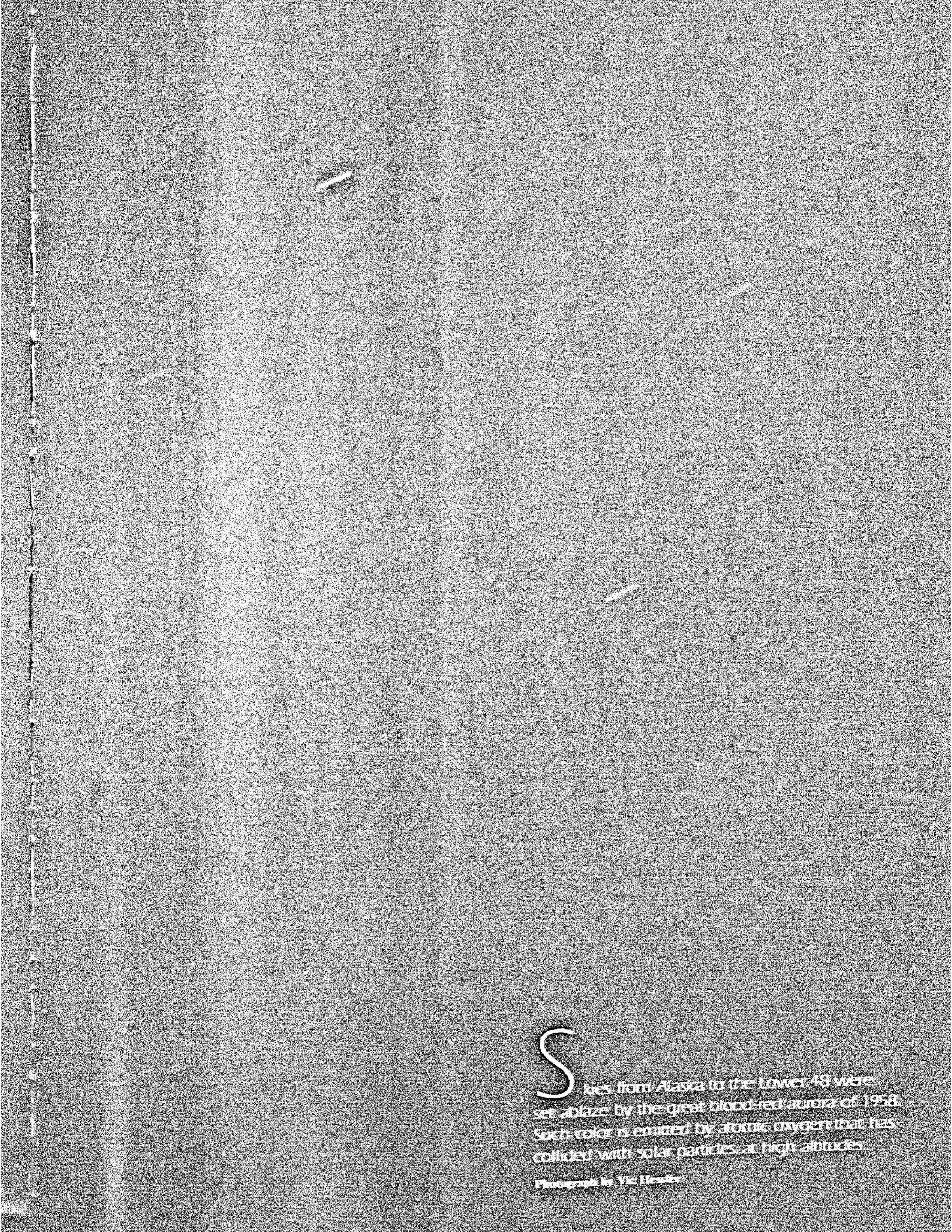
Are dazzling auroras a danger? They falsify radar images and can alter a missile's course.

