SCIENCE NEWS 2000 January 15, 2000 Vol. 157 No. 3 p. 45

The Importance of Being Electric

Scientists aim to explain sprites

By OLIVER BAKER

One evening last summer, scientists stationed in Colorado pointed low-light video cameras and detectors northeast across the Great Plains and for 3 hours, stared into the mostly dark band of sky above a South Dakota thunderstorm.

Their goal was to capture, in images and data, faint, ephemeral shapes that flash into existence and disappear in a fraction of a second. A glimpse with the naked eye suggests the folds of a curtain or a smear on the sky, perhaps red—or maybe green. Caught by a camera, however, these glowing forms may resemble angels, carrots, or columns. The images are so dim and brief that they stretch the physiological limits of perception. In fact, they stretch technological limits, too.

Only 10 years ago, scientists didn't believe that these fleeting figures exist (SN: 2/12/94, p. 100). However, in just their brief stakeout last summer, the Colorado-based researchers documented 774 of them, says Walter A. Lyons of FMA Research in Fort Collins.

These recently authenticated apparitions are sprites, natural phenomena that occur at 5 to 10 times the altitude of the cloud tops, high above electric storms. By coordinating measurements from telescopes, planes, balloons, and a battery of other devices, scientists now have come to see these creatures almost as familiar (SN: 12/21&28/96, p. 391).

Theorists believe that they've identified the ingredients of nature's recipe for sprites, even if the proportions remain to be worked out. "I think the basic mechanisms are there," says atmospheric and space scientist Robert A. Roussel-Dupre of Los Alamos (N.M.) National Laboratory. These mechanisms, he says, suggest a close kinship between sprites and lightning—and a dash of the otherworldly.

The first fuzzy images caught by conventional-speed video cameras gave rise to the archetypes researchers use to sort sprites. An angel has a relatively bright oval head, an airy nimbus, and a vestment that flares toward the ground.

A classic carrot looks similar but has foliage in lieu of a nimbus and tapers at the bottom. Columns are straight, as the name implies, and sometimes they break up into sections, as if cemented by unlit bands of mortar.

Sprites stand about as tall as Manhattan tilted on end. A 50-kilometer-thick band called the mesosphere roughly defines the sprites' habitat. An invisible ceiling holds them to about 95 km above Earth's surface, while a less well-defined floor keeps them above about 30 km.

Sprites appear in the split seconds that follow touchdown of a lightning stroke, but in just a small fraction of cases. Almost without exception, they follow only a rare, especially powerful form of lightning that has a polarity opposite the norm.

Atmospheric physicist Mark Stanley hunts sprites from Langmuir Laboratory, which sits at an altitude of 10,600 feet, atop Mt. Baldy in arid central New Mexico. Cloud and lightning data tell him where to search. He links to the Web site of the privately run National Lightning Detection Network (NLDN), which triangulates readings from ground-based sensors nationwide and reports the location, size, and polarity of lightning discharges as they occur. Two other sites show Stanley radar and infrared satellite images of clouds.

Based at New Mexico Tech in the nearby town of Socorro, Stanley says that Langmuir gives him a nearly 360-degree outlook. Visibility extends so far, he says, that often as he watches sprites dance on the horizon, the curve of Earth shields the storm and lightning from view. Typically, Stanley says, his targets stand about 500 km away, southwest over Mexico.

Sprite-producing storms often pass near Langmuir in the summer, he says, but they seldom allow close-up viewing. "These storms are big," says Stanley. "The region that's producing sprites could be surrounded by 100 km or more of cloud deck, which blocks your view."

Making a visual record of a sprite calls for a special camera, Stanley says. Researchers use "intensified" video recorders, which employ a technology that some military night-vision devices also use.

Sprites are so fast that a camera operating at the conventional 16 frames per second typically catches just a single portrait. In these images, the events in a sprite's life run together like the blur of a hummingbird's wings.

Recently, however, a few sprite researchers have used intensified cameras that shoot 1,000 to 6,000 frames per second and cost about $100,000. Footage from these cameras gives sprites a new look. Angels sport Polynesian skirts of glowing tendrils. Carrots appear ornate, like flowering thistle bushes or jellyfish.

