

Above the Air Is Better

In This Chapter

- ◆ Rockets take us above the atmosphere to study the Sun
- ◆ NASA has launched a series of Orbiting Solar Observatories
- ◆ Crewed spacecraft have studied the Sun
- ◆ Views from over the solar poles are rare and reveal the solar wind

One of the popular exhibits at the Smithsonian's National Air and Space Museum in Washington, D.C., is the backup module to the one that astronauts used on NASA's Skylab Mission. This space station was an early attempt to make scientific observations from space, and the Sun was at the center of the astronauts' attention. The Sun has been the subject of study since the beginning of the space age.

The Air Is Blocking Your View

Several technological developments from World War II proved useful to astronomy after the war ended in 1945. The Sun, as the nearest and brightest celestial object, was the first focus of attention.

The Sun and Radar

Radar was developed especially by American and British scientists in the 1930s and 1940s, following some earlier roots. Radar, which stands for radio detection and ranging, involved the development of electronic devices to detect reflected radio signals sensitively. For a time, it was a military secret that the Sun was a strong emitter of radio waves, for it blocked radio observations when it was active. For example, all radio communications were blocked in England on a range of radio bands for two days in February 1942. Everyone's first thought was that the Germans had worked out a way of blocking radar, but then James Hey realized that the strongest static began when the Sun rose and ended when the Sun set. Though he connected this static with a large sunspot group that was on the Sun, his reports were kept secret until the war was over. An American radio scientist also figured out that the Sun was giving off radio waves, yet couldn't publish until the war was over.

During and after the war, almost nobody thought that the Sun would be significant for astronomy, and it took an amateur astronomer, Grote Reber, to use radio waves to map the sky. He found various radio sources other than the Sun and wrote a scientific article announcing solar radio radiation in 1944. His article was the first to be published that announced the Sun as a radio source.

Other scientists later tracked several kinds of radio bursts. Understanding and predicting them had obvious applications to the security and availability of communications. But radio waves come through a window of transparency down to Earth's surface every day, so they are not the subject of this chapter.

High Above the Atmosphere

The Earth's atmosphere blocks out all the radiation shorter than visible light. In particular, ultraviolet, x-rays, and gamma rays do not penetrate through the atmosphere to the Earth's surface. Thus we must go up into space to study them. Observing the sky from space started with the V-2 rockets captured from Germany; perhaps a hundred of these rockets were brought back to the United States. Rocket scientist Wernher von Braun and most of his team came with them. In the late 1940s, American scientists began using the rockets. The military background of the rockets explains in part why scientists at the U.S. Naval Research Laboratory were pioneers in using them.

The rockets stay aloft for about a half hour, of which about five minutes is prime viewing time. A door on the rocket opens, and a telescope or camera points at the Sun, so many things must happen quickly and many things can go wrong. But even though fewer than half the rockets succeeded, the scientists obtained ultraviolet spectra of the

Sun. These spectral lines revealed conditions in the upper levels of the Sun's atmosphere. At first, the resolution of the spectral lines was poor and the spectra did not go very far into the ultraviolet. But gradually, the quality of the observations improved. Through the late 1950s, many images and spectra were obtained of the solar x-rays and ultraviolet. The data backed the idea that the solar corona is very hot and gave a variety of details. Furthermore, the capabilities left American astronomers ready to plunge ahead when satellites were first launched.

Science was transformed and the space age began on October 4, 1957, when the Soviet Union launched Sputnik. Though Sputnik itself was not a research satellite, its existence galvanized the scientific establishment in the United States and elsewhere. Not coincidentally, 1957–1958 was the 18-month International Geophysical Year (IGY), when scientists all around the world teamed up to concentrate on getting data about the Sun and its relation to the Earth. Preparing for the IGY led to the growth of solar astronomy and solar observatories.

Soon thereafter, NASA began a series of solar observatories in space, beginning with Orbiting Solar Observatory 1 (OSO-1) in 1959. Gradually, the reliability of the spacecraft and the quality of the observations increased. For example, by OSO-6, the resolution obtained was much improved; OSO-8 carried cameras capable of high-speed observations of spectral details. The Soviet Union also sent some spacecraft aloft to make solar observations, though not with such a series of vehicles.



