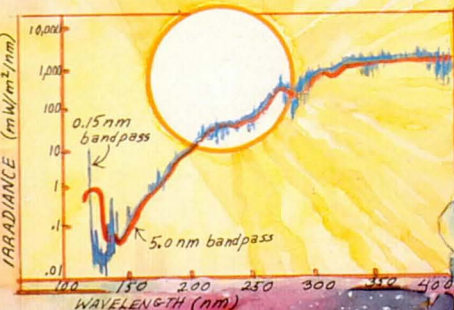
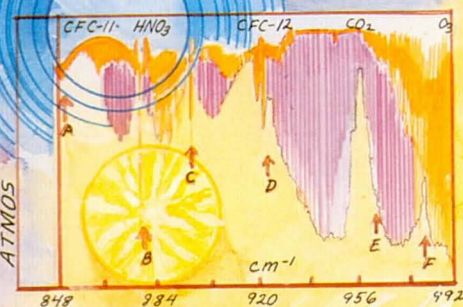


ATLAS 1: Encountering Planet Earth



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ATLAS 1: Encountering Planet Earth

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NASA

National Aeronautics and
Space Administration

Prologue: Our Perspectives of Earth

For thousands of years, people have peered outward from Earth toward a sky seemingly framed by land- and seascapes. This ever-present Earth reference gives us a sense of location, and we tend to think of the world as an immense and permanent entity whose visible horizons are our boundaries.

Apollo 8 astronauts on their way to the Moon were the first humans to look back on the planet and view the entire sunlit Earth at a glance. Photographs that they made from the vantage point of space changed forever our planet-bound perspective. Never before had we seen the crisp beauty of our blue-and-white world, like a star sapphire embedded in the vast blackness of space, or witnessed the whole Earth as a sparkling panorama of oceans, ice

caps, continents, and clouds — a unity without political boundaries.

For the first time, humans saw the smallness of Earth in comparison to the immensity of the Universe and marveled anew at the knowledge that diminutive Earth is the only planet in the solar system that supports life as we know it. We began to perceive Earth as a spaceship — a dynamic body moving through space and interacting with its surroundings.

For most of Spaceship Earth's history, living things have been passive passengers, subject to the vagaries of climate and geography. In the last 200 years, however, the human population has grown from an estimated 900 million to over 5 billion, and the effects of feeding, clothing, and housing so many people have literally changed the face of the planet. Today, the human race actively influences Earth's future through its choices about how natural resources will be managed; decisions made about pollution control, population growth, and land use now have global consequences.

Earth is our home. To protect it and ourselves, we must first understand the forces that create and maintain our life-sustaining environment. We must also become more aware of and understand the significance of our activities in relation to that environment. It is especially important to study Earth's atmosphere and its response to the impacts of a rapidly growing human population.

The atmosphere is Earth's sheltering mantle within which chemicals, magnetic forces, and sunlight interact and safeguard life on the planet. To understand this interplay of matter and energy, we must consider Earth from our two vantage points. Our historical, Earth-bound position allows us to monitor individual locales closely; the more recent global vista from space provides us the opportunity to observe Earth's atmosphere, land masses, seas, and lifeforms as one integrated system. Both perspectives will help us understand our world more fully so that we can be responsible guardians of Earth.







THE ATLAS 1 MISSION

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COLOR ILLUSTRATIONS

The Space Shuttle circles Earth, its payload bay open toward the planet. As the spacecraft enters orbital sunrise, scientific equipment points at the Sun through layers of the atmosphere. Some of these instruments measure the amount and characteristics of sunlight penetrating the atmosphere and reaching their sensors; another records solar energies for later comparisons with sunlight reflected by the atmosphere.

After the brief sunrise, the pilot maneuvers the Shuttle so that its payload bay points toward the Sun. During this orbital day, the spacecraft is commanded to make fine adjustments automatically, allowing its science instruments to observe the Sun and measure the total amount of radiant energy it produces. After solar observations, the pilot again changes the attitude of the orbiter, turning the bay toward space on the nightside of Earth. During these orbital nights, a very sensitive telescope focuses on galaxies and other objects that emit high-energy ultraviolet light, while another instrument searches for the faint lights produced when particles from magnetic fields high above Earth enter the upper atmosphere.

Later in the mission, the pilot rolls the spacecraft so that its payload bay is again toward Earth. In this attitude during the next several orbital nights, yet another instrument beams a stream of electrons into the atmosphere below and observes how the Shuttle and the atmosphere respond to the charged particles.

To place the ATLAS 1 payload in each of its required attitudes, STS-45 will have one of the most varied maneuvering plans of any Spacelab mission.



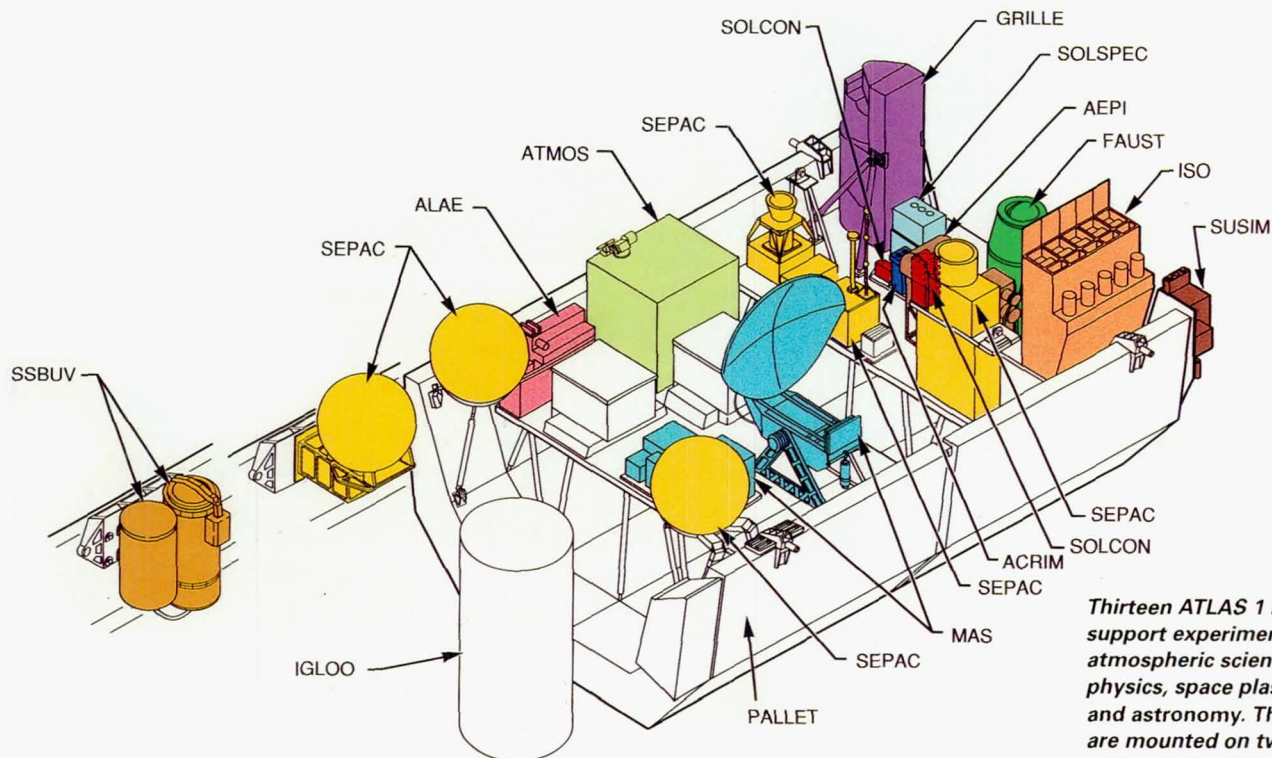
The mythological Greek god Atlas is an appropriate symbol for the first Atmospheric Laboratory for Applications and Science mission. The science conducted during the flight is in support of our planet's environmental health. A figure of Atlas holding a globe on his shoulders was first used by Gerardus Mercator, a Flemish geographer and mapmaker, in the late 16th century. The word atlas later came to be applied to collections of maps and charts.

Several National Aeronautics and Space Administration (NASA) science programs examine the dynamic balance of sunlight, atmosphere, water, land, and life that governs Earth's environment. Among these is a series of Space Shuttle-Spacelab missions, named the Atmospheric Laboratory for Applications and Science (ATLAS). During the ATLAS missions, international teams of scientists representing many disciplines combine their expertise to seek answers to complex questions about the atmospheric and solar conditions that sustain life on Earth.

To understand the nature of Earth, we must study our planet in the context of its surroundings. We know that Earth's atmosphere and the near-Earth environment change in response to external influences, such as solar activity, magnetic storms, and barrages of galactic and cosmic radiation, as well as to internal disturbances, such as dust and ash deposited in the atmosphere by clearing and burning activities and volcanic eruptions. We also know that certain chemical by-products of manufacturing and agribusiness operations enter the atmosphere, where they may alter the established balance. The ATLAS

program specifically investigates how Earth's middle and upper atmospheres and climate are affected both by the Sun and by products of industrial and agricultural activities on Earth.

ATLAS 1 is the first in a series of missions that will contribute substantially to the existing library of information about Earth. The mission's science operations signal the beginning of a comprehensive and systematic collection of data that will help establish benchmarks for atmospheric conditions and the Sun's stability. The investigations should also help scientists determine how humans influence the atmosphere; thus, we may be better able to distinguish those factors that are beyond our control from those we impose upon it (anthropogenic effects). Other data will increase our understanding of astronomical objects and phenomena that emit high-energy radiation. Several ATLAS 1 experiments that study the atmosphere and the Sun are also scheduled for subsequent ATLAS missions, when they will gather additional information to refine models of how energy from the Sun reacts with Earth's atmosphere.



Thirteen ATLAS 1 instruments support experiments in atmospheric sciences, solar physics, space plasma physics, and astronomy. The instruments are mounted on two Spacelab pallets in the Shuttle payload bay and on the starboard wall of the bay just forward of the pallets.

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The ATLAS 1 instruments are attached to the Spacelab pallets at Kennedy Space Center.

Science Payload

During the ATLAS 1 mission, scientists from the United States, Belgium, the Federal Republic of Germany, France, Japan, The Netherlands, Switzerland, and the United Kingdom will conduct 14 complementary and compatible investigations representing four disciplines: atmospheric science, solar science, space plasma physics, and ultraviolet astronomy. The experiment teams will study the chemistry, physics, and dynamics (movements) of the middle and upper atmosphere; measure the Sun's energy that arrives in Earth's environment; study how magnetic fields and electrified gases link the Sun and Earth; and examine sources of ultraviolet radiation in the Milky Way and other galaxies. Exploring different phenomena, each investigation will make its particular contribution to our understanding of the interactive nature of the Universe.

Thirteen investigations study the Sun-Earth system, focusing on the middle and upper atmosphere. By analyzing each experiment's results and comparing these with data from related studies, scientists can develop a more thorough understanding of Earth's atmospheric features and their variations. Another experiment, an astronomy investigation, collects faint ultraviolet light from distant sources. As they examine this radiation, astronomers will learn more about physical conditions in other regions of space.

The ATLAS missions use elements of Spacelab, a laboratory built by the European Space Agency and installed in the Shuttle's payload bay. The laboratory has several components that can be flown together or separately. The ATLAS 1 instruments will be mounted on Spacelab pallets, two U-shaped platforms that are exposed directly to space when the Shuttle

ATLAS 1 Instruments and Their Spaceflight Chronologies

Instrument	Ground-Based Observations	Rocket, Balloon, Satellite	OSS-1	Spacelab 1 1983	Spacelab 2 1985	Spacelab 3 1985	Future ATLAS Missions
Atmospheric Science							
• Atmospheric Lyman-Alpha Emissions (ALAE)*				■			
• Atmospheric Trace Molecule Spectroscopy (ATMOS)	■	■				■	■
• Grille Spectrometer (Grille)*		■		■			
• Imaging Spectrometric Observatory (ISO)*	■			■			
• Millimeter-Wave Atmospheric Sounder (MAS)†				■			■
• Shuttle Solar Backscatter Ultraviolet (SSBUV) Spectrometer‡		■					■
Solar Science							
• Active Cavity Radiometer Irradiance Monitor (ACRIM)		■		■			■
• Measurement of the Solar Constant (SOLCON)				■			■
• Solar Spectrum from 180 to 3,200 Nanometers (SOLSPEC)				■			■
• Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)			■		■		■
Space Plasma Physics							
• Atmospheric Emissions Photometric Imaging (AEPI)*	■			■			
• Space Experiments with Particle Accelerators (SEPAC)*				■			
Ultraviolet Astronomy							
• Far Ultraviolet Space Telescope (FAUST)*		■		■			

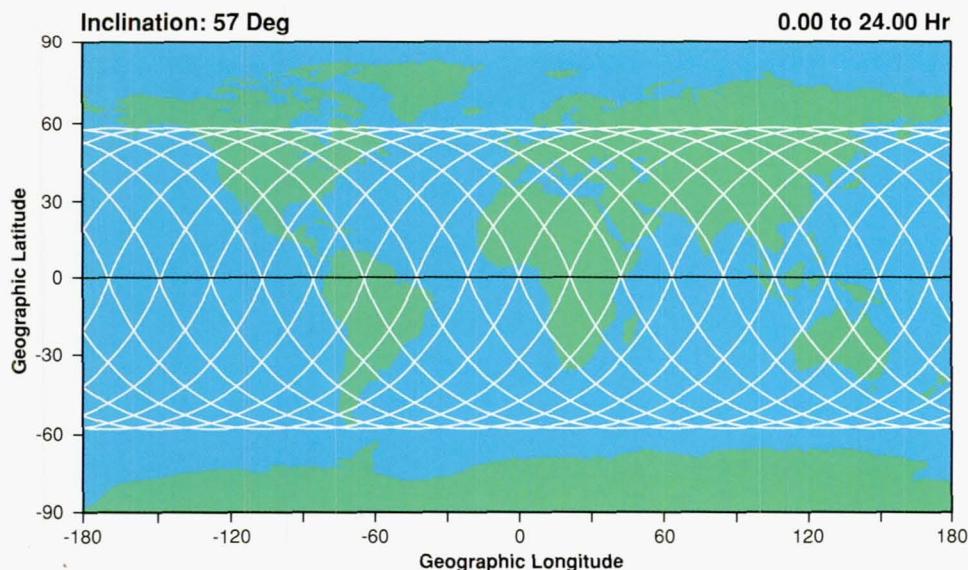
* These instruments are making their last Spacelab flights on ATLAS 1.

† A Spacelab 1 instrument was the precursor to the MAS.

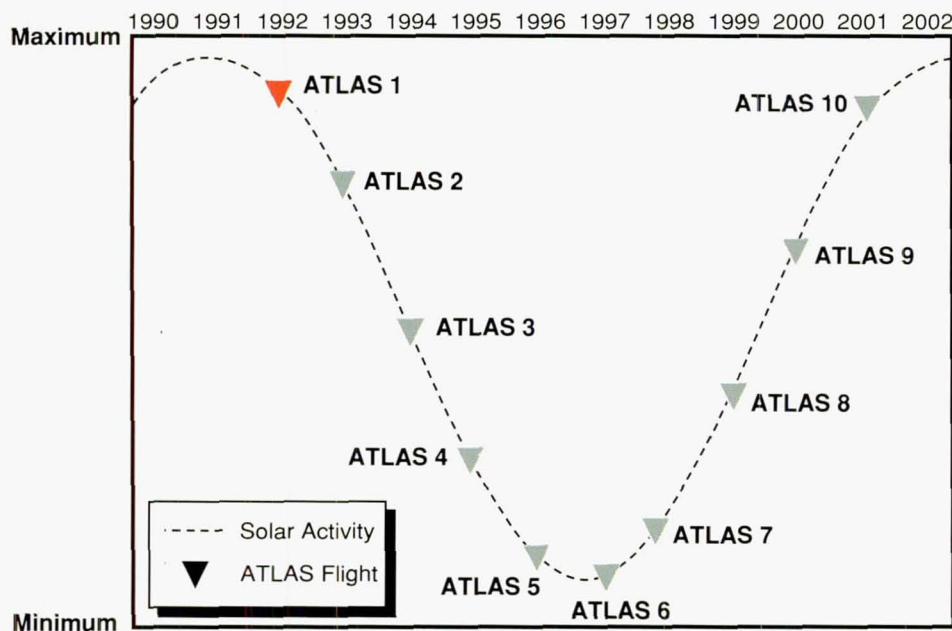
‡ SSBUV is co-manifested with the ATLAS 1 mission and will gather data that will enhance the atmospheric and solar investigations. SSBUV has flown on STS-34, STS-41, and STS-43 in 1989, 1990, and 1991, respectively.

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The ATLAS 1 orbital altitude and inclination afford scientists a variety of observation points from which to study the atmosphere, the Sun, and astronomical targets. White lines on this map of the planet indicate the path of the orbiter over Earth during one 24-hour period.



The ATLAS series of missions, spanning a complete solar cycle, will measure changes in Earth's atmosphere related to changes in the Sun's energy output.

bay doors are open. A cylindrical, pressurized container, called an igloo, will house the instruments' power supply, a command and data handling system, and a temperature control system.

Most of the ATLAS 1 payload has flown on previous Spacelab missions. Data collected during these earlier missions improved our scientific understanding of interactions among the Sun, Earth, and the atmosphere and helped researchers develop the more sophisticated ATLAS 1 experiments and equipment.

Flight Characteristics

The ATLAS 1 orbit follows a path that reaches 57 degrees above and below the equator — about as far north as Juneau, Alaska, and a little farther south than Tierra del Fuego, Argentina. This route and the length of the mission (7 to 10 days) allow scientists to collect data from most of the atmosphere during orbital day, night, sunrise, and sunset at latitudes extending from the tropics to the auroral regions and over diverse geographies (rainforests and deserts, oceans and land masses). When the crew changes the Shuttle's orientation, instruments can also view astronomical targets and observe atmospheric phenomena occurring in the night sky.

The ATLAS Program

No single set of atmospheric and solar measurements made during one brief 7- to 10-day spaceflight is sufficient to characterize the ever-changing environment surrounding Earth. To understand the constitution of the atmosphere under a variety of conditions, for instance, scientists must gather comprehensive data over a longer period of time. To better define the Sun's effect on the atmosphere, the period for studies should span at least a complete 11-year solar cycle. To meet these criteria, a series of 10 ATLAS missions is scheduled at 12- to 18-month intervals over the next decade. Flying at various times of the year to record seasonal differences in atmospheric characteristics, each mission will build on the results of earlier flights and of other missions, such as the Upper Atmosphere Research Satellite. In this way, scientists can compile a more detailed picture of the behavior of Earth's

atmosphere, including its responses to solar variations.

The ATLAS missions capitalize on the Space Shuttle's ability to carry a large payload into orbit, position highly calibrated experiments in orbital locations that are beneficial for data gathering, and return the hardware to be used again. Scientists can thus analyze data, pinpoint areas of research that require further exploration, and design advanced studies in light of answers found, discoveries made, mysteries encountered, and questions raised. Scientists and engineers can then prepare and recalibrate instruments to support the next generation of experiments. The ability to recalibrate sensitive instruments after each mission so that the data they collect are consistent from one flight to the next is a major advance that enhances space-based investigations. If necessary, the instruments can also be refined, refurbished, and redesigned.

Because the Shuttle can orbit Earth for a week or more, instruments aboard the orbiter are able to gather data continually or serially under diverse conditions and at different times of day and night. By comparing these data, scientists can uncover new information about the particular phenomena under investigation.

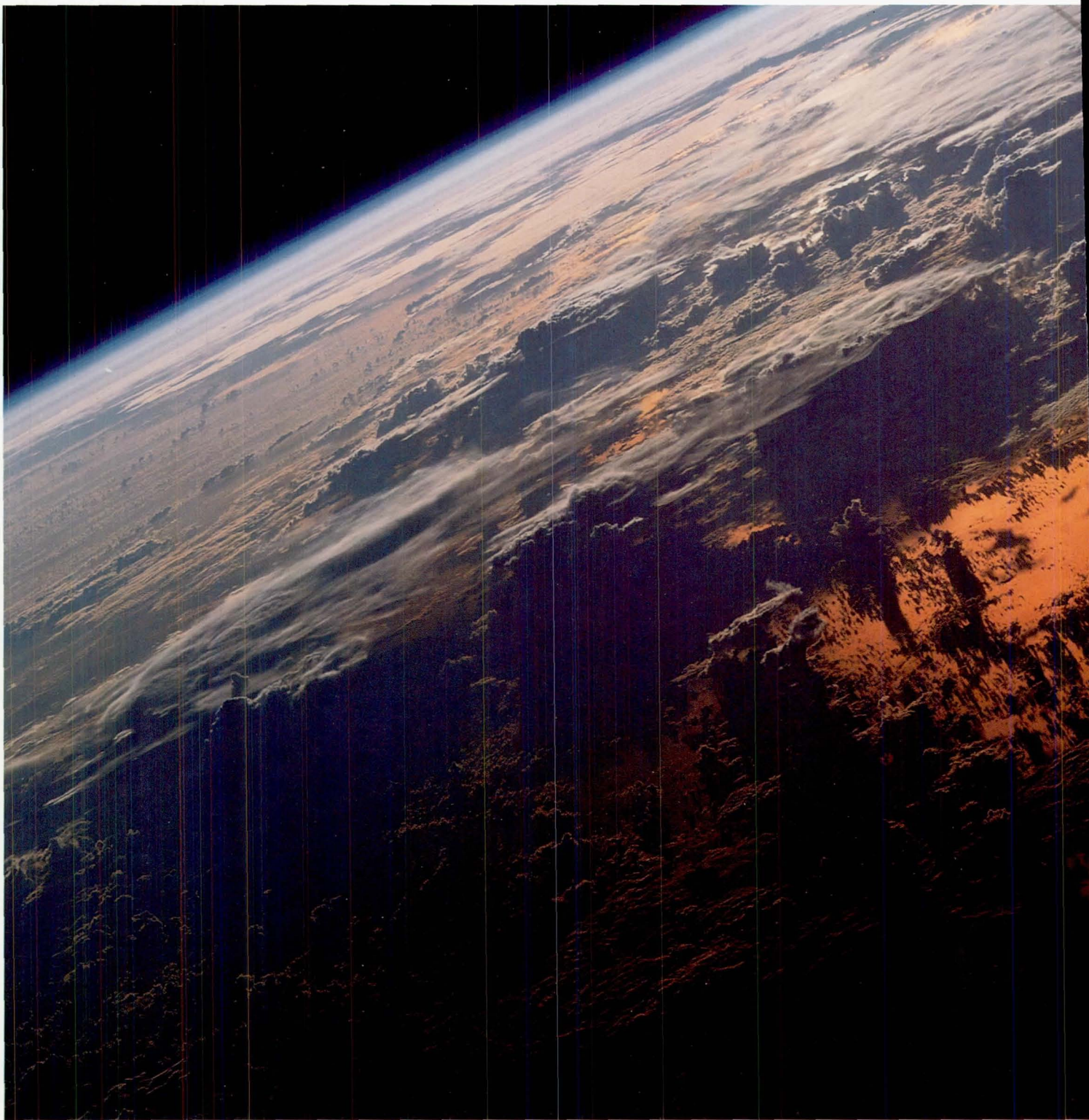
The Shuttle also allows people to work in space, a boon to many science investigations and a necessity for others. Acting as a team, researchers on the ground and crew members in orbit can perform science operations, take advantage of experiment opportunities as they arise, and, if necessary, make selective repairs or adjustments to science instruments.

In addition, the Shuttle's orbit provides advantageous viewing locations from which instruments can observe the atmosphere, the Sun, and astronomical targets. For the ATLAS experiments, the ability to look upon Earth from high in the atmosphere is an opportunity to study many physical processes and chemical reactions that are not visible from Earth. The orbital altitude also provides a view into the Universe that is unobstructed by the atmosphere, a feature crucial to astronomy observations on ATLAS 1.

The ATLAS program is part of the U.S. Global Change Research Program, one of the largest scientific undertakings of all time. The Global Change Research Program, a unified study of the planet from its deep interior core to the outermost atmospheric regions, involves scientists from the many Earth System Science disciplines that investigate terrestrial, climatic,

ATLAS 1 Mission Facts

Flight number	STS-45
Length of mission	7 to 10 days
Launch	1992
Launch site	Kennedy Space Center, Florida
Prime landing site	Kennedy Space Center, Florida
Shuttle altitude	296 km (183 mi)
Orbital inclination	57 degrees to the equator
Shuttle attitudes	payload bay toward Sun; payload bay toward Earth; payload bay toward space
Number of crew members	7



*Investigations
conducted during
the ATLAS missions
will improve our
understanding of
Earth's planetary
evolution.*

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atmospheric, and solar interactions. The ATLAS missions will increase scientific knowledge of the Sun and of the middle and upper regions of Earth's atmospheric envelope. Data amassed by the ATLAS experiments will help scientists compile a more comprehensive portrait of the influence of the Sun on the atmosphere.

ATLAS investigations will collect data in concert with an array of other experiments in space and on the ground. Information gathered during successive ATLAS flights will provide a long-term chronology for identifying and tracking trends or changes in atmospheric composition, solar output, and other conditions affecting Earth.

Because much of the ATLAS equipment will be calibrated before and after each flight to ensure accurate measurements, the instruments can be used during the missions to cross-calibrate related equipment on Earth and aboard other spacecraft operating at the same time. By comparing ATLAS data with complementary information from these other instruments, scientists can validate experiment data and confirm their findings.

As part of NASA's ongoing quest for knowledge about Planet Earth, the ATLAS missions will help scientists and engineers prepare future experiments and equipment. Based on data and operational experience gained from the ATLAS flights, researchers will design investigations that make continuous observations, thus providing significant opportunities to increase our understanding of the phenomena that influence our home planet.

The ATLAS missions, in concert with other NASA programs, will gather information critical to our understanding of Earth's atmosphere. For example, the first missions in the ATLAS series will fly while the Upper Atmosphere Research Satellite (above) is in orbit. The complementary investigations of these two programs will not only add to our store of knowledge about the atmosphere but will also gather data needed to plan future atmospheric research.

ATLAS and the Mission to Planet Earth

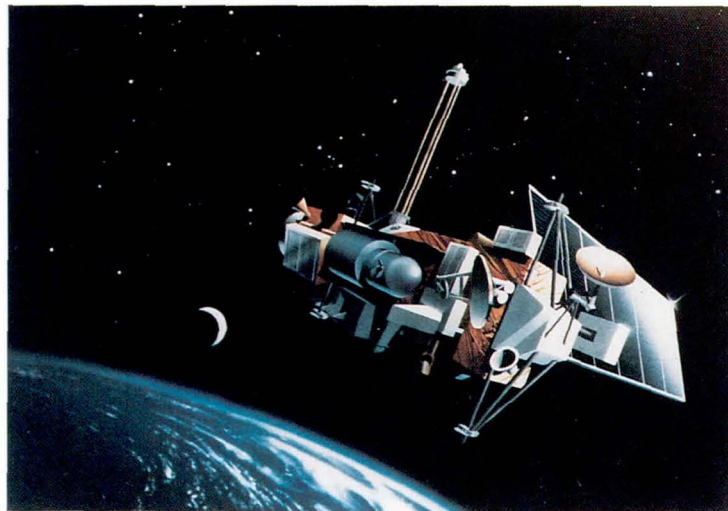
**Is Earth experiencing global warming?
Is the hole in the ozone layer expanding?
How do we determine and understand the causes of these changes? Are they reversible?
What are their implications for humans?**

Seeking answers to these and other questions, the government-wide U.S. Global Change Research Program will extensively study short- and

the data gathered will help scientists distinguish between natural influences and the impact of human activities on the environment. With this

knowledge, we may be able to identify changes that suggest shifts in the balance of the components of our environment so that decision makers can devise appropriate strategies for slowing or halting those changes that are harmful to our planet.

