

Skylab

AND THE

SUN

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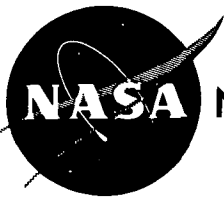
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SKYLAB AND THE SUN

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OFFICE OF MANNED SPACE FLIGHT / OFFICE OF SPACE SCIENCE

PREFACE

The purpose of this brochure is to familiarize the reader with the Sun and what we expect to gain by observing it. The articles in the brochure were supplied by scientists, astronauts and engineers, individuals all closely associated with the ATM Program and all deeply dedicated to making it a success.

Appended are several sources for information to facilitate the exchange of ideas and results.

L. N. Werner
Skylab Program Office

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FOREWORD

Since the earliest crude observations of the Sun by Galileo Galilei, man has taken giant strides in increasing his knowledge of the Sun and the universe. Advances in instrumentation and the ability to use a better location for observations, especially satellites above the disrupting effects of the Earth's atmosphere, have been significant factors in shaping the course of astronomical research.

Scientific instruments with which to make these observations from above the atmosphere have evolved from the early small rocket payloads to the large high resolution man-operated instruments developed for the Apollo Telescope Mount (ATM) which will significantly enhance our capability to better study and understand the activities of the Sun.

The ATM carries five large experiment telescope packages to permit simultaneous viewing of solar activity in different wavelengths.

The ATM experience will contribute to the evolution of future advanced orbiting observatory systems and help define instruments which will perform astronomical observations of a quality well beyond the capabilities of any ground-based or space instrumentation known today.

The ATM program will, for the first time, permit the evaluation of man's utility and ability to operate complex scientific instruments in a space environment. The first ATM mission may well be the beginning of the modern era of astronomy.

Dixon L. Forsythe
ATM Program Manager
National Aeronautics & Space Administration

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THE SKYLAB PROGRAM

DESCRIPTION

Skylab is an experimental space station launched in 1973 by the NASA. The station is a 100-ton complex of highly versatile laboratories that have the capability for multipurpose scientific investigation unmatched by any institution on Earth. The three-man Skylab crews perform more than 50 major research programs developed by specialists from universities, observatories, medical schools, hospitals, health institutions, and other public and private agencies in the United States and abroad.

Moving at a velocity of 5 miles/sec at an altitude of 235 nautical miles, Skylab orbits the Earth in an easterly direction in an orbit canted 50° from the plane of the equator. During 8 months of service, Skylab covers an area 3450 miles wide on either side of the equator. Skylab will criss-cross every section of the United States and will be visible for as long as 10 min at sunrise or sunset; the complex resembles a large star streaking southeast or northeast. The station completes one revolution every 93 minutes, its many delicate sensors finding and recording new information about the Sun and the Milky Way, the atmospheric sheath, the remote sections and the composition of the Earth, and about man himself.

OBJECTIVES

The Skylab Program objectives are:

- Advancement of the sciences: To increase knowledge of medicine, astronomy, Earth meteorology, physics, and other fields, including the effects of space and solar system phenomena on the Earth environment
- Practical applications: To perfect sensing and data systems for use in agriculture, forestry, oceanography, geography, geology, water and land management, communications, ecology and pollution-control applications, and to develop zero-g manufacturing techniques
- Durability of man and systems in space: To determine the ability of man, materials, and systems to maintain their qualities and capabilities during a long period of weightlessness

- Space-flight effectiveness and economy: To improve space-flight technology to develop long-duration mission capability for future programs

MISSION PROFILE

The Skylab workshop was launched by a two-stage Saturn V vehicle from Pad A of launch complex 39 at the NASA John F. Kennedy Space Center (KSC) and was inserted into a nearly circular orbit. In the first 7.5 hours of flight, Skylab jettisoned the payload shroud, maneuvered into a Sun-pointing mode, rotated the Apollo telescope mount (ATM) solar observatory 90° to an operating position, and deployed all solar-cell power arrays. The ATM pointing-control system maintains the sun-pointing attitude, and the Skylab is pressurized to 5 psia [3.7 psia oxygen (O₂), 1.3 psia nitrogen (N₂)] to prepare for docking with the manned command and service module (CSM) and the astronauts' entry.

After Skylab lift-off, a Saturn IB vehicle launches the CSM and three crewmen from Pad B at the KSC launch complex 39. First, the CSM is inserted into an interim elliptical orbit at an altitude of 93 to 138 miles above the Earth. Using the service propulsion system, the CSM climbs to an altitude of 235 nautical miles, to rendezvous with Skylab, and dock with the axial port of the multiple docking adapter (MDA), completing the cluster. The crewmen enter and activate the Skylab for habitation. The CSM is powered down, allowing operation of only essential elements of the communication, instrumentation, and thermal controls systems. Crewmen conduct assigned experiments which, on Flight 2, emphasizes medical and solar research and the evaluation of the long-term habitability of the Skylab; the Earth resources experiments also are activated and their operation verified. On the 27th day, the crewmen will prepare Skylab for storage in orbit; on the 28th day the crewmen will board the CSM, undock, deorbit, and land in the Pacific recovery area.

Sixty days later, a second CSM with a three-man crew will be launched from the KSC. Orbital insertion, rendezvous, and docking will be the same as for Flight 2, but Flight 3 will have more

emphasis on solar astronomy and Earth resources experiments. Flight 3 is planned for up to 56 days. Assuming nominal mission duration and deorbit, landing will be in the Pacific recovery area.

The third CSM and crew will be launched approximately one month after the Flight 3 crew returns to Earth. Flight 4 will complete the objectives of the planned experiments.

KEY MISSION EVENTS

Flight 1

Day 1: The unmanned Skylab is launched; inserted into operational orbit; pressurized for entry of the crewmen; and the ATM is deployed.

Flight 2

Day 1: The first CSM is launched, rendezvous with Skylab, and docks; the crewmen enter and power up the orbiting cluster.

Days 2 to 25: The astronauts man the laboratory to conduct sequences of experiments.

Day 26: One crewman exits, maneuvers outside the station to the ATM, and retrieves and replaces film.

Days 27 and 28: The crew deactivates experiments and prepares the Skylab systems for a 2-month unmanned storage in orbit.

Day 28: The CSM is undocked, deorbited, and returned to Earth with the crewmen and the experiment film, specimens, and records.

Flight 3

Days 1 and 2: The second crew and CSM are launched, rendezvous, dock, and reactivate the dormant Skylab.

Days 3 and 4: The crew conducts mission experiments.

Day 5: An extravehicular activity (EVA) is performed to load film into the ATM.

Days 6 to 28: Mission experiment operations are performed.

Day 29: An EVA is performed to retrieve film from and to reload the ATM.

Days 30 to 53: Mission experiment operations are continued.

Day 54: An EVA is performed for the purposes of retrieving and replacing ATM film and inspecting degradation of thermal coatings.

Days 55 and 56: Skylab and the experiments are deactivated for a 1-month period of unmanned storage.

Day 56: The CSM is separated, deorbited, and returned to Earth.

Flight 4

Days 1 and 2: The crewmen and CSM are launched, and rendezvous and dock with the Skylab; the Skylab is activated.

Day 3: An EVA is performed to load film in the ATM.

Days 4 to 53: Mission experiment operations are performed.

Day 54: An EVA is performed to retrieve ATM film.

Days 55 and 56: Skylab systems are deactivated.

Day 56: The crew and the CSM separate from Skylab, deorbit, and return to Earth.

THE SUN*

By Herbert Friedman

Chief Scientist E. O. Hulburt Center for Space Research
U. S. Naval Research Laboratory

Eight minutes ago, daylight now entering your window escaped the surface of the Sun, but its energy was created deep within the surface of the solar furnace before the birth of civilization. Each second, four million tons of solar hydrogen transforms itself to radiant energy which eventually floods into space. Yet the Sun is so huge that it can continue to consume itself at this rate for billions of years to come, as it has for five billion years past. Thus our star shines steadily over eons of time, to light the moon and planets, and sustain all life on Earth.

But the peaceful Sun can erupt at times with a tremendous burst of energy. Then streams of invisible radiation and immense clouds of solar gas strike the atmosphere high above us. Shielded by a protective blanket of air, our senses receive no inkling of the storm above, but its power shows in a host of mysterious and awe-inspiring events.

Throughout history these effects went almost unnoticed by man, except for the spectacle of the northern lights. But with the invention of telegraphy and radio, the electrical and magnetic disturbances became a matter of practical concern.

Today, scientists also worry about the hazard to man in space if he should be exposed to a blast of solar storm particles. Because of their enormous energy, they can damage and even destroy human cells.

Just such a solar outburst took place at 2:37 p.m. on November 12, 1960, when astronomers in Michigan detected a brilliant explosion on the face of the Sun. Six hours later, a gigantic cloud of solar hydrogen gas, 10 million miles across and still trailing halfway back to the Sun, 93,000,000 miles away, collided with Earth at a speed of about 4,000 miles a second.

Though inaudible and invisible, the collision dissipated more energy in the Earth's high atmosphere than the most destructive hurricane,

*Reprinted with permission of the author and the National Geographic Society (November 1965 issue).

covering every square mile of the globe. It started a violent chain of disturbances on Earth, an electrical and magnetic storm of mammoth proportions.

Compass needles wavered erratically, and for hours all long-distance radio communications were blacked out. Teletypes printed gibberish. Airplane pilots lost contact with their control stations, and the Coast Guard could not reach its weather ships in the North Atlantic.

Overhead, sheets of flaming red northern lights flashed in the night sky, bright enough to be seen through overcast and clouds. In northern areas, electric lights flickered in farmhouses as if a thunderstorm raged, yet the air and sky were clear and silent.

For more than a week, such chaotic conditions continued. They were clearly the results of a sun on the rampage. But if this picture of the violent Sun seems impressive to you, let me assure you that such a storm amounts to no more than a tiny ripple in the usual steady flow of solar energy.

All too often we take the Sun for granted, forgetting how totally we depend on its benign flood of heat and light. It is the Sun whose radiation moves the atmosphere and makes weather and climate; causes ocean water to evaporate and then fall as rain; gives us most of our useful energy through coal, oil, and wind and water power; and produces our food through sunshine absorbed by plants.

CITY'S WARMTH

The Sun's power staggers the imagination: In one second, this star of ours (the Sun is, after all, just one of an estimated hundred billion stars in the Milky Way) radiates more energy than man has used since the beginning of civilization. The Sun delivers to us in just three days as much heat and light as would be produced by burning the Earth's entire oil and coal reserves and all the wood of its forests. Yet Earth receives only about one two-billionth of the Sun's radiant energy.

Engineers have developed solar cells that produce electric current when sunlight hits them. Such cells power electronic gear on spacecraft,

such as TIROS and Mariner IV**. Solar devices catch the Sun's rays to heat homes, swimming pools and ultrahigh-temperature furnaces, and a portable solar stove is being developed for use in fuel-poor countries.

If in such a manner we could collect and efficiently use the sunlight falling on just the city of Los Angeles, it would supply more energy than is consumed in all the homes on Earth. The Sun produces this life-supporting energy so steadily that astronomers cannot detect with certainty as much as one percent variation in the total output.

What makes the Sun shine so steadily? Primitive man thought of the Sun as a ball of fire, but scientists determined long ago that the Sun was not merely burning like a great ball of coal. Indeed, if it were merely coal it would have burned for only a few thousand years, and would have turned to cold cinders billions of years ago. Some other explanation was required.

STELLAR ATOM ENERGY

Finally, in 1925, Sir Arthur Eddington, a brilliant British astronomer, proposed the answer now accepted as correct: It is atomic, or nuclear, energy that fires the stars. This energy—the same as that of the hydrogen bomb—comes from the process we call nuclear fusion, in which the nuclei, or cores, of hydrogen atoms collide, uniting to form helium nuclei and giving off bursts of energy.

No other process we know of could possibly pour out such sustained quantities of energy. Moreover, we know that for the Sun to stabilize at its present size, it must have a temperature and pressure at its core sufficient to support nuclear reactions.

Thus, deep within the Sun, each second, 564 million tons of hydrogen are converted to 560 million tons of helium. The remaining four million tons each second radiate away as heat and light.

If the Sun has been shining at its present brightness since the Earth was formed nearly five bil-

lion years ago, each pound of solar matter must have yielded already at least 4,000,000 kilowatt-hours of energy. At that rate, a pound of the Sun would keep a kitchen stove going with all burners on for several hundred years.

Fantastic as the Sun's outflow of energy must appear, the nuclear fusion actually goes on at a slow pace, atomically speaking. The Sun may be considered as a very slow-burning hydrogen bomb, since it takes, on the average, about a million years for two hydrogen nuclei to collide and fuse. These tiny particles, even in the Sun's dense interior, are on the average almost as far apart, in proportion to their size, as the Earth and Venus. Moreover, they require a head-on crash at extraordinarily high speeds in order to fuse.

HUMAN "HOTTER" THAN SUN

Only because the Sun is so large is its total production of energy so enormous. *Pound for pound*, the Sun actually produces less heat than the human body. If the mass of the Sun could be matched with live bodies and if the normal human metabolism of those bodies could continue, they would generate more heat than the Sun now radiates.

How do we know this? It's a simple matter of arithmetic: The Sun's output of radiant energy, divided by the Sun's mass, shows a daily production of two calories a pound. By contrast, the average human body generates something like 10 calories a pound each day.

Mankind is now embarked on a great new adventure—the exploration of space. More than half the scientific satellites launched by agencies of the United States government are, in one way or another, devoted to the study of the Sun's activity and its close relationship to Earth's environment.†

My own agency, the Office of Naval Research, is deeply involved in studying the Sun; we maintain a series of satellites called SOLRAD in orbit at all times for solar radiation measurements.

Until very recently, man's view of the heavens was seriously hampered by a murky, shimmering

**And of course, the Skylab.

†This was the case at the time this article was written.

atmosphere, which distorts light beams and blots out the Sun's atmospheric X-rays and much of its ultraviolet and infrared radiation. Henry Norris Russell, the noted Princeton astronomer, once jested, "All good astronomers go to the moon when they die so that they may observe the universe without the interference of a dirty atmosphere."

But beginning in 1946, rockets became available to carry small telescopes and spectrographs above the atmosphere, and for a few minutes of each rocket's flight the ultraviolet and X-ray emissions of the Sun can be studied. Within recent years balloons have lifted heavy telescopes and cameras above 99 percent of the atmosphere, to an area where the distortion of visible light is largely eliminated.

And now ‡ satellites, such as the Orbiting Solar Observatories of the National Aeronautics and Space Administration, provide stable platforms that can point 80 pounds of instruments steadily at the Sun, with fine accuracy. Dozens of solar ultraviolet and X-ray pictures can be transmitted to Earth daily.

SUN MESSAGES

Radio astronomy, which is only about a third of a century old, provides another effective tool for studying the higher levels of the solar atmosphere. During World War II, British radar engineers were puzzled when their instruments tracked intense static signals descending into the western ocean, instead of Nazi bombers coming from the east. They found that such ghost signals rose and fell with the rising and setting of the Sun, which was sending out its own radio messages.

The Sun's emanations constantly flicker and pulsate, with frequent violent outbursts. Astronomers tune in on these broadcasts with sensitive antennas. Using huge radar transmitters, they can bounce beams off the swollen outer atmosphere of the Sun and probe its structure and movements.

‡ Refers to 1960, the next Orbiting Solar Observatory will point about 250 lbs steadily at the Sun with nearly 100 times greater stability.

The years 1964 and 1965 were designated the International Quiet Sun Years (IQSY). Observers in 43 countries kept a diary of the face of the Sun at a time when it is relatively undisturbed by sunspots and solar storms.

The IQSY is sequel to the International Geophysical Year (1957-1958), when scientists studied the Sun and Earth under conditions of maximum solar activity. Changes since 1958 have been substantial, since solar activity goes from active to quiet to active again in an average cycle of about 11 years.

In these coordinated international surveys, solar telescopes take regular pictures of the Sun through various filters; mountaintop observatories watch the Sun's outer atmosphere through coronagraphs; magnetographs make magnetic maps of the Sun's face; radio telescopes capture the Sun's radio signals as wavy lines and numbers on paper tapes; and satellites, rockets, and balloons monitor the solar winds and storms and the Sun's output of high-energy radiations such as X-rays.

At the U. S. Naval Research Laboratory's E. O. Hulburt Center for Space Research in Washington, D. C., we are especially interested in rocket and satellite observation of X-rays, which can't be detected from the ground. They tell us much about the most energetic processes on the Sun. In two decades at the laboratory, I suppose I have instrumented more than 50 rockets and a dozen satellites for this kind of research. §

When astronomers examine the Sun with a solar telescope, its edge appears sharp as if it marked a definite surface. This apparent surface is in fact a transparent, though highly luminous, layer of gas about 200 miles thick, called the photosphere. From the photosphere comes most of the light we get from the Sun. At the bottom of the photosphere, the gas becomes so opaque that no light from the interior can escape through it directly.

Thus the photosphere is a thin, bright shell that surrounds the main body of the Sun like an

§ Complete through 1965; many more have since been instrumented and flown by the Hulburt Center.

onion skin. Outside this layer lie two others—a region of flamelike outbursts of gas called the chromosphere, and an almost endless outer atmosphere called the corona.

As we look at the Sun from Earth, we can “see” only these three layers directly—through visible light, infrared, and radio, observed by ground observatories, and through ultraviolet and X-rays detected by instruments in rockets and satellites. All that we know of the Sun’s hidden interior must, therefore, be deduced from observation of these external features.

The ancients held many strange notions about the flaming ball that courses daily across the sky. Epicurus, the Greek philosopher, estimated about 300 B. C. that the sun “is just as great as it appears”—that is, about two feet in diameter. To Anaxagoras, another Greek philosopher, the Sun was “a mass of red-hot metal” larger than the Peloponnesus. Even some Eskimos, until recently, believed that after the Sun set in the western ocean, “he” was paddled back in a kayak through the night, to the eastern horizon.

Modern astronomers can gauge the size and distance of the Sun very accurately, using triangulation with other celestial objects. Its diameter of 864,000 miles compares with Earth’s 8,000. The Sun’s distance from Earth averages 93,000,000 miles, a length scientists use as the astronomical unit for measuring the solar system. Since Earth’s orbit is slightly elliptical, the actual distance varies from 91 to 94 million miles.

