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Sprites Trigger Sky-High Chemistry

High-altitude lightning is visually stunning, but is it also a player in atmospheric chemistry?

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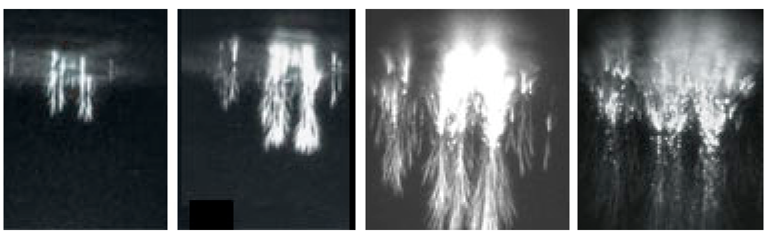


Courtesy of Steven Cummer

Jellyfish In the Sky This sequence of video frames outlines how a lightninglike sprite unfolded in the atmosphere high above the thunderstorm that triggered it this past Aug. 13 in the foothills of the Rockies. The entire sequence spans less than 3 milliseconds.

In less time than it takes a hummingbird to flap its wings once, a recently discovered form of high-altitude lightning can come and go, but not before spreading its multiple-branching red streamers with blue tips over 10,000 km^3 of the atmosphere. The largest mountains on the planet could fit within the same volume with lots of room to spare.

"These things are huge," says physicist Davis Sentman of the University of Alaska, Fairbanks. In 1993, he was one of the first scientists to suggest that these massive, albeit sub-eyeblink, electrical events called sprites could be significant players in the fantastically complex brew of atmospheric chemistry. Their come-and-go shapes have been variously described as resembling jellyfish, picket fences, palm trees, and upside-down carrots.

Although pilots and others had for decades sporadically claimed to catch glimpses of what would become known as sprites, only in 1989 was the first sprite caught on film. And it was an accident.

On July 9 of that year, the late University of Minnesota atmospheric physicist John Winckler, a longtime investigator of high-altitude phenomena, was at an observatory about 40 miles northeast of the Twin Cities, testing a low-light-level video camera system for a forthcoming rocket test. During the test, the camera recorded a flash of light above the horizon. Without intending to, Winckler and his students had become the first to capture a sprite on tape. It was a transformative accident that rendered sprites a defensible, verifiable phenomenon to study.

Ever since, a slowly growing club of researchers has been chasing sprites and related so-called transient luminous events (TLEs) with names like "blue jets," "giant jets," "elves," and "trolls."

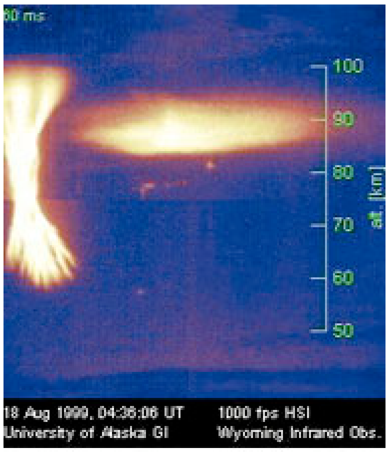
Largely missing from the sprite-smitten mix of space scientists, electrical engineers, physicists, and others who have added TLEs to their research portfolios, however, have been chemists. The time is ripe for them to join the investigation, Sentman says. "Researchers have identified the basic physics," he says. "The chemical aspects are relatively unexplored."

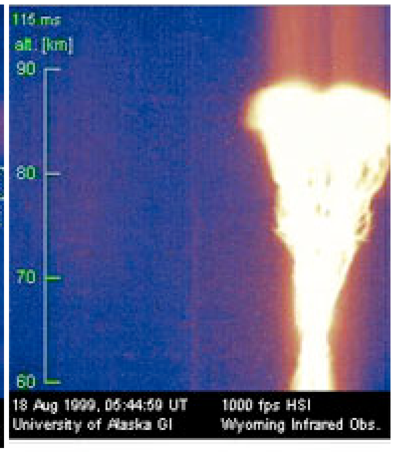
TLEs are so high up in the atmosphere, usually obscured by intervening clouds, and so short-lived that it's not surprising to those who study them that they had remained essentially unknown prior to the availability of high-speed video cameras that work well in low-light conditions. "They are so brief, all you can see is a glimpse," remarks Hans Stenbaek-Nielsen. Several years ago, with Sentman and other University of Alaska colleagues, Stenbaek-Nielsen began to unveil the fantastic, often multibranching formation of sprites by recording them with high-speed cameras at rates up to 1,000 frames per second.

