Beyond the Skylab Effect: The depths of an ionospheric hole

Scientists spent a year trying to figure out the strange occurrence of May 14, 1973, before they were finally able to give it a name: The Skylab Effect. The symptom was the sudden disappearance of most of the free electrons in a portion of earth's ionosphere, leaving a huge "hole" that spread over some 2.5 million square kilometers and lasted for hours. It was detected by its effect on radio transmissions from the ATS-3 satellite, which was being monitored by receivers as far apart as Massachusetts, Illinois and Labrador, but the explanation at first was a mystery.

Analysis subsequently revealed that the signals just happened to have been passing through the expanding exhaust cloud from the second stage of the Saturn V rocket that was carrying the Skylab space station into orbit from its Florida launchpad. The high altitude of the second-stage ignition caused the exhaust to be released into the ionosphere, where it combined with the abundance of positively charged oxygen atoms (O^+) to speed up by 1,000-fold the formation of positive molecular ions that are efficient at gobbling up the local free electrons (which are negatively charged). It was "a dramatic ionospheric phenomenon," wrote Michael Mendillo of Boston University and colleagues in their report, "unique in magnitude and in spatial and temporal extent."

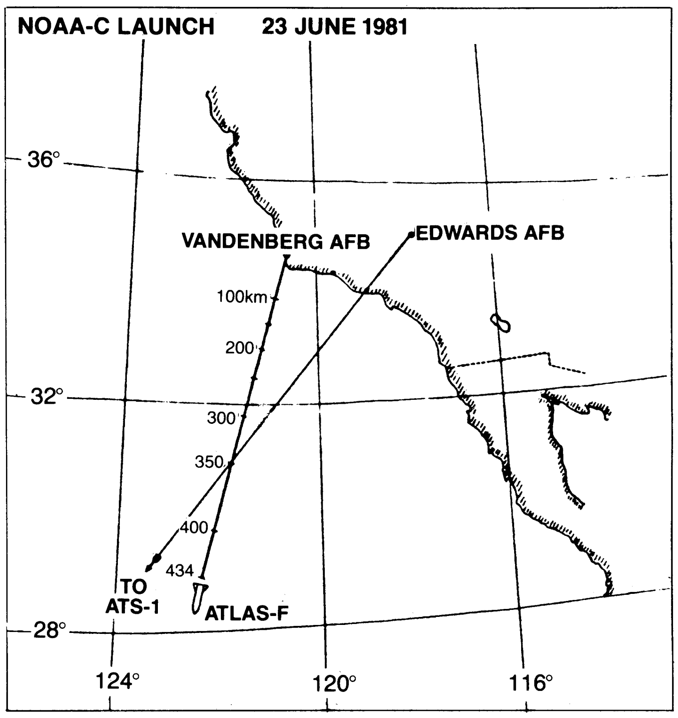
The study of ionospheric holes has grown considerably since its unexpected beginning. They can occur naturally near the equator (where the earth's magnetic field lines are parallel to the surface), when portions of the less-electron-rich lower ionosphere sometimes percolate up to shove the overlying electron supply out of the way. Numerous ionospheric studies are conducted in the low latitudes for that reason, but holes have also been deliberately created by releasing quantities of water vapor and carbon dioxide (typical rocket exhaust products) from sounding rockets. Radio astronomers have suggested that holes over their antennas could offer a whole new "window" to the sky, letting in low-frequency signals normally blocked by the ionosphere.

Mendillo, in fact, together with Paul Bernhardt of the Los Alamos National Laboratory, is coordinating a plan in which the second flight of Europe's Spacelab facility aboard the space shuttle (now set for November 1984) will be used to form holes over several radio observatories and radar installations for a variety of experimental purposes. Researchers studying the hole created by the 1979 launch of the HEAO-3 satellite were even convened by the Department of Energy to see whether holes could serve as a tool for evaluating the possible environmental effects of the many launchings required for the in-orbit construction of solar-power satellites. The HEAO-3 hole was monitored not only by several scientific teams, but also by 156 amateur radio operators organized to report on radio-propagation effects up and down the East Coast.