When we compare Earth’s size with that of the Sun, we find that the Sun would hold some 1,300,000 Earths, and that it contains nearly 330,000 times as much mass as the Earth. Since gravitational pull depends directly on the mass, but decreases with the square of the distance from the center of the body, a man on the Sun would weigh some two tons.

“INTELLECTUAL BORING”

Having determined the Sun’s mass and diameter, the astrophysicist can then deduce the temperature, density, and pressure at all distances from the center to the surface, even though he is un-

able to see deeper than the 200 miles of the luminous photosphere. Sir Arthur Eddington described this deductive process as “intellectual boring.”

As a result of this boring, we have good reason to believe that at the center of the Sun, close to half a million miles deep, pressure reaches 100 billion atmospheres. (An “atmosphere” is 14.7 pounds per square inch, the weight of the column of air over a square inch of Earth’s surface at sea level.)

To produce such great pressure, we know that gas must be heated to a temperature of about 16,000,000° C. (Astronomers, like other scientists, use centigrade. To convert to Fahrenheit, multiply by 9/5 and add 32.)

How hot is 16 million degrees? Sir James Jeans, in *The Universe Around Us*, calculates that a pinhead of material at the temperature of the Sun’s core would emit enough heat to kill a man a hundred miles away.

Although the density at the center of the Sun must be about 11.4 times that of solid lead, the Sun remains gaseous everywhere. That is, the atoms are free to move about, unlike those in a solid, which are fixed in a regular pattern. However, the atoms in the core are not normal. Most of their outer electrons have been sloughed off by collisions of atoms, and rush about as free particles.

Normal atoms cannot get closer than about a hundred-millionth of an inch because their outer electrons would touch. Electrons, which are negatively charged, repel one another. Thus they keep atoms widely spaced—widely, that is, in atomic terms. But when electrons are stripped away, the remaining nuclei can approach very much closer. That is why the Sun’s inner core can be so extremely dense. The bare nuclei are more tightly squeezed.

X-RAYS TURN VISIBLE

If we could go into the Sun’s interior to make measurements, we would find that roughly 90 percent of the energy that eventually floods out into space is produced within a central core which reaches only one-quarter of the distance to the surface.

In this nuclear furnace the fantastically hot, dense gas is almost pitch black, since nearly all its radiation is invisible X-rays produced by nuclear reactions and the collisions of fast-racing nuclei and electrons.

The path of an X-ray as it escapes from the core of the Sun resembles the zigzagging track of the steel ball in a pinball machine. Even though the rays travel at the speed of light, 186,300 miles a second, the devious trip to the surface takes about 20,000 years!

During that long period the X-rays gradually change. Each time one is deflected, the frequency of its vibration is reduced slightly, and its wavelength is increased. In time, all the X-rays gradually turn into ultraviolet and visible light.

To understand this relationship, think of X-rays, ultraviolet, and visible light as all being cousins, or related forms of electromagnetic vibration, on a spectrum, or scale, like that of a piano. Just as each note on the piano varies from its neighbors by its frequency (the rate at which its string vibrates), so do vibrations in the electromagnetic spectrum. X-rays are comparable to high notes, ultraviolet represents notes with a somewhat lower frequency, and visible light waves fall still lower, near the middle of the keyboard, so to speak. Farther down the scale come infrared and then radio waves, the "low notes." These, too, are electromagnetic vibrations, differing from light only in their rate of vibration.

At three-quarters of the distance to the surface, the solar interior has cooled to about 150,000°C, and the density has fallen to about a tenth that of water. Up to this point, the Sun's energy has been transferred in radiant form. Radiant energy travels directly by waves moving with the speed of light, as when one feels the heat of a fire at a distance.

Now, however, still more than 100,000 miles below the surface, the Sun's gas begins to convect, like boiling water, and energy seeths upward in a turbulent flow of hot gas. Convection occurs when chaotic masses of gaseous atoms flow in currents, each atom carrying its own parcel of energy all the way.

Finally the Sun's energy reaches the surface and there, in the photosphere, its form is again changed, being largely converted once more to radiation that leaves the Sun to flood through space.

SUNSPOTS VISIBLE

Aristotle taught that the Sun was a globe of pure fire without blemish. This belief persisted until Galileo's time, when the newly invented telescope showed that dark spots come and go across the face of the Sun.

Normally, bright Sun blinds the naked eye, but when fog and haze reduce the glare we can readily detect large sunspots, especially near sunrise or sunset. Two hundred years ago, people thought the spots were solid mountaintops protruding above an ocean of glowing lava, the photosphere. They reasoned that the photosphere would have high and low tides. As the tide ebbed, the higher mountaintops would show as dark bodies.

In 1774, however, Alexander Wilson, a Scottish astronomer, observed that spots had inclined edges, like the slopes of a crater, leading to a dark interior inside the brilliant shell. Sir William Herschel, the British court astronomer, proposed about 1800 that a spot reveals the surface of a cold, solid crust. Above this surface, he thought, were two cloud layers, the outer being brilliant and hot, and the inner, a cool, protective shield, shading the crust. According to this notion, a spot would appear when the clouds parted to reveal the underlying cool crust.

Herschel went so far as to suggest that the dark interior of the Sun supported intelligent life. So great was his authority that the idea of a cool solar surface persisted through most of the first half of the nineteenth century, even though it is simple to calculate that such a sun could not shine for more than a day or two.

Actually, the surface of the Sun, the photosphere, appears granular at its base, as though it were paved with cobblestones. A sunspot begins to form as a dark pore in the midst of the fine granular pattern. Soon several pores coalesce with each other to form a spot. Sometimes the spot lasts only a few hours, but occasionally one will grow and persist for weeks or months.

ROTATION VARIES

The shape of the spot most often resembles a funnel 400 or 500 miles in depth. In the dark central area the temperature is only about $4,200^{\circ}\text{C}$. This is hotter than the hottest blast furnace on Earth; yet compared to the $5,700^{\circ}\text{C}$. temperature of the surrounding photosphere, the spot appears cool and dark.

A relatively small spot measures only a few thousand miles in diameter, roughly the size of the Earth. The largest spot group on record, in 1947, expanded to more than seven billion square miles.

Sunspots act as markers on the clear disk of the Sun and show us that its globe rotates from east to west, but in a very peculiar way. Unlike the solid Earth, the Sun does not rotate uniformly at all latitudes. A spot close to the equator, for example, completes a rotation in 25 days; one at 30° latitude takes 26 days; the rotation of the polar zone may take as long as 34 days.

Thus the gaseous Sun twists on its axis so that the equatorial regions rotate faster than the polar caps. Most of the changing features observed on the surface of the Sun must be related in some way to this contortion.

During quiet periods of the 11-year solar cycle, months may pass without visible spots. At peak periods, as in 1957, spots may number as many as 25 at one time.

Some people have tried to link the number of sunspots to the number of admissions of mental cases to psychiatric hospitals, to the behavior of the stock market, to the pattern of annual growth rings in trees, or to the catch of Atlantic salmon. None of these proves out. But sunspots are clearly connected with radio communications, magnetic storms, and the auroras, or northern and southern lights.

Some of the oldest indirect evidence of the cyclic nature of solar activity is documented in records of auroras, which are a direct product of solar bombardment. Unlike magnetic phenomena, which are revealed only by delicate instruments, the strange lights of the auroras can be seen at times by all the world.

Ancient peoples were terrified and awe-struck by the flaming, pulsating, brilliant red and green glows. Aristotle wrote about them as long ago as the fourth century B. C. In the Middle Ages, auroras were often described as fiery dragons, burning spears, beams of fire, or divine revelations. Superstitious folk interpreted the infrequent and sporadic nature of the heavenly spectacles as portents of the end of the world.

From such auroral accounts, science historians have traced the 11-year sunspot cycle back more than 2,000 years. By use of the spectroscope, an instrument which breaks white light into its familiar rainbow spectrum, we measure the magnetism of sunspots. The magnetic field strength is enormous—comparable to the most intense fields produced in modern particle accelerators, such as the Brookhaven synchrotron. But Brookhaven produces such a powerful field over only a few thousand square feet. When we consider that the sunspot field often covers an area big enough to blanket ten earths, we know that a major portion of the energy in the solar atmosphere is bound up in magnetic fields.

LIGHT YIELDS STAR'S SECRETS

As every high-school science student learns, a magnetic field can be established in the laboratory by a steel horseshoe magnet, or by an electric current flowing in a coil of wire. Now there are certainly no solid-steel magnets in sunspots, so their magnetism must come from tremendous electric currents, carrying as much as 10 million million amperes.

Some scientists suggest that these huge currents originate in the highly convective gas surrounding the inner nuclear furnace. The streams of hot gas carry burned nuclear fuel outward, and cooler gases carry fresh fuel toward the center. Because of the rotation of the Sun, these circulating streams may be twisted into whirls which detach like smoke rings, rising to break through the photosphere and thus to form pairs of spots.

Why are sunspots relatively cool? Possibly gas within a spot flows out along lines of magnetic force and cools by expansion.

In the 1830's, the French philosopher Auguste Comte wrote that man must reconcile himself to

eternal ignorance of the composition of the stars. How utterly wrong he was! By analyzing the quality of sunlight arriving from 93 million miles away, we can tell what the Sun is made of just as accurately as if a sample of the star had been brought to our Earthly laboratory.

Atoms radiate light with precise frequencies that uniquely identify different elements—somewhat like the tones and overtones that produce the specific color or quality of a musical instrument. The ear can pick out the various frequency components of instrumental sounds with much greater discernment than the eye can resolve the light waves in a color mixture. But one of the astronomer's key instruments, the optical spectroscope, does what the eye cannot, and permits us to isolate the different "tunes," or characteristic frequencies, of every known atom.

Perhaps the most remarkable accomplishment of astronomy is the spectroscopic discovery that all stars are made of the same atoms we find on Earth.

In 1814, Joseph von Fraunhofer, a young Bavarian lens designer, stumbled upon a most surprising phenomenon. He was trying to isolate pure colors from sunlight, to test the refraction—the bending of light rays—by his telescope lenses. When Fraunhofer looked at the rainbow spectrum of sunlight with his instrument, he noticed many fine dark lines interrupting the smooth progression of color from red to violet. At first he blamed his glass for imperfections, but soon he became convinced that the dark lines were a true feature of sunlight.

The solar Fraunhofer line spectrum can be used as a "fingerprint" of the elements in the Sun, for each element shows its own combination of lines. Hydrogen, for example, produces a simple spectrum with just a few dark lines; iron has more than 3,000. By means of Fraunhofer lines, about 70 of the 92 elements naturally occurring on Earth have been identified in the Sun.

Furthermore, the character of the spectral lines—whether they appear sharp or fuzzy, dark or only half-shaded, slightly shifted toward the red or toward the blue end of the color spectrum—offers the astrophysicist tremendous amounts of information: He can deduce temper-

ature, pressure, density, and composition; the strength of gravity, density of radiation, electric force, magnetic force, degree of turbulence, and convective movements in the region of the Sun where the spectrum line is produced.

The Fraunhofer spectrum tells us that the Sun consists principally of hydrogen. Hydrogen atoms are roughly 10 times as abundant there as helium, the next most abundant element, and 1,000 times as abundant as carbon, nitrogen, or oxygen, which are so common on Earth. Except for the overabundance of hydrogen and helium, the chemical composition of the solar atmosphere is much the same as that of Earth's crust.

Like the other close-in planets of the solar system—Mercury, Venus, and Mars—the Earth has lost most of its hydrogen and helium. But the Jovian planets—Jupiter, Saturn, Uranus, and Neptune—because they are cold and very heavy, retain a great deal of the original hydrogen and helium and thus more closely resemble the Sun.

SUN'S EXPRESSION CHANGES

In white light we see mainly the lower levels of the photosphere with its granules and sunspots. The Fraunhofer lines originate in the higher portions of the photosphere where it is cooler—the darker the line, the higher and cooler its region of origin.

In 1889, George Ellery Hale, father of the world's largest optical telescope, the 200-inch on California's Palomar Mountain, invented a most useful variation of the spectroscope called the spectroheliograph. In essence it is a highly selective filter that enables astronomers to narrow down their view of the Sun to that of a single line of the color spectrum. Thus as the spectroheliograph scans the face of the Sun, it sees only one color, such as the red line of hydrogen or the violet line of ionized calcium.

Each line is produced in the Sun at a level where the temperature is just right. Thus the spectroheliograph can probe deeper and deeper into the Sun's atmosphere, photographing the entire face of the Sun at each level. And at each layer the face of the Sun takes on a remarkably different complexion, and the expression is constantly changing.

Hovering near sunspots, self-luminous clouds resemble fluffs of wool in white light. They are called faculae, Latin for "little torches." The surface of the Sun, when photographed with a spectroheliograph in the violet light of ionized calcium, takes on a mottled appearance, like the skin of an orange. Near the sunspots the mottles concentrate into bright patches called plages, French for "beaches."

ECLIPSE ERROR FATAL

A few thousand miles above the photosphere, the solar atmosphere is so thinned out that it becomes virtually invisible in the glare of the photosphere. But when an eclipse masks the face of the Sun, we see a very interesting profile.

If the eclipse occurs at sunspot maximum, the corona assumes a symmetrical shape with petal-like streamers resembling a large dahlia with the black moon at the center. At sunspot minimum, great equatorial streamers stretch millions of miles, distorting the symmetry.

Most of what we know of the Sun's outer atmosphere comes from studies of the solar eclipse, perhaps the most dramatic of all nature's spectacles.

The earliest historical record of an eclipse dates back more than 4,000 years to October 22, 2137 B. C., and is documented in the Chinese classic *Shu Ching*. This book contains regulations of the emperor regarding his royal astronomers and their eclipse predictions:

"Being before the time, the astronomers are to be killed without respite; and being behind the time, they are to be slain without reprieve."

Although eclipse-manship is no longer a matter of life or death, astronomers have often risked great personal danger in eclipse expeditions. One English astronomer traveled 75,000 miles to six eclipses, but because of clouds or rain saw only one. A French astronomer, Pierre Janssen, was so intent on photographing the eclipse of 1870, during the Franco-Prussian War, that he risked German rifle fire to escape from the siege of Paris in a balloon. Unhappily, when he reached the eclipse path over the African coast, rain hid the event.

In 1842, astronomers in southern Europe were the first to take careful note of the very faint, extended outer atmosphere of the Sun. As the moon blocked out the brilliant disk, a pearly white corona with delicate streamers and curved arches stood revealed. Close to the black edge of the moon, a reddish ring encircled the Sun, giving rise to the name "chromosphere." From this ring, luminous red clouds and streamers of gas called prominences looped high into the corona.

Each century sees about 237 solar eclipses. Approximately one-fourth are total, and on the average two total eclipses occur every three years. Among other institutions, the National Geographic Society has been active in eclipse observations, with nearly a dozen expeditions since the early '30's.

But in spite of the most persistent efforts, more than a century of eclipse studies has given us less than a hundred minutes' worth of observation! We still know relatively little about the true structure of the chromosphere and corona.

TEMPERATURE PARADOX

Presumably the temperature of the Sun's atmosphere should get progressively cooler the farther one measures out from the Sun's surface. Recall that the temperature deep in the thermonuclear furnace is about 16 million degrees, and drops steadily to about 5,700 degrees at the surface. In the solar atmosphere we would expect even cooler gas.

But the spectrum of the chromosphere and corona reveals a very interesting paradox: The temperature there begins to rise again, shooting up to above 100,000 degrees in less than 10,000 miles, and eventually climbing to several million degrees.

How can the chromosphere and corona derive their high temperatures through a much cooler photosphere?

Astrophysicists believe that the seething, bubbling granules at the Sun's surface break like ocean waves and create a tremendous rumbling roar of sound. As these waves of sound rush

upward into more rarefied gas, they accelerate until supersonic shocks occur, which heat the gas to its high temperatures.

Pictures of the rim of the Sun show a fountain-like structure. Thousands of tongues of gas, called spicules, spring as jets above the bursting granules. They surge up from the base of the chromosphere and fall back again in five to ten minutes, rising with speeds of 10 to 15 miles a second to heights as great as 6,000 miles. Some of the spicules seem to vanish into the corona.

At any instant as many as 100,000 spicules cover the face of the Sun, and for this reason the chromosphere has been called "the spray of the photosphere."

CORONA NOT STATIC

With the coronagraph telescope, which artificially eclipses the Sun's disk, we can see huge streamers of bright gas often looping as high as a hundred thousand miles into the corona, and dipping back to the photosphere as much as half a million miles away. These prominences, when photographed in time-lapse motion pictures, show continuous changes in their over-all shapes and complicated internal streaming.

Prominences usually appear to spring from sun-spot groups. Their arched structure indicates strong magnetic fields—just as iron filings form curved lines on a sheet of paper when a magnet is placed under them. Where the streamers are anchored to the photosphere, violent convection twists and shifts the lines about, causing the arches to react in spectacular whipping, streaming, and eruptive patterns high into the corona.

The corona is not a static atmosphere that blankets the Sun the way our own atmosphere hugs the Earth. Because the corona is so hot, it continually expands into space—relatively slowly at first, perhaps a thousand feet per second. But the rising coronal gas accelerates rapidly, because there is almost no interplanetary gas pressure to resist the expansion. Ultimately it may reach 500 miles per second. This "solar wind" of hydrogen steadily blows out through space and races toward the Earth and other planets.

The wind that reaches Earth today left the solar surface about 10 days ago. Actually it never penetrates the atmosphere since it is deflected by Earth's magnetic shield, which bulges out thousands of miles from the surface.

How far does the wind reach? We are not sure, but calculating from its speed and strength, it must travel at least to Neptune, 30 times farther than Earth from the Sun, and possibly to Pluto, 40 times farther than Earth.

Modern eclipse expeditions took on a new look in 1958, when scientists first attempted to use rocket astronomy to determine which layers of the solar atmosphere emit X-rays and ultraviolet. The expedition was a joint venture of ground-based astronomers, under the leadership of Dr. John W. Evans of the Sacramento Peak Observatory in New Mexico, and a team of rocket specialists from the U. S. Naval Research Laboratory, under my direction.

The eclipse began at sunrise on the equator near New Guinea and raced across the Pacific Ocean for about 8,500 miles to the coast of Chile near Valparaiso, where it left the Earth at sunset. In its long path—never more than 150 miles wide—the eclipse missed all the large South Pacific islands, and could be observed on land from only a few coral atolls.

ROCKETS TAKE SUN'S PULSE

The astronomers chose the atoll Puka Puka in the Danger Islands—about 2,300 miles south of Honolulu—on which to set up their spectrographs. To support the rocket part of the expedition, the Navy provided a floating hotel, machine shop, and laboratory—a landing ship called the *Point Defiance*.

