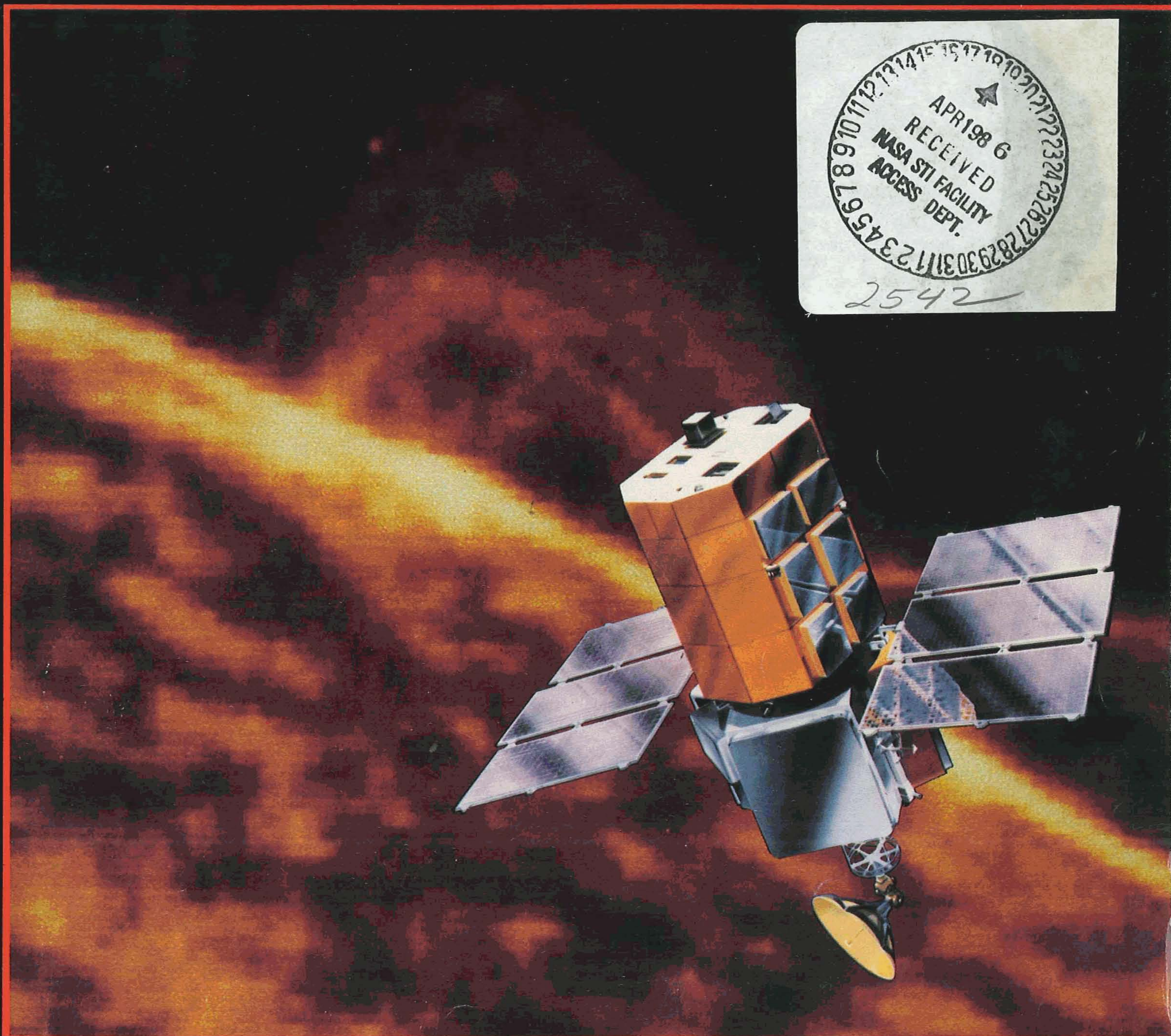
RENEWING SOLAR SCIENCE



THE SOLAR MAXIMUM REPAIR MISSION

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RENEWING SOLAR SCIENCE

THE SOLAR MAXIMUM REPAIR MISSION

National Aeronautics and
Space Administration

Goddard Space Flight Center

by Valerie Neal for the Office of Space Science and Applications, Multimission Modular Spacecraft/Flight Support System Project Office.

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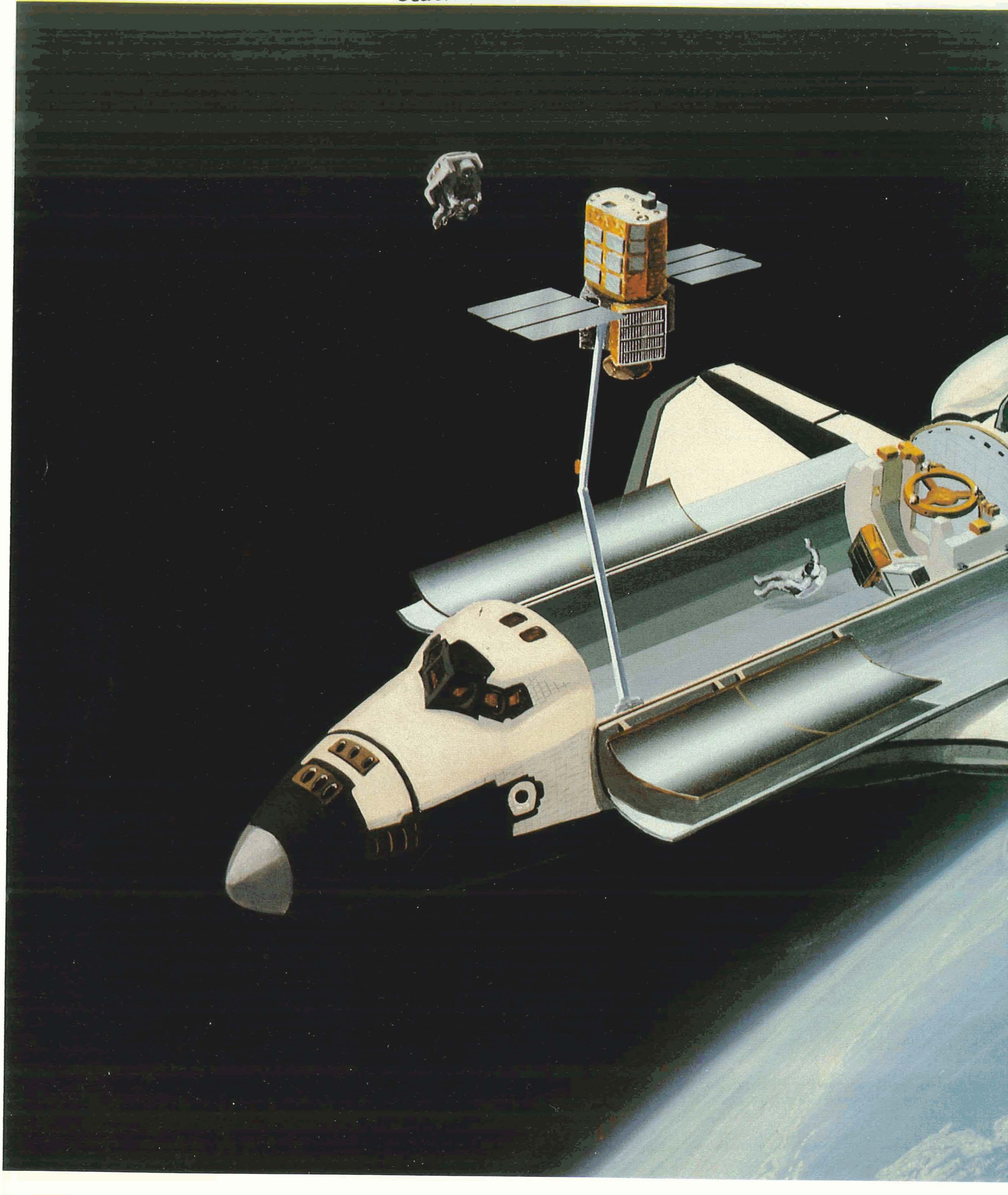
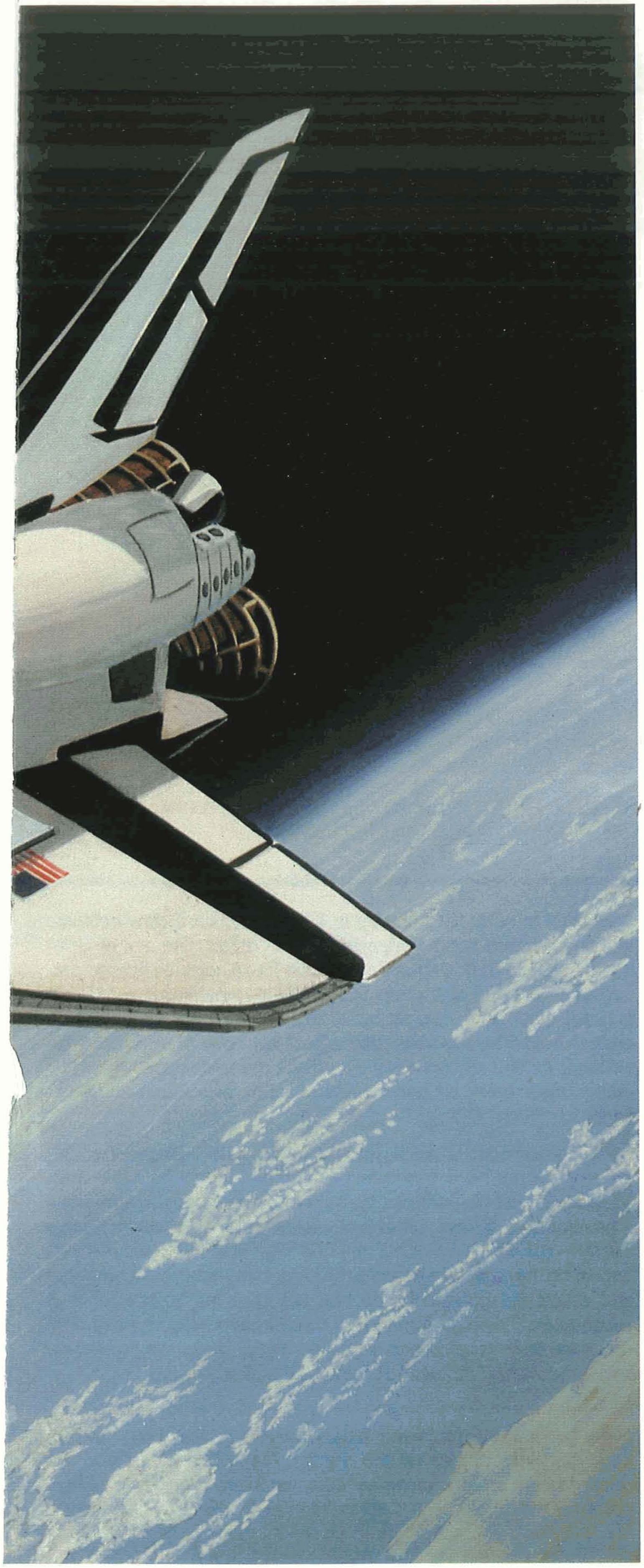




High above the clouds and filtering atmosphere, ideally located to watch the sun, an elaborate solar observatory moves idly through space, operating at a mere fraction of its full capability. Once the source of a wealth of information about energetic events on the sun, the satellite is a victim not of age but of a technical problem. Of the seven advanced scientific instruments on board, only three continue to function. The others require very precise pointing and stability, which the spacecraft no longer can provide.