In the Feb. 22 *Geophysical Research Letters* (**2006,** *33*, LO4104), electrical engineer Steven A. Cummer of Duke University and his coworkers reported video observations of scores of sprites made in the foothills of the Rocky Mountains at up to 7,200 frames per second. The scientists captured the images this past summer from a perch at the Yucca Ridge Field Station in Fort Collins, Colo., using an electronic camera designed to study fast phenomena like explosions. The fastest frame rates produced slow-motion imagery equivalent to stretching one second of normal-speed video into about five minutes of super-slow motion. The time between each frame was less than a millisecond.

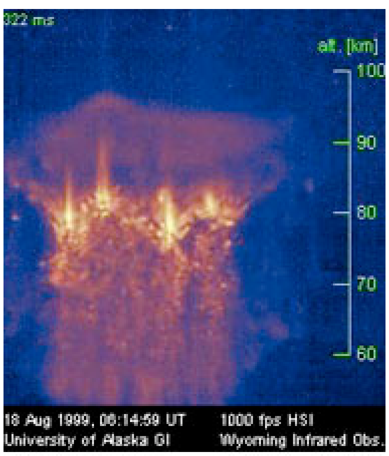
Sprites are thrilling to anyone who sees one. High-speed video recordings reveal that as they unfold, thick columns and finer streamers propagate and branch at faster-than-lightning speed both upward and downward from initiation points that often reside in the upper mesosphere at altitudes of 80 or 90 km. To get to the stratosphere from these initiation points, you would have to descend at least 30 km. This summer, Cummer's team observed what it argues to be a newly recognized phenomenon: colliding streamers. "The points of streamer collisions appear to become long-persisting sprite beads, which have been suggested previously to affect mesospheric chemistry," the researchers note in their *GRL* paper, referring to bright spherical features apparent in sprite images.

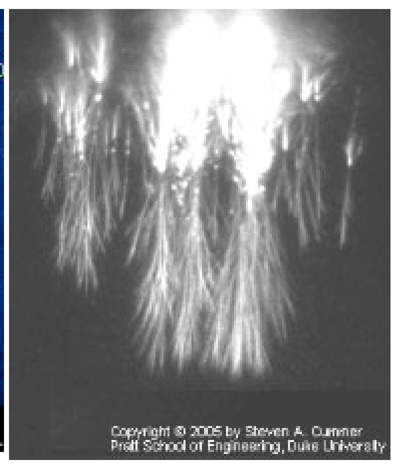
SPRITES VIDEOS





Video 1 Video 2





Video 3 Video 4

When captured at 1,000 frames per second, sprites reveal themselves in all of their lightning-fast, branching, luminous splendor. Hans Stenbaek-Nielsen of the University of Alaska, Fairbanks, captured the first 3 videos in 1999. The clocks in the videos tick off time in milliseconds. The scale bars on the sides of the frames indicate that the sprites are unfolding in the mesosphere, which ranges in altitude from about 50 to 100 km. The fourth video, from Steven Cummer of Duke University and his colleagues, was obtained this past summer in Colorado in the foothills of the Rockies. The frame rate in this case is 7,500.

* Quicktime is required to view videos.

What sets the stage for most sprites is normal lightning flashes, particularly the cloud-to-ground flashes that occur toward the end of strong thunderstorms, and especially the minority of strikes that carry positive charge to the ground instead of negative charge. By way of this transport of charge, these strikes intensify the electric field between the cloud and the layer of the atmosphere that lies above, also known as the mesosphere. When the strength of this field surpasses the so-called dielectric breakdown threshold of the mesosphere, the atmosphere stops behaving like an insulator and becomes a conductor. The electric field in the affected region accelerates electrons to great speeds, and these electrons collide with and excite atmospheric molecules, predominately neutral nitrogen and oxygen.

This is where a lot of interesting chemistry comes into play, Sentman surmises. TLE researchers have long known that the electron impacts in the mesosphere generate several excited states in both the neutral and ionized forms of nitrogen. The predominant red color of sprites and the blue of blue jets-lower altitude TLEs that unfold in the stratosphere just above thunderstorms-are due to these excited states relaxing and emitting photons. Sentman's models of the process suggest that various neutral and ionized molecular combinations of carbon, nitrogen, oxygen, and hydrogen ought to form. Excited oxygen species fail to add their own light to the display because they apparently vent their extra energy in lightless, collision-based relaxation processes, Sentman says.