Our six solid-fuel rockets, 1,500-pound combinations of Nike-booster first stages and Asp second stages, pointed like arrows from the deck. The Asp second stages would enter the eclipse shadow about 100 miles up, reach a peak of 150 miles, and splash into the sea 60 miles astern about six minutes after firing.

Eclipse day dawned gray and overcast where the *Point Defiance* lay to, 30 miles off Puka Puka. At 8:38 we fired the first rocket, 10 minutes

before totality. Two more were fired during the brief interval of totality. Sixteen minutes later No. 4 flashed into the sky. Rocket No. 5 balked, but the sixth rocket took off almost on schedule.

When the smoke had cleared, our thoughts shifted to our colleagues on Puka Puka. The sad story that we picked up shortly after on the radio told of rain and clouds that completely ruined their observations. A year's preparation before embarking, months of effort on Puka Puka—all had come to naught.

When we scanned our radio telemetry records from the rockets, the signals clearly showed that X-rays are produced high in the corona. Even with the Sun's disk covered, 13 percent of the X-rays remained unobscured. In contrast, the ultraviolet rays were completely eclipsed at totality, indicating that they originate at the fringe of the photosphere. Furthermore, as the Moon blotted out individual sunspot areas, the X-ray flow diminished abruptly, proving that sunspot groups emit concentrated X-rays.

Sunspots, plages, prominences—these dramatic activities of a quiet Sun pale into insignificance compared to the explosive phenomenon known as a solar flare. A large flare can erupt with the force of a billion hydrogen bombs within an hour's time, releasing enough energy, if it could all reach Earth, to melt the north and south polar ice.

This tremendous power is released by a brilliant burst of light and all other electromagnetic wavelengths, from X-rays and ultraviolet to infrared and radio waves; by protons and electrons accelerated to more than half the speed of light; and by clouds of ionized, or electrified, gas that sweep through space at hundreds of miles per second. It was such a flare that disrupted earthly communications so strikingly in November, 1960.

CLOUD SPAWNS SOLAR SYSTEM

Sometimes a large flare can be seen in white light; in fact, the earliest record of a flare is probably an 1859 account by an English astronomer named Richard Carrington, who thought he had witnessed the splash of a gigantic meteorite.

Only a generation ago, most astronomers believed that the solar system originated in a near collision between the Sun and another star, and that the material of the planets was torn loose from the Sun by the tremendous gravitational pull of the passing star.

Today's view, however, holds that the Sun and the planets condensed from an enormous turbulent cloud of gas and dust. The Sun grew steadily warmer because of its immense gravitational energy. In time the protostar began to glow brightly, and its core temperature rose millions of degrees.

Hydrogen nuclei, impelled by the tremendous heat, collided with such violence that thermonuclear fusion could occur, and nuclear energy, rather than gravitational energy, began to keep the star hot.

Some theoretical calculations indicate that the proportion of hydrogen in the core of the Sun has decreased from about two-thirds to about one-third in the past five billion years. Temperatures have risen somewhat, and the sun has grown about five percent larger in diameter and about 25 percent more luminous. The great majority of stars follow this gradual trend of evolution.

The Sun today is a very ordinary star—a yellow dwarf midway between the largest and the smallest, and between the hottest blue stars and the coolest red stars. To Earth-based observers, it is a hundred billion times brighter than any other star, though it would appear puny if it were matched at the same distance against the more brilliant stars. Rigel, for example, is 15,000 times more luminous, and 36 million suns could be fitted into Antares, a red supergiant.

What of the future? Will the Sun burn out? In time the core will deplete its hydrogen. With the core spent, the thermonuclear reactions will spread to outer portions where unused hydrogen still exists.

As the reaction zone moves closer to the surface of the Sun, the tremendous nuclear heat at its core will also move outward, forcing the Sun to expand, and the total amount of radiated heat and light will increase. The Sun will then become a giant red star like Antares: It will blow

up to a monstrous ball of extremely rarefied, red-hot gas large enough to engulf Mercury, Venus, the Earth, and Mars, the four nearest planets.

When will the sun reach this stage? We have no cause for immediate concern—it may take another five billion years!

SUN'S END IS DWARF STAR

Finally, when all its hydrogen has been converted to helium, the Sun will cool and shrink, ultimately becoming a white dwarf no bigger than the Earth but weighing several tons per cubic inch.

Not all stars reach this peaceful demise. Stars much more massive than the Sun end their evolution in a catastrophic explosion which fills vast regions of space with debris. Eventually this material recondenses into new stars. Our Sun is such a second-generation star, and man on Earth is made of secondhand atoms left over from a star that exploded before the Sun was born.

We know this because the Sun contains an excess of heavy elements, such as iron, that could not have been produced by the simple nuclear burning of hydrogen, the primeval material of the universe.

Meanwhile, the Sun is our bridge to the stars. It is the only star whose surface and atmosphere we can study in fine detail, and it typifies the great majority of stars in the Milky Way. In its spectacular flare outbursts, we can observe the interaction of hot gases, intense magnetic fields, and shock waves under conditions man cannot simulate in his laboratories.

But we stand today on the threshold of existing new knowledge. Rockets and satellites will probe ever deeper toward the zones of intense solar activity. With such magnificent new tools to observe the Sun, the coming years should bring a revolution in our understanding of Earth's bright and awesome companion in the heavens—and the myriad greater and lesser stars beyond.

SOLAR STUDIES IN PERSPECTIVE

G. K. Oertel
NASA Headquarters

S. D. Jordan
Goddard Space Flight Center

THE SUN AND LIFE ON EARTH

The Sun provides virtually all of the heat, light, and general energy we use.

For example, the Sun provides the energy that drives the atmosphere and is responsible for the weather. Variations in local solar input give rise to seasons. "Solar energy" lifts water vapor from the oceans and lets it rain down on land and in reservoirs for hydroelectric power plants. Oil and coal contain solar energy stored by life forms millions of years ago. The only exception in practice is nuclear energy.

Interesting, but so what? After all, the Sun has been pretty much the same and is believed to be incapable of changing its average output appreciably in less than hundreds of thousands of years. Ice ages? Maybe, but not for us or our children. (Unless we manage to change our atmosphere enough to alter the net solar energy absorbed). So, why not leave the Sun alone and just keep using its energy?

Solar energy is free and comes in at a tremendous rate. Solar power farms are now under study, such as one planned by astronomers Aden Meinel and his wife Marjorie. We study the Sun to unlock its secrets: the Sun probably produces all of its energy by burning hydrogen to helium in various ways. If we could do the same on Earth, we would have enough fuel in our oceans for millions of years at current consumption rates. The research effort in this field suffers from the same types of problems as our attempts to explain solar flares and other plasma-magnetic field phenomena on the Sun.

We also study the Sun because of its vagaries: the flow of solar energy is not all steady. A highway carries mostly cars and trucks of moderate size and speed, but small numbers of oversized and overloaded trucks or speeding cars can cause hazards and damage of many kinds.

Similarly, some solar emissions are highly energetic or otherwise singular and can cause impor-

tant effects on Earth. Many of these effects are mentioned or discussed in Dr. Friedman's 1965 article in the National Geographic Magazine which is reprinted in this brochure: scrambled telegram messages, interruption of shortwave radio communications, and others.

The magnetic storms which are caused by the arrival of solar plasma hours to days after solar flares can cause some curious effects, not only on a compass. Oilmen making electro-magnetic measurements deep in wells find their highly sensitive electrical instrumentation inoperable due to interference from magnetic storms. Commercial power systems have been blacked out by high voltage surges during magnetic storms. The 1971 crash of an airliner in Alaska caused more than 100 fatalities and occurred during a magnetic storm due to an as yet unexplained electronic communications failure. It is still under investigation.

Another area of investigation concerns the weather. One look at the energy involved in a storm system shows that the solar radiations which give rise to aurorae, communications blackouts, and magnetic storms are quite weak by comparison. Yet, we know that a single careless skier, or the sound from a shot fired nearby, can set off a deadly avalanche in the mountains, with effects which are incredibly greater than the cause. We also know that weather prediction is far from perfect for some reason.

Is there, then, any evidence that solar activity affects the weather or the climate? Many experts think so. Others oppose the idea vehemently. In the avalanche, solar energy has been "used" to bring water from the sea and store it as snow on the side of a mountain until the mass is barely stable. Could solar energy be similarly stored in the atmosphere to the point of near instability where a small effect such as solar high-energy radiation can trigger the formation of a storm system? This would not necessarily violate any laws of physics, but the mechanism is not known. Some possibilities have been proposed, but none are generally accepted. Investigation continues because there is really a good deal of evidence.

Douglass at the University of Arizona claimed early in this century that the growth of trees—

evidence in the annual tree rings—shows cyclic variations with the 11-year solar activity cycle. He claimed that he could trace back the solar cycle for many centuries working simply from tree rings.

Just a few years ago Russians claimed that they found cyclic variations of deposits in various lakes and that they could trace back the solar cycle for millions of years from these variations.

A Russian weather forecaster in Siberia used solar measurements so successfully that he triggered a conference of Russian astronomers and meteorologists in 1972 to discuss his approach and to improve weather forecasting throughout the Soviet Union.

The National Center of Atmospheric Research (NCAR) at Boulder, Colo., and scientists at many academic institutions have maintained or recently acquired a strong interest in solar activity effects on the weather and climate. NCAR and NASA are jointly sponsoring a workshop on this subject to be held at the Goddard Space Flight Center late in 1973, with the goal to identify what is necessary to understand the phenomenon and to perhaps use it for the benefit of all who are affected by the weather—and who is not?

Solar studies with Skylab and other observatories will help understand the way in which solar high-energy radiation is generated, how it travels to Earth, and how much arrives here. Meteorological studies will pinpoint the reaction of the atmosphere—predict the effects on climate and weather. Perhaps, if we will learn enough, we will some day see the Sun and its relevant features on the TV screen and be given the weather forecast for a week or even a month or be told to plant more of one or another crop next year. We don't know the limitations to this sort of forecasting, but there is enough promise to investigate.

The study of the Sun is part of astronomy and as such a branch of basic research, done for the sake of expanding human knowledge about the universe in which we live.

We don't always expect fringe benefits from basic research, but we often get them. When

Faraday studied electricity, its use was not foreseen for any practical purpose, and Faraday is said to have received support for this "useless tomfoolery" only by claiming that some day somebody would find a way to tax it.

It is not easy to see how the Sun could ever be taxed. But it is a basic research effort with exceptional promise for practical applications.

The Sun is the center of the solar system. Its radiations and emissions affect everything within that system, from planets like Earth and Mars to comets and spacecraft.

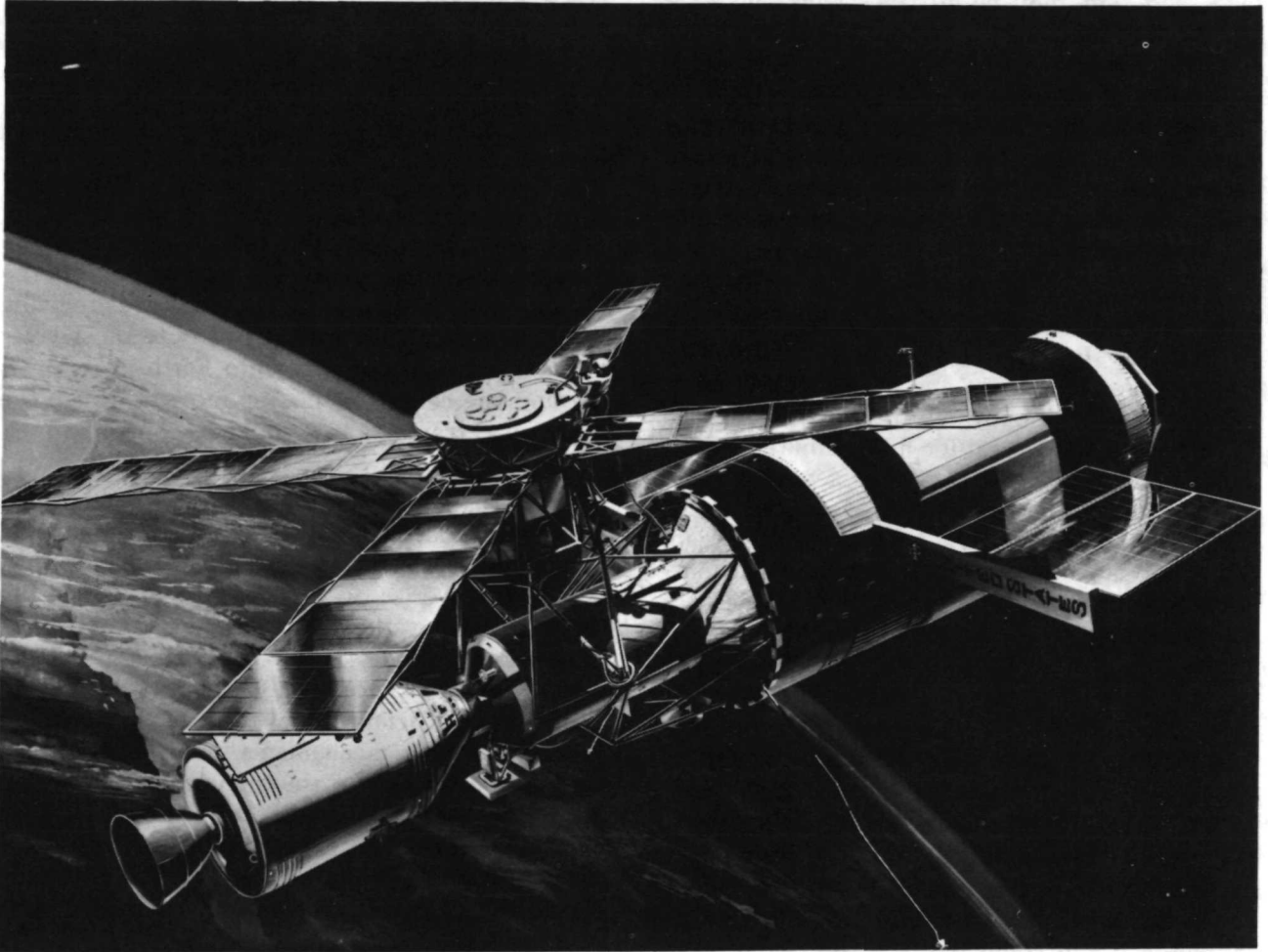
Its atmosphere expands out into space in a steady stream called solar wind and engulfs the entire solar system. In a real sense, we are living on a cool island within the hot outermost layer of the Sun, and our spaceship Earth in its orbit around the center of the Sun moves through the solar wind trailing a large wake.

The Sun is a giant laboratory in space in which physical processes can be studied on a scale which cannot be produced in the laboratory. Many discoveries were made in studying the Sun, including the light element helium. The high-energy processes of modern astrophysics have counterparts on the Sun where they can be studied in sufficient detail to arrive at an understanding of the mechanisms involved. The Sun serves as a testbed of the theory of gravitation—it did so centuries ago for Kepler and Newton who discovered and explained the laws of planetary motion. (The falling apple that reputedly struck Newton on the head did, of course, make its own unique contribution). Einstein's theory of gravitation (general relativity) is tested through solar and related studies, because the Sun has the strongest gravitational pull of any body close enough for detailed study.

The Sun is a star—the only one close enough for accurate and prolonged study. It has served as the dictionary for our reading of the universe's billions of other stars. The theories of stars must pass their most rigorous test—the explanation of the Sun. The Sun's mass loss, through the solar wind, radiations, and perhaps even dust; its spin-down through solar wind drag; its mysterious oblateness which indicates a rapidly spinning

inner core; its failure to produce the nuclear reaction products called "neutrinos" which could confirm or disprove the theory of nuclear energy production in its interior; the curious temperature structure which a "cool" (10,000° F) inner atmosphere supporting a hot (millions of degrees) outer layer; the mysterious structures in

its atmosphere including sunspots, polar caps, streamers, and many others; all are among the many riddles which the Sun is presenting, and which will require years of intensive study, from space, from the ground, and with pencil and paper, before the answers will be in hand. Skylab will be a giant step forward.



Skylab orbits Earth 270 miles in space. A suited astronaut changes film in the Apollo Telescope Mount's instruments. The Apollo Telescope Mount is the space laboratory's solar observatory. Elements of the orbiting cluster are, from left: the Apollo spacecraft which carries the Skylab crew between Earth and the space station, the Multiple Docking Adapter, Airlock Module, and the Orbital Workshop which contains crew quarters and laboratory facilities. The 118-foot-long Skylab contains about the same volume as a moderate two-bedroom house.

SKYLAB SOLAR STUDIES

Edward G. Gibson*
NASA Scientist-Astronaut

The solar Apollo Telescope Mount (ATM) missions represent the first step taken by our country's space program toward a large and sophisticated manned space observatory. This opportunity to obtain data of unmatched quality will advance appreciably our knowledge of the Sun as well as demonstrate the value and feasibility of future manned astronomical observatories now in the planning stages.

The success of the ATM missions depends to a large extent on the scientific knowledge, training, and decision-making capabilities of both the astronauts and the ground support team.

The opportunity to exercise scientific judgment during flight and to enhance significantly the value of the data returned, arises directly from the nature of solar observations.

We are close enough to the Sun to see much detailed structure in its atmosphere. Because of the complexity of this structure and the wide range that has been observed in its characteristic time for change (from many years down to seconds), a wide variety of observations is possible. Thus, decisions must be made which determine the amount of new and significant information in the returned data.

The role of the onboard observer can be simply stated. He is presented with television pictures of the Sun at several wavelengths in the electromagnetic spectrum, as well as with other indicators of the state of solar activity. Instruments which are capable of high data-acquisition rates and which can be operated to observe only a

*Dr. Gibson is the Scientist Astronaut on the Third Skylab Mission.

small portion of the Sun are available for use by the observer. However, he is constrained by limited quantities of photographic film in all but one of the instruments. Hence, the scientific value of the returned data is dependent upon the ability of the onboard observer to make judicious decisions concerning when, at what rate, and from where on the Sun to take data with each instrument.

By operating above the Earth's atmosphere, the ATM gains several advantages over ground-based observatories. On the ground, only the solar radiation that falls within several relatively narrow windows in the optical, infrared, and radio regions can be measured. The remaining radiation is absorbed by the atmosphere. However, once in orbit, instruments can measure directly the total spectrum, including the ultraviolet and X-ray portions, which promise new information on the higher energy processes taking place on the Sun.

