image: The beautiful “pine-needle” streaks of light created by Japan’s *Senko-hanabi, a.k.a. “sparkling fireworks,”* are caused by liquid droplets and their trajectory as the droplets fragment.
Credit: Chihiro Inoue

Video: Successive Fragmentation of Droplet in Sparkling Firework

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Abstract: R37.00003 : Direct cascade of droplet fragmentation in sparkling fireworks," by Chihiro Inoue and Emmanuel Villermaux is at 1:56-2:09pm PST, November 22, 2016 in Room Portland Ballroom 252
For more information about the APS DFD 2016 meeting, visit: http://apsdfd2016pdx.org/

MORE MEETING INFORMATION

USEFUL LINKS
Main meeting website: http://apsdfd2016pdx.org/
Technical program: http://meetings.aps.org/Meeting/DFD16/Content/3199
Meeting/Hotel site: http://apsdfd2016pdx.org/?page_id=30
Press Room: http://www.aps.org/newsroom/index.cfm
Look for live updates on Twitter throughout the meeting with *#APSDFD*

PRESS REGISTRATION
We will grant free registration to credentialed journalists and professional freelance journalists. If you are a reporter and

would like to attend, contact Julia Majors (jmajors@aip.org, 301-209-3103) who can also help with setting up interviews and obtaining images, sound clips, or background information.

LIVE MEDIA WEBCAST

A press briefing featuring a selection of newsworthy research will be webcast live from the conference on Monday, November 21st. The first briefing at 2:00pm (EST) is about the forensic analysis of blood spatter and how changing the position of your fingers can help you swim faster. The second one at 4:00pm (EST) is about cat's Velcro-like tongues and bubbles. More information can be found at the following link: https://www.aps.org/units/dfd/pressroom/

ABOUT The DIVISION OF FLUID DYNAMICS OF THE AMERICAN PHYSICAL SOCIETY

The Division of Fluid Dynamics of the American Physical Society exists for the advancement and diffusion of knowledge of the physics of fluids with special emphasis on the dynamical theories of the liquid, plastic and gaseous states of matter under all conditions of temperature and pressure. https://www.aps.org/units/dfd/

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