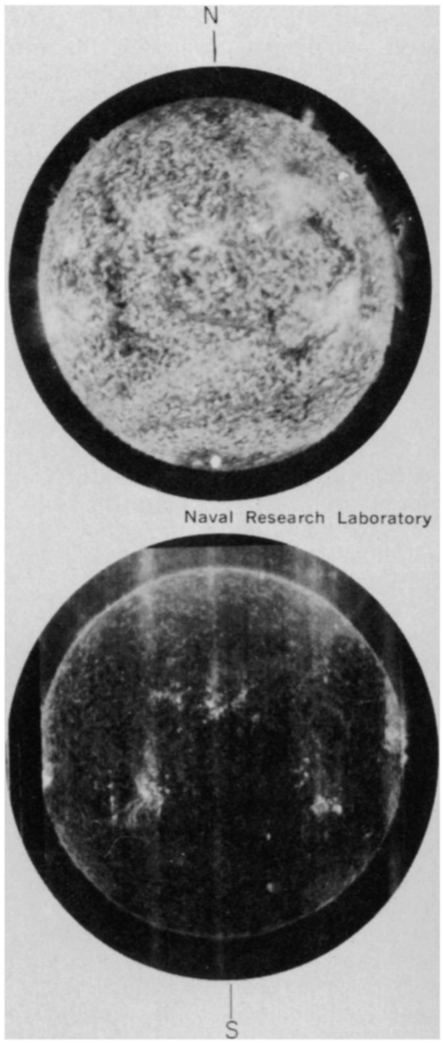
Peeking Beneath the Sun's Skirts

by Everly Driscoll



Structure at transition zone (top) disappears suddenly in corona (bottom).

Corona in X-rays: Holes, bright dots, active zones

Solar scientists are getting an eyeful this summer—more than they had ever hoped for.

Their sensitive solar instruments on board Skylab are clicking away in unison like finely tuned machines. (Such flawless performance is not guaranteed on any space mission let alone on a patched-up space station.) The resulting photographs of the sun have a clarity and resolution never before achieved. And that monstrous, churning, ever-changing ball of gas spewing out enough energy to feed a solar system (SN: 1/27/73, p. 61) is turning out to be much more complex than they ever imagined.

After only two months of looking through the telescopes' eyes at some 40,000 pictures of their favorite star, the scientists sit knee-deep in unanalyzed data, speak of mind-boggling phenomena and structure, and confess they don't know what it all means—yet. But the answers about how the sun works are all there just awaiting discovery, and they know it.

The sun is full of mystery, the true teaser of science.

The six telescopes in orbit photograph the sun simultaneously over a broad range of the electromagnetic spectrum (the first time this has been done). The photographs reveal features on the sun only hinted at before from rocket flights and ground based studies: features in the corona (the hot, thin outer atmosphere), the transition region, the chromosphere (the lower atmosphere) and the photosphere (the surface).

The corona has yielded some of the biggest surprises. Before Skylab, most scientists studying the corona called it the quiet, homogeneous outer layer of the atmosphere. No more. "The quiet homogeneous corona doesn't exist anymore," says Giuseppe A. Vaiana of American Science and Engineering.

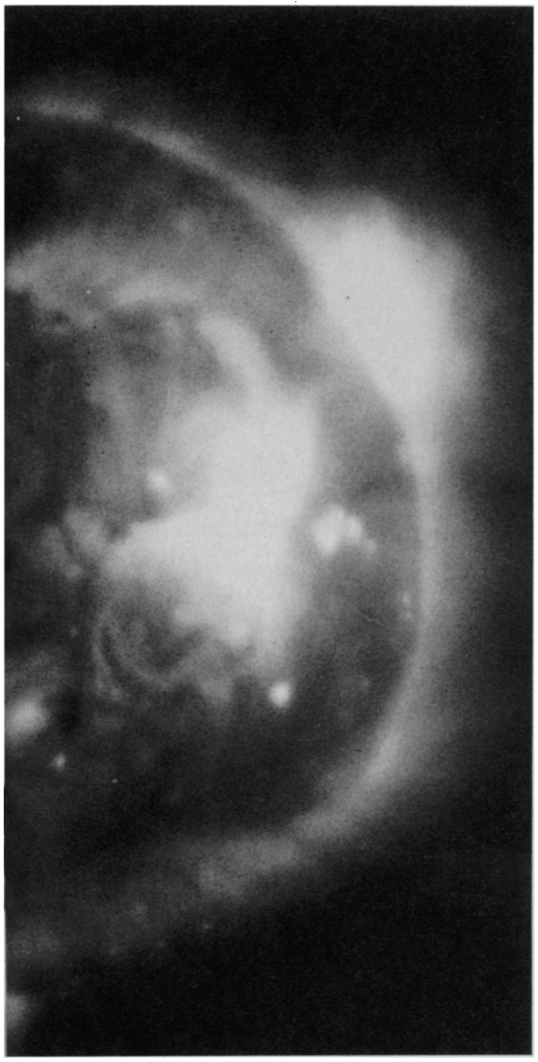
Robert MacQueen of the High Altitude Observatory in Boulder agrees. "We see changes—dramatic, large-scale changes day by day and even orbit by orbit. We are impressed with the bewildering array of structure. The corona is a dynamic beast."