When the corona (the Sun's very tenuous outer atmosphere) is observed out to several solar radii by occulting the disk of the Sun, only the region close to the surface can be seen because of the relatively bright background light of the daylight sky. The bright background is caused by light from the Sun's disk which has been scattered by our atmosphere and is small, relative to the faint corona, only during times of total eclipse. Because a total eclipse lasts only a few minutes, observations from above the atmosphere are required to study both the three-dimensional structure of the corona as it rotates with the Sun and the full history of coronal processes.

Finally as sunlight passes through our turbulent atmosphere, refraction limits the resolution with which the Sun can be viewed. However, on a space observatory like the ATM, the resolution of an instrument is limited only by the diffraction limit of its optics and its pointing stability.

THE ATM SOLAR OBSERVATORY

Owen K. Garriott*

NASA Manned Spacecraft Center

Dixon L. Forsythe

NASA Headquarters

Eugene H. Cagle

NASA Marshall Space Flight Center

The Apollo Telescope Mount (ATM) has been designed and developed to house and support manned telescopes for studying the Sun. In many respects it achieves the operational capability and flexibility of some of our more-advanced instruments in ground-based observatories, but extends their range to wavelengths visible only above the Earth's atmosphere. It reflects the strong desire of many leading astronomers to conduct experiments from space, above Earth's obscuring atmosphere, at wavelengths below about 3000 Å.

The 22,000-lb ATM contains an octagonally-shaped structure supporting most of the subsystem components and elements. This structural frame surrounds a large cylindrical canister, the housing for the scientific instruments. The cylinder itself measures approximately 7 ft in diameter and 11 ft long. An internal cruciform structure divides the cylinder into quadrants to house and support the 2200 lb of experiment instrumentation. It serves as an optical bench to provide the necessary stability so critical to instrument pointing and acquisition of high-quality data.

To help maintain this stability, a loop within the skin of the cylinder circulates liquid coolant. This thermal-control system is self-contained within the canister. The walls are composed of cold plates that absorb the heat dissipated in the experiment package. The water/methanol cooling fluid transfers heat absorbed from the cold plates to radiators on the exterior side of the experiment canister, where it radiates into space. This active coolant system maintains an average temperature within the experiment package of approximately 53° F. Each experiment, moreover, has its own thermal-control heaters, designed to maintain its temperature within $\pm 1^\circ$ throughout the length and width of

the instruments. Many precautionary measures have been taken to avoid any fluid leakage which could contaminate the optical elements of the instruments. All fluid lines and components are located on the outside to avoid leakage into the canister.

Besides these thermal controls for the experiments, a passive system regulates the ATM supporting rack structure and the components mounted on it. And a thermal shield attached to the "Sun" end of the canister and rack minimizes solar heating of these system components while the ATM points directly at the Sun for data acquisition.

The Attitude and Pointing Control System (APCS) consists of two separate but interrelated control subsystems. Its primary portion provides attitude control and stabilization for the entire Skylab assembly. The other, the Experiment Pointing Control (EPC), stabilizes and fine-points the ATM experiment package.

The primary system consists mainly of computers, sensors, cold-gas thrusters, and three Control Moment Gyros (CMGs). It controls the Skylab attitude in the presence of disturbing torques of both internal and external origin. Internal disturbances include brief transients produced by crew motion. More important will be the small, but steady, venting torques, only a few tenths of a foot-pound in magnitude. Every precaution has been taken to keep these venting torques low. External disturbances consist primarily of gravity-gradient and aerodynamic torques, which reach a magnitude of about 7 ft-lb, but are largely cyclic and therefore contribute less to an accumulation of momentum.

Each CMG is mounted within double gimbals, and any two of the three can provide the necessary spacecraft stability. Attitude control with CMGs offers major advantages for orbital operations such as Skylab's which require long duration and minimum contamination. Nominally, the CMGs will not require assistance from either cold-gas thrusters or small rocket motors that are ordinarily used as control devices; these could contaminate the optical surfaces of many of the scientific experiments.

*Dr. Garriott is the Scientist Astronaut on the Second Skylab Mission.

The constant-speed CMG wheels are oriented as a group in the proper direction to absorb the momentum required to hold the entire Skylab attitude within 3 arc min of the desired direction at all times. Venting torques and non-cyclic components of the external torques will gradually cause more and more momentum to be stored in the CMG configuration. To avoid "saturation," the ATM digital computer observes the way momentum is accumulated each orbit and commands a small (≤ 15 deg) Skylab attitude change on the dark side of each revolution. This sufficiently alters the components of the relatively large gravity-gradient torques about each vehicle axis to keep the stored momentum within the CMG capacity. Sun sensors and three-axis rate gyros provide the attitude reference for all these maneuvers.

If the required momentum should exceed the capacity of the CMGs, however, they can be assisted by a cold-gas Thruster Attitude Control System (TACS). These thrusters are used automatically whenever the CMGs reach 95% of capacity. TACS also provides control during initial solar acquisition and CMG spin-up. Further redundancy allows the reaction control system on the Service Module to be used for attitude maneuvering and CMG desaturation, if necessary.

The Experiment Pointing Control (EPC) system provides fine-pointing control and stability for the experiment package, further isolating it from disturbance torques to the Skylab assembly. The entire 6000-lb instrument canister rides within two-axis gimbals, located around the canister center of gravity. Pitch and yaw control can be provided within an accuracy of ± 2.5 arc sec for periods up to 15 min, using fine-pointing Sun sensors for attitude reference. The experiment packages can be offset-pointed within a ± 24 -arc-min square centered on the solar disc. A roll ring allows the experiment package to be manually commanded to any desired roll orientation throughout ± 120 deg.

The electrical-power distribution systems for the ATM and the orbital workshop (OWS) are interconnected, permitting power sharing between modules. If desired, however, the networks can be separated for independent operation. The ATM electrical power system (EPS) nominally

will supply continuous power of 3800 W. It consists of four solar-cell-array wings, one deployed in each quadrant from the "Sun end" of the rack structure; 18 "charger-battery-regulator" modules, mounted on the rack structure, that condition, store, and control the solar-array electrical output; and associated wiring and distribution networks.

A Charger-Battery-Regulator Module (CBRM) performs the functions its name implies. Depending on the orientation of the panels to the Sun (usually perpendicular), the available solar-panel output varies from 0 to about 580 W at 55° C. This power is fed to the charger section of the CBRM, which converts the wide range of voltage inputs to the level required to charge the battery section (24 nickel-cadmium cells in series). A regulator section maintains the voltage output between 27.1 and 30.4 v. Each of the 18 CBRMs has a dual output, feeding two isolated buses. Each bus, acting independently, can handle all system loads.

Many of the more significant ATM features are summarized in the following design and performance tables.

ATM CHARACTERISTICS

GENERAL SPECIFICATIONS

Size	
Rack length	155.67.; octagonal flats—131 in.
Canister length	136.2 in.; diameter—82 in.
Weight (lb)	
Rack, 16,128; Canister, 3772;	
Experiments 2,311 =	22,211
Power (Average)	
3800 W - includes	306 W for experiments
Orientation	
Automatic Pointing Accuracy (Sun-centered)	$\pm 2\frac{1}{2}$ arc-sec
Operational Pointing Accuracy (Astronaut Control)	$\pm 2\frac{1}{2}$ arc-sec, pitch and yaw ± 10 arc-min in roll
Stability	$\pm 2\frac{1}{2}$ arc-sec/15 min, pitch and yaw $\pm 7\frac{1}{2}$ arc-min/15 min, roll
Offset: Range	± 24.21 arc min
Slew Rate	80 arc-sec per 1 sec
Thermal-Control Active Cooling	50 ± 3 F
Onboard Display	2 TV display tubes (7-in. diam)

PERFORMANCE REQUIREMENTS FOR SINGLE CMG

Dynamic Performance:

Rotor Angular Momentum, ft-lb-sec	2300
Rotor Speed, rpm	9100
Rotor Acceleration Time, hr	14
Maximum Torque, ft-lb	122
Threshold Torque, ft-lb	0.16

Physical:

Weight, lb	418
Volume, cu ft	16.7
Mounting	4-point CG
Performance life, hr	10,000

A great deal of attention has been given to the problem of minimizing contamination of the environment around Skylab. Since water vapor, other gases, and particulate matter can have a significant effect on the collection of undistorted data, all materials used in Skylab were carefully selected for low outgassing characteristics. All sources of venting from the Skylab assembly have been thoroughly reviewed with respect to the nature of the vented gases and materials; and, where necessary, corrective measures have been taken.

THE SCIENTIFIC INSTRUMENTS

E. M. Reeves

R. W. Noyes

G. L. Withbroe

Harvard College Observatory

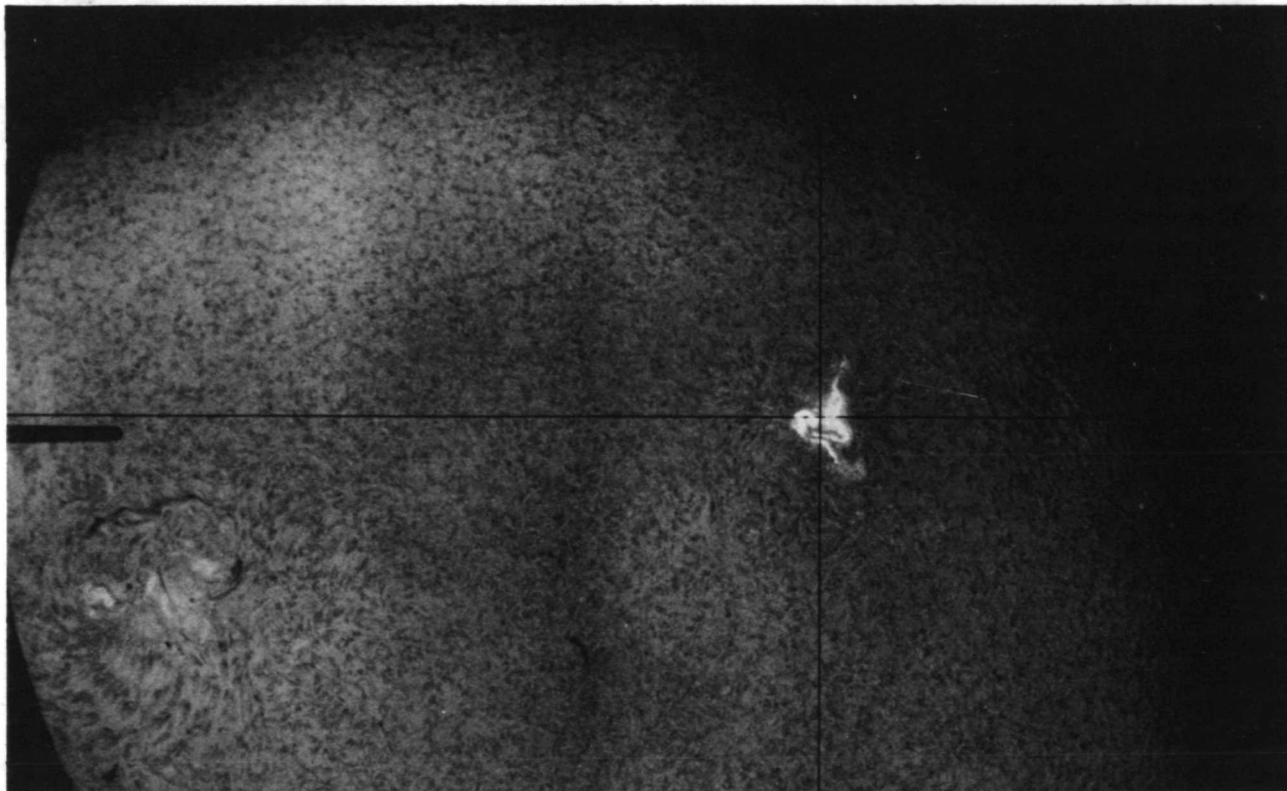
The solar experiments occupy the central core of the ATM in a space approximately 2 meters in diameter and 3.3 meters long. The experiments include an X-ray spectroheliograph provided by American Science and Engineering Company (ASE), an X-ray telescope by Marshall Space Flight Center (MSFC), a white-light coronagraph from the High Altitude Observatory (HAO) of the National Center for Atmospheric Research, an ultraviolet spectrograph, and an XUV spectroheliograph from the Naval Research Laboratory (NRL), and an EUV spectrometer-spectroheliometer from the Harvard College Observatory (HCO).* Two H α telescopes are

*Distinction is maintained between the extreme ultraviolet (EUV) region between 300 and 1300 λ , denoted XUV because it borders on the soft X-ray region.

carried to provide video images to the astronaut for instrument-pointing at selected solar features, and one of these contains a photographic film camera for a permanent pointing record. With the exception of the Harvard instrument, the ATM instruments are predominantly photographic and require the recovery of film canisters by astronaut extra-vehicular activity. The Harvard instrument is photoelectric and its data are recorded and then transmitted to Earth by telemetry every orbit.

The telescopes are pointed at selected solar features by moving the entire spar assembly, with attached instruments, in pitch, yaw, and roll by use of either the video displays of the Sun in h α or the numerical readout from a fine Sun-sensor located on the forward end of the spar. Roll is maintained with reference to a star tracker. The stability of the pointing is expected to be better than ± 2.5 arc sec over a 15-min. period.

The astronaut will point the instruments in response to instructions and predictions from the ground, and will also act on his own interpreta-



Class M4 X-ray flare at its peak, photographed June 16, 1973 in the red light of hydrogen alpha by the Harvard College Observatory H-alpha Telescope on Skylab. The astronauts use the cross hairs to enable them to boresight Skylab's solar telescopes on specific targets of interest. (Courtesy of E. Reeves, Harvard College Observatory).

tion of several onboard visual displays. These include not only the two H α images mentioned earlier, but also an XUV image in a broad spectral band from 170 to 630 Å, a soft X-ray image in the region 2 to 10 Å, a white-light coronal image, an X-ray history chart record, a 6 cm radio monitor and a 0 to 8 Å X-ray scintillation detector.

The two H α telescopes have zoom lenses permitting the astronaut to select a field of view between 4.4 and 35 arc min. Spatial resolution of the H α video display is about 2 arc sec. H α wavelength discrimination is provided by solid etalon Fabry-Perot filters with 0.7 Å half width. The H α telescopes have movable crosshairs, which will be aligned to the entrance apertures of the Harvard and NRL ultraviolet spectrometers; pointing for the other instruments is less critical since they have wide fields of view.

The broadband XUV monitor (provided by NRL) has spatial resolution of only 20 arc sec, but it will reveal features in the transition layer and low corona such as "holes," bright coronal knots, or coronal flaring regions that are not evident in the H α display. Images from the XUV monitor will be transmitted to the ground on a daily basis to assist in-flight support activities at the Mission Control Center, Houston.

The X-ray monitor (part of the ASE instrument) will provide the astronaut with X-ray images having a spatial resolution of about 1 arc min and will be used to monitor the X-ray emissions of active regions.

These displays may be used, for example, to determine the location of a flare when the 0 to 8 Å scintillation detector, an automatic device in the ASE instrument, indicates the onset of an X-ray burst with intensity above a predetermined threshold. Other indicators of flare onset include the 6-cm radio burst detector and the X-ray history event record (provided by Marshall Space Flight Center (MSFC) which will indicate whether the general level of soft X-ray activity has been rising or falling over the preceding hours.

The white-light coronal display (derived from the HAO coronagraph) has a spatial resolution

of 30 arc sec and sensitivity of 10^{-10} of the solar disk intensity; it should reveal the presence of coronal streamers, although its main purpose is to check alignment of the coronagraph.

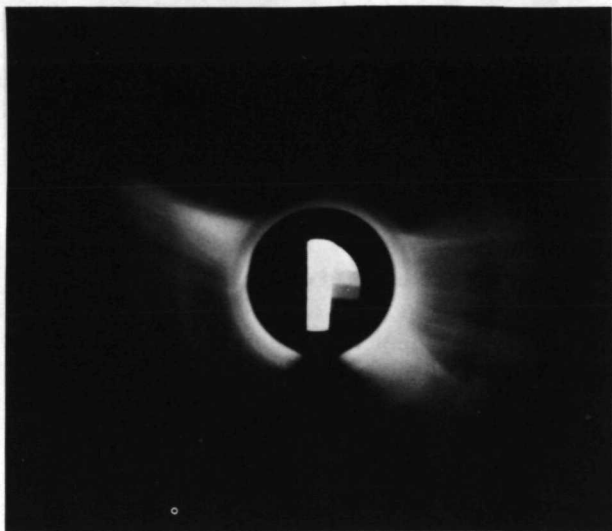
The ATM is generally operated from the control console by the astronaut who directly initiates instrument observing sequences. However, during *unattended* periods, when astronauts are on board Skylab but not present at the console, limited operation of several of the instruments is possible by ground command. Furthermore, the Harvard spectrometer, the ASE X-ray telescope, and the HAO coronagraph will also be operated for 8 to 12 hrs per day during the two *unmanned* intervals between the three-manned visits.

WHITE LIGHT CORONAGRAPH (HAO)

The white-light coronagraph experiment will photographically monitor the coronal brightness and polarization from 1.5 to 6.0 solar radii over a wavelength band extending from 3500 to 7000 Å. The instrument consists of an externally occultated coronagraph designed to reduce the instrumentally-scattered light to levels on the order of $10^{-10} B_{\theta}$, where B_{θ} is the mean solar radiance. A removable camera contains a 750-ft. roll (8,025 exposures) of Kodak special film 026 - 02, a Panatomic-X-type emulsion with improved reciprocity characteristics. The camera is detachable and will be replaced with additional film-loads during astronaut extravehicular activity.

The net angular resolution of the coronagraph film combination has been measured to be 8.2 arc sec, corresponding to a distance of about 6000 km in the corona. Because this resolution corresponds to a system response of about 3% for an input contrast ratio of 1.6:1, a somewhat higher spatial resolution should be achieved in the actual coronal photographs.

Because of the vignetting function caused by the presence of the external disk assembly, the effective coronal radiance is "flattened" over the field of view. The net mean coronal brightness at the film plane varies by a factor of only 5 from 1.5 to 6 R, because of the vignetting action.



