On Sprites and Their Exotic Kin

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About 15 years ago, on a clear dark night on the Minnesota prairie, a young scientist testing his auroral imaging camera discovered giant flashes of light illuminating the sky above the distant thunderstorms. Without knowing it at the time, Robert Franz had observed what became known as “red sprites” (1). Researchers wondered how such a spectacular phenomenon, visible to the naked eye and in our immediate surroundings, could have gone unnoticed for so long. Of course, it had not gone unnoticed: Scientists had not paid attention to eyewitness accounts through the years.

The discovery sparked considerable research activity, particularly in the United States, where hot humid air masses sweeping up from the Caribbean and the Pacific power frequent summer thunderstorms. The Rocky Mountains serve as a perfect platform from which scientists during the night can point their sensitive video cameras over the thunderstorms on the plains. Over the past decade, such studies have turned up a surprising collection of optical emissions above thunderstorms, such as “blue jets” and “elves” (see the figure). The question of whether sprites and jets affect the atmosphere in important ways—for instance, through altering greenhouse gas concentrations in the stratosphere and mesosphere or modulating the atmospheric electric circuit—is receiving increased attention.

But what are sprites? They are luminous flashes that last from a few milliseconds to a few hundred milliseconds. The larger sprites may reach from 90 km altitude almost down to the cloud tops, extending more than 40 km horizontally. They are often carrot-shaped (2) and made up of bundles of filaments with diameters of 100 m or less (3), but can also take other forms, such as a collection of vertical columns.

Sprites are thought to be generated by the electric field pulse that travels upward toward the ionosphere from a positive cloud-to-ground (+CG) stroke of lightning. The electric field amplitude, $E$, decreases more slowly with altitude than does the atmospheric pressure, $p$. At a certain altitude, the ratio $E/p$ will therefore cross the threshold for electrical breakdown (4). Above ~90 km, the atmosphere is a good electrical conductor and the field is shorted out. High-speed optical imaging has indicated that the sprite discharge propagates downward from an initial altitude of ~75 km, and then shoots upward as a recoil (5).

The spectral content of optical emissions (color) (6) and the electromagnetic radiation observed in the extremely low frequency (ELF) range (10 Hz to 1 kHz) (7) both indicate that electric currents flow in sprites. It also seems clear that, in contrast to the fully ionized channels of conventional lightning, sprites are weakly ionized. Both normal lightning return strokes and sprites have electron energies of a few electronvolts (eV) or 20,000 to 30,000 K (8). Thus, sprites can be classified as a form of lightning and are sometimes referred to as “high-altitude lightning.”

It has been suggested that an electrical breakdown mechanism carried by relativistic electrons also operates in sprites (9). The idea is that free relativistic seed electrons generated by cosmic rays start an upward ionization avalanche, creating additional high-energy electrons. The existence of this process is supported by observations of $\alpha$- and $\gamma$-radiation from the atmosphere above thunderstorms (observed by the Compton Gamma Ray Observatory), which suggest emission of bremsstrahlung by MeV-energy electron beams in the upper atmosphere (10). The role of relativistic breakdown in sprites remains a topic of intense research.

Blue jets, a less frequently observed class of high-altitude emissions, were discovered during a NASA aircraft campaign performing the first dedicated search for optical emissions above thunderclouds (11). Jets are partially ionized, luminous cones of primarily blue light that propagate upward from the top of thunderstorms at speeds of ~100 km/s, reaching some 40 km altitude. They are often generated when substantial charge buildup in a cloud occurs without relaxation through conventional lightning discharges. On one occasion, a jet was seen to trigger a sprite, creating a direct, high-conductivity electrical connection from cloud top to ionosphere (12).

The last of the three most common optical emissions, the elves, are microsecond-duration luminous rings at about 90 km altitude, centered over a parent lightning stroke, that rapidly expand outward with the speed of light (13). They are not discharges, but rather a result of atmospheric heating by the electromagnetic pulse generated by a powerful lightning stroke (14).