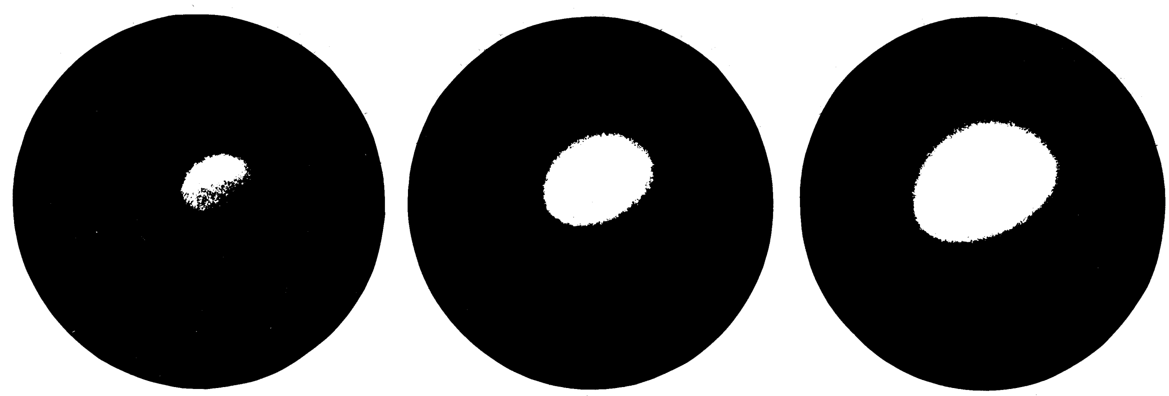
A possibly record-breaking crowd of hole-watching scientists, however, may be the group that congregates this September in Natal, Brazil, for Project BIME, the Brazilian Ionospheric Modification Experiment. There, a sounding rocket will trigger a hole in the lower ionosphere by dispersing a payload of water vapor and CO_2, after which scores of instrument-laden research teams will look to see whether the effect "bubbles up" to produce a natural instability overhead.

Kicking up ionospheric disturbances from beneath can also be done with a more literal kind of "kick." The shock wave from the eruption of Mt. St. Helens shook up the ionosphere enough to be detected over thousands of kilometers. Four months ago, Los Alamos researchers raised a similar kind of disturbance by setting off 600 tons of high explosives on the New Mexico desert at White Sands.

A variety of techniques are being used to study ionospheric holes. While high-



To record an ionospheric hole's electron content and visible airglow from the same position, researchers set up instruments at a spot near California's Edwards Air Force Base, where the ATS-1 satellite's radio signals (key to the electron measurements) would go after passing at the proper altitude through the exhaust cloud of an ascending Atlas-F rocket.



A-2:57:37 B-2:58:05 C-2:58:36

The growth of an ionospheric hole is shown in this photo sequence of the expanding airglow cloud produced by excited oxygen atoms created from the recombination of free electrons and the NOAA-C satellite's Atlas-F rocket exhaust. (Times are a.m., PST.)

Illustrations: Baumgardner, Spence, Mendillo altitude satellites can indicate the declining numbers of electrons by the changing polarization of radio signals beamed through the hole, lower-level probes such as the Atmosphere Explorers can pass a mere 200 or 300 km above the ground to count the electrons directly. Because radar impulses can be bounced off the ionosphere like light reflecting from a mirror, an ionospheric hole can show up as a weakening in the radar reflection. At the recent San Francisco meeting of the American Geophysical Union, S.H. Knowles of the U.S. Naval Research Laboratory told of using a radio-astronomy interferometer to monitor—and even map—ionospheric irregularities by their effect on reception of natural radio emissions from space.

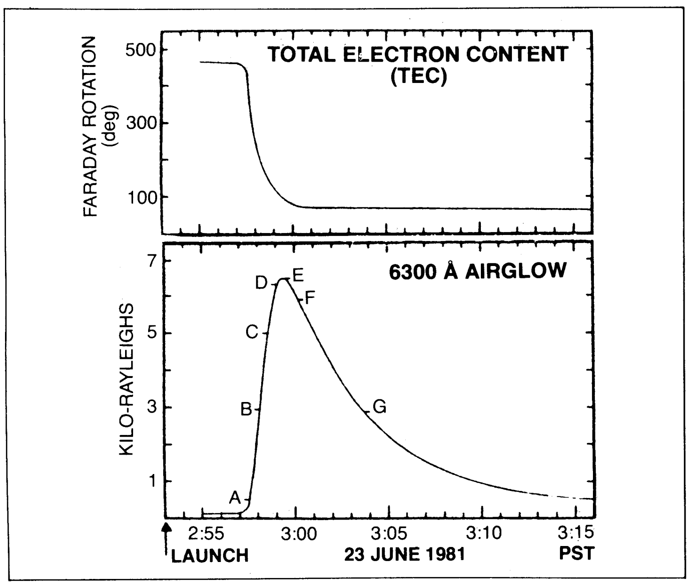
Ionospheric holes (like the ionosphere itself, to say nothing of the radio and radar signals used to tell the difference) are invisible phenomena, for all their dramatic growth and ultimately vast size. Yet they have a visible aspect. The electron-gobbling reactions that produce a hole can yield oxygen atoms in excited states that emit photons of light in a glowing cloud, whose picture can be taken to provide an "optical signature" of the otherwise unseen effect.

