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ABSTRACT

This booklet contains illustrations of the upper atmosphere, describes some recent discoveries, and suggests future research questions. It contains many color photographs. Sections include: (1) "Where Does Space Begin?"; (2) "Importance of the Upper Atmosphere" (including neutral atmosphere, ionized regions, and balloon and investigations); (3) "Airglow"; (4) "Aurora"; (5) "Recent Discoveries" (those made by manned and unmanned spacecraft); (6) "Future Research" (describing spacelab missions, tethered satellite, the International Solar-Terrestrial Physics Program/Global Geospace Science Mission, and others); (7) "Unanswered Questions"; (8) "Conclusion"; and (9) "Sources" (listing general and technical materials). (YP)

Threshold of Space

Threshold of Space

By John Bird

NASA

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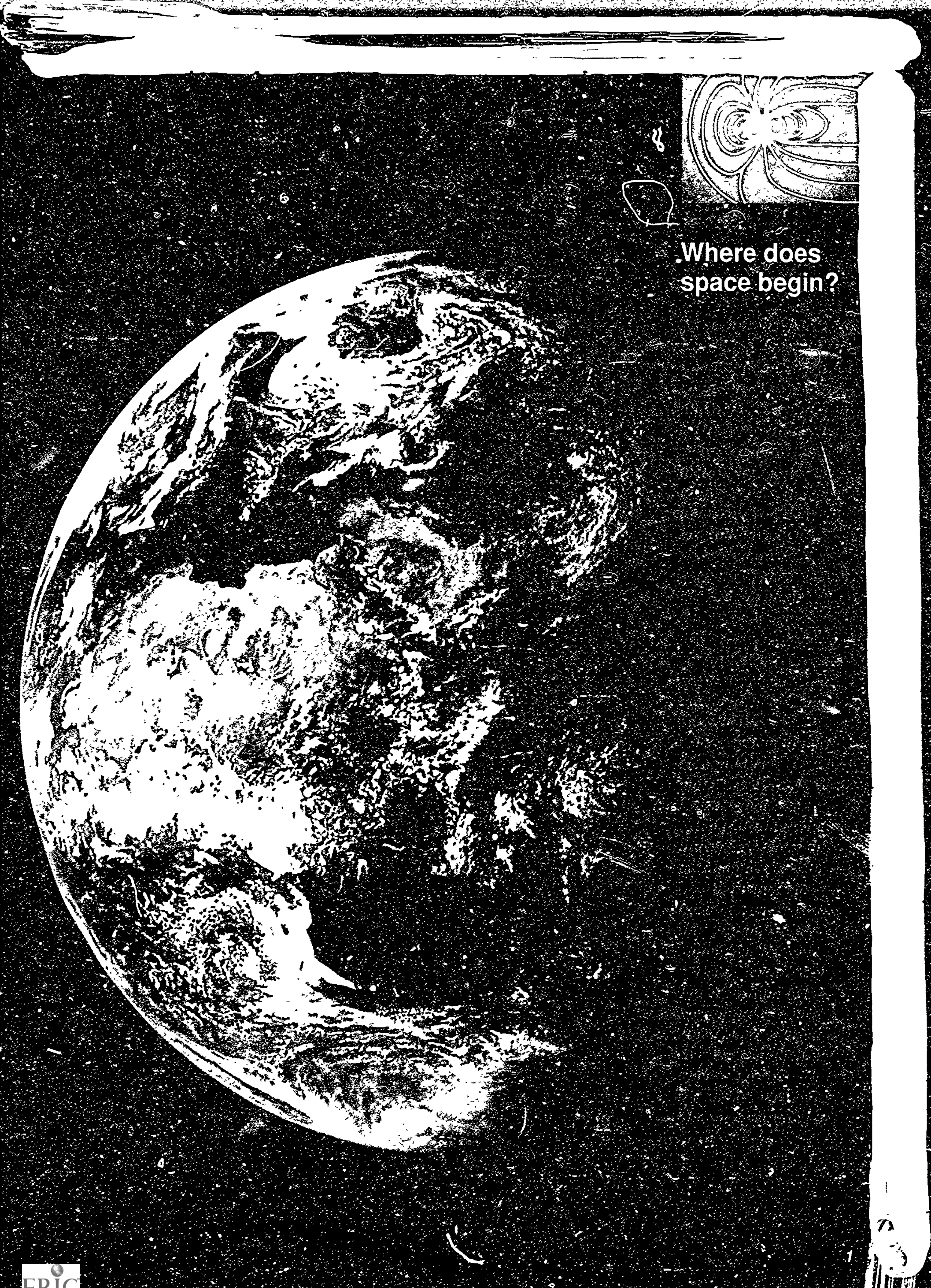

Where does
space begin?

Importance of the upper atmosphere

We are conscious of the weather, but largely unaware of the atmosphere above the clouds. However, what happens in this higher atmosphere affects the atmosphere below the clouds. Indeed, at the bottom of the atmosphere, we see only the end result of diverse processes extending from Earth's surface to interplanetary space.

Rather than being isolated and independent, these regions interact and interconnect. They form a chain from the surface of Earth—through the atmosphere and our solar-terrestrial environment—to the Sun. Ultimately, all disturbances in this environment originate inside the Sun. These disturbances spread through the chain via solar wind and radiation to influence our weather, our climate, and even our communications. More importantly, the processes in this chain are finely tuned to a delicately balanced equilibrium compatible with life on Earth.

All regions of the atmosphere interact to provide conditions essential to life and to protect life in many ways. The atmosphere provides life's most fundamental needs for survival: pressure, proper temperature, and oxygen. Without them there would be no life on Earth. Without the atmosphere, one side of our planet would be frozen; the other would be cooked by solar radiation. Fortunately, the atmosphere transmits just the right amount of sunlight and contains just the right mixture of oxygen, nitrogen, and carbon dioxide to sustain life.

We are inescapably surrounded by the atmosphere and its influences. Besides fulfilling our basic needs, how does the atmosphere influence us? It determines our climate and weather, including hurricanes, flash floods, tornadoes, and lightning. It also influences the flow of pollution, such as acid rain. Variations in weather may even influence our moods.

Even the thinnest part of our atmosphere is important. Less than 0.1 percent of our atmosphere (by mass) is above 50 kilometers (31 mi), yet it occupies a volume much larger than Earth. The Sun's rays must cross this region before reaching us. Further, the upper atmosphere is important to radio communications.

Neutral Atmosphere

Just where does the lower atmosphere end and the upper atmosphere begin? For the human body, the upper atmosphere begins a few kilometers above sea level; for a spacecraft it could be considered to begin at about 160 kilometers (99 mi). Without a generally accepted altitude to mark it, the upper atmosphere can best be understood by starting on the ground and moving upward to examine it, layer by layer. Our atmosphere is considered to be composed of layers. We distinguish these layers by temperature and by composition. Both methods are shown in the illustration on page 2. In the temperature classification system, each layer is characterized by its unique temperature variation, or gradient.

Where do the layer names come from? Troposphere is from the Greek word *tròpos* meaning to turn, implying that this region is turning and creating weather as we know it. Stratosphere comes from the Latin word *stratum*, meaning layer. Mesosphere comes from the Greek word *mesos*, meaning middle. Thermosphere comes from the Greek word *therme*, meaning heat. Exosphere means external to the atmosphere.

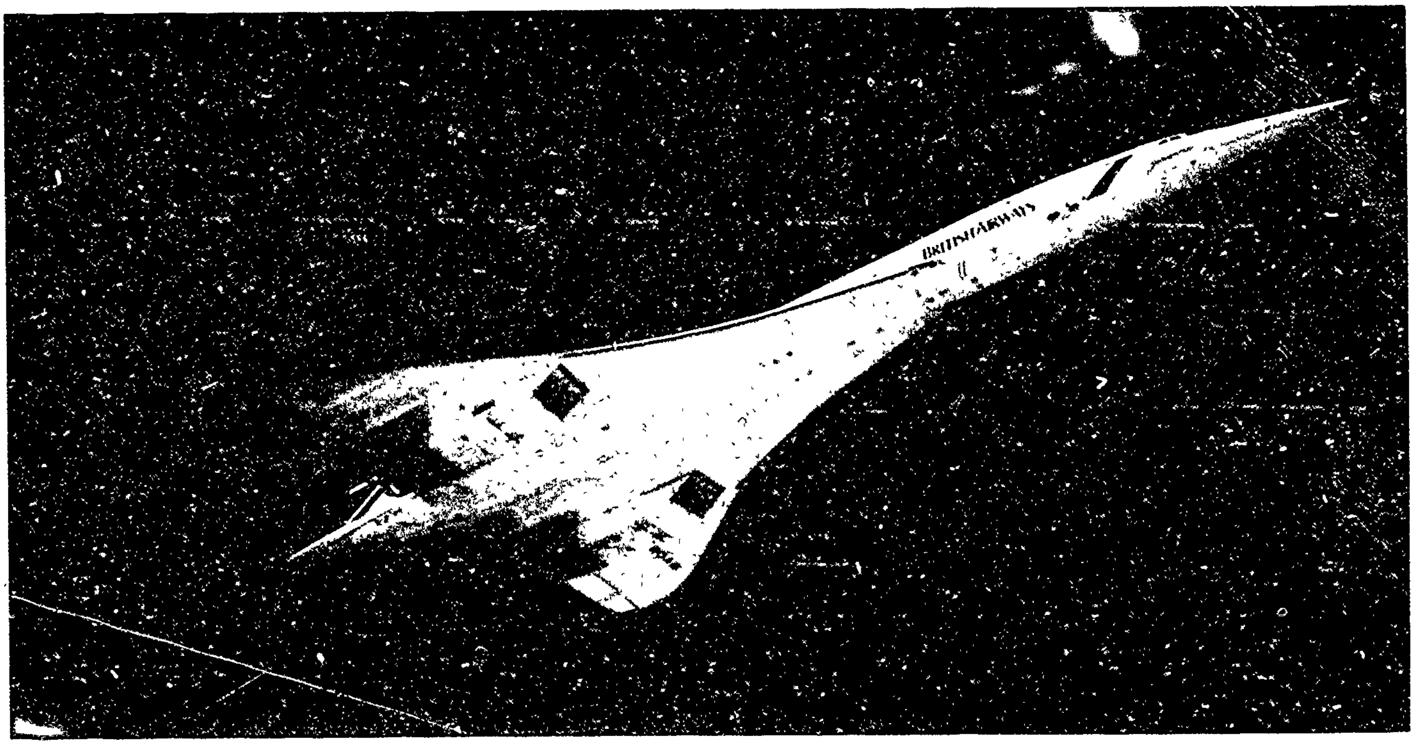
Troposphere

In the lowest layer, or troposphere, the temperature decreases the higher you go. You may have noticed this if you have ever been on a mountain. Some mountains remain snow-capped all year because of their elevation.

The troposphere has many other important characteristics, including weight and pressure, that are essential for life.

Although we are usually oblivious to the air that surrounds us, air exerts a pressure of about 101,000 pascals (14.7 psi). And

Earth as seen from a balloon at 37 km. Most of the atmosphere is below.



Concorde

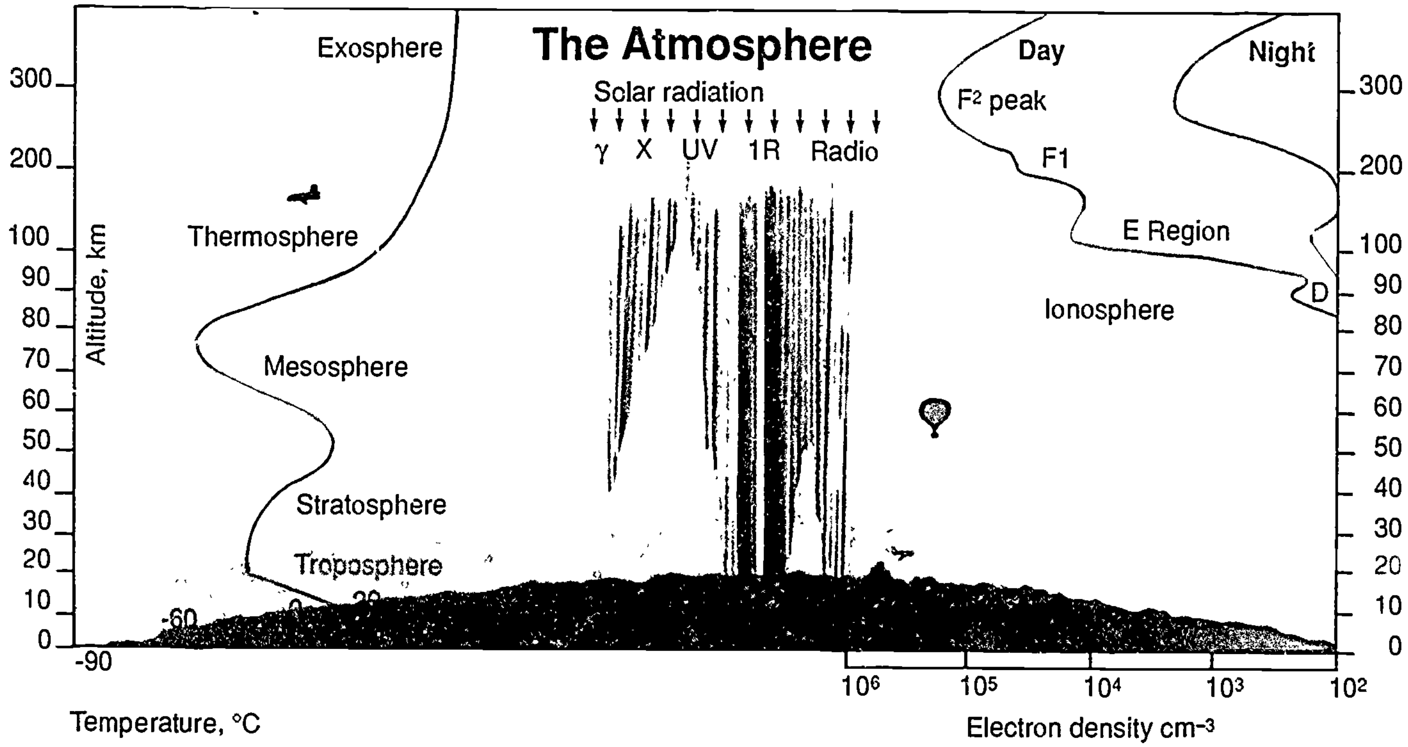
air has weight. In fact, a refrigerator contains roughly .45 kilograms (one pound) of air. Why don't we feel the weight of the air? We do not feel the weight because we are surrounded by it, just as we do not feel the weight of the water in a swimming pool when we are in it. If we were not in the air or the water, we could easily notice its weight. How? Could you carry a swimming pool? No, it has too much weight. Similarly, if you were in a huge vacuum chamber you would find that a room-size box of air would be heavy.