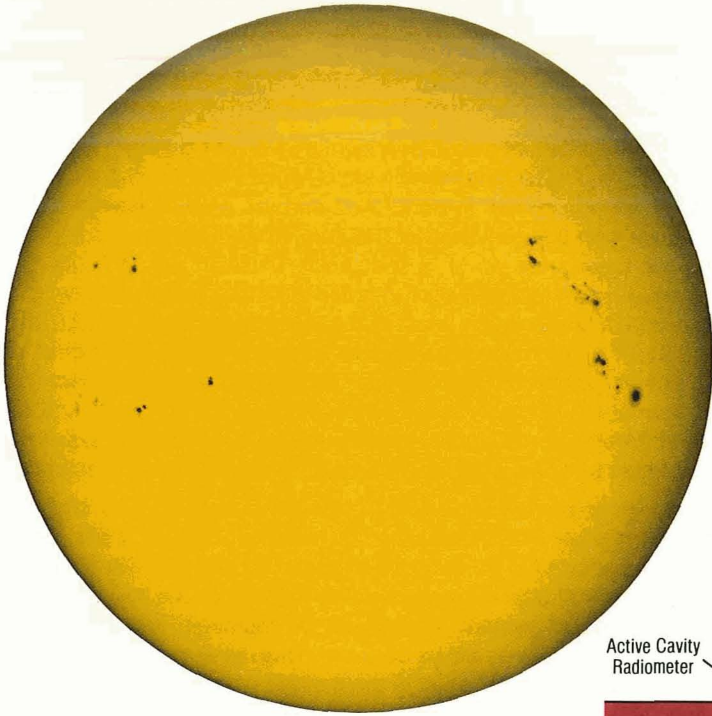
Such is the plight of the Solar Maximum Mission, commonly known as Solar Max. Just nine months after launch in February 1980, fuses in the attitude control system failed and the satellite lost its ability to point with fine precision at the sun. To the dismay of solar scientists around the world, a spectacular mission abruptly faltered. Although a few instruments continued to send valuable data despite the loss of fine pointing, most of the instruments were useless and those still operating lost the benefits of partnership in a coordinated observing program. The mission was declared a success, because its operation, though abbreviated, fulfilled the success criteria established before launch. However, its reduction from the expected two years to nine months meant a significant loss to solar science.

Although its performance now is severely curtailed, Solar Max will not remain idle indefinitely. The first satellite of a new breed, Solar Max is designed to be serviced in space by a Space Shuttle crew. In 1984, the Shuttle will make a repair visit to the satellite. The faulty attitude control system module will be replaced, and two of the scientific instruments will be serviced. This repair visit should revive Solar Max for at least several more years of coordinated observations of the sun.

The Solar Maximum Repair Mission will demonstrate the satellite servicing capabilities of the Space Shuttle for the first time. It will also revive the most ambitious and successful solar flare research program ever attempted. The purpose of the Solar Max Repair Mission is to restore the operational capability of the only major solar observatory currently in space. Because no comparable new observatory is planned, this renewal of solar science is imperative for improved understanding of the sun and its effects on Earth's environment. ✸

During the Solar Maximum Repair Mission, managed by Goddard Space Flight Center, the Shuttle will rendezvous with the satellite for repair operations in orbit.

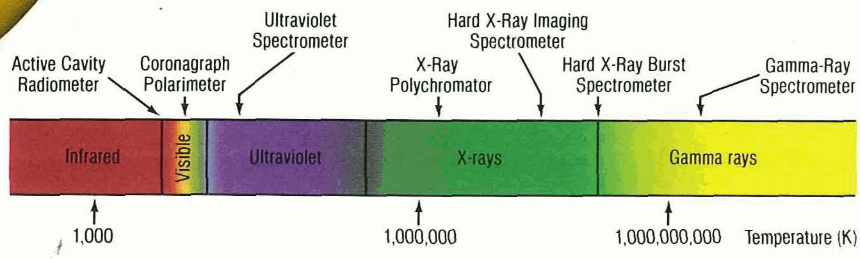
THE SOLAR MAXIMUM MISSION



Left: A white light photograph of the sun taken on April 10, 1980, shows two sunspot regions (to the right) well studied by Solar Max. For some reason, the upper group of sunspots did not produce flares, but the lower group produced them in profusion. Passage of these two active regions across the sun caused the first big decrease in the solar constant, measured by the Active Cavity Radiometer on Solar Max.

Right: Layers of the sun can be identified by their characteristic temperatures and electromagnetic emissions. Extreme temperature differences result in several mysterious phenomena. For example, relatively cool prominences exist within the 150 times hotter corona, like ice cubes within a furnace.

Below: Portions of the electromagnetic spectrum covered by Solar Maximum Mission instruments.



The Solar Maximum Mission was named and scheduled to coincide with the peak period of activity in the current solar cycle. In repeating eleven year cycles, the frequency of sunspots and related energetic solar events rises to a maximum and then begins to wane. The Solar Max Mission occurred during the second most active period since sunspots were first recorded centuries ago.

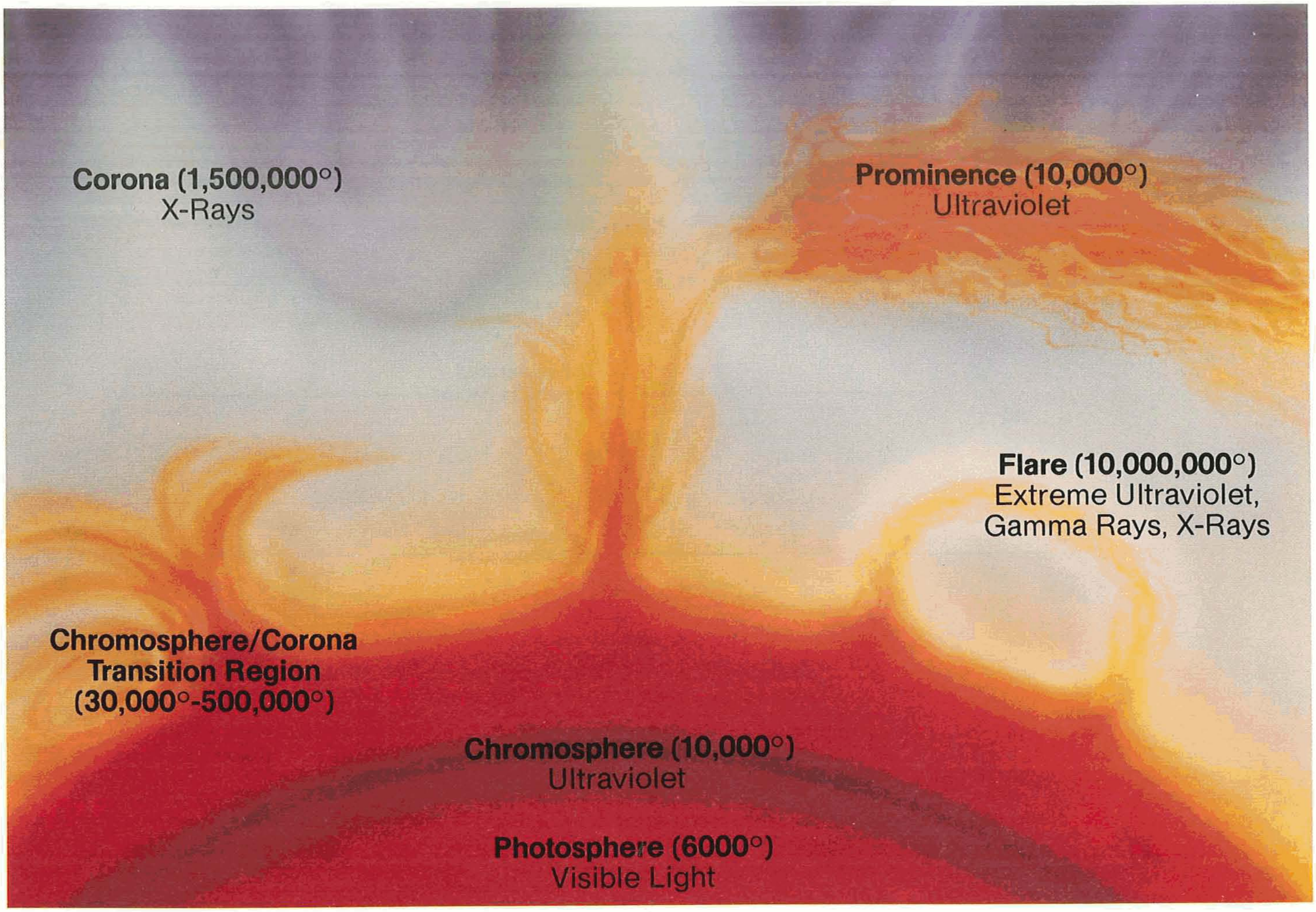
The solar cycle is vivid evidence that our sun is not quiet, steady, and changeless. Instead, the sun is moody, its behavior largely unpredictable. Its most violent outbursts are solar flares, enormous explosions of superhot gas that can cover a billion square miles on the sun and send debris speeding millions of miles through space. Solar Max is dedicated to the study of solar flares, the buildup and release of flare energy, and the explosive ejection of solar radiation and particles through space. It also measures with vastly improved accuracy the value of the "solar constant," the total radiant output of the sun received at Earth.

Flares create shock waves and gusts in the solar wind, the electrified, magnetized gas (called plasma) that originates near the sun and flows through the solar system. When these gusts jolt Earth's magnetic field, dramatic environmental effects are triggered. Auroras dance more jauntily across the polar skies, radio communications are garbled or silenced, surges in powerlines can cause outages that darken entire cities, and the safety of orbiting spacecraft and astronauts is jeopardized.

Prediction of solar flare activity is difficult and unreliable because the flare process is not yet understood in detail. The aim of Solar Max flare research is to improve basic knowledge of energy processes in the sun and other stars, thereby enabling scientists to forecast when and how unusual solar activity will affect Earth's environment. The scientific rationale of the Solar Max Repair Mission is to extend and enhance the unique research capability of this orbital observatory for better understanding of the sun and solar flares.

Current knowledge of solar flares is incomplete because the flare process cannot be duplicated in a laboratory. Instead, flare characteristics must be deduced from their electromagnetic emissions – gamma-rays, X-rays, ultraviolet, visible, and radio waves. Flares are associated with sunspots, the dark blemishes that occasionally appear on the solar disc where strong magnetic fields have emerged and where the normal rise of hot gas from the solar interior is suppressed. The strong magnetic fields in and around these dark spots are often tangled and stretched by the motion of gas in and below the visible "surface" of the sun, the photosphere.

Suddenly brilliant flares explode in higher layers of the solar atmosphere between sunspots and release intense bursts of energy. Typically, flares erupt several thousand miles above the sun in the chromosphere or the low corona. Solar flares are cataclysmic. Within seconds, temperatures in a flare region rise millions of degrees, X-ray emissions increase dramatically, and a billion tons of solar matter can be spewed far into space. Flares usually last only a few



minutes, but their effect on the sun may linger for hours. Their effect on Earth begins almost immediately. Eight minutes after its emission at the sun, ultraviolet radiation reaches Earth and affects the upper atmosphere (ionosphere). The impact of matter ejected by flares on Earth's magnetic field (magnetosphere) occurs within one to four days.

What provokes these explosive outbursts? What triggers the hot flashes that release such tremendous energy? Are flares the symptoms of some hidden process deep within the sun? The questions are many, and most of the answers are unsatisfactory because it is difficult to observe solar flares in adequate detail.

Obviously, scientists cannot study solar flares at close range; they depend upon information gained from a vast distance. The sharper the focus of these remote observations, the more insight they provide into the sun's mysterious behavior. Solar flare research requires very detailed information about flare sites, emissions, and activity over time. The techniques and instruments for gaining these three kinds of information differ greatly; usually, getting high resolution data about one flare feature means sacrificing some precision elsewhere.

Because no single instrument can monitor the many features of solar flares, Solar Max carries a variety of complementary instruments that can watch the sun simultaneously. Each instrument by itself is versatile enough to make different kinds of observations. Such a comprehensive and coordinated study of flares has never been attempted before.