PROBING THE LIGHT FANTASTIC

BY MARCIA BARTUSIAK

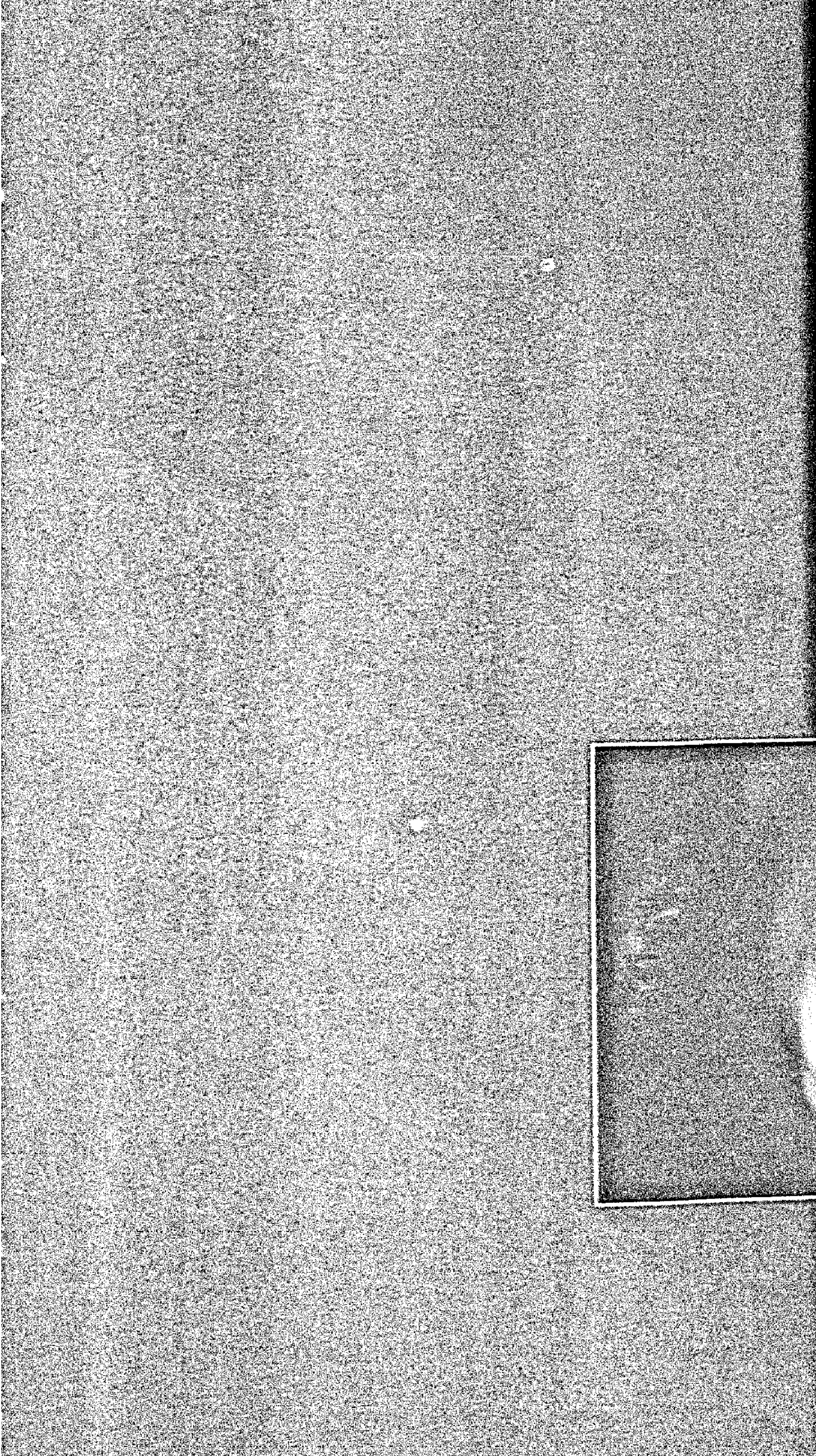
To the uninitiated, the faint haze above the hills to the north seems to be the misplaced first rays of a rising sun. But it is hours before dawn, and as the haze becomes more distinct, the sky fills from horizon to horizon with ribbons of pale light, yellow-green arcs tipped in red that playfully dash and dart across the Arctic heavens as though invisible hands were shak-



Skies from Alaska to the Lower 48 were set ablaze by the great blood-red aurora of 1958. Such color is emitted by atomic oxygen that has collided with solar particles at high altitudes.

Photograph by Vic Hessler

During brilliant auroral displays in 1972, a large transformer in British Columbia exploded and circuit breakers from Maine to Texas tripped.



ing a gigantic luminous curtain. The aurora borealis is one of the most spectacular light shows on Earth. When an auroral storm is raging, the upper atmosphere becomes the world's largest color television set. Electrons and protons blown off the surface of the sun race in from deep space, collide with the very thin atmosphere (the giant TV screen) and excite the atmospheric molecules to higher energy levels. The molecules give up this excess energy in a brilliant fountain of visible light, and nature's TV screen begins to shimmer in cascading sheets of color.