Launched in 1991, the first

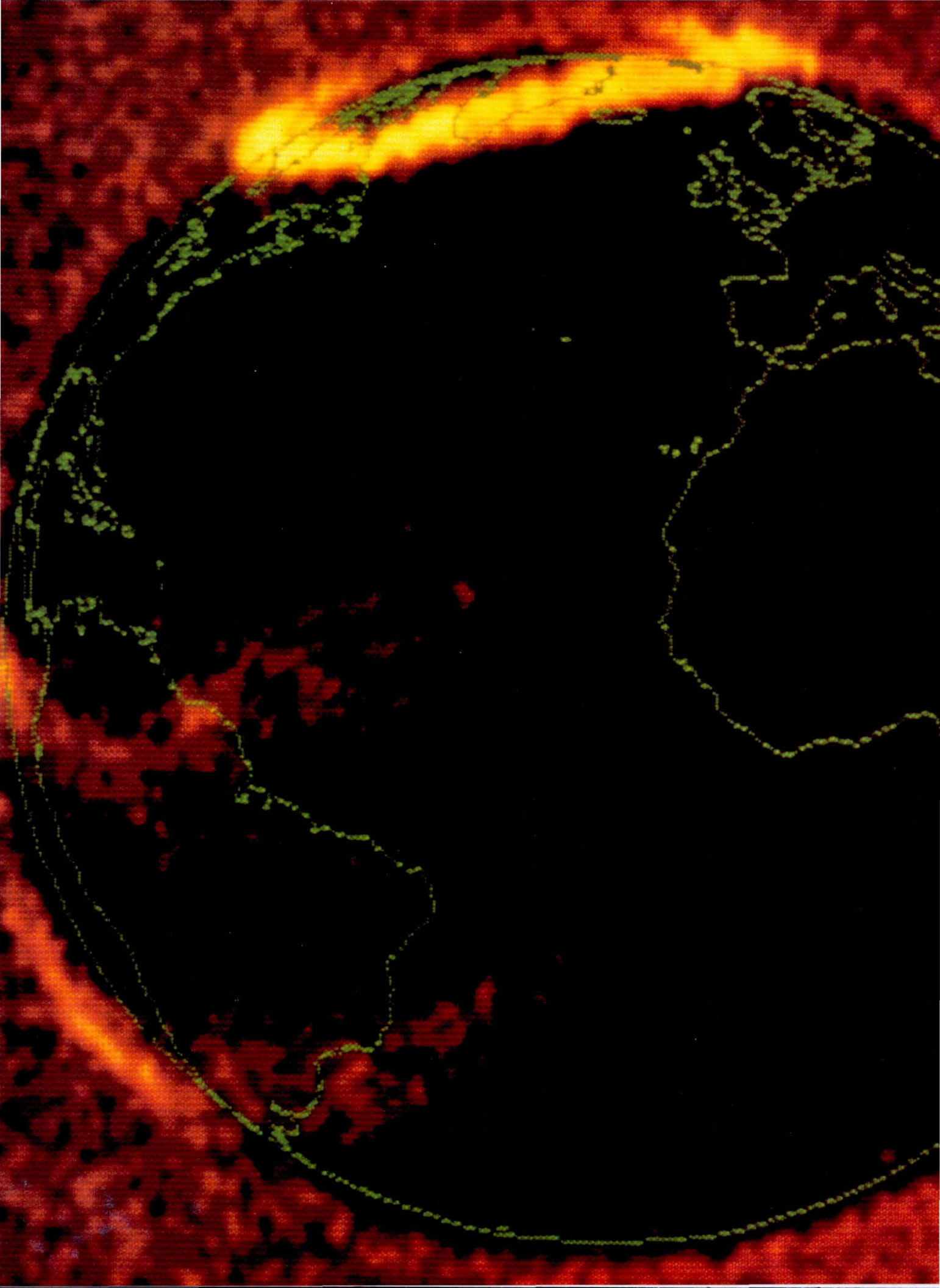


long-term variations in conditions that are critical to our understanding of the planet's environment. Mission to Planet Earth is NASA's contribution to the Global Change Research Program, and ATLAS is an essential part of this effort.

For Mission to Planet Earth, spacecraft will place instruments in Earth orbit, the only place where they can monitor the planet on a global scale for long periods of time. Mission to Planet Earth satellite instruments will make long-term, worldwide measurements, observing the interactions of large systems, such as the atmosphere, oceans, and land masses. Coordinated with aircraft and ground observations,

Mission to Planet Earth satellite, the Upper Atmosphere Research Satellite, is now studying temperatures, winds, chemical composition, and other conditions in the upper atmosphere. Smaller satellites and their instruments, such as the Total Ozone Mapping Spectrometer, will follow. Later, the Earth Observing System, a series of polar-orbiting satellites carrying groups of related instruments, will provide simultaneous and long-term observations of related environmental systems.

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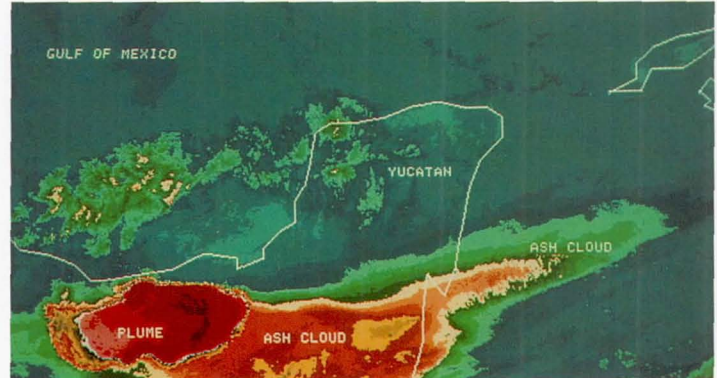
Protected by the Atmosphere

Earth is engulfed in an envelope of gases, electrically charged atoms and molecules, and magnetic fields, but from the ground, we can only catch glimpses of this physical tangle that surrounds us.

Our most obvious clues to its presence are weather in the lowest part of our atmosphere, blue skies, multicolored sunsets and sunrises, and twinkling stars. Most of the web of energy — created when radiation from the Sun interacts with chemicals in the atmosphere and with powerful magnetic forces emanating from Earth's interior — is invisible to us. From space, however, we can use instruments that are many times more sensitive than the human eye to watch this activity and probe the secrets of the atmosphere.

With sensitive instruments located high in Earth's atmosphere, scientists can produce images of upper atmospheric activity that cannot be seen from the ground. This view of Earth, for instance, imaged in ultraviolet light (118 to 165 nm) by an auroral imaging photometer aboard the Dynamics Explorer 1 spacecraft in 1982, shows the active aurora over the polar regions. In the lower left, the photograph reveals arcs produced by bands of atomic oxygen that surround the planet's tropical regions. The diffuse glow around the planet is created when Lyman-alpha radiation from the Sun is scattered by atomic hydrogen in Earth's upper atmosphere. Earth's limb and coastal outlines are overlaid on the image.

Photograph:
L.A. Frank and J.D. Craven,
University of Iowa.

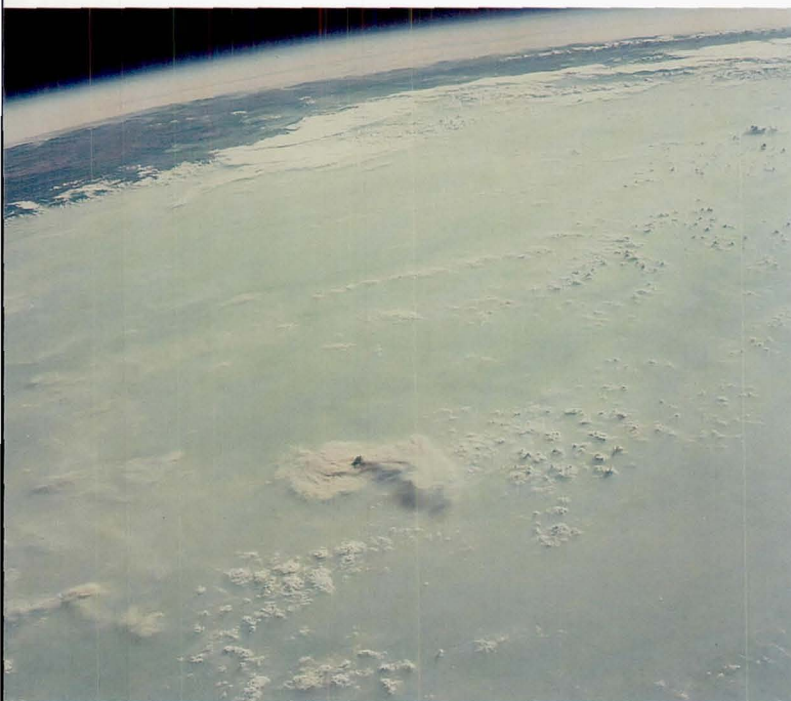


Earth's atmosphere is a precious natural resource: it soaks up radiant energy, recycles water and other chemicals, and acts in concert with electrical and magnetic forces to absorb charged particles from the Sun. As the primary conduit of energy from the Sun, the atmosphere both nurtures and sustains life on Earth. Without this protective and energizing blanket, Earth would become barren of life as we know it.

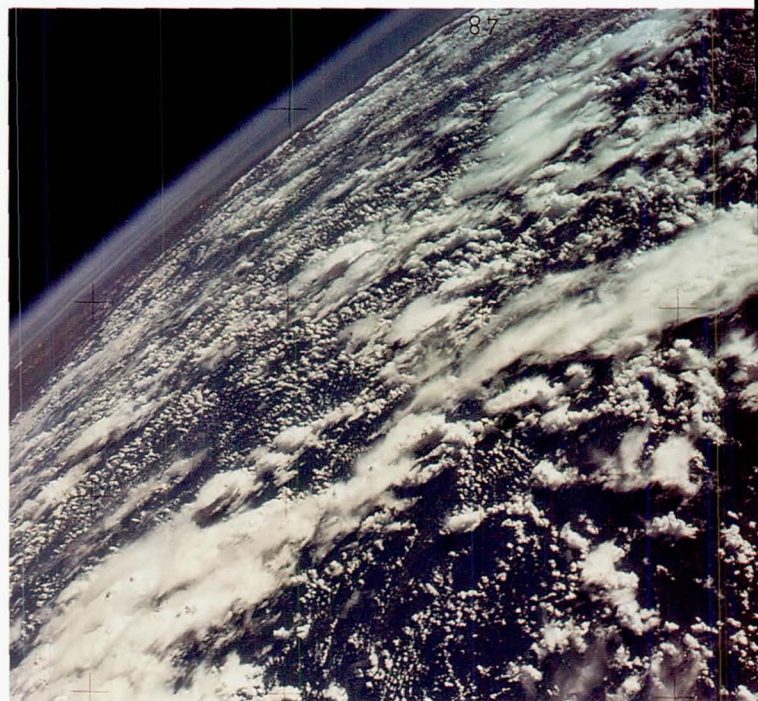
Earth's atmosphere, composed mainly of nitrogen and oxygen, with traces of carbon dioxide, water vapor, and other gases, acts as a buffer between our planet and the Sun. Its chemistry and physics determine the amount and energies of sunlight that reach Earth's surface. It absorbs most of the more energetic portions of solar radiation, which are harmful to living things, while allowing radiation that warms and energizes the planet to reach Earth's surface. Like a blanket, the atmosphere also holds in some of the infrared (thermal) radiation emitted by Earth's surface and, under ideal conditions, works to maintain the relatively mild climatic conditions we enjoy today.

The atmosphere also recycles chemicals and contributes to the efficiency of natural systems that sustain life. Some chemicals find their way into the atmosphere from Earth. Volcanoes, for example, spew ash and gases formed deep within the planet into the air. There, they mix with other chemicals, form aerosols

Volcanic activity is one of the natural events that influences the world's climate. In 1982, a Mexican volcano (El Chichón) erupted, and its extensive ash clouds and dust lowered global air temperatures as much as 0.55 °C (1 °F) for 2 to 3 years. This false-color thermal infrared image of the eruption, made by the NOAA-6 satellite, shows the ash cloud that carried tons of dust and sulfuric acid more than 10 miles into the atmosphere.



This 1988 picture, taken aboard STS-26, shows how burning of the Amazon rain forests has blanketed the region with smoke.



A photograph of the same region, made in 1973 during a Skylab mission reveals a clear lower atmosphere.

(small airborne particles), and return to Earth's surface. Burning and construction activities also contribute to the amount of particulate matter in the atmosphere, as do sea spray and natural wind erosion. Many elements and compounds — both those that occur naturally and those that are produced by industrial and agricultural processes — move between Earth's surface and the atmosphere, taking part in chemical reactions in both regions. These include water vapor, carbon monoxide, carbon dioxide, nitrogen and nitrogen oxides, oxygen, methane, sulfur compounds, and other chemical species.

Today, scientists are concerned that significant changes in the chemistry of Earth's atmosphere may enhance the natural process that warms our planet. This process, known as the greenhouse effect, keeps Earth's temperatures above what would be expected for the planet if it had no such atmosphere. If the greenhouse effect is intensified and Earth's average temperatures change, a number of plant and animal species — including humans — might be threatened with extinction.

Since the beginning of the Industrial Revolution, the effects of human activities on the atmosphere have increased

significantly. As industries became more dependent on the burning of fossil fuels (coal, oil, and gas) for power, the natural recycling of carbon between the atmosphere and Earth's surface was altered. Burning releases billions of tons of carbon contained in these fossil fuels much faster than natural processes do. At the same time, the destruction of forests and the expansion of deserts have reduced the amount of vegetation available to remove carbon from the atmosphere through photosynthesis. Consequently, concentrations of carbon dioxide, a minor but very important constituent of the atmosphere, that had remained fairly constant since the end of the last ice age (10,000 years ago) have risen by about 35 percent over the last 300 years (from 260 to 350 parts per million). The present concentration level is above the highest recorded in our geophysical past. Carbon dioxide traps infrared radiation, and increased amounts in the atmosphere may enhance the greenhouse effect, thus contributing to the warming of Earth's lower atmosphere.

Although less abundant in the atmosphere than carbon dioxide, methane, a natural product of digestion and biological decay in bogs and swamps, is more effective

at absorbing infrared radiation. Its atmospheric concentrations have increased from 700 to 1,700 parts per billion in the last 3 centuries. Methane's increase is believed to be a result of fossil fuel burning, the growing number of acres dedicated to rice growing and landfills, and increasing populations of cattle, which produce methane during digestion. At present however, our understanding of the causes for this increase is incomplete.

In addition to carbon dioxide and methane, other chemicals present in the atmosphere in only small concentrations produce effects far greater than just their abundance would suggest. The roles of many of these trace molecules are not understood as well as those of the more abundant constituents. To define the influence of each species, scientists must determine its concentration and the chemical reactions in which it participates.

To understand how the atmosphere evolved to support life on Earth, how it is maintained, and how it continues to change, we must better comprehend its complex workings. The analysis of data gathered by ATLAS 1 atmospheric science instruments will help scientists characterize the dynamic nature of the protective blanket that makes life on Earth possible.

The Greenhouse Effect

Earth's atmosphere acts like a greenhouse, warming our planet in much the same way that an ordinary greenhouse warms the air inside its glass walls. Like glass, the gases in the atmosphere let in light yet prevent heat from escaping. This natural warming of the planet is called the greenhouse effect.

Greenhouse gases — carbon dioxide, methane, nitrous oxide, and others — are transparent to certain wavelengths of the Sun's radiant energy,

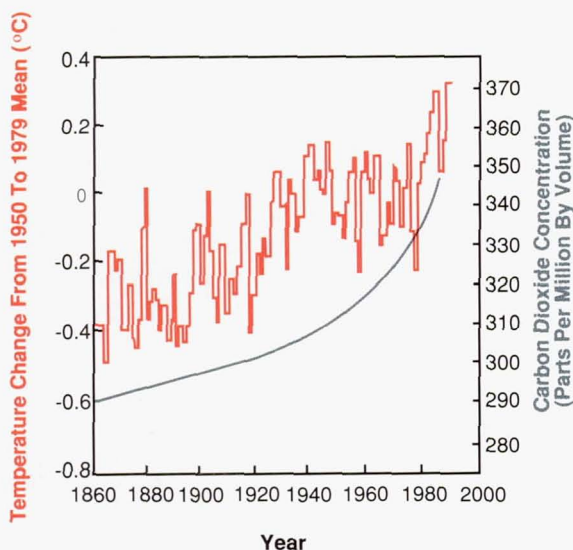
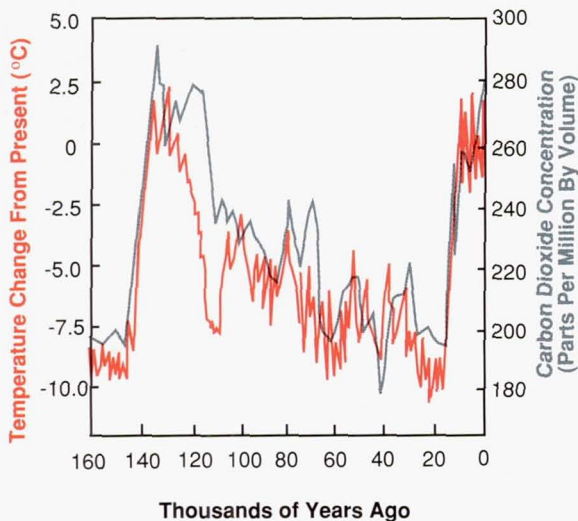
allowing them to penetrate deep into the atmosphere or all the way to Earth's surface. Clouds, ice caps, and particles in the air reflect about 30 per-

cent of this radiation, but oceans and land masses absorb the rest, then release it back toward space as infrared radiation. The greenhouse gases and clouds effectively prevent some of the infrared radiation from escaping; they trap the heat near Earth's surface where it warms the lower atmosphere. If this natural barrier of atmospheric gases were not present, the heat would escape into space, and Earth's mean global temperatures could be as much as 33 °C cooler [about -18 °C (-0.4 °F) as opposed to 15 °C (59 °F)].

Over the centuries, the concentration of greenhouse gases, especially carbon dioxide, has fluctuated naturally, and the greenhouse effect has moderated the temperature of Earth accordingly. Now, our efforts to provide for Earth's growing population are releasing greenhouse gases into the atmosphere at rates greater than any other phenomena. As we burn fossil fuels and clear forests, for example, we increase the level of carbon dioxide in the atmosphere. Our gasoline-dependent transportation systems also enhance the greenhouse effect, contributing to the concentrations of low-level ozone, produced when sunlight interacts with pollutants from vehicle exhaust.

What impact are these human activities and others having on the greenhouse effect? While there is consensus among scientists that the increase in greenhouse gas concentrations will create a rise in the mean global temperature, the science community disagrees over whether global warming has been observed yet and over the actual time frame and consequences of the warming trend. Will the warming take place gradually over centuries or rapidly over decades? How will an enhanced greenhouse effect change established ecosystems and regional agriculture? Will plant populations be able to keep pace with climatic changes and adapt to different growing conditions? As land ice melts, how much will ocean levels rise, and how many people will be displaced from today's coastal areas? What will be the effect on other animal populations as rising oceans flood their fertile breeding grounds and as increasing numbers of people encroach on already dwindling habitats?

Knowledge gained during the ATLAS missions will help answer questions about changes occurring in the atmosphere and will prepare scientists to advise citizens and policymakers worldwide as they evaluate the steps necessary to conserve and protect our atmosphere and, thus, ourselves and our plant and animal co-travelers on Spaceship Earth.



The Thermosphere

Temperatures in the thermosphere [85 to about 600 km (53 to 372 mi)] soar as the Sun's energy (at wavelengths of less than 120 nm) ionizes atoms and molecules and spawns a variety of chemical reactions. Here, molecular oxygen, molecular nitrogen, and atomic oxygen absorb extreme ultraviolet wavelengths (below 102.7 nm). Reactions that take place in the thermosphere, where temperatures range to 1,727 °C (3,141 °F), occur much faster than they would under the lower temperature conditions closer to Earth.

The Mesosphere

In the mesosphere [50 to 85 km (31 to 53 mi)], temperatures drop from -3 °C (27 °F) in lower altitudes to -93 °C (-135 °F) at higher altitudes. The mesosphere and the region immediately below it, the stratosphere, are referred to as the middle atmosphere. Mesospheric chemistry is dominated by atoms and molecules in two energy states. Species that exist at conventional energy levels are referred to as ground-state atoms and molecules; their excited forms contain higher than usual energies. Excited atoms and molecules arise from photochemical reactions and are reservoirs of energy. The excited species, not easily sustained at lower altitudes, play a major role in mesospheric chemistry. Some species can stay in excited states for minutes or even hours, rather than fractions of seconds. In these states, the excited species may emit characteristic wavelengths of light (signatures) from which it is possible to determine their chemical concentrations. They may also take part in chemical reactions that emit typical signatures.

The Stratosphere

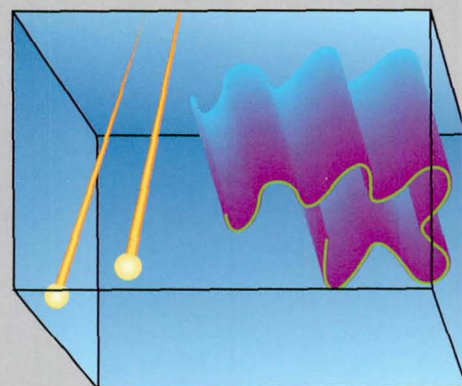
The stratosphere extends from just above the troposphere to roughly 50 km (31 mi). It is a dry layer where temperatures steadily increase from -52 to -3 °C (-62 to 27 °F). In the stratosphere, chemicals are in their molecular and atomic forms. Here, temperature and chemistry are primarily determined by concentrations of ozone, a form of oxygen that absorbs and scatters ultraviolet sunlight. Stratospheric temperature, for example, peaks at about 50 km (31 mi), the altitude of the ozone layer where the most ultraviolet radiation is absorbed.

The Troposphere

The atmospheric layer nearest Earth's surface is the troposphere, which extends to altitudes of about 8 to 15 km (5 to 9 mi). The troposphere is the densest layer of the atmosphere and the region that contains essentially all of Earth's weather. In this region, temperatures generally decrease as altitude increases. Visible sunlight passing through the atmosphere heats Earth's surface, while gases in the lower atmosphere trap infrared radiation reflected by the planet. These conditions produce a temperature profile that is warmer at Earth's surface and cooler at progressively higher altitudes. Within the troposphere, average temperatures drop from about 17 °C (62 °F) at sea level to about -52 °C (-63 °F) at the tropopause, the boundary between the troposphere and the stratosphere. Molecules of nitrogen and oxygen make up the bulk of the troposphere. A variety of other constituents, including ozone, nitrogen oxides, and carbon monoxide, are found in the troposphere in lesser and varying amounts.

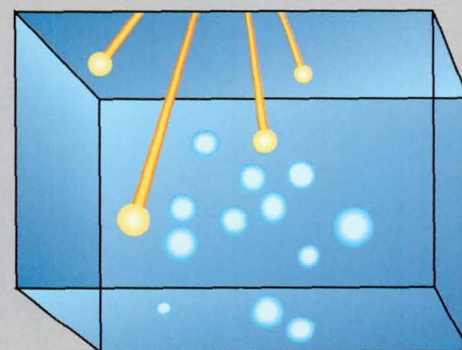
THERMOSPHERE

85 to 600 km
(53 to 372 mi)
Meteors; Auroras



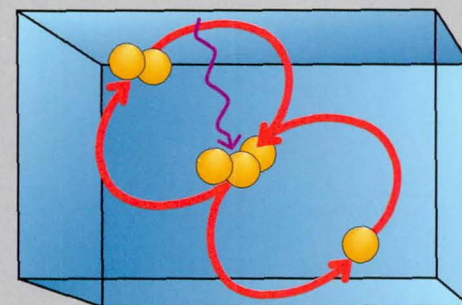
MESOSPHERE

50 to 85 km
(31 to 53 mi)
Meteors;
Excited and
Ground-state
Molecules



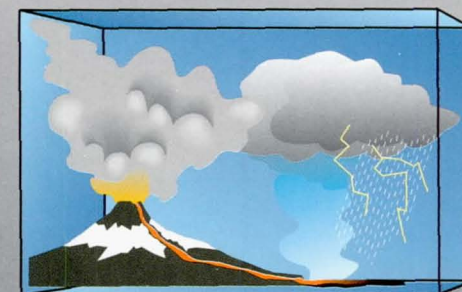
STRATOSPHERE

15 to 50 km
(9 to 31 mi)
Ozone Layer;
Middle Atmospheric
Heating



TROPOSPHERE

0 to 15 km
(0 to 9 mi)
Weather;
Chemical
Transport

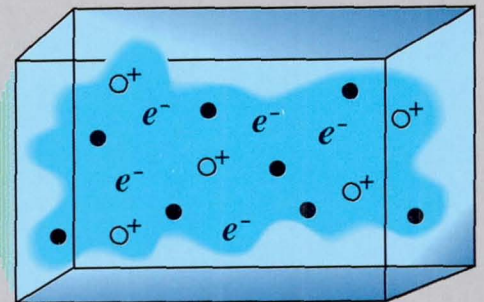
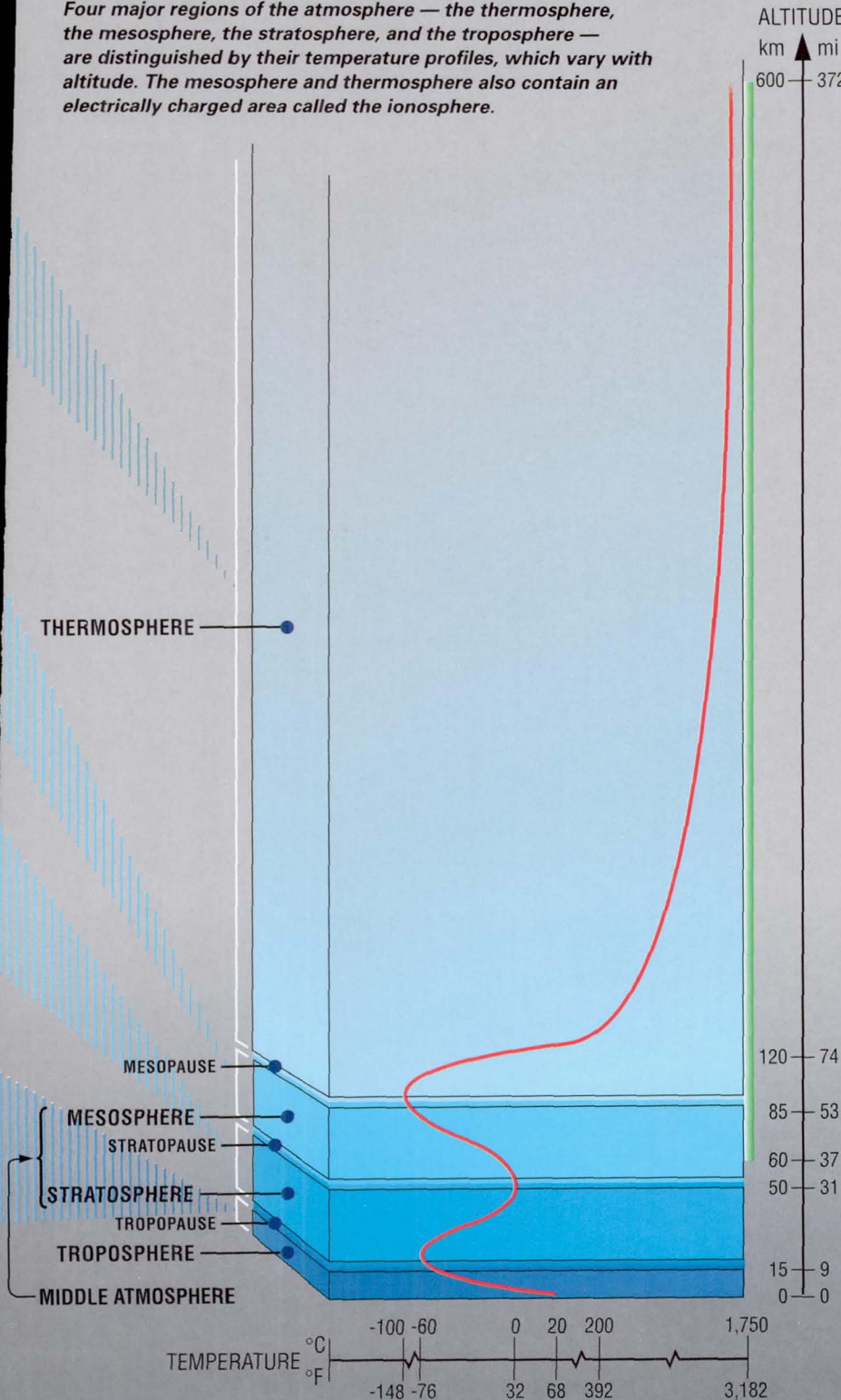


Regions of the atmosphere are distinguished and described by chemical makeup, temperature, electromagnetic characteristics, and vacuum conditions. The ATLAS 1 atmospheric experiments investigate the layers that are defined by their temperature characteristics, which result from the interaction of sunlight with the chemicals in the particular regions.