Solar Scribblings

Computers were much more rudimentary when the OSO projects were the latest thing, and there was little imaging that computers were capable of doing. When OSO-4 data came down to Earth, we at the Harvard College Observatory had printouts of numbers showing the strength of intensity from various regions on the Sun. We sat down with markers to color in the regions of similar intensities. I remarked then that it was good to be using the skills I had mastered in kindergarten. The senior professors joined us students in the coloring.

People Aloft

The current methods of lofting rockets are very wasteful. A huge tank of rocket fuel goes aloft with a smaller rocket carrying the payload attached. The Apollo program was devoted to bringing people to the Moon safely and returning them to Earth. It brought 12 astronauts on 6 missions to land on the Moon during 1969–1972. But then, though three additional Apollo missions to the Moon had been planned, they

were cut for lack of funds. The program was perhaps a victim of its own success, since the last several Apollo missions had brought back so many moon rocks and sent back so much information that funders (not scientists!) deemed future missions unnecessary. Apollo 17 from 1972 remains the last time that people went to the Moon.

But NASA had some additional giant Saturn V rockets. They devised a space laboratory to go into Earth orbit, using the empty fuel tank of one of the Saturn V rockets as a laboratory. Attached to that Skylab was the Apollo Telescope Mount. This set of telescopes and instruments was largely devoted to solar observations. Skylab was launched in 1973.