For millennia, auroras (named after Aurora, Roman goddess of the dawn) have awed and mystified inhabitants of the polar regions (in the Southern Hemisphere, the phenomenon is known as aurora australis). Now, after years of extensive probing of the auroral atmosphere by satellites, rockets and other space-age instruments, the northern and southern lights have begun to yield their secrets.

During an aurora, the influx of charged particles does more than light up the sky. It also plays havoc with the ionosphere (a layer of charged atoms, or ions, in the upper atmosphere). Short-wave radio signals that normally bounce off that layer can be wiped out, become garbled or detour unexpectedly. Alaskan cabdrivers, for example, have been known to take their orders from New Jersey dispatchers during moments of intense geomagnetic activity. Meanwhile, false images can pop up on early-warning radars set up to watch over transpolar air traffic.

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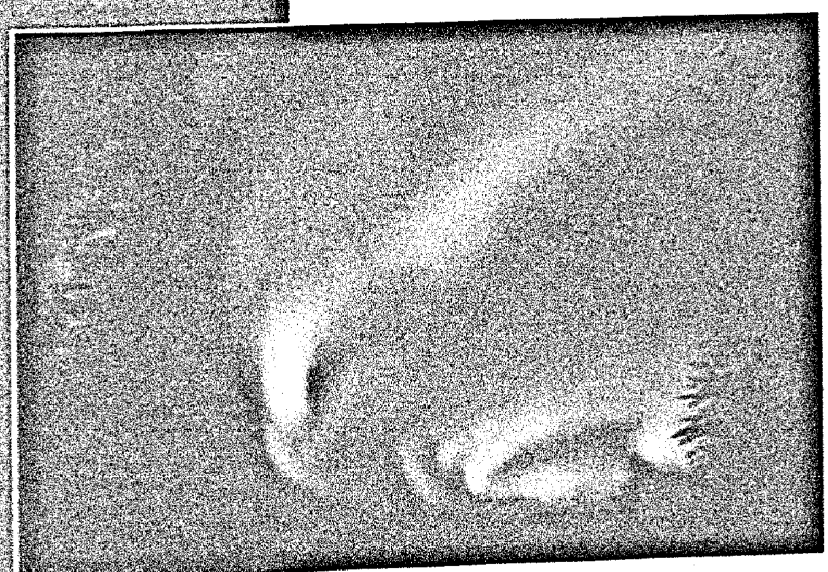


A corona (left) is the intense light seen when an aurora is right overhead. (Above) As a typical auroral storm begins, arcs and rays build up to form a curtain. A large-scale wave then surges westward, curling and folding it; to the east, the curtain breaks into patches. Within hours, activity ceases, perhaps to begin again.