The photographs reveal clearly for the first time the whole range of coronal features, from the intensely active regions to the weakest bright points, filament boundaries and the limb brightening in coronal holes.

But the most impressive scenes in the corona are the ribbon-like structures that look like piles of spaghetti. These are the magnetic fields believed to trigger much of the sun's spectacular events. The fields themselves cannot be seen. But the plasma that follows the field lines can. These looped features, says Vaiana, emphasize that the major force controlling and shaping the corona are the magnetic fields. The ribbons change with time, both in shape and in spectrum (what frequencies of light they emit). This was a surprise. "For decades we've been looking at the magnetic fields during flares and the fields never seemed to change," says Goetz Oertel, chief of solar science at NASA headquarters. Not only do the fields change, they sometimes change drastically. During a flare they may get unstable, blow up or combine. The larger ribbons become prominences that arch for hundreds of kilometers out in the corona. (See related story on Aug. 10 prominence, page 123.)

On the other hand, during the June 15 flare (SN: 6/23/73, p. 402), the changes were not large-scale at all. "The increase of surface brightness registered during the event [flare], from its moment of triggering to its peak, was in excess of a thousand," says Vaiana. But "the resulting structural changes in the region which flared are minimal in comparison with those shown previously. This indicates that

Solar scientists are ecstatic with results from the Skylab solar telescopes as the instruments' eyes are stripping the sun layer by layer.



American Science and Engineering
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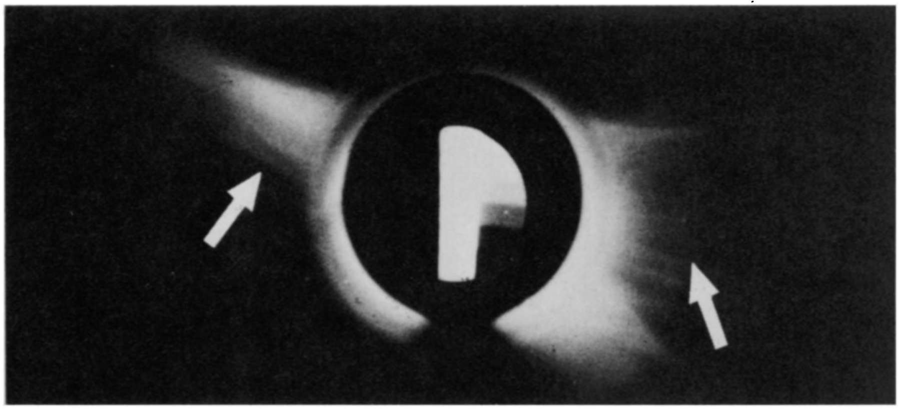

High Altitude Observatory
Instrument disk blocks out sun to show coronal streamers and voids (arrows).

large-scale restructuring [of the fields] is not a *necessary* consequence of large flares." Why the fields change drastically at one time and not at another is still not understood. It could be that restructuring is related to changes in some way on the surface.

Another dramatic mystery are the huge areas of the sun called coronal holes. These are visible in the pictures as dark areas that spread up to half a million kilometers across the sun. The holes—sometimes called polar caps because one is at each pole—are usually about a million degrees cooler than the rest of the corona. Previously they were thought to be regions of little activity. They are most likely connected with unipolar magnetic fields rather than bipolar fields. It is thought the solar wind escapes through these holes.

