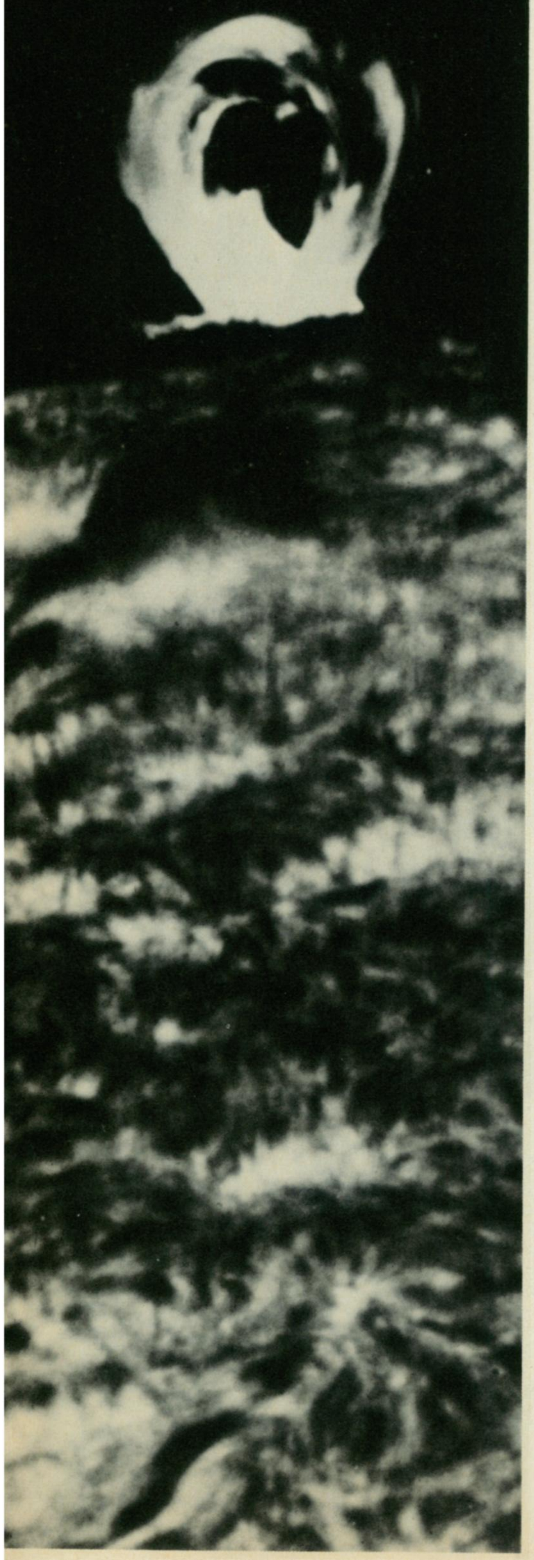
Solar Study: THE YEAR OF THE SUN



With new spaceborne instruments, understanding of the sun has doubled in the last decade. But major questions remain. 1973 may bring some answers.

by Everly Driscoll

A visitor from another galaxy, one of the billions in the universe, would not be able to distinguish the sun from among the 100 billion other stars in the Milky Way galaxy. As a star, the sun is quite ordinary.

"It's a dwarf of the spectral type G. . . . quiet and well-behaved compared to some of its more gigantic or bombastic relatives," notes Robert Howard of Hale Observatories. Its magnetic fields are two orders of magnitude weaker than the smallest fields detectable in stellar measurements. Some stars rotate as fast as 450 kilometers per second, but the sun rotates at only 1.9 kilometers per second. The nearest stars similar to the sun in luminosity and size are Epsilon Eridani and Tau Ceti about 11 light-years away.

"We can only infer from the stars what we see in great detail in the sun," says Werner M. Neupert, a principal investigator on the Orbiting Solar Observatory 7 (oso), which is providing much of what new has been learned about the sun. "The sun is a laboratory where we observe a great variety of physical processes taking place right before our eyes."

The ancients thought the earth was the center of the universe; Copernicus said the sun was. It was not until 50 years ago that man indeed discovered his real position in the universe. Not only is the solar system not in the center of the universe, it is not even in the center of the galaxy. Instead, it is in one of the spiral arms about 30,000 light-years from the center. It is revolving around the center at 250 kilometers per second. It takes 225 million years for the solar system to complete one journey around the galaxy.