Photograph of the solar corona made on June 5, 1973 by the High Altitude Observatory White Light Coronagraph on Skylab, which views the corona from 1.5 to 6 solar radii from Sun center in the 3500 - 7000 angstrom band. The photograph shows coronal forms caused by the interaction of electrons and magnetic fields in the outer solar atmosphere. The bright disk of the Sun is occulted by the instrument. The black shadow at the bottom is caused by the support for the occulter, and the white figure on the occulter is used for calibration. (Courtesy of R. MacQueen High Altitude Observatory)

A step wedge, illuminated by sunlight, and calibrated relative to the intensity of the mean solar disk over the range of $10^{-8} B_{\theta}$ to $10^{-10} B_{\theta}$ is imaged on each picture frame by a supplementary optical system. In addition, a television display at the ATM console provides means for improving the quality of the data through direct astronaut observation of the coronal image and the pointing and internal alignment.

Four picture-taking modes are available to the coronagraph experiment. Two modes cycle three linear polaroids through the field of view to allow determination of line-of-sight electron densities in the corona. Two additional modes provide rapid film-taking sequences for following transient phenomena in the corona.

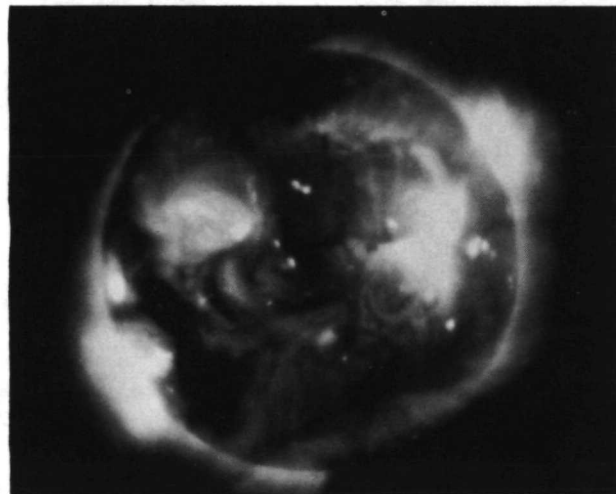
X-RAY SPECTROGRAPHIC TELESCOPE (ASE)

The ASE X-ray spectrographic telescope has a primary optical system consisting of a nested pair of coaxial and confocal grazing-incidence mirrors of paraboloid-hyperboloid design. These

mirrors provide a geometrical collecting area of 42-cm^2 and form a soft X-ray image of the Sun 1.92-cm in diameter. The field of view is 48 arc min and the on-axis resolution is 2 arc sec. The image is recorded photographically on 70-mm Kodak S0-212 film, a Panatomic-X-type emulsion without an overcoating.

A filter wheel with five filters and a blank opening is in the optical path and provides broad band X-ray filtergrams in the 3.5 to 60 Å range. An X-ray transmission grating with 1440 lines/mm can be inserted into the optical path to provide spectrally dispersed images. The spectral resolution is 0.15 Å and the grating will work best for bright, small features such as flares.

Several operating modes are possible. In the *single* mode, one sequence of exposures, each a factor of four longer than the last from 1/64 sec to 256 sec, through a single filter is obtained. This mode provides sufficient dynamic range to encompass virtually all expected coronal X-ray phenomena. To observe rapidly varying features, such as flares, the instrument can be switched into *high* rate mode wherein an abbreviated sequence (e.g. 1/64 sec to 1 sec.) is repeated with



X-ray photograph of the solar corona obtained May 28, 1973 by the American Science and Engineering X-ray Telescope on Skylab. The solar corona is the very thin outer portion of the Sun's atmosphere. Structures with temperatures higher than one million degrees can be observed. The loops, arches, and other features seen in the photograph are produced by the interaction of the Sun's magnetic field and the ionized gas of the corona. (Courtesy of G. Vaiana, Solar Physics Group, American Science and Engineering, Inc., Cambridge, Massachusetts)

an interval between exposures of 0.2 sec. Less rapid time variations can be observed in the *low* rate mode in which the interval between exposures is 12 sec. A *programmed* mode is available in which the instrument is operated in the *high* rate for four min and the *low* rate for 9 min. In the *flare auto* mode, operation is initiated automatically by the X-ray scintillation detector.

In addition to the above primary system, the instrument contains an uncollimated X-ray scintillation detector and an X-ray "finder" telescope. The scintillation detector, which monitors the 0 to 8 Å X-ray flux, provides a visible and an audible alarm to alert the astronaut to the onset of a flare, controls automatic operation of the film camera, and provides eight-channel pulse-height spectra in the range 10 to 80 keV. The 0 to 8 Å flux is displayed on the astronaut's display panel and is up-dated every second. By logarithmic compression a dynamic range in flux of five decades is possible. The pulse-height data are telemetered to ground and a complete spectrum is generated every eight sec. The "X-ray finder" telescope provides the astronaut with a TV image of the Sun, one arc min in resolution, in the wavelength band 2 to 10 Å. The "finder" is aligned with the main telescope so that the astronaut can use it to point to bright features such as flares.

The instrument can be operated during *manned*, *unattended*, or *unmanned* periods of the Skylab. However, during the latter two periods, the capability of varying the experimental modes is limited.

X-RAY TELESCOPE (MSFC)

The Marshall Space Flight Center (MSFC)-Aerospace instrument employs a glancing-incidence telescope to produce an image of the Sun on S0-212 film. The telescope has two optical elements: an internally-reflecting paraboloidal primary element and a hyperboloidal element, one focus of which is coincident with the focus of the paraboloid. It has an effective focal length of 190.5 cm and a collecting area of 14.8 cm², giving an effective photographic f-ratio of f/44. The resolving power of the instrument on-axis is limited by the film to approximately 3

arc sec. Off-axis the resolution is slightly degraded by coma and curvature of field. These alterations, together with vignetting, limit the useful field of view to approximately 38 arc min.

The telescope operates at all X-ray and EUV wavelengths above about 5 Å, but the response is limited to certain wavelength bands of interest defined by thin metal foils. The filters are carried on a wheel immediately in front of the film plane.

Up to 7000 frames of solar X-ray photographs may be taken with one film cassette, containing 1000 ft of S0-212 film. Four such cassettes will be used during the full Skylab mission. The instrument may be operated in several modes: a *patrol* mode for observations of the quiet Sun and in the presence of moderate activity, and *active* and *flare* modes employing shorter exposure times for the observation of active regions and flares.

In addition to the telescope, the MSFC instrument contains two proportional counters which monitor the soft X-ray flux from the whole Sun. One of these has an aluminum window (1.71 mg/cm²) and is sensitive in the wavelength region 8 to 20 Å, while the other has a beryllium window (45.3 mg/cm²) and is sensitive in the region of 2 to 8 Å. The pulses from each counter are sorted electronically into amplitude bands to perform coarse spectral analysis of the solar X-radiation. The output from either counter can be displayed on the history plotter on the astronaut's console, to give a guide to the rate of change of the solar X-ray flux, and hence to the level of solar activity.

ULTRAVIOLET SPECTROMETER-SPECTROHELIOMETER (HCO)

The Harvard experiment is designed to perform solar observations in the extreme ultraviolet (EUV) wavelength range from approximately 280 to 1350 Å with a spatial resolution of 5 arc sec. An off-axis parabolic mirror images the Sun on the entrance slit of the 0.5m concave-grating spectrometer. Small rotations of the mirror permit the instrument either to (a) build up two-dimensional rasters of a 5 arc min region of the

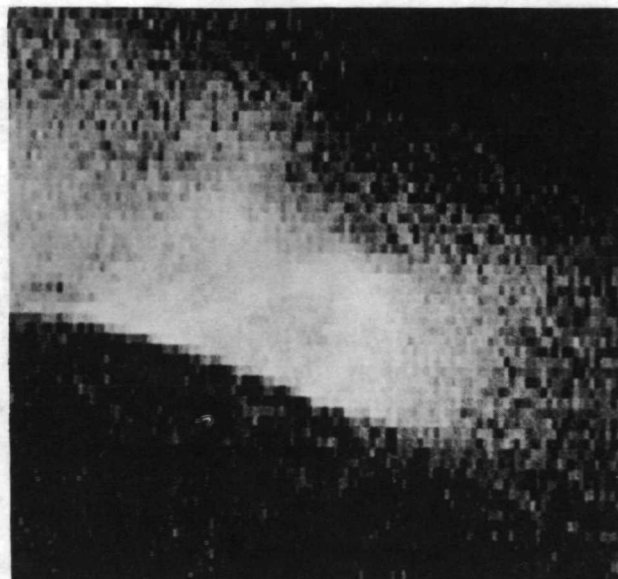
Sun in 5 min of time: or (b) to scan a single raster line of 5 arc min length every 5 sec of time, in order to study more rapidly evolving phenomena. The iridium-coated f/12 mirror has a 2.3-m focal length, producing a solar image 21.4 mm in diameter.

Light from a 5-arc-sec square portion of the solar image enters an EUV concave-grating spectrometer containing an original gold grating, ruled at 1800 mm^{-1} , and the spectrum is imaged at a focal surface which contains seven independent, open-channel, electron-multiplier detection systems. In the reference grating position, the intensity from the selected portion of the Sun is recorded simultaneously at seven important wavelengths. These wavelengths contain spectral lines which span the temperature range from 10^4 to 2×10^6 K, covering the chromosphere, transition region, and corona. A slight rotation of the grating places $\text{Ly}\alpha$, $\text{Ly}\beta$, $\text{Ly}\gamma$, and the Lyman continuum in position for simultaneous recording. Many other polychromatic positions of the grating produce chance coincidences of interesting groups of lines. The grating can also be positioned to select for study any desired single wavelength in the range $280 < \lambda < 1350 \text{ \AA}$. After the grating position is selected, square rasters, single-line rasters, or continuous monitoring of any desired point (40-ms time resolution) may be performed. In an important alternative mode, the instrument with stationary mirror is positioned at a selected solar feature and the grating is scanned continuously, thus obtaining a complete spectrum of the feature with 1.6 \AA resolution in 3.8 min.

This instrument is capable of operation in the *manned*, *unattended*, or *unmanned* modes. However, in the latter two cases the capability for precision pointing at selected fine-scale structure is much reduced.

XUV SPECTROHELIOGRAPH (NRL)

The NRL extreme ultraviolet spectroheliograph is a slitless objective grating spectrograph operating over the wavelength range 150 to 630 \AA . Sunlight entering the instrument is both dispersed and focused by a single concave grating (focal length 200 cm, 3600 lines/mm) which is rotated between two positions to select either the short wavelength range 150 to 335 \AA or the



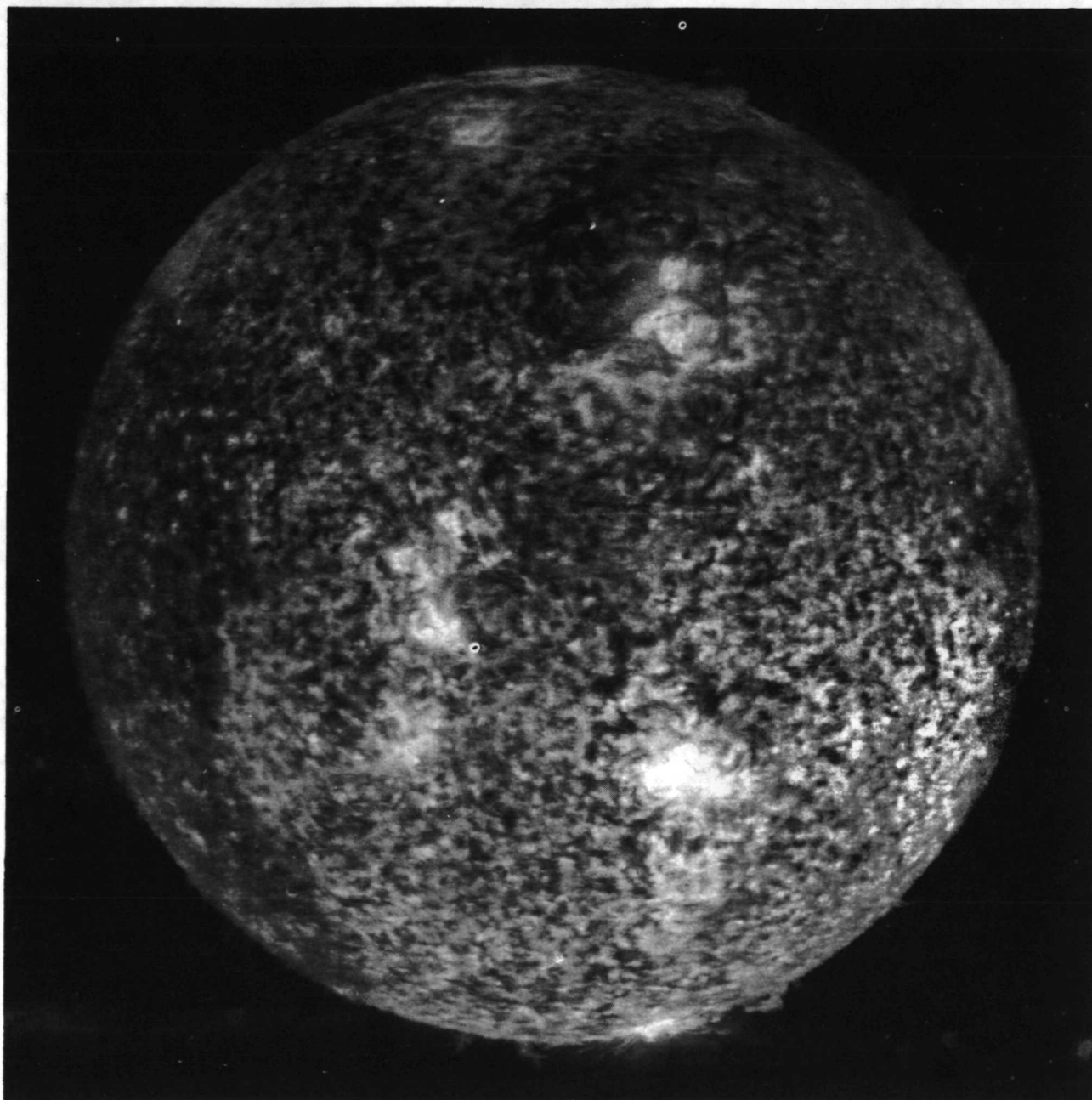
Coronal loop prominence at the solar limb in the 417 Angstrom emission line of Fe XV, recorded photoelectrically by the Harvard College Observatory Scanning UV Spectroheliometer on Skylab, June, 1973. To obtain this picture, the instrument scanned over a five-by-five-arc-minute area, recording the 417 Angstrom emission from discrete five-by-five-arc-second segments of the solar atmosphere. (Courtesy of E. Reeves, Harvard College Observatory).

longer range 321 to 630 \AA . The only other active optical element is a thin (0.1 micron) aluminum filter in front of the individual Kodak 104 (formerly SWR) film strips (35 x 258 mm), which acts to exclude stray light of wavelength longer than 835 \AA .

The resultant solar spectrum appears as a series of superimposed monochromatic images of the Sun, one for each emission line in the wavelength range. Some images are overlapped, especially those below approximately 230 \AA that arise from highly stripped iron (Fe VIII - XVI), but other images such as He I 584 \AA , He II 304 \AA , Mg IX 368 \AA , Fe XV 284 \AA , and Fe XVI 335 \AA are fairly well separated.

Because small, intense features are well separated, spectroheliograms of flares and active regions can be obtained in several hundred emission lines.

The field of view of the instrument is approximately 60 arc min and the dispersion is 1.29 $\text{\AA}/\text{mm}$. Spectral and spatial resolutions are interdependent. The spatial resolution is 2 to 10 arc



Section of a spectroheliogram obtained by the Naval Research Laboratory XUV Spectroheliograph operating unattended on Skylab just prior to the beginning of manned operation. The principal image in this section is from the He II 304 Angstrom line, in which coronal holes, the chromospheric network, active regions and limb features can all be observed. The complete spectroheliogram from which this image was selected contains a series of images, dispersed in wavelength, from the various ultraviolet line emissions. (Courtesy of R. Tousey, Naval Research Laboratory)

sec, depending on the wavelength, and is best at the central portion of each range and degraded at the ends of the range. The spectral resolution is approximately 0.13 \AA for a well defined feature 10 arc sec in extent. Time resolution de-

pends on the exposure time, which varies from the shortest exposure of 2.5 sec to prolonged manual exposures of up to 48 min. On the three manned missions there are respectively 200, 400, and 200 film strips available.

UV SPECTROGRAPH (NRL)

The NRL ultraviolet spectrograph is a double-dispersion, high-resolution spectrograph with spatial and spectral fields defined by an entrance slit. A primary mirror (focal length 100-cm) forms a solar image on a fixed slit. Light from the slit is diffracted by either of two pre-disperser gratings, which select the wavelength band (970 to 1970 Å, or 1940 to 3940 Å), for final dispersion by the main concave grating (radius of curvature 200 cm; 600 lines/mm), which focuses the slit spectrum on the photographic film.

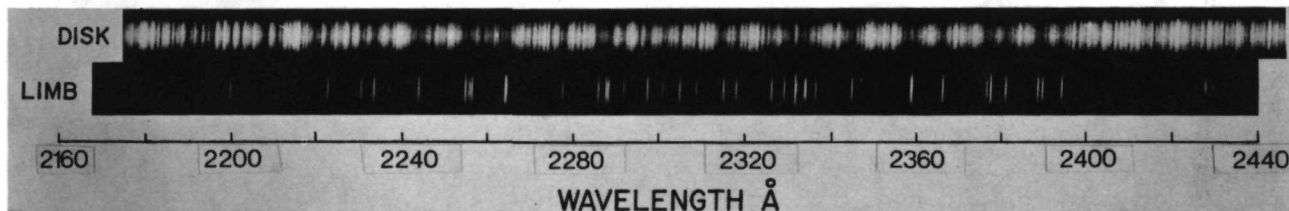
The pre-disperser gratings are ruled in 10 strips of differing dispersion, approximating a continuously changing dispersion. This technique increases the speed of the instrument by reducing the residual astigmatism to approximately 1 arc min; it does not produce a spectrum having spatial resolution along the slit. Eight spectra are recorded on each Eastman Kodak-type 104 film strip. The entrance slit defines the spatial resolution of 2×60 arc sec, and the two values of wavelength resolution, 0.04 Å and 0.08 Å, in the short and long wavelength ranges respectively, result from the slit width and dispersions of 4.2

Å/mm and 8.3 Å/mm in the two wavelength ranges. Time resolution varies from the shortest exposure of 0.15-sec to long manual exposures up to 48 minutes.