Four major regions of the atmosphere — the thermosphere, the mesosphere, the stratosphere, and the troposphere — are distinguished by their temperature profiles, which vary with altitude. The mesosphere and thermosphere also contain an electrically charged area called the ionosphere.

The Ionosphere

Upper regions of the atmosphere [above about 60 km (37 mi)] are also characterized by significant amounts of charged gases, called plasmas, that move across atmospheric borders. This region, called the ionosphere, may extend to altitudes of about 1,000 km (620 mi), depending on time of day and magnetic conditions. The range and movement of plasmas at higher altitudes are also influenced by Earth's magnetic fields and a high-speed wind of charged particles (electrons and protons) from the Sun, called the solar wind.



IONOSPHERE

60 to 600 km
(37 to 372 mi)
UV light strips electrons
from neutral atoms and/or molecules.

O⁺ = Ionized Atom
● = Neutral Atom
e⁻ = Free Electron

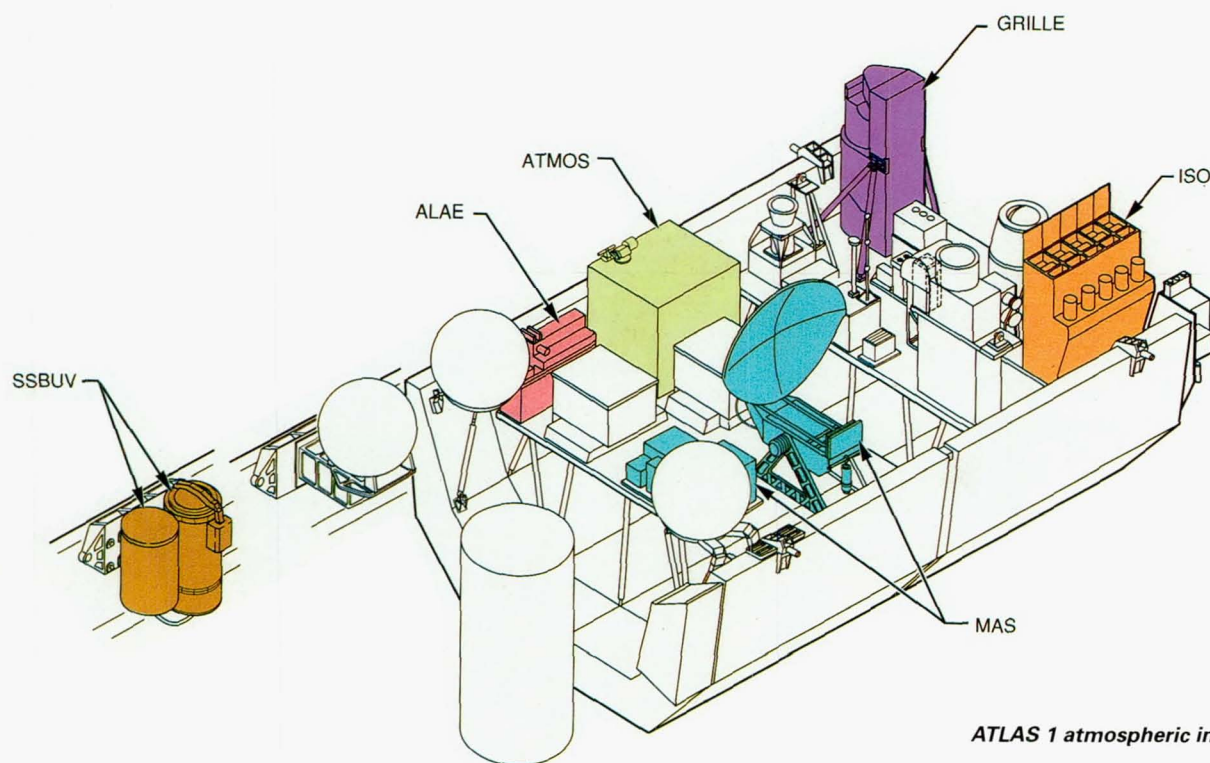
Atmospheric Variability

Gases in the upper atmosphere and ionosphere constantly undergo changes triggered by variations in ultraviolet sunlight, by reactions between regions, and by air motions. Many of the photochemical reactions cause atoms and molecules to emit light of very specific wavelengths, ranging from the extreme ultraviolet to the infrared and beyond. These light signatures are called spectral features. By measuring fea-

tures across a large portion of this wavelength range, the composition of the atmosphere at a particular time can be inferred. With sensitive instruments, trace amounts of some chemicals can be measured with a precision of parts per trillion.

The many simultaneous measurements of temperature, pressure, chemical makeup, and solar radiation made during the ATLAS 1 mission will begin a decade-long program to characterize the atmosphere's complex variability. Six

atmospheric science experiments on ATLAS 1 study the middle and upper atmosphere with a variety of remote sensing techniques that help correlate atmospheric composition, temperature, and pressure with changes in solar radiation. From the data gathered by these experiments, scientists can broaden their understanding of the dynamic chemical constitution of these regions. This information will help scientists improve models of atmospheric behavior and better monitor changes in the atmosphere.



ATLAS 1 atmospheric instruments

Measuring Radiation

When we look at a source of light, whether it be a candle or a star, our eyes respond to a particular range of energy that makes up what we call visible light. Visible light, however, is only a small portion of the electromagnetic spectrum, the whole range of radiant energies from radio waves to gamma rays.

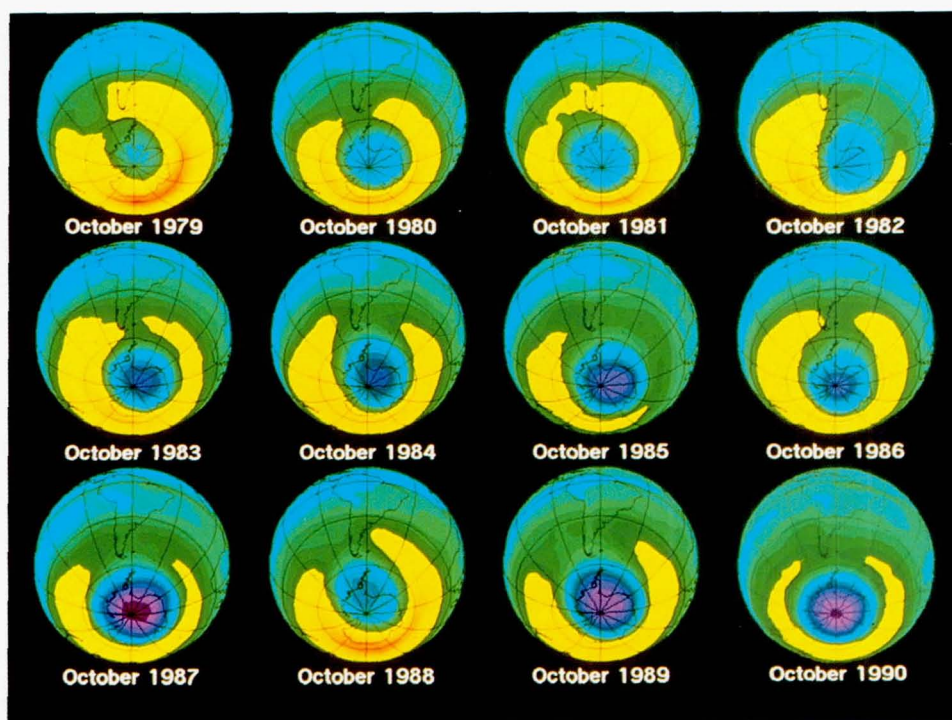
Radiant energy travels in wave-like patterns, and scientists often describe regions of the electromagnetic spectrum by wavelength, the measure of the distance between crests of each wave and one indicator of energy level. The length of low-energy radio waves, for example, may be several thousand kilometers, while high-energy gamma radiation is measured in trillionths of meters.

The portions of the electromagnetic spectrum of interest to ATLAS 1 investigators — microwave, infrared, visible, and ultraviolet — have wavelengths ranging from thousandths to ten-billionths of a meter. Microwaves and infrared and visible light, which are lower energy photons, are most often described in units of measure called millimeters (mm, one thousandth of a meter), micrometers (μm , one millionth of a meter, also known as a micron), or nanometers (nm, one billionth of a meter); ultraviolet light, a higher energy radiation, is measured in either nanometers or Angstroms (\AA , one ten-billionth of a meter), the unit of measure commonly used by ultraviolet astronomers.

Stratospheric Ozone

In the stratosphere, a 10-km (6.2-mi) thick layer of ozone absorbs short-wavelength solar ultraviolet radiation (200 to 300 nm), shielding Earth from these harmful energies and heating the middle atmosphere. This process also provides the energy for other stratospheric chemical reactions.

Stratospheric ozone, however, is particularly reactive and susceptible to destruction by a number of atmospheric trace chemicals, especially to members of the chlorine, nitrogen, and hydrogen chemical families. These species are produced at Earth's surface by both natural and synthetic processes, then rise high enough in the atmosphere to be broken down by ultraviolet sunlight. Increased concentrations of these breakdown products in Earth's atmosphere have led to periodic depletions of the ozone layer. Under the unique meteorological conditions of the Antarctic, for instance, these ozone depletions can be quite large, producing a seasonal "hole" through which ultraviolet radiation can penetrate deeper into the atmosphere. The concern is that, with a reduced stratospheric ozone layer, life on Earth may be exposed to radiation that could increase the incidence of skin cancers and cataracts and destroy certain plants that are crucial to several food chains.



The continuing growth of the ozone hole over Antarctica is evident in these 12 color plots of the October mean ozone concentration from 1979 to 1990. The reds and yellows represent higher concentrations of ozone, while the greens, blues, and purples indicate regions of reduced ozone levels. The Total Ozone Mapping Spectrometer aboard the Nimbus 7 satellite gathered the above data.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Chemical Notation

Scientists often use a standard notation when referring to chemical elements and compounds. In atmospheric chemistry, the following are particularly relevant.

Ar	argon
CH ₄ (CH ₃ D)	methane (methane containing deuterium)
Cl	chlorine
ClO	chlorine monoxide
ClONO ₂	chlorine nitrate
CO	carbon monoxide
CO ₂	carbon dioxide
D	deuterium (heavy hydrogen)
H	hydrogen (atomic form)
HCl	hydrogen chloride
He	helium
HF	hydrogen fluoride
H ₂ O (HDO)	water (water containing deuterium)
NO	nitric oxide
NO ₂	nitrogen dioxide
NO _x	nitrogen oxide (collective reference to NO and NO ₂)
N ₂	nitrogen (molecular form)
N ₂ O	nitrous oxide
N ₂ O ₅	dinitrogen pentoxide
O	oxygen (atomic form)
O ₂	oxygen (molecular form)
O ₃	ozone
OH	hydroxyl
S	sulfur

These notations appear in many of the following data plots and sidebars.

The Photochemistry of Ozone

The photochemistry of ozone is extremely complicated. To understand how humans interfere in the intricate chemical reactions that maintain a relatively constant ozone concentration, we must first grasp more fully the natural processes involved in ozone production and destruction. ATLAS 1 atmospheric and solar investigations will add to our understanding of these processes.

In the presence of sunlight, ozone molecules take part in many complex chemical reactions, some of which increase the concentration of ozone, while others decrease it. The net result of these naturally occurring reactions is a fairly constant ozone concentration; however, products of human activity are now entering the atmosphere at increased rates, inducing potentially catastrophic reactions.

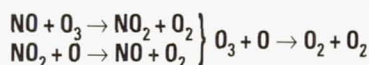
When ultraviolet (UV) sunlight strikes oxygen molecules (O₂) in the stratosphere, it frees oxygen atoms (O) that combine with molecular oxygen to form ozone (O₃).



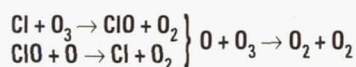
An ozone molecule struck by ultraviolet radiation breaks down to produce molecular oxygen and a free oxygen atom, which can then recombine with other oxygen atoms and molecules, again forming ozone.



Certain chemicals, such as nitrogen compounds and chlorofluorocarbons, are particularly destructive to ozone through catalytic cycles in which one molecule of a chemical may destroy thousands of ozone molecules. Nitric oxide (NO), for example, typically destroys ozone by combining with it to produce nitrogen dioxide (NO₂) and oxygen. The nitrogen dioxide is then available to combine with free oxygen atoms, producing another nitric oxide molecule and molecular oxygen. The net result is a loss of one ozone molecule and one atomic oxygen.



Chlorofluorocarbons are widely used on Earth as refrigerants, foam-blowing agents, cleaners, and aerosol propellants. These materials are non-reactive in the troposphere, but when they enter the stratosphere, they are dissociated by ultraviolet sunlight. The resulting chlorine atoms (Cl) destroy ozone and upset the usual balance. After reacting with ozone, the chlorine atoms are again free to destroy other ozone molecules. This catalytic cycle is similar to that of nitrogen. Ozone and atomic oxygen are lost, but there is no net change in the number of chlorine atoms.



While nitrogen compounds can speed up the destruction of ozone, they can also nullify this effect. Nitrogen compounds complicate the ozone-chlorine photochemistry by combining with and removing certain chlorine compounds. When nitrogen dioxide reacts with chlorine monoxide (ClO), for example, the product, chlorine nitrate (ClONO₂), temporarily removes the reactive nitrogen and chlorine atoms from ozone-destroying cycles.



Because the ozone layer is so important in maintaining an environment that supports life on Earth, it is imperative that we identify the natural atmospheric reactions influencing ozone concentrations so that we can distinguish and determine the effects of anthropogenic products on the photochemistry of stratospheric ozone.

Atmospheric Lyman-Alpha Emissions

Principal Investigator: Dr. Jean-Loup Bertaux

Service d'Aéronomie du Centre National de la Recherche Scientifique (CNRS)

(Aeronomy Service of the National Center for Scientific Research)

Verrières-le-Buisson, France

■ The Atmospheric Lyman-Alpha Emissions (ALAE) experiment measures the relative abundances of two varieties of hydrogen atoms in the upper atmosphere. These abundances should be constant below the altitude at which atmospheric turbulence ends and should change above that altitude. The location of the transition between lower turbulence and calmer upper regions, somewhere between 100 and 115 km (62 and 71 mi) is not known exactly. The ALAE instrument will map the altitude of the transition region over the globe, helping scientists determine patterns of turbulence. By comparing results with similar data gathered from the upper atmospheres of other planets, scientists will have a better understanding of this transition region on Earth and its role in the loss of water since the formation of the planet.

Water enters the troposphere by evaporation from Earth's surface. Convection, primarily over the tropical latitudes, can then transport water vapor into the stratosphere. Additional water vapor is produced in the stratosphere as methane is oxidized. Higher in the atmosphere (probably in the mesosphere), water molecules are broken apart by photodissociation, and the resulting hydrogen appears in the forms of atomic and molecular hydrogen. Deuterium, a heavier form of hydrogen, is transported to the stratosphere by the same evaporation and convection processes. Deuterium-containing water and methane have chemistries similar to that of regular water and methane. As a result, both atomic hydrogen and deuterium can be found in the thermosphere.

At about 100 km (62 mi), however, hydrogen and deuterium atoms begin to separate according to their differences in mass. The lighter hydrogen atoms (atomic

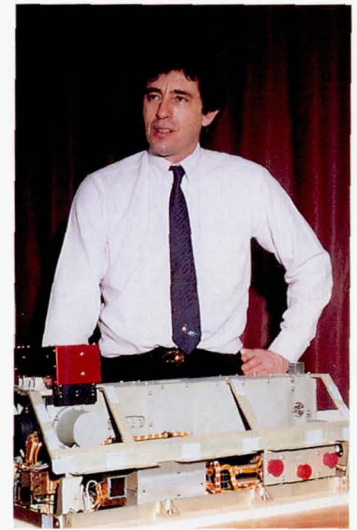
weight 1) rise higher than deuterium (atomic weight 2) and are lost to space. Because deuterium atoms are held closer to the planet by gravity, the overall ratio of hydrogen to deuterium in the atmosphere changes. Deuterium enrichment over geological time is very small on Earth but is thought to be a major clue to understanding the atmospheric development of Mars and Venus. The present day deuterium/hydrogen ratios on these planets indicate that, since their formation, they have lost, respectively, 6 and 100 times the amount of water that remains. Using ALAE findings to help determine our planet's current atmospheric deuterium/hydrogen ratio, scientists will be able to formulate a more definitive idea of the present rate of water evolution in Earth's atmosphere.

The ALAE instrument detects a particularly intense wavelength of ultraviolet light, called Lyman-alpha, which is radiated by both hydrogen and deuterium. The atoms emit this radiation at slightly different wavelengths, however; hydrogen emits at 121.566 nm, while deuterium produces a 121.533-nm emission. Because Lyman-alpha radiation is absorbed in the lower atmosphere, it can only be observed from space.

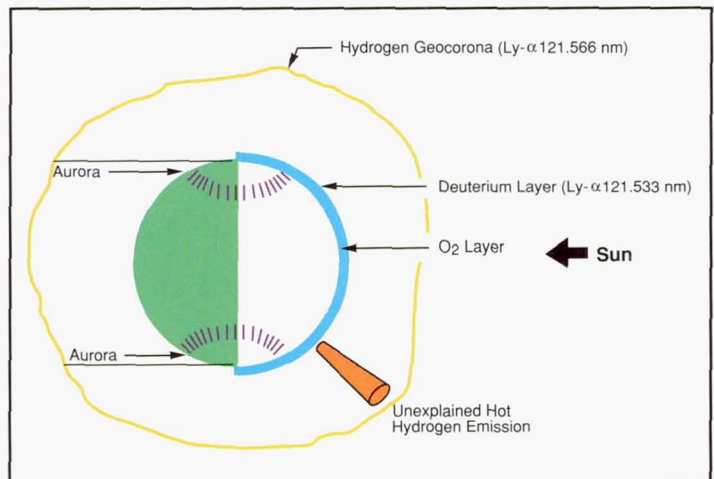
In 1983 aboard Spacelab 1, the ALAE instrument detected three new atmospheric features: a deuterium layer at 110 km (68 mi), emissions of atomic hydrogen in auroras during day and night por-

tions of the orbit, and a hot hydrogen emission of uncertain origin outside the auroral region. During the ATLAS 1 mission, the ALAE instrument, which is five times more sensitive than the equipment that flew on Spacelab 1, will measure Lyman-alpha emissions from the deuterium layer, the hydrogen geocorona [a region of Earth's atmosphere extending out to about 100,000 km (62,000 mi)], and even from the space between planets.

The instrument can also be used in the study of other geophysical phenomena. It detects Lyman-alpha wavelengths produced by hydrogen nuclei (energetic protons) that combine along magnetic fields to form hydrogen atoms. This radiation is particularly noticeable at the high latitudes where auroras appear.



Principal Investigator Dr. Bertaux displays the ALAE instrument.



ALAE scientists discovered three atmospheric features during Spacelab 1: a deuterium layer at 110 km (68.2 mi), atomic hydrogen emissions from auroras during both daylight and nighttime, and an unexplained hydrogen emission outside the auroral region.

Spectral coverage: 121.5 ± 3 nm

Spectral resolution: 0.001 nm

Field of view: 3 deg

Detectors: photomultiplier tubes

Scanning mirror capability: 140 deg

Data rate: 200 b/sec

Mass: 12.5 kg

Atmospheric Trace Molecule Spectroscopy

Principal Investigator: Dr. Michael R. Gunson
NASA Jet Propulsion Laboratory
Pasadena, California, USA

■ The Atmospheric Trace Molecule Spectroscopy (ATMOS) experiment measures the chemical and physical composition of the atmosphere at altitudes between 10 and 150 km (6 to 93 mi). These concentration/height profiles will be compared with ATMOS measurements from other missions as part of an investigation of global, seasonal, and long-term changes in the concentrations of many atmospheric chemical species.

To validate models of stratospheric chemistry, it is very important to gather simultaneous measurements of the vertical profiles of different gases, especially the chlorofluorocarbons. By examining the ratios of constituent amounts determined from these measurements, stratospheric dynamics may be better understood. Since models of stratospheric chemistry are used to predict the future evolution of the stratosphere, their validation is exceedingly important.

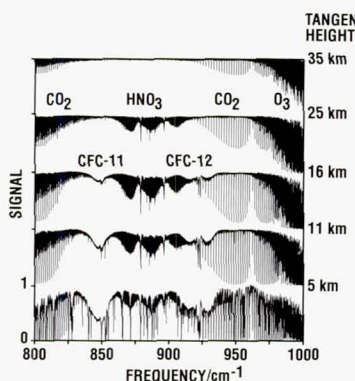
During Spacelab 3, ATMOS made the first simultaneous inventory of the majority of important trace gases, including most of the molecules involved in ozone photochemistry. Scientists identified over 25 different gases and measured the concentrations and vertical distributions of several chlorofluorocarbons, most of the nitrogen-oxygen compounds, ozone, carbon monoxide, carbon dioxide, water, and methane. The instrument also detected several previously unobserved molecules and confirmed the presence of others, particularly dinitrogen pentoxide and chlorine nitrate. These two gases, although present at levels less than a few parts per billion, are important tem-

porary reservoirs of more reactive molecules involved in photochemical processes leading to ozone loss.

The ATMOS instrument, observing 2- to 3-km (1.2- to 1.8-mi) vertical segments of the atmosphere, can distinguish trace molecules at concentrations as low as a few parts per trillion. With this level of sensitivity, it can also measure the composition of the atmosphere to the very high and rarefied levels of the mesosphere and thermosphere above 90 km (56 mi).

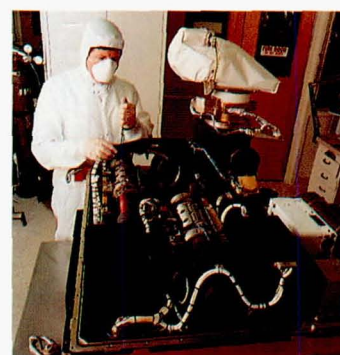
The experiment measures solar infrared radiation at wavelengths between 2 and 16 μm after it has passed through the atmosphere during orbital sunrises and sunsets; this technique is known as limb sounding. Because the important atmospheric trace molecules absorb very specific wavelengths within this infrared spectral band, absorption patterns identify each molecule present as well as its concentration. The ATMOS instrument makes successive measurements as the line of sight between it and the Sun passes through the atmosphere; thus, the change in concentration with height for all the upper atmospheric gases can be determined.

During the ATLAS 1 mission, ATMOS will also make direct measurements of the Sun's infrared spectrum. Similar observations from Spacelab 3 provided unique data for solar physicists interested in the composition of the outer layers of the Sun. Uncontaminated by the effects of Earth's atmosphere, these measurements allowed scientists to identify additional gases in the Sun's hot and turbulent atmosphere.

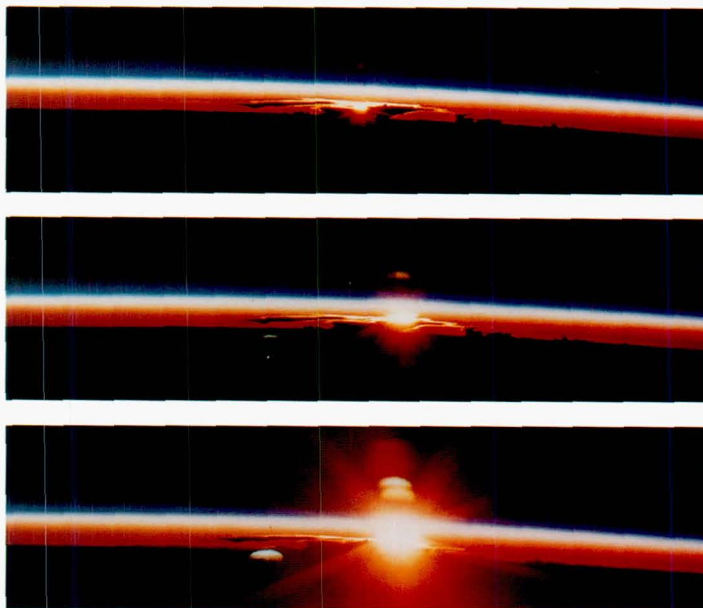


ATMOS will record absorption features of molecules in the atmosphere, such as these molecular signatures of two chlorofluorocarbons (CFC-11 and CFC-12), nitric acid (HNO₃), carbon dioxide (CO₂), and ozone (O₃). These Spacelab 3 data show how the spectral signature of each molecule changes with altitude. Signal values of 0 and 1 refer to the relative amount of solar infrared energy transmitted by the atmosphere, and the wavelengths recorded range from 10 to 12.5 μm .

Spectral coverage: 2 to 16 μm
Spectral resolution: 0.01 cm^{-1}
Spectral precision: 0.001 cm^{-1}
Vertical resolution: 2 km
Field of view: 1, 1.4, 2, 2.8 mrad
Aperture: 7.5 cm (dia.)
Scanning rate: 0.5 m/sec
Scan time: 2.2 sec
Data rate: 16 Mb/sec
Mass: 250 kg



The ATMOS instrument's intricate optical equipment is checked during this preflight inspection.



This series of photographs, taken during Spacelab 3 in 1985, records an orbital sunrise. The top picture shows the sky just before sunrise, while the bottom image captures daybreak. As the Sun rises or sets through the atmosphere, the dispersion of chemicals by altitude and latitude (from the tropics to auroral regions) can be determined by limb sounding. The ATMOS instrument measures solar infrared radiation passing through Earth's limb.

Grille Spectrometer

Principal Investigator: Dr. Marcel Ackerman
Institut d'Aéronomie Spatiale de Belgique
Belgisch Instituut voor Ruimte Aeronomie
(Belgian Institute for Space Aeronomy)
Brussels, Belgium

Co-Principal Investigator: Mr. Jean Besson
Office National d'Études et de Recherches Aérospatiales
(National Institute for Aerospace Studies)
Châtillon, France

During ATLAS 1, the Grille Spectrometer will observe the global distribution of active trace gases at altitudes between 15 and 140 km (9 to 87 mi), studying those molecules that absorb infrared radiation in the 2.5- to 10- μ m spectral band. Most trace atmospheric molecules effectively reveal their identity and concentrations by absorbing and emitting infrared radiation at these wavelengths. The Grille Spectrometer observes ozone, carbon monoxide, carbon dioxide, methane, water vapor, nitrogen dioxide, nitrous oxide, nitric oxide, hydrogen fluoride, and hydrogen chloride.

During Spacelab 1, the Grille's measurements of carbon monoxide and carbon dioxide up to 130 km (81 mi) revealed several regions where these chemicals' concentrations changed quite abruptly with altitude and latitude; as yet, these transition zones are not well understood. Researchers also discovered a large concentration of nitric oxide in the mesosphere. Furthermore, measurements of water vapor and carbon monoxide indicated that these molecules exhibit different photochemical behaviors at different latitudes and as the seasons change.