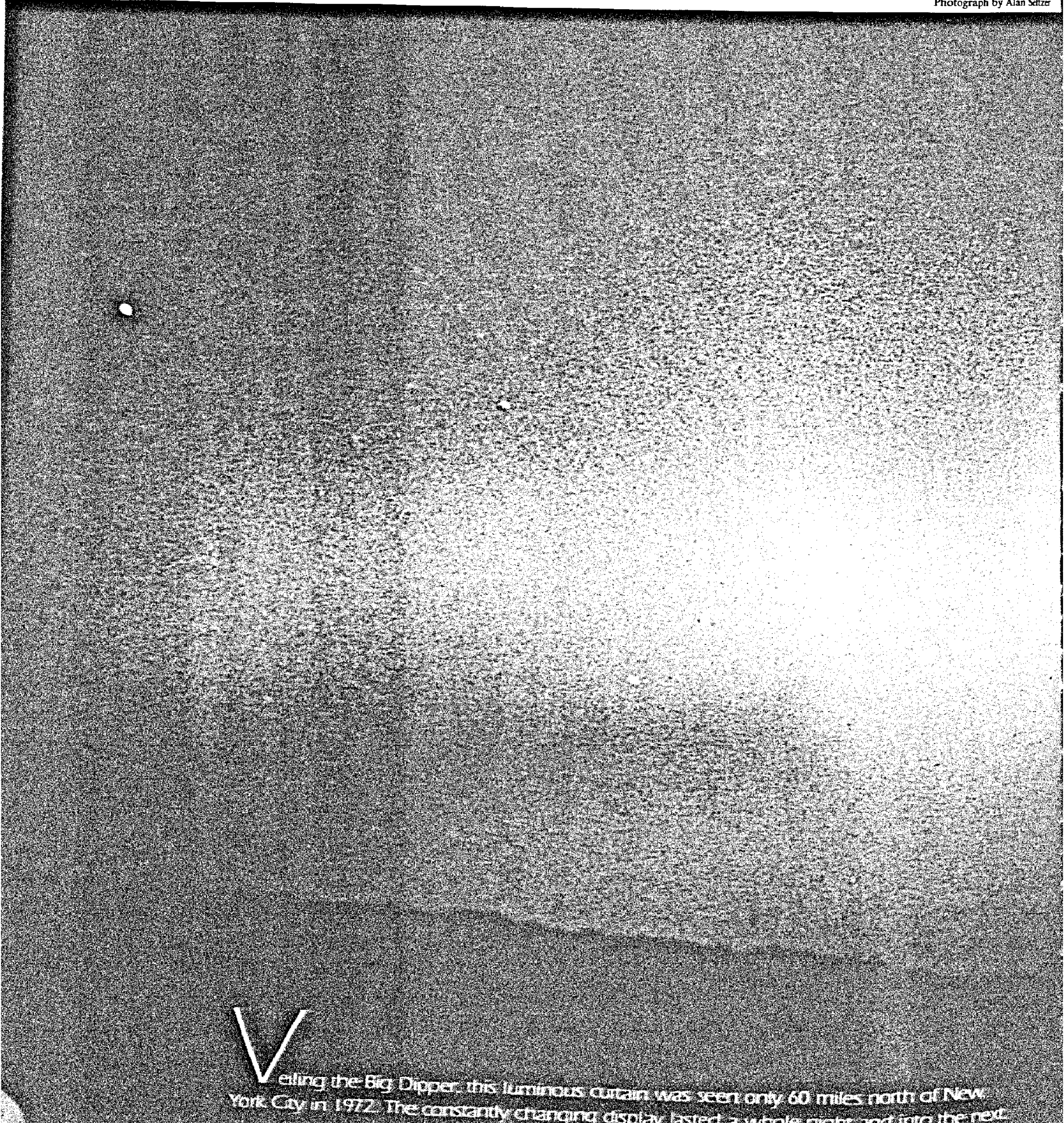
Photographs: left by George Cresswell; above by Lee Snyder

The heating and the resulting expansion of the upper atmosphere during an auroral event may alter the course of a ballistic missile headed across the poles. The upward movement of the atmosphere also increases the drag on a satellite with a polar orbit, and so reduces its lifetime.

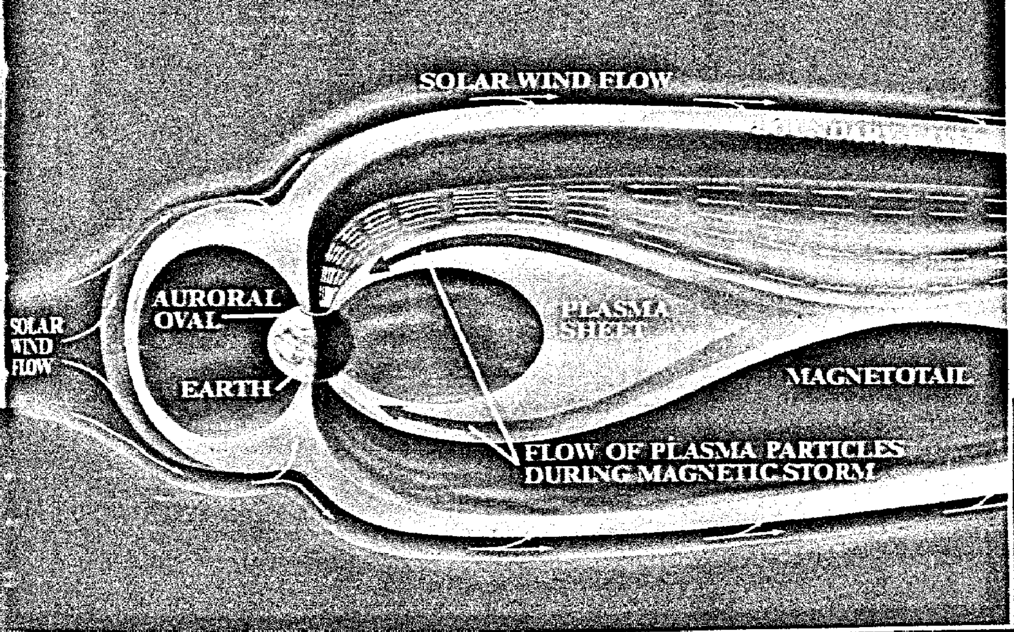
The changing currents flowing along an auroral curtain cause intense electrical currents to start surging through lengthy conductors such as power transmission lines, telephone cables and oil pipelines. "More than one hundred amperes of current can start running through the Alaska oil pipeline," notes aurora expert Syun-Ichi Akasofu, of the Geophysical Institute of the University of Alaska in Fairbanks, one of the world's most active aurora research facilities. Such a current might cause significant corrosion along the length of the pipeline.