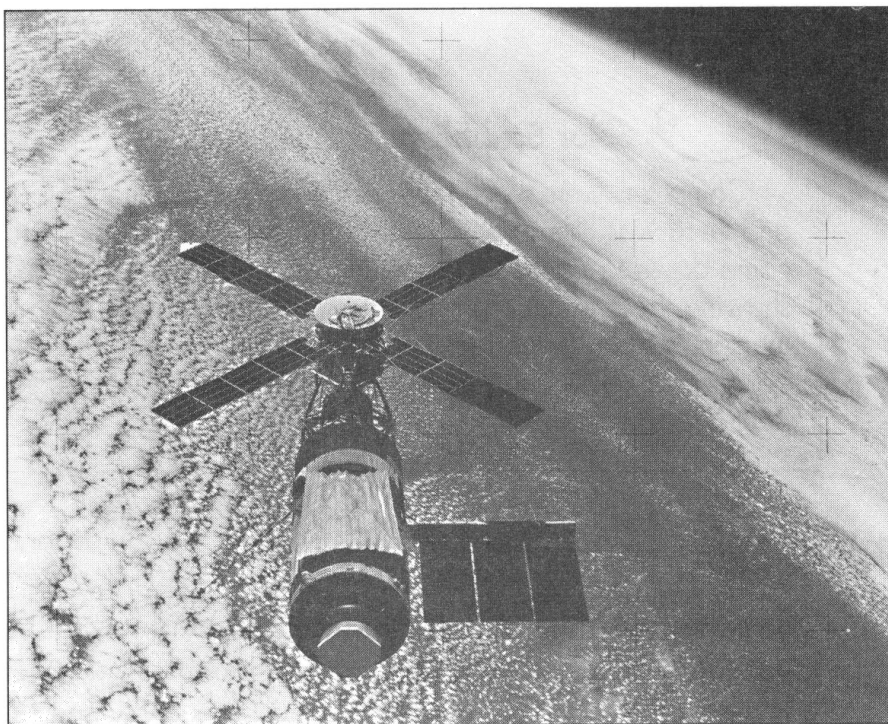


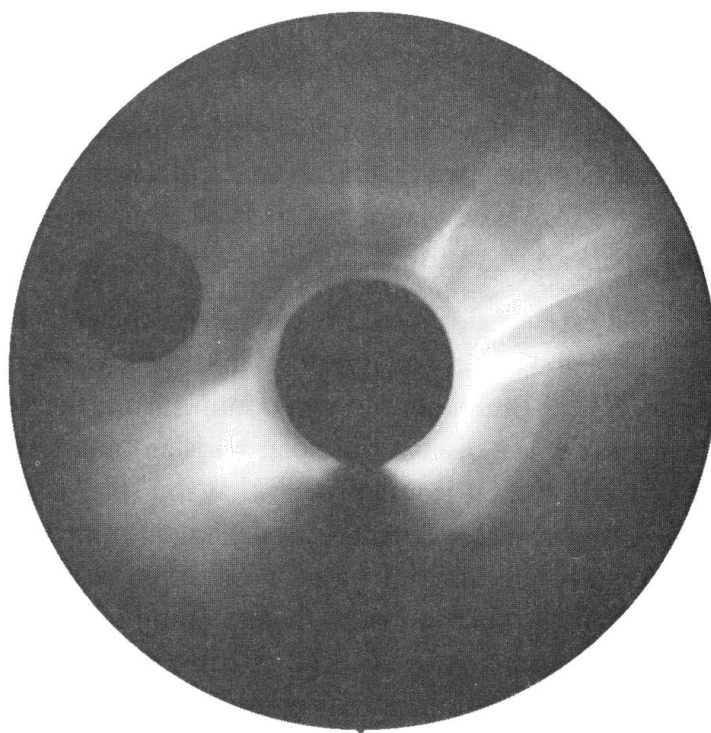
Solar Scribblings

Skylab was not launched very successfully. A shield meant to protect the mission from micrometeoroids broke loose and tore off one of the giant solar panels meant to provide power. The first crew of astronauts to visit Skylab had its repair as their first task. They devised an umbrella to replace the shield, which also kept Skylab usable cool by blocking sunlight from hitting it directly. Over the next eight months, three crews of astronauts successfully used the Apollo Telescope Mount.

Skylab, with its remaining solar panel and jury-rigged sunshade. It carried several solar telescopes on its Apollo Telescope Mount.

(NASA's JSC)





An image with Skylab's coronagraph. Note the size of the Moon (left), which was near to but not in the field of view; a total solar eclipse was visible from Earth that day.

(NASA)

The Apollo Telescope Mount's instruments included two devices to study the solar ultraviolet. It also included a coronagraph to observe the outer corona in visible light. And it had x-ray telescopes that gave the finest x-ray images yet available. The resolution of the x-ray images was so fine that it became clear how dependent the heating of the solar corona was on the Sun's magnetic field; the corona was hottest over the high-magnetic-field sunspot regions. These observations led to the quick demise of the old theory that sound waves from below the photosphere heated the corona.



Solar Scribblings

One of the Apollo Telescope Mount's x-ray telescopes was built by the American Science and Engineering Company in Cambridge, Massachusetts. Soon thereafter, the whole scientific group moved over to the Harvard-Smithsonian Center for Astrophysics. Its head, Riccardo Giacconi, went on to make many discoveries in x-ray astronomy, for which he received the Nobel Prize in Physics in 2002. Giacconi had earlier become head of the Space Telescope Science Institute and then of the European Southern Observatory. American Science and Engineering retained its expertise in x-ray work and is a major provider of x-ray machines used at security checkpoints in airports.

Solar to the Max

The next major solar spacecraft was timed to coincide with a maximum of the solar-activity cycle. It was therefore especially well situated to study flares and other activity. This Solar Maximum Mission (SMM) was launched in 1984. It carried instruments from both American and European institutions.

Among the devices that SMM carried aloft was a coronagraph that was capable of more detailed images than earlier space coronagraphs. Another interesting instrument measured with great precision how much energy was coming from the Sun day after day and how it changed over time. We discuss this solar constant and its measurement in Chapter 26. Suffice it to say here that it was proved that the solar constant wasn't really constant. Furthermore, though the solar constant declined for a while, it was clear that the rate was too high to continue, since the Sun would then waste away quickly. Still, there was some relief when the solar constant began going back up, showing that it kept in phase with the solar-activity cycle. The instrument also showed that the presence of a large sunspot on the Sun reduced the total solar radiation measurably.