The spectrometer also recorded methane and nitrous oxide concentrations at higher altitudes

than are accessible to instruments on balloon flights. Because methane and nitrous oxide are not generated in the atmosphere but are products of biological decay and fossil fuel burning, they are good indicators of how gases migrate vertically from Earth. To monitor the amounts of chlorine and fluorine in the middle atmosphere, the Grille's stratospheric measurements of hydrogen chloride and hydrogen fluoride were compared with results of earlier balloon flights. Less hydrogen chloride was found than expected.

The Grille Spectrometer measures the absorption of infrared radiation during orbital sunrises and sunsets. Two detectors collect two infrared wavelength ranges so that scientists can make simultaneous observations of atmospheric components linked by chemical and/or dynamic processes.

During ATLAS 1, the spectrometer will also measure atmospheric chemicals that emit infrared radiation. Operating in its emission mode, the instrument can observe specific species, particularly nitric oxide, during the daylight part of the orbit. This information will play a very important role in our understanding of how molecules behave in the presence of sunlight.

Spectral coverage: 2.5 to 10 μ m

Spectral resolution: better than 0.1 cm^{-1}

Grille: 15 x 15 mm

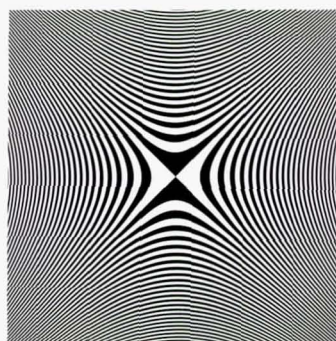
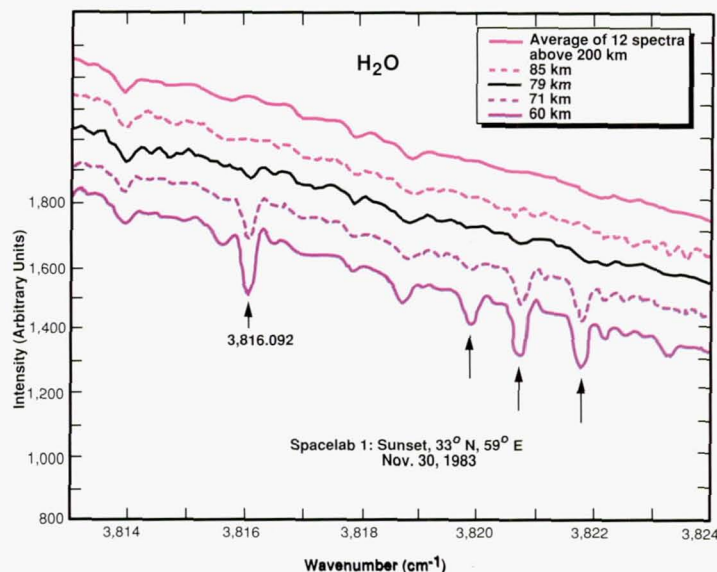
Minimum width of grille zones: 0.1 mm

Mirror oscillation frequency: 436 Hz

Data rate: 52 kb/sec

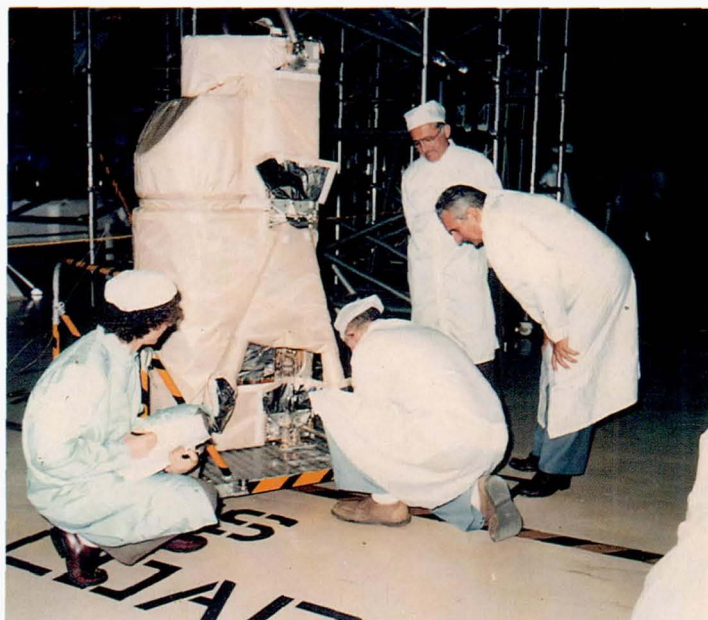
Data sets: vertical distribution of several species from ground level up to 140 km every 3 to 5 min

Mass: ~150 kg



Using the Grille Spectrometer aboard Spacelab 1, scientists detected water vapor at high altitudes. [The above wave-number range (3,814 to 3,824) corresponds to a wavelength range of 2.615 to 2.621 μ m.]

This photograph of the grille shows its transmitting (light) and reflecting (dark) zones.



Grille team members ready the instrument for spaceflight.

Imaging Spectrometric Observatory

Principal Investigator: Dr. Marsha R. Torr
NASA Marshall Space Flight Center
Marshall Space Flight Center, Alabama, USA

■ During Spacelab 1, the Imaging Spectrometric Observatory (ISO) surveyed the atmosphere and made the first spectral measurements over a broad wavelength range of dayglow (the faint light produced by excited atoms and molecules) in both the mesosphere and thermosphere. Several unexpected phenomena were recorded. Among these were unusual spectral lines from molecular nitrogen ions that indicated their energy levels were being raised by photochemical activity. The ATLAS 1 experiment, rather than making broad spectral surveys, will focus on specific questions raised by the Spacelab 1 results. In particular, the ISO will take "snapshots" of the mesosphere, producing simultaneous spectral and spatial images of the region between 70 and 90 km (43 and 56 mi). These images will provide information on chemical constituents such as atomic oxygen, molecular oxygen, hydroxyl, nitric oxide, and their excited states. By characterizing these species, scientists will learn much about the photochemistry of the mesosphere. In addition, the ISO will observe the thermosphere, attempting to distinguish emissions that occur naturally from those induced by the Shuttle's movement through the atmosphere.

Five ISO spectrometers cover different, though overlapping, spectral bands. They gather faint light signatures (in the 30- to 830-nm range) from the mesosphere, thermosphere, and ionosphere to study the chemical reactions that control the behavior of the upper atmosphere. These signatures also reveal the solar wavelengths absorbed. Some of this energy is stored and released at night as airglow. The ISO instrument also observes these emissions.

The ISO experiment makes measurements from above the

lower atmosphere; therefore, scientists are able to observe spectral features that are not visible from the ground and are not limited to nighttime observations, as they are on Earth. They can also determine how the composition of the atmosphere changes with latitude, longitude, altitude, and time of day; how much solar ultraviolet light reaches Earthspace; and how energy is dissipated in the middle and upper atmosphere.

At certain times during its observing sequences, the ISO instrument will also record the Sun in extreme ultraviolet wavelengths (30 to 125 nm). These are the solar photon energies that drive the chemistry of the upper atmosphere, and it is important to measure this particular input and to correlate it with chemical behaviors.

Spectral coverage: 30 to 830 nm

Spectral resolution: 0.05 to 0.6 nm

Field of view: 0.65 x 0.01 deg

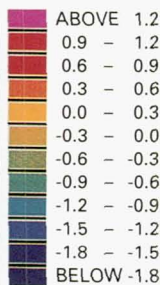
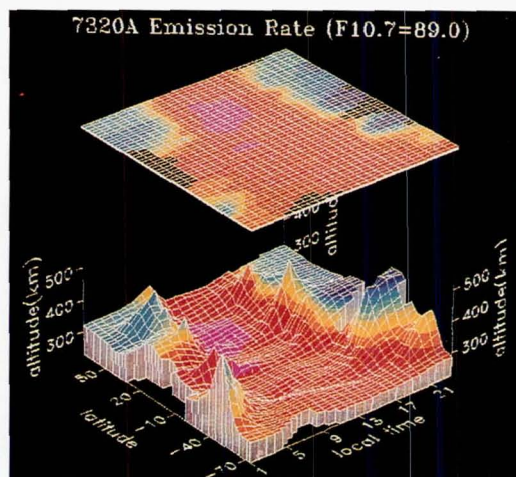
Data rate: 128 kb/sec

Data set: images ~1,100 wavelengths simultaneously

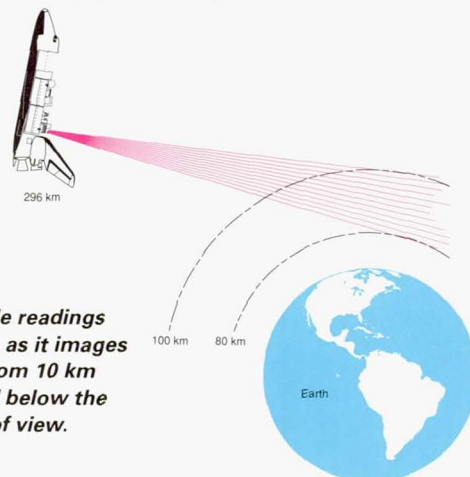
Mass: ~250 kg



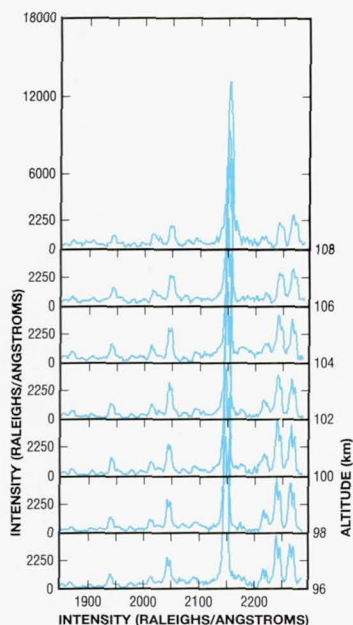
Spacelab 3 crew members photographed this aurora and airglow, the uniform line transecting the auroral curtain. Atomic oxygen produces the red airglow emission. Using the ISO instrument, scientists will study emissions of a number of mesospheric chemical species.



This theoretical three-dimensional computer image models airglow emitted by oxygen ions at 7,320 Å (732 nm) during a period of low solar activity. (F10.7 is an index of solar activity; its value of 89 indicates low activity.) The plot shows the peak oxygen ion emission rate. On orbit, the ISO instrument will view through similar chemical topologies, gathering data that will be compared to the predicted intensities. The scale is the logarithm of the volume emission rate in photons/cm³/sec. The image at left reveals predicted atmospheric disturbances produced by the Shuttle.



ISO makes multiple readings of the atmosphere as it images the atmosphere from 10 km (6.2 mi) above and below the center of its field of view.



On Spacelab 1, the nitric oxide spectral signature was observed simultaneously by the ISO at 2-km (1.2-mi) intervals between 96 and 108 km (59.5 and 66.9 mi).



Members of the ISO team prepare the instrument in a clean room at Marshall Space Flight Center.

■ The Millimeter-Wave Atmospheric Sounder (MAS) uses limb-scanning millimeter-wave spectroscopy to study the photochemistry of ozone in Earth's middle atmosphere. Many important atmospheric molecules emit millimeter-wave radiation at well-defined frequencies. The MAS instrument measures the strength of these emissions at specific frequencies. The investigation uses a parabolic antenna that scans Earth's limb to collect spectral information at different altitudes in the middle atmosphere. The MAS spectral measurements will help scientists determine the vertical distribution of ozone and several atmospheric constituents and conditions important in ozone photochemistry, such as chlorine monoxide, water vapor, temperature, and pressure.

The MAS experiment will provide a complete set of simultaneous measurements that are particularly relevant to the study of catalytic cycles related to ozone loss. Chlorine monoxide, formed predominantly by the photodissociation of chlorofluorocarbons in the middle atmosphere and subsequent reactions of the breakdown products with ozone, is the key player in chlorine-catalyzed ozone photochemical loss. Evidence suggests that dramatically increased chlorine monoxide concentrations result in high ozone loss rates during the Antarctic spring and are the mechanism for the formation of the ozone hole. Concentrations of chlorine monoxide, however, are extremely difficult to determine. The MAS will supply important global measurements of this molecule.

Water vapor, too, plays a central role in ozone photochemistry because it is the source of active hydrogen compounds that dominate ozone photochemical loss above 50 km (31 mi). It is also a primary tracer of motion in the middle atmosphere; therefore, MAS water vapor measurements will provide information pertinent to understanding the distribution of ozone and the mechanics of chemical transport.

Millimeter-Wave Atmospheric Sounder

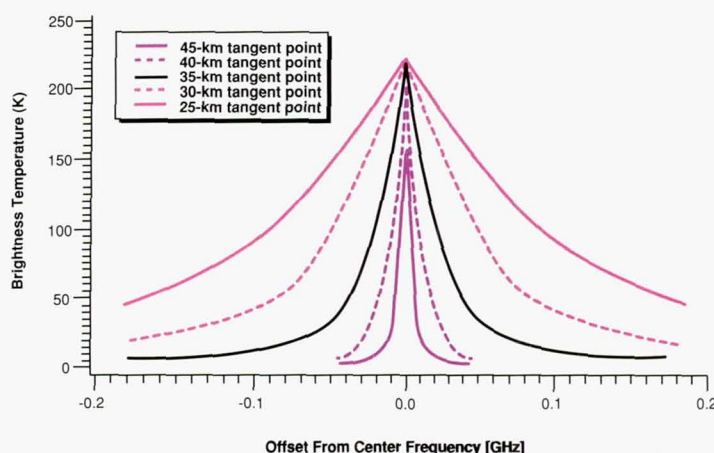
Principal Investigator: Dr. Gerd K. Hartmann
Max-Planck-Institut für Aeronomie
(Max Planck Institute for Aeronomy)
Katlenburg-Lindau, Federal Republic of Germany

Co-Principal Investigators:
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Institut für Angewandte Physik
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University of Bern
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Institut für Fernerkundung
(Institute for Remote Sensing)
University of Bremen
Bremen, Federal Republic of Germany

Dr. Phillip R. Schwartz
Naval Research Laboratory
Washington, D.C., USA

O₃ Center Frequency = 184.378 GHz



Data gathered by the MAS instrument are expected to yield information on the photochemistry of ozone. In this chart, ozone emission data, simulated for five altitudes in the stratosphere, show the relationship of temperature, altitude, and emission frequencies.

Frequencies recorded: 61, 62, 63, 183, 184, 204 GHz

Spectrometer: 50 channels each for temperature, water vapor, ozone; 30 channels for chlorine monoxide; 30 channels each for 2 pressure lines (total of 240 channels)

Vertical resolution: ≥ 4 km

Highest resolution: 200 Hz

Antenna diameter: 1 m

Data rate: 86.4 kb/sec

Mass: 203 kg

ORIGINAL PAGE
COLOR PHOTOGRAPH

Shuttle Solar Backscatter Ultraviolet Spectrometer

Principal Investigator: Mr. Ernest Hilsenrath
Goddard Space Flight Center
Greenbelt, Maryland, USA

Many chemical reactions in the atmosphere are temperature dependent. To calculate accurately the production and loss rates of certain chemicals involved in ozone photochemistry, for instance, scientists must know the temperature profiles of the atmosphere. The MAS temperature measurements are, therefore, especially important in ozone studies.

A comparison of MAS measurements made during successive ATLAS missions will be indispensable as scientists monitor long-term trends in the global

distribution of ozone, particularly the changes associated with human activities. Another beneficial aspect of the MAS presence on the ATLAS 1 and 2 missions will be its under-flight of the Microwave Limb Sounder instrument on the Upper Atmosphere Research Satellite. This instrument uses a technique similar to that of the MAS to measure ozone, water vapor, and chlorine monoxide in the middle atmosphere. Simultaneous measurements by each instrument should increase confidence in measurements from both.

■ The Shuttle Solar Backscatter Ultraviolet (SSBUV) spectrometer operates in concert with a series of similar instruments flying on the National Oceanic and Atmospheric Administration's polar-orbiting satellites. These instruments measure the amount and distribution of ozone in the stratosphere by observing solar ultraviolet radiation and the resulting ultraviolet radiation that scatters off Earth's atmosphere and back toward space.

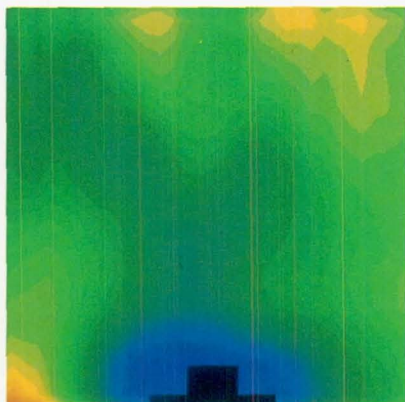
To map the ozone accurately over the long term, measurements must be extremely precise and stable. In a space environment, however, high-energy radiation often degrades the sensitivity of space-flight hardware, causing the calibration of the instrument to drift and decreasing the reliability of the data collected. It is thus important to identify any changes in an instrument's accuracy to distinguish instrument drift from true ozone trends.

The SSBUV spectrometer will help scientists determine the reliability of ozone data gathered by satellite instruments, which are in orbit for long periods. Designed for Shuttle flights, the SSBUV undergoes a rigorous calibration

before and after flights, and its calibration is checked during each flight. The SSBUV observations can then be used as a "yardstick" for comparison with satellite data. The instrument flew on the Shuttle in 1989, 1990, and 1991, providing important data for determining ozone trends.

During the ATLAS 1 mission, the SSBUV will make coincidental measurements with satellite backscatter spectrometers measuring ozone. (Coincidental measurements are possible when the orbital paths of the Shuttle and the satellite cross over the same spot in the atmosphere within 60 minutes of one another.) By comparing the reliable SSBUV data with those gathered by satellites, scientists can then determine the calibration of satellite instruments and know how to correct ozone data for calibration drift. SSBUV measurements will also be compared to solar irradiance measurements made by solar investigations aboard both ATLAS 1 and the Upper Atmosphere Research Satellite.

The SSBUV measures atmospheric backscattered solar radiation in 12 wavelengths, as well as incident solar ultraviolet



The Limb Infrared Monitor of the Stratosphere experiment aboard the Nimbus 7 satellite measured the vertical distribution of water vapor in the middle atmosphere for use in models of stratospheric dynamics and chemistry. In this color plot of the zonal mean distribution of water vapor in May 1979, the blue and darker green values are lower water vapor concentrations (approximately 2 to 4 parts per million by volume) over the tropics. Two arms of lower concentrations are evident, showing dry air being transported more quickly southward than northward during northern spring. The data confirm atmospheric models that include branches of dry air extending north and south of the equator at pressures of about 7 millibars. These atmospheric motions affect the distribution of various stratospheric constituents, including ozone.



Principal Investigator Dr. Gerd Hartmann (third from left) joins other science and engineering team members during the last test of the MAS instrument before shipment to Kennedy Space Center. The microwave antenna and associated electronics (right) are mounted on a protective frame for test purposes.

radiation. Because ozone absorbs solar radiation in these particular wavelengths, the concentration of ozone in the stratosphere can be determined from the ratio of back-scattered radiation to the incident ultraviolet light. This ratio is a measure of the amount of light absorbed, which is related to the amount of ozone in the stratosphere.

Variations in the back-scattered radiance at the 12 wavelengths also indicate how ozone is distributed vertically. Ozone absorbs shorter wavelengths of ultraviolet radiation more strongly than it does longer ones. Shorter wavelengths are backscattered from higher altitudes. The longer wavelengths penetrate deeper into the atmosphere and are scattered from lower levels.

The SSBUV has three modes of operation: Earth viewing, solar viewing, and calibration. While viewing Earth during orbital day, the instrument records backscatter radiance over the 45-minute daylight portion of an orbit. Several 30-minute solar viewings and 60-minute calibrations will occur early, middle, and late in the ATLAS 1 mission.

Spectral coverage: 180 to 400 nm

Spectral resolution: 1.1 nm

Field of view (spectrometer): 11.3 x 11.3 deg

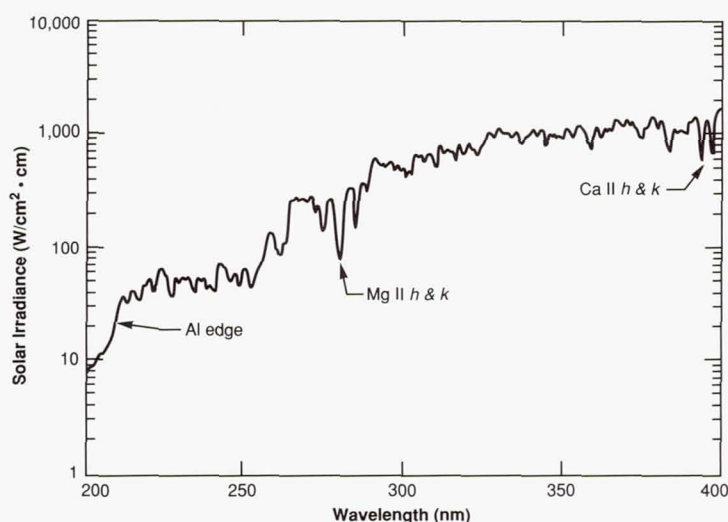
Field of view (cloud cover radiometer): 11.3 x 11.3 deg

Field of view (solar aspect sensor): 64 x 64 deg

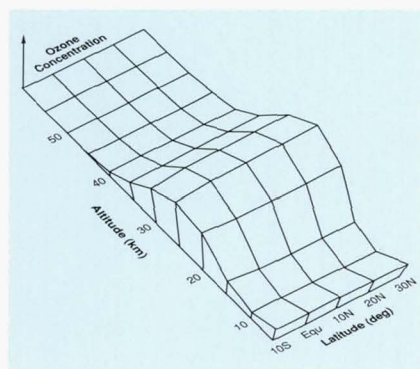
Field of view (4 horizon aspect sensors): 6 deg (nominal)

Data rate: 1.6 kb/sec

Mass: 450 kg



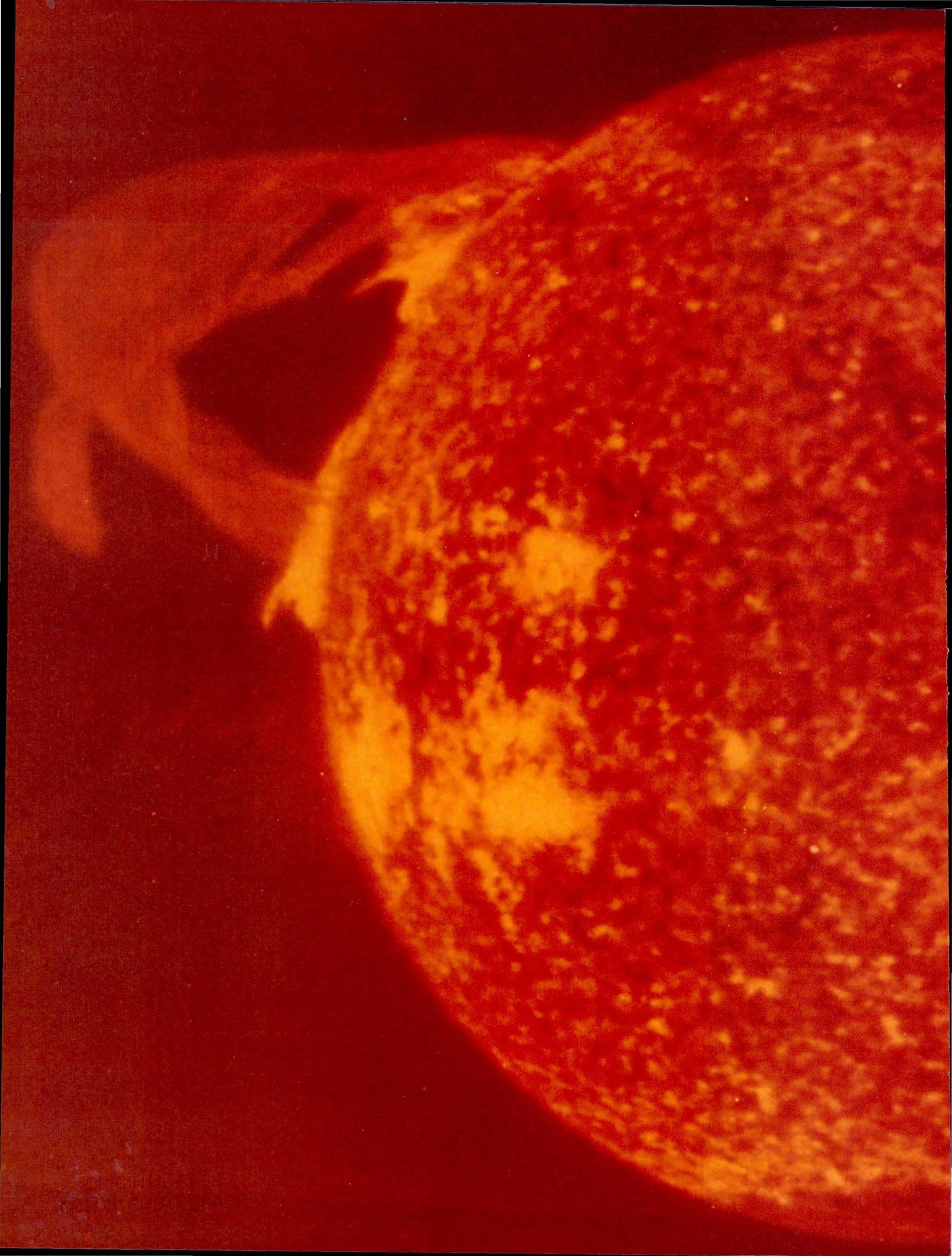
The SSBUV instrument made measurements of mean solar irradiance during STS-34 in October 1990. In the plot at left, spectral signatures of three solar metals can be identified. The aluminum edge (Al edge) indicates the energy region of the solar spectrum that activates chemistry in the stratosphere. This feature is never seen from the ground because ozone absorbs this wavelength of radiation. The magnesium (Mg II h and k) signature is an indicator of solar activity, which was high at the time of the observation, corresponding to the solar maximum period of 1989 and 1990. The calcium (Ca II h and k) feature is visible from the ground and is also used as a measure of solar activity.



During STS-34, the SSBUV instrument recorded solar ultraviolet light and back-scattered radiation over 40 degrees of latitude and at altitudes ranging from 10 to 60 km (6.2 to 37.2 mi). The data indicated that ozone concentrations are greatest in the stratosphere between 20 and 30 km (12.4 and 18.6 mi) and that ozone concentrations over the equator are lower than at more northerly latitudes.



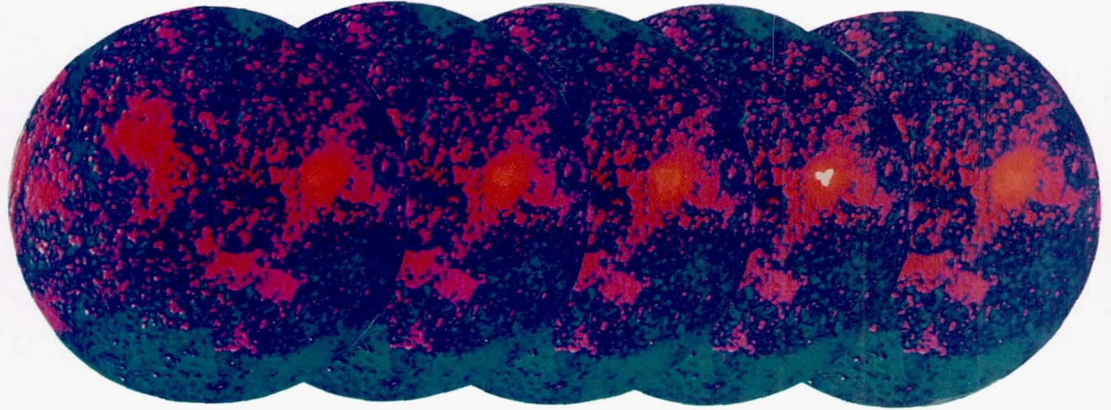
A technician at Kennedy Space Center prepares the SSBUV for integration on the Shuttle. On ATLAS 1, the instrument will be housed in two Get-Away Special containers mounted on the starboard payload bay wall just forward of the two Spacelab pallets. The container on the left holds data, electronics, power, and control systems; the one on the right contains the spectrometer.