Other basic conditions for life—proper temperature and oxygen—are also found in the troposphere, but only near the surface. What happens as we go higher?

From the top of a mountain at roughly 5 kilometers (3.1 mi), we can see clouds below. Small private aircraft usually fly below this altitude because their rate of climb reduces as the air becomes thinner. At this altitude, whether we are in an unpressurized aircraft or on a mountain, we need supplementary oxygen unless we return to lower altitudes within a few minutes.

We may acclimatize or adapt to the thinner air, but this involves living at successively higher altitudes over a period of weeks. It is possible to live about 4.2 kilometers (2.6 mi) as do some people in Tibet; however, at this altitude, we are above virtually all plant and animal life. Our bodies are physiologically incompatible with this elevation. Without acclimatization or supplementary oxygen, it is hard to breathe, and night vision deteriorates. At 4.2 kilometers (2.6 mi) these effects are immediately apparent, but the threshold level may be as low as 1.6 kilometers (1 mi) for someone accustomed to sea level.

To climb higher into the sky, let's take a commercial jet. We soon pass the height of the summit of Mt. Everest at 9 kilometers (5.6 mi) and continue up to a cruising altitude of 10.6 kilometers (6.6 mi). From here we see a few thin wispy clouds around us and puffy white cumulus clouds far below. If the aircraft were not pressurized and equipped with its own oxygen supply, we would last a few minutes at most. Winds at this height are strong, frequently exceeding 161 kilometers (100 mi) per hour. Temperatures are also extreme: –50° C (–58°F) is typical.

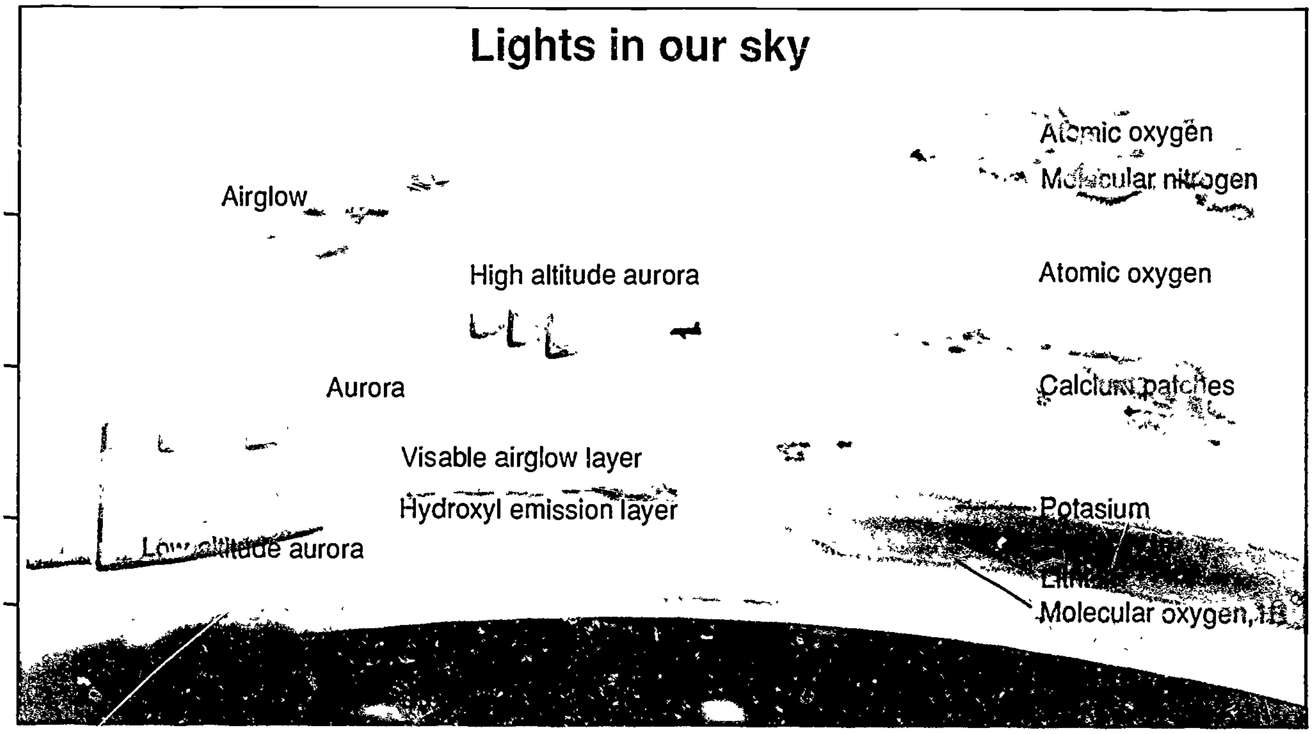


At 11 kilometers (6.8 mi), we reach the top of the troposphere. This dividing line is called the tropopause. The exact altitudes delimiting the layers of the atmosphere change with local air temperature and depend on variables such as time of year, place on Earth, and local weather conditions. Although there is no precise distinction, the division between the upper and lower atmosphere is often considered to be near the top of the troposphere. Generally, meteorology is the realm of science that studies events below this altitude. Aeronomy is the corresponding science that studies events of the neutral atmosphere above this height.

Stratosphere

To venture into the stratosphere, we need a Concorde supersonic airliner, a military jet, a rocket, or a helium balloon. Continuing up with a helium balloon, we notice that the temperature is near –50°C, and all clouds are now below. The air appears clear because there is no dust or water vapor. We could survive in the stratosphere up to 12.8 kilometers (8 mi) by breathing pure oxygen. But because we are going higher, we will need to wear spacesuits. At 20 kilometers (12.4 mi), we are above 90 percent of the atmosphere and the sky becomes a dark violet merging into black. At this height we begin to notice the curve of Earth. At 30 kilometers (18.6 mi), the extremely low pressure means almost no atmosphere is available to absorb the heat generated by our bodies. We are warm when in the sunlight, but cold when in the shade of the balloon. Our balloon will go no higher because the air above is so thin, the amount of helium in the balloon is now heavier than the amount of air it is displacing. So we let out some of the helium and float safely back to Earth.

The delicate balance of nature continues to be apparent even in the stratosphere. Ozone is an important chemical that exists throughout the stratosphere. It absorbs harmful ultraviolet radiation from the Sun. Even a small dose of ultraviolet radiation causes sunburn, but in greater doses it causes mutations and skin cancer. The maximum concentration of ozone is at 25 kilometers (15.5 mi) but even there it is a minor constituent, or component, of the



atmosphere. Ozone is an example of a trace constituent having an important influence on our lives. Some trace components in the stratosphere can be active and important to the chemical balance.

Certain activities threaten to deplete the protective ozone layer. Chloroflurocarbons for example, can rise to the stratosphere where they decompose to produce chlorine that consumes the ozone. It was once thought that supersonic aircraft produced chemicals that would destroy ozone, we now know that nitrogen oxides from these aircraft actually produce ozone. Thus, not only can the total amount of ozone be expected to change, but also the vertical distribution may change. We do not know what the consequences may be. Clearly, we must learn more about the stratosphere.

Mesosphere

Far above the reach of aircraft, and below the reach of spacecraft, lies the mesosphere, with its steadily declining temperature making it become the coldest part of the atmosphere. A mysterious no-man's land, this region can be reached by only the largest helium balloons.

The mesosphere is above 99 percent of the atmosphere and extends from 50 to 80 kilometers (30 to 50 mi). Even at these altitudes, the composition of the air is virtually the same as at sea level. However, the minor components are different. In the mesosphere, for example, atomic oxygen is created in minor amounts by the interaction of ultraviolet light from the Sun on molecular oxygen.

Thermosphere

The next region is the thermosphere. It extends from 80 to 300 kilometers (50 to 180 mi) and is characterized by increasing temperature. As implied by its name, the thermosphere is hot. In fact, it is as hot as 500°C (932°F) to 2000°C (3632°F) depending on the level of activity on the Sun's surface. In and above the thermosphere, the composition of the atmosphere is different from the mix of 78 percent nitrogen, 21 percent oxygen below. Above 100 kilometers (62.5 mi), the composition is not uniform, so the region between 100 and 300 kilometers (60 to 180 mi) is called the heterosphere, and the atmosphere below is called the homosphere. The constituents are well mixed in the homosphere.

Minimum orbital altitude—the lowest altitude at which a spacecraft can orbit Earth for a reasonable time—is about 150 kilometers (93.2 mi). However, it is possible to have an elliptical orbit where the minimum altitude, or perigee, is much lower. For example, the Space Shuttle is initially sent into orbit at 100 kilometers (62.5 mi), where the main engines burn out. This is twice the maximum balloon altitude. Even though a spacecraft can orbit in the thermosphere, there is a slight drag force because of the thin atmosphere. This causes the spacecraft to slow down gradually until it eventually reenters the lower atmosphere and burns up. But, as orbital altitude increases, drag decreases, and the spacecraft may stay in orbit longer.

Exosphere

The exosphere extends from 300 kilometers (180 mi) to the undefined region where the atmosphere gradually merges with interplanetary gases. Hydrogen and helium are the main gases of the exosphere, but the density of these gases is low.

Weightlessness

Now that we are at orbital altitudes, are we above gravity? How high does gravity go? Earth's gravity is cut in half at about 1600 kilometers (960 mi), but gravity exists throughout the universe. To explore this further, imagine an office building 250 kilometers (150 mi) tall. In an office on the top floor we have the same view of Earth that astronauts have from the Shuttle. Inside the pressurized building we are comfortable, but we would of course need to wear spacesuits if we open a window. Except for the view, the office is typical. Looking outside, we see a black sky even though it is noon and sunlight fills the office. We are not weightless. We do not even feel lighter.

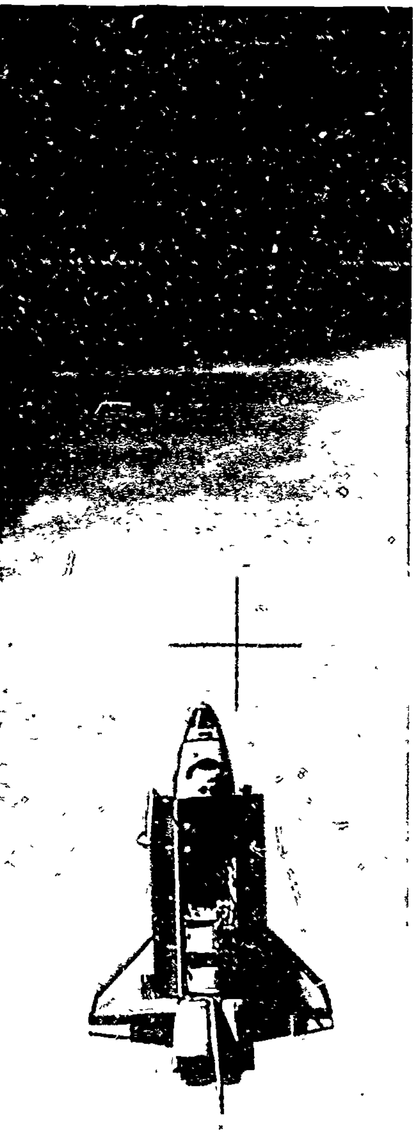
Suddenly, a bright star appears against the black sky. It is a Space Shuttle 50 kilometers (30 mi) away and approaching at 8 kilometers (5 mi) per second. A few seconds later it flies by within a kilometer of us. We see it clearly but only for a fraction of a second, just long enough to see two spacesuited astronauts floating around in it

Why are they weightless if we are not?

They are weightless because they are in free fall. Any object in free fall is weightless unless the object is acted upon by some outside force, such as wind. You are weightless when you are jumping off a diving board.

But how can the astronauts be falling if they are travelling horizontally? The Space Shuttle appears to be flying horizontally because it flies parallel to Earth's surface, but gravity is still pulling it down. The resulting path follows the curve of Earth.

Does gravity reduce with height? Yes. But even at the top of our 250-kilometer (150-mi) building, gravity is reduced only slightly. We have to go hundreds of kilometers higher before our weight drops significantly.