Solar Max is designed to meet the conflicting demands for spatial (size), spectral (wavelength), and temporal (time) resolution. Six different instruments monitor flare radiation in some part of the electromagnetic spectrum from visible light through ultraviolet and X-ray emission to gamma rays, while a seventh monitors the total radiant output of the sun. Some measure across a broad spectral range; others focus on small target areas. All are sensitive to solar changes that occur within minutes or seconds, yet all can track a solar flare for hours. When one instrument announces detection of a flare in progress, the others can quickly shift their attention. With unprecedented clarity and precision, Solar Max offers continuous and simultaneous viewing of many important features of solar flares. Fine pointing and stability of the spacecraft are essential for acquiring such high-resolution data.

The first months of the mission were extremely successful as Solar Max kept its eyes on the sun. Careful orchestration of the instruments resulted in the most detailed look at solar flares ever achieved. Hundreds of flares were recorded, and the cumulative new data base is unsurpassed. Solar Max instruments set new standards of accuracy and precision and led scientists to a number of "firsts" – discoveries, confirmations, and new answers to old questions.

However, it is the nature of scientific research that the answer to one question normally raises several new ones. Therein lies the prime reason for repairing Solar Max: to begin another, more incisive phase of flare research. The Solar Maximum Repair Mission represents a renewal of solar science. ✷

ORIGINAL PAGE
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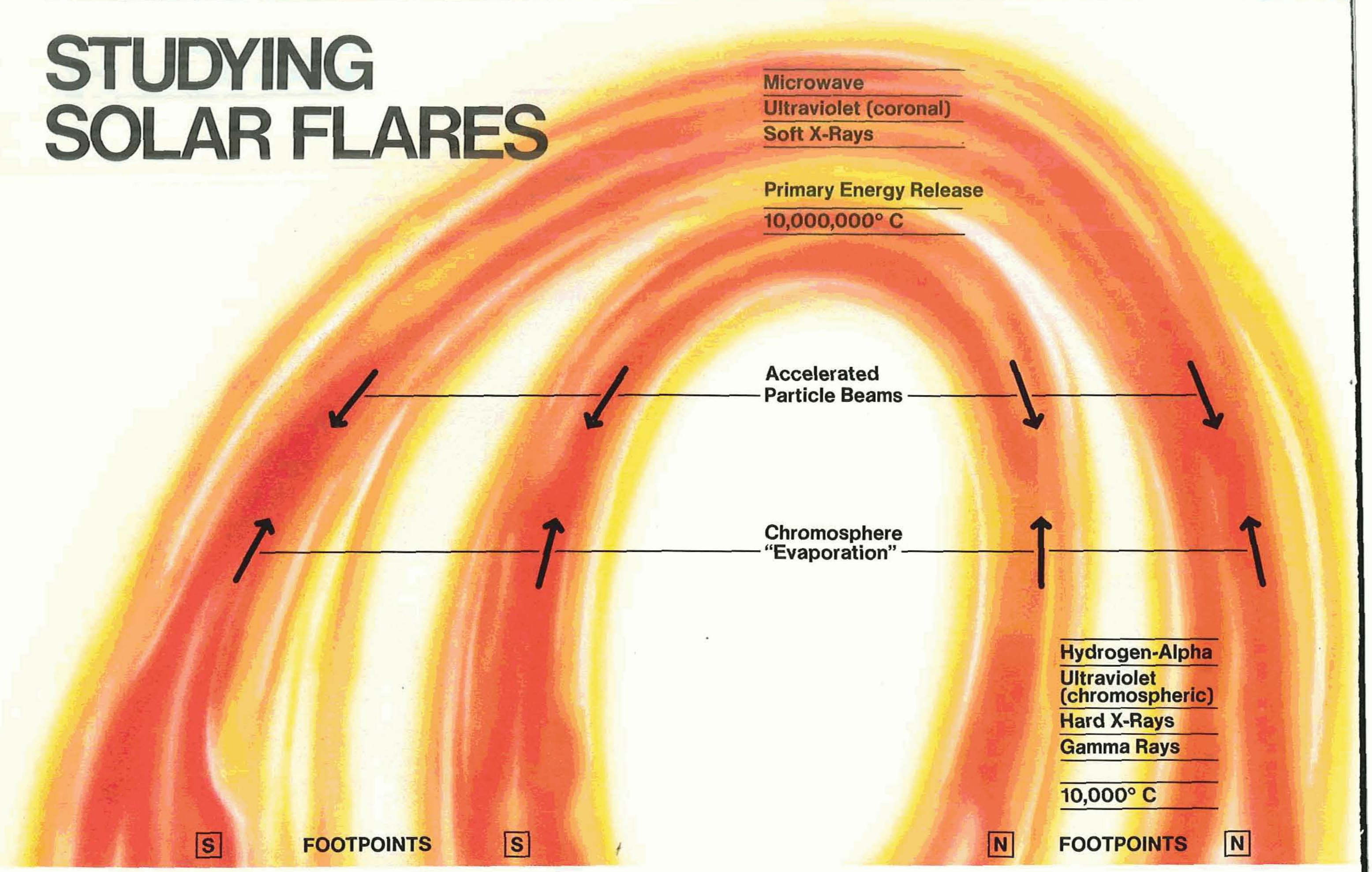
STUDYING SOLAR FLARES



Among astrophysicists, solar flares are a controversial subject. A number of theoretical explanations and candidate models exist, but better measurements are required before the flare process can be understood. Scientists need accurate measurements of flare temperatures by remote "thermometers" sensitive over ranges of millions of degrees. They also need detailed measurements of the composition and density of ionized gas (plasma) in flares, as well as coordinated observations across the electromagnetic spectrum. Comparison of different types of emission yields valuable information about the sources, extent, and evolution of flare output.

Prior to the Solar Max Mission, scientists knew more about general conditions favorable to flare activity than about the specific causes and sequences of events. Although Solar Max performed well for nine months and revealed significant new information about the sun's turbulent activity, its demise so early in its planned two-year lifetime represented a major loss of potential knowledge.

If the spacecraft is repaired and the mission resumes, it will be possible to fulfill the original goals of Solar Max science – to study in detail the buildup, release, and effects of flare energy. The Repair Mission also offers a unique opportunity to expand the scope of Solar Max investigations, to address a new set of goals that have arisen from Solar Max discoveries to date, and to exploit the full range of the instruments' capabilities.

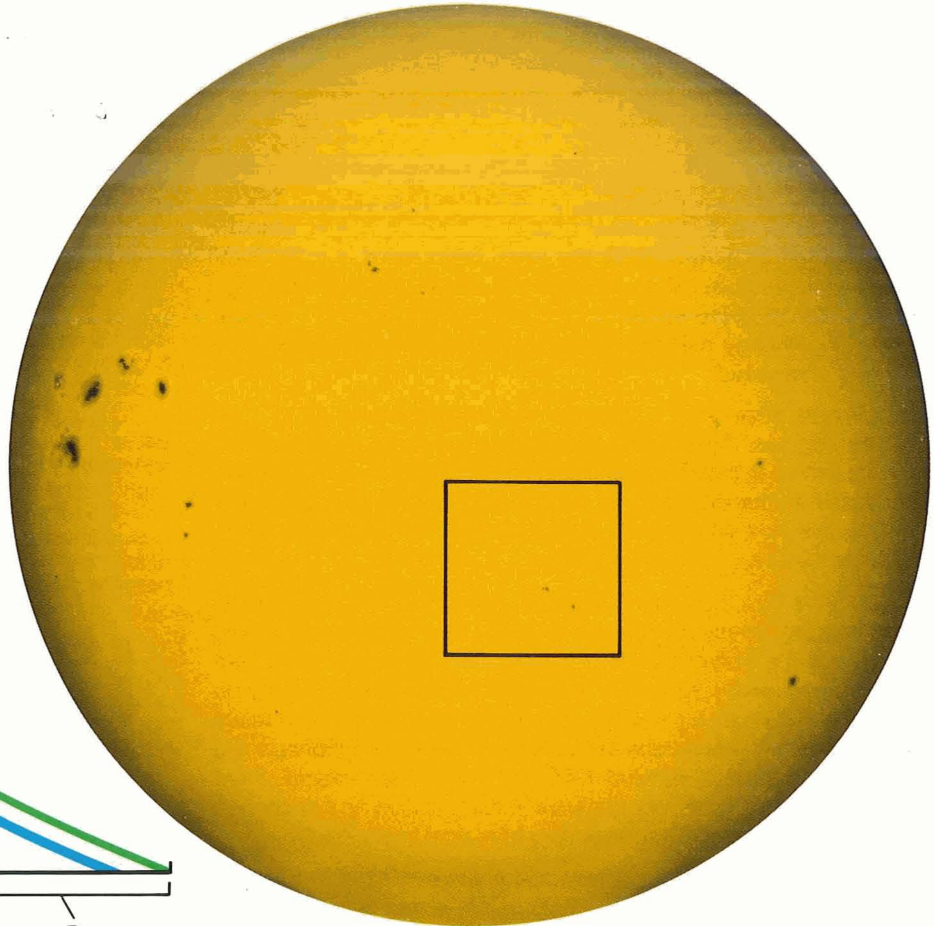
Many early Solar Max findings invite deeper investigation. Reacquisition of solar data and a refined observing program will enable scientists to pursue intriguing leads from the original mission. Recent advances in theory and observational techniques, as well as improved control and data acquisition through the new Tracking and Data Relay Satellite System (TDRSS), will enhance the science return of Solar Max.

The following summaries highlight the major scientific accomplishments of the Solar Maximum Mission and some of the issues that researchers expect to address in the renewed mission.

The Flare Puzzle □ Solar flares are complex phenomena that are difficult to study because they cannot be seen in detail in visible light nor can a single instrument view a flare as a whole. The problem is that flares span an immense range of temperatures, and each temperature excites electromagnetic radiation in different parts of the spectrum. Thus, a flare as seen in visible light is quite different from the same event seen in ultraviolet, which in turn differs from the flare seen in X-rays. Because scientists cannot see all of a flare at once, they must assemble a composite picture by studying different parts of the flare separately with different instruments operating simultaneously. The flare puzzle is a major challenge in solar science.

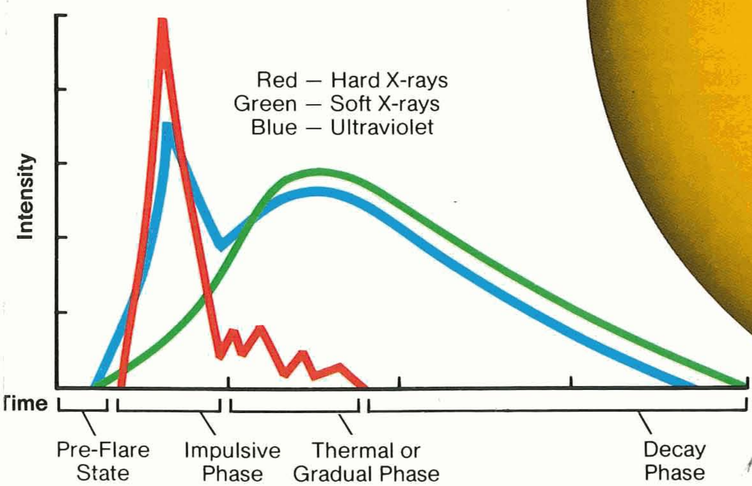
Flares seem to derive energy from magnetic fields, but the exact energy balance or "budget" of the storage and release process is not yet understood. X-ray photographs of flare sites reveal loop structures that span tens of thousands of miles and rise to comparable heights. (By solar standards, however, the loops are so small that observation is a real challenge for instrument design.) These loops consist of plasma confined by magnetic fields. Solar Max observations indicate that flares may erupt when two or more loops collide. The primary energy release seems to occur where the loops

Left: Flares may be triggered when two loops of magnetic fields collide and interact. High-energy charged particles speed through these loops and "excite" the flare plasma to emit various kinds of radiation.



Right: A white light photograph of the sun taken from the Marshall Space Flight Center observatory on May 21, 1980, shows several sunspot groups in active regions. A major flare was associated with the small sunspot group near the center of the solar disc. Images on the next page reveal how different Solar Max instruments saw the same flare region.