POWERED BY A STAR

Deep in the core of the Sun — 93 million miles from Earth, temperatures and pressures approach extremely high levels. Under these conditions, the nuclei of atoms of the major chemical elements involved in solar nuclear reactions, hydrogen and helium, fuse and release tremendous amounts of energy that move outward toward the Sun's surface.

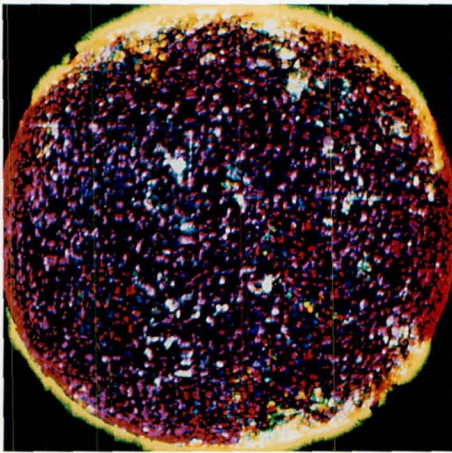
The energy released in the Sun's interior during this nuclear fusion radiates from the Sun's surface in all directions. The portion of the radiant energy that reaches the top of Earth's atmosphere in the form of X-rays, ultraviolet light, visible light, infrared radiation, and radio waves is called the total solar irradiance, or solar constant. This energy is essential to sustain life on Earth.



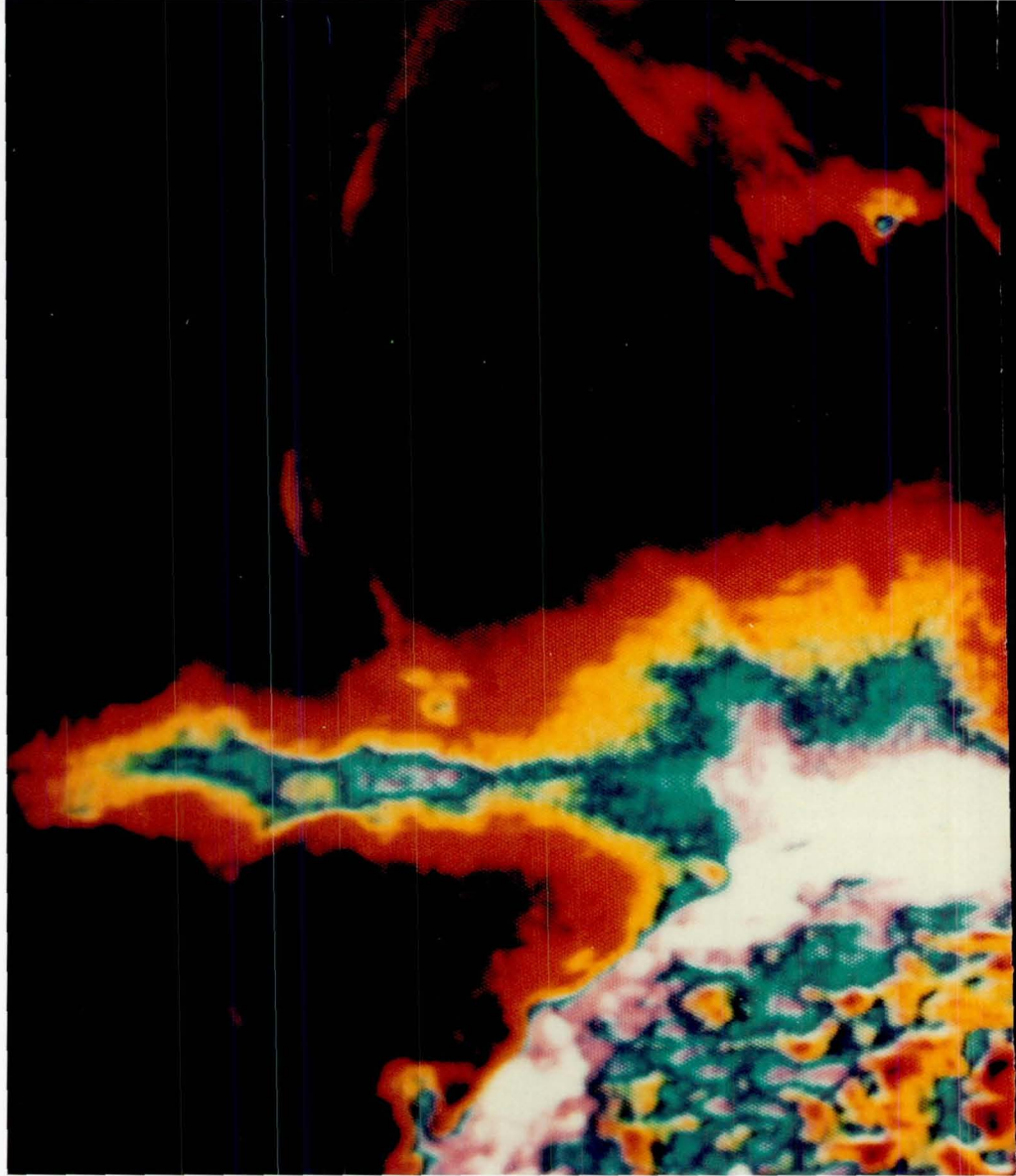
As this solar flare erupts from the Sun's surface, it releases high-energy radiation that spreads throughout the solar system. Life on Earth depends upon the continuous influx of solar energy, the amount of which varies with the activity level of the Sun.

All life depends on the transmission of energy from the Sun to Earth. The Sun radiates a specific amount of energy to Earth. Some of this energy is reflected back to space; the rest is absorbed by the planet, which in turn radiates an equal amount. If the total amount of solar radiant energy arriving at Earth's upper atmosphere changes or if the atmosphere interferes with the transmission, absorption, or reradiation of solar energy, Earth may receive too little energy or retain too much heat, resulting in potentially dramatic changes in climate. Historically, average global temperature changes as small as 2 to 3 degrees over several centuries are thought to have caused droughts and such climatic events as the Little Ice Age, which lasted about 400 years (from approximately A.D. 1450 to 1850). This general cooling of the planet created many unusual meteorological conditions. During that period, for instance,

Skylab crew members photographed sudden, powerful solar flares on the Sun's surface. Bright spots appearing in the two images on the far right of this composite image are produced by the high-energy activity.



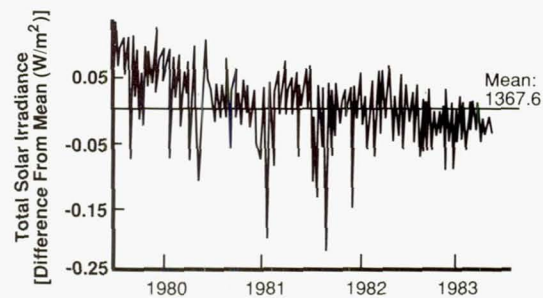
These ultraviolet photographs demonstrate the difference in energy output during the solar cycle. (Above) The Sun is quiet, and ultraviolet emissions are significant but not spectacular. (Right) High-energy ultraviolet radiation increases dramatically during a solar flare.



During the Solar Maximum Mission, it was discovered that the "solar constant" does indeed change. (Top) Short-term variations in the solar constant have been linked to the rotation of a large group of sunspots across the Sun's surface. (Bottom) The causes of long-term variations have not yet been as clearly identified.



Effect: Dip Lasting a Few Days
Cause: Large Numbers of Sunspots



Effect: Long-Term Decrease
Cause: Unknown

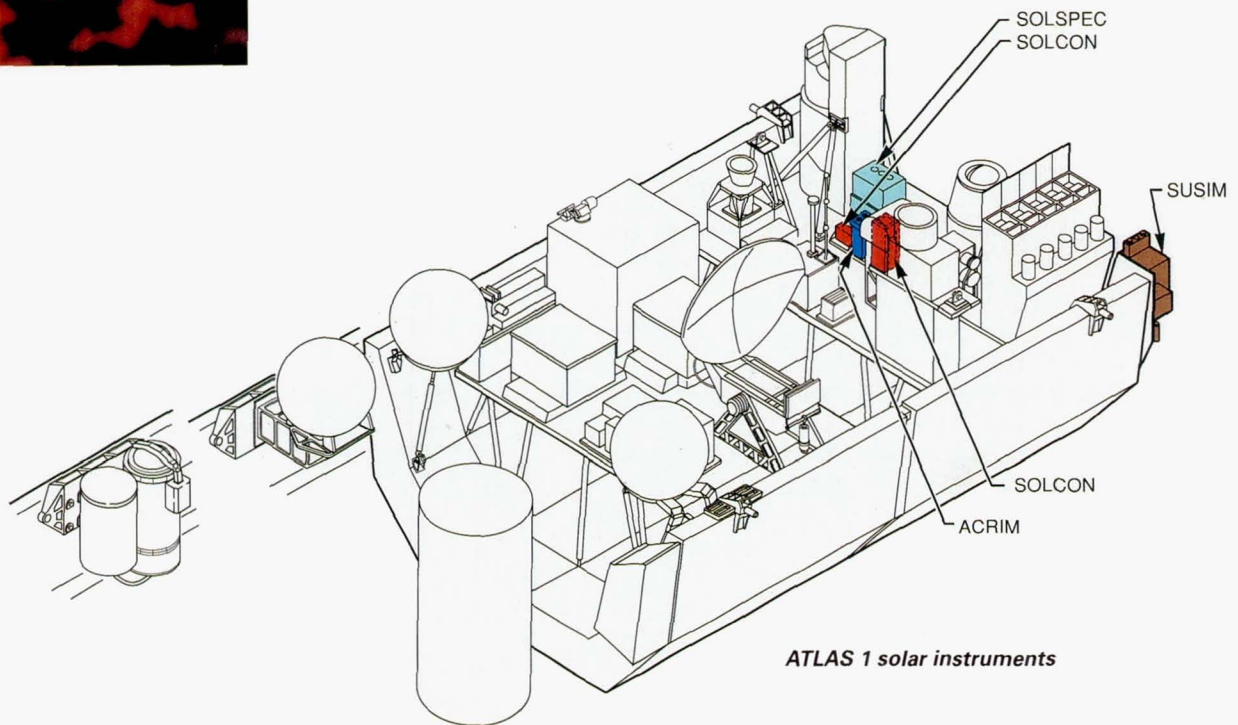
snow fell and lay for months on the high mountains of Ethiopia, where today it is unknown. A 1-percent or less variation in the solar constant may be sufficient to produce such thermal conditions again.

It is important to measure both long- and short-term variations in the total solar irradiance, as well as changes in solar output at specific wavelengths, particularly in the ultraviolet and X-ray components. Long-term variations in total irradiance and in high-energy output take place over the years-long solar cycle, while short-term variations occur on a days-long time frame. Both these cycles and types of variations can have important effects on the temperature and chemical composition of the upper atmosphere.

Although the total solar irradiance is thought to be relatively constant over time, recent measurements have determined that it can vary by nearly 0.1 percent during an 11-year solar cycle, the period during which the occurrence of solar flares, sunspots, and other magnetic activity on the Sun changes from one extreme (maximum or minimum) to the other and back.

Recent solar constant measurements made by the Solar Maximum Mission satellite set the figure at 1,367 watts per square meter; however, the accuracy of these measurements varies by as much as 0.25 percent, a magnitude of error too large for reliable climatological predictions. (An accuracy of at least 0.1 percent is required.) It is important to measure these variations as precisely as possible to anticipate the effect they may have on Earth's climate and weather. If a number of today's most precise instruments measure the solar constant in concert with one another, at the same time, and from the same location over a period of years, each measurement will improve the ability of solar scientists to determine the solar constant and increase scientific confidence in that value.

Two ATLAS 1 solar monitoring experiments, using extremely sensitive instruments that employ slightly different techniques, will measure the Sun's total irradiance. Two other solar experiments will add to our understanding of how variations in the Sun's energy output affect the chemistry of the atmosphere.



ATLAS 1 solar instruments

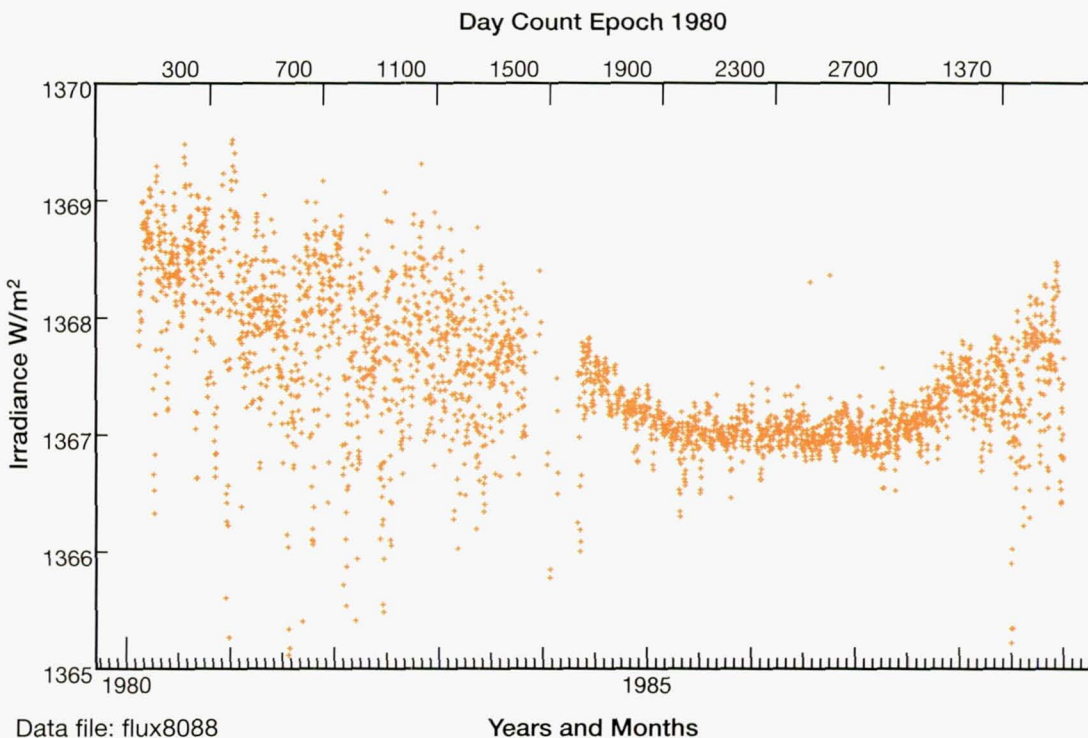
Active Cavity Radiometer Irradiance Monitor

Principal Investigator: Dr. Richard C. Willson
California Institute of Technology
Jet Propulsion Laboratory
Pasadena, California, USA

■ The Active Cavity Radiometer Irradiance Monitor (ACRIM) measures the total solar irradiance from ultraviolet through infrared wavelengths with high accuracy and precision. It is part of an ongoing program that compiles a highly precise, long-term solar total irradiance database using a series of identical instruments aboard satellites and Shuttle missions. A key component of this program is flight-to-flight precision, which provides a continuing record of the relativity of the measurements. Through successive comparisons, the precision of the satellite measurements can be sustained even if an overlap of satellite ACRIM instruments does not occur. In addition, the Shuttle ACRIM can be recalibrated so that it provides a benchmark of accuracy for satellite data.

An ACRIM instrument is flying on the Upper Atmosphere Research Satellite, and others will be aboard Earth-observation satellites. Periodic reflights of the ATLAS ACRIM are essential to ensure the long-term calibration of data gathered by these instruments.

Data from the ACRIM experiment will be compared to those made at the same time by the Measurement of the Solar Constant investigation. These instruments will help establish the total solar radiation scale for the International System of Units. By comparing measurements of the solar constant



made during later ATLAS missions, scientists can further refine the accuracy of this scale.

The ACRIM contains three electrically self-calibrating sensors that measure solar irradiance. Each sensor is comprised of two cavities. The power required to maintain constant temperature differences between the two cavities is used to determine the total solar flux in absolute units. The change in the amount of electrical heating needed to maintain the temperature difference when the shutter of the solar-viewing cavity is open (letting sunlight enter) and when it is closed is proportional to the heat generated by the irradiant solar flux.

This plot shows more than 9 years of mean daily solar irradiance measured by the predecessor of the ATLAS 1 instrument, ACRIM 1, aboard the Solar Maximum Mission satellite. The change that occurs in the data pattern between 1984 and 1985 is the result of repairs made to the satellite in 1984. (The hiatus of observations in 1984 preceded the repairs.) After the satellite's attitude control system was replaced, the ACRIM instrument was again able to collect highly resolved data on gradual changes in the activity level of the Sun and, thus, the day-to-day variations in total irradiance.



ACRIM team members test the instrument (left rear) after its arrival at Kennedy Space Center.

- Spectral coverage: 18 to 3,000 nm
- Cavity field of view: ± 10 deg (max), ± 2.5 deg (operational)
- Effective cavity absorptance: 0.999980 ± 0.000020
- Single sample irradiance precision: $\pm 0.012\%$
- Length of single measurement cycle: ~ 2 min
- Uncertainty for single shutter cycle: less than ± 50 ppm

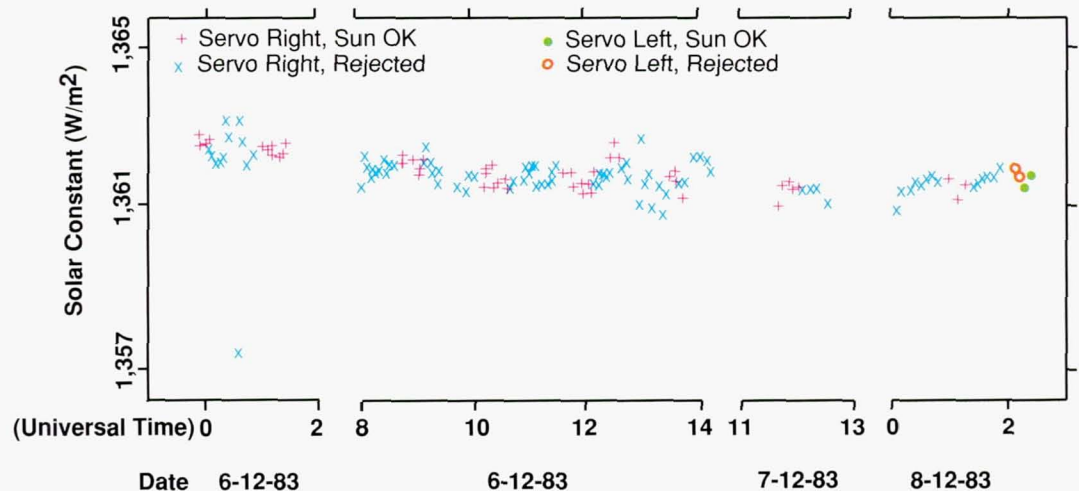
Measurement of the Solar Constant

Principal Investigator: Dr. Dominique A. Crommelynck
 Institut Royal Météorologique de Belgique
 (Belgian Royal Institute of Meteorology)
 Brussels, Belgium

The Measurement of the Solar Constant (SOLCON) experiment improves the accuracy of measurements of the total solar energy arriving at the atmosphere and searches for long-term variations in the value of the solar constant. Continuous, more accurate measurements of the solar constant will allow future generations to identify solar and climatic trends over the centuries.

The SOLCON instrument is a high-resolution, self-calibrating radiometer. Because its precise electrical, optical, mechanical, and thermal characteristics are known, the instrument does not require a radiative source to be calibrated.

The experiment determines total solar radiation by measuring how much power is required to maintain a heat balance between two cavities. When the radiometer is pointed toward the Sun, the shutter covering one of the cavities is opened. A heat balance system then compensates for the added heat until the heat fluxes are balanced between the open and the closed cavities. The shutter is then closed, and power is adjusted to its original value automatically. The difference in power during open and closed operations is a function of total solar radiation. During the mission, the sequence will be repeated several times, opening and shuttering the same cavity.



Analysis of data gathered by the SOLCON instrument during these four Sun-observing sequences on Spacelab 1 determined the value of the solar constant for these periods to be 1361.5 ± 2.3 watts per square meter.



*Principal Investigator
 Dr. Crommelynck displays
 the SOLCON instrument.*

Spectral coverage: 20 to 4,000 nm
Absolute accuracy: $\pm 0.1\%$ (estimate)
Sensitivity: better than 0.05%
Field of view: 9 deg
Data rate: 43 b/sec
Mass: 13 kg

ORIGINAL PAGE
 COLOR PHOTOGRAPH

Solar Spectrum Measurement from 180 to 3,200 Nanometers

Principal Investigator: Dr. Gérard O. Thuillier

Service d'Aéronomie du CNRS

(Aeronomy Service of the National Center for Scientific Research)

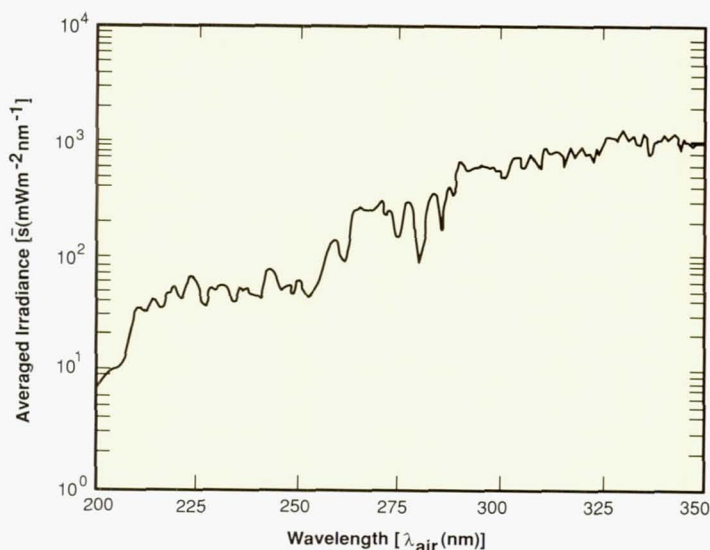
Verrières-le-Buisson, France

Although most solar energy is contained in the visible light that reaches Earth's surface, the solar energy present in X-ray and ultraviolet wavelengths can vary significantly during the solar cycle and change the amount of energy available for chemical reactions in the middle and upper atmospheres. The Solar Spectrum Measurement from 180 to 3,200 Nanometers (SOLSPEC) investigation will measure solar radiation from 180 to 3,200 nm (ultraviolet through infrared) to determine how solar energy is distributed by wavelength, to understand how this energy distribution varies over time, and to identify and quantify the connections between variations in solar energy and atmospheric changes. Using data gathered by the SOLSPEC instrument, scientists will be able to identify the

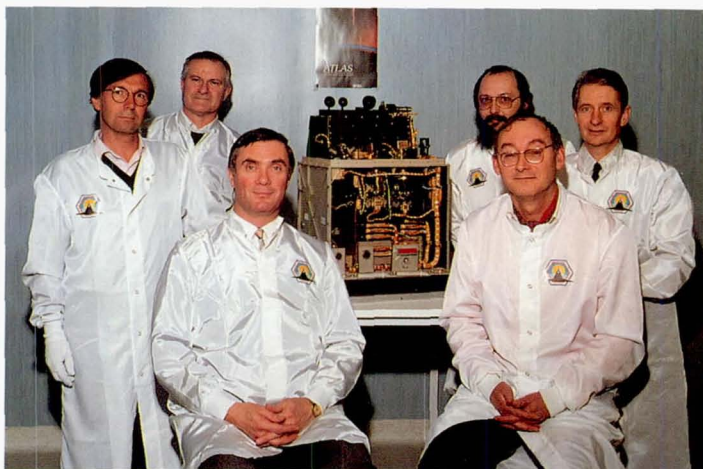
atmospheric regions likely to respond to particular variations in solar infrared, visible, and ultraviolet ranges; thus, they will be better able to anticipate atmospheric changes.

The SOLSPEC data will be compared to other ATLAS 1 solar monitoring measurements and to information gathered during later ATLAS flights. Such successive comparisons will enable scientists to monitor long-term variations in solar radiation output.

The SOLSPEC instrument consists of an onboard calibration device and three double spectrometers that record solar ultraviolet, visible, and infrared radiation. Once a day during the ATLAS 1 mission, the SOLSPEC is calibrated, and during the Shuttle's Sun-pointing attitudes, the instrument is activated.



SOLSPEC scientists determined the mean of 19 undisturbed spectra, recorded during Spacelab 1, to develop this chart of solar irradiance.



Principal Investigator Dr. Thuillier, third from left, poses with the SOLSPEC instrument and other members of the science team.

Spectral coverage: 180 to 3,200 nm

Bandpass in ultraviolet and visible: 1 nm

Bandpass in infrared: 20 nm

Total number of bandpasses: 1,950

Precision of individual bandpass: 0.01 nm

Photometric accuracy: 5% in ultraviolet; 1% in infrared and visible

Time to record solar spectrum: 13 min

Number of spectra per activation: 3

Data rate: 500 b/sec

Mass: 3.2 kg

Solar Ultraviolet Spectral Irradiance Monitor

Principal Investigator: Dr. Guenter Brueckner
Naval Research Laboratory
Washington, D.C., USA

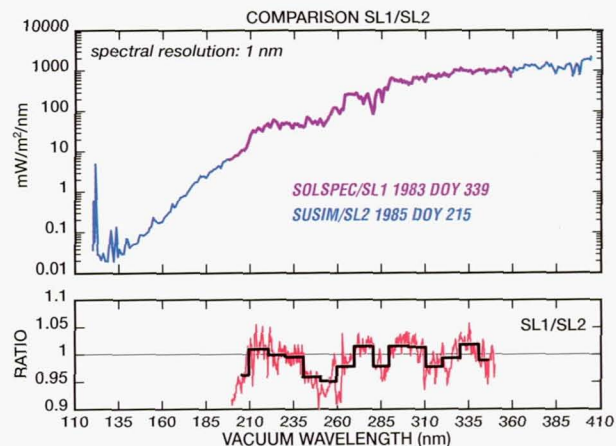
■ Ultraviolet light from the Sun is the primary source of energy for Earth's atmosphere, where it sets into motion and controls chemical, dynamic, and radiative processes. Additionally, the ultraviolet component of sunlight varies much more than visible radiation, which is the largest component of the Sun's total irradiance. Variations in solar ultraviolet radiation over a solar cycle bring about changes in a number of atmospheric conditions, including the concentration of stratospheric ozone.

Scientists studying the role of ultraviolet radiation in atmospheric physics require accurate measurements to determine how this part of the Sun's spectrum varies over a solar cycle. This information, in turn, allows researchers to assess

the magnitude of related changes that may be wrought in the atmosphere. As part of a continuing program to determine both long- and short-term variations, the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) instrument will make very accurate measurements of the Sun's ultraviolet radiation at wavelengths between 110 and 410 nm, a range of the solar ultraviolet spectrum for which there is much uncertainty about its absolute intensity.

SUSIM's design and a rigorous calibration regimen before, during, and after spaceflight allow scientists to address both the question of the Sun's ultraviolet flux and one of the technical challenges of measuring this flux: the determination of how much the ultraviolet light being measured degrades the accuracy of the measuring instrument. Unless the extent of degradation is known, it is impossible to distinguish real changes in solar radiation from the loss of instrument accuracy. By comparing readings from SUSIM's two independent optical systems, investigators are able to track even very small changes in the instrument's sensitivity.

ATLAS 1 will be SUSIM's third spaceflight. During Spacelab 2, it produced highly accurate spectra that are within a few percent of the SOLSPEC data from Spacelab 1. This is the closest agreement of solar ultraviolet irradiance measurements yet achieved by two independently calibrated instruments. While the ATLAS 1 SUSIM is making measurements, a SUSIM instrument on the Upper Atmosphere Research Satellite will also be taking data. Comparisons of the data gathered by the two instruments will be used to characterize any long-term drift in the satellite instrument.