Space Shuttle seen from temporarily free-flying Shuttle satellite.

Ionized regions

Ionosphere

Rather than characterizing layers of the atmosphere by temperature variations, we can identify the series of layers, or regions, by the presence and density of electrically charged particles.

Where do these charged particles come from? Atoms contain oppositely charged particles called protons and electrons. If an electron, which is negatively charged, leaves an atom, the result is a free electron. The remaining, positively charged atom is called an ion. The density of the free electrons is referred to as electron density. The electron density, or number of electrons in a given volume such as a cubic centimeter, is the same as the ion density. Electron density in the atmosphere increases by height, from nearly zero at 50 kilometers (30 mi) to a peak at 180 to 300 kilometers (110 to 180 mi), then it decreases.

This region of ions, called the ionosphere, is shown in the illustration on page 6. Note that the ionosphere is divided into subregions called C, D, E, and F corresponding to different electron density variations. The term "region" is used rather than "layer" because the altitudes of the regions vary from one location to the next. The ionosphere, which is composed of charged particles, is imbedded within the thermosphere, which is composed of neutral particles. As a result, all of these particles are mixed together.

The ionosphere is important because ions and electrons affect radio waves. For example, radio waves are reflected by the ionosphere, allowing communications around the world. Further, all satellite communications must transmit radio waves through the ionosphere, where complex interactions occur.

You may have noticed that radio reception from stations far away improves at night. This is because the D region, which absorbs radio waves, disappears or is greatly reduced at night (as shown in the illustration on page 6). What causes this? Solar radiation during the day causes atoms to separate into ions and electrons in a process called ionization. At night, the ions tend to recombine with electrons to form neutral particles, causing the D-region ionosphere to disappear. But other mechanisms maintain some ionization at night.

Solar flares can cause radio blackouts. How? Radiation from a flare enhances ionization and therefore enhances electron density in the D region on the daylight side of Earth. This increase in electron density corresponds to an increase in absorption of radio waves in the D region. Since radio waves must cross this region before they can be reflected to their destination, they are absorbed along their path.

Above 1000 kilometers (621 mi), the ionosphere merges into the heliosphere, where helium is found. The heliosphere in turn merges into the protonsphere at an altitude of a few thousand kilometers where helium and hydrogen atoms are dominant. Ionized particles are mixed with the much lower-density neutral particles of the exosphere. So, like the exosphere, the ionosphere gradually merges with interplanetary gases.

Above the ionosphere most particles are ionized and are therefore in the plasma state. Plasma is neither gas, liquid, nor solid; it is the fourth state of matter. On an astronomical scale, plasma is common. In fact, over 99 percent by volume of the universe is plasma. For example, the Sun is made of plasma. Fluorescent light contains plasma, and fire is plasma.

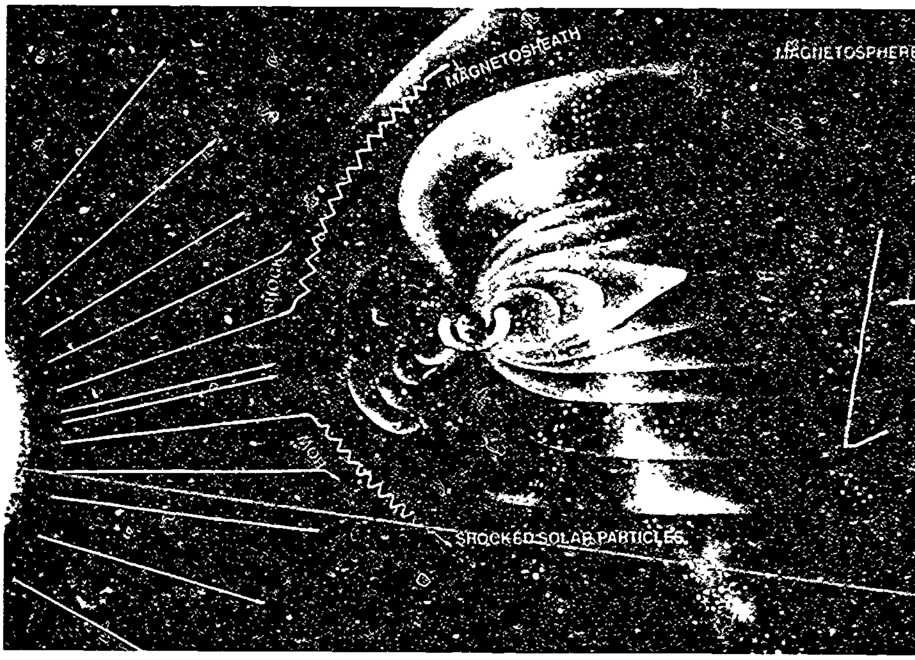
Magnetosphere

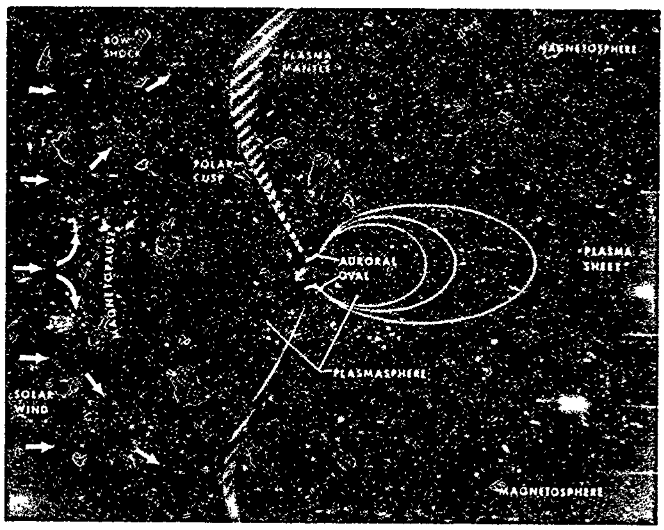
Deep inside Earth, flows of molten metal sustain a huge magnetic field around Earth. The shape of the magnetic field lines would be similar to those of a simple bar magnet, however, the solar wind causes a distortion. Facing the Sun, the magnetic field is compressed by the supersonic solar wind to form a shock wave. As shown in the illustration top right, the cross-section of this shock wave has the shape of a bow and is called a bow shock. On the other side of Earth, the charged particle environment contained by Earth's magnetic field (the magnetosphere) stretches hundreds of thousands of kilometers in a long magnetotail. At its base, the magnetosphere merges into the ionosphere. All particles in the outer magnetosphere are electronically charged while only a fraction is charged in the ionosphere.

The near-Earth space environment, including the magnetosphere, the ionosphere, and the upper atmosphere, is known as geospace. Together with the solar wind and the Sun, the entire system is known as the solar-terrestrial environment.

As shown in the illustration to the right, the magnetosphere includes a complex system of interacting electric and magnetic fields, electric currents, and particle flows. In 1958 doughnut-shaped radiation belts were discovered using satellite *Explorer I*. These regions are known as the Van Allen radiation belts. Two belts—the inner and outer radiation belts—contain the most energetic particles of a larger doughnut-shaped region called the plasmasphere.

High-powered electrical currents in the magnetosphere are connected through the ionosphere. The aurora (described in detail later in this book) gives us visual clues to processes occurring in the magnetosphere.





Top: The magnetosphere of Earth is shaped by the solar wind.

Above: Regions of the magnetosphere.

Photos:

1 *Helium balloon during inflation. Two helium input tubes speed inflation during this critical phase when the thin plastic is exposed to wind.*

2 *Balloon after inflation shown with parachute lying on the ground, and the payload on "Tiny Tim."*

3 *Just after a balloon is released, it begins to pick up the parachute and payload.*

4 *Balloon during ascent, after it is free. The parachute and payload hang below.*

5 *Recovery of a scientific balloon payload.*

Balloon investigations

Many investigations of the atmosphere have been conducted with helium balloons sent into the stratosphere. Investigations utilize the balloon's unique capability to fly at altitudes far above the reach of any aircraft, although still far below the reach of any spacecraft.

In addition to *in-situ* stratosphere experiments, balloon payloads often carry telescopes and cosmic-ray detectors aloft to take advantage of the clear sky at these altitudes. As shown in the illustration of the sky, only a small part of the electromagnetic spectrum reaches the ground. Harmful radiation such as gamma rays and X-rays, as well as most infrared light, is absorbed gradually before it reaches the surface. However, at balloon altitudes enough radiation is present and transmitted in these wavelengths to allow gamma ray, X-ray, and infrared photographs of the cosmos. Therefore, with balloon-borne telescopes, we may literally study the Sun, our galaxy, and other galaxies in a different light.

For example, infrared light is invisible to the human eye, but telescopes can pick it up. This is fortunate because some astronomical objects give off most of their energy as infrared light. However, because this light is absorbed by water in Earth's atmosphere, telescopes on the ground can detect little of it.

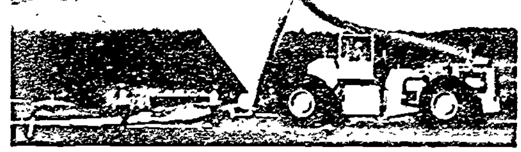
Balloon-borne telescopes fly above most of the water vapor in the atmosphere, and are more sensitive to infrared light. They have another advantage over ground-based telescopes, because the atmosphere itself emits infrared light. Flying high above much of Earth's atmosphere, balloon-borne telescopes have a much clearer view of the sky.

Infrared light can, however, pass through interstellar dust clouds, giving an unobstructed view of the universe not possible with visible light. This occurs because the infrared wavelength is greater than the diameter of the dust particles. The interstellar particles, less than one micron in diameter, are about the size of smoke particles. They originate in stars and are ejected into the interstellar environment. If we could see through the dust clouds that block our view in visible light, we could observe otherwise unknowable portions of our own galaxy.

The helium balloons required for these flights are not at all like regular hot-air balloons. They are hundreds of meters high and made from plastic thinner than household garbage bags. Upon launch, a small amount of helium is added to the top of the balloon. The bottom of the balloon is attached to the top of a parachute. The parachute is attached to the payload, which in turn is on a truck. As the balloon rises, it picks up its own deflated portion, then the parachute, and finally the payload.

As the balloon rises, the atmospheric pressure surrounding it decreases, allowing the balloon to expand. When it reaches its peak altitude, it is fully inflated to a nearly spherical shape. To bring the payload back down, an explosive bolt is fired. This separates the payload and the parachute from the balloon. The balloon is destroyed, and the payload floats gently back to the ground.

Balloons, of course, are not the only way to study the upper atmosphere. Other methods utilize ground-based stations, aircraft, rockets, satellites, and manned spacecraft.



Ground-based instruments include scatter radar facilities that monitor the temperature and winds in the thermosphere.

Before we look at satellite and spacecraft investigations, let's look at the structure of the atmosphere beyond ballooning altitudes.

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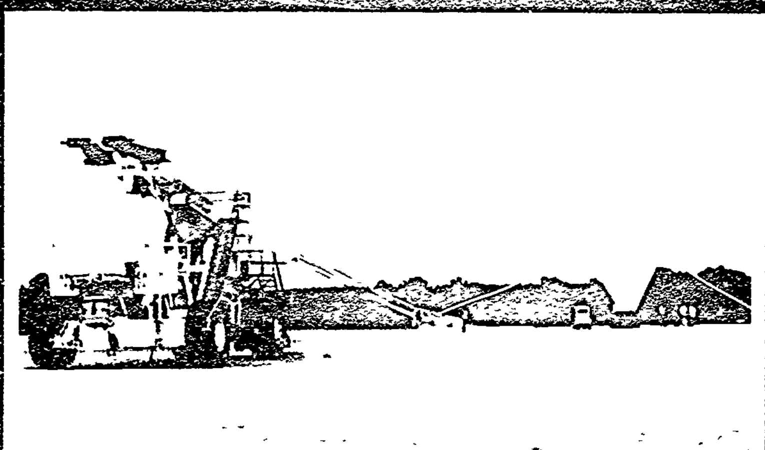