Solar Scribblings

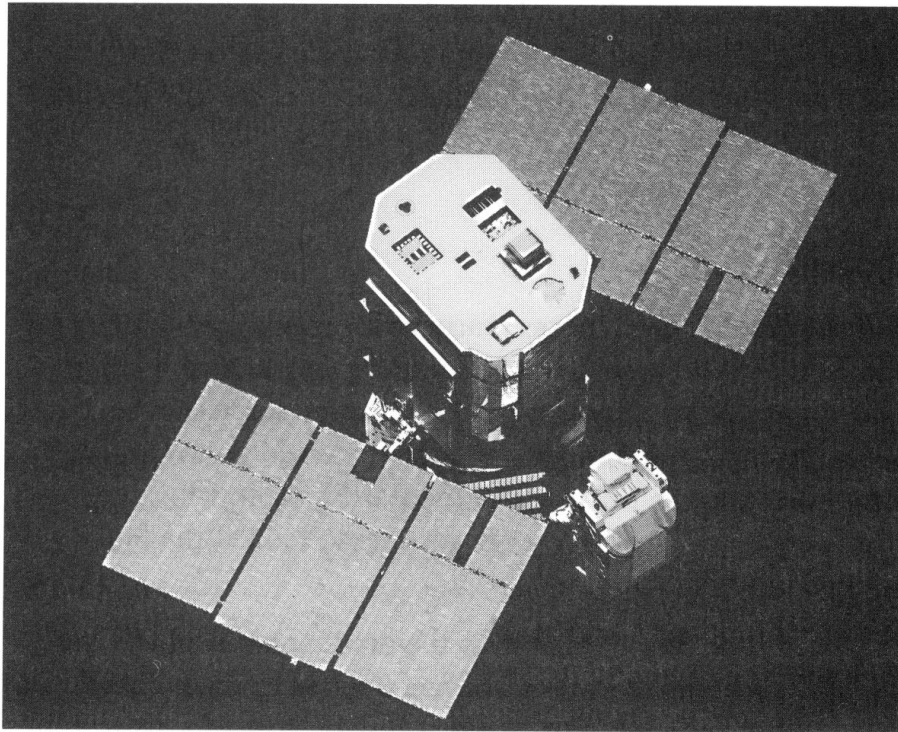
I had a personal interest in the measurements of the solar constant by Solar Maximum Mission. On the oral exam for my Ph.D. some years earlier, I had been asked what effect the presence of a large sunspot had on the Sun's total emission. I hemmed and hawed, since I didn't know the answer and I could argue it theoretically either way. It was possible that the sunspot just blocked enough radiation to be measurable. But it was also possible that the radiation that didn't come through the sunspot heated adjacent areas and that the total amount of emission was the same. Nobody told me that they had asked a question that had no known answer! Anyway, I passed.

For its work at wavelengths shorter than the visible, Solar Maximum Mission carried a gamma-ray spectrometer, three x-ray telescopes that were able to measure spectra, and a telescope to measure polarization and spectra in the ultraviolet. Its coronagraph, for use in a wide range of visible light, concentrated on one quadrant of the Sun at a time. It also carried a device to measure the solar constant, the total amount of energy emitted by the Sun each second as received by a square centimeter at the top of the Earth's atmosphere. We discuss results from this Active Cavity Radiometer Irradiance Monitor (ACRIM) in Chapter 26.

Although SMM gave excellent results for many months, nine months after launch it started spinning uncontrollably. The spacecraft seemed entirely out of touch. NASA wanted to show that its astronauts could fix things in space, perhaps as a precursor to its efforts in building crewed space stations and in part to show the worth of the space-shuttle program. A crew of astronauts went aloft in 1984 and succeeded in bringing SMM into the space shuttle's cargo bay, where they fixed it. When they dropped it off, it lasted another five years.

Fun Sun Facts

Solar Maximum Mission was the last major mission that NASA put into space using single-use rockets. The subsequent larger missions have been launched from space shuttles, though several smaller missions were launched from rockets.



An astronaut attached himself to SolarMax to repair it.

(NASA's JSC)

Spacelab

At its inception, the space-shuttle program was promoted as a cheap way to get things into space. Unfortunately, it hasn't worked out that way. And when the *Challenger* space shuttle exploded in 1986, killing the astronauts aboard, our view of the program as an inexpensive Space Transportation System, trucking objects safely into space, was transformed. Was it really worth using humans to launch systems that could have been carried aloft by robotic spacecraft? The question was compounded by the February 1, 2003, break-up of the space shuttle *Columbia* as it re-entered Earth's atmosphere,

killing the seven astronauts. As of this writing, with investigations of the *Columbia* disaster underway, it is impossible to foresee the future of the crewed space program or its shuttle component.

The space shuttles were at first held out as homes for space laboratories. A Spacelab module was prepared, and it was hoped that it would be launched many times. As it turned out, it was used only a couple of times. Solar instruments were aboard Spacelab 1 when it spent 11 days in orbit in 1983. Spacelab 2 was aloft for a week in 1985. Very high-resolution images were obtained of fine structure on the solar surface with the Solar Optical Universal Polarimeter (SOU). Because these observations were steady in quality, free of variations caused by seeing effects in Earth's atmosphere, the evolution of such small regions of the photosphere could be followed. Both images and magnetic-field measurements were obtained so that the two could be correlated. Other instruments were devoted to solar ultraviolet studies. Spacelab 3 was also aloft in 1985—actually three months before Spacelab 2—and took solar spectra. In all these cases, many other instruments were devoted to other fields, such as life sciences and materials science.