Solar ultraviolet spectra gathered 20 months apart by different instruments agree within 3 percent in the wavelength range between 200 and 350 nm. The SOLSPEC instrument collected its data (red) during Spacelab 1, while the SUSIM data (blue) were gathered during Spacelab 2. (DOY indicates "day of year.")



Technicians at Kennedy Space Center integrate the SUSIM instrument with the OSS-1 payload.

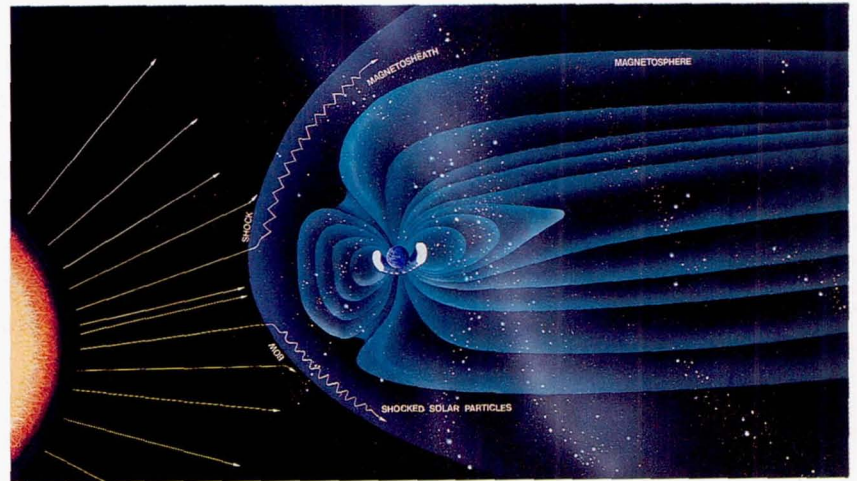
Spectral coverage: 110 to 410 nm
Spectral resolution: 5 nm, 0.15 nm
Accuracy: 5% absolute
In-flight calibration source: deuterium lamp
Data rate: 156 b/sec
Mass: 86 kg



SHEATHED IN PLASMA

More than 99 percent of the Universe is plasma. The Sun, like other stars, is a huge plasma ball heated by nuclear fusion, and what matter there is in the space between Earth and the Sun is mainly in the form of plasma.

Although plasma fills most of the Universe, nature rarely produces it on our planet's surface. Plasma phenomena, such as auroras, however, do occur in Earth's atmosphere. In terrestrial laboratories, it is impossible to replicate all the plasma processes in stars, comets, or even in our own atmosphere, but to truly understand these phenomena, we must learn how matter behaves in a plasma state. The best laboratory in which to study plasma in its natural state is interplanetary space where plasma exists over large areas.



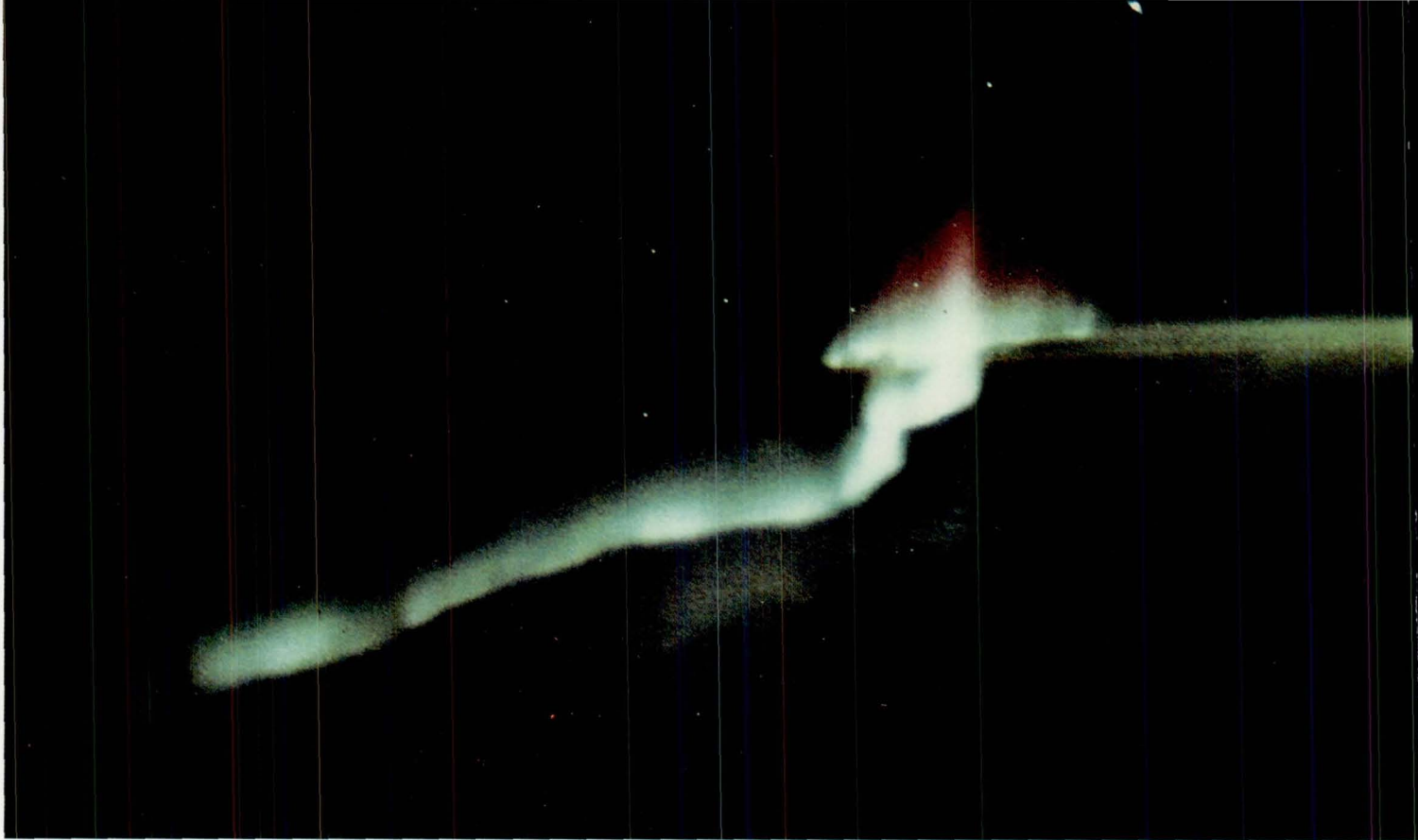
The Ionosphere and the Magnetosphere

In this artist's concept, the full aurora borealis circles the North Pole. The shimmering curtains of light are produced by the interaction of electrified particles from the Sun with Earth's magnetic field.

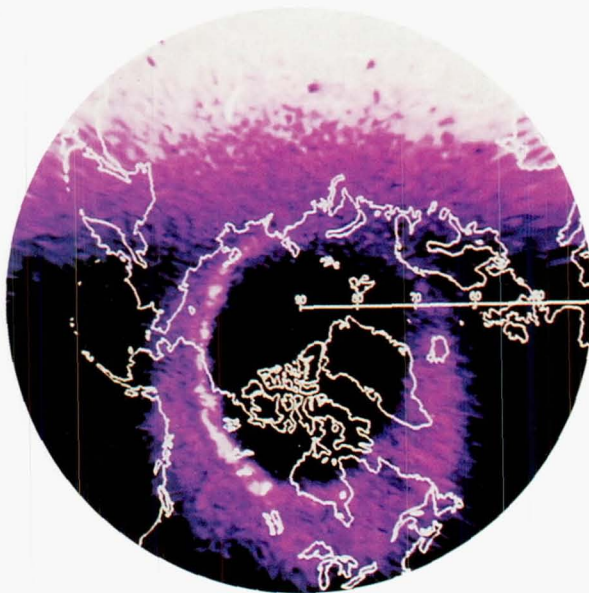
The closest place for on-site plasma studies is the vast region of plasma that extends from our planet's upper atmosphere into interplanetary space. Plasma begins to dominate Earth's environment in the upper reaches of the atmosphere where molecules are ionized by ultraviolet and X-ray radiation from the Sun.

The ionosphere forms the base of the magnetosphere, a plasma region dominated by Earth's magnetic field. Energetic plasma from the Sun (the solar wind) blasts the magnetosphere at around 500 km (310 mi) per second. This wind of particles flows around the dayside of Earth. On the night-side of the planet, the solar wind, along with plasma from Earth's ionosphere, forms a comet-like tail that is millions of miles long.

The solar wind interacts with Earth's magnetosphere, producing the massive electric generator that surrounds the planet. Where the solar wind initially encounters Earth's outermost magnetic fields, a bow shock forms. Just behind this region is an area inhabited by solar wind particles slowed and heated (shocked) by the bow shock. This region is called the magnetosheath.



Some particles from the solar wind are pulled toward Earth and interact with molecules to color the sky in blue, green, pink, purple, or red auroras. This aurora was photographed during Spacelab 3.



The Dynamics Explorer 1 satellite imaged full auroras in ultraviolet light. This 1981 image of the auroral oval records ultraviolet light emitted by atomic oxygen.

Photograph:
L.A. Frank and J.D. Craven, University of Iowa.



The processes responsible for the beautifully eerie northern and southern lights also cause power blackouts and telecommunications disturbances.

Some particles from the solar wind leak into the magnetosphere, and magnetic fields in the solar wind can react with Earth's magnetic field and plasma to create electric fields deep inside the magnetosphere. These fields circulate plasma and accelerate electrons and ions to high energies. Together, the solar wind and the magnetosphere form a giant electric generator.

The plasma in the ionosphere experiences varying conditions and is composed of several constituents, exposing instruments on the orbiting Shuttle to a wide range of plasma densities and temperatures and a rich variety of physical interactions. These conditions are impossible to simulate in Earth-based laboratories. In the natural ionospheric laboratory, there are no boundaries, such as walls, to complicate plasma dynamics and interactions. This allows instruments to make accurate measurements of many plasma interactions that affect our atmosphere and life on our planet.

Three ATLAS 1 investigations use sophisticated detectors to study space plasma. While each experiment has specific objectives, instruments often work in coordinated campaigns to study specific phenomena.

The Aurora and Atmospheric Airglow

From space, our atmosphere is like a large television screen filled with glowing patches of light where chemical reactions are taking place. Even though chemical events may occur far from the Shuttle, sensitive onboard instruments can make images of tell-tale light emissions displayed on the atmospheric TV. Scientists record this light show to learn more about

the chemical species that populate the atmosphere, where they are located, how they move along magnetic fields, and how they react with the Shuttle.

People who live in the northernmost areas like Alaska or work in the southernmost regions like Antarctica often see colorful lights produced by Earth's natural electromagnetic generator; these shimmering expanses of light are auroras, commonly called the northern and southern lights. Charged particles from the magnetosphere follow magnetic fields and are accelerated toward Earth at the magnetic poles where they strike molecules in the upper atmosphere, staining the sky with the red and green lights of oxygen and hydrogen and the purples and pinks of nitrogen. A typical 3-hour aurora discharges approximately 100,000 megawatts of power into the atmosphere — more than the total generating capacity of all the power plants on Earth. Strong auroral storms are often associated with static in radio and television broadcasts, loss of satellite communications, and power disruptions.

The altitude and inclination of the ATLAS 1 mission will give scientists a unique view of auroras, which occur at altitudes ranging from about 90 to 300 km (56 to 186 mi). Most views of the aurora have been from the ground where only limited parts can be glimpsed.

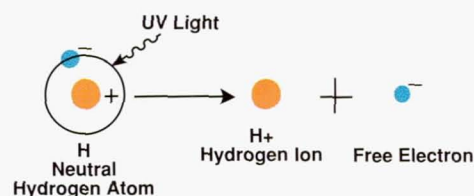
Depending on the season, locations in the northern hemisphere (over northern Canada) or in the southern hemisphere (over Antarctica) will be dark and suitable for auroral studies. This larger view of the aurora will give scientists information on its complex structure and chemical composition. Scientists can record not only visible light but also auroral ultraviolet light that does not penetrate Earth's lower atmosphere and is not seen from the ground. Features imaged in the ultraviolet can be compared to visible features to help piece together what occurs during these ghostly light displays.

Photographs will also be made of atmospheric airglow, the visible bands of red, blue, white, and violet above and parallel to Earth's horizon that are produced as the Sun ionizes chemicals in the atmosphere. This chemical fluorescence is too

What is Plasma?

Most of us are familiar with matter's common forms. We know that water can be a solid (ice), a liquid, or a gas (steam). In these states, atoms are electrically neutral: they have no charge.

In the upper atmosphere, atoms are exposed to intense ultraviolet and X-ray radiation from the Sun. Under these conditions, matter may change to yet another form called plasma. For example, a hydrogen atom, which has one proton and one electron, may exist in the atmosphere as a neutral atom. Ultraviolet light can energize the atom and strip away its electron, leaving a positively charged hydrogen ion and a negatively charged electron.



In the atmosphere, several species of neutral atoms are ionized, leaving ions and free electrons mixed with neutral atoms. Unlike the neutral atoms, the charged ions and electrons in this plasma are affected by electric and magnetic fields, and the motions of the charged particles generate magnetic fields and electric currents. This leads to a complex set of interactions that makes plasma difficult to contain and sustain.



Enclosed by walls in a laboratory on Earth, an electron beam spirals around magnetic field lines and ionizes nitrogen gas, causing the purple glow. In like manner, scientists will inject electron beams into the atmosphere to learn how particles move through plasma.

faint to be seen from Earth and must be studied from space. Scientists can use these images of the airglow to study the distribution of many atmospheric species.

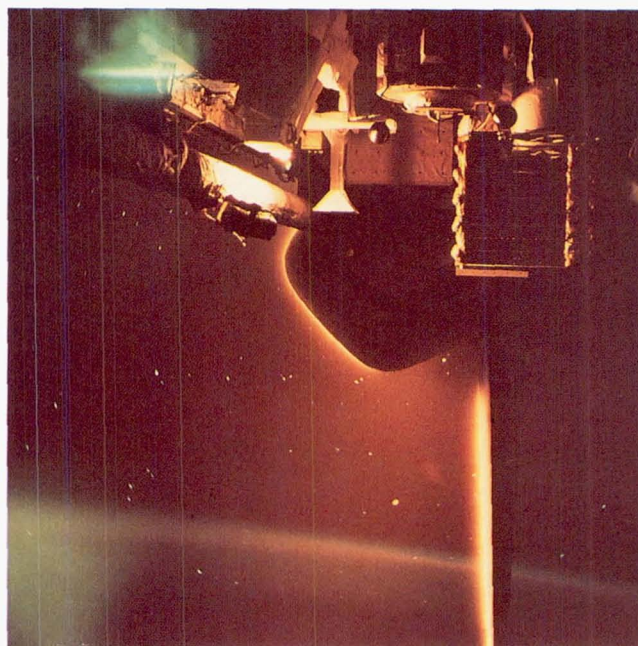
Particle Beams and Plasma Waves

Beam and wave injection experiments are helping scientists understand processes such as auroras. These experiments may also yield clues about particle beam activities detected in solar flares and in the vicinity of Jupiter and Saturn.

In active experiments, investigators will introduce a known stimulus, such as a beam of electrons, and measure the environment's response to test hypotheses about the natural processes of particle acceleration, wave movement, and chemical and energy releases. Electron beams emitted from ATLAS 1 instruments will travel along magnetic field lines; by mea-

suring the path of these beams, scientists can discover how particles are accelerated and guided into the plasma environment.

In auroras, particle interactions with magnetic fields and the atmosphere are complex and difficult to study because conditions vary rapidly, and a wide range of energies is present. Artificial mini-auroras can be created in space by instruments that stimulate plasma near the Shuttle. Instead of waiting for nature to perform, scientists will turn space into an active laboratory, conducting experiments in which they control such parameters as experiment timing, total energy used to stimulate the environment, and location in the atmosphere. By knowing the energy of the beam used to create an artificial aurora, investigators can better understand the response of the atmosphere to specific energy injections.



Shuttle glow is produced as the spacecraft travels through the ambient plasma and neutral atmosphere.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Waves are generated naturally by the constant mixing and flowing of plasma and by sudden disturbances such as lightning or particle beam injections. Plasma waves are important mechanisms for transferring energy from one region of the atmosphere to another where it may be deposited, absorbed, or transformed and carried elsewhere. When scientists excite the ionospheric plasma with an electron beam, waves are created that move energy and matter up and down between the ionosphere and the magnetosphere. In such an experiment, scientists can study how energy and matter are moved naturally in Earthspace.

Shuttle and Plasma Interactions

Scientists also want to know what effects the space environment has on large spacecraft. Will vehicles build up electrical charges that disturb operations? Will chemical reactions create glows that prevent important astronomical observations or contaminate sensitive scientific instruments?

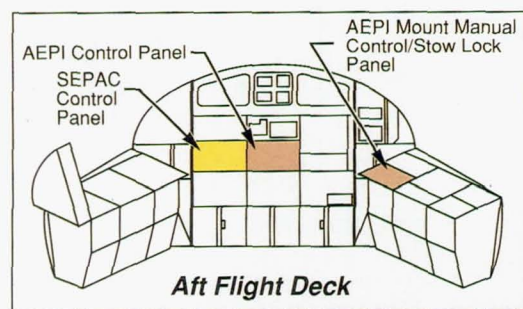
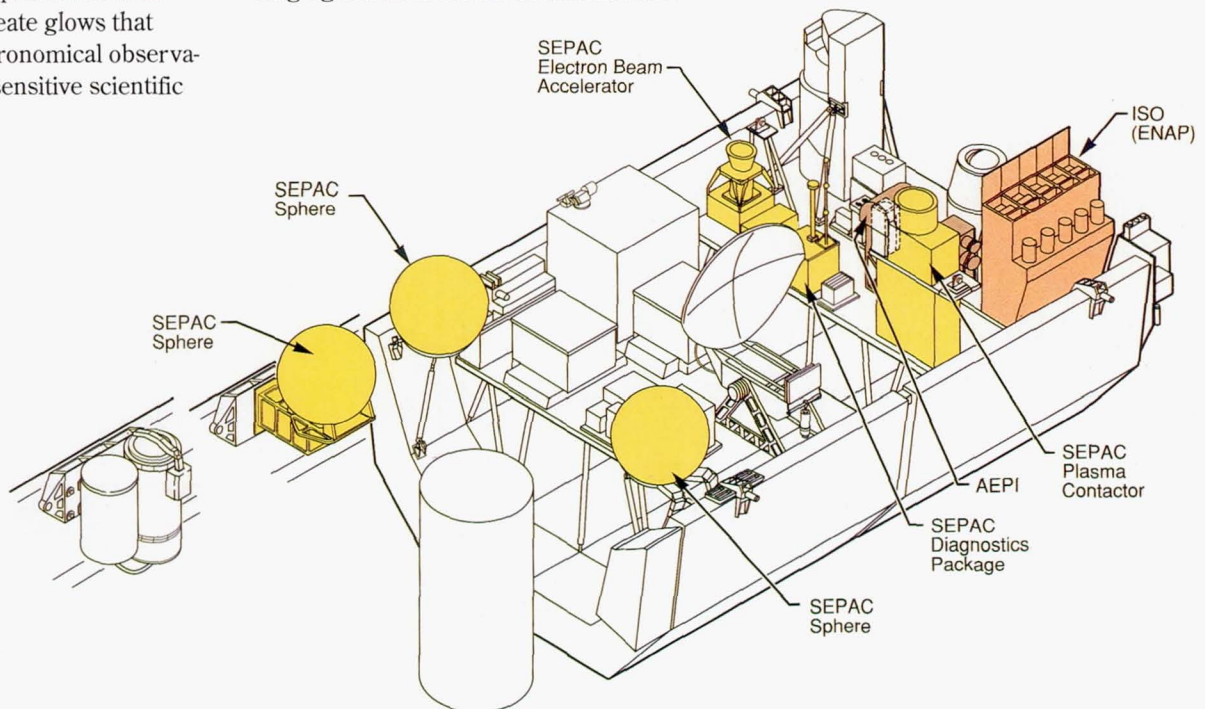
The Shuttle can be used as an instrument to study spacecraft disturbances. Orbiting Earth at around 27,350 km (nearly 17,000 mi) an hour, the Shuttle disturbs the plasma, creating effects similar to a motorboat crossing a lake. It pushes waves ahead and leaves a wake behind. Just as water wets the boat, the Shuttle is bathed in an electrical charge and shines from chemical reactions taking place between its surfaces and the plasma. ATLAS 1 instruments will study Shuttle glow and measure electrical interactions between the Shuttle and the surrounding ionosphere.

The Ring Current

ATLAS 1 instruments will survey natural phenomena such as the energy deposited in the upper atmosphere by energetic particles trapped in part of the magnetic field ringing Earth. Ions and electrons follow

trajectories that spiral along magnetic fields, reflect from one hemisphere to the other, and drift slowly around Earth; however, ions and electrons drift in opposite directions. This drift generates a current, called the ring current, that varies in strength but can reach several million amperes. The ring current plays a significant role in worldwide magnetic storms.

Some of the ring current ions collide with neutral atoms and lose their charge (by gaining an electron). These high-energy uncharged atoms may rain down from the magnetosphere into the atmosphere closer to Earth where they produce very faint light emissions that can be detected by an ATLAS 1 instrument. These emissions reveal clues about the numbers, locations, and energies of particles found in the ring current.



ATLAS 1 space plasma physics instruments

Atmospheric Emissions Photometric Imaging

Principal Investigator: Dr. Stephen B. Mende
Lockheed Palo Alto Research Laboratory
Palo Alto, California, USA

■ Above Earth, the Atmospheric Emissions Photometric Imaging (AEPI) experiment will observe atmospheric light emissions such as auroras and airglow. The AEPI's low-light television cameras are not only ideal for imaging the natural aurora but can also record artificial auroras created by another ATLAS 1 instrument, the Space Experiments with Particle Accelerators (SEPAC) electron generator. For one of the AEPI and SEPAC joint experiments, SEPAC will fire a stream of electrons downward, where they will collide with atmospheric molecules to produce light. AEPI will take pictures of the light, which is an artificial aurora, and SEPAC instruments will monitor the environmental effects of the interaction. The AEPI will also record emissions from other SEPAC electron beam experiments.

Auroras that occur naturally in the atmosphere will also be studied. AEPI instruments will take filtered images of emissions that originate from specific atmospheric constituents, including ions, excited by auroral electrons.

During its first flight on Spacelab 1, the AEPI studied global patterns of magnesium ion emissions, atmospheric airglow, and Shuttle glow. The low-light-level television camera produced images of the atmosphere, and filters isolated faint emissions of metastable oxygen, magnesium ions, and other elements. Magnesium ions are deposited at altitudes of 100 to 200 km (62 to 124 mi) by meteors during entry into the atmosphere. Winds and magnetic fields drive the ions up to higher altitudes. By comparing images of magnesium emissions to the known configuration of Earth's magnetic field, investigators were able to show that the clouds of magnesium ions line up along the magnetic field.

Scientists can use the glow of magnesium ions to trace magnetic fields lines in the same way that simple school experiments use iron filings on paper to outline the fields produced by an ordinary magnet. The AEPI will continue its observations of magnesium ions as part of efforts to systematically map magnetic fields and neutral atmospheric winds during the ATLAS 1 mission.

During Spacelab 1, the AEPI observed atmospheric airglow. Airglow is generated as the atmosphere converts solar energy into chemical energy in the daytime and releases the chemical energy as light at night. The AEPI was able to observe the airglow near Earth's limb, giving a good picture of how the brightness of the airglow varies with height. Viewing the airglow from a slant also enhanced the apparent brightness of the emissions to the instrument. It was discovered on Spacelab 1 that the airglow layer shows a wave-like structure when observed from orbit. On ATLAS 1, several of these observations will be repeated to study the nature of the waves. The AEPI also observed Shuttle glow during Spacelab 1. It had been suggested that Shuttle glow may be emitted by hydroxyl ions near the Shuttle; however, the AEPI measurements showed that hydroxyl in Earth's airglow is different from the color and spectra of Shuttle glow. This means that another species is involved in the chemical reaction that causes the Shuttle to glow. Since the Spacelab 1 mission, the AEPI investigators have participated in other Space Shuttle and laboratory experiments and have shown that Shuttle glow is caused by emissions of nitrogen dioxide, which is formed on the Shuttle by a catalytic reaction. For ATLAS 1, the AEPI will again study any glows surrounding the Shuttle and the airglow circling Earth.

Still camera: 35-mm camera with image intensifier and spectrometer

Detectors: Filtered low-light-level television

- UV and visible; intensified charge-coupled device

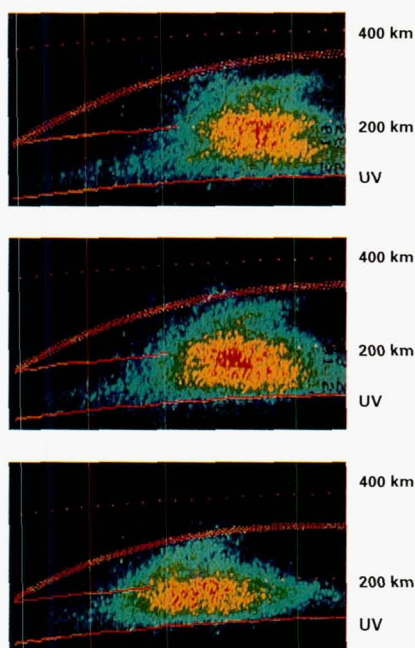
Unfiltered low-light television

- visible only; intensified charge-coupled device

100-channel filtered array photometer

Pointing range of detectors: 40 to 155 deg

Mass: 242 kg



These 1983 Spacelab 1 video frames show ionized magnesium clouds high in the ionosphere over the Pacific. The clouds were imaged in 2,800-Å (280-nm) ultraviolet light. The lower solid curve is the ultraviolet horizon produced by the ozone layer.



Principal Investigator Dr. Mende inspects the AEPI instrument at Marshall Space Flight Center.

Space Experiments with Particle Accelerators

Principal Investigator: Dr. James L. Burch
Southwest Research Institute
San Antonio, Texas, USA

■ In the Space Experiments with Particle Accelerators (SEPAC) investigation, physicists inject electron beams with known energies and currents into the atmosphere to monitor the resultant structures and energies of artificial auroras. By comparing features of artificial auroras with those of natural ones, they can learn more about complicated processes that produce auroras.

The SEPAC investigators will also use the Shuttle as a mobile laboratory to study how a large craft interacts with the space plasma environment. On Spacelab 1, the SEPAC electron accelerator emitted electron beams, a magneto-plasma-dynamic arc jet produced pulses of argon ions, a neutral gas generator released neutral gas, and several passive probes observed the shape of the beam and measured wave and particle interactions.

When the electron beam accelerator was operated above current levels of about 0.1 ampere, the character of the beam changed dramatically because of a strong discharge, and the entire payload bay was brightly illuminated; at lower current levels, only the beam and the hot cathode of the electron accelerator could be seen. The beam raced into space, but many

electrons scattered back to the Shuttle, causing a bright glow on its surfaces and in the thin atmosphere. During electron beam emission, the Shuttle became positively charged and attracted electrons from the atmosphere to balance the current shot from the beam. On ATLAS 1, more experiments of this type will be done to explore the response of the Shuttle and the space plasma to beam firings of different energies.

During Spacelab 1, SEPAC emitted electrons that charged the Shuttle positively. This charge was neutralized by injecting a pulse of plasma simultaneously with the electron beam. The ionized gas neutralized the charge of the Shuttle instantly, and the Shuttle remained neutral for several milliseconds, indicating that injection of plasma is an effective way to eliminate unwanted spacecraft charges. On ATLAS 1, a plasma contactor that continually produces plasma will be used to maintain the desired neutral charge. Conductors also collect electrons, so three 1-m (3.3-ft) diameter conducting spheres have been added to SEPAC's equipment for ATLAS 1.