Below: Usually, a flare begins with a sudden flash of hard X-ray and ultraviolet radiation, followed by a slower rise of soft X-rays and a gradual fading of the soft X-ray and ultraviolet glow.



collide and electrons are accelerated to energies of 10 to 100 thousand electron volts (keV).

The feet of flare loops rest in sunspot regions of opposite magnetic polarity. The loops arch upward through the next layer of solar atmosphere, the chromosphere, through the transition zone between the chromosphere and the corona, and into the corona, the sun's outer atmosphere. During a flare eruption, X-ray and ultraviolet flashes appear almost simultaneously, within seconds, at footpoints as far apart as 100,000 kilometers (60,000 miles). How does energy travel so rapidly, yet stay confined within the loop? The acceleration, transport and containment of plasma and particles, and the energy within flares are not fully understood.

The fact that flare loops are not uniform in structure, temperature, or density further complicates research. Physical conditions differ greatly at different heights along the loop, and various kinds of radiation originate in different parts of the flare. High and low temperature areas, for example, differ greatly in physical characteristics. The lack of uniformity from one flare to the next poses a number of theoretical and observational problems; it is one of the major reasons that a large sample of flares must be observed.

Not all of the data fit snugly together and many pieces of the solar flare puzzle are still missing. Repair of the Solar Max spacecraft will restore the capability to collect highly accurate, coordinated information about the shape, movement, and content of solar flares. With the insight gained from nine months of observation and three years of data analysis, scientists know better than before what they need to watch and how they should measure it. Furthermore, because the solar cycle has progressed four years, the repair mission will occur during a quieter, waning phase, though still punctuated by strong flare activity. Scientists now have an unforeseen chance to make comparisons between different phases of solar activity.

Flare Signatures ☐ Because flares are exceedingly hot, their major radiations occur in much shorter wavelengths than the visible light emitted from the sun's surface. Thus, scientists must observe flares with special instruments designed for extreme ultraviolet and X-ray wavelengths. The highly ionized atoms of particular chemical elements in the superhot flare plasma emit radiation in distinctive bands of the electromagnetic spectrum, especially in X-rays. With special filters, one can see flares in the "light" of many constituents of flare plasma, including hydrogen, helium, carbon, oxygen, neon, magnesium, silicon, sulfur, calcium, and iron. One can also see normally invisible features by viewing them in ultraviolet or X-ray wavelengths. Material ejected by flares into the sun's corona can be seen in visible light by blocking out the entire solar disc and making an artificial eclipse.

By techniques of spectral analysis collectively called "plasma diagnostics," scientists can discover in flare emissions many clues to the temperature, composition, density, and mass motions of flares. The concentrated Solar Max effort to date has been sufficiently complete that a spectral "atlas" of flares is now being compiled.

Solar flares have a variety of characteristic signatures. The boldest is written in X-rays, which are emitted when electrons are heated to extremely high temperatures and accelerated to higher energies. Rapid heating and particle acceleration occur in solar flares. The resultant X-rays are rich in diagnostic information about flare plasma. Because the intensity of X-ray emissions from highly ionized elements is temperature dependent, X-rays can be read as thermometers that indicate the temperature of the emitting plasma. X-ray data may also provide information about turbulence within a flare.

Solar flares produce X-rays at both ends of an energy spectrum: more energetic "hard" X-rays (less than 1 Angstrom wavelength) and less energetic "soft" ones (1-100 Angstrom wavelength). Bursts of hard X-rays signal the onset of a flare. Typically lasting from 10 to 100 seconds, hard X-ray bursts seem to emanate from the footpoints of flare loops. They indicate the deceleration of very high energy electrons (16-30 keV), accelerated elsewhere in the flare, depositing energy sufficient to raise the plasma temperature by millions of degrees.

Soft X-rays arise from plasma in the temperature range of 1-50 million degrees. They seem to originate primarily between footpoints, well up in the flare loops. During a flare, soft X-ray brightness increases in intensity for 5 to 10 minutes, then decays gradually. Soft X-rays indicate the presence of electrons in the energy range of 0.1 to 10 keV.

Three Solar Max instruments watch the sun in X-rays: the Hard X-Ray Imaging Spectrometer, the Hard X-Ray Burst Spectrometer, and the X-Ray Polychromator. Together they have measured flare temperatures with unprecedented precision and collected data on the state of the plasma before, during, and after flares. As a result of successive observations in fractions of seconds, scientists are now able to read a detailed X-ray history of flare events. Flare plasma appears to be very complex in composition and to change significantly in temperature over very brief time intervals.

The X-ray instruments have revealed many surprises. An unsuspected class of flare events, coronal flares, is one such discovery. Confined to the corona, with no observable change in the lower layer (chromosphere) where flares typically arise, coronal flares appear several hours after a major flare. This impressive phenomenon warrants further investigation. For the first time, a giant X-ray arch was observed to linger for hours over the site of a decayed flare. Coordinated radio telescope observations from the ground linked this arch to a major postflare radio noise storm. The relationship between postflare X-ray and radio emissions remains to be explored. Other data showed a disappearance of matter from the chromosphere at the same time soft X-rays appeared above. The possibility of evaporation of the chromosphere when flare energy is deposited there is relevant to the mass and energy balance mechanisms of solar flares.

Ultraviolet radiation is mainly the signature of cooler plasma that ranges in temperature from 10 thousand to 250 thousand degrees. Ultraviolet flashes occur simultaneously with X-ray bursts, but they are concentrated in high density "kernels." Because ultraviolet emissions arise from cooler, lower regions of the chromosphere, they provide a deeper look at the sites of flare activity.

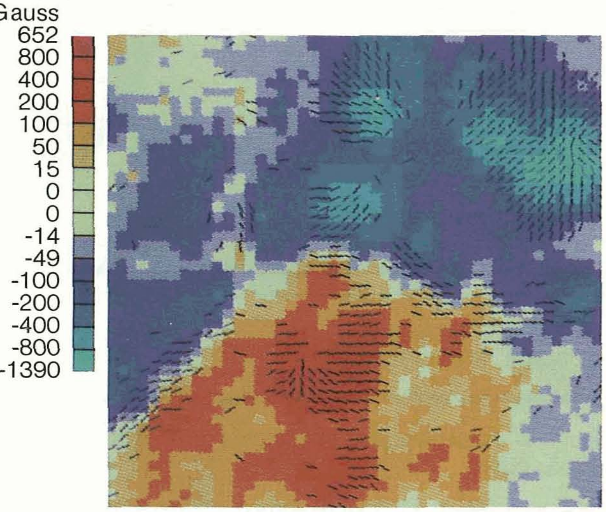
The Ultraviolet Spectrometer/Polarimeter on Solar Max is a versatile diagnostic tool for density, velocity, and magnetic measurements. The wavelength range of the instrument is 1150-3600 Angstroms. In concert with the X-ray instruments, the ultraviolet instrument gives a more complete picture of flare energy transport than previously possible. Continuous ultraviolet observations also provide, for the first time, a good look at instabilities in preflare plasma, before the dramatic temperature increase of flare eruption. This new information is an essential piece in the puzzle of flare energy buildup.

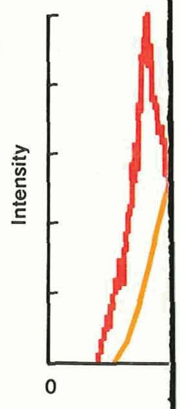
Few flares are powerful enough to release gamma rays, the extremely energetic emission that is a signature of very highly accelerated

May 21, 1980 ☐ Several Solar Max instruments can view the same flare region at once for a comprehensive look at events occurring there. Coordinated observations from ground-based instruments provide additional information. All of these images record a major flare observed on May 21, 1980.

Right: Viewed through a hydrogen-alpha filter, the flare appears very bright against the solar background. This image of the chromosphere at about 6000° was taken at the Marshall Space Flight Center observatory.

Below: This image represents the magnetic field at the surface of the sun, as measured by the Marshall Space Flight Center Vector Magnetograph. The field points away from the solar surface in red areas and toward the surface in blue areas. Black line segments indicate the orientation of the magnetic field in the plane of the solar surface, perpendicular to the line-of-sight.

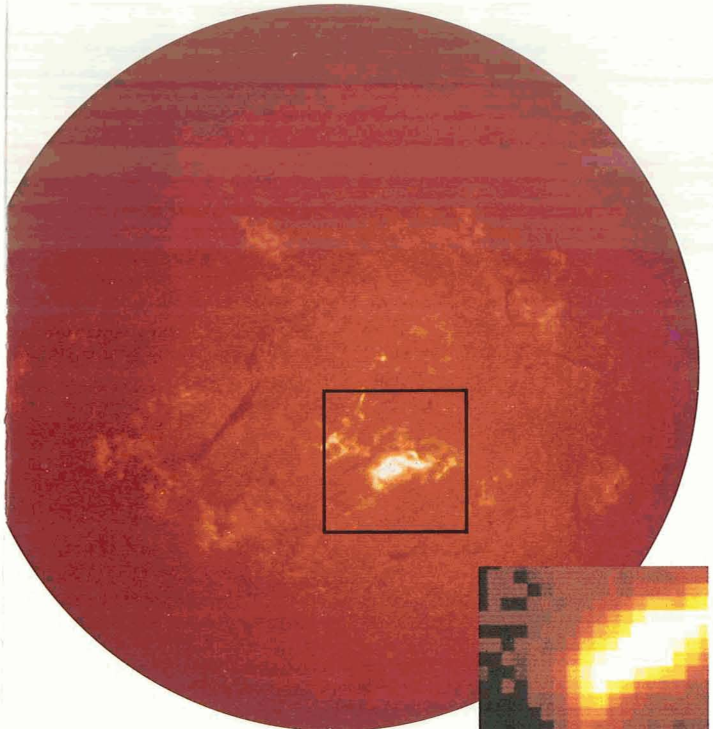


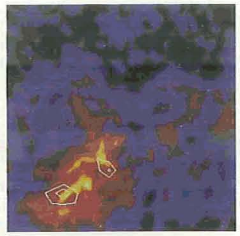


April 30, 1980 ☐ Because Solar Max instruments can view the same solar region for a long time it is possible to watch a flare develop. The following images present a history of a flare observed by several instruments on April 30, 1980. By studying data obtained before, during, and after a solar flare event, scientists can better understand the processes of energy build-up and release.

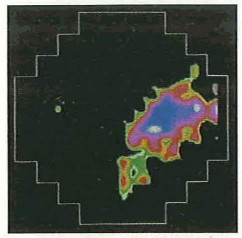
The first two frames show magnetic field structures observed by the Ultraviolet Spectrometer/Polarimeter in the light of ionized carbon, 90 minutes before the flare erupted.

Twenty minutes before the flare explosion, a small loop appeared, rising into the region of the overlying magnetic structures. The loop brightened as it rose, particularly at the footpoints and the top. Fifteen minutes elapsed between these two images.

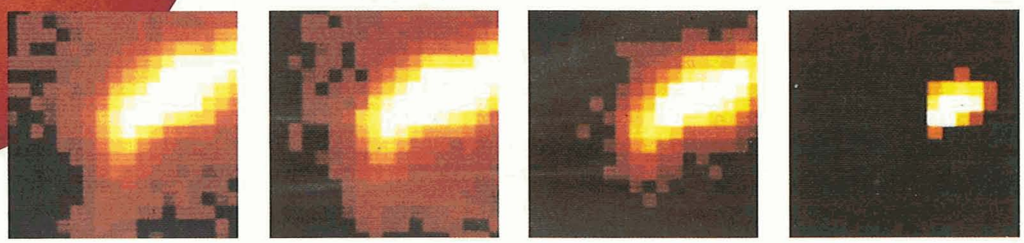




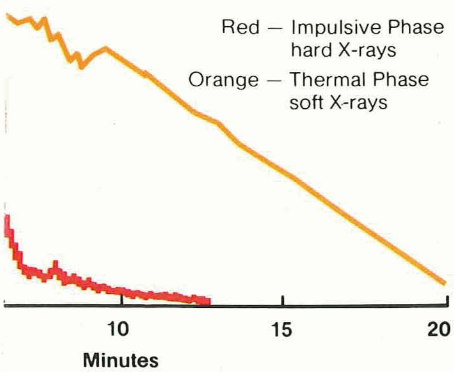
Seen in the light of ionized magnesium by the Ultraviolet Spectrometer/Polarimeter, the structure of the flare becomes visible. The bright yellow ribbons indicate the opposite footpoints of an arcade of flaring loops in the chromosphere. The white contours show areas of hard X-ray emission (16-30 keV) observed simultaneously by the Hard X-Ray Imaging Spectrometer. This was the first direct evidence that hard X-rays come from the footpoints rather than the tops of loops during the impulsive phase, or onset, of a flare.