In 1972, auroras generated during a powerful series of solar flares caused a 230,000-volt transformer in British Columbia to explode, and it also tripped circuit breakers from Maine to Texas. In parts of the Midwest, power flow dropped by almost half for several minutes. During a spectacular display in 1859, the induced currents were so strong that tele-

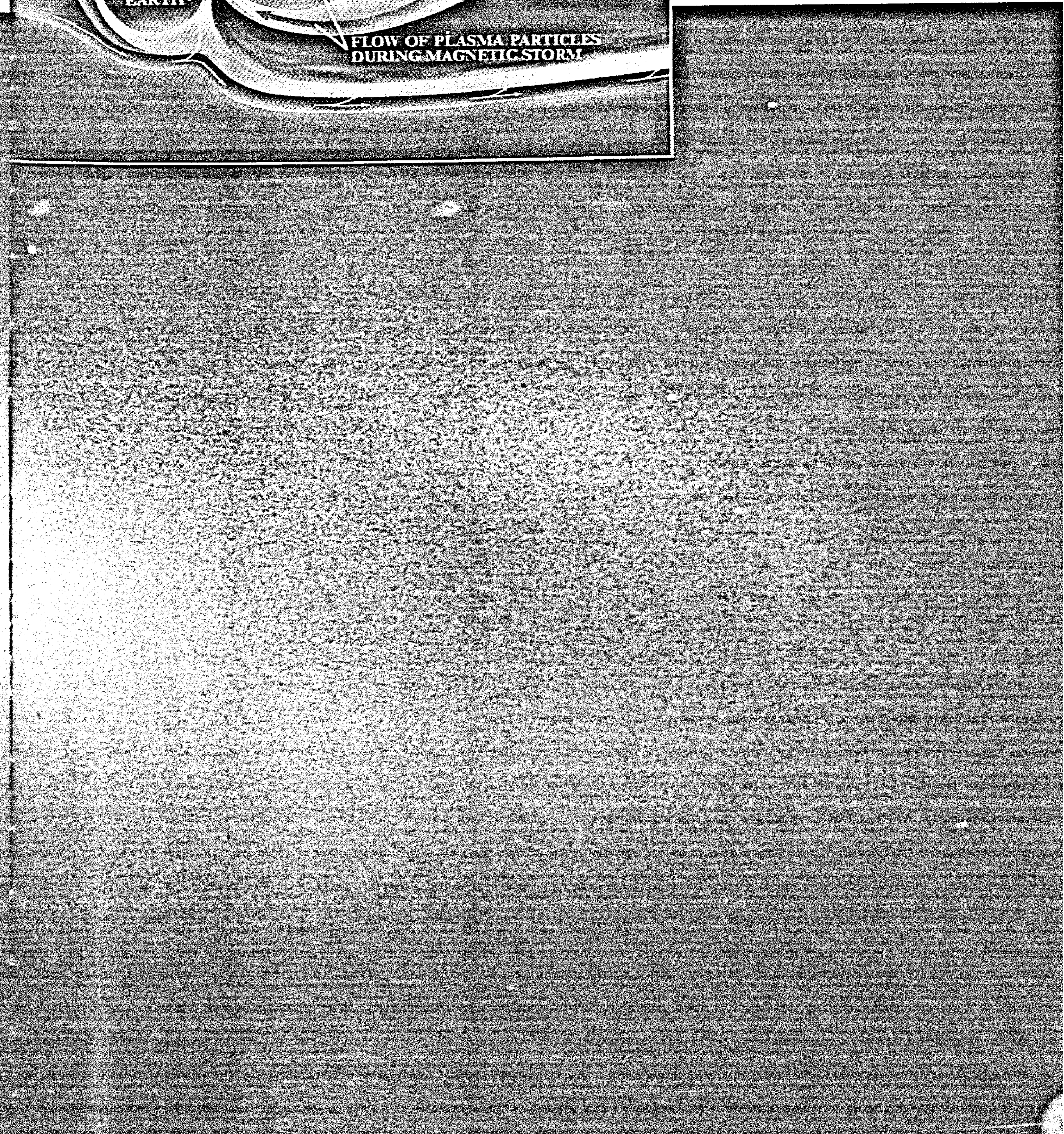
Photograph by Alan Seltzer



Veiling the Big Dipper, this luminous curtain was seen only 60 miles north of New York City in 1972. The constantly changing display lasted a whole night and into the next



Auroras occur when solar wind particles leak into Earth's magnetic field (seen in cross section from above the Equator). Some particles pour into the day side of north and south auroral ovals, causing weak auroras; some go into the magnetotail and become part of the plasmasheet. When gusts of solar wind shake the magnetotail, the plasmasheet is squeezed; its particles then flow into the night side of the oval.
Diagram by Ian Worpole



Multiple bands, a typical auroral formation, shimmer over Alaska. A nearly identical aurora could be seen at the same time in the Southern Hemisphere on the same magnetic field line. These lines loop high above the Equator, linking the two hemispheres.

(Left inset) In 1981, the full globe with an entire auroral oval was photographed for the first time by a special camera on NASA's Dynamics Explorer 1. (Right) Capturing all the fury of a sudden auroral storm, this series of pictures was shot over the course of only nine minutes, using a fish-eye lens aboard a NASA jet.

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graph operators in the United States could send messages from Boston to Portland without batteries!

Sometimes the normal airflows in the auroral regions of the upper atmosphere are completely altered as the aurora heats up the rarefied gases. Wind velocities can increase from a norm of 300 miles per hour to 900 or more, and temperatures can increase as much as 1,000 degrees to 2,200 degrees Fahrenheit. Since, however, there are only a trillion atoms per cubic centimeter at auroral altitudes, practically a vacuum by surface standards, the actual effects of these extreme conditions are much reduced.

AURORA-WEATHER LINK?