The instrument contains a white-light, slit-jaw, video camera system using an image dissector tube which presents the astronaut with a display for pointing the instrument very near the solar limb. This is also used to secure coalignment between the NRL spectrograph, the HCO spectrometer, and the H α video display, thus making it possible to observe the same solar features with the UV and EUV instruments and also have a photographic record in H α that establishes the identity of the feature. A third use of the white-light video system is to operate a servo-system that controls the primary mirror so that spectra across the limb can be made at automatically selected positions that are held stable to $\gamma 1''$. In the three missions there are, respectively, 200, 400, and 200 filmstrips available, each capable of eight exposures.

SUMMARY OF INSTRUMENT CHARACTERISTICS

The principal characteristics of the six ATM instruments are summarized in the following table.



Spectra in the 2170 to 2450 Angstrom band from the Naval Research Laboratory ultraviolet spectrograph on Skylab. The illustration compares the photospheric Fraunhofer absorption spectra, photographed with the instrument on the solar disk, and the chromospheric and coronal emission spectra photographed with the instrument aimed at the edge (limb) of the disk. (Courtesy of R. Tousey, Naval Research Laboratory)

Summary of ATM Instrument Characteristics

Name	Institution	Wavelength Range	Wavelength Resolution	Spatial Field	Spatial Resolution	Temporal Resolution	Unmanned/Unattended Operation
White-light coronagraph	HAO	3700-7000 Å	---	1.5 - 6.0 R	8.2 arc sec	≥ 40.5 s	Yes
EUV spectrometer-spectroheliometer	HCO	280-1350 Å	1.6 Å	5 x 5 arc min 5 arc min x 5 arc sec 5 arc min x 5 arc sec	5 arc sec	5 min 5 s 40 ms	Yes
X-ray spectrographic telescope	ASE	3.5-60 Å	(see text)	48 arc min	2 arc sec	≥ 2.5 s	Yes
X-ray telescope	MSFC	3-53 Å	(see text)	38 arc min	2 arc sec	≥ 3.5 s	No
XUV spectroheliograph	NRL	150-630 Å	0.13 (10 arc sec)	60 arc min	2-10 arc sec	≥ 2.5 s	No
UV spectrograph	NRL	970-3970 Å	0.04-0.08	48 arc min	2x60 arc sec	≥ 0.15 s	No

CREW OPERATIONS AND CREW TRAINING

Owen K. Garriett
Johnson Space Center

Dixon L. Forsythe
NASA Headquarters

Eugene H. Cagle
Marshall Space Flight Center

Crew participation in the solar observation studies should greatly increase the scientific return.

For instance, many solar features will be resolved for the first time at EUV and X-ray wavelengths—e.g., narrow filaments, supergranules, flare centers, prominence structure, and coronal structure.

A crewman on board the spacecraft will be able to assure the proper target identification and tracking. With such high resolution (1 arc-sec corresponds to about 700 km on the solar disc), even solar rotation contributes as much as 9 arc-sec per hour of target motion and becomes significant at longer exposure times.

Of particular importance, the ATM instruments will see a variety of transient phenomena—active prominences, perhaps coronal fluctuations concurrent with radio noise bursts, filament oscillation, and, of course, flares. These transients typically may last from 10 min to an hour or more, although some flares reach peak intensity in less than 5 min. To respond with sufficient promptness requires surveillance by trained observers at the telescopes, assisted by the necessary set of onboard sensors.

There are also limited means of “failure circumvention.” Although it would be desirable to have included a repair capability in the design of each instrument, the original time schedules did not allow this. Console switches will allow manual backup of many automatic functions (aperture door signals, operating modes, exposure lengths, etc). Other, more direct examples of failure circumvention include a manual means to align the internal occulting disc of the coronagraph and, during extravehicular activity (EVA), there is a manual means of removing a mirror from the coronagraph optical path.

Although the ATM includes several photoelectric sensors, photography remains a valuable

means of rapidly storing large quantities of data. The availability of crewmen makes possible the retrieval and return of exposed film in the command module.

Major advantage of manned participation may eventually be found in operational flexibility. Each instrument is designed to extend our observational knowledge of the Sun in spectral, spatial, or temporal resolution. We should expect the results to alter the best-laid plans for observing sequences. Since Skylab flights involve three manned missions, with one to two months between each flight, a preliminary review of the filmed data from each flight will permit making revisions to priorities or observing programs in time for the next flight.

An extensive program trains all the Skylab crewmen in solar observing, since all three men on each mission participate in the ATM operations. The training program includes a 50-hr lecture sequence in basic solar physics by Professor Frank Q. Orrall of the University of Hawaii.

From these lectures, the crewmen have gained a better understanding of the major problem areas to which ATM observations can contribute—how energetic particles are accelerated and released, how flares form and propagate, what relative abundances are of the various chemical elements in the Sun, how solar energy is generated, transported, and dissipated in the solar atmosphere, especially the corona, and how the solar wind relates to coronal structure.

They have visited solar observatories around the country and spent many hours studying edited film and slides. They have discussed the experiment systems and their objectives with the Principal Investigators.

The final element in the training sequence is practice in the ATM portion of the workshop simulator. This equipment includes all controls and displays of the actual spacecraft and permits the full range of normal operations as well as many off-nominal situations to be examined. All visual displays are accurately coordinated with crew activity, such as pointing telescopes, operating aperture doors, and spacecraft maneuvering. H-alpha film is used in these displays,

with additional processing to simulate views expected in the EUV and X-ray ranges for simultaneous display.

As Herbert Friedman of the Naval Research Laboratory commented: "Every range of the spectrum that we have searched from space has brought unexpected and fascinating surprises, and the potential has barely been scratched." The Skylab training program is designed to provide an optimum means of recognizing and exploiting surprises at the time of their discovery.

Through the ATM program, many advancements in engineering technology have been made that will contribute to the development of advanced astronomical systems for future space-oriented missions. Larger and more advanced instruments were conceived, incorporating focal lengths greater than 2 meters, highly precise optics, advanced detectors and power supplies, stable optical beds, and internal, active thermal-control systems. ATM truly opens a new era in astronomy—a pioneering discipline in the world of science.

THE SOLAR JOINT-OBSERVING PROGRAM

E. M. Reeves

R. W. Noyes

G. L. Withbroe

Harvard College Observatory

The ATM instruments are capable of concurrent observations of solar features. In many cases the coordinated data are far more valuable than those obtained by the same instruments operating independently. For example, the ATM will obtain simultaneous photographs of the corona at visible, XUV, and X-ray wavelengths; together the data will permit a unified study of the inner and outer corona.

The ATM experimenters have developed a number of observing programs designed to take best advantage of this capability for coordinated observations. These Joint Observing Programs (JOPs) are designed around specific problems in solar physics. In general, relevant ATM instruments observe the same feature either simultaneously or in close succession during the performance of a JOP.

The JOPs are carried out by executing a succession of fundamental observing sequences or "building blocks," of which 23 have been defined. Each building block provides for a specific type of observation, such as spatially-resolved observations of faint or bright features, spectral studies of faint or bright features, high time resolution. The building blocks consist of prescribed switch settings for the various instruments, plus a few additional settings to be specified by the ATM experimenters just before execution (for example, specifying the wavelength to be observed by the Harvard spectroheliometer). Since the operation of the building blocks will be thoroughly rehearsed before the mission, astronaut operations in orbit are somewhat simplified, and the astronauts may concentrate on telescope pointing or other scientific decisions.

There are other advantages to the JOP approach to ATM observations. The observing time available to the ATM can be scheduled more efficiently. Determining the daily observing program and near-real time changes to that program is greatly simplified, since it is necessary only to schedule different building blocks. The difficul-

ty of coordinating ATM observations with related ground-based observations is greatly lessened, because the entire ATM is concentrated on a single objective at a given time.

The JOPs, useful as they are, would be incomplete if they involved only observations by the ATM instruments. A number of important studies that can be carried out only from the ground, are necessary to provide a truly comprehensive view of the phenomenon under study. Some of the relevant ground-based observations are described below.

JOINT OBSERVING PROGRAMS

The Joint Observing Programs* can be divided into several general areas.

- Synoptic observations of the chromosphere and corona
- Observations of active regions
- Observations of quiet regions
- Observations of prominences and filaments
- Observations of flares and other transient phenomena
- Non-solar observations

Synoptic Observations of the Chromosphere and Corona

One of the major objectives of the ATM is the acquisition of a long uninterrupted series of observations showing the daily evolution of important solar features over many solar rotations. The primary ATM data obtained under this program will be photographs acquired by the High Altitude Observatory white-light coronagraph, the American Science and Engineering Co., and MSFC X-ray experiments, and the Naval Research Laboratory XUV spectroheliograph. White-light and X-ray observations will be obtained at least every 12 hrs over a period of up to eight months by using the manned and unmanned operating capabilities of ATM. The NRL spectroheliograph will obtain full-disk XUV spectroheliograms every three days during the times when ATM is manned.

*See Appendix for complete list of JOP's.

In addition to the ATM observations, it is desirable to obtain a variety of ground-based measurements.

Daily magnetograms are especially needed to provide information on photospheric magnetic fields. These data can be used to calculate coronal fields, for comparison with the coronal fields deduced directly from the X-ray, XUV, and white-light observations.

Measurements of the polarization of coronal emission lines are also important for determining the structure of coronal magnetic fields.

Coronal emission-line intensity and profile measurements can yield temperature, density, and structural information to supplement the ATM X-ray, EUV, and XUV data.

White-light K-coronameter data between 1.0 and 1.5 R are needed to cover the area not seen by the ATM coronagraph.

The ATM provides primarily data on the high chromosphere and corona in this observing program. Therefore, it would be useful to have regular coverage of the low chromosphere and photosphere with full disk spectroheliograms or filtergrams in Ca ⁺K, H α , and other appropriate lines, as well as the visible continuum.

Active Regions

A second important ATM Joint Observing Program is the study of active regions. Some of the objectives of this program are listed below.

Data will be obtained on the three-dimensional temperature and density structure of active regions and how this structure evolves with time.

Changes in the temperature/density structure before, during, and after solar flares and other transient phenomena such as filament activations, surges, etc. will be observed.

The temperature and density structure of active regions will be related to the three-dimensional structure of the magnetic field.

Data on transient phenomena associated with chromospheric and coronal heating processes will be sought.

Information on velocity fields in the transition zone and corona above active regions will be probed.

The ATM will be used to observe individual active regions of different types: young regions, old regions, rapidly developing regions, regions that are prolific producers of flares, quiescent, stable regions, etc. Several regions will be observed at least once a day as they pass across the disk from limb to limb.

The ATM will obtain many different types of active region data. The HAO coronagraph will provide data on the density and structure of the outer corona. The ASE and MSFC X-ray experiments will yield temperature and density information on the inner corona. The NRL XUV spectroheliograph and the Harvard EUV spectrometer in the raster mode will provide information on temperature and density in the inner corona, transition layer, and chromosphere in lines ranging from coronal lines such as Fe XVI λ 335 and Fe XV λ 284 to chromospheric lines such as the H I, He I, and He II resonance lines. The NRL spectrograph and the Harvard spectrometer in the spectrum-scanning mode will obtain spectral measurements between 300 and 4000 Å at selected positions in active regions. These spectra will contribute a wealth of information on conditions throughout the upper photosphere, chromosphere, transition layer, and inner corona. Thus the ATM data permit the study of active regions, in a manner never before possible, by inter-relating physical conditions in a region from its base in the photosphere to its outermost extension into the corona.

Obviously many types of ground-based data will be a valuable complement to the ATM observations. By observing in collaboration with ATM, the solar physics community can make unique contributions to our knowledge of solar activity, especially if a reasonably complete set of observational programs can be arranged. The combination of ATM and ground-based observations should then provide a storehouse of data from which the astronomical community will draw for many years.

Several examples of useful ground-based observations follow.

Observations of the photospheric layers of active regions, that is, photospheric faculae. Valuable observations can be obtained in the visible continuum as well as in atomic lines or molecular lines such as CN and CO. These data will be important for constructing models of photospheric faculae that can be tied into models for the high layers derived from ATM and other data.

Magnetic observations with high spatial resolution and sensitivity are clearly essential to understanding the structure of active regions. Numerous structures in X-ray photographs appear to be related to the structure of the coronal magnetic field, and suggest that the joint analysis of X-ray, XUV, and magnetic data will be very fruitful.

The measurement of forbidden* line intensities and profiles when active regions are at the limb, when combined with ATM observations, should produce extensive data in lines covering a wide range of excitation and ionization, thereby making possible an excellent determination of temperature and density.

White-light observations of the inner corona between 1.0 and 1.5 R are needed to supplement the ATM coronagraphic data.

Spectra and spectroheliograms in chromospheric lines such as H α , Ca ⁺K, He λ 10830 and others would be valuable. For example it would be useful to study He λ 10830 along with the ATM observations of the He I and He II resonance lines and the He I continuum.

Observations of photospheric and chromospheric velocity fields are also needed. This is particularly true when ATM is attempting to observe velocity fields in the transition zone and corona above active regions.

High resolution X-ray spectra by rocket-borne instruments will compliment the ATM broadband X-ray images in the determination of inner corona temperature and density structure.

* Forbidden lines are spectra which are not expected to pass through Earth's atmosphere, but occasionally do.

The Quiet Sun

A third area of interest is the study of the quiet Sun. The ATM X-ray and XUV instruments are able to resolve structures on a scale of a few arc sec. This is adequate for observing the chromospheric network and how it changes with height from the chromosphere into the corona. The ATM data will be used to construct three-dimensional models for typical quiet areas and areas with unusually faint or bright network. The observations and resulting models should provide insight into the energy balance of the chromosphere transition layer and corona.

One outstanding problem in this regard is determining where, relative to the network, the heat conducted downward from the corona is deposited in the chromosphere and how it is dissipated by radiative or mechanical mechanisms.

Another area of investigation is the study of the evolution of the network in the chromosphere and higher layers, both over a short time (hours) and over a longer period of up to two days.

Important coordinated ground-based observations for network studies include magnetograms with high spatial resolution (a few arc sec) and high sensitivity; observations of the photospheric and chromospheric network in appropriate lines in the visible spectrum; measurements of photospheric and chromospheric velocity fields in relation to the network.

Center-to-limb observations are another field of interest. The NRL UV spectrograph will obtain spectra at precisely-defined positions from center to limb. These spectra may be obtained at the equator, along other lines of constant latitudes, over the poles, or crossing the limb over active regions or coronal "holes."

At the same time the Harvard instrument will obtain spectra and spectroheliograms at corresponding locations, and the X-ray instruments as well as the NRL XUV spectroheliograph will obtain highly resolved images at the limb. Among other things they will study the coronal effects of spicules and other chromospheric limb phenomena.

To supplement the ATM data it is desirable to acquire ground-based spectra and spectroheliograms showing spicular structure in H α , Ca ⁺K, He 10830, or He D₃, as well as center-to-limb data in various lines. Forbidden coronal-line observations and white-light corona data are also important.

The study of oscillations in the chromosphere and corona is another important area of investigation. Present evidence for an extension of the "5-min" chromospheric oscillation into the high chromosphere and corona is rather weak, largely owing to the lack of good spatial resolution of the observations. The Harvard instrument on the ATM, operating in the line-scan mode, will attempt to observe intensity fluctuations through simultaneous observations over a range of heights from the chromosphere to the corona with 5-sec time resolution. The X-ray telescopes and the XUV spectroheliograph will also obtain coordinated data, but with time resolution of about 1 min.

The ATM will observe an area whose coordinates can be easily specified to a ground-based observer. The most suitable place is probably the center of the disk.

Desirable ground-based observations are measurements of the variation with time of continuum and line intensities and of velocities, preferably measured with lines formed at a variety of heights in the photosphere and chromosphere. Precise timing is essential so that phase information can be obtained from the ATM and ground-based data. Measurements of magnetic fields with high spatial resolution and the best possible time resolution and sensitivity are also essential.

Prominences and Filaments

The ATM will provide important new observational data for the study of prominences and filaments. For example, observations of H I, He I, and He II resonance lines and continua will contain new information about the temperature and density of the cool layers of prominences that are observed from the ground in the Balmer lines and continuum, helium lines, and metallic lines.

In addition the ATM will observe intermediate stages of ionization of carbon, nitrogen, oxygen, neon, silicon, magnesium, and iron lines that provide information on the interface between cool prominence material and the hot coronal gas in which it is imbedded.

Finally, the ATM will also observe XUV and X-ray emission from the corona surrounding the prominence or filament. Observation of prominences both at the limb and when they are on the disk as filaments will yield information about the three-dimensional structure of prominences and the related coronal features.

A variety of coordinated ground-based observations relative to these studies involve magnetic field measurements both in the prominence and in underlying photosphere; spectra of emission lines of H I, He I, He II, metallic lines, and the Balmer continuum; observations of the coronal structure associated with the prominence, by use of forbidden lines and white-light emission; measurements of proper motions and Doppler shifts in the prominence.

Flares

For the study of flares and other transient phenomena the ATM has several unique and powerful capabilities. Because of the presence of a trained astronaut-observer, the ATM can respond quickly to the occurrence of transient events.

For the first time it will be possible to study the simultaneous development in time and space of the UV, EUV, and X-ray emitting portions of the flare plasma. This will permit simultaneous observation of the flare over the very wide temperature range between 4000 and 10⁷°K. In addition to the flare itself, the ATM will study the region surrounding the flare before, during, and after the flare. To this end solar forecasters from the National Oceanic and Atmospheric Administration will be working closely with the ATM experimenters and providing information on active regions likely to flare. The objective of ATM observations in the flare program is to obtain a diverse and extensive collection of data that can be used to determine physical conditions (temperature and density) in the flare plas-

ma and the surrounding medium, and to determine how these conditions changed before, during, and after the flare.

The ATM will observe flares either by pointing at the flare in order to get simultaneous UV, EUV, XUV, and X-ray observations or by using Sun-center pointing so that the coronagraph can observe the response of the outer corona to the flare; in the latter case the wide field-of-view instruments (NRL spectroheliograph and the two X-ray telescopes) can observe the flare, although the NRL spectrograph and HCO spectrometer cannot.

The ATM will also be used to study other types of transient phenomena such as surges, filament activations, eruptive prominences, and coronal phenomena associated with Type II, Type III, and Type IV radio bursts.