The Voyage of Ulysses

In the *Odyssey* by Homer, the Greek hero Ulysses journeys for many years on his way home from the Trojan wars. The spacecraft Ulysses is undergoing an even longer journey through the solar system. It was launched in 1990 from a space shuttle, but it headed outward in the solar system even though it eventually would go toward the Sun. All previous spacecraft had been in the plane of the Earth's orbit, which corresponds roughly to the Sun's equator. Thus, we never get a good look at the Sun's poles, since the Sun is tipped only slightly.

Fun Sun Facts

Ulysses was originally supposed to be a pair of spacecraft, known as the Solar Polar Mission. But a funding crisis led the United States to back out, angering its European partners. Eventually, one European spacecraft was launched by NASA, making it a joint NASA/ESA mission.

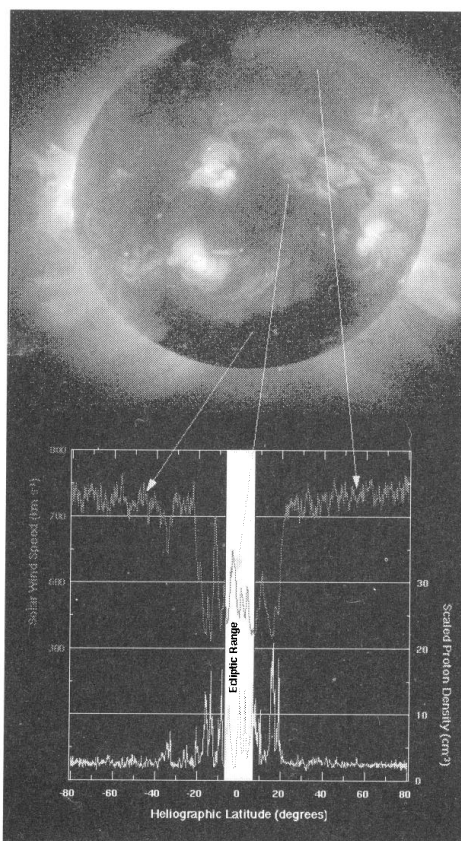
But getting high over the Sun's poles would be very expensive in terms of fuel if we went there directly. So Ulysses was first aimed at Jupiter. A gravity assist from Jupiter—almost like bouncing off it, though the only impact was through gravity—then sent Ulysses high over the Sun's south pole. After passing over the south pole in 1994, Ulysses curved back and flew over the Sun's north pole in 1995. It next went back to the outer solar system, only to return to the Sun again. It then flew over the Sun's south pole in 2000 and the north pole in 2001. Ulysses's main task was to study the solar wind, the outflow of the solar corona.

For reasons of funding, Ulysses didn't carry a camera, so we don't have images looking down at the Sun's poles. But Ulysses is carrying instruments to measure particles that hit it and to measure the magnetic fields it encounters.

Ulysses's unique perspective led to many discoveries. For example, it sampled a huge bubble in the solar wind.

Ulysses is funded until late 2004, allowing it to complete a whole sunspot cycle, though it is at a different location at each time, making it difficult to disentangle what variations come from changes in the Sun and what variations come from the spacecraft's varying location.

The Sun's north and south magnetic poles interchanged at the peak of the solar-activity cycle, which occurred in 2001–2002. So the remaining time for Ulysses will allow it to see how the heliosphere settles down following the major change in magnetism. One way the heliosphere will be studied is by observing the Sun's magnetic field. When the field is strong, it bends cosmic rays from beyond the Sun, deflecting them away from the Earth. So cosmic-ray sampling will be a key to understanding the changes in the heliosphere.



The graph shows the speed of the solar wind (top curve) and the density of gas (bottom curve) as Ulysses went from over the Sun's south pole to over its north pole. Before Ulysses, only the region marked with the vertical bar in the middle had been sampled.

(LANL, NASA/JPL, and ISAS)

The Least You Need to Know

- ◆ Early solar astronomy used rockets and satellites to get above Earth's atmosphere.
- ◆ Rockets and spacecraft study especially the ultraviolet and x-rays, with some visible coronagraphic work.
- ◆ Astronauts have handled and repaired solar spacecraft.
- ◆ With an assist from Jupiter's gravity, Ulysses went over the Sun's poles.