"It turns out these are not simply coronal holes," says Richard Tousey of the Naval Research Laboratory. The holes extend down well into the chromosphere where the temperatures are only 50,000 degrees C. Why is the chromosphere different in these holes? "We may well be getting a clue about the inside of the sun," says Oertel.

The pictures show another surprise—bright points that look like forest fires scattered over a planet as viewed from space. The bright points also dot the coronal holes, which may indicate the holes are not completely devoid of activity after all. One would expect the bright points to be little active regions (some of them could be flaring, which would be an even *greater* mystery) and thus be found only in the equatorial zone between 40 degrees north and 40 degrees south where much of the sun's violent activity occurs. But they aren't. They are distributed all over the disk, which is a puzzle.

Oertel thinks the bright points may be a new kind of solar activity. In the lower chromosphere, such bright points can be seen in each of the so-called supergranulation cells. Then as one moves up through the chromosphere and transition zone via the telescopes, most of the bright points disappear. In the corona there is about one bright point for every 10 or 20 cells.

The X-ray photographs show the corona head on. The white-light coronograph, however, uses an occulting disk, and reveals the outer corona as its material surges into space. Although the material is seen above the limb, or edge of the sun, it is actually coming from all over the sun—front and back. These finely structured, thin lines are called streamers. They are free electrons that probably follow magnetic field lines out into space. "We really don't know what streamers are," says Oertel. He thinks they could mark the boundaries between the magnetic field layers.

What causes streamers, where they originate and how they are shaped are questions MacQueen hopes to answer by observing the streamers daily as they rotate in the corona. They could be shaped like a cylinder, the Eiffel tower, or a thin sheet.

One picture of the streamers reveals black strips running almost parallel to the streamers. MacQueen calls them "coronal voids" because the regions are void of free electrons. They could be areas where the streamers have moved from, and in the process, swept out the electrons. On the other hand, the presence of coronal voids may be an indication that there is actually no background corona. Most scientists have thought a background corona—a general distribution of free electrons—surrounds the sun. If there is no such background, the outer corona would be composed merely of a lot of streamers.

Tousey has been studying the sun now for 27 years—first with captured German V-2 rockets and then with other rockets. He regards the Skylab work as the culmination of his career. His instrument photographs the sun in the extreme ultraviolet. Both it and the ultraviolet scanning spectroheliometer of E. M. Reeves of Harvard College Observatory look down into the sun—

through the hot corona and the atmosphere to the surface. The two instruments can actually distinguish and photograph six layers of the sun: the visible surface where the temperatures are 6,500 degrees C; just above the surface where the temperature *falls* to its minimum of 4,200 degrees; then the lower and upper chromosphere where the temperatures rise in a 1,000-kilometer distance from 4,200 degrees up to 50,000 degrees; then the transition zone, a thin layer only 100 kilometers or so where the temperatures soar from 50,000 degrees up to 700,000 degrees; and last, the corona, where the temperatures jump to a million degrees in the holes and 3 million to 4 million in active regions.

"The theories about how atmospheric temperatures should change with height just do not apply anywhere in the solar atmosphere," says Reeves of his findings. "Our assumptions about the sun just aren't good enough. They will have to be improved."

One surprise concerned the supergranulation structure: Tousey and Reeves found it was not restricted to the surface or the lower chromosphere at all. "It preserves itself all the way up through the chromosphere and the transition zone," says Reeves. "Then poof. At the corona the structure becomes smeared and almost disappears. That tells us something."

What changes occur so abruptly at the corona to make this structure disappear? Reeves thinks it might have something to do with the energy transfer from the surface to the corona. That same energy transfer is what is believed to cause the high corona temperatures.

This heating of the corona could be due to shock waves that propagate up from the surface and dump energy in the corona. Reeves has a chance to see the effects of these shock waves with his instrument. They would show up as fluctuations in the intensity of the radiation and density of the plasma.

Another enigma is that while most of this chromospheric network smears out, not all structure does. Some structure, such as the bright points, "are like soda straws that stick up all the way to the corona," says Reeves.