But do any of these effects filter down to the lower atmosphere and affect the surface weather? Some claim there is circumstantial evidence. Dry cycles in the western United States have been linked to periods of low solar and auroral activity. Is this coincidence, or does the aurora play a part in some subtle way? It is also known that the aurora increases the density of nitric oxide, which then moves down into the stratosphere and diminishes the protective ozone layer surrounding the Earth. But some scientists believe the effects are minimal. "I can't really see how auroras could affect our weather down here on the ground to any great extent," says Alaska geophysicist Charles Deehr. "The aurora is ten times higher than our cloud layers. The sunlight that is constantly falling on the Earth is much more powerful. What the aurora may do is act like a trigger, setting off a weather pattern that's about to occur."

Of the scientists engaged in auroral research, those at Alaska's Geophysical Institute are in an enviable position. The ring-shaped zone of high auroral activity that surrounds the north geomagnetic pole runs right through the interior of the forty-ninth state. This is because the Earth's magnetic field lines form a sort of funnel in the polar regions that stretches up and out toward deep space—a ready-made runway for incoming auroral particles. In this way, Alaska, Antarctica and other polar lands become windows where interplanetary electric and magnetic phenomena can be studied directly from the ground.

Each year, during the peak aurora-viewing season, Institute staff members brave the bitter polar nights to study the fiery display with a veritable army of instruments: a network of magnetometers senses each tiny change in the Earth's magnetic field as the aurora passes overhead; special low-light television cameras capable of 3-D pictures capture the fluctuating dance of light; rockets pierce the glowing veil; and radar beams bounce off the fluorescent arcs and bands, determining the density and temperature of the auroral particles. Meanwhile, satellites orbit overhead, continually scanning the Earth's electromagnetic environment.

Such testing has shown that the aurora is not an isolated fluke of nature but, rather, the *visible* manifestation of a large electrical-current system that is continually pumping millions of megawatts of electromagnetic and thermal power into the upper polar atmospheres. At times, this current exceeds the total electrical generating capacity of the United States. "It's too bad we can't tap into that source," laments one aurora expert. "Our country's energy needs would be solved in a minute."