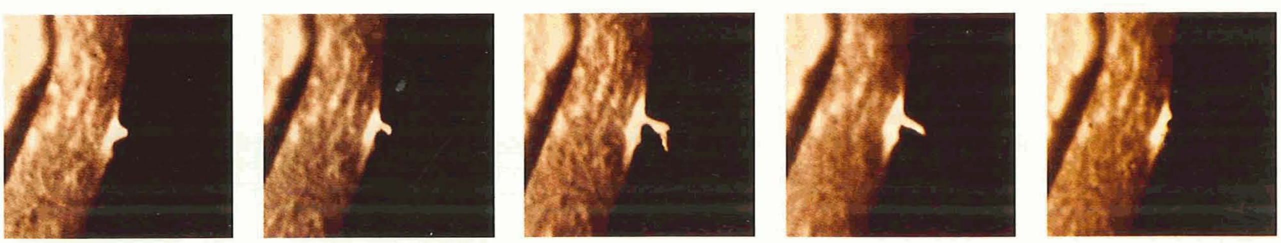
In this image of the impulsive phase of the flare, made by the Hard X-Ray Imaging Spectrometer, the color scale indicates soft X-ray (3.5-8 keV) intensity. The least intense emission is green and the most intense is blue. The two white patches mark the location of high-energy X-rays (16-30 keV), believed to be the two footpoints of a magnetic loop.

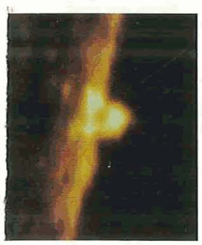


The X-Ray Polychromator produces simultaneous maps of an active region at seven different X-ray wavelengths. These four images show the region just after the peak of the flare. Each image (from left to right) represents emission from plasma at a different temperature: ionized oxygen (3 million degrees), ionized magnesium (4½ million degrees), ionized silicon (8 million degrees), and ionized iron (30 million degrees).

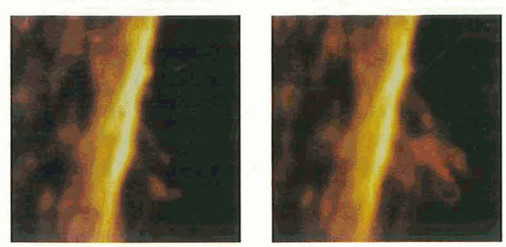


Left: This timeplot shows the two distinct phases of the May 21st flare event. Hard X-rays originate from electrons accelerated during the explosive release of energy in the impulsive phase. Soft X-rays are produced as the plasma is heated by the high-energy particles in the thermal phase. The intensity of X-ray emission drops as the plasma cools down to its original temperature.





The appearance of X-rays in the impulsive phase was seen in the light of "excited" hydrogen from an observatory on the ground. The top of the loop broke open when it contacted the magnetic fields above, filling the overlying region with hot plasma at several tens of millions of degrees. Eleven minutes elapsed between the first and last images.



The last two frames show the radiation from ionized carbon as the loop cooled back to 100,000 degrees. This radiation reappeared as the X-rays disappeared.

particles (above 1 million electron volts or 1 MeV). Since gamma ray radiation travels at the speed of light from the sun to the Earth in just 8 minutes, it arrives well ahead of most flare debris and alerts us to the possible onslaught of high-energy solar particles. Gamma radiation from the sun also carries clues to very high energy processes in other stars.

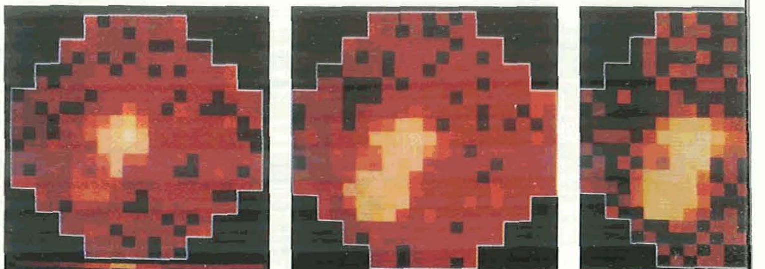
A Gamma Ray Spectrometer aboard Solar Max already has observed more gamma ray events than the total previously recorded and has seen features never viewed before. This instrument detected high-energy neutrons near Earth for the first time following a tremendous solar flare on June 21, 1980. A particularly exciting event occurred on June 3, 1982, when the satellite detected intense neutron radiation for some 20 minutes after a major flare. These Solar Max observations confirmed the theoretical prediction that flares are capable of producing extraordinarily high-energy particles. More than a dozen new spectral features, predicted but never before observed, have been detected in a few of the strongest flares. These features appear when very high energy particles disrupt atomic nuclei near the sun's surface. The gamma ray "signature" gives new insight into rare and unusually powerful solar flare activity.

Valuable information about flare effects can be gleaned from the sun's normally invisible halo or corona. By artificially eclipsing the sun and by viewing it from above the atmosphere against the black background of space, one can observe the corona in visible light (4000-7000 Angstroms). The reward is to witness coronal mass ejections – huge high-speed disruptions of the sun's outermost atmosphere. The Solar Max Coronagraph/Polarimeter has viewed scores of these massive ejections of solar material moving through the corona after flares. Variations in the density of ejected coronal plasma also have been observed, but the exact correspondence between coronal structures and flares has not yet been determined.

Flare Maps ☐ Where on the sun do flares occur? Where within a flare are the sources of emissions? These basic questions about the location of flares are difficult to answer because the structure of the sun's atmosphere is complex and variable. The sun consists of layers of gas, each having its own temperature and density. The layers are knitted together by a tangled, pervasive magnetic field. When a flare occurs, the characteristics of the plasma and, presumably, the magnetic field at the flare site change so rapidly that it is almost impossible to pinpoint what is happening where and when.

Several Solar Max instruments, however, can map solar structures vertically through the various temperature layers of the solar atmosphere as well as horizontally throughout a single layer. Combined magnetic data from the Ultraviolet Spectrometer/Polarimeter and a ground-based magnetograph allow three-dimensional maps that reveal, for the first time, how the magnetic field varies from a sunspot all the way up into the transition region (4,000 miles). The X-Ray Polychromator images flare-producing active regions in seven different wavelengths simultaneously. The resultant multicolor images show flare loops and structures extending through all layers of the solar atmosphere. The Coronagraph/Polarimeter routinely discriminates the different density zones in the corona; magnetic field configurations can be inferred from the observed density structures. This instrument also can discriminate (crudely) different temperature zones, a major advance in coronal mapping technique.

These mapping investigations are important for theoretical modeling of solar activity. Solar Max data indicate the complexity of flare sites and challenge simplistic models of flare structure and activity. Better maps of flare regions should help scientists understand why some sunspot groups erupt with flares while others grow and decay without these catastrophic events. This understanding is necessary if we are ever to predict solar flares.



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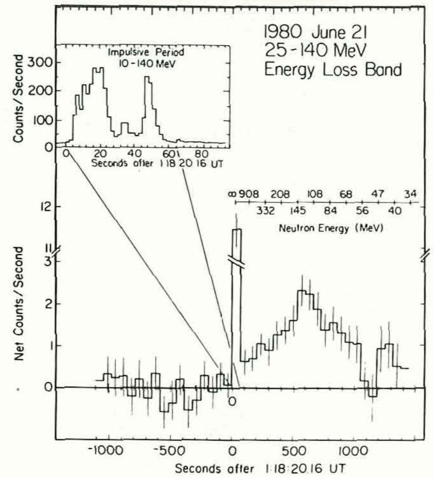
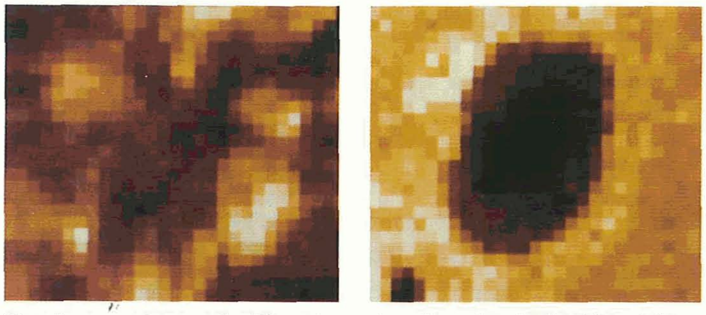
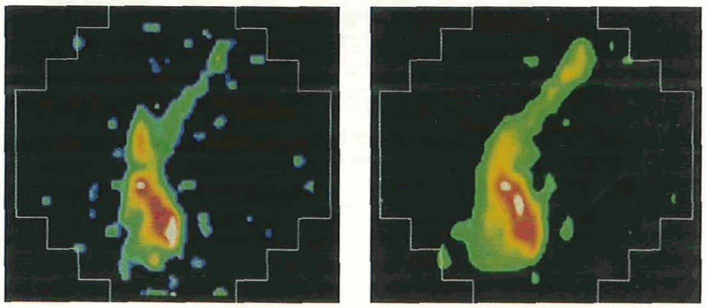


This graph of data obtained by the Gamma Ray Spectrometer on June 21, 1980, records the first detection of extremely high energy neutrons near the Earth after a major flare. These neutrons flowed past the satellite for 17 minutes. The energy scale corresponds to the neutron arrival times; the first neutrons had energies around 500 million electron volts (MeV) while later arrivals ranged in energy down to about 50 MeV. The inset chart shows gamma radiation during the one-minute impulsive phase of the flare.

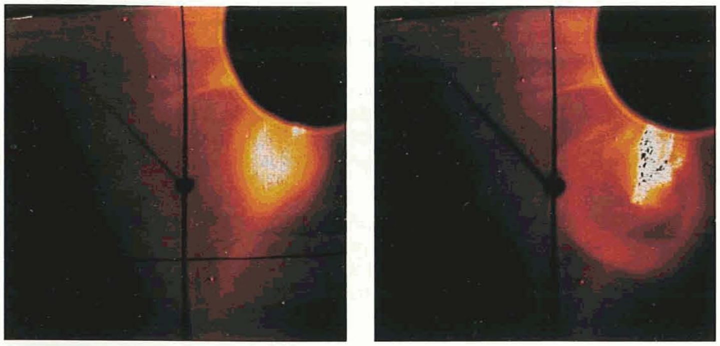


Simultaneous images in different wavelengths, taken by the Ultraviolet Spectrometer/Polarimeter, show the transition region at 100,000° (left) and the photosphere below at 6,000° (right). The picture on the right is a sunspot at the solar surface; the picture on the left shows sections of magnetic loops extending upward around the sunspot.