To date, sprites have mostly been studied from the ground over the U.S. plains during the summer thunderstorm season. During the summer of 2000, the first ground campaign from Europe documented sprites over southern France and northern Italy (15). These observations have added momentum to initiatives such as the satellite project TARANIS (Tool for the Analysis of Radiations from Lightnings and Sprites), proposed for the microsatellite program of the French space agency, Centre National D’Etudes Spatiales (CNES). If selected, TARANIS could propel Europe to the forefront of sprite research.

Other European initiatives include the integrated science team network SPECIAL (Space Processes and Electrical Changes Influencing Atmo-
The Beauty of Symmetry

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Since ancient times, human beings have connected beauty with symmetry. In science, this correlation is found in many areas, from the fundamental laws of physics to the products of modern chemistry. The \( \text{C}_{60} \) molecule exemplifies the beauty of symmetry: It has icosahedral \(( \text{I}_h \)\) symmetry, the highest possible symmetry for molecules \((1)\). Much more complicated molecules (here termed “clusters”), formed by self-assembly from simple ingredients, can also have \( \text{I}_h \) symmetry or at least be highly symmetric. Two examples of such fullerene-like clusters are presented by Bai et al. on page 781 \((2)\) and Moses et al. on page 778 of this issue \((3)\). These structures will be considered here in the context of recent achievements in nanometer-scale cluster chemistry.

The cluster reported by Bai et al. is icosahedral and has two basic segments: 20 six-membered \( \text{P}_4\text{Cu}_2 \) rings and 12 pentagonal \( \text{P}_5 \) rings. Hence, despite its complex composition, it contains the basic 20 hexagons and 12 pentagons of \( \text{C}_{60} \) (comparable to the distorted truncated icosahedron (brown, top right in the figure)) \((2)\).

The cluster of Moses et al. contains an icosahedral \([\text{Ni}_{12}(\text{uL}_{12}-\text{As})^3]^{-}\) fragment at the center of an \( \text{As}_{30} \) dodecahedron (fullerene cage) \((3)\). The interpenetrating nature of the \( \text{As}_{30} \) dodecahedron and the \( \text{Ni}_{12} \) icosahedron (see the figure, top left) gives rise to a polyhedron with 60 triangular faces, corresponding to an icosahedral geodesic polyhedron. A similar topology is found in the very stable, easily accessible icosahedral “\( \text{Mo}_{12} \)” molybdenum oxide cluster \((4)\), in which 12 pentagonal units are linked by 30 spacers. The cluster shows an unprecedented series of interpenetrating distorted Platonic and Archimedean solids (all of which are shown in the figure), with all atoms located in the surface. A similar shell structure, built from an icosahedron and a rhombicosidodecahedron, has been observed in a \( \text{Pd}_{24}\) cluster with a \( \text{Pd} \) core and \( \text{CO} \) and \( \text{PEt}_3 \) ligands \((5)\) (see the figure).

Clusters of \( \text{Pd} \) and \( \text{Au} \) with spherical metal cores are usually obtained by reducing a solution of the metal complexes (related experiments were first performed by Michael Faraday). The prototype for such clusters is the \( \text{Al}_{13} \) cluster, with a cuboctahedral environment of the central \( \text{Au} \) atom (this structure is similar to an icosahedral arrangement). The sizes of larger species of that type—such as \( \text{Pt}_{39} \)—are controlled by “magic numbers” corresponding to full shells of the cuboctahedral structure \((6)\). Clusters with more complex metal atom cores are also known for \( \text{Al} \) and \( \text{Ga} \) \((7)\). In the largest aluminium cluster, \( \text{Al}_{17} \), the central \( \text{Al} \) atom nevertheless has an approximate icosahedral environment. Giant complex clusters with metal chalcogenide (\( \text{S}, \text{Se}, \text{Te} \)) cores have also been synthesized. The largest has a spherical \( \text{Al}_{18} \text{S}_{94} \) core with \( \text{S}_{10}, \text{S}_{34}, \) and \( \text{S}_{50} \) shells \((8)\).

The preference for (highly) symmetric electromagnetic radiation and electrical discharges on the chemistry of the stratosphere and mesosphere, the effects of space particle radiation, and the possible influence on the electromagnetic radiation balance through modification of greenhouse gas concentrations (which increase absorption of radiation) at these altitudes. Studies of sprites also promise to improve our understanding of the elusive mesosphere, perhaps the least understood layer of Earth’s atmosphere.