The sun is the source of energy for life on earth. "After 10 years of data from orbiting solar observatories [oso 7 was launched in September 1971] man's understanding about the sun has almost doubled," says Stephen P. Maran of the Goddard Space Flight Center. But several major questions about the sun's behavior remain unanswered.

Scientists have dubbed 1973 "The Year of the Sun," and they are hoping data from the most complex array of solar telescopes ever launched—on the coming Skylab—will help solve some of the problems. The Apollo Telescope Mount, as the array is called, will allow physicists to observe solar radiation across the entire spectrum. This year is a particularly important one, because the sun is in the quiet phase of its 11-year cycle. "Until we can understand the quiet sun, we have little chance of explaining phenomena such as active regions, prominences and flares," says solar astronomer Leo Goldberg, director of the Kitt Peak National Observatory in Arizona.

The sun is a ball of gas with a diameter 109 times the earth's. Energy is generated in the interior at temperatures of 15 million degrees K. by nuclear processes and radiated to within 100,000 kilometers of the surface where physicists think there is a convection zone. Above it is the surface layer (photosphere), which is about 500 kilometers thick. The visible surface is characterized by granulation cells. The temperature of the surface averages 6,000 degrees K. with the exception of sunspots—"refrigerated" areas about 2,000 degrees cooler.

Above the surface is a reddish transitional zone (the chromosphere), where temperatures rise rapidly. Howard thinks the thickness of the region up to where the temperature reaches 10,000 degrees K. could not be more than 2,000 kilometers. The temperature then jumps to 100,000 degrees and then to 200,000 degrees in a region he thinks is only about 20 kilometers thick. Physicists aren't sure about this because of the role slender spike-like prominences may play in temperature and gas distribution. These spicules can be seen shooting up from the chromosphere. Maran and John C. Brandt, also of Goddard, cite the vital statistics of these jet-like projections: diameter, 800 kilometers, length, 3,000 kilometers (some say 10,000 kilometers), and average lifetime, 15 minutes. J. M.

Beckers of the Sacramento Peak Observatory estimates there are 400,000 spicules in the chromosphere at any given minute.

In the corona, the tenuous halo around the sun that extends far out into space, the temperatures rise to about 1.7 million degrees K. above the quiet regions of the surface. OSO 7 data show that above the active regions, like sunspots, the temperatures rise to 3 million and 4 million degrees and that over the poles the temperatures drop to 1 million degrees. Temperatures in some flares are as high as 40 million degrees.

What causes this incredible rise in temperature between the surface and the corona? "That is a fundamental problem," says Goldberg, "the question of energy generation and transport." Granules, supergranulation cells, spicules and the vertical oscillations of the atmosphere may be sources of mechanical energy for heating up the upper two regions, he thinks.

The solar atmosphere has been observed to oscillate vertically with a well-defined period of five minutes. These oscillations may be caused by gravity waves, sound waves, or hydromagnetic waves driven by disturbances moving vertically out of the granules. The granules live for only about two and a half minutes and vary in size from 400 to 1,000 kilometers in diameter.

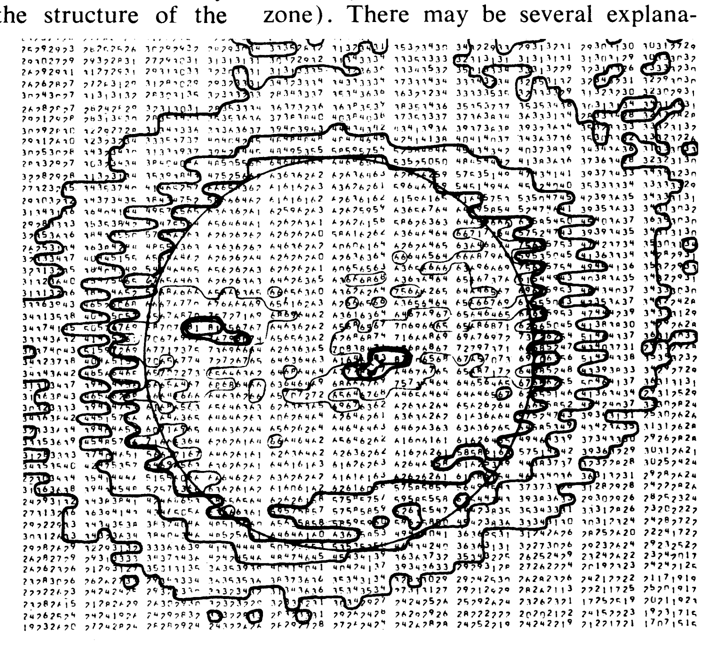
Supergranulation cells, seen in the photosphere, vary from 15,000 to 30,000 kilometers in diameter and live as long as a day. Matter is believed to well up in the centers of these cells and move radially outward at speeds of 500 meters a second. "We can only guess at how the cells originate," says Goldberg. "But whatever their origin, the convection associated with this supergranulation redistributes the magnetic field and by channeling the flow of wave energy, creates inhomogeneities in temperature and density in the chromosphere and corona. At the edges of these cells, where the magnetic field is concentrated, appear the spicules.

