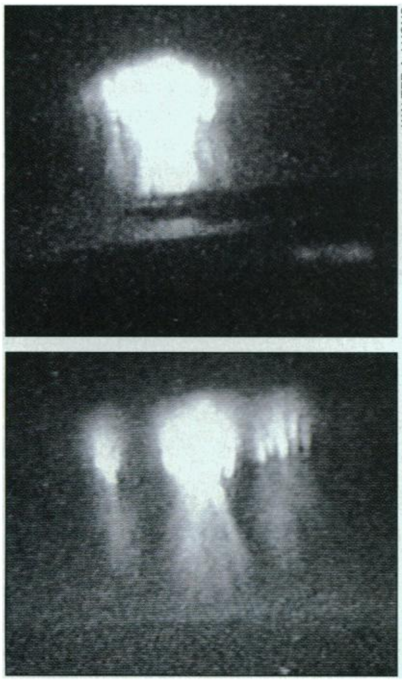
ATMOSPHERIC RESEARCH

Atmospheric Scientists Puzzle Over High-Altitude Flashes

It was a dark and stormy night. No, it wasn't the opening of a bad Victorian novel, just a perfect night for meteorologist Walter Lyons to watch for what was once thought to be a rare phenomenon—faint flickers of light high in the atmosphere over thunderstorms. That night last summer, as a huge, lightning-charged storm hundreds of kilometers northeast of his Colorado house did its part to feed the great flood of 1993, Lyons got his first naked-eye view of his quarry: "a faint, almost curtainlike gauze of salmon-colored orange-red." Lyons, who works at Mission Research Corp. in Fort Collins, Colorado, captured that flash and many others on an ultra-sensitive video camera. Over 15 nights of monitoring last summer, he collected more than 600 examples—enough to convince his colleagues that optical flashes are not at all rare.



WALTER A. LYONS

The light fantastic. Flashes over some thunderstorms can span the stratosphere.

But they are mysterious, and their mystery has deepened now that investigators have stumbled on what may be counterparts to the optical flashes at other wavelengths. In one of these serendipitous findings, a satellite launched last year to test ways to monitor nuclear blasts detected microsecond radio flashes, apparently linked to thunderstorms, that are 10,000 times more intense than the radio crackling such storms normally generate. In another discovery, reported in this issue of *Science* (p. 1313), the orbiting Compton Gamma Ray Observatory—intended to study powerful celestial gamma-ray sources like supernovae and pulsars—picked up gamma-ray flashes originating in the upper atmosphere suspiciously close to some storms.

When the mystery was limited to optical flashes, investigators found it easiest to ascribe them to the electric fields generated by thunderstorms. Now that its scope has broadened, thunderstorms still seem the most promising culprit, but the power of the radio and gamma-ray bursts seems beyond the reach of an ordinary storm. The gamma-ray flashes "leave your jaw open," says Davis Sentman of the University of Alaska. They are "in an energy regime orders of magnitude above anything anyone imagined. I would guess all these observations [optical, radio, and gamma-ray flashes] are tied up with each other, but no one has come up with a comprehensive theory yet."

Observation and theory have come furthest for the optical flashes, which may have been spotted for the first time more than 100 years ago. The atmospheric science community didn't take much notice, however, until 1989, when R. C. Franz, Robert Nemzek, and John Winckler of the University of Minnesota happened to catch one on video tape while testing a low-light-level camera. Now that Lyons has recorded 600 of them, adding to the 18 captured by a camera on the Space Shuttle and 19 recorded by Sentman and Eugene Wescott from a high-flying aircraft, the flashes' appearance—if not their true nature—is coming into focus.

Variously described as carrot-, turnip-, or jellyfish-shaped, optical flashes are no brighter than an average aurora and much shorter lived, persisting for a few tens of milliseconds or less. Their roots may or may not touch thunderstorm cloud tops, but they rise to altitudes of as much as 80 or 100 kilometers, just into the lower ionosphere, and span 10 or more kilometers. Over some storms, they flicker every couple of minutes or so; over other storms, even violent ones, they may never appear.