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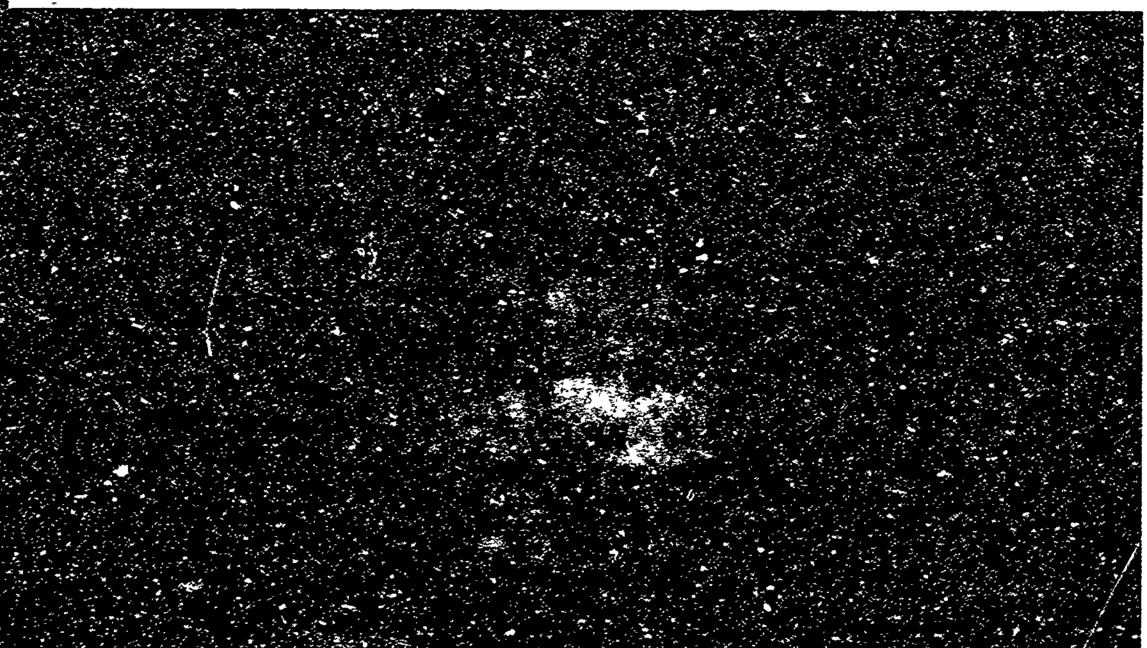
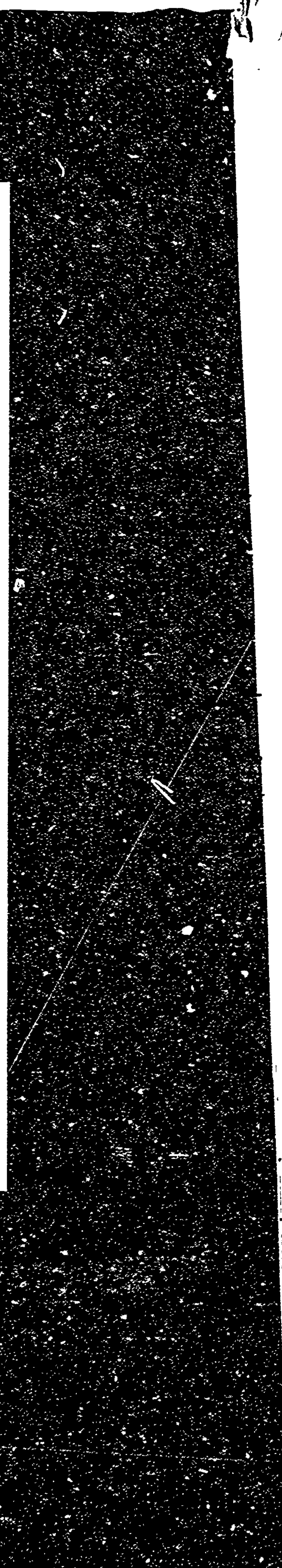
Top: Aurora and airglow from Shuttle mission.





Above: Edge-on view of the airglow layer, showing the dim red aurora above and the clouds below.

Right: Spectacular view of the green-blue southern aurora and the red airglow layer seen from Skylab.

Airglow

What is it?

Although the night sky appears black, sensitive instruments can see colorful layers extending hundreds of kilometers high. These colors are not visible to the naked eye, but appear as a dim glow in the night sky away from city lights on a moonless night. A tree or any other object will be visible against the sky. About half of this light comes from continuously glowing regions in the sky extending from 50 kilometers (30 mi) to hundreds of kilometers from the ground. This light emission is called airglow. The rest of the light in the moonless night sky comes mainly from stars, planets, and the scattering of sunlight by interplanetary gases and dust.

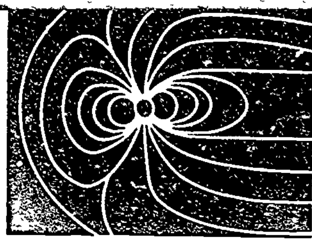
Airglow also exists during the day. However, this dayglow is not visible to the human eye because the scattered sunlight is much brighter. Only recently have we begun to study dayglow, so it is not as well understood as nightglow. Optical instruments can more readily observe twilight glow, that is, the dayglow seen from the night side of Earth.

A prominent feature of twilight glow is the emission of light from alkali metallic vapors. Lithium, sodium, and potassium form overlapping layers. An interesting feature of the lithium layer is that its brightness increases following atomic bomb tests performed in the atmosphere. The source of these and other metallic vapors above 100 kilometers (60 mi) is thought to be meteor vaporization.

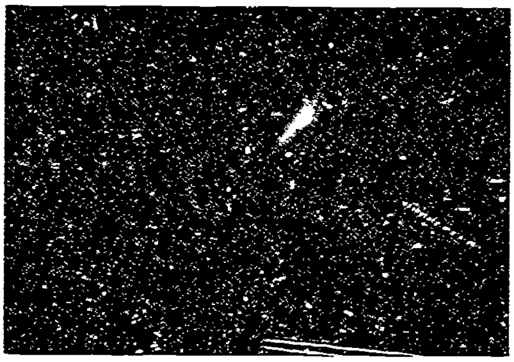
Airglow was not discovered until the early part of this century when spectrums of the night sky revealed light emitted from atomic oxygen. These atoms are the source of airglow. They are produced mainly by the breaking up of oxygen atoms during the day by solar ultraviolet.

Spacecraft observations

From orbit astronauts have an amazing view of the airglow. When they are on the night side of Earth, they clearly see the brightest region of airglow as a thin layer about 100 kilometers (60 mi) above the horizon. Other airglow regions that are not bright enough for the human eye can be photographed by the astronauts. The brightest subvisual airglow regions are the red emissions from atomic oxygen at 250 kilometers (150 mi) and the infrared emissions from molecules below 100 kilometers (60 mi).



Aurora



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What is it?

Some of nature's most beautiful displays are seen in the sky: rainbows, sunsets, and stars. Another is the aurora—a spectacular light show seen in the night skies at northern latitudes. Colorful bands of light flicker and dance across the sky. People living in Alaska are lucky because they can see the aurora on almost any clear night. But in summer the nights up north are short, or there is no night at all, so the best time to see the aurora is in the winter. Further south, the aurora appears less frequently.

People have always been curious about the aurora, citing it in folklore and mythology throughout the ages. Scientific studies of the aurora also date a long way back, specifically to 1621 and a French scientist named Gassendi. He documented his observations in a physics book in which he referred to what he saw as the *aurora borealis*, meaning northern dawn. The aurora is popularly known as northern lights.

In 1773 the corresponding phenomenon in the Southern Hemisphere, *aurora australis* (southern dawn), was first reported by Captain Cook. He observed it when he sailed the Indian Ocean.

By 1873 the northern auroral zone was mapped and was found to be a ring around the north magnetic pole. Spectral measurements, that is, measurements of the component colors, were initially made in the early 1900s. An international campaign during 1957-58 was organized to study the aurora. This led to our current general understanding of the aurora, but there are still many unanswered questions.

Although auroral displays most frequently occur in northern latitudes of 65 to 70 degrees, they sometimes occur at lower latitudes. For example, a famous display was seen in India and Egypt during 1872. Very low-latitude auroras are usually red. In 1938 such a display was chased by a fire brigade sent out to extinguish a fire at Windsor Castle in London.

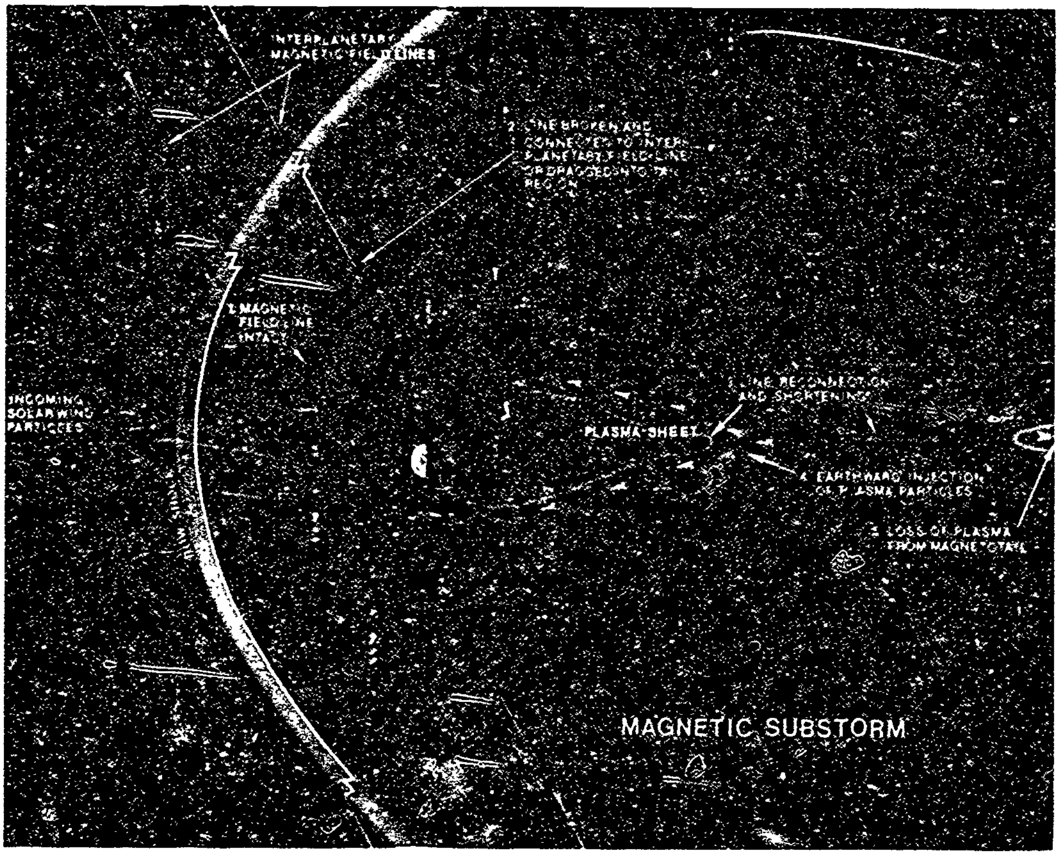
The aurora appears in many different forms: arcs with rays, bands, pulsating surfaces, and draperies. One of the most common form is a blue-green flickering drapery moving across the northern sky. Narrow, vertical, luminous columns with rapid fluctuations in intensity are common. The lower border is often intense and sometimes red. Typically, a display lasts a few minutes and occurs a few times per night. Strangely enough, there have been reliable reports of people hearing the aurora, although there is yet no scientific explanation or confirmation.

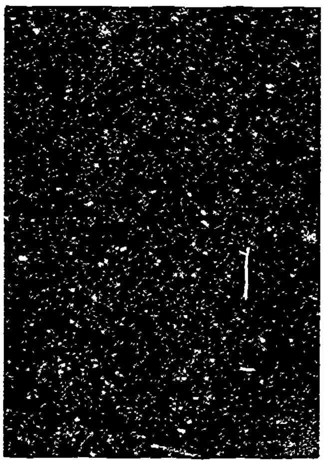
4

Photos:

1. *Red auroral rays.*
2. *Mutiple auroral bands.*
3. *Red corona.*
4. *A spectacular view of the brown airglow layer and aurora. The high altitude is red. This photo was taken between Antarctica and Australia on Shuttle flight 51-B, Spacelab 3.*

Left: Processes involved in a magnetic storm.





Above: This bright red aurora is rare and occurs only during the Sun's most intense magnetic storms.

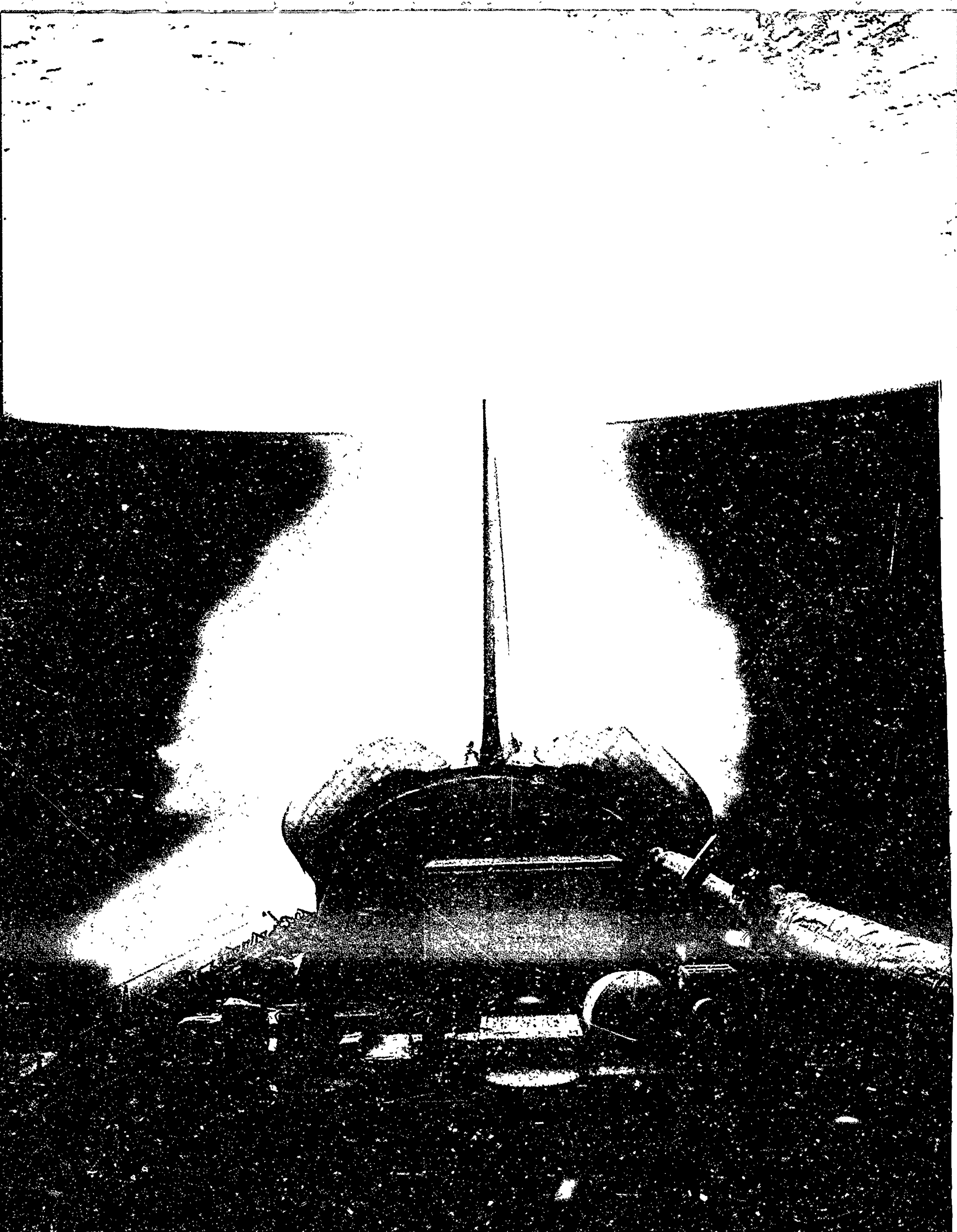
Right: A solar flare–the source of intense auroral displays.