Auroras actually begin on the surface of the sun, where electrons and protons boil off and speed away into interplanetary space at hundreds of miles per second. As this solar wind approaches the Earth, the tenuous plasma collides with and moves around the planet's protective magnetic field (this field is generated by the motion of the fluid portion of Earth's iron core). The high-speed solar wind reshapes the field into a comet-shaped cavity called the magnetosphere. The sunward "nose" of this magnetic cocoon extends some 40,000 miles from the Earth, while the nightside "tail" stretches out for a few million miles.

As the solar wind blows downstream along the edges of this magnetic cavity, some of the particles leak in and become part of an immense reservoir called the plasmasheet that runs down the length of the magnetotail. The particles that leak in are carried back toward the Earth by the flow of the plasmasheet, eventually to

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RIPS IN THE SUN

Astronomers have long known that explosive solar flares and periodic sunspots account for the Earth's splashy, flickering auroras. More recently, however, they have identified a third cause: coronal holes, rips in the surface of the sun, discovered during NASA's Skylab program.

The outermost layer of the sun is a blanket of searing gas called the corona. This blinding shroud is usually rather uniform in character, with temperature, density and radiation levels remaining more or less constant across its breadth. On occasion, however, such tidiness is not maintained. Like a tear in a sheet of fabric, great jagged patches of low density, decreased temperature and weak radiation sometimes rend the corona's surface.

The most significant result of coronal holes is a change in the sun's magnetic field. Ordinarily composed of neat lines that radiate out from the poles and arch gently back, the magnetic field bursts open in the vicinity of a coronal hole. When one of these portals appears, gusts of solar wind—in the form of charged particles traveling at a million miles per hour—burst out into surrounding space. As the coronal hole rotates with the sun, the aperture in the field moves with it. The solar particles are thus eventually directed toward Earth.

Roughly four days after it leaves the sun, this high-speed stream of solar wind reaches the vicinity of our planet, where it hits and rattles Earth's own magnetic field. This causes other particles stored within the field to rush down magnetic channels to the poles; there, simple interactions with atmospheric molecules give us the brilliant auroras.

Strangely then, a process that begins as nothing more than a ragged wound in the surface of the sun ends as a burst of color in the skies above Earth.

—Jeffrey Kluger

Photographs: left by Malcolm Lockwood/Geophysical Institute, University of Alaska; inset courtesy of NASA, camera designed by Louis A. Frank, University of Iowa; above courtesy of NASA

LIGHT FANTASTIC

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precipitate down the sides of those "funnels" poised over the two polar regions.

Thus, surrounding each geomagnetic pole, where the edge of the magnetic funnel meets the upper atmosphere, there is a constant ring-shaped glow. This auroral oval, which appears to a satellite's special eyes as a shimmering tiara that crowns the Earth, brightens, fades, contracts and expands depending on the current pouring into it.

The path of the auroral particles streaming in along the Earth's magnetic field lines is traced out as a thin, glowing curtain hanging in space from 60 to hundreds of miles above the Earth. Atomic oxygen gives the aurora its characteristic yellow-green color and on occasion can make it appear blood red. If the electrons are energetic enough to penetrate to an altitude of 60 miles, they can cause nitrogen molecules to emit a crimson red color—the origin of the red trim that sometimes occurs in the auroral drapery.

The solar wind is always blowing, so a current is continually present in the auroral oval. But the question still remains: what causes the magnetosphere to go into sudden and sporadic convulsions, dumping millions of amperes of current into the polar regions and giving rise to the legendary light show? For well over 10 years the most attractive hypothesis has been a storage model: energy from the solar wind gradually accumulates in the magnetosphere and is suddenly released by a catastrophic trigger. Thomas Potemra, a space scientist at the Johns Hopkins Applied Physics Laboratory (APL), explains: "The idea is to envision the Earth's magnetic field lines as rubber bands that stretch way out into the magnetotail, on the dark side of the Earth. The particles stored back there in the plasmasheet cling to these 'rubber bands.' But when there's a major disturbance like a solar flare coming out of the sun, a shock wave hits the front of the Earth's magnetosphere and shakes the whole thing like a big tree. The 'rubber bands' snap, shooting the auroral particles down into the Earth's poles."

NATURAL GENERATOR

But Syun-Ichi Akasofu has never been quite comfortable with that model. He thinks the highly energetic charged particles flowing out of the sun and racing past the Earth's magnetic field look more like a gigantic natural generator whose power would *continually* drive the auroral currents. Sometimes the generator will be in low gear (quiet aurora); sometimes it will rev up with heightened solar activity, thereby increasing the flow of plasma out of the plasmasheet and driving the auroral discharge more powerfully.