A team of modelers at the Sodankylä Geophysical Observatory (SGO) at the University of Oulu in Finland also has been investigating potential sprite chemistry. In a nearly completed four-year initiative known as CAL (Coupling of Atmospheric Layers) funded by the European Commission, the team has modified the Sodankylä Ion Chemistry (SIC) model for simulating atmospheric chemistry that might be occurring at altitudes between 50 and 150 km. This region hosts both sprites and elves, which are circular TLEs that expand outward at the top of the mesosphere like a solitary ripple in water. The SIC model, a work always in progress, encompasses nearly 80 ionized and neutral species engaging in upward of 400 reactions.

Meanwhile, researchers like electrical engineer Victor Pasko of Pennsylvania State University, University Park, have been searching for clues about sprite chemistry in their laboratories. Pasko subjects atmosphere-like gas compositions to electric fields strong enough to produce needle-thin plasma filaments that mimic the streamers of sprites.

"If you look at streamers in the laboratory and in sprites, the optical data tell us they are the same phenomenon," Pasko says. Because the pressure in the mesosphere is much lower than at the surface of Earth, streamers that have submillimeter diameters in gas mixtures at ground pressure could grow in the upper atmosphere into streamers many kilometers long and 100 meters wide or wider.

The streamers born in Pasko's laboratory are filaments of plasma composed of electrons and positively charged ions, and these can initiate gas-phase reactions. For example, Pasko has observed optical emissions in the laboratory due to the dissociation of oxygen molecules into atomic oxygen and suggests that the same thing happens in sprites. Streamers in sprites have the ability to generate highly active chemical species that, in Pasko's view, "can effectively 'treat' thousands of cubic kilometers of atmosphere."

Whether working with computer modelers or laboratory plasmas, all sprite researchers run into the same confidence-knocking reality that Pasko states rather simply: "The chemistry is complicated."

"We have a complicated model with badly known parameters," such as reaction rates under mesospheric conditions, says Esa Turunen, head of SGO's Aeronomy Division. "We are trying to do things at ground pressure and then make conclusions about what is happening in sprites," Pasko adds, with an inflection in his voice indicating that the basis for such ground-to-sprite extrapolations is fraught with uncertainties.

Better, researchers say, would be to have tools in place that could directly measure and monitor the chemistry born in sprites, blue jets, and other TLEs. This task might be comparable to photographing fairies, except that scientists know that sprites really do exist. The lack of direct measurements of TLE chemistry inspires questions like the one that blares across the CAL team's homepage: "Are sprites and blue jets only pretty and beautiful like rainbows, or do they significantly impact the atmosphere?"

> A strong thunderstorm can produce a sprite or two every minute, each time leaving behind a chemical residue.

The answer could go either way. A strong thunderstorm can produce a sprite or two every minute, each time leaving behind a chemical residue. "So you have a chemical factory high in the atmosphere that follows the thunderstorm," Sentman says. Considering that sprites are produced every day in many places around the world, the chemical consequences in the mesosphere conceivably could be significant, he says.

At the moment, however, Sentman suspects that TLEs are in fact pretty nightlights that wield little lasting influence in atmospheric chemistry. After all, Sentman notes, "when the sun comes up in the morning, it's like an 800-pound gorilla arriving on the scene." The massive input of solar energy into the atmosphere probably erases any temporary mark TLEs might have produced overnight.

Those hoping that TLEs are more than bit actors in global atmospheric chemistry still have a ledge to stand on. A hallmark of complex phenomena like ecosystem dynamics and atmospheric chemistry is that tiny changes in the system's initial conditions can have large-scale consequences down the line. For sprite researchers, Sentman says, the relevant question here might go like this: If you put an end to all of the sprites in the world, would anybody but poets notice or would Bangladesh be flooded?

Given that the role of sprites and other TLEs in the overall terrestrial machine remains unknown, Pasko, Sentman, and their kindred researchers feel confident that their quest to uncover more of the dynamics, distributions, physical mechanisms, and chemistry of sprites is worth the effort. Joining the fray does have its risks, Sentman points out.

"Everyone who gets involved gets the bug. It's like getting malaria; you can't get rid of it."

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