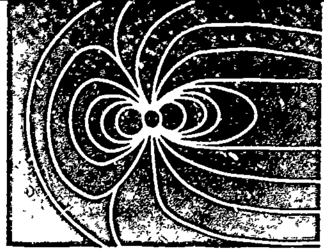
How does it occur?

To understand the aurora, we must start inside the Sun. There, a complex interaction of radiation and convection maintains the gaseous region called the Sun's corona. At temperatures over a million degrees Celsius, the corona continuously gives off particles collectively called the solar wind. When the solar wind reaches Earth, it interacts with Earth's magnetic field, causing electric currents that travel along the magnetic field lines. Much like a magnet, these field lines focus down at the polar regions, directing the electric currents to the ionosphere in the polar regions. The electrical power is scattered as it is converted to light—the diffuse aurora.

Spectacular auroral displays are caused by bursts of solar wind particles originating in magnetic storms on the Sun. These particles reach Earth directly from the Sun and from the far regions of the magnetosphere, especially the magnetotail that is oriented away from the Sun. Earth's magnetic field guides and electric fields in space accelerate particles toward the auroral regions.

The auroral regions are rings surrounding the north and south magnetic poles and may be easily seen from space. Their light is created by the interaction of solar wind particles with ions in Earth's atmosphere. The colors are characteristic of the components of the atmosphere and the altitude. The power created by a magnetic storm hitting the ionosphere is about half due to particles and about half due to electric currents.





Recent discoveries

Recently, much attention has been focused on understanding the upper atmosphere. One such concern is over spacecraft glow. Others include the results of Spacelab I and unmanned spacecraft experiments.

Spacecraft glow

Since the discovery of a mysterious glow over the Shuttle on STS-3 in early 1982, the phenomenon of spacecraft glow has been under investigation. Surfaces facing the velocity vector (i.e., into the solar wind) were found to be covered with a faintly glowing, thin orange layer. The layer is visible to the naked eye during the night side of each orbit.

This phenomenon is of great importance because of its impact on future experiments in the cargo bay and on other satellites such as the Space Telescope. An example of a problem created by spacecraft glow is that instruments designed to observe faint stars will have a more restricted field of view since they will be unable to look over the surfaces of the orbiter.

A similar effect was found on the Atmosphere Explorer-C satellite. The glow was caused by an interaction of the thin atmosphere with the satellite, which was moving at 8 kilometers (5 mi) per second. As the altitude increased, the effect decreased, suggesting its dependence on atmospheric density.

In March 1982 the STS-3 crew, Jack Lousma and Gordon Fullerton, took photos of the glow without realizing it. They photographed electron beams from the Vehicle Charging and Potential experiment during the night portion of an orbit. When the photos were developed on the ground, the glow was seen emitting from a region 5 to 10 centimeters (2 to 4 in) thick just above the surface of the Orbital Maneuvering System (OMS) pods. When the *Columbia* thrusters were fired, the glow increased. When a surface was exposed to the direct flow of the rarified atmosphere, the glow could be seen. It was particularly evident over the surfaces of the tail and OMS pods.

A fanlike glow was also observed extending from the tip of the tail to a distance of a few meters. One method used to determine the thickness of the glowing layer was to observe stars in the background while the orbiter was in a slow roll. By knowing the roll rate and the time it took for a star to disappear behind the glow, scientists could calculate the thickness of the glowing layer. Knowing the thickness of the layer provides scientists with a clue to the cause of the glow. From the thickness they can estimate the time required for the atomic molecular species to emit the light. The length of time depends on what the emitting species is, and thus the duration of each constituent color helps reveal the source composition. One species found was atomic oxygen; this is not surprising because the atmosphere at those heights is mostly oxygen.

Further studies were conducted on STS-4 by mission Commander T.K. Mattingly. The object was to find a color spectrum of the emitted light. The glow was photographed through a grating device attached to the camera. A grating acts like a prism, splitting light into its constituent colors. If the relative amount of each color is known, the composition of the material producing the light can be determined. Because the glow was faint, photos had to be taken at night when the Moon was not visible. This occurred for only 12 minutes of each orbit and only during the early part of the mission. Also, since the crew was busy, only a few photos were taken. Exposure times ranged from 50 to 400 seconds. On this flight the glow was not as bright as observed on STS-3, which was thought to be due to the higher altitude of STS-4. Also, the vehicle orientations were different. The color of the light was found to be mostly red extending toward infrared.

Firing of the Orbital Maneuvering System (OMS) engines caused this bright glow at the aft end of Space Shuttle* Challenger *on STS-7.

Glow appears on the tail and engine pod, and in the cargo bay of the Shuttle. Earth's airglow layer is in the background.

On STS-5 an improved camera system was used. Astronauts Joe Allen and Robert Overmyer photographed the glowing layer of the atmosphere at an altitude of 100 kilometers (60 mi). This airglow intensity was used to determine the absolute brightness of the vehicle glow. On this flight, samples of different materials were put on the Remote Manipulator System (RMS) arm and the glow was found to be different for each material. A similar experiment was conducted on STS-8.

On STS-9 (Spacelab 1) the crew took further glow photography, using the same camera system as on STS-5. One of the pallet-mounted instruments, called the Imaging Spectrometric Observatory (ISO) also looked for the glow, but the results are still being analyzed. It is difficult to distinguish one source of light from another because there are many sources that can cause the payload to glow. For example, when the thrusters fire, their glow lights up the payload bay and enhances the vehicle glow. Thruster firings occur often, and the resulting glow lasts a few seconds, so they are an independent problem. Other sources of light in the payload bay are faint but show up on film. They include starlight and reflections of the airglow. Even lightning on the ground was found to light up the cargo bay on STS-9.

Another Spacelab 1 experiment, called the Far Ultraviolet Space Telescope (FAUST), ended up with fogged film. The glow phenomena may have been the cause. From ground telescopes observing STS-9, it appeared that the nose of the Shuttle was glowing. This experiment will be done again.

Although not totally understood, the glow appears to be due to the impact of high-altitude oxygen atoms with lower altitude oxygen molecules. It is not clear whether the oxygen itself is giving off the glow, or whether the oxygen reacts with the surface on impact, causing some other molecule to glow. If the latter is the case, the most likely molecule would be OH, or hydroxyl, which emits red light. However, a combination of processes may be the cause. So far, the mechanism has been narrowed to three possible chemical reactions involving OH, carbon monoxide, and molecular nitrogen.

Many further investigations are planned. Spectroscopic analysis will be made of the glow on future flights. Scientists will continue working to determine the cause. The full extent of the impact on future payloads will then be realized.

Spacelab 1

Spacelab 1 demonstrated the viability of utilizing the Shuttle as a scientific laboratory for many disciplines, including atmospheric sciences.

For example, the ISO obtained dayglow spectra by looking both away from and toward Earth. Height profiles of nitric oxide and other constituents were also obtained. ISO observations of the mysterious Shuttle glow suggested two possible mechanisms as the cause. One is surface catalysis, in which molecules leave the surface and later radiate. The other mechanism is plasma discharge, in which the atmosphere around the vehicle glows like the aurora from electron impact.

Recently discovered bands of ultraviolet light 300 kilometers (180 mi) above Earth's surface have led to improvements to the FAUST to keep its film from fogging.

The Atmospheric Emissions Photometric Imaging (AEPI) experiment looked at magnesium ions that come from vaporizing meteors. The light from these ions was so strong that one of the scientist-astronauts thought the illumination was possibly due to "resonance scattering." But the Shuttle was too far below the horizon for this to occur. AEPI and a few other Spacelab 1 instruments will be reflown on another mission, called Earth Observation Mission-1 (EOM-1).

Another Spacelab experiment involved photography of the recently discovered wave patterns in cloud-like structures at 85 kilometers (51 mi) altitude. These hydroxyl clouds are seen in the infrared region and were photographed at night by the Spacelab crew. In another experiment, the astronauts observed light emission from hydrogen in the dayside aurora for the first time.

Unmanned spacecraft

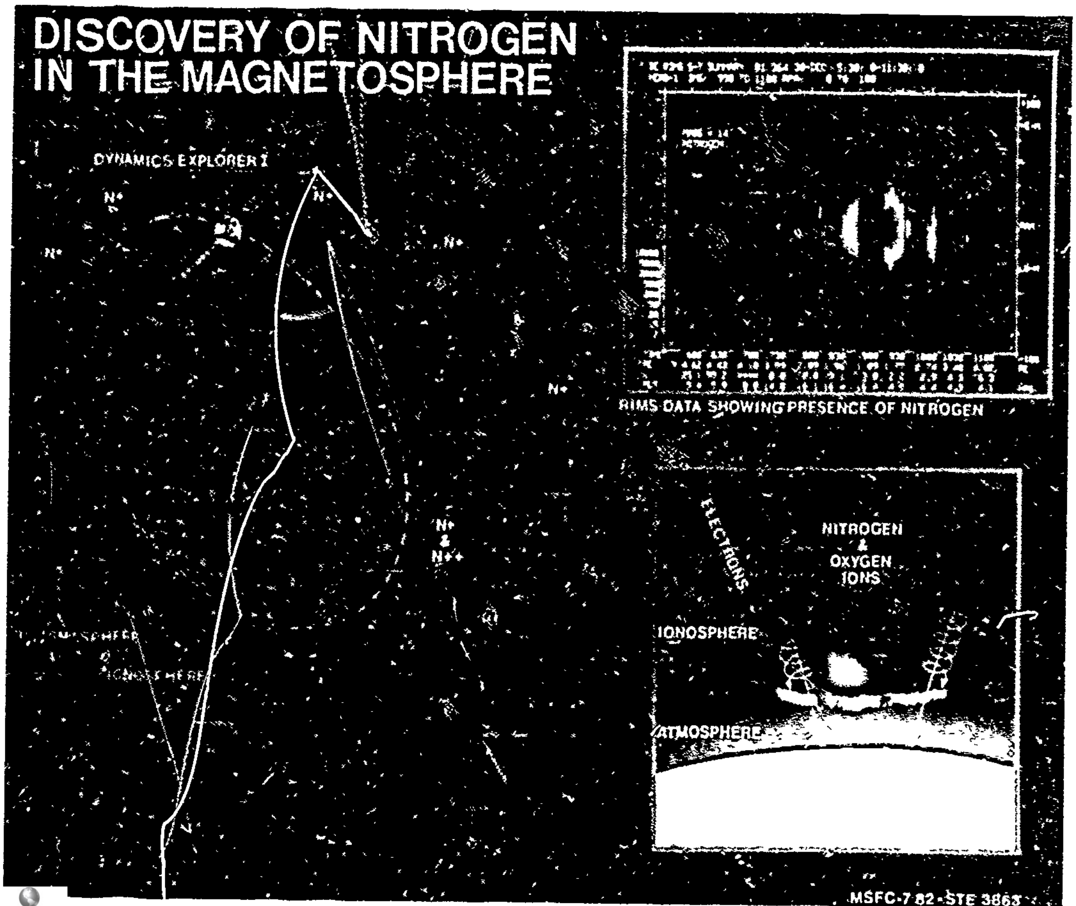
In addition to the discoveries in the upper atmosphere made using the Shuttle, many important discoveries have been made by unmanned spacecraft.

For example, two Dynamics Explorer satellites have been monitoring winds and temperatures of the thermosphere and trace constituents in the magnetosphere. These satellites discovered that particles accelerate not only downward to the auroral regions, but upward as well. Above 800 kilometers (480 mi) at high latitudes there is a continual flow of hydrogen, helium, and oxygen ions, called the polar wind.

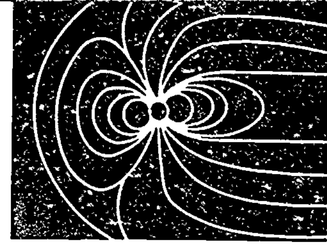
Using data from Dynamics Explorer-1, nitrogen was discovered in the magnetosphere. Scientists speculate that this nitrogen comes from the ionosphere, confirming the idea that Earth, in addition to the Sun, is a major source of ions in the magnetosphere.