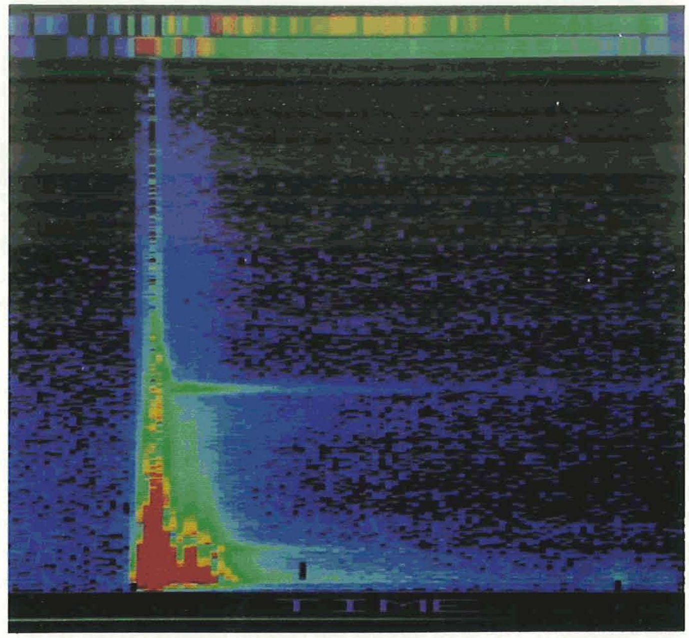


Images from the Hard X-Ray Imaging Spectrometer show the location of X-ray sources. Soft X-rays range from least intense (blue) to most intense (red). The white patches represent high-energy X-ray sources, probably footpoints of a magnetic loop. In the second image taken about one minute later, only one of the footpoints shows up. The other bright patch, in a new location, is believed to be near the top of the magnetic loop, now filled with hot plasma at 20-30 million degrees.

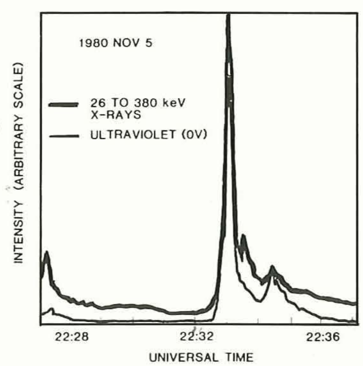
Left: The Hard X-Ray Imaging Spectrometer provides a different view of the filling of a magnetic loop with hot, X-ray emitting plasma, represented here in the lighter shades of yellow. This sequence of images of a flare on April 12, 1980, shows **(a)** the bright onset of the flare; **(b)** brightening of another point about one minute later and evidence of a connecting magnetic loop; **(c)** approximately two minutes later, X-ray emission throughout the whole loop, with a brightness comparable to that at the original flare site.



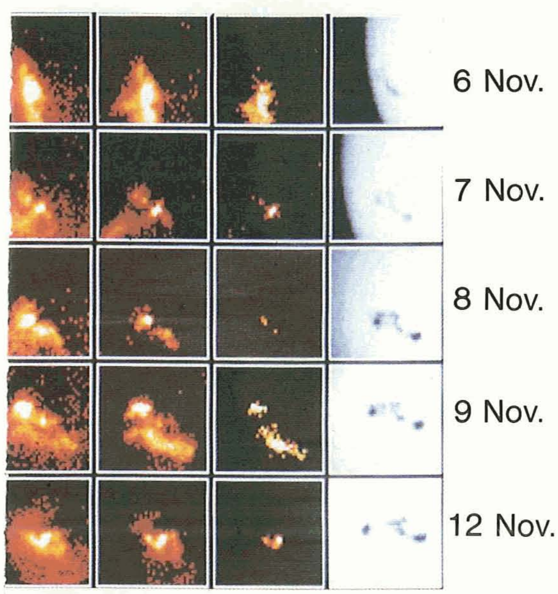
Two white light images taken by the Coronagraph/Polarimeter on August 18, 1980, show an ejection of matter into the corona. The event was associated with an eruptive prominence below. The first frame shows material moving into the corona; in the second, taken a half hour later, the corona appears as an expanding ring around the material.



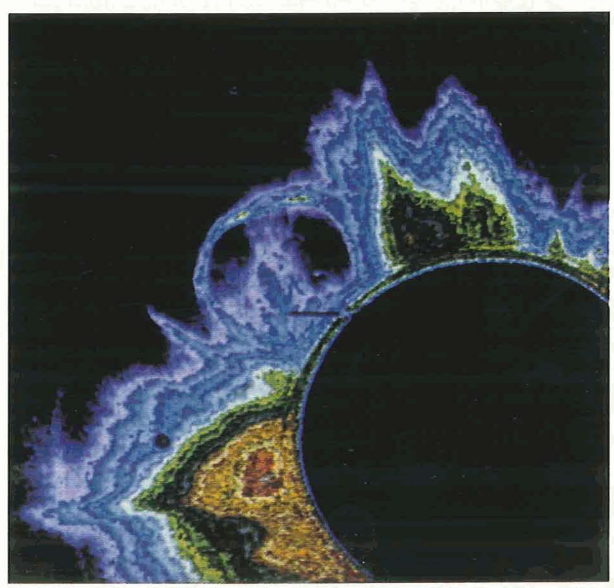
The large spike to the left of this image represents gamma ray emission during a large solar flare on June 3, 1982, which bathed Solar Max in neutrons for more than 20 minutes. The horizontal streak near the center indicates gamma radiation from neutrons captured in the sun, and the lower streak represents neutrons arriving at the spacecraft.



The almost perfect correlation between these two curves proves that electrons accelerated to high energies in the primary energy release of a flare lose their energy by collision with the upper chromosphere, where ultraviolet emission can be formed. The X-ray plot is from the Hard X-Ray Burst Spectrometer; the ultraviolet plot is from the Ultraviolet Spectrometer/Polarimeter.



· X-Ray Polychromator can follow the development of an active region for s. The white light images on the right show an active region moving across sun. As it produced flares, the region underwent many changes. Images n three X-ray channels represent different temperatures; ionized oxygen) at 3 million degrees, ionized magnesium at 4½ million degrees, and zed silicon at 7 million degrees. The hottest component (silicon) was the st variable.



Right: Zones of different density in the sun's outermost layer (corona) are mapped in various colors in this Coronagraph/Polarimeter image. Areas of greatest density appear orange; least dense areas are purple.

The Subtle Sun ☐ The solar radiant energy flux, over all wavelengths, that reaches Earth is called the "solar constant" because its value (as measured with previous instruments) does not seem to change markedly. This energy interacts with the terrestrial atmosphere, oceans, and land masses to drive atmospheric circulation and weather systems. The amount of solar energy is a critically important factor in the delicate balance of our biosphere. Changes of only a few percent are thought to affect global ice coverage, sea level, and mean temperature.

The approximate value of the solar constant is 1368 watts per square meter, though it is difficult to measure accurately from underneath Earth's atmosphere. Access to space and the development of advanced instruments, however, provide an opportunity to measure total solar radiation directly and precisely.

Solar Max carries an Active Cavity Radiometer Irradiance Monitor that is hindered only a little by the satellite's attitude control problems. The monitor can detect changes in the solar energy flux as small as one-thousandth of one percent; indeed, it has detected a long-term dimming of the sun by one tenth of one percent during its first two years of continuous operation. Over shorter periods of days to weeks, larger variations in total solar energy output have been correlated with magnetically active regions; for example, dark sunspot patches temporarily reduce the radiant energy output by up to two tenths of one percent.

The instrument also discerned minute, periodic variations in radiant output at five minute intervals, as if the sun were "breathing." The significance of these oscillations in the solar constant is not yet fully understood, but they seem to arise from waves that move deep into, and even through, the sun. Thus, these brightness fluctuations offer insight into phenomena and structures in the solar interior.

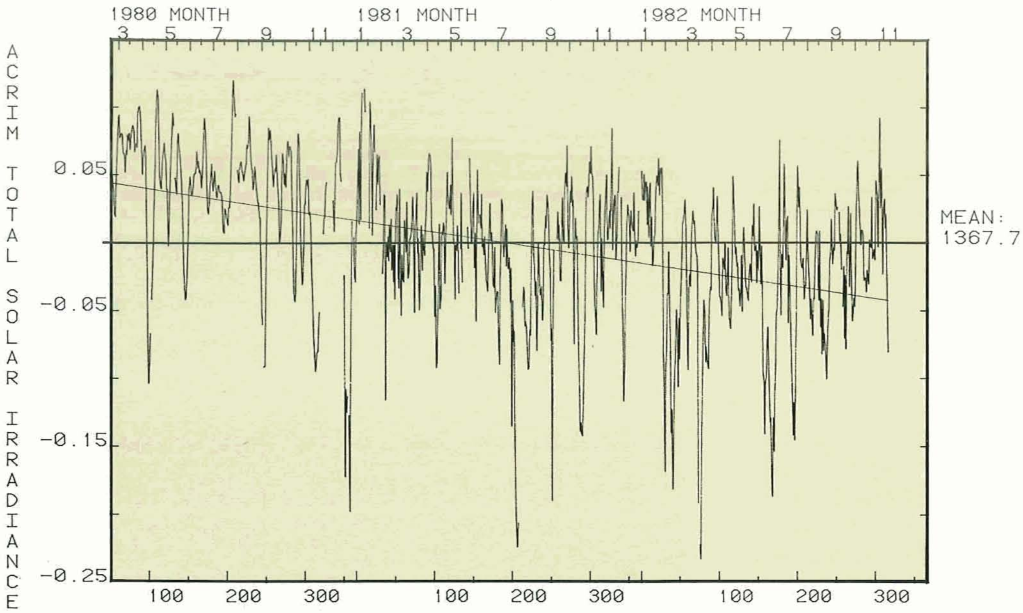
Only by long-term monitoring can scientists detect variations in the sun's total energy output linked to the solar activity cycle. Both solar physicists and terrestrial climatologists are interested in the changing value of the solar constant. The as yet unanswered question is whether small but persistent trends have a subtle effect on Earth's weather and climate. Continued monitoring, over many years and many solar cycles, is necessary before convincing correlations can be made.

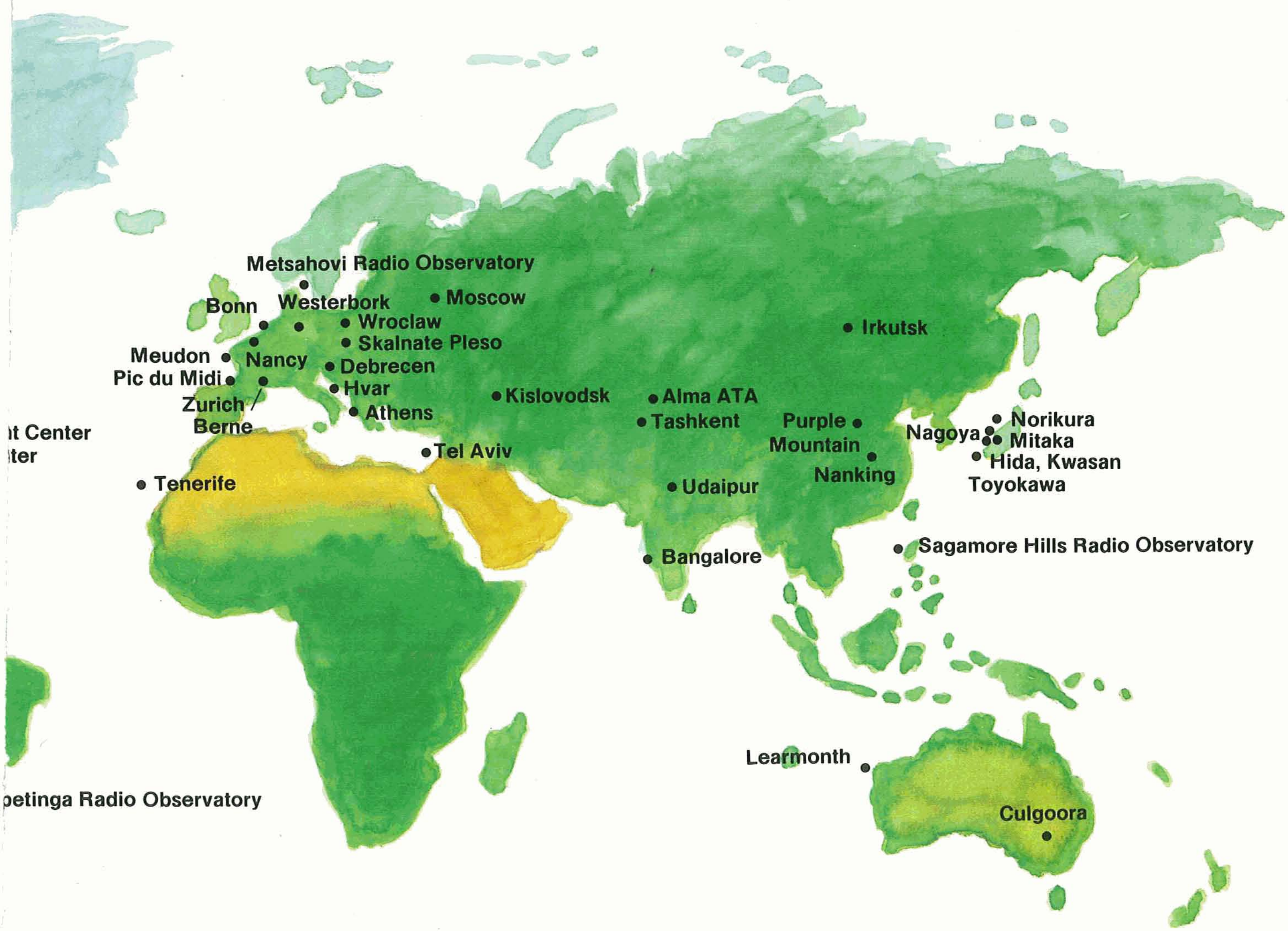
Solar Maximum Year ☐ The Solar Maximum Mission is part of a coordinated international program involving a worldwide network of observatories. More than 400 scientists from some 60 institutions in 17 foreign nations and the United States have participated in collaborative observational and theoretical studies of solar flares. In the solar science community, 1980 was designated the Solar Maximum Year. The scientific success of the Solar Max Mission results not only from the operation of the satellite but also from the Solar Maximum Year activities. Renewal of the Solar Max Mission presents the opportunity for another united, international effort to solve the solar flare puzzle.