The SEPAC operations on Spacelab 1 also resulted in the detection of very low-frequency radio waves and the acceleration of

Electron beam accelerator: • energy: 100 to 7,500 eV

• current: 0.1 to 1.6 A

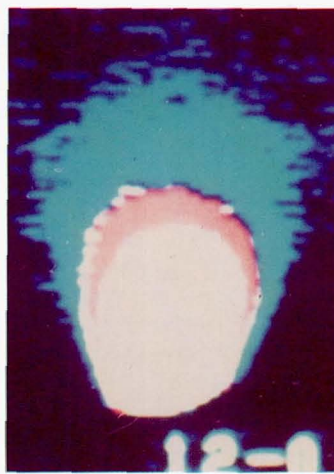
• beam pulse: 0.01 to 5 sec

Plasma contactor: to maintain orbiter charge neutrality

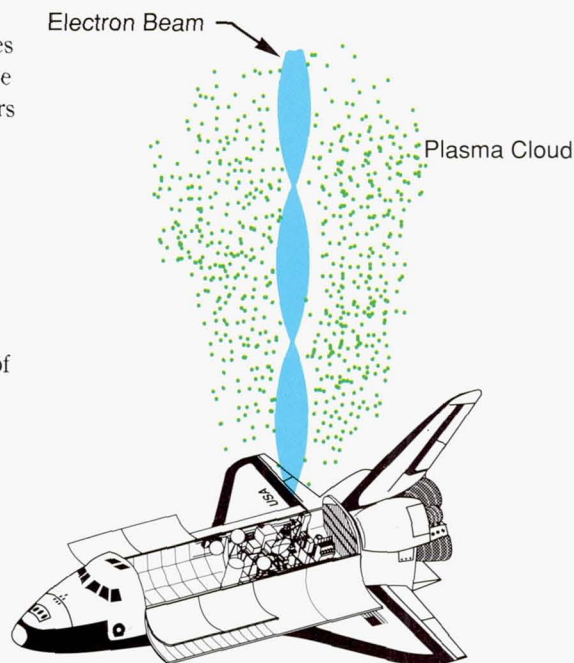
Plasma diagnostics package

Beam modulation: up to 8 kHz

Mass: 473 kg



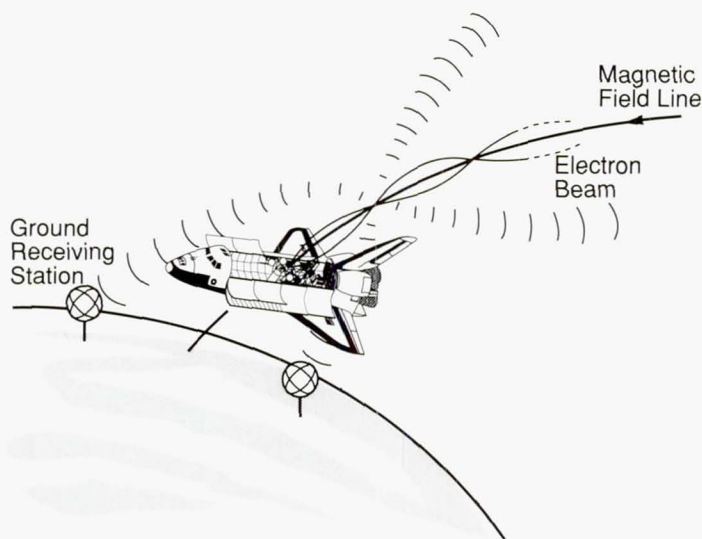
This false-color computer graphic shows intensity levels of the light produced when neutral atoms in the atmosphere were heated by energetic argon plasma emitted from the SEPAC plasma source during Spacelab 1. The white color represents the highest intensity (near the opening where the plasma is released); the red and green represent successively lower levels of light. The intensity readings were taken from an image recorded by the SEPAC television camera.



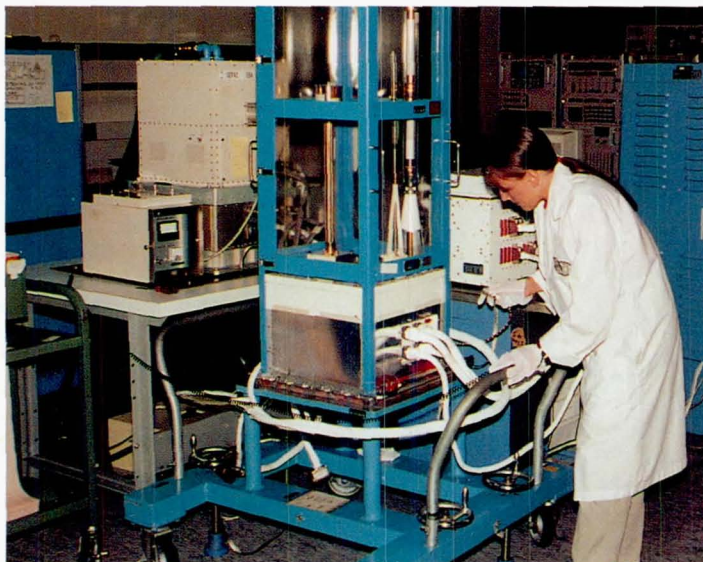
As the electron generator emits a beam, the plasma contactor releases xenon plasma to neutralize the charge built up on the Shuttle by the electron beam emission. AEPI television cameras and SEPAC passive probes monitor how the electrons interact with the surrounding plasma.

electrons up to 5,000 electron volts (eV). These waves are an indication of beam-plasma instability. ATLAS 1 experiments will also study the stability of the electron beam. When the density of the beam gets high, a plasma beam discharge occurs; the beam breaks apart, radio waves are emitted, and electrons are energized. This process is of interest because it is a basic occurrence in most plasmas. Waves the beam emits, energized electrons, and AEPI images of the beam will be used to determine beam stability.

Investigators also want to study the propagation of the radio waves generated as the electron beam is turned on and off or modulated. The resulting train of pulses may travel for distances of hundreds of meters, perhaps even kilometers, and thus will act as very low-frequency radio antennas. Since electromagnetic theory states that changing currents produce electromagnetic waves (radio waves, in this case), SEPAC will emit pulsed electron beams that will act as virtual antennas. Metal antennas will not be needed to guide the beam current in a magnetized plasma like the ionosphere, which is why these beams are called virtual antennas. Ground stations at many sites in the U.S. and Japan will determine how well the radio signal propagates to the ground from the SEPAC beam at very low frequencies.



An electron beam may be useful as a "virtual" antenna for very low-frequency communications. A virtual antenna does not use a physical conductor to carry current. For SEPAC, scientists will switch the electron beam on and off to transmit energy along magnetic fields. Ground observatories will try to detect the resultant radio waves.



A member of the SEPAC team tests experiment hardware.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Energetic Neutral Atom Precipitation

Principal Investigator: Dr. Brian A. Tinsley
University of Texas at Dallas
Richardson, Texas, USA

■ By observing the faint emissions from high-speed, uncharged atoms penetrating the thermosphere at night, scientists can tell how nature moves plasmas around Earth. The Energetic Neutral Atom Precipitation (ENAP) experiment will use the Imaging Spectrometric Observatory during orbital night when the Shuttle's attitude points the instrument above the horizon at the thermosphere.

Energetic atoms originate in the ring current, part of the Van Allen belts, two broad bands of intense radiation that surround Earth and consist of charged solar-wind particles that are captured by the planet's magnetic field. Ions of hydrogen, helium, and oxygen encircle Earth at altitudes that extend to 40,000 km (24,800 mi) above the equator. Eventually, some of the ions collide with neutral hydrogen in the exosphere, the outermost extension of the lightest gases in our atmosphere. The collisions neutralize the charges on the ions, and they become high-speed neutral atoms, no longer trapped by Earth's magnetic field. Freed from this bond, most fly outward into interplanetary space, but some precipitate into the thermosphere. Their impact creates a glow, or low-latitude aurora, that can be detected by the ISO.

The energies of the ring current ions (and of the neutral atoms that they become) range up to 100,000 eV. Their collisions with nitrogen molecules and oxygen atoms in the thermosphere produce characteristic spectral lines detected by the ISO. An additional emission seen during more intense low-latitude auroras is the red line of oxygen at 6,300 Å. This emission is not caused by energetic neutral

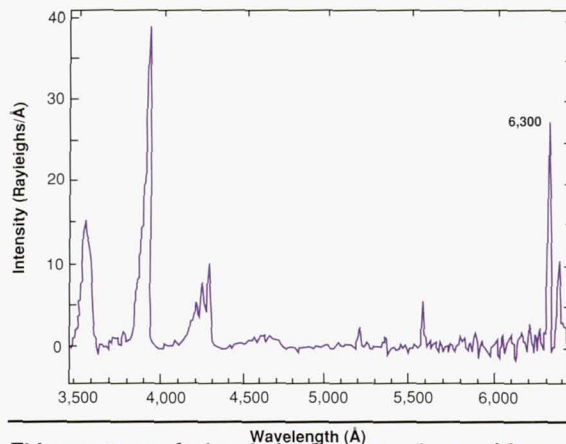
atoms but by large currents of low-energy electrons (about 10 eV) that can be generated when the ring current heats the plasmasphere, the uppermost region of Earth's ionosphere. When the low-energy electrons are absent, the ISO will detect a whitish aurora.

By studying these fingerprints of atoms and ions, scientists can learn about the ring current. During intense magnetic storms, even ions produce optical emissions; the compressed ring current dumps ions along magnetic fields that dip down into the thermosphere where these ions collide with local gases. Only the most intense magnetic storms generate sufficient optical emissions to be visible to the human eye, but the ISO is much more sensitive than the eye and can detect the effects of much weaker storms.

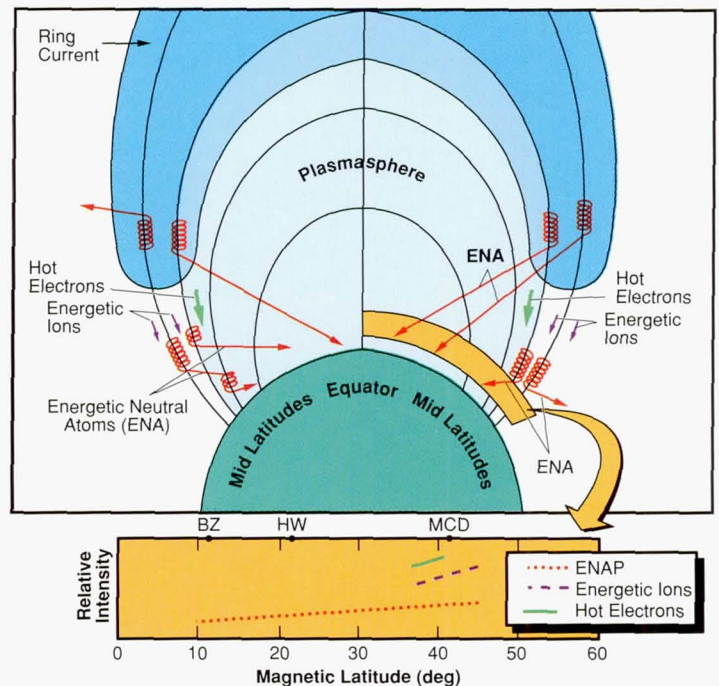
The ISO will observe daytime atmospheric spectral emissions primarily, but it can be used at night for ENAP operations. Nighttime is best for observations of energetic neutral atom precipitation because these emissions are quite faint. Because the instrument is very sensitive and airglow emissions at lower altitudes obscure ground observations, the ISO can record faint emissions and ultraviolet emissions that are not visible from the ground.

Instruments on spacecraft in interplanetary space have detected energetic atoms during magnetic storms and made primitive images of the ring current. In the future, specialized instruments may be able to make higher quality images that show the distribution of hydrogen, helium, and oxygen ions and their energies, as well as the location and the nature of the growth and decay of the ring current. ENAP will take the first step by measuring the optical signature of the ring current. From the latitude

and time variations of different emissions, scientists hope to understand the nature of neutral atom precipitation, its effects on the thermosphere, and the possibilities for using these particles to image the ring current.



This spectrum of a low-latitude aurora observed from southwest Texas in 1983 was probably produced by energetic neutral atom precipitation. The ISO instrument will record similar data for ENAP investigators.



Energetic ions in the ring current are neutralized when they collide with hydrogen in the outer regions of Earth's space. When the resulting energetic atoms rain down into the thermosphere, they create low-latitude auroras that the ISO instrument will detect. The enlarged segment of the illustration charts relative intensities as recorded by ground stations in Brazil (BZ) and Hawaii (HW) and at the McDonald Observatory (MCD) in Texas.



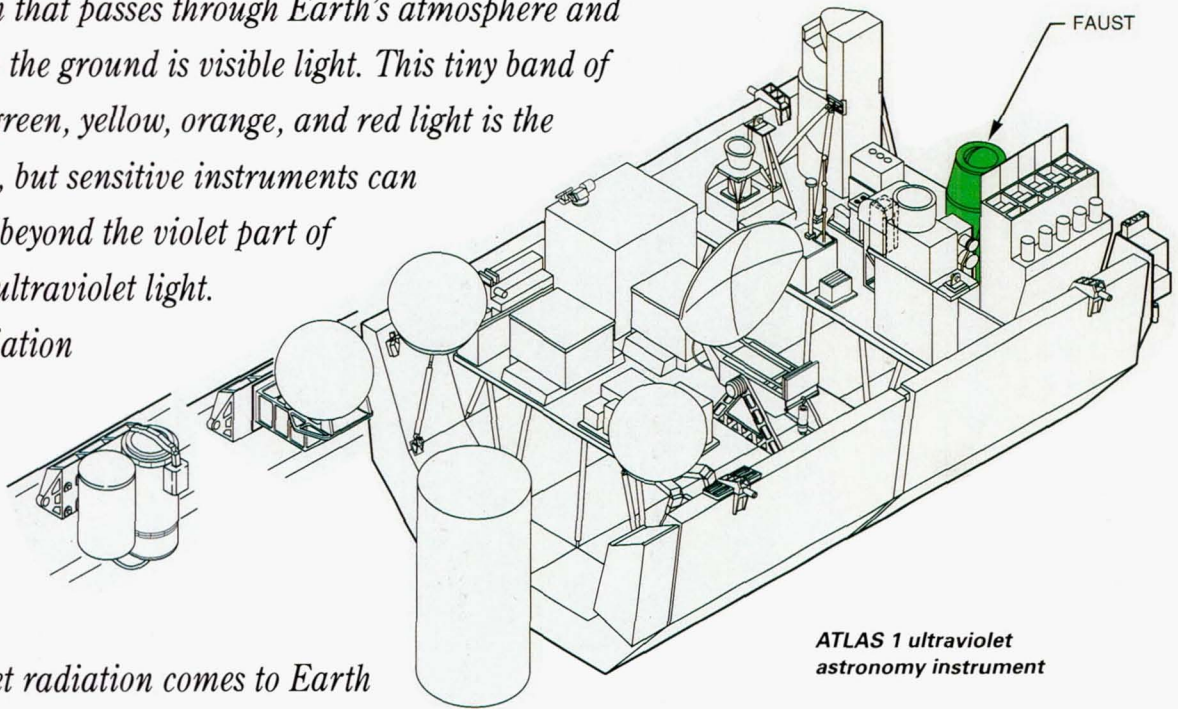
Immersed in Ultraviolet Light

Most of the radiation that passes through Earth's atmosphere and reaches telescopes on the ground is visible light. This tiny band of violet, indigo, blue, green, yellow, orange, and red light is the one that humans see, but sensitive instruments can detect radiation just beyond the violet part of the visible rainbow: ultraviolet light. Most ultraviolet radiation entering Earth's atmosphere, however, is absorbed by the stratospheric ozone layer.

Cosmic ultraviolet radiation comes to Earth from many distant places in the Universe; stars that die in violent explosions, huge clusters of stars with millions of members, and congregations of hundreds of billions of stars called galaxies all emit ultraviolet radiation. To learn about these fascinating places beyond our solar system, we must place telescopes above virtually all of our atmosphere where they can detect ultraviolet radiation before it is absorbed.

Both spiral and elliptical galaxies appear in this color photograph of the Fornax Cluster of galaxies.

Photograph:
Royal Observatory, Edinburgh, and
Anglo-Australian Telescope Board.



**ATLAS 1 ultraviolet
astronomy instrument**

Ultraviolet wavelengths range from about 100 to 4,000 Å and are shorter and more energetic than visible light. (By comparison, visible light spans the region from about 4,000 to 7,000 Å.) The ultraviolet spectrum is so big that astronomers break it into three parts: the extreme ultraviolet (100 to 1,000 Å), the far ultraviolet (1,000 to 2,000 Å), and the near ultraviolet (2,000 to 4,000 Å). Since ultraviolet wavelengths are more energetic than visible ones, they reveal some of the more violent processes in the Universe.

A few pioneering ultraviolet photography experiments have been flown on satellites and rockets, and the Astro-1 Spacelab mission was dedicated to high-energy astronomy. Most of the sky, however, has never been imaged in the ultraviolet. During the ATLAS 1 mission, a telescope will electronically record far ultraviolet radiation from faint, distant targets to produce images that reveal relative brightness, location, and structure.

Far Ultraviolet Space Telescope

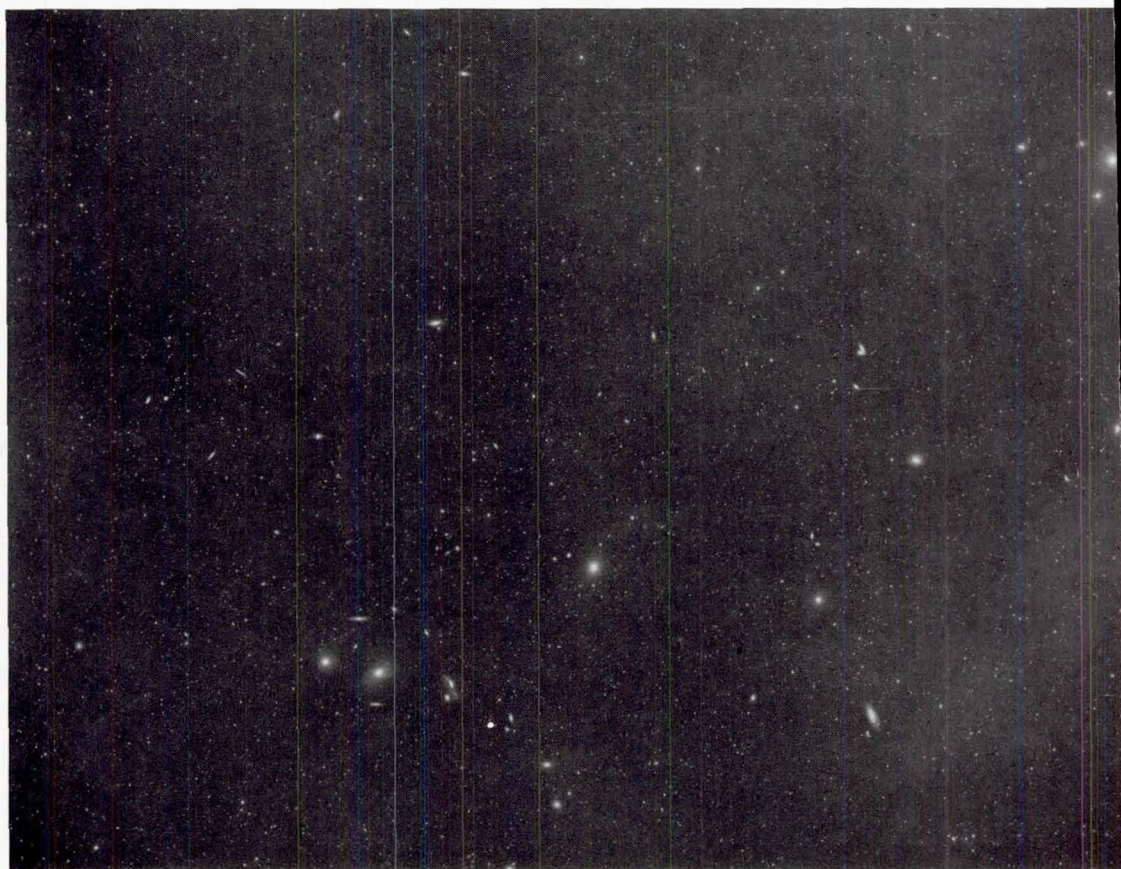
Principal Investigator: Dr. Stuart Bowyer
University of California at Berkeley
Berkeley, California, USA

■ The Far Ultraviolet Space Telescope (FAUST) is designed to observe faint ultraviolet sources in the 1,300- to 1,800-Å region of the spectrum where ultraviolet wavelengths are emitted by many astronomical objects. This specialized telescope is designed to view large areas of the sky, 8 degrees in diameter (16 times the apparent diameter of the Moon). The instrument's wide field of view and sensitivity make it possible to take detailed pictures of large-scale phenomena, which cannot be investigated with other telescopes.

For ATLAS 1, FAUST is scheduled to view its targets during orbital nights. One of its goals is to image clusters of galaxies. There are many sizes and types of galaxies: pinwheel-shaped spirals like our Milky Way, ellipses, and irregular shapes with no simple form. Galaxies congregated in groups, and FAUST has a large enough field of view to record these galactic clusters. The telescope can survey an area of the sky, looking simultaneously at 100 or more galaxies. The images will also record the ultraviolet brightness among nearby small groups of galaxies. Astronomers can use the data to determine which galaxies are most active, particularly in their rate of star formation, and can observe their ultraviolet emissions in greater detail with other orbiting ultraviolet telescopes.

Another goal is to combine several scans to compile a map of 50 to 100 galaxies in the Virgo region. Of particular interest is the galaxy M87. Visible light, radio-wave, and X-ray images of this galaxy show huge jets of material being ejected from its center. Astronomers may learn more about these emissions by studying ultraviolet photographs of the galaxy.

Within the myriad galaxies are hundreds of billions of stars



that astronomers also want to study: ultraviolet radiation is emitted by young, hot stars and hot, older stars near their death. Astronomers are also interested in giant stars and their remains: supernova remnants, which are extended nebulae of gas and dust that linger thousands of years after a star dies in a violent explosion. When a star explodes, its core is heated to billions of degrees, and the ejected gas remains hot thousands of years later. Since it is so hot, it glows with ultraviolet radiation.

When FAUST flew on the Spacelab 1 mission, it captured the first far ultraviolet photograph of the complete Cygnus Loop supernova remnant, the remains of a star that exploded some 20,000 years ago. The image yielded information that showed how the explosion affected the interstellar medium

(the normally cool, less dense dust and gas between the stars).

FAUST can also gather data from stars, supernova remnants, and galaxies that may be identified as individual objects and that emit ultraviolet radiation; thus, astronomers will learn about the intensity of ultraviolet light emitted by these discrete sources. For example, FAUST has the capability to detect many galaxies and measure their intensities. Scientists can use these data to understand how intensities vary from galaxy to galaxy and whether intensity can be correlated with other properties of the galaxies. Will, for instance, elliptical galaxies be brighter in ultraviolet than spirals or vice versa?

In addition to the individual sources that can be resolved, there is a general, diffuse glow of ultraviolet radiation coming from the

The Virgo cluster is a nearby rich cluster that contains several thousand galaxies. In this wide-field photograph, the larger fuzzy images are galaxies and the point-like images are stars in our own galaxy that appear in front of the cluster. At the very center is the giant elliptical galaxy M87, the most massive galaxy in the cluster. Two other dominant galaxies, M84 and M86, lie to the upper right of M87. Some spiral galaxies, similar in shape to our Milky Way, can be seen viewed edge on.

Photograph:
1960 National Geographic Society –
Palomar Observatory Sky Survey.
Reproduced by permission of the California
Institute of Technology.

heavens. Some of this glow comes from sources within the Milky Way Galaxy (mostly from starlight scattered by dust particles in the interstellar medium); however, some comes from beyond this galaxy, from the many distant, faint, unresolved galaxies in the depths of extragalactic space. This portion of the ultraviolet background will not be completely uniform, since the galaxies are not uniformly distributed. They gather in groups, clusters, and gigantic superclusters that stretch across hundreds of millions of light-years. These giant conglomerations deep in space give rise to an ultraviolet background with spatial variations that reflect the variety of the clusters themselves. By studying these spatial intensity variations (or fluctuations), astronomers can learn more about the groupings of distant, faint galaxies. This, in turn, will help unravel the riddles of the large-scale structure and evolution of the Universe.

Only a few images were obtained during FAUST's first flight because its film was fogged by a strong, local source of ultraviolet light, overexposing most of the images. The intense radiation that contaminated the film was determined to be non-astronomical, most likely caused by glowing arcs of atomic oxygen that encircle Earth at tropical latitudes. For ATLAS 1, investigators have modified the instrument to record arriving photons electronically rather than on film as exposures made over time.

The electronic detectors will be able to determine what is producing non-astronomical signals, such as the ones that compromised the Spacelab 1 observations. Understanding the causes of the interference — whether it is natural or induced by the Shuttle — is important because future space telescopes will be viewing under similar conditions. With FAUST,

Spectral coverage: 1,300 to 1,800 Å

Angular resolution: 2 arc min

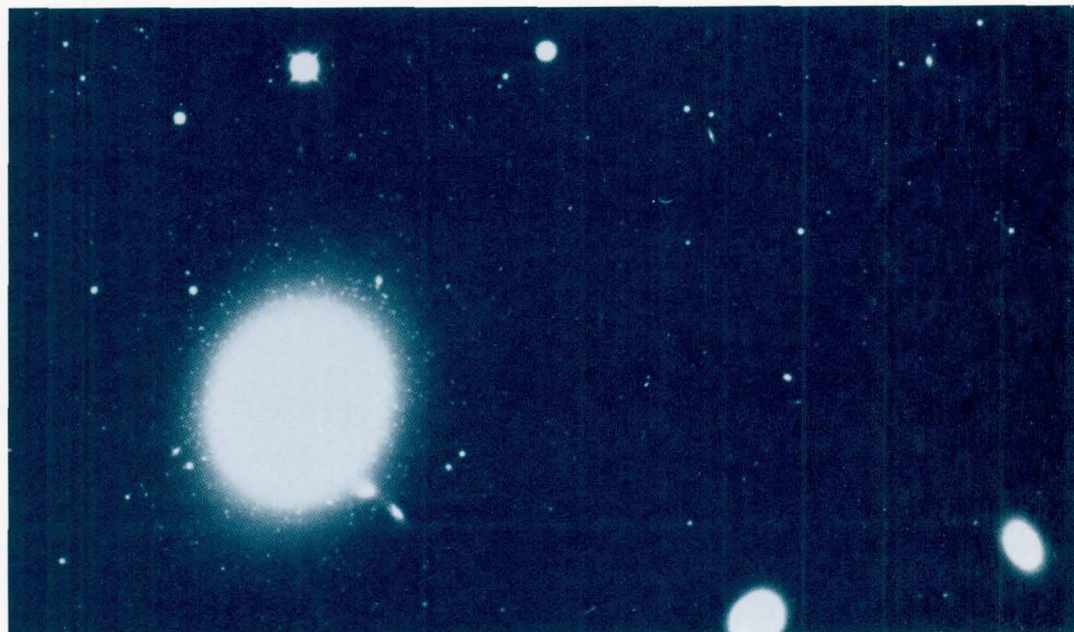
Aperture: 150 cm²

Field of view: 8 deg

Imaging capability: 2 arc min

Data rate: 4 Mb/sec

Mass: 93 kg



The FAUST surveys will reveal galaxies at various stages of evolution, show interactions between galaxies, and identify invisible hot material between the galaxies. The spiral galaxy M81 was imaged in ultraviolet light (upper left) by NASA's Astro Observatory, which was flown aboard the Shuttle in December 1990, and in visible light (lower left) by the Kitt Peak National Observatory near Tucson, Arizona. The ultraviolet photograph reveals regions where new stars are forming at a rapid rate. The bright spots in the curved spiral arms of the galaxy are concentrations of very young, hot stars; these areas are not apparent in the visible photograph because the stars emit mostly ultraviolet light.

Upper photograph:
UIT/Kitt Peak National Observatory.
Lower photograph:
Kitt Peak National Observatory.