For the first time, the aurora was recently seen from space in the shape of a giant Greek letter *theta*, and was found to occur regularly. Photographs of *theta*-auroras were taken in ultraviolet light by Dynamics Explorer-2.

Ultraviolet images have been provided by the Air Force HILAT satellite and by a Canadian instrument on the Swedish *Viking* satellite.



Dynamics Explorer discovers nitrogen in the magnetosphere.



Future research

Spacelab missions

Spacelab missions will be flown regularly in support of various disciplines, including those involving the upper atmosphere.

Earth-Observation Mission-1

The Earth Observation Mission-1 (EOM-1) will refly some Spacelab-1 experiments. These include the ISO and AEPI experiments that will observe airglow.

Another Spacelab payload, the Atmospheric Trace Molecule Spectroscopy experiment, will look at the Sun just above Earth's horizon. Because the atmosphere will absorb some of the Sun's light, the remaining light that reaches the instrument will provide clues about the composition of the atmosphere.

Space Plasma Lab

Passive and active techniques will be used to probe Earth's environment from Space Plasma Laboratory, which will be flown every 18 months. The first flight of Space Plasma Lab originally was called Spacelab-6, but was renamed.

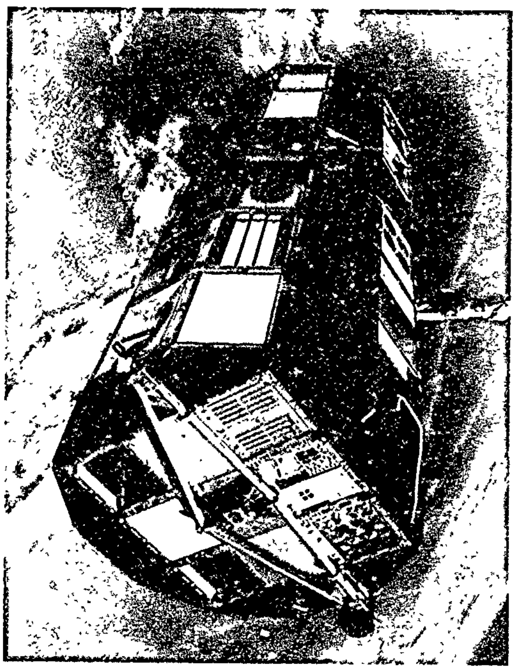
Many details of the first flight have been planned. It is scheduled for launch in the early 1990s using the Shuttle. The mission will last seven days; the orbit will be at an altitude of 300 kilometers (180 mi). The lab will be composed of two pallets and a short module where the astronauts will work. A pallet-only configuration is also possible. These components will be carried in the cargo bay. This payload has a mass of 11,000 kilograms (12 tons) of which 3000 kilograms (3.3 tons) are experiments. In either case, payload specialists will be part of the crew. Orientation of the Orbiter will be such that the yaw axis is parallel to the magnetic field lines of Earth; that is, the wings will be perpendicular to Earth's surface.

Eleven experiments are planned in three categories: injection of radio waves and particle beams into the atmosphere; experiments deployed by the RMS, including a free-flying package; and optical sensing experiments. All involve the study of plasma (see Ionosphere section).

To study the plasma surrounding Earth, Space Plasma Lab-1 experiments will support each other with coordinated measurements. They all will analyze the same phenomena using different techniques. One technique will transmit radio beams into the upper atmospheric plasma and measure the reflected waves. It will be utilized by an experiment called Waves in Space Plasma (WISP) and will transmit radio waves ranging from 300 hertz (300 cycles per second) to 300 million hertz. Different frequencies will travel different distances into the atmosphere. By analyzing the reflected beam, the electron density at various altitudes may be determined. The antenna used for this experiment will be about 300 meters (330 yards) long.

Two of the experiments will inject particle beams into space. In the Vehicle Charging and Potential (VCAP) experiment, a pulsed electron gun will emit a beam, and the returning current will be measured. The beam causes the vehicle to become electrically charged. This electrical charge on the surface of the Orbiter will be measured with respect to the surrounding plasma.

In the second beam injection experiment, Space Experiments with Particle



Far left: Future studies of Earth's environment will rely heavily on the Shuttle.

Left: Long Duration Exposure Facility (LDEF) during deployment from Shuttle.

Accelerators (SEPAC), some investigations will study plasma phenomena in the vicinity of the Orbiter and some will study it from far away. Vehicle charge neutralization and beam plasma physics will be studied close to the Orbiter. In another experiment, neutral gas will be released from the cargo bay and an electron beam injected into it. The interaction will create a glow that another experiment will observe. To analyze the atmosphere down to 100 kilometers (60 mi), the SEPAC Electron Beam Accelerator will inject pulses to probe the ionosphere.

Further investigations of the plasma environment surrounding the Orbiter will be done with experiments deployed on the Remote Manipulator System or its arm. One of these experiments is called Theoretical and Experimental Study of Beam Plasma Physics (TEBPP). Interactions of beams from other experiments with the surrounding plasma will be analyzed with this instrument package, including an energetic particle spectrometer, pulsed plasma probes, a sweeping plasma wave receiver, an electron probe, a neutral particle density detector, and a photometer system. To determine the density and composition of ambient ions, the Energetic Ion Mass Spectrometer (EIMS) includes eleven-channel electron multipliers, a retarding potential analyzer, and a magnetic analyzer.

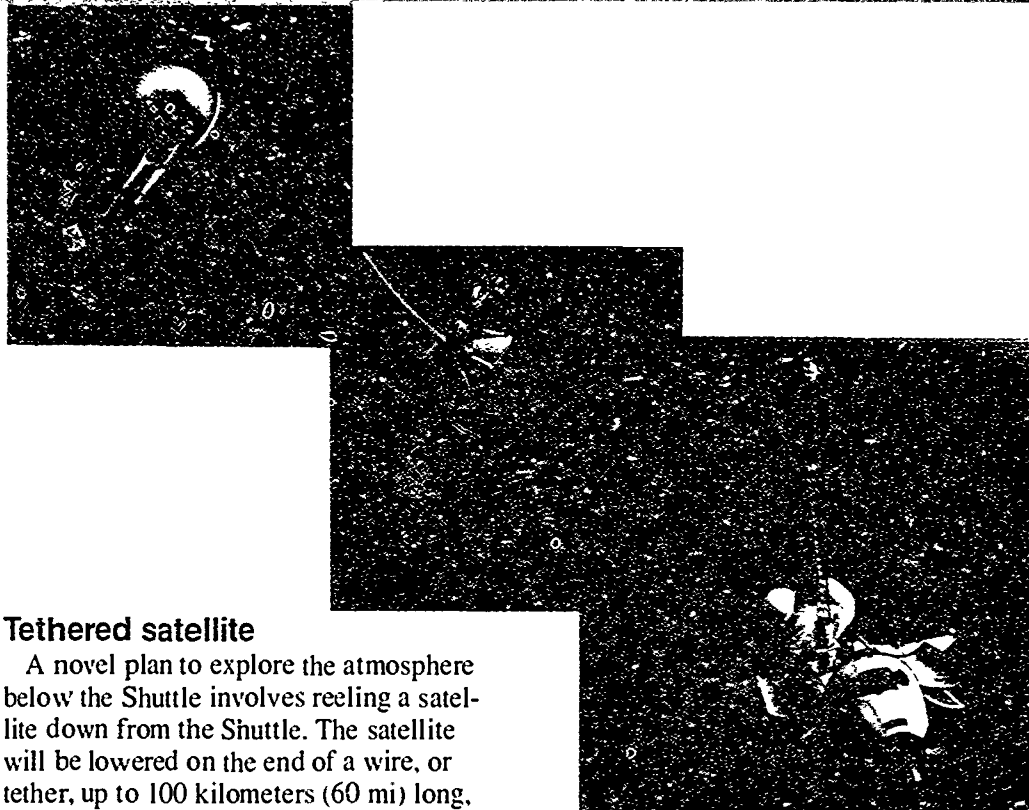
The Recoverable Plasma Diagnostics Package (RPDP) will be an instrument package deployed by the RMS and set free. It will take measurements as far as 100 kilometers (60 mi) from the Orbiter and then be retrieved. Other operational modes include use of RPDP as a tethered satellite or use only on the RMS. Instruments to be included in the package include an ion mass spectrometer, a triaxial magnetometer, electric and magnetic field sensors, and a composition analyzer. Nonrecoverable subsatellites called Magnetosphere Multiprobes (MMP) will be deployed in various locations to measure plasma waves simultaneously.

Other Spacelab instruments will optically observe the plasma phenomenon. One of these, the Wide Angle Michelson Doppler Imaging Interferometer (WAMDII), was developed in Canada. WAMDII is an imaging device that will map winds and temperatures as functions of height, latitude, and time of day. Particular attention will be paid to winds near auroral forms and near airglow irregularities. The data will complement results from a Fabry-Perot interferometer on the Dynamics Explorer satellite, which have already been published.

Another imaging experiment is the Atmosphere Emissions Photometric Imaging (AEPI) experiment, which was flown on Spacelab 1. It consists of a low light-level television camera and a Photon Counting Array. These instruments are mounted on a two-axis gimbal made from a modified Apollo Telescope Mount Star Tracker from Skylab and thus can be steered. The camera has a wide-angle and a telephoto lens that will be used to observe beams injected by other experiments and natural light sources such as aurora and airglow.

Another optical experiment is the Energetic Neutral Atom Precipitation (ENAP) experiment. It will utilize five spectrometers to observe visible and ultraviolet emissions from a range of altitudes. Still another experiment that will examine light emission at various heights is the Atmospheric Lyman Alpha Emissions (ALAE) experiment. Lyman alpha is an ultraviolet spectral line, or color, emitted by hydrogen. Examination of this light will reveal the temperature of the hydrogen.

Space Plasma Lab will be an evolutionary system to be modified as required by scientific objectives, but the basic facility will remain the same. Therefore, the turnaround time will be minimized to yield maximum scientific return, making it a valuable element of the Space Transportation System.



Tethered satellite during deployment from the Space Shuttle.

Tethered satellite

A novel plan to explore the atmosphere below the Shuttle involves reeling a satellite down from the Shuttle. The satellite will be lowered on the end of a wire, or tether, up to 100 kilometers (60 mi) long, with payloads weighing up to 500 kilograms (1100 lb), according to current proposals. Atmospheric composition, magnetic field variations, plasma flow interactions, aerodynamic measurements, and electrodynamic effects are all of interest.

Previous *in-situ* studies of this region have been conducted only by rockets that continually change altitude. The difference in gravity at the different heights of the Shuttle and the satellite will cause tension in the tether, and the satellite on the end will remain in a fixed position relative to the Orbiter. Therefore, it would be stable straight up or down from the spacecraft. After the experiments are completed, the satellite will be reeled back into the Orbiter at 10 meters (33 feet) per second or more. To begin deployment, the satellite could be separated from the Orbiter on a 50-meter (165-foot) boom to provide a slight difference in gravitational attraction. Alternatively, it could be given a slight push with springs.

Various materials have been proposed for the tether: Kevlar, Teflon, copper alloy, and nylon are some materials that have been investigated. For electrodynamic experiments, a conducting tether will be used; other experiments will call for an insulating tether.

The first flight is planned for the early 1990s, probably above 125 kilometers (75 mi). Aerodynamic effects below this height are being considered in the design, but the behavior of such a system is still unknown. Subsequent flights would occur about once a year. An early flight will use a magnetometer to map Earth's magnetic field. The initial electrodynamic experiments will use a 1-meter (3.3-foot) diameter conducting sphere.

International Solar-Terrestrial Physics Program/ Global Geospace Science Mission

Over the next few decades, scientists studying the space environment near Earth will try to develop a comprehensive understanding of its interactive regions. These regions include the magnetosphere and the ionosphere. Together with the rest of Earth's near-space environment, these regions are known as geospace.

This ambitious goal to understand geospace in detail will be realized only with a large network of observational stations on the ground and in space. By taking simultaneous complementary observations in many places, it will be possible to piece together the puzzle of this complex system.

To achieve this goal, the International Solar-Terrestrial Physics (ISTP) program is being developed by NASA, the European Space Agency (ESA), and the Institute of Space and Astronautical Science (ISAS) of Japan. The prime phase of the ISTP program will be 1989 through 1995.

A key element of the program is the Global Geospace Science (GGS) mission that involves several complementary spacecraft. They will be in different orbits and will have the maneuvering capability of large-orbit modifications. Scientific objectives of the GGS mission include tracing particle and energy flows from the solar wind to our atmosphere, determining the nature and influence of plasma processes, and investigating the origin and loss of plasma near Earth. Plasma atoms are electrically charged, or ionized. Theoretical work will involve the synthesis of mathematical models to simulate geospace. A comprehensive study of geospace as a whole has not been previously attempted.