In order to understand the complex phenomena associated with flares it appears necessary to have a diverse and extensive collection of observations of many kinds. In addition to the ATM data it is important to have magnetograph data, K-coronameter data, radio noise information, coronal observations with forbidden lines, extensive $H\alpha$ coverage and other satellite data such as gamma-ray, X-ray, and solar wind measurements.

Nonsolar Observations

Although the ATM was designed for solar studies, it is capable of making other types of

observations. These may be divided into three classes: study of the terrestrial atmosphere; observation of the lunar libration points; observation of night sky sources.

The ATM can be used to study Earth's atmosphere through measurements of the absorption of solar UV and X-ray radiation by the terrestrial atmosphere near the times of spacecraft sunrise and sunset. The variation with height of the densities of major atmospheric constituents such as O, O₂, and N₂, as well as some minor constituents, can be determined from the extinction measurements made at different wavelengths.

Observations of the lunar libration points will be acquired with the HAO coronagraph. The object will be to verify the accumulation of dust particles at several lunar Lagrange points, and to determine the density and dimensions of the accumulation region.

The ATM may also be used to acquire EUV and X-ray observations of a variety of night sky sources such as early-type stars, X-ray sources, nebulae, and galaxies. Through use of pictures of the star field acquired with the coronagraph and X-ray filtergrams, accurate positions of a number of X-ray sources can be determined. Absolute X-ray fluxes may also be measured for selected sources.

The HCO instrument may be able to measure the EUV radiation from many early-type stars and other objects emitting strongly in the EUV.

SKYLAB ASSOCIATED SOLAR PROGRAMS

G. K. Oertel
NASA Headquarters

The flight of Skylab will open a new era in solar astronomy. The analysis and interpretation of the data will form the basis for many solar studies during the rest of the decade. Similar to a total solar eclipse, the Skylab has stimulated scientists at many ground-based solar observatories around the world to coordinate their observing plans with Skylab; to prepare special and unique instrumentation to be ready in time for the Skylab missions; and to make arrangements for eventual access to the Skylab data themselves.

It makes good sense to do this, because solar phenomena are very complex and require a complement of observations from space and from the ground for a successful study of their nature. Some of these phenomena are also never quite the same and require simultaneous observations—otherwise one can never quite be sure if the Skylab result at a given time was typical or exceptional. Finally, the Skylab will return a wealth of information which deserves scrutiny by all interested solar physicists—the investigator groups will thus be complemented by many interested researchers from all parts of the United States and from abroad.

This section describes the most important Skylab associated solar programs. These programs provide for supporting and coordinated ground-based or space observations, and operational support. A coordinated program was instituted by the ATM investigators to enable ground-based observers and space experimenters to cooperate productively with the Skylab observations. Some of the scientists at the institu-

tions in the coordinated program will be working closely with the Skylab investigators and will get access to Skylab data before it becomes widely available, they are guest investigators and comprise the collaborative program.

Several of the ground-based observatories were supported by NASA in preparation for special solar observations for Skylab. The Supporting Research and Technology Program was supplemented by a rigorous Skylab Ground-based Astronomy Program. X-ray spectroscopy, not included in the ATM payload, will be provided by the Sounding Rockets Program and by Orbiting Solar Observatory 7 (OSO-7), including a special OSO guest investigator program. The ultraviolet spectroscopy experiments on ATM will be calibrated with sounding rockets in the CALROC Program.

Finally, the National Oceanic and Atmospheric Administration (NOAA) provides real time information about the Sun to the ATM science room at Houston and to ground-based observers.

Many of these programs are interconnected. For example, an astronomer at a ground-based observatory may well provide NOAA with routine information about the Sun, coordinate his detailed observations with Skylab, and be a guest investigator on one of the ATM experiments. The instrumentation he uses might well have been updated with Skylab Ground-Based Astronomy Program (SGAP) support, and part of his salary might be paid by the Supporting Research and Technology Program. One of his co-workers might well fly a sounding rocket with X-ray spectrometers and/or make coordinated observations as an OSO-7 guest investigator.

COORDINATED OBSERVING PROGRAM

E. M. Reeves

R. W. Noyes

G. L. Withbroe

Harvard College Observatory

The previous description of the JOPS emphasizes the usefulness of synchronized observations of the same feature by ground-based observers all over the world. This section describes the methods proposed by the ATM scientists to facilitate coordination of these observations.

The ATM scientists plan to carry on close collaborative (guest investigation) programs with a few ground-based observers, involving joint participation in the planning, acquisition, and analysis of both ground-based and ATM data.

A much wider participation is also envisioned, whereby any observer who cares to, may make relevant coordinated observations. This is best arranged before Skylab launch, but if, after the data are acquired, it appears that a coordinated analysis of ATM and other sets of data would be useful, this can also be arranged.

In order to encourage participation by interested observers, a ground-based analogue of the Joint Observing Programs has been organized, consisting of a set of Coordinated Observing Programs (COPs).

Planning activities for the COPs were initiated jointly by the ATM principal investigators, and resulted in an exploratory meeting at the Kitt Peak National Observatory in September 1971. Approximately 120 scientists from 13 countries represented groups involved in theoretical and experimental solar physics. The purpose of this initial meeting was to discuss which coordinated observations would optimize the interpretation of both ATM and ground-based solar data in terms of the physical phenomena in the solar

atmosphere under study. Also included in the discussions were certain related technical areas such as magnetograph requirements, and use of densitometers in data reduction.

As a result of the discussions at Kitt Peak Observatory a number of Task Groups were formed. Each of these groups is under the chairmanship of a non-ATM scientist.

Each problem-oriented COP group is concerned with ground-based observations relevant to a particular JOP.

The technique-oriented groups are concerned with use of equipment or techniques that clearly cut across all of the COPs. The chairmen of these groups have surveyed the existing and proposed instrumentation in their fields, as well as the degree of participation by various observatories.

Participation of task group members in COP activities ranges from simple exchange of information and discussion, through general agreements to acquire relevant data, to expressions of intent to coordinate their observations with ATM rather closely. In several cases detailed collaborative arrangements are being made with individual ATM experimenters.

The number of participants in the Coordinated Observing Program has now risen to approximately 250. These are kept advised of activities in the task groups of interest through the Coordinated Observing Program Office at Harvard College Observatory. General program information or specific information such as the details of the JOPs and building blocks and lists of proposed COP observations can be obtained by writing to Dr. Robert O Doyle, Harvard College Observatory, 60 Garden Street, Cambridge, Massachusetts, 02138 (USA).

ATM GUEST INVESTIGATION PROGRAM

G. K. Oertel
NASA Headquarters

The ATM Guest Investigator Program was instituted to recognize those investigators outside the Skylab experiment groups who will work closely with a Skylab experimenter and who will get access to Skylab data prior to its submission to the National Space Science Data Center. Guest investigators are appointed for a specific ATM experiment by NASA Headquarters. They are expected to arrange for prompt analysis, interpretation, and publication of the Skylab results.

See appendix for ATM Guest Investigators, appointed or proposed.

SKYLAB GROUND-BASED ASTRONOMY PROGRAM (SGAP)

Bill J. Duncan
Marshall Space Flight Center

The Skylab Ground-based Astronomy Program (SGAP) broadens the astronomical community participation in Skylab by encouraging the acquisition of complimentary data from the ground simultaneously with the Skylab orbital observations, and enhances the usefulness of Skylab data for solar physics research by increasing the spectral coverage. It provides additionally-needed new instruments and upgrades existing equipment of many leading solar observatories to obtain increased spectral coverage and observation time with a variety of sophisticated instruments during the ATM mission time.

The SGAP thus encourages the involvement of the participating solar observatories in the coordinated and guest investigator programs. This will result in a better return on the Skylab investment through additional data as well as through additional contributions to analysis and interpretation.

SGAP is managed by the Marshall Space Flight Center's Space Sciences Laboratory, where the author is project manager and Dr. Mona Hagyard is project scientist.

The participating astronomical observatories and their SGAP tasks are:

1. The University of Hawaii is constructing a specialized instrument, a photoelectric differential coronal photometer, for an observational investigation of the Sun's active coronal regions. Observations will be from the 10,000-foot-high observatory on Mt. Haleakala on the island of Maui. This instrument will simultaneously measure the intensities of several visible coronal spectral lines which arise from chemical elements observed by the Skylab instruments. Skylab and SGAP data will be used to determine the rates of energy loss and gain from active regions and the effects of flare events on the corona. Dr. John Jefferies is the principal investigator for this effort.
2. At Kitt Peak's McMath solar telescope in Arizona, Lockheed Missile and Space Company will operate a system called spec-

tra-spectroheliography that can comprehensively map visible emissions from the solar atmosphere for use with Skylab data.

In addition to the Kitt Peak solar telescope and vacuum spectrograph, a wide-exit aperture and a specially-constructed movie camera, capable of rapid film advance, are used to obtain spectral maps of regions of the solar disk with high spatial resolution (to one half arc second).

A high-speed microdensitometer-computer system is being added to allow rapid analysis of the spectral data to obtain solar velocity and magnetic field maps of regions of interest. Dr. Alan Title is the principal investigator.

3. The National Bureau of Standards is upgrading calibration capabilities in support of the Skylab, notably the CALROC effort by developing a hydrogen arc source of known radiant flux for the calibration of spectrometric-detector systems over the region of 500 to 3700 Å; conducting a study to determine the effects on photocathodes caused by removal or addition of monolayers of contaminants in vacuum (wavelength region of interest is 500 to 1500 Å); establishing a capability for radiometric calibration down to 200 Å by using the NBS synchrotron facility. Windowless diodes are being developed as transfer standards in this spectral range. The principal investigators for NBS are Drs. W. L. Wiese and Robert Madden.
4. California Institute of Technology is installing a 65 cm aperture solar telescope at its observatory at Big Bear Lake in California, a site selected as the result of an earlier survey for good astronomical "seeing" conditions. It will be used for high resolution studies of active regions in conjunction with ATM.

Provisions are being made for use of various cameras and detector systems as well as a vacuum spectrograph at the Coudé focus. Filtergrams will be made in lines extending from the 3933 Å calcium K-line to the 10830 Å helium line. Dr. Harold Zirin is the principal investigator.

5. The Lockheed Solar Observatory at Rye Canyon is preparing two telescope systems for observations during ATM operation. On one telescope, studies in a spectral line of helium (5876 Å) will direct attention to observing solar flares and transient events during periods of high disk activity, and to limb prominence observations during periods of low disk activity.

The other telescope is being fitted with a filter for high resolution photographic studies of a spectral line of ionized calcium (8542 Å) which is believed to originate at an intermediate level in the solar atmosphere and is extremely valuable in relating Skylab X-ray and XUV data to filtergrams and spectroheliograms taken at wavelengths originating at lower levels in the chromosphere. Drs. Sara Martin and Harry Ramsey are the principal investigators.

6. The University of California at San Diego is using a 1.5m Cassegrainian telescope on Mt. Lemmon, Arizona for exploratory observations of solar flares in the infrared. Beam switching techniques with a broadband sub-millimeter radio meter system are used. These observations should allow differentiating among the major theories of white-light flare emission. Dr. Hugh Hudson is the principal investigator.
7. Lockheed Missile and Space Company at Palo Alto, California is doing a theoretical

study of helium emissions in the visible and ultraviolet from solar active regions. Results of these studies will allow the interpretation of Skylab and ground-based observations in terms of density and temperature in different parts of the solar atmosphere. Dr. J. L. Kulander is conducting the study.

8. The Uttar Pradesh State Observatory in India is doing a study of dissociation and excitation equilibria of various molecules in the photosphere, in sun spots and faculae. Detection equipment is being supplied to India on loan for an observational program using their existing horizontal solar telescope and its associated spectrograph. The data will help in testing and improving models of the cooler regions in solar atmosphere. Dr. M. C. Pande is the principal investigator.

The Applied Physics Laboratory of Johns Hopkins University is preparing to support Skylab with spectral observations of solar radio bursts (500 to 1000 MHz). With the 0.1 sec time resolution available from their spectrograph and 60-ft-diameter antenna, and in conjunction with Skylab data, it is possible to investigate the emission mechanism and measure electron densities, and estimate the sites of source region, from frequency drift rate determinations. Mr. Bruce Gotwols is the principal investigator for this effort.

SOLAR X-RAY SPECTROSCOPY

J. M. Weldon
NASA Headquarters

One effort to optimize the return from the investment in solar astronomy represented by the ATM is a strong sounding rocket program. Since the selection of the ATM experiment payload, rocket experiments using X-ray spectrographs have demonstrated a need for high resolution X-ray spectra data which the ATM payload was not designed to provide.

It is now recognized that a substantial enhancement in our understanding of physical processes in the lower corona can be realized if we complement the high resolution X-ray imagery which ATM will achieve with collimated high resolution spectra from X-ray spectrometers on sounding rockets and Orbiting Solar Observatory 7(OSO-7) during the ATM mission.

As many as nine Aerobee class sounding rockets will be launched from the White Sands Missile Range in New Mexico during the manned portions of the eight month ATM mission. The NASA Office of Space Science is supporting solar scientists at the Aerospace Corporation, American Science and Engineering Inc., the Lockheed Missile and Space Company, the University of Chicago* to prepare the necessary instrumentation. The payloads consist of various crystal spectrometers, each adjusted to record with high resolution the X-ray emission over se-

lected portions of the soft X-ray solar spectrum. Mechanical grid collimators are used to define the precise areas on the Sun from which the observed X-ray originate.

The rocket experimenters will assess the solar conditions from ground-based observations, maintain cognizance of the particular observing program being implemented aboard the ATM, and time their launches to coincide with the appropriate ATM observations. Their instruments will be programmed to view the same regions on the Sun being investigated by the ATM, to insure the data can be effectively correlated for post-mission analysis and interpretation.

The X-ray and far UV spectrometers on the Goddard Space Flight Center's experiment on OSO-7 will be used in a similar fashion to provide needed X-ray spectroscopy information. The Goddard experimenters have agreed to make available part of their observing time for OSO guest investigators wishing to coordinate OSO-7 observations with Skylab.

With the detailed fine structure of the Sun from the ATM X-ray photographs and the temperatures, densities and elemental abundances from the rocket spectroscopy flights, it will be possible to test existing models of solar phenomena, construct new ones, and to begin to understand their roles in the solar energy and mass transfer processes in the solar atmosphere, problems of fundamental importance in studying the Sun.

* And the U.S. Naval Research Laboratory

ATM CALIBRATION ROCKET (CALROC) PROGRAM

Clayton M. Spencer
Marshall Space Flight Center

The ATM ultraviolet instruments may change in efficiency or optical performance during the extended eight-month Skylab Mission. The changes are expected to result from space environmental effects which can reduce the reflectivity of optical surfaces, shift photographic film characteristics, and degrade photoelectric detector performance characteristics. The resulting uncertainties will seriously impact several aspects of data interpretation.

The CALROC Project was initiated to provide periodic recalibration of the Naval Research Laboratory's (NRL) S082A and S082B UV experiments, and the Harvard College Observatory's (HCO) S055 UV experiment. The calibration will be done by flying sounding rockets with instruments similar to the NRL and HCO ATM experiments to altitudes of 150 to 175 miles and acquiring data on a specific solar region while the Skylab astronauts are taking data with the ATM.

After the ATM data is returned to Earth and processed, it will be compared to the CALROC data and calibration factors derived for application to all Skylab data. The CALROC instruments will be calibrated a few days before flight and rechecked just after flight to assure their accuracy.

The HCO CALROC package includes a telescope, scanning spectrometer, and photomultiplier detectors while the NRL CALROC includes two spectrographs, a spectroheliograph and heliograph with film cameras to record the data. An H- α TV camera is also included for real time monitoring and control.

The CALROC launches will take place from White Sands Missile Range, New Mexico, as close as possible to special Skylab observations. The principal investigators for the ATM will select the spot on the Sun to be observed on the day before the proposed CALROC flights. Mission Control at the Johnson Space Center, Houston, will then relay the coordinates to the astronauts so that both the ATM and CALROC are observing the same area.

The NRL CALROC launch will take place about eight days after a manned mission begins. As the rocket nears an altitude of about 150 kilometers (93 miles), on its way to a maximum altitude of 250 kilometers (155 miles), film cameras will automatically be turned on and data will be collected for about five minutes. The payload, weighing some 268 kilograms (590 pounds), will then descend to Earth by parachute. Once the film has been developed and the coordinates verified, Skylab astronauts will begin their observations.

The CALROC launch for the HCO experiment will occur about seven days later. CALROC data will be gathered as the rocket, carrying a payload of about 218 kilograms (480 pounds), soars to its maximum altitude of 290 kilometers (180 miles). The period of observation will last about four minutes and the data will be sent back by telemetry.

The order of the CALROC launches for the next manned mission will be reversed. The HCO launch will take place about eight days after the manned launch with the NRL launch following about seven days later.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

SOLAR FORECAST SERVICES

R. B. Decker
National Oceanic and Atmospheric Administration

To obtain the best results from the ATM manned observations, the ATM principal investigators will provide the astronaut with daily ATM observing schedules in the form of Joint Observing Programs (JOPs) to be accomplished. The principal investigators will continuously monitor solar activity from ground observatories in order to change this schedule when needed. These two elements, daily scheduling and continuous monitoring, require a real time operational solar observational and forecast system.

The National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce has such a system, the Space Environment Forecast Services, (SEFS). SEFS had been developed to satisfy the radiation safety considerations of the Apollo missions, as well as to meet the operational needs of National and International organizations concerned with the impact of solar events upon their particular effort.

SEFS with considerable NASA support operates solar observatories at Boulder, Colo., Grand Canaries, Spain, and Carnarvon, Australia, and an operational solar forecast center at Boulder. Recently the Air Weather Service (AWS) of USAF joined with SEFS to greatly expand continuous solar observational capability through the addition of solar observatories at Athens, Greece, Puerto Rico, and Hawaii.

This network of observatories provides continuous monitoring of the Sun in several wavelengths (white light, hydrogen α , several discrete radio wavelengths) but it does not include all solar observations, as coronal intensities and solar magnetic fields etc. Arrangements were made with the following solar observatories to provide these additional data:

Calcium—McMath Observatory, Pontiac, Michigan

Calcium—Haleakala Observatory, Maui, Hawaii Islands

Solar Magnetic Fields—Aerospace Observatory, Los Angeles, Calif.

Solar Magnetic Fields—Big Bear Observatory, Big Bear Lake, Calif.

Sweep Frequency—CSIRO Observatory, Culgoora, Australia

Coronal Intensities—Mauna Loa Observatory, Hawaii, Hawaii Islands.