Whatever instrument they use, sprite watchers record a running time stamp by tapping into the signal of Global Positioning System satellites. With this reference and the notes of observers at other sites, researchers can triangulate sprites' exact locations and link individual sprites to discharges measured by the NLDN.

Because sprites often appear just tens of milliseconds apart—and just thousandths of a second may separate a sprite from its parent lightning stroke—an exceptionally precise clock is required.

Not only does lightning seem to give birth to sprites, but the two phenomena appear to share physical attributes. Both the tortuous filaments of brilliant light below the clouds and the faint, flitting behemoths above arise from a chain reaction called electrical breakdown, theorists argue.

An electric field—such as one between Earth and a hovering thundercloud—sets the stage for breakdown. It begins when a single electron escapes from its orbit within a gas molecule and the field accelerates it.

If the electron speeds up enough, when it smashes into another molecule, it knocks another electron loose. With successive collisions, an avalanche of electrons ensues, completing breakdown.

The swath of liberated electrons form an electrically conducting trail within the otherwise insulating air. In a lightning stroke, a gargantuan surge of current flows through the trail from a cloud to the ground. Often lasting more than a second, the surge is so intense that it widens the path 10-fold and produces an intense white light.

In the gentler, mesosphere-dwelling sprites, no great surge takes place, says theorist and electrical engineer Victor P. Pasko of Stanford University. Instead, the avalanche of electrons continues, generating a smaller electric current that persists less than a tenth of a second.

Sprites are tamer than lightning because the electric field above a cloud is weaker than the field below, Pasko says. The weaker field can trigger breakdown only above a critical altitude. There, air molecules are sparse and electrons have plenty of runway, so they can attain breakdown speed before they slam into a molecule. Avalanches develop over much greater distances than below the cloud, Pasko says. This is the reason for sprites' bloated proportions.

Breakdown makes sprites glow because many collisions don't knock electrons from molecules but bump them up to higher energy levels. When these molecules relax, they release energy as light.

A particularly powerful type of lightning discharge creates the fields that trigger most sprites, Pasko says. These fields occur only rarely and briefly.

The lightning strokes, rather than drawing charge from a cloud's underside, spirit charge away from the cloud's tops, which form a continuous, shifting stratum within a thunderstorm. Because the charge in the top half of a storm cloud is positive, the lightning that favors sprites shows up as a positive current in NLDN data. So, researchers can easily distinguish it from the more common strokes of negative current.

According to Carl L. Siefring of the Naval Research Laboratory in Washington, D.C., contemporary computers can't handle the complexity of translating the breakdown theory into a prediction of the exact shapes of sprites. The expanse of sky that a sprite fills is too large to represent in detail. Yet there are visual features of sprites, he says, that do provide some evidence for the breakdown theory.

He cites recent work by Stanley and his colleagues. Using a high-speed camera, the researchers captured pictures of sprites igniting at 75 km, sending tendrils down immediately and, after a delay, upward. The researchers present their findings in the Oct. 15, 1999 Geophysical Research Letters.

To Siefring and others, the advancing tendrils of light suggest breakdown reactions racing through the mesosphere. The height at which sprites spark to life also roughly agrees with what theorists like Pasko estimate to be the critical altitude for breakdown.

Siefring points to another line of evidence that links sprites' glow with the flow of electricity. While Stanley captured sprites on high-speed video, electrical engineer Steven A. Cummer of Duke University in Durham, N.C., recorded radio waves, monitoring frequencies below those detected by the NLDN sensors.

In the Oct. 15, 1999 Geophysical Research Letters, Stanley and Cummer superimpose a sprite's images and electrical signals, matching them with a precision finer than a millisecond.

The electrical record shows two roughly triangular pulses occurring about 2 milliseconds apart. The first pulse occurs while the mesosphere images are dark. It coincides with a large, positive cloud-to-ground lightning stroke and has the features of the signal generated by lightning's initial surge, the researchers say.

At the onset of the second pulse, the first indication of a sprite appears. The initially small patch of light then expands and brightens while the electric signal rises. The light fades as the pulse declines. This pulse, the researchers argue, reflects electricity flowing within the sprite.