Six spacecraft are required to monitor the plasma source and storage regions simultaneously. Primary sources of plasma in geospace are the solar wind, which is a continual flow of gases from the Sun, and the ionosphere. Primary storage regions are the tail of the magnetosphere and the electric currents that surround Earth. To cover these four regions, the six space craft are:

- **Wind** – This NASA spacecraft will monitor the solar wind upstream from Earth, at a distance of 6 to 250 Earth radii (6 to 250 times the average Earth radius of 3959 miles).
- **Polar** – This NASA spacecraft will measure plasma flows from the ionosphere and flows into high latitude regions from space. It will be in a polar orbit 6 by 250 Earth radii. This orbit will allow excellent views of the aurora. Images of the aurora will be recorded every minute, so the data transmission rate for this spacecraft (42 kilobits per second) will be much higher than the others. These images of the aurora will be obtained at various narrow wavelength bands, from X-ray through visible.

Logo : International Solar-Terrestrial Physics program, a worldwide cooperative program to study the Earth-Sun system.

- **CRRES** – This joint NASA/Air Force spacecraft will monitor the ring-shaped current that surrounds Earth. This current acts as an energy and particle storage region. The spacecraft will be placed in geosynchronous orbit at about 6.6 Earth radii. CRRES stands for "chemical release radiation effects satellite."

- **Geotail** – This spacecraft (a joint collaboration between NASA and ISAS) will orbit from a lunar flyby and back to a distance of a few Earth radii. It will monitor energy and particle storage mechanisms in the tail of the magnetosphere, or geomagnetic tail.

- **SOHO** – This spacecraft (NASA/ISAS) is designed to investigate the physics of the solar interior, the corona, and the solar wind.

- **Cluster** – This project (NASA/ISAS) consists of four small explorer-class craft positioned in a halo orbit to investigate the spatial and temporal characteristics of various small-scaled plasma structures in the solar wind and the magnetosphere. One of the cluster craft will be launched 18 months in advance to support the GGS program for its equatorial science objectives.

The Geotail spacecraft will be built by ISAS. The others will be built by NASA. European labs will contribute by sharing in the responsibility of building instruments for the NASA spacecraft.

Some of these spacecraft will be launched from the Shuttle's cargo bay. Payload Assist Modules will then propel them to their required orbits. Liquid propellant on board each spacecraft will allow maneuvering. Other ISTP spacecraft will be launched using expendable launch vehicles (ELVs).

Basically, all spacecraft will be similar. They will weigh between 600 and 900 kilograms (1320 and 1980 lb) and will incorporate spin stabilization at 10 to 20 rpm. They will consume 200 to 300 watts of power from solar arrays. Data will be stored on tape recorders and played back to the telemetry system. The spacecraft will be designed to last at least 3 years. Instruments on board the spacecraft will monitor magnetic fields, electric fields, plasma waves, plasma composition, and energetic particle velocities.

A tentative launch schedule has already been planned. CRRES will be launched in 1989, with both Wind and Polar launched in 1992 to supplement measurements to be made by the ESA-Solar Polar Mission. SOHO and Cluster will be launched in 1994.

In addition to space observations at key points in geospace, complementary ground-based observations will be made. These observations will focus on the processes of upper atmospheric heating by electric currents. To facilitate such observations, radar, magnetometer, and photometer sites throughout the world will be employed. Responsibility for deployment and operation of these facilities will be shared by a series of programs.

The DARN program will utilize a network of radar facilities located in northern latitudes. These facilities will detect back-scattered radio waves from the ionosphere that will reveal information about the structure of the ionosphere, including irregularities. Other radar facilities in eastern Canada and northern Europe will complement DARN.

MAINSTEP is a program to study the ionosphere from Halley Station, Antarctica. Data from the instruments will be incorporated into the GGS data base.

CANOPUS will study the aurora and the ionosphere. This Canadian program will involve observation facilities throughout northern Canada and will support the GGS mission.

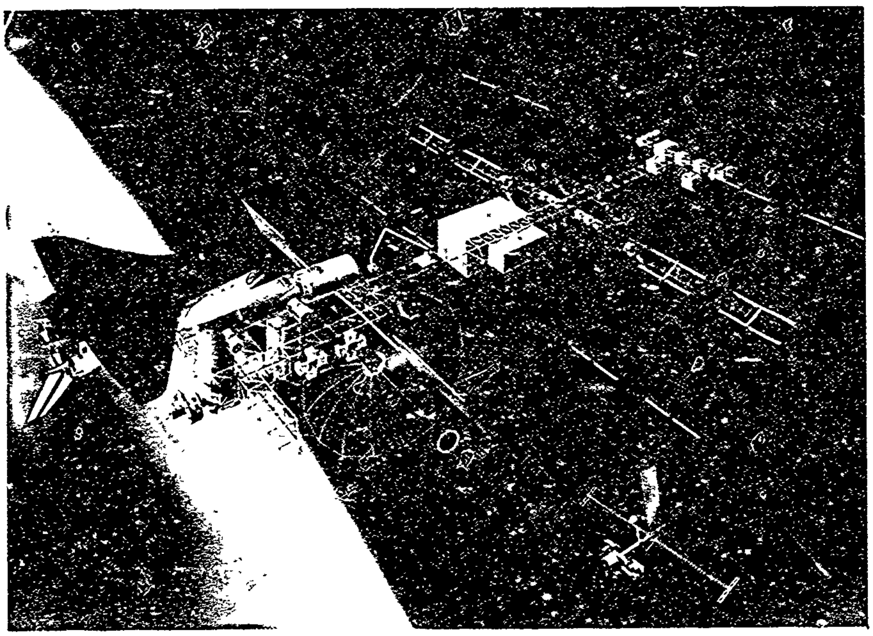
Sondrestrom Radar, located in Greenland, will also support the GGS mission by providing data on the ionosphere.

Numerous orbital geometry configurations will exploit the capability of these spacecraft for maneuvering. For example, the Wind spacecraft will fly in two different types of orbits. One involves a double-lunar swingby in which the spacecraft passes by the Moon on the way out to a distance of 200 Earth radii. The other possible Wind orbit is called the L 1 halo. In this geometry the spacecraft will orbit the famous L 1 liberation point. At this point in space, 240 Earth radii away, a spacecraft can maintain its position with respect to Earth while consuming relatively little fuel.

As a result of the GGS mission, our knowledge of Earth's environment will be greatly enhanced. It will then be possible to make much better predictions of events in geospace.

Other future programs

New technologies in areas such as optical remote sensing have recently advanced to the stage where the troposphere, stratosphere, and mesosphere can be effectively monitored from orbit. Orbiting platforms will therefore be ideal for studying the atmosphere over a range of latitudes, longitudes, and altitudes, as well as over long periods of time.



Above: Power Tower reference configuration of Space Station.

Space Station

The Space Station will play an important role in upper atmospheric research because it will be inhabited by men and women available to service and operate instruments. They will adjust experiment alignment, focusing, and calibration. The Shuttle will service the station, replacing necessary supplies and expendables such as liquid coolants for optical detection systems. Another advantage of the Space Station for atmospheric research will be the many instruments that can make simultaneous measurements of temperature, wind, cloud cover, and other atmospheric parameters. General purpose facilities for monitoring the atmosphere may include lidar and microwave facilities. The microwave facility will help us understand the relationship between the ocean and the atmosphere.

These flights to the Space Station, besides its many other missions, will increase the Shuttle launch rate. The Shuttle launches may therefore become a source of pollution because of the aluminum clouds given off by the solid rocket boosters.

Lidar

One of the most promising new methods for studying the upper atmosphere involves lasers. Lidar, or light detection and ranging, is a technique in which a laser is fired into the sky and the reflection is observed. With Lidar, the height of any atmospheric constituent may be determined, including trace constituents.

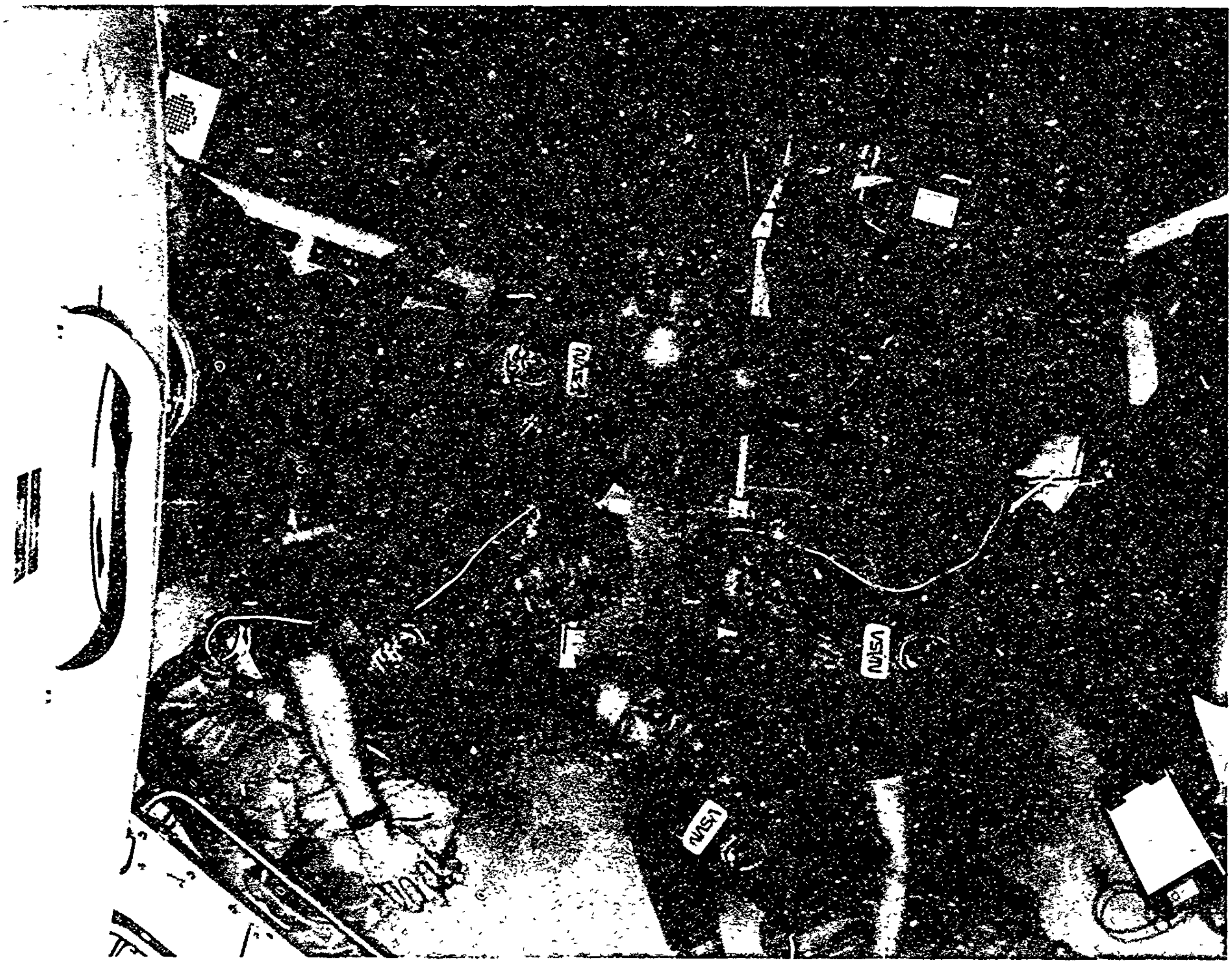
A multiuser Lidar facility on the Shuttle, and later on the Space Station, will monitor the global atmosphere. Vertical distributions and flow patterns of constituents such as pollutants and water vapor will be monitored and analyzed.

Other key measurements will include heights of cloud tops and distributions of trace constituents, such as ice, ozone, and water vapor. Because it is dangerous to look into a laser beam and because it is possible someone on the ground could happen to look skyward when the laser is fired, the design must consider the safety of people on the ground.

Long Duration Exposure Facility

The Long Duration Exposure Facility (LDEF) is another Shuttle-launched multiuse facility for collecting information about the upper atmosphere. Launched on Shuttle Mission 41-C, LDEF is designed to fit the cargo bay. It is a 12-sided cylindrical frame, 4.3 meters by 9.1 meters (14.2 feet by 30 feet). It weighs 9700 kilograms (10.7 tons).

LDEF's surface is covered by an assortment of materials that interact with the upper atmosphere while in orbit. After a



few months, the LDEF is retrieved by the Shuttle and brought back to Earth. Its test materials, mounted on trays on its surface, are sent to scientists for analysis. By studying the effects of long exposure to conditions in orbit, scientists can determine the best materials for protection of future orbiting spacecraft and facilities such as the Space Station.

LDEF will also carry materials such as glass fiber and plastic composites that may be used as structural components in future space structures, as well as materials with various insulative coatings. Lenses and mirrors will be flown to test their durability against the accumulative effects of radiation.

Certain LDEF experiments will focus on the problem presented when particles of the atmosphere cause electrical currents to form on the spacecraft surface. The effects of weightlessness on crystals and seeds will be the focus of the other LDEF experiments.

LDEF is gravity-gradient stabilized, that is, it is placed in an orientation so that the slight variation in gravity from one end to the other keeps it in exactly the same orientation. This stabilization technique will be used on the Space Station. LDEF is placed in a vertical orientation by the Shuttle's RMS, and held until all vibrations stop. It is then released.

Astronauts in Spacelab.

Upper Atmosphere Research Satellite

NASA's Upper Atmosphere Research Satellite (UARS) program will provide data on temperatures, winds, compositior , and other conditions in the upper atmesphere. Studies will emphasize the stratosphere and mesosphere to determine their response to natural phenomena, such as solar activity, as well as to the activities of humans. The Shuttle will launch UARS into a 630-kilometer (370-mi) orbit at 57-degrees inclination. This high inclination of the orbital plane will allow coverage of most of Earth's surface. The spacecraft is 7 meters by 3 meters (23 feet by 9.9 feet), weighs 5000 kilograms (5.5 tons), and will consume 1.5 kW of electrical power.