Akasofu's theory has raised a few eyebrows in some aurora research circles; opponents are sure that energy storage and triggered release—the rubber-band theory—still play a major role in magnetic disturbances on Earth, especially since the aurora is so sudden and explosive. Replies Akasofu, "The magnetosphere is a big container, so there must be some storage of energy. But I don't expect more than twenty percent of an aurora's power to come from such a mechanism."

With the aurora so intimately linked with the condition of the solar wind, monitoring of that ever-changing river of charged particles allows for short-term predictions of magnetospheric disturbances. From August 1978 until September of this year, the International Sun-Earth Explorer (ISEE) provided such a service. This vigilant satellite was parked a million miles from Earth, far upstream in the solar wind. From there, it could immediately relay to Earth the wind's speed and the strength and direction of its magnetic field a full hour before the solar stream hit the Earth's magnetosphere.

But with man expanding his activities to the polar regions and to near-Earth space (auroral curtains stretch into the altitude range of an orbiting space shuttle), the need for longer and more reliable lead times is becoming more pressing.

> To create artificial auroras, scientists use rockets that shoot beams of electrons into the upper atmosphere.

Solar flares are observed and warnings routinely given out now. But the missing link, says Akasofu, is determining just how the sun is changing certain solar wind parameters. When the wind's magnetic field is pointing north, for example, the auroral ovals are dim and contract toward the poles. But if a solar flare makes the wind a bit gusty and the field lines flip toward the south, magnificent displays can occur. That's when the oval expands toward the Equator and the lower latitudes have a chance at seeing an aurora.

Going beyond passively photographing auroras, scientists are also probing them with rockets and creating their own artificial atmospheric light shows. From the Poker Flat Research Range 30 miles north of Fairbanks, the only university-operated rocket facility in the world, the Geophysical Institute researchers launch Nike-Tomahawk rockets ("the Model A Ford in rocket transportation," according to Neal Brown, supervisor of the range). For a flight lasting about six minutes, each rocket carries a 200-pound payload of magnetometers, optical scanners and particle counters to an altitude of about 150 miles to study the personality of a specific auroral display.

LUMINESCENT IONS

"We can also use the rocket to 'kick' the atmosphere ourselves and see how it responds. In a sense, create a man-made aurora," says Hans Stenbaek-Nielsen from the Fairbanks group. Sometimes this is done by taking a compact electron accelerator up on a rocket and shooting beams of high-energy electrons into the upper atmosphere, forming faint auroral streaks. Another technique is to place a detonator on the rocket and explode metallic barium into the upper atmosphere. "It's like tossing dye into a stream," says space physicist Eugene Wescott. "The barium is ionized by solar ultraviolet radiation and begins to emit a bluish-purple glow. These luminescent ions move in reaction to the electric and magnetic fields out in space and string out along the field lines like beads on a wire."

The use of chemical tracers in space will soon be extended even farther. The United States, Great Britain and West Germany are now collaborating on a venture known as the Active Magnetospheric Particle Tracer Explorers, a test that involves three satellites to be launched in 1984. The German and British probes will travel sunward for tens of thousands of miles, far outside the Earth's protective magnetosphere. Then 16 canisters of barium and lithium will be blown intermittently off the German spacecraft. "Once this dye is dropped into the solar stream," says APL's Potemra, "the British satellite on the outside of the magnetosphere and the American satellite circling the Earth inside the magnetic cavity will follow the progress of the particle clouds with sensitive detectors. They'll try to see how these particles leak into the magnetosphere and how they energize in their journey toward Earth."

The aurora has now been poked with rockets, probed with high-power radio beams and photographed with film and TV cameras—and for good reason. Its glow and dancelike shimmerings offer scientists the chance to diagnose the "health" of the Earth's magnetosphere, man's largest plasma laboratory. Already, some of the peculiar wanderings of auroral particles have been found to break the accepted rules of plasma physics. Knowledge of these dynamics may help others to control plasmas in our Earthbound laboratories, thereby helping us to harness fusion as a source of energy. In astrophysics, it will certainly lead to new understandings of solar flares, of the magnetospheres of other planets such as Jupiter and Saturn, and of highly magnetized celestial bodies such as pulsars. The beauty of the aurora, it appears, is more than skin-deep. ■