To understand how flares develop and release energy, scientists must observe many flares in many wavelengths. The Solar Max Year was organized to encourage simultaneous viewing of specific areas of the sun by all participants. The team of investigators met daily in the Solar Max Operations Facility at NASA's Goddard Space Flight Center in Greenbelt, Maryland to review progress, choose solar targets for viewing, and plan the next day's viewing schedule, which was telexed to interested observatories immediately after the meeting. This plan enabled scientists around the world to collaborate with the Solar Max team in observation and, eventually, in data analysis. At some observatories, flare patrols issued forecasts, watched the sun for signs of flare activity, and notified all participants of specific solar viewing targets. Optical and radio telescopes on

Right: The Active Cavity Radiometer Irradiance Monitor is the first instrument able to make measurements precise enough to detect subtle changes in total solar radiance. Since Solar Max was placed in orbit, the monitor has recorded a persistent decrease in the "solar constant," the value of the sun's radiant energy received at the Earth. To date, this trend amounts to a decrease of approximately one-tenth of one percent.

Below: Many observatories around the world participated in the Solar Maximum Year research program. Renewal of the Solar Maximum Mission offers another opportunity for coordinated flare observations by instruments on the ground and on the satellite.


1980 MONTH
1981 MONTH
1982 MONTH
ACRIM TOTAL SOLAR IRRADIANCE
0.05
-0.05
-0.15
-0.25
MEAN:
1367.7
100
200
300


Metsahovi Radio Observatory
Bonn
Westerbork
Moscow
Wroclaw
Skalnate Pleso
Meudon
Nancy
Pic du Midi
Debrecen
Hvar
Zurich
Berne
Athens
Kislovodsk
Alma ATA
Tashkent
Irkutsk
Purple Mountain
Nanking
Nagoya
Norikura
Mitaka
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iter
Tel Aviv
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Udaipur
Bangalore
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the ground as well as instruments on balloons, rockets, and satellites operated together with the orbiting observatory to watch designated areas on the sun.

Such an ambitious and concentrated solar flare research effort was unprecedented. The scientists continue to meet in workshops to discuss solar flare theory and observations. This continued team effort and peer review promotes a unified rather than fragmentary study of solar flares. The workshops offer a public forum for proponents of competing flare models, and they stimulate rapid and close communication among solar scientists.

At the focus of this cooperative research effort, Solar Max became a valuable scientific resource. Its full potential was just beginning to be exploited when the satellite was crippled. Restoration of Solar Max operations will revive the coordinated solar flare research program and keep intact the links between solar scientists around the world.

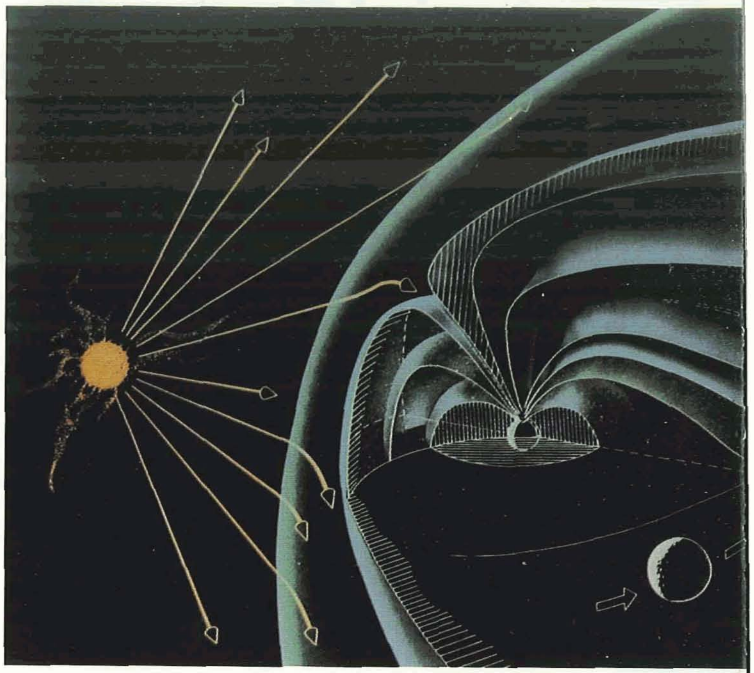
Sun-Earth Links □ A renewed Solar Maximum Mission is important to the search for solar-terrestrial connections. Explosions on the sun have an impact on Earth; flares change the intensity and composition of solar radiation and matter that bombard our planet. Resultant magnetic storms in Earth's space environment occasionally disrupt communications, endanger orbiting spacecraft, damage power stations and pipelines, and alter the chemistry and physics of the atmosphere. Evidence suggests that solar activity influences terrestrial weather and climate, but the physical links are not yet identified.

Renewal of Solar Max offers three major benefits to solar-terrestrial studies. Better understanding of the flare process should enable better prediction of flare events and the disruptive radiation that may affect spacecraft or vulnerable electronic equipment on the ground. An extended Solar Max Mission also enables longer-term measurements of total solar output; accumulation of these data is necessary for correlating changes in Earth's weather and climate with changes in solar radiation. Finally, coordinated observations of Earth's atmosphere will reveal how ozone and other constituent gases vary with solar activity.

The Sun as a Star □ The sun is our nearest star, the only one scientists can examine at sufficiently close range to resolve its structures. The complex solar processes of particle acceleration and energy release happen even more dramatically elsewhere in the universe. The better scientists understand the sun's behavior, the more insight they have into the mysterious activity of more distant stars.

One of the open issues in contemporary astrophysics is the nature of stellar magnetic activity. How do magnetic fields and plasmas interact? What role do magnetic structures play in energy storage and release? Solar Max is providing some answers to questions about the sun's magnetism. Because knowledge gained by studying the sun may guide the interpretation of stellar data, Solar Max science is also relevant to astrophysics. In particular, the sudden heating of material to extremely high temperatures is relevant to theories of stellar flares and loss of stellar mass. By watching the sun carefully, we may discern the secrets of many other stars.

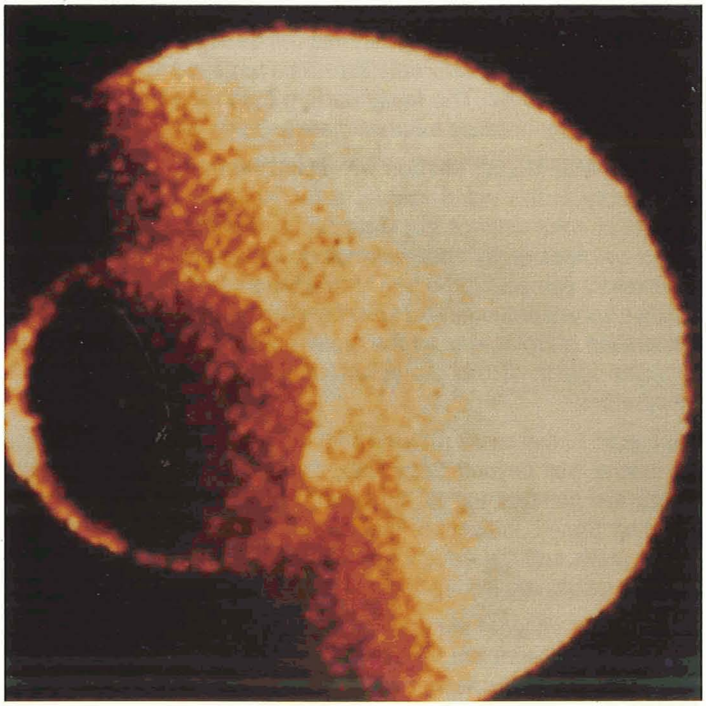
Flares and Fusion □ The sun is a highly efficient generator of energy by nuclear fusion. Experimenters are determined to duplicate the fusion process in their laboratories, but they have not yet solved the problem of how to contain a multi-million degree gas within a magnetic field long enough to sustain nuclear reactions. In solar flares, however, hot plasma is readily confined along magnetic field lines. Possibly Solar Max science will stimulate further dialogue between scientists studying fusion energy in the laboratory and scientists studying analogous processes that occur on the sun. ✸



Left: Solar Maximum Mission research is an essential part of the effort to understand the sun's influence on the Earth's magnetosphere and atmosphere.

Below: Auroras are visible evidence of the far-reaching effects of solar flares. Auroral activity increases markedly as solar particles bombard the Earth's upper atmosphere after a flare outburst.

Below, right: Seen from space, the aurora rings the Earth's polar regions with a tremendous discharge of energy. This image was made by an instrument aboard the Dynamics Explorer satellite on another mission managed by Goddard Space Flight Center.



SOLAR MAXIMUM REPAIR MISSION

In the past when an orbiting spacecraft or scientific instrument suffered massive failures, the scientific community on Earth was almost helpless. Typically, the opportunity to extend human knowledge was lost, along with a considerable investment of talent and material resources. The risk of equipment failure shadows any research project in space. The best insurance has always been redundancy, the expensive incorporation of backup components in instruments sent into space.

Now the Shuttle era introduces new options for ensuring the success of scientific missions. As access to space becomes more convenient with the Shuttle, it is now possible to send repair crews and spare parts on service calls to ailing satellites. It makes sense to design modular satellites with replaceable parts for on-orbit repair service. The Solar Maximum Repair Mission is the first demonstration of this new capability.