"How much energy is transported by each process and where in the atmosphere it is deposited is still unknown," says Goldberg.

Sunspots, prominences and flares characterize the most active period of the sun cycle. Solar physicists now think that changes in the sun's magnetic fields cause the onset of this active period. Magnetic fields of a few hundred gauss are detected, and then appear the first sign of the dark sunspots. The lifetimes of spots vary. The average ones begin to disappear after about 12 days, and the brighter region representing the close-packed magnetic fields begins to disperse.

There are several types of prominences, some lasting as long as a month. Physicists think they are condensations of ionized material in a somewhat arched configuration in the corona. The material appears to be suspended in the magnetic field lines, but how it keeps its form for so long is unknown.

Scientists don't agree on the nature of flares. "One can describe the sequence of events that the flare triggers," says Goldberg, "even though the finger on the trigger, so to speak, is still unidentified." Howard defines flares as a sudden release of large amounts of energy in a relatively small volume above the surface. The problem, he says, is to find the means of storing this amount of energy in the chromosphere or corona and then to find a mechanism for its sudden release. One explanation is that the energy release is caused by an instability in the structure of the magnetic field, although the nature and location of this instability are not known.



Computer picture of sun and corona produced by OSO 7 shows regions of different ultraviolet intensity. The coming Skylab will place a whole array of sun-monitoring instruments into orbit.

NASA/NRL

Electrons associated with the flares emit radio bursts. Other electrons trapped in the strong magnetic fields in the lower atmosphere radiate impulsive bursts of microwaves and X-rays. The electrons collide with atoms in the atmosphere to produce the flare seen in hydrogen-alpha light (the flare itself is probably an aftereffect of other activity). The plasma is heated, says Goldberg, to perhaps 40 million degrees K. and emits soft X-rays, ultraviolet, radio and microwaves. Last year scientists observed for the first time gamma rays emitted during a flare (SN: 10/7/72, p. 231). "We are trying to observe where all these different phenomena take place," says Neupert. "Both ground-based and space observations are needed to solve these questions."

Neupert is also observing coronal "holes": areas deficient in X-ray and ultraviolet radiation. "The holes are not subtle," says Neupert. They are long-lived and cooler—about one million degrees instead of the average 1.7 million degrees, and the gas pressure in the hole is roughly a third the normal value.

Scientists also are not sure about their models of the solar interior. Energy comes from nuclear reactions in the core in which hydrogen is transmuted into helium by fusion. Theoretically neutrinos should be emitted as byproducts of this nuclear reaction. Some neutrinos have been seen, but the rate is much less than predicted (SN: 9/25/71, p. 210). The model is based on a core that is not rotating (although Robert H. Dicke of Princeton has suggested the core is rotating every 24 hours) and on a sun that is unmixed vertically (except in the convection zone). There may be several explanations for the missing neutrinos. The experiment itself may be in error, or the models for the interior may be wrong, or the nuclear parameters used to calculate the rates of nuclear process are wrong. (In fact, Maran says, they may all be wrong.) A fourth possibility was proposed recently by F. W. W. Dilke and D. O. Gough of the University of Cambridge. The sun's overstability might cause the core to mix every few hundred million years, affecting the total energy released by the sun (reducing luminosity by five percent). They suggest this may induce the ice ages on earth and temporarily depress the flow of neutrinos.

The missing neutrino problem is new. What heats the corona and what causes flares are old problems. Says one physicist of the challenge ahead: "There probably are a lot more surprises being held in store for us by our favorite star." □