At the AGU meeting, Boston University Observatory curator Jeffrey Baumgardner described the results of what he says was the first experiment to simultaneously photograph an ionospheric hole's growing airglow cloud and radio-monitor its disappearing electrons from the same location. The occasion was the launching, last June 23, of the Atlas-F rocket carrying the NOAA-C weather satellite from a pad near Edwards Air Force Base in California's Mojave Desert. The electron count would be made using transmissions from the ATS-1 satellite, poised over the equator at longitude 149°W, so Baumgardner, together with Mendillo and BU undergraduate Harlan Spence, set up the group's instruments at the earth-end of a line from ATS-1 through the anticipated hole. This placed the installation near the little town of North Edwards, where electricity was provided via extension cord from a nearby church.

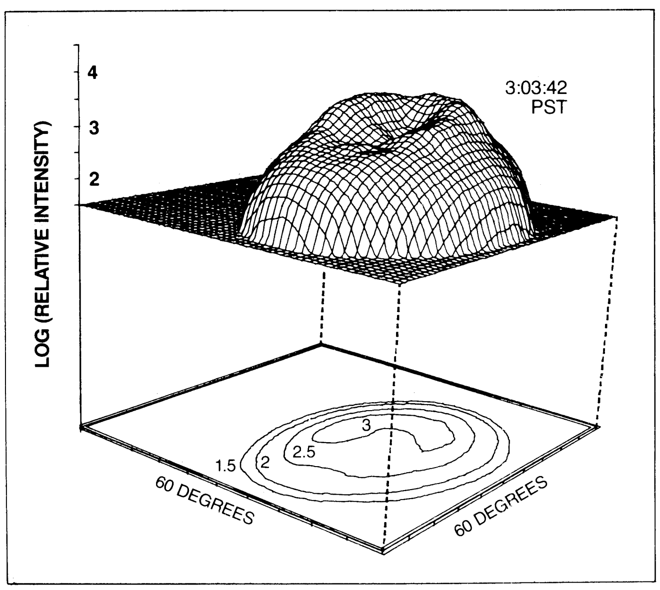
To take the airglow cloud's picture, the group used a narrow-band 6300 Å filter sensitive to emissions from the excited oxygen, and mounted the filter on an ordinary single-lens reflex camera equipped with an image-intensifier. A 60° lens would show the cloud's early growth stages, while a 180° "fisheye" lens would be used when the cloud got too big for the standard optics to handle. Aligned with the camera was a photometer to measure the absolute brightness at the center of the cloud, while the ATS-1 receiver completed the package.

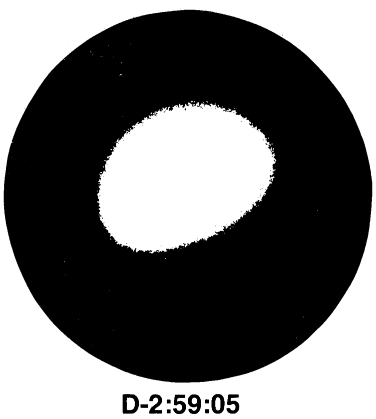
The results are shown here and on the cover. As the hole formed, the electron count along the path from ATS-1 dropped by more than 60 percent, from 30 trillion to 11.6 trillion per square centimeter, the researchers report. Analysis of the ionospheric changes during the event will be published in GEOPHYSICAL RESEARCH LETTERS. Experiments will continue, as scientists study what's in a hole. —*J. Eberhart*

Sudden drop in free-electron content (upper graph) signals the hole's formation, while photometer measurements reveal evolving airglow cloud (lower graph), with letters matched to photos below.



Graph shows horizontal extent of airglow in bottom right photo, with vertical axis representing cloud's brightness. Central brightness dips as cloud approaches ring shape (see cover photo).

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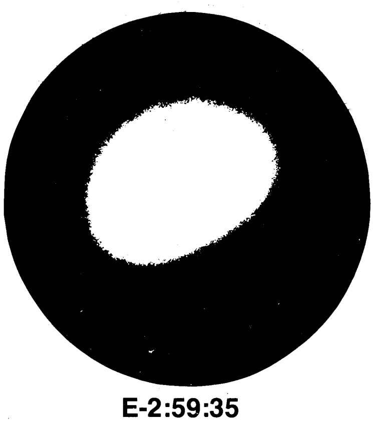
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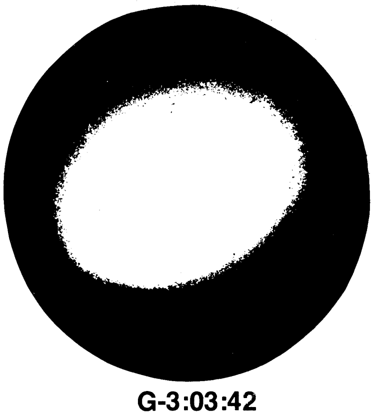
F-3:00:15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