N64-30339

DISCOVERIES FROM SPACE EXPLORATION

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Space science is the collection of problems in science to which space vehicles can make some specific contribution not achievable by ground-based experiments. At the present time this field includes broad segments of the traditional disciplines of the earth sciences, physics, and astronomy. In later years the biological sciences will join this group in an important role, as explorations of the Moon and planets provide opportunities for studying the conditions under which physical life may have developed. Some highlights of recent space research will be reviewed here.

GEODESY

Important results have been achieved in determining the internal structure of our own planet with the aid of near-Earth satellites. A satellite's orbit is determined by the distribution of mass within the Earth. If the Earth were a perfect sphere, under the attraction of the mass point at the Earth's center of gravity, the satellite would move in an ellipse whose plane would keep a constant orientation in space.

Actually, the plane of a satellite's orbit rotates slowly in space because of the additional force of attraction exerted by the equatorial bulge. Studies of the orbital rotation rates of a number of satellites have yielded a very precise value for the height of the equatorial bulge. These indicate a discrepancy between the observed value of the flattening and the value that should exist on the assumption of hydrostatic equilibrium. Hence the interior of the Earth is not in hydrostatic equilibrium; the Earth must have a mechanical strength within its interior or some other cause for departure from static equilibrium which is sufficient to maintain its shape in spite of the stresses applied to the mantle by the excess equatorial bulge.

There are other departures of the geoid from the shape of hydrostatic equilibrium, in addition to the discrepancy in the flattening. These departures, which have been determined primarily from the analysis of the Vanguard I orbit, include a pear-shaped component, or third harmonic, in the expansion of the gravitational field.

The departures from the figure of hydrostatic equilibrium are of very great significance because they represent variations in the force of gravity, and these depend on the entire distribution of mass within the planet; they are therefore more significant for the gross structure of the planet than the simple topographical variations, such as mountains, which represent the distribution of the mass at the surface only.

Detailed analysis of these gravitational variations yields a figure of the Earth in which there is a positive anomaly, or a lump, in the region of the western Pacific near Indonesia and the Philippines; a depression, or negative anomaly, in the Indian Ocean; and a large negative anomaly, or hole, in the Antarctic (fig. 1).

Although these depressions and elevations are relatively minute, they are exceedingly significant because

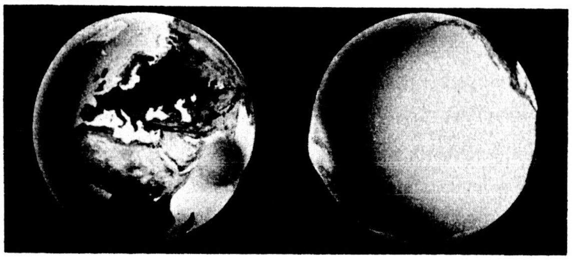

FIGURE 1.—Shape of Earth.

they represent variations in the force of gravity, or the amount of matter per square centimeter, in the regions in question. For example, the depression in the Indian Ocean is only 60 meters deep, but it signifies that the force of gravity there is so weak that the waters of the sea are not drawn together to the depth that they would be if the whole Earth were subject to a uniform gravitational force.

These anomalies are correlated with the rate at which heat flows through the body of the Earth to the surface. The correlation is such that where the geoid is anomalously high, the heatflow is anomalously low. On the average, the flow of heat outward through the crust of the earth is 60 ergs/cm^2-sec. In the depression of the geoid near India, the flow of heat is substantially higher, 80 ergs/cm^2-sec. At the elevation of the geoid in the western Pacific, the flow of heat is substantially lower, about 40 ergs/cm^2-sec.

This kind of correlation would be expected if there is a mass transport, or convection of matter, from the deep interior of the Earth to the surface in these regions. If there were an upward motion through the interior of the Earth, which carried relatively warm material from below to the surface, this upward-moving column would have a lower density than its surroundings, and therefore the mass per square centimeter in the column, and the gravitational force on the surface of the Earth about it, would be lower than on the average. At the same time, the heat transported upward by the warm column would add to the normal release of radioactive heat throughout the mantle and crust; thus, above that same upward-moving column there would be an exceptionally large rate of heat flow through the surface.

The converse would hold for a descending column, which would carry a relatively dense and therefore relatively cold material from the surface layer to the interior of the Earth. Above the cold and dense column the gravitational force would be relatively great, and a bump would appear in the sea level there. That is presumably the cause of the elevation in the western Pacific.

METEOROLOGY

In geocentric order, the next major area of investigation in space science concerns the atmosphere and the control exerted over it by the Sun. This field of research includes questions related to the circulation of the winds in the lower atmosphere and to the vertical structure of the atmosphere at higher altitudes.

Regarding atmospheric circulation, eight Tiros satellites have been launched in the past 4 years, all carrying vidicon cameras for the global study of the cloud cover; Tiros II, III, IV, and VII carried in addition a set of infrared detectors for the measurement of the intensity of infrared radiation emitted from the atmosphere.

The cloud-cover photographs have already yielded results of great interest when correlated with ground observations, and they have the promise of leading to a substantial improvement in weather forecasting by providing global and nearly continuous coverage of regions of weather activity. The matter of global coverage is critically important, because the success of weather forecasting has been found to increase rapidly with the size of the region covered by the observations; yet at the present time large parts of the globe are very poorly covered, and constitute regions in which weather activity can develop and grow without detection before moving out into the inhabited areas. The sparsely covered territories include the polar regions, the major deserts, and the southern oceans. Satellite coverage will greatly strengthen the hand of the meteorologist by filling in these blank portions of the global weather map and may be expected to have important consequences for the economies of this country and the world.