Earth Radiation Budget Experiment

When the Sun's energy reaches Earth, some is reflected and some is absorbed by the atmosphere. Because Earth emits energy, a balance is established whereby the incoming radiation balances the outgoing. This balance is called the radiation budget. To help us understand the energy balance between Earth and space, the Earth Radiation Budget Experiment (ERBE) will measure the incoming and outgoing radiation, part of which is sunlight and heat that penetrates the atmosphere.

Three satellites will be used in the ERBE system. Two (NOAA-F and NOAA-G) will be launched from California by Atlas rockets into 830-kilometer (575-mi) altitude polar orbits. The third, the Earth Radiation Budget Satellite (ERBS), was launched by the Shuttle into a 57-degree orbit and deployed by the RMS. The spacecraft's own propulsion system lifted it to its final altitude of 610 kilometers (379 mi).

One instrument to be used is the Stratospheric Aerosol and Gas Experiment (SAGE II). It will look at the Sun tangentially through the stratosphere with a telescope. The spacecraft will see the Sun set on each orbit. The line of observation will descend through successively lower layers of the atmosphere. Inside the spacecraft a spectrometer, which acts like a prism, ' eaks up the light into its constituent colors. It detects changes in the color of the Sun as the light is absorbed by constituents of the stratosphere. The remaining colors, or spectra, will reveal the presence of ozone, water vapor, nitrogen dioxide, or other chemicals. Thus the composition at different altitudes can be monitored.

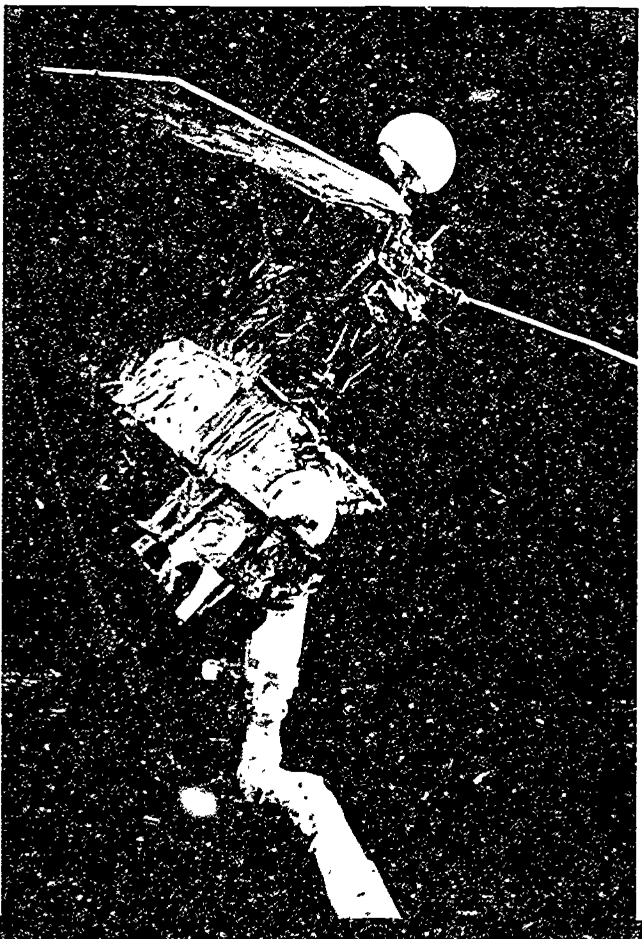
Another instrument to be used is the ERBE Non-Scanner (ERBE-NS). It includes five sensors: two will provide wide-angle observations of Earth, two will provide a narrow-field view, and one will monitor the Sun's radiation.

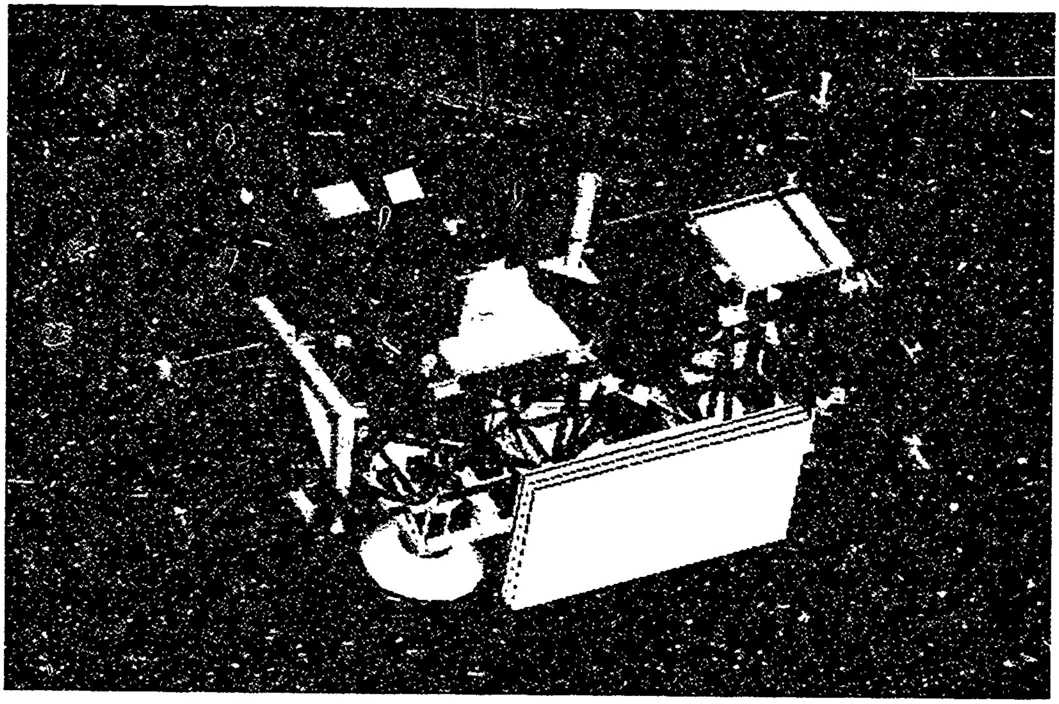
The third instrument is called the ERBE scanner (ERBE-S). It will measure radiation reflected by and emitted from Earth.

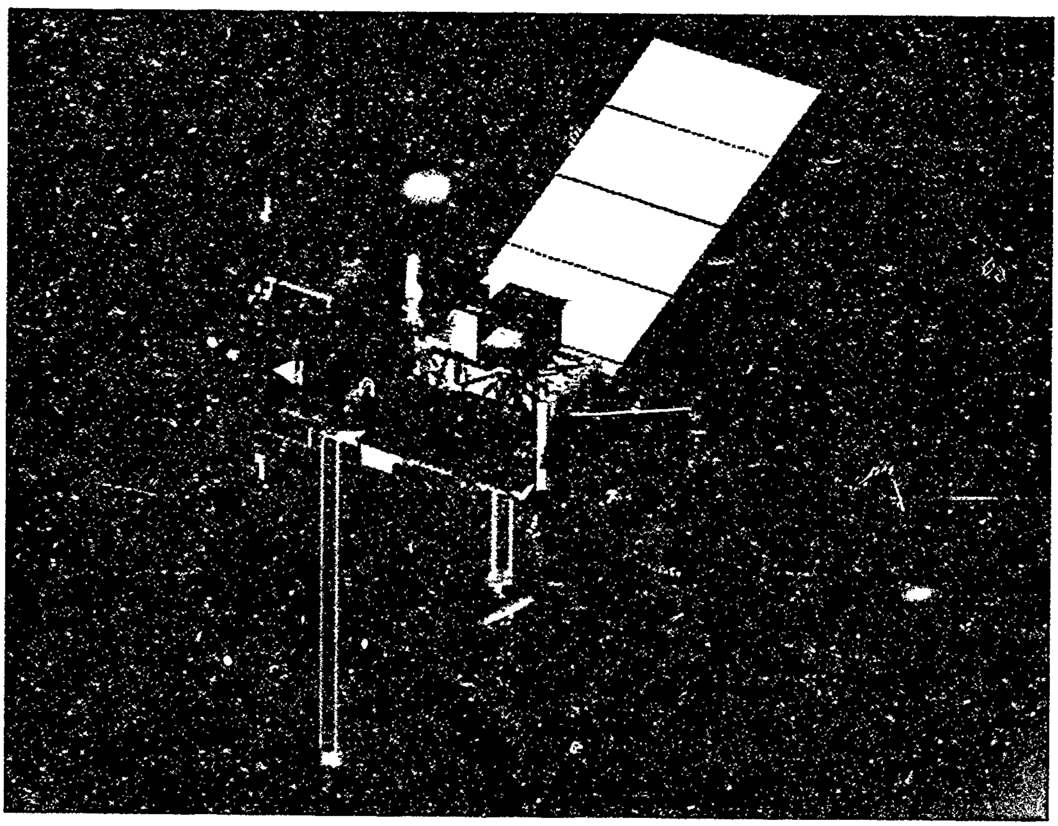
ERBE data will supersede data from the Nimbus series spacecraft, because the ERBE will be more accurate.

Other future programs to study the upper atmosphere include the Magnetic Field Satellite and the Geopotential Research Mission, which will study Earth's gravitational field. The Ulysses mission will use a satellite orbiting the Sun and will provide complementary data.

Below right: Earth Radiation Budget Satellite (ERBS) during deployment from Shuttle. Blue image is reflection of aft flight deck on window.







Left: (both photos) Upper Atmosphere Research Satellite (UARS).

Unanswered questions

Although we basically understand the processes occurring in the upper atmosphere, many details are missing. We do not know the relative importance of the diverse processes, nor do we know how the upper atmosphere interacts with other regions in the Earth-Sun system. We know little about the composition of the magnetosphere or the consequences of solar wind. How, for example, does the upper atmosphere influence our weather below? What do auroras tell us about events in the far regions of the magnetosphere?

If we can better understand our geospace system, we will better understand similar systems throughout the universe, such as those around Jupiter and Mercury or around astronomical objects such as radio galaxy NGC 1265. (The magnetosphere of NGC 1265 stretches 100,000 light years into space.)

By studying our own upper atmosphere we also can learn about the auroras, airglow, and atmospheres of other planets. Airglow, for example, was observed on Mars by Mariner 6. Intense aurora were discovered in Jupiter's atmosphere, but the source of the radiation is unknown.

Many important questions about spacecraft glow have been raised recently. What is the cause of the glow phenomenon? How will it influence future space instruments, such as optical instruments designed to see faint light sources? How will it influence placement of instruments in orbit and design of the Space Station system? Most importantly, how will our upper atmosphere influence long-term physical, chemical, and biological trends in our environment?

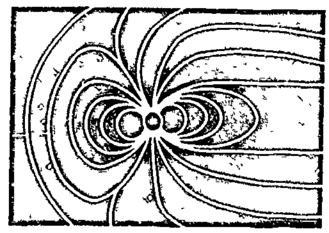
One possible source of these long-term changes is carbon dioxide in the atmosphere. Over the last century, carbon dioxide in the atmosphere has been increasing as a result of the use of fossil fuels. Today, oil and coal combustion are still our primary energy sources. The consequences of continued dependence on fossil fuels are unknown, but a significant increase in atmospheric carbon dioxide could result, causing climatic changes. To reduce this risk, we may need to limit the use of fossil fuels and instead derive our energy from wind, solar, or nuclear sources.

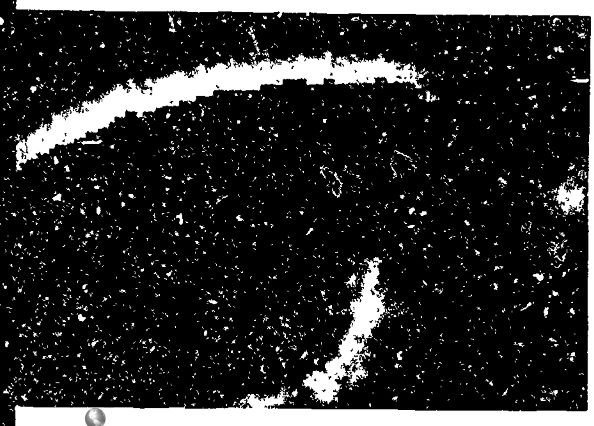
How can we predict the long-term changes in the upper atmosphere? Will changes in the upper atmosphere result in global heating or cooling? A slight change in the energy reaching Earth from the Sun could result in a one-degree centigrade increase in average air temperature, significantly melting the polar caps, increasing the sea level worldwide, and flooding all coastal areas.

Scientists are working on these questions, and within the next generation we hope we will have enough answers to prevent disastrous changes in our atmosphere.

Far left: Earth viewed over North Pole in the ultraviolet. These consecutive images show the aurora and geocorona that surround Earth.

Below: Auroral arc system obtained by simultaneous observation in ultraviolet and visible light.





Conclusion

We have only begun to probe the mysteries of our upper atmosphere. Yet research has already provided a wealth of knowledge on the interactions of the Sun and Earth that occur in the upper atmosphere. With a continuing worldwide effort, we are also beginning to understand the influence of technological and industrial achievement on our atmosphere. This research will lead to a better understanding of our most precious resource—our environment.

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