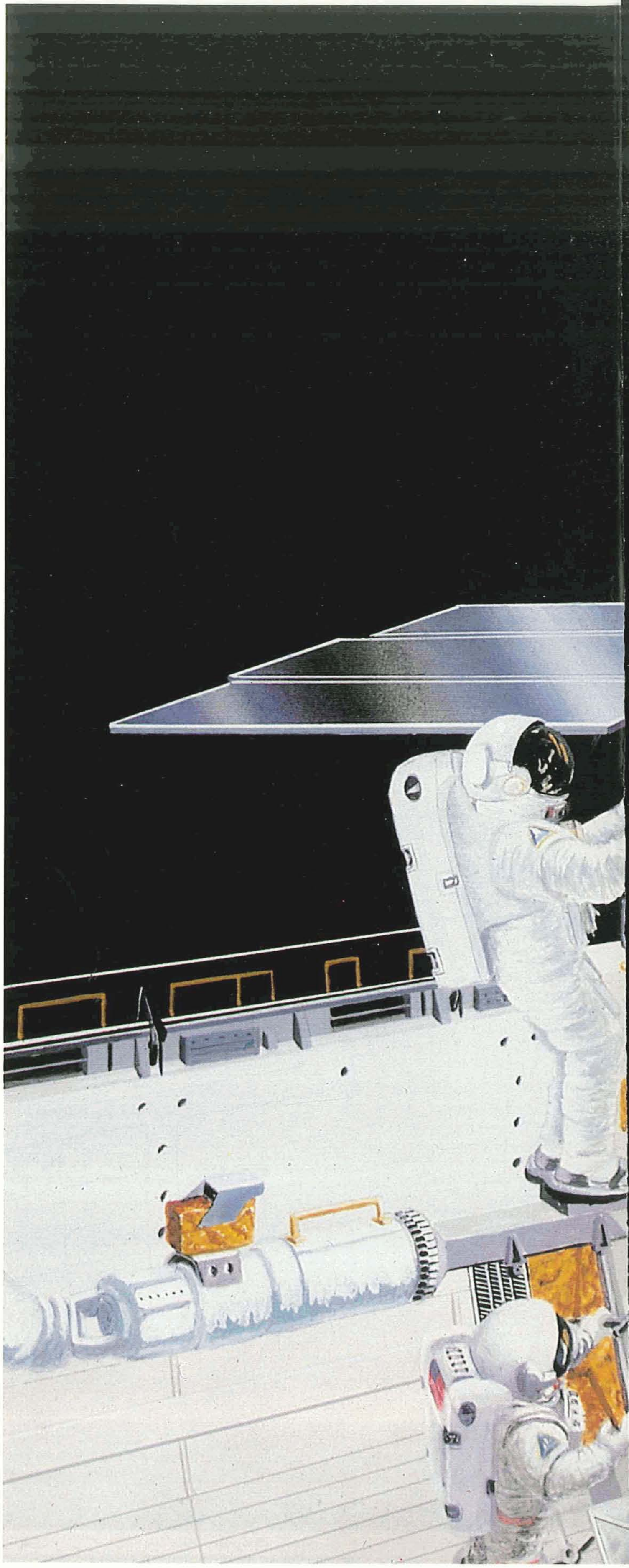
During the mission, the Shuttle crew will rendezvous with the satellite, capture it, and mount it in the cargo bay for repairs. The faulty attitude control system module will be replaced with a spare, and two of the seven scientific instruments will be serviced. After checkout, the repaired Solar Max satellite will be removed from the Shuttle and returned to orbit. The faulty parts will be returned to Earth for analysis, and for possible refurbishment and use on another mission.

The Solar Max Repair Mission will revive the most advanced solar observatory in the world and its solar flare research effort. This renewal of solar science will yield significant new information that cannot be obtained by observatories on the ground. Only an orbital observatory can watch the sun long enough and precisely enough to gain a full understanding of solar flare energy buildup and release. Restoration of Solar Max by the repair mission is estimated to cost only one-fourth of the replacement cost of this incomparable observatory.

The impact of this repair mission on the practice of science in space will extend well beyond Solar Max. Orbital servicing and modular design are planned for all the major observatories of the future, including Space Telescope, the Landsat series, the Gamma Ray Observatory, and the Advanced X-Ray Astrophysics Facility. Servicing operations are also planned for space station research facilities.

Extended operational life and full exploitation of instrument capabilities despite technical failures are now possible. New tools and techniques are available for use, and soon experienced repair crews will be available, too. Design of scientific instruments for orbital repair service is advantageous economically and technically, for it is possible to extend the life of a mission by replacing failed parts, upgrading equipment as technology advances, reboosting a satellite when its orbit drops, replenishing consumables such as fuels or coolants, or retrieving instruments for refurbishment on the ground.

The capability for orbital retrieval and repair is a considerable benefit to the practice of science in space. The Solar Maximum Repair Mission offers a new basis for confidence in the success of science missions in the Shuttle age. ✱



During the Solar Maximum Repair Mission, astronauts will replace faulty components to restore operation of the spacecraft and its scientific instruments.

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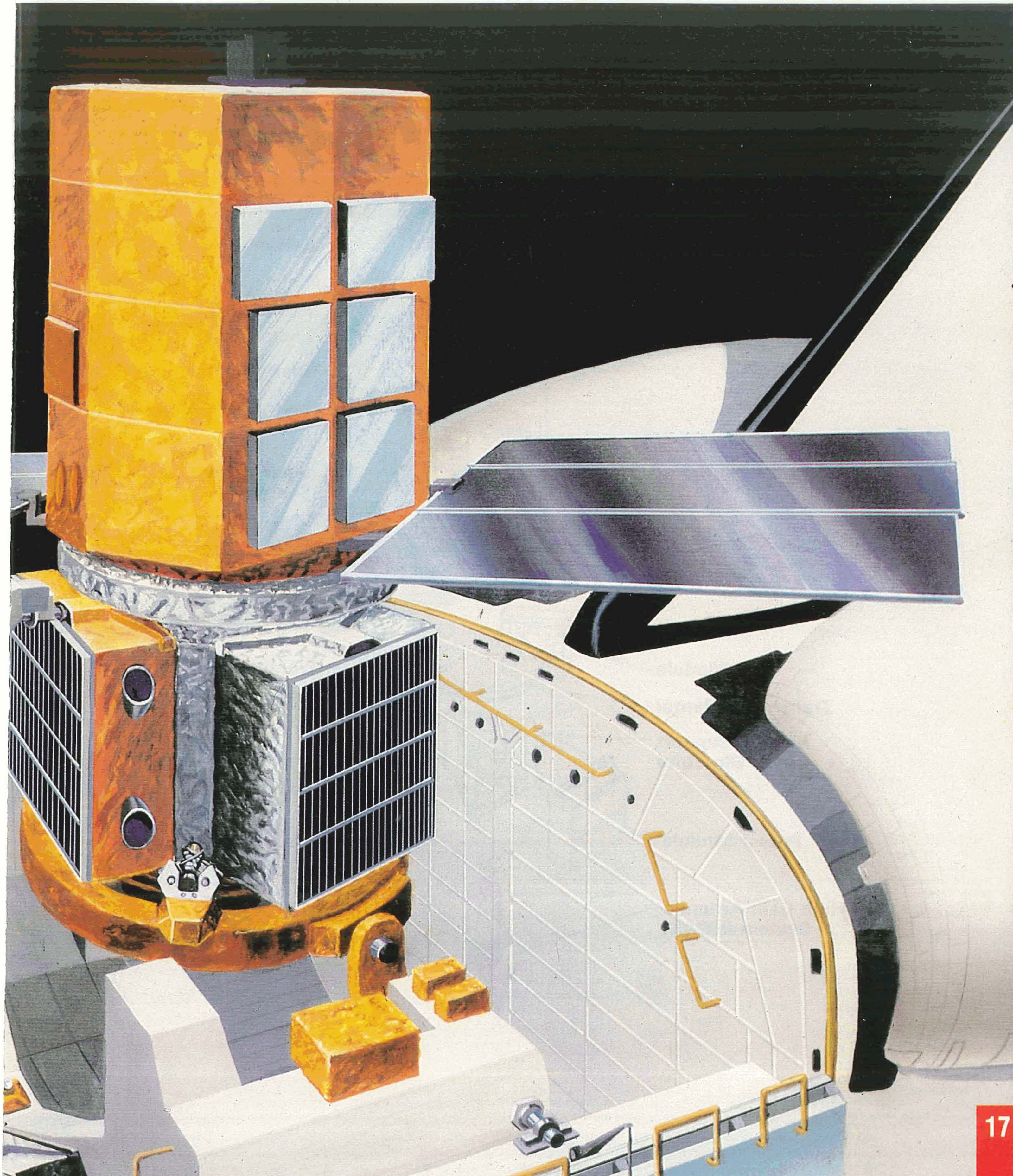
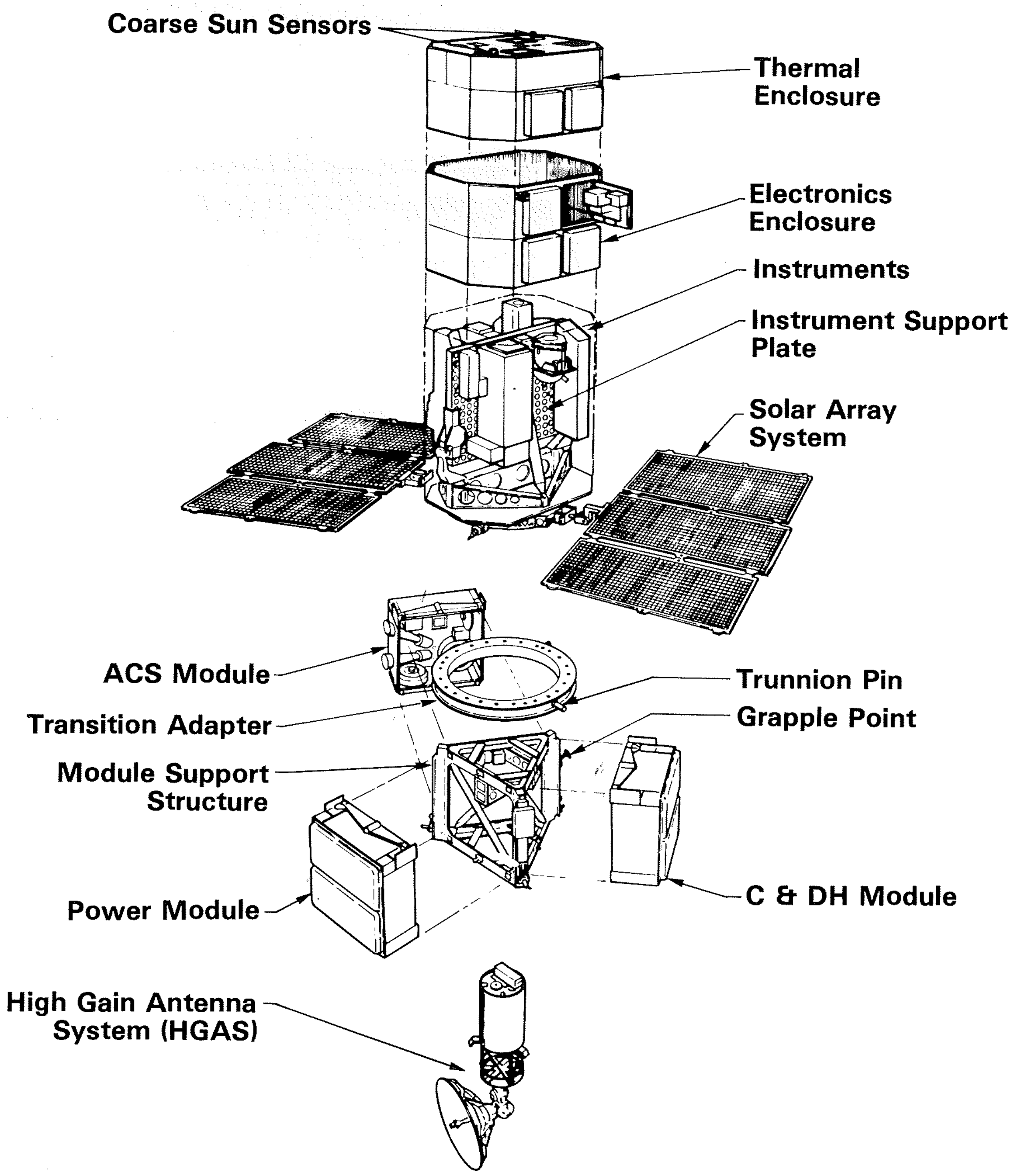
COLOR PHOTOGRAPH



SMM OBSERVATORY EXPLODED VIEW



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