Color images are rare, but theorists believe that any explanation of sprites must account for their hues. In the June 15, 1998 and the Sept. 15, 1998 Geophysical Research Letters, Pasko and his colleagues presented computer simulations of electrical events in the mesosphere following a positive lightning stroke.

Besides calculating the critical altitude at which a breakdown-driven sprite should emerge, the theorists have predicted the shape of the radio pulse that the breakdown should generate and the color it should appear.

According to color video images and raw light measurements, sprites predominantly glow red—of the exact shade that nitrogen molecules emit after they've received the lowest boost of energy they can absorb, Pasko says. The amount falls within the narrow range of energies that he and his colleagues predict for the accelerated electrons generated by the breakdown.

The tendrils of an angel's Polynesian skirt, however, are blue. Although nitrogen molecules can emit this hue, too, explaining it poses a challenge to the breakdown theory, says Umran S. Inan, a Stanford colleague of Pasko's. Blue light takes more energy to produce than red light, implying considerably stronger collisions between electrons and nitrogen molecules in air.

There's another problem with the tendrils, says Roussel-Dupre. They hang down too far. He and other theorists have calculated that 50 km is about as low an altitude as breakdown should go. Yet observers sometimes see tendrils graze the cloud tops that hover at 10 to 15 km, he says.

Roussel-Dupre says that sprites may need an explanation in two parts—top and bottom. To account for sprites from the waist down, he invokes an otherworldly connection—cosmic rays.

Raining continuously on Earth from space, cosmic rays pack so much energy that they shatter molecules in the upper atmosphere and generate a maelstrom of subatomic fragments and radiation that fizzles out at about the height of clouds.

With cosmic rays in the picture, says Roussel-Dupre, the length and color of angels' skirts could explain another vexing conundrum: Bursts of gamma rays hurtling out of the atmosphere from the vicinity of thunderstorms. Satellites have detected the bursts.

In the atmosphere, only cosmic ray impacts could provide the energy it takes to produce gamma rays, Roussel-Dupre says. Furthermore, only a massive electric field—such as that created by a positive lightning stroke—could turn this energy around and send it flying back in the direction from which it came.

The question remains whether this scenario happens within sprites. The observation that gamma rays emanate from thunderstorms is suggestive evidence, he says, but not proof.

Roussel-Dupre and his colleagues presented calculations in the March 15, 1999 Geophysical Research Letters. They reported that they can explain both the amount of gamma rays that satellites have detected and the blue tendrils that sprite watchers have seen.

Their calculations also explain why the process would occur only in the lower part of sprites, Roussel-Dupre says. The particles that come hurtling upward from thunderstorms are by-products of cosmic ray collisions and not the cosmic rays themselves, he says. They're electrons, careering at nearly the speed of light, that start heading upward on a lucky rebound. Only the high-intensity field created fleetingly by a positive lightning stroke can sustain this upward momentum, he says.

This sustenance runs out because Earth's magnetic field pushes electrons sideways, out of the cloud's influence, particularly when the electrons are moving fast. At the latitudes of the Great Plains, where observers usually search for sprites, this happens at midsprite height, Roussel-Dupre says.

Siefring notes that theorists are doing well at explaining the details of sprites as they've emerged, but he hopes to see their hypotheses put through more of a shakedown. "Right now," he says, "a theoretician can choose any [electric] field he or she wants because no one's measured it."

Siefring says he endorses the grand designs of Edgar A. Bering, a physicist at the University of Houston. Last summer, Bering organized about half the world's sprite-analyzing talent, by Lyons' reckoning, for an observational campaign centered on the Great Plains.

About 40 space and terrestrial scientists at mountain-top observatories, field stations, and an airport in Otumwa, Iowa, coordinated their efforts as an unmanned NASA balloon lofted a panoply of instrumentation through the ozone layer to an altitude of 32 km—more than three times as high as commercial jets fly. The balloon lifted off as thunderstorms formed on the eastern slopes of the Rockies.

The results of that enterprise have only started to emerge. On the basis of data Bering has seen, however, he predicts that theorists indeed will face some new work.

"I don't think many of the extant models are going to survive confrontation with our data," says Bering.

An air of mystery may surround sprites for a while longer. □