The measurement of infrared radiation is less important than cloud-cover photography for the immediate objectives of weather forecasting, but it should have greater importance for the basic objectives of long-range forecasting and the understanding of the causes of weather.

Although the Sun is the original source of energy, most of the solar radiation is in the visible band of wavelengths which passes freely through the atmosphere. This visible radiation reaches the surface of the Earth where it is absorbed and heats the ground to a temperature in the neighborhood of 235° K. The ground emits radiation corresponding to this temperature. For a glowing body at a temperature of 235° K, most of the energy is radiated at wavelengths in the far infrared. This infrared radiation is strongly absorbed by several constituents of the atmosphere, including water, carbon dioxide, and ozone. The absorption of infrared from the ground by these molecules heats the lower atmosphere, which reradiates the absorbed energy, partly upward to outer space and partly downward to provide additional heating of the surface. (The additional heating of the surface by the return of infrared from the atmosphere is referred to as the "greenhouse effect." On the Earth it is sufficient to raise the temperature by about 55° K, so that the average temperature of the surface of our planet becomes 290° K.)

Local variations in the amount of water vapor, and in other circumstances which control the penetration of visible light and the reradiation of infrared, lead to regional variations in the temperature and pressure of the atmosphere, which in turn provide the driving force for large-scale weather activity (fig. 2 and 3).

If a good spectral distribution of infrared intensities is available, we can obtain from it the temperature distribution in the lower atmsophere, as well as the global variations in the total transfer of energy. These are vital data for the atmospheric physicist seeking the causes of weather.

In addition, the cloud-cover information obtained from satellites can be used to estimate the amount of incoming visible radiation which actually reaches the ground. The difference between the incoming visible radiation and the outgoing terrestrial radiation in the infrared region makes up the energy balance of the Earth and the atmosphere, which is the fundamental datum for long-range prediction.

These are the general circumstances which underlie the development of weather activity. The details of the process involve the following considerations. The intensity of infrared radiation emitted from the ground is determined by the temperature of the ground: the higher the ground temperature, the stronger the infrared radiation. The absorption of this infrared in the atmosphere is largely determined by the water vapor present, this being the principal absorbing constituent. It is also affected by any clouds which may be present since liquid water droplets also absorb infrared strongly. Thus, the most important factors which control the outgoing infrared radiation are, in order: the ground temperature, the amount of water vapor in the atmosphere, and the extent and height of the clouds.

It is seen that the distribution of cloudiness plays an important role in the determination of both the inflow and the outflow of energy through the Earth's atmosphere. Thus far the distributions of clouds—amount, types, and approximate heights—have all been taken from ground-based observations. Satellite observations by television cameras enable us to obtain extensive cloud-cover data on a global scale in a relatively short period of time.

Albert Arking of the Goddard Institute for Space Studies has compared the Tiros results with a climatological mean cloudiness compiled from ground observations by K. Telegadas and J. London (1954) for the Northern Hemisphere. The broad features are in agreement, although there are small numerical disagreements at some latitudes. The most noticeable disagreement, which occurs around 20° S. latitude, is probably due to the incorrectness of the assumption that cloudiness is the same during southern winters as during northern winters.

These results are preliminary, but this approach seems to be promising, and it is hoped that the temporal and geographical variations in the distribution of energy balance will now be available through the use of both outgoing and incoming radiation

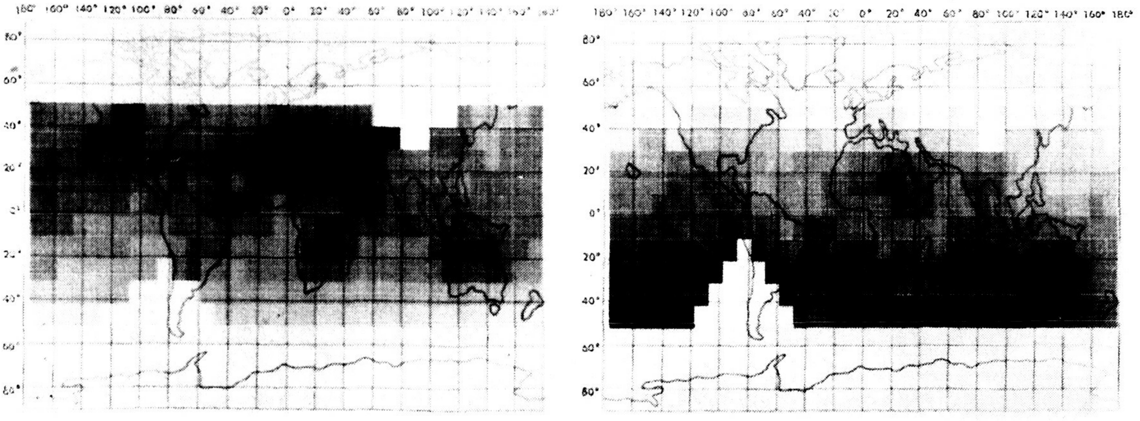

FIGURE 2.—Energy balance, summer (left) and winter (right) of 1961. From Tiros III