In spite of this inconsistency, lightning is the power source most often invoked. In a theory sketched out in 1925 by the British meteorologist C. T. R. Wilson, the electric field generated by a lightning bolt might propagate upward until the atmosphere becomes thin enough for the field to ionize it by ripping electrons from molecules of nitrogen or oxygen. The electrons, accelerated by the field, would crash into other gas molecules, punching up their energy levels so that the excited molecules emit light of a characteristic color when they fall back to their normal energy levels—the same process that generates the ghostly light of the aurora. That scenario could explain why the light originates some distance above a storm and why it can have the orange-red color Lyons noted: That's just the color of light emitted by excited nitrogen molecules, he notes.

For the 100 radio bursts picked up by the ALEXIS satellite, a link with lightning is equally tempting but more problematic, says Daniel Holden of Los Alamos National Laboratory, principal investigator of the satellite's Blackbeard radio experiment. The instrument can't determine a radio burst's location, but it did tend to pick up the flashes when the satellite was passing over regions where the local time was late afternoon or late night—times when thunderstorm activity is at its height. What's more, electrons accelerating within a lightning bolt routinely give off radio waves—the cause of the crackling heard on an AM radio during a storm.

But Holden and his colleagues are at a loss to explain why electrons accelerated by lightning would generate radio emissions as powerful as the ALEXIS flashes. Nor can they explain why the flashes are thousands of times shorter than a typical lightning discharge, notes Holden, or why they come in closely spaced pairs.

The dozen gamma-ray flashes detected during the past 2 years aren't easy to explain as the products of ordinary thunderstorms, either. The flashes do tend to come from the areas of Central and South America, Africa, and Southeast Asia where thunderstorms are most frequent. And in each of the seven cases in which satellite cloud images of the emission region could be found, the images showed a major storm complex, likely to be riddled with lightning. But the gamma rays can't be coming from the storms themselves, as Gerald Fishman and his colleagues at the Marshall Space Flight Center point out in their *Science* paper. The gamma rays would have to originate above 30 kilometers—well above the cloud tops—otherwise they would be absorbed by the atmosphere long before they reached the orbiting detector.

At first, Fishman and his colleagues thought that ruled out the storms as an energy source. But, delving into the literature, they realized that there may be ways for a storm to transfer energy to the upper atmosphere. One possible mechanism is lightning bolts rising straight out the top of a thunderstorm toward the ionosphere, something pilots have reported on rare occasions but no one has ever photographed. The other possibility is Wilson's discharge mechanism, the suggested cause of high-altitude optical flashes. Electrons accelerated by either mechanism could in turn emit gamma rays when they slam into high-altitude gas molecules.

But there's one catch: To judge from the range of gamma-ray energies recorded in orbit, the electrons would need energies of over 1 million electron volts. Accelerating electrons to those energies, at least by Wilson's mechanism, would take lightning 30 times more powerful than the typical bolt.

Such "superbolts"—enormous, cloud-to-cloud bolts extending tens of kilometers or even 100 kilometers horizontally—have been sighted, notes Lyons, and he suspects they might trigger optical flashes as well. The storms that consistently produce flashes, he has found, are the very biggest ones, spanning a few hundred kilometers and known as mesoscale convective systems (*Science*, 30 August 1985, p. 848). Storms on that scale, he says, are the most likely to unleash superbolts. Superbolts might also explain why the flashes tend to be concentrated not over the heart of these storms, where ordinary lightning activity peaks, but over the less active margins, which might be anchor points for the long-range lightning.

Space physicist Gennady Milikh of the University of Maryland and his colleagues have independently done calculations that support Lyons' speculation that big, horizontal lightning bolts would be particularly effective triggers for high-altitude optical flashes. But testing that and other ideas will take intensive observations, and researchers will be flocking to the High Plains this summer to make them. Cross your fingers for more dark and stormy nights.

–Richard A. Kerr

Additional Reading

W. A. Lyons, "Characteristics of Luminous Structures in the Stratosphere Above Thunderstorms as Imaged by Low-Light Video," *Geophysical Research Letters* **21**, 875 (1994).