To further augment the solar data base provided to the ATM PIs, the following facilities have voluntarily offered to contribute their real time solar data as follows:

Catania Observatory, Sicily—Calcium

Sacramento Peak Observatory, New Mexico—Coronal Intensities, Calcium and Solar Magnetic Fields

Kitt Peak Observatory, Arizona—Calcium and Solar Magnetic Fields

Mt. Wilson Observatory, Calif.—Solar Magnetic Fields

Sagamore Hill Observatory, Mass.—Sweep Frequency Radio Data

GSFC, Greenbelt, Md.—OSO-7 X-ray and EUV maps and ATS-1 proton data

NRL, Washington, D. C.—OSO-7 EUV maps and SOLRAD X-ray fluxes.

To fully use the solar data from any of these sources, it became necessary to obtain a wire-photo transmit/receive capability. This wire-photo transmission system enables solar observatories to transmit 8-in. solar photographs directly to the ATM investigators at the Mission Control Center is made using ordinary voice telephone circuits without appreciable loss in photographic quality.

Solar data from these many sources will be analyzed by the NOAA solar forecasters and the ATM investigators (co-located with the ATM science team at the Skylab mission control center. NOAA solar forecasters will prepare short period (1 to 6 hr) forecasts and longer period (6 hr to 3 days) forecasts in response to ATM needs. Using these forecasts, the ATM team will generate daily ATM observing schedules. After integration into the overall Skylab schedule, the ATM observing schedule will be transmitted to the Skylab astronauts. Variations or changes to these ATM observing schedules may be made by the astronaut, or upon request of the ATM principal investigators when necessitated by actual solar activity.

APPENDIX

Access to Scientific Data

ATM DATA

Approximately one year after receipt of the ATM scientific data at the principal investigator's institution, all data will be stored at the National Space Science Data Center (NSSDC). After submission of the data to the NSSDC (1975) any interested party will be entitled to access by arrangement with the NSSDC.

Requests for data should be forwarded to:

National Space Science Data Center
Code 601.4
Goddard Space Flight Center
Greenbelt, Maryland 20771, USA

NOAA DATA

At the conclusion of the last Skylab mission the National Oceanic and Atmospheric Administration's solar forecasters will compile a data book containing all of the available solar data collected by the NOAA-affiliated solar observatories during the period February 1973 through March 1974. Microfilm copies of this data book will be made available to any interested party.

Requests for data should be forwarded to:

Environmental Data Service
National Oceanic and Atmospheric Administration
Boulder, Colorado 80302, USA

INFORMATION FOR TEACHERS

The National Aeronautics and Space Administration has published a brochure on solar astronomy intended for use by high school science teachers. By having this information at hand, the teacher will be able to formulate opinions on the educational benefits that can be obtained from applying data from the Skylab experiments to specific curriculum elements. The data will be made available in various forms such as photographs, film strips, voice tapes, instrumentation tapes, etc., and can be used as, or applied to, educational aids that illustrate many of the principles discussed in high school curricula.

Requests for detailed information and copies of the brochure: *Information for Teachers, Volume I*, should be forwarded to:

Director, Educational Program Division
Code FE
National Aeronautics and Space Administration
Washington, D. C., 20546

INFORMATION FOR COORDINATED OBSERVERS

Many solar scientists in the USA and throughout the world have indicated a desire to assist in the evaluation of the ATM data through simultaneous observations with their solar observing equipment.

To support them, and others interested in the ATM Skylab mission, an ATM/alert message code was devised, using the Stonyhurst coordinate system. The ATM/alert message, depicting the daily planned ATM observations schedule, will be disseminated worldwide through a teletype network operated by the National Oceanic & Atmospheric Administration (NOAA) as part of their service under the International Ursigram and World Days Service (IUWDS). The scheduled ATM observing program and hourly revisions will also be transmitted over radio stations WWV and WWVH (5, 10, 15, and 20 MHz) between 22 and 27 minutes after each hour. In the Eurasia area, similar daily broadcasts are anticipated based on the interest expressed to the local Regional Warning Center. The WWV broadcasts can be monitored also via telephone: 499-7111 (Boulder, Colo.).

Information about the Coordinated Observing Program and specific information needed to decode the ATM/alert message can be obtained by writing to:

Dr. Robert O. Doyle
Harvard College Observatory
60 Garden Street
Cambridge, Massachusetts, 02138, USA

JOINT OBSERVING PROGRAM

ATM JOINT OBSERVING PROGRAMS SUMMARY

JOP-1A	Chromospheric Network: Near Suncenter	JOP-8A	Coronal Transients: H-Alpha Crew-Detected Events
JOP-1B	Chromospheric Network: Within 2 Arc Minutes of Limb	JOP-8B	Coronal Transients: WLC Crew-Detected Events
JOP-1C	Chromospheric Network: At Limb	JOP-8C	Coronal Transients: Ground-Detected Events
JOP-1D	Chromospheric Network: Bright Spot	JOP-8D	Coronal Transient Wait
JOP-1E	Chromospheric Network: Evolution	JOP-9	Solar Wind
JOP-2A	Active Regions: Rapidly Developing	JOP-10	Lunar Libration Clouds
JOP-2B	Active Regions: Long Term Evolution—Disk	JOP-11A	Chromospheric Oscillations and Heating: Data from Quiet and Active Regions
JOP-2C	Active Regions: Long Term Evolution—Limb	JOP-11B	Chromospheric Oscillations and Heating: Velocity Fields in the Chromosphere and Corona
JOP-2D	Active Regions: Structure	JOP-12A	S055 Calibration
JOP-2E	Active Regions: Sunspots	JOP-12B	S082A and B Calibration
JOP-2F	Active Regions: Chromospheric Velocities	JOP-12C	Film Canister
JOP-2G	Active Regions: Ellerman Bonds	JOP-12D	S082B Slew Calibration
JOP-3A	Flares: Disk or Limb	JOP-12E	Lunar Calibration
JOP-3B	Flares: Limb	JOP-12F	S055 Periodic Recalibration
JOP-4A	Prominence Structure	JOP-13	Night Sky Objects
JOP-4B	Filament Structure	JOP-14	Solar Eclipse
JOP-4C	Evolution of Prominences and Filaments	JOP-15A	Coronal Holes: Disk
JOP-5A	Limb Profile Studies: XUV Spectrum along Constant Latitude Lines	JOP-15B	Coronal Holes: Limb
JOP-5B	Limb Profile Studies: XUV Spectrum at North and South Poles	JOP-15C	Coronal Holes: Evolution
JOP-5C	Limb Profile Studies: Limb Scans	JOP-15D	Coronal Holes: Velocities
JOP-6	Synoptic Observations	JOP-16	Disk Transients
JOP-7	Atmosphere Extinction	JOP-17A	Coronal Bright Spot: XUV or X-ray Structure
		JOP-17B	Coronal Bright Spot: Evolution

Additional JOP's considered for third manned Skylab mission to include comet observations.

ATM INVESTIGATING TEAMS

LIST OF ATM PRINCIPAL INVESTIGATING TEAMS

Experiment S052, White Light Coronagraph

High Altitude Observatory
Boulder, Colorado 80302

R. M. MacQueen, principal investigator
R. Broussard
A. Csoeke-Poeckh
J. T. Gosling, Co-investigator
E. G. Hildner, Co-investigator
R. Munro, Co-investigator
A. I. Poland, Co-investigator
C. Ross

Experiment S054, X-ray Spectrographic Telescope

955 Massachusetts Ave.
Cambridge, Mass. 02139

Giuseppe Vaiana, principal investigator
R. Chase
T. Davis
R. Giacconi
L. Gollub
S. Kahler
A. S. Krieger
R. Petrasso
K. Silk
A. Timothy

Experiment S055, UV Scanning Polychromator Spectroheliometer

Harvard College Observatory
60 Garden Street
Cambridge, Mass. 02138

E. Edward Reeves, principal investigator
R. Doyle
A. Dupree
P. Foukal
L. Goldberg
M. C. E. Huber
R. Noyes

W. Parkinson
E. Schmahl
J. G. Timothy
J. E. Vernazza
G. L. Withbroe

Experiment S056, Hi-Resolution X-ray Telescopes

Marshall Space Flight Center
Huntsville, Ala. 35812

J. Milligan, principal investigator
G. Chapman
A. C. deLoach, Co-investigator
E. Frazier
R. Hoover
T. Janssens
J. McGuire
D. McKencie
J. Underwood, principal scientist
A. Walker
R. Wilson

Experiment S082A, Coronal Spectroheliograph Experiment S082B, Chromospheric Spectroheliograph

U.S. Naval Research Laboratory
4555 Overlook Ave. S. W.
Washington, D.C. 20390

R. Tousey, principal investigator
D. Bohlin
G. Brueckner
W. Crockett
T. Makes
R. Mason
O. Moe
K. Nicolas
G. D. Purcell
V. Scherrer
R. Schumacher
N. Sheeley
M. VanHoosier
K. Widing

ATM GUEST INVESTIGATIONS

COLLABORATIONS AFFILIATED WITH EXPERIMENT S052

Name	Institution	Investigation
M. Altschuler	High Altitude Observatory Boulder, Colorado	Global Electron Diversity Structure of the Corona Structure
S. J. Bame	Los Alamos Scientific Laboratories Los Alamos, New Mexico	Solar Wind Measurements with IMP6 and IMP7
H. Bridge	Massachusetts Institute of Technology Cambridge, Mass.	Solar Wind Observations with Explorer 47
H. Courten	Dowling College Oakdale, New York	Cometary Objects
A. Dollfus	Paris Observatory Paris, France	Coronal Radio Physics
G. A. Dulk	Univ. of Colorado & CSID Boulder, Colorado	Coronal Radio Physics
W. C. Erickson	Univ. of Maryland College Park, Md.	Solar Radio Burst
R. R. Fisher	Sacramento Peak Observatory Sunspot, New Mexico	Photoelectric FE XIV Observations and Coronal Density Model
R. T. Hansen	High Altitude Observatory Boulder, Colorado	Coronal Transients: K-Coronameter Density Observations
A. Maxwell	Harvard College Cambridge, Mass.	Coronal Radio Spectra
G. A. Newkirk	High Altitude Observatory Boulder, Colorado	Coronal Magnetic Field Models and Meter Radio Bursts
G. W. Pneuman	High Altitude Observatory Boulder, Colorado	Energy Balance in Coronal Structures
J. M. Rankin	Univ. of Iowa Iowa City	Pulsar Electron Sensity Determinations with NP0532
B. Rickett	University of California San Diego, Calif.	Interplanetary Velocity Fluctuations
K. V. Sheridan	Csiro Observatory Culgoora, Australia	Coronal Radioheliograph Observations
W. J. Wagner	Sacramento Peak Observatory Sunspot, New Mexico	Coronal Transients: FE XIV Cinematography

**COLLABORATIONS AFFILIATED
WITH EXPERIMENT S054**

Name	Institution	Investigation
L. Acton	Lockheed Research Lab. Palo Alto, Calif.	Rocket X-ray Spectroscopy
M. Altschuler	High Altitude Observatory Boulder, Colorado	Coronal Structures
R. Blake	Univ. of Chicago Chicago, Illinois	Rocket X-ray Spectroscopy
R. Bracewell	Stanford University Palo Alto, Calif.	Radio Astronomy
R. Catura	Lockheed Research Lab. Palo Alto, Calif.	Rocket X-Ray Spectroscopy
R. T. Hansen	High Altitude Observatory Boulder, Colorado	White Light Coronal Data
J. Harvey	Kitt Peak National Observatory Tucson, Arizona	Correlation of Magnetic Field and X-ray Structure
R. Howard	Hale Observatories Pasadena, Calif.	Correlation of Magnetic Field and X-ray Structure
J. Jeffries	University of Hawaii Honolulu, Hawaii	Coronal Observation of Active Regions/Forbidden Line Intensity Ratios
M. Landini	Arcetri Astrophysical Observatory Florence, Italy	Models of X-ray Emission Structures
A. Lazarus	Massachusetts Inst. of Technology Cambridge, Mass.	Solar Wind Studies
W. Livingston	Kitt Peak National Observatory Tucson, Arizona	Correlation of Magnetic Field and X-ray Structure
G. A. Newkirk	High Altitude Observatory Boulder, Colorado	Coronal Structures
M. Oda	Tokyo Astronomical Observatory Tokyo, Japan	Solar Flare Studies
G. W. Pneuman	High Altitude Observatory Boulder, Colorado	Coronal Structures
J. A. Pounds and J. H. Parkinson	Univ. of Leicester Leicester, England	Rocket X-ray Spectroscopy
G. Righini	Arcetri Astrophysical Observatory Florence, Italy	Magnetic Field Separator and Chromospheric Models of X-ray Emitting Structures
E. Roelof	Univ. of New Hampshire Durham, N. H.	Interplanetary Extension of the Corona

Z. Svestk	Fraunhofer Institute Friburg, Germany	Type III Bursts in Active Regions
T. Takakura	Tokyo Astronomical Observatory Tokyo, Japan	Solar Flare Studies
J. Wilcox	Stanford University Palo Alto, Calif.	Solar Sector Structure
J. B. Zirker	University of Hawaii Honolulu, Hawaii	Coronal Observation of Active Regions/Forbidden Line Intensity Ratios

**COLLABORATIONS AFFILIATED
WITH EXPERIMENT S055**

Name	Institution	Investigation
J. M. Beckers	Sacramento Peak Observatory Sunspot, New Mexico	Chromophere Oscillations and Quiet Sun Extension of the Network into Corona
A. Gabriel	Aru Culham Laboratory Abingdon, U.K.	Line Identification and Abundances; 1973 Eclipse
D. N. Hall	Kitt Peak National Observatory Tucson, Arizona	Chromospheric Oscillations; Excitation of Helium in Network; Prominences and Active Regions
R. T. Hansen	High Altitude Observatory Boulder, Colorado	Coronal Transients
J. W. Harvey	Kitt Peak National Observatory Tucson, Arizona	Excitation of Helium in Network; Prominences and Active Regions
R. D. Hudson	Johnson Space Center Houston, Texas	Structure of Terrestrial Atmosphere
J. Jefferies	University of Hawaii Honolulu, Hawaii	Solar Prominences
C. Jordan	Aru Culham Laboratory Abingdon, U.K.	Line Identification and Abundances; 1973 Eclipse
W. C. Livingston	Kitt Peak National Observatory Tucson, Arizona	Solar Prominences
G. A. Newkirk	High Altitude Observatory Boulder, Colorado	Coronal Transients
R. W. Nicholls	York University Canada,	1973 Eclipse and Lunar Observations
R. Norton	National Oceanic & Atmospheric Admin- istration Boulder, Colorado	Structure of Terrestrial Atmosphere
F. Q. Orrall	Univ. of Hawaii Honolulu, Hawaii	Solar Prominences

G. Simon	Sacramento Peak Observatory Sunspot, New Mexico	Chromospheric Oscillations; Quiet Sun Extension of Network into Corona
C. Slaughter	Kitt Peak National Observatory Tucson, Arizona	Chromospheric Oscillations
R. J. Speer	Aru Culham Laboratory Abingdon, U.K.	1973 Solar Eclipse
E. Tandberg- Hanssen	High Altitude Observatory Boulder, Colorado	Solar Prominences
J. B. Zirker	University of Hawaii Honolulu, Hawaii	Solar Prominences

**COLLABORATIONS AFFILIATED
WITH EXPERIMENT S056**

Name	Institution	Investigation
L. Acton and R. Catura	Lockheed Research Laboratories Palo Alto, Calif.	Rocket X-ray Spectroscopy of Coronal Regions
R. Blake	Univ. of Chicago Chicago, Illinois	Rocket X-ray Spectroscopy of Coronal Regions
D. W. Datlowe and L. Peterson	Univ. of California San Diego, Calif.	Studies of Hard X-ray Flares with OSO-7
G. Elwert	University of Tuebingen Tuebingen, W. Germany	Structure of Active Regions
W. Glencross	Univ. College London London, England	Evolution of Active Regions
D. Intriligator	Calif. Inst. of Technology Pasadena, Calif.	Relationship between Coronal X-ray Structure, Interplanetary Sector Structure and Solar Wind
J. H. Parkinson and J. A. Pounds	Univ. of Leicester Leicester, England	Rocket X-ray Spectroscopy of Coronal Regions
D. Rust	Sacramento Peak Observatory Sunspot, New Mexico	
J. B. Zirker	University of Hawaii Honolulu, Hawaii	
A. B. Walker	Aerospace Corp. Los Angeles, Calif.	Rocket X-ray Spectroscopy of Coronal Regions

**COLLABORATIONS AFFILIATED
WITH EXPERIMENTS S082A & S082B**

Name	Institution	Investigation
C. Brown	Naval Research Laboratory Washington, D.C.	Atmospheric Model Calculations: Distribution of Ozone and NOx

G. Doschek	Naval Research Lab. Washington, D. C.	Flare Studies
B. Edlén	Lund, Sweden	Identification of XUV Emission Lines
A. Green	Univ. of Florida Gainesville, Florida	Solar Spectrum from 2000 Å to 3000 Å Relating to Ozone
F. Hudson	Sandia Corporation Albuquerque, N. M.	Atmospheric Model Calculations; Distribution of Ozone and NO _x
R. Kelly	Naval Post-Grad. School Monterey, Calif.	Identification of Lines in XUV Solar Spectrum
R. Kreplin	Naval Research Lab. Washington, D. C.	Comparison of SOLRAD and ATM Data
J. Linsky	University of Colorado Boulder, Colorado	Model Solar Atmosphere Calculations
M. Longmire	Western Kentucky University	Distribution of O ₂ in Earth Atmosphere from Observations of Schumann-Runge Band
R. Meier	Naval Research Lab. Washington, D. C.	Distribution of Hydrogen and Oxygen in Earth Atmosphere
D. Prinz	Naval Research Lab. Washington, D. C.	Distribution of Hydrogen and Oxygen in Earth Atmosphere
G. Simon	Sacramento Peak Observatory Sunspot, New Mexico	Chromospheric Network Studies Chromospheric Network Studies
Skriv Anek	AFCRL New Bedford, Mass.	XUV Flare Observation Studies
S. Tilford	Naval Research Lab. Washington, D. C.	Distribution of Ozone and NO _x and Atmospheric Model Calculations
J. Zirker	Univ. of Hawaii Honolulu, Hawaii	Flare and Active Region Studies