In this closeup of M87, a jet of material streaming from the galaxy's center is visible. Astrophysicists can learn more about this violent activity by viewing M87 in ultraviolet wavelengths, which reveal more energetic processes than visible light.

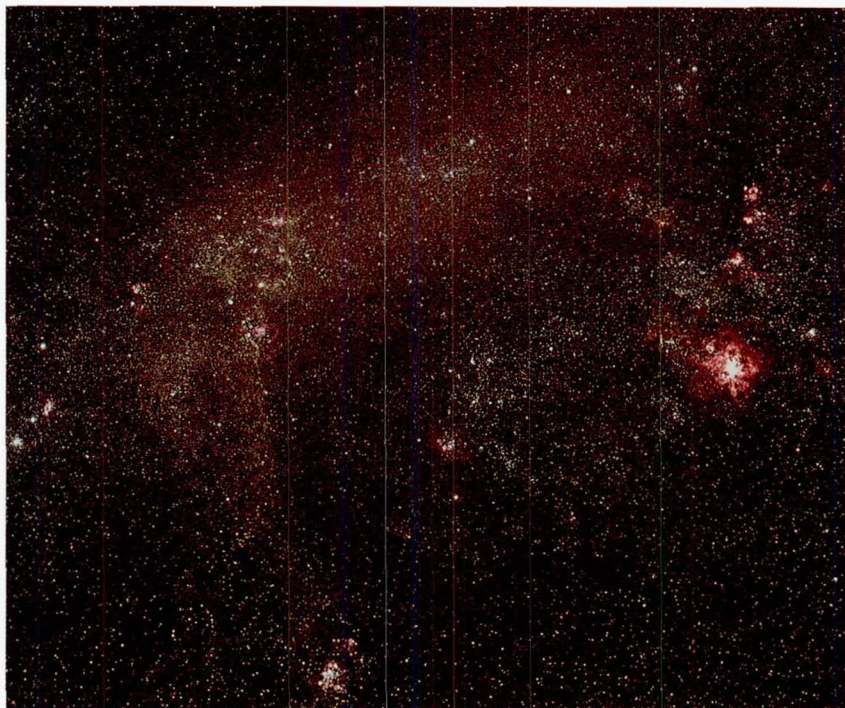
Photograph:
Kitt Peak National Observatory.

ORIGINAL PAGE
COLOR PHOTOGRAPH

no data need be lost, because unwanted high-radiation emissions can be distinguished from emissions from astronomical objects. The time of arrival of each photon will be recorded so that it can be correlated with other parameters such as the Shuttle's position over Earth, the position of the Sun, engine thruster firings, and other occurrences. From these correlations, investigators can deduce the causes of possible interference.

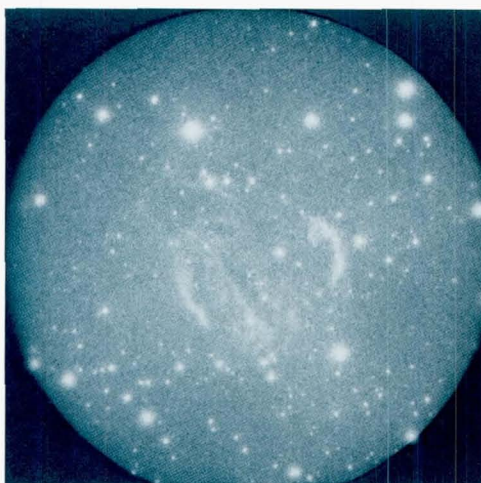
The electronic system has other advantages: it is easier to calibrate than the film system, and data are in a form that can be analyzed immediately by computer. Calibration tests indicate that in 10 minutes the improved FAUST can detect 17th magnitude stars, which are 25,000 times fainter than the dimmest star visible to the naked eye. At longer exposure times, the telescope will detect diffuse sources as faint as 27th magnitude per square arc second, making FAUST the most sensitive ultraviolet camera ever flown in space.

During orbital night, the commander or pilot will orient the Shuttle to the appropriate attitude for each observation, and the telescope will be turned on automatically by an onboard computer. If automatic operations fail, the telescope can be operated manually by the crew in the aft flight deck. Data from FAUST will be transmitted directly to the ground where investigators accumulate photon data and view ultraviolet images of the sky.



The closest galaxy to the Milky Way is the Large Magellanic Cloud, which has an irregular shape. The brightest area on the right is known as the Tarantula Nebula because of its shape. A star exploded in this region in 1987 and became the first supernova visible to the naked eye in almost 400 years. The supernova released much energetic ultraviolet radiation.

Photograph:
Kitt Peak National
Observatory.



FAUST took this 2-minute exposure of the Cygnus Loop, a supernova remnant located about 1,500 light-years from Earth. The image revealed the small-scale structure of the interstellar medium around the supernova. The ATLAS 1 images will show even more of this structure because longer exposures (up to 20 minutes) are planned.

Dr. Michael Lampton, an ATLAS 1 alternate payload specialist and FAUST co-investigator, examines the FAUST telescope.



ATLAS 1 OPERATIONS

Before a payload ever gets off the ground, people representing many professions — managers, scientists, engineers, technicians, clerical personnel, and others — spend years preparing it for flight. By launch day, everyone is working together as a team with a common goal: a successful mission with maximum scientific return for each investigation.

Mission Management

The ATLAS 1 mission is sponsored by the Office of Space Science and Applications and directed by the Flight Systems Division at NASA Headquarters in Washington, D.C. From this office, the ATLAS program manager and program scientist define the mission's science goals, select experiments, and budget funds for investigator teams, hardware development, payload integration, mission operations, mission planning, and the publication of scientific results from the ATLAS 1 mission.

NASA Headquarters works closely with Marshall Space Flight Center in Huntsville, Alabama, the field center assigned to manage the ATLAS 1 mission. Here, the mission manager directs a team effort to ensure that the science payload satisfies the needs of the scientists, uses Shuttle-Spacelab resources efficiently, and operates well during flight. The mission management team coordinates the various activities that must be completed before the mission, working closely with other NASA centers that prepare the Shuttle and Spacelab for launch, conduct flight operations, and collect and distribute data. During the mission, the team aids the crew and scientists in monitoring the payload, collecting data, solving problems, and rescheduling science operations as necessary.

The principal investigators, the chief scientists for each experiment, also play an important role in developing the ATLAS 1 mission plan. They form an Investigator Working Group and convene periodically before and during the mission to advise the management team on science-related issues and payload operations. The mission scientist leads the investigator group and coordinates its activities with the mission management team.

Mission Management Team

Program Manager
Mr. Earl J. Montoya

Mission Manager
Mr. Anthony M. O'Neil

Assistant Mission Managers
Ms. Teresa B. Vanhooser
Mr. Gerald C. Maxwell

Chief Engineer
Mr. Robert E. Beaman

Program Scientist
Dr. Jack A. Kaye

Mission Scientist
Dr. Marsha R. Torr

Assistant Mission Scientist
Mr. Paul D. Craven

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Investigators help match the experiments' requirements to available Spacelab resources, such as electrical power and crew time. They are involved in selecting and training members of the science crew, who will perform the experiments in space. They also carefully identify experiment priorities in the event that the mission is shortened or lengthened. During the mission, they meet regularly to maximize science return by evaluating science activities, taking advantage of unexpected opportunities, and working together to solve problems.

Operations in Space

Every minute in space counts. Shuttle missions only last a little over a week, and

many experiments must be accomplished on ATLAS 1. When the Shuttle lifts off the launch pad, years of planning come to a climax as scientists on the ground and their colleagues in space prepare to complete the planned experiments.

The timeline, an around-the-clock, minute-by-minute schedule of events, is prepared in advance and followed as closely as possible during the mission. All the crew activities, experiment requirements, Spacelab resources, and Shuttle maneuvers are merged into an efficient operating plan. Each experiment is assigned time slots during which it receives the necessary attitude, power, crew attention, and computer support for operation. During the flight, the timeline

can be revised in response to changes, but the goal is to adhere to the master schedule as closely as possible.

During the ATLAS 1 mission, both the crew in space and the mission management and investigator teams on the ground will work in shifts so that science operations can continue 24 hours a day. The science crew members trained to do the experiments work two 12-hour shifts, each with one mission specialist (NASA astronaut) and one payload specialist (scientist-crew member).

Those supporting the science mission on the ground work at Marshall Space Flight Center in the Spacelab Mission Operation Control Facility's Payload Operations Control Center. This facility contains banks of television monitors, computers, and communications consoles for talking to the crew in space and to personnel in the Shuttle Mission Control Center at the Johnson Space Center in Houston, Texas. A science operations area is set up at the Marshall facility for the principal investigator teams who monitor experiments, analyze data, and may talk with the crew to complete research. One of the most exciting Spacelab capabilities is this communication network between the scientist in space and the scientist on the ground.

The Shuttle will be launched from the Kennedy Space Center in Florida. About 40 minutes after the spacecraft enters its orbit, the payload bay doors will be opened, and crew members will begin activating the Spacelab subsystems. Experiment activity is scheduled to start about 4 hours after liftoff. Once the instruments are activated, the Shuttle will be positioned to begin observing sequences.

Many of the ATLAS experiments require precise pointing at the Sun, at specific spots in the atmosphere, or at astronomical objects. This requires the commander and pilot to maneuver the Shuttle to exact attitudes at specific times. For much of the mission, the Shuttle will be positioned with the payload bay pointed at Earth for instruments that view the atmosphere. For three periods (early, middle, and late in the mission), the Shuttle will be pointed toward the Sun for measurements of its energy. During some



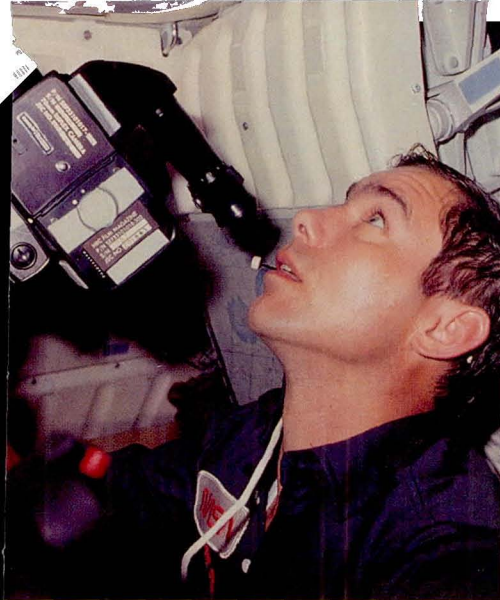
Mission Manager Anthony O'Neil, standing, briefs the crew, scientists, engineers, and other members of the ATLAS 1 team on the status of the mission during a training session at Marshall Space Flight Center.



Payload Specialists Dr. Dirk Frimout and Dr. Michael Lampton familiarize themselves with experiment procedures in the aft flight deck trainer at Marshall Space Flight Center.

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Astronaut Brewster Shaw photographs scientific activities of experiments in the Shuttle payload bay during Spacelab 1. ATLAS 1 crew members will also use the onboard cameras to record some atmospheric responses.

nighttime orbits, the instruments point toward space to observe the upper atmosphere and the stars. Other attitudes allow viewings of atmospheric chemicals highlighted at sunrise and sunset on the Earth's horizon, the natural aurora around the North or South Poles or the artificial aurora created by electron beams from experiment equipment on the Spacelab pallets, chemical airglows and magnetic fields throughout space, and other phenomena of interest.

Most of the atmospheric and solar instruments operate automatically, making observations at the times preprogrammed into their computers. In some cases, the crew will use keyboards in the aft flight deck to enter observational sequences. The astronomical instrument also runs automatically, sending data directly to the ground. Some of the space plasma physics instruments can run automatically, but the interactive experiments work best when the crew controls them. Crew members will take photographs of interesting features, select filters for observations, and use television displays to align video cameras on the pallet to make observations. They will fire the electron beam and report on any visual effects. They must also work closely with the flight crew to assure that the Shuttle is positioned properly along magnetic fields or over ground observatories for certain experiments.

About 12 hours before landing, the crew will deactivate the instruments, and shortly thereafter, the payload bay doors will close for reentry and return to Earth.

Preparing for the Next Mission

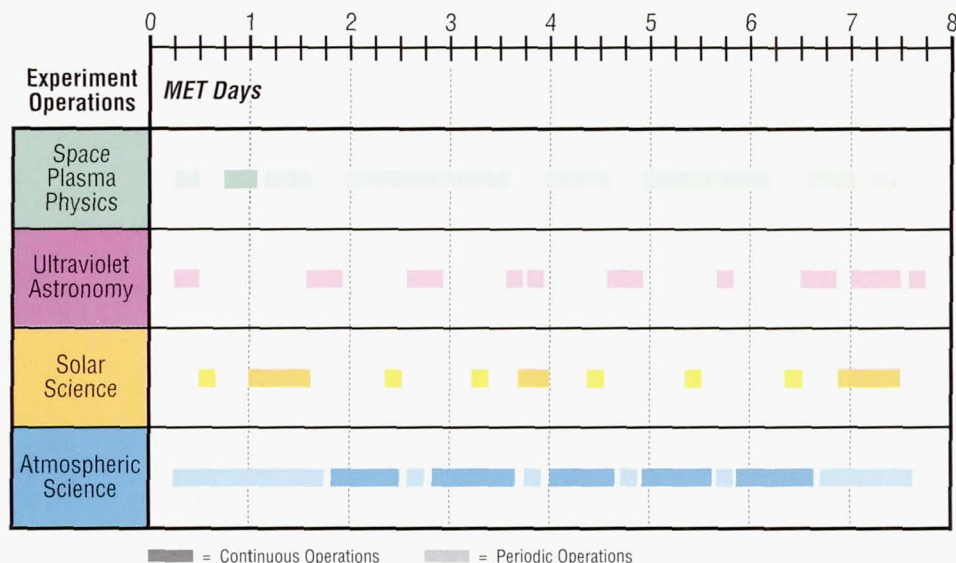
Throughout the ATLAS 1 mission, data collected by the instruments — enough to fill hundreds of videos and computer tapes — will be relayed to Earth. By the time the Shuttle touches down, investigators will already have ideas about what questions to ask during future missions or how to improve instrument operations.

Because scientists will have studied some of this information briefly as it was sent to the ground during the flight, by the end of the mission they may have new data on certain atmospheric constituents, know what auroral pictures seem to be of interest, or be excited by the way the electron beam acted during an experiment.

While the scientists will have worked long hours at their consoles during the

mission, glimpsing the promise that the data hold, most of their work will lie ahead. During the weeks after the mission, the flood of data transmitted from space will be separated and organized by experiment at a special data processing facility at NASA's Goddard Space Flight Center in Greenbelt, Maryland. These data will include computer tapes, voice recordings, and videotapes that will be sent to investigators for analyses that may last several years.

Some of the scientists will use data from ATLAS 1 to prepare for the next mission in the series, scheduled to follow about a year later. Based on ATLAS 1 results, they may formulate new questions, change observations to study a phenomenon that proved to be of special interest, or decide to conduct the experiment again without modifications. Because these sophisticated instruments are returned to the ground, investigators can also recalibrate and refurbish or upgrade components before future flights.



This simplified timeline shows the general schedule of experiment operations throughout the mission. Often, several instruments will be operating simultaneously, each requiring power, computer resources, telemetry, and possibly, crew attention. Because the available Spacelab resources must be shared among the investigations, their operations must be scheduled very carefully.

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ATLAS 1 CREW

The ATLAS 1 flight crew consists of seven members whose various responsibilities are critical to the success of the mission. Once in space, the orbiter crew — a commander, a pilot, and an orbiter mission specialist — will operate and maneuver the Shuttle, maintain the Shuttle's subsystems, and ensure flight safety. The science crew, comprised of two mission specialists and two payload specialists, will manage the Spacelab and perform experiments.

Orbiter Crew

Each Shuttle mission is commanded by a veteran NASA astronaut who oversees all operations and ensures that procedures are carried out correctly. The pilot and orbiter mission specialist, also NASA astronauts, help the commander fly the Shuttle and operate the orbiter systems. The pilot plays an important role in the ATLAS experiments, because the Shuttle must be moved often so that instruments are in their optimal viewing and operating positions. In addition, the orbiter mission specialist may assist the science crew with research.



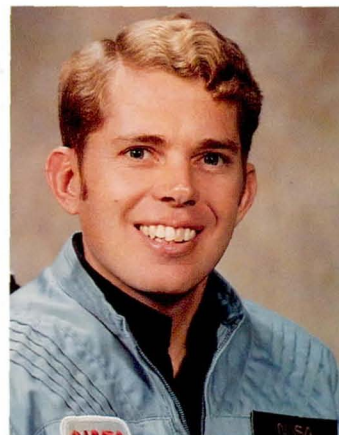
Commander

Col. Charles F. Bolden, Jr. (USMC) graduated from the United States Naval Academy in 1968 with a B.S. in electrical science and received an M.S. in systems management from the University of Southern California in 1978. He became a naval aviator in May 1970 and flew more than 100 sorties into Southeast Asia. In June 1979, he graduated from the U.S. Naval Test Pilot School and was assigned to the Naval Air Test Center's Systems Engineering and Strike Aircraft Test Directorates. Col. Bolden was selected by NASA as an astronaut in 1980. In 1986, he served as pilot of STS-61C, which made a night landing at Edwards Air Force Base. He also served as pilot of STS-31, during which crew members deployed the Hubble Space Telescope. Col. Bolden has served as Technical Assistant to the Director of Flight Crew Operations; as Chief of the Safety Division at Johnson Space Center; and as Astronaut Office Liaison to the Safety, Reliability, and Quality Assurance Directorates of the Marshall Space Flight Center and the Kennedy Space Center. ATLAS 1 will be his third mission.



Pilot

Lt. Col. Brian Duffy (USAF) graduated from the United States Air Force Academy in 1975 with a B.S. in mathematics and received an M.S. in systems management from the University of Southern California in 1981. He completed Undergraduate Pilot Training in 1976 and was selected to fly the F-15 aircraft. In 1982, he graduated from the U.S. Air Force Test Pilot School and served as the director of F-15 tests at Eglin Air Force Base. Lt. Col. Duffy became an astronaut in 1986. In his initial technical assignment, he participated in the development and testing of computer software to be used on future Shuttle flights. He then served as Technical Assistant to the Director of Flight Crew Operations. Lt. Col. Duffy currently represents the Astronaut Office in all matters concerning the ascent phase of flight. ATLAS 1 will be his first mission.



Orbiter Mission Specialist

Capt. David C. Leestma (USN) graduated from the United States Naval Academy in 1971 with a B.S. in aeronautical engineering and received an M.S. in aeronautical engineering from the U.S. Naval Postgraduate School in 1972. He became a naval flight officer in October 1973. Capt. Leestma was selected by NASA to be an astronaut in 1980. He was a mission specialist on STS-41G, during which he and Dr. Kathryn Sullivan performed an Extravehicular Activity (EVA) to demonstrate the feasibility of satellite refueling. Following this flight, Capt. Leestma served as Capsule Communicator for nine Shuttle missions. In 1989, he flew as a mission specialist on STS-28, which carried a Department of Defense payload. He is currently Deputy Director of the Flight Crew Operations Directorate. ATLAS 1 will be his third mission.



Science Crew

The four members of the science crew are responsible for conducting the ATLAS 1 experiments. During each shift, one mission specialist and one payload specialist will be on duty. Both the mission specialists and payload specialists are familiar with the experiments; the mission specialists also ensure that all necessary Spacelab services are available for smooth experiment operations.

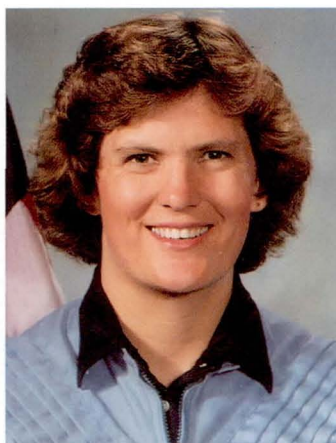
Mission Specialists

Two mission specialists, selected from NASA's astronaut corps, will operate the Spacelab systems and make sure that the payload has the needed support from the orbiter and that the spacecraft is in the right position. These career astronauts are also scientists and work with the payload specialists to operate the science instruments.



Dr. C. Michael Foale

graduated from Queen's College, the University of Cambridge, with a B.A. in physics in 1978 and a Ph.D. in laboratory astrophysics in 1982. There, his research interests included vacuum ultraviolet spectroscopy and celestial maser spectroscopy. In June 1983, Dr. Foale joined the NASA Johnson Space Center Mission Operations Directorate and was responsible for payload operations on four Shuttle missions. He was selected as an astronaut in 1987. In 1988, Dr. Foale was assigned to support and fly the Shuttle Avionics Integration Laboratory simulator, which provides verification and testing of the Shuttle flight software. More recently, he was reassigned to develop EVA assembly and rescue operations plans for Space Station Freedom. ATLAS 1 will be his first spaceflight.



Dr. Kathryn D. Sullivan

graduated from the University of California at Santa Cruz in 1973 with a B.S. in earth science and received a Ph.D. in geology from Dalhousie University in 1978. Her research interests include oceanography, remote sensing, and planetary geology. In 1979, NASA selected her to be a mission specialist. In 1983, Dr. Sullivan flew on the STS-41G mission, during which she deployed and operated the Shuttle Imaging Radar-B experiment, for which she was also a co-investigator. On this same mission, she became the first U.S. woman to perform an EVA, when she and Capt. David Leestma proved the feasibility of satellite refueling. During the STS-31 mission in 1990, she helped deploy the Hubble Space Telescope. Dr. Sullivan is also an oceanographer with the rank of Lieutenant Commander in the Naval Reserve. ATLAS 1 will be her third mission.

Payload Specialists

The ATLAS 1 payload specialists are professional scientists recommended by the principal investigators to act as the eyes and ears for scientists on the ground. They are integral members of the science teams whose training and experience in atmospheric physics, solar physics, space plasma physics, and astronomy qualify them to perform the investigations in space. Payload specialists are responsible for operating science instruments or conducting detailed experiments. Two payload specialists will oversee the ATLAS 1 science operations in flight. Two alternate payload specialists will act as liaisons between the science crew and investigators on the ground.



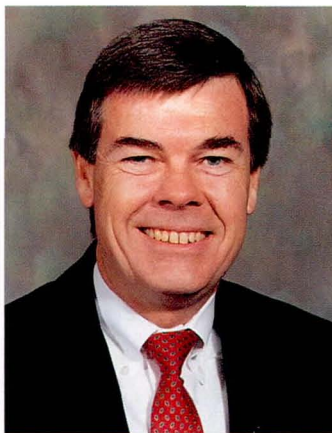
Dr. Dirk D. Frimout

received his Ph.D. in applied physics at the University of Ghent in Belgium in 1970 and performed post-doctoral work at the University of Colorado in 1971. While working at the Belgian Institute for Space Aeronomy from 1964 to 1978, he participated in many space experiments that studied the atmosphere. After joining the European Space Agency (ESA) in 1978, Dr. Frimout acted as crew coordinator and experiment coordinator for several European experiments aboard Spacelab 1, Spacelab 3, and Spacelab D1. Presently, Dr. Frimout is the Spacelab Utilization Manager in the Promotion and Utilization Department of the COLUMBUS Directorate of ESA, which is responsible for developing the COLUMBUS module for Space Station Freedom. He is also a co-investigator for the Grille Spectrometer. ATLAS 1 is his first spaceflight.



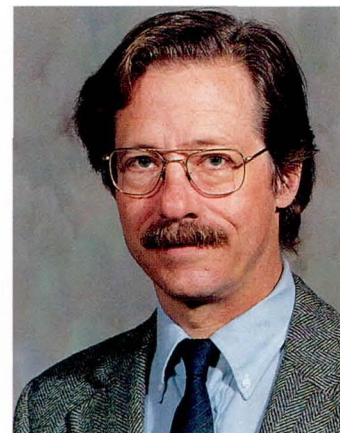
Dr. Byron K. Lichtenberg

received a B.S. in aerospace engineering from Brown University in 1969, an M.S. in mechanical engineering from the Massachusetts Institute of Technology (MIT) in 1975, and an Sc.D. in biomedical engineering in 1979, also from MIT. In 1983, he flew as the first U.S. payload specialist on Spacelab 1. Dr. Lichtenberg designed the head restraint system for the NASA Kennedy Space Center linear acceleration sled and is a co-investigator for several Spacelab experiments, including the Mental Workload and Performance Experiment, to be conducted during the First International Microgravity Laboratory mission, and the MIT/Canadian Vestibular Experiments, part of the Spacelab 1, Spacelab D1, and Spacelab Life Sciences-1 missions. Dr. Lichtenberg also has written many articles about biomedical engineering and spaceflight. ATLAS 1 is his second mission.



Dr. C. Richard Chappell

graduated from Vanderbilt University with a B.A. in physics in 1965 and received his Ph.D. in space science from Rice University in 1968. He was the mission scientist for the Spacelab 1 mission and is currently the Associate Director for Science at Marshall Space Flight Center, where he is involved in solar-terrestrial research and hardware development. Dr. Chappell has been a principal investigator or co-investigator on several experiments that have flown or are scheduled to fly on the Shuttle, including the ATLAS 1 SEPAC investigation. He also has written many papers in the field of space physics. Dr. Chappell is an alternate payload specialist on ATLAS 1.



Dr. Michael L. Lampton

graduated from the California Institute of Technology in 1962 with a B.S. in physics and from the University of California at Berkeley in 1967 with a Ph.D. in physics. His particular research interests are space physics, X-ray and ultraviolet astronomy, and optical and electronics engineering. Dr. Lampton served as an alternate payload specialist for the Spacelab 1 mission. He is an alternate payload specialist for ATLAS 1 and one of the ATLAS 1 FAUST co-investigators.

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Epilogue: Future ATLAS Missions

*Earth and its
immediate
vicinity —
perhaps the
most important
scientific
specimen of all*

The ATLAS 1 mission marks the beginning of a multidisciplinary program to conduct systematic and continuing studies of the inner solar system, with a particular focus on Earth's atmosphere. Because the atmosphere is dynamic and complex, no one mission or family of missions can collect more than what amounts to a still photograph of the chemical and physical conditions present during a particular moment in time. A definitive description of the atmosphere can only be developed over decades, perhaps even centuries. Each experiment that gathers information about conditions in the atmosphere, however, is extremely valuable and contributes to an overall understanding of its true and changeable nature.

Many ATLAS 1 experiments continue earlier flight investigations. The current studies are based on results gathered by instruments aboard satellites, rockets, balloon flights, and earlier Shuttle missions. The results of the ATLAS 1 investigations will be analyzed in light of and compared with data gathered simultaneously by similar or identical instruments on other spacecraft and with results of experiments aboard later ATLAS flights. In turn, these missions will build on the findings and discoveries of their predecessors, reflying refined and improved experiments and instruments.

Each ATLAS science discipline, with its particular emphasis, experiment programs, and instruments, creates a body of information critical to our understanding. During future global research efforts, knowledge gained through the ATLAS program will supply some of the atmospheric and solar information that will complement the findings of other scientists — geologists, hydrologists, biologists, and oceanographers — who are also working to compile a more complete mosaic of Earth's systems.

Today, as never before, we have the opportunity to shape the environmental future of Earth. For millions of years, the Sun has been the primary agent of environmental change on and around Earth, but in the last 200 years, the human race has emerged as another determining factor. We now share the guardianship of Planet Earth with a star. We can choose to risk the consequences of haphazard or unwise resource management practices, or we can seize the opportunity to actively direct Earth's atmospheric and climatic evolution toward health and balance. The ATLAS missions increase our ability to make wise decisions as stewards of the resources of our home planet.

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- pg. 1 ATLAS 1 payload. Michael Maroon, Teledyne Brown Engineering
- pg. 12-13 Atmospheric layers. Linda Styles & Brien O'Brien
- pg. 32 Auroral concept. Paul Fjeld (courtesy of the Canadian Space Agency)

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National Environmental Satellite, Data, and Information Service
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Kitt Peak National Observatory
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