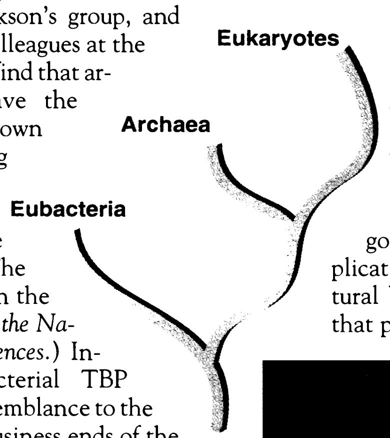
MOLECULAR EVOLUTION

Archaea and Eukaryotes Grow Closer

Once upon a time, biologists drew the tree of life with two main branches. The prokaryotic kingdom, containing single-celled organisms, such as bacteria, that lack nuclei, occupied one limb; the other limb housed the eukaryotic kingdom, comprising all the rest of life, from single-celled paramecia to *Homo sapiens*. But that simple picture changed in 1977 when evolutionist Carl Woese of the University of Illinois discovered that a group of strange organisms he originally called archaebacteria, which were then classified as prokaryotes, appear to differ as much from other bacteria as they do from eukaryotes. That placed the archaebacteria, which generally live in extreme environments such as super-hot ocean hydrothermal vents, in their own kingdom—the Archaea—a separate branch on the tree of life.

But Woese's finding left unanswered the question of *where* that branch belongs on the tree. Did it split off the main trunk before the eukaryotes diverged from the other bacteria (known as eubacteria)? Or did it branch off later, and if so, from which limb? Evidence that appears to answer that question is emerging in the form of similarities in the molecular machineries that Archaea and the eukaryotes use in the first step of gene expression, the transcription of genes into RNA. The latest advance comes from Stephen Jackson and his co-workers at Cambridge University in England, who report on p. 1326 that they have cloned an archaebacterial gene that closely resembles the gene for a key eukaryotic transcription factor, and that the factor seems to function much the same in the Archaea as in humans. "The finding in effect cements what was considered probable before," says Woese, namely that archaebacteria and eukaryotes are each other's closest cousins.

The evidence for this association has been building for the past 5 years. Researchers found that several archaebacterial proteins involved in gene transcription resemble those of eukaryotes more than those of eubacteria. And in 1990, Wolfram Zillig's group at the Max Planck Institute for Biochemistry in Martinsreid, Germany, as well as that of Michael Thomm at the University of Regensburg, Germany, found gene control sequences in archaebacterial DNA that resemble the TATA box, a regulatory sequence found in eukaryotic, but not eubacterial, genes. Now, Jackson's group, and Gary Olsen and his colleagues at the University of Illinois, find that archaebacteria also have the transcription factor, known as the TATA binding protein (TBP), that acts through the TATA box to activate gene expression. (The Olsen results appear in the 10 May *Proceedings of the National Academy of Sciences*.) Indeed, the archaebacterial TBP bears a remarkable resemblance to the human protein; the business ends of the proteins are 40% identical.



Such similarity implies a common function for the proteins in archaebacteria and eukaryotes, and further work by the Jackson group suggests that is the case. The researchers showed that archaebacterial TBP binds the TATA-like sequence from archaebacteria, just as the eukaryotic counterparts do. Moreover, the binding is enhanced by the involvement of the archaeal form of a transcription factor called TFIIB, recently found to be shared by archaebacteria and eukaryotes, but not prokaryotes. This implies the archaebacterial proteins work together to promote transcription, as their homologs do in eukaryotes. Jackson's group also found that archaebacterial TBP even binds to two human proteins that regulate gene transcription by linking up with TBP. "Even though it diverged from the eukaryotic line of descent over 3 billion years ago, it can still interact with eukaryotic factors," says Jackson.

The implication, Woese says, is that the Archaea and eukaryotes descended from a common lineage that had already split off from the eubacterial lineage. "Here is an essential component of the transcriptional apparatus that must have arisen in the common archaeal and eukaryotic lineage, that did not occur in bacteria," he notes. Moreover, the Olsen group performed a quantitative analysis of nucleotide changes that suggests the Archaea have diverged less from the common ancestor they share with the eukaryotes than the eukaryotes have. If so, says Woese, the Archaea may act as a key to that long-lost ancestor, providing "a fine reading on the origins of the eukaryotic cell."

The impact of the finding goes beyond its evolutionary implications, says Yale University structural biologist Paul Sigler. He notes that proteins from extreme heat-loving organisms often form very stable crystals, which may aid efforts by his group and others to crystallize TBP-containing protein complexes from heat-loving archaebacteria and thus to learn more about the protein-protein interactions central to archaeal gene transcription. And because these complexes resemble those of eukaryotes, our strange new neighbors on the evolutionary tree may help us to better understand ourselves.

–Marcia Barinaga

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New relations. Archaea like this one, *Methanospirillum hungatei,* may share an ancestral lineage with eukaryotes.