As in the early days of lunar exploration, the solar explorers may well have found more questions than answers so far. But they admit they are only on the ground floor looking up with their Skylab 1 data. The astronauts of Skylab 2 are now doubling the time and photography at the solar telescopes. The Skylab 3 crew will get even more. (They will also have a chance to train these sensitive instruments on the planet Mercury and on the comet Kohoutek.)

"We have just had a quick peek-a-boo," says Reeves. "Now we have to go back and do a lot of hard work." □

A massive explosion in the sun's corona

An explosion in the sun's corona that spewed out into space more material than the mass of earth occurred Aug. 10 before the watchful eyes of the Skylab 2 astronauts and their sensitive solar telescopes. Enormous loops of material surged out from the corona at velocities greater than a million kilometers per hour and to distances greater than three and a half solar radii. Scientists working in Houston this month think they may have captured on film the loops as far out as six solar radii.

The event was first noticed by an observatory on the Canary Islands. Astronomers there immediately sent word to the Space Environmental Services Center in Boulder, Colo., the solar weather bureau, which then alerted the Houston scientists. It was the day off for astronauts Alan Bean, Owen Garriott and Jack Lousma but they were so excited they remained glued to the solar telescopes for more than two hours.

Solar scientists call the explosion a "coronal transient" for lack of a better word. During this part of the sun's cycle, such events occur only two or three times a year.

"It was quite a rare phenomenon," says Ernest Hildner of the High Altitude Observatory in Boulder. Hildner, along with 50 other solar scientists, are in Houston off and on studying the results from Skylab.

Scientists don't yet know what causes these events. They believe it has to do with instability in the magnetic field lines confining the plasma in the corona. When these fields suddenly become rearranged, says Hildner, the material is expelled. "Ionized material, hot gaseous plasma on the magnetic field lines, is very much like little pieces of split-shot sinkers on rubber bands [instead of lines], if you're a fisherman," says Hildner. "The magnetic field lines are stretchy and gravity sags them down with the weight of the material that's lying on the magnetic field lines. But if some sudden restructuring of the field line occurs, then this material can be flung outward. We expect that these loops trace out lines of the magnetic fields."

Before the explosion occurred the coronal structures (magnetic field lines) in the area were fan-shaped. After the explosion, a lot of the tenuous material was gone and there were far fewer radial structures, says Hildner. So the explosion did result in restructuring of the fields. What triggers the series of events, however, rmains to be determined. Although the event occurred behind the limb, scientists are pretty sure it happened in an active region—number 76. This region had exhibited two filaments, or prominences, and the scientists are now speculating that the explosion involved both filaments.

One unexplained characteristic of the event is the lack of radio bursts. Two radio observatories were working during the time and observed only a very slight increase in background radiation. "Ordinarily," says Hildner, "you would expect this enormous ejection to excite the plasma which exists in the corona and cause it to emit radio waves. It didn't. That's a puzzle to everybody."

——*Everly Driscoll*

A decade of planetary exploration

This is a decade of unmanned exploration of the planets. Last year the world saw the first closeup photographs of Mars, taken from orbit by Mariner 9. The following tally of spacecraft planned or already launched shows that in the next eight years five planets will be visited by no fewer than 14 unmanned spacecraft.

NAME	MISSION	LAUNCH	ARRIVAL
Pioneer 10	Jupiter flyby	March 2, 1972	Dec. 3, 1973
Pioneer 11	Jupiter flyby	April 5, 1973	December 1974
Soviet Mars 4	Mars lander or orbiter	July 21, 1973	February 1974
Soviet Mars 5	Mars lander or orbiter	July 25, 1973	February 1974
Soviet Mars 6	Mars lander or orbiter	Aug. 5, 1973	February-March 1974
Soviet Mars 7	Mars lander or orbiter	Aug. 9, 1973	February-March 1974
Mariner Venus-Mercury	Venus flyby Mercury flyby	Nov. 3, 1973	February 1974 March 1974
Viking	Mars lander and orbiter	August 1975	June 1976 Land July 4, 1976
Viking	Mars lander and orbiter	August 1975	June-July 1976 Land Aug. 1976
Mariner Jupiter-Saturn	Jupiter flyby Saturn flyby	August 1977	April 1979 February 1981
Mariner Jupiter-Saturn	Jupiter flyby Saturn flyby	Sept. 1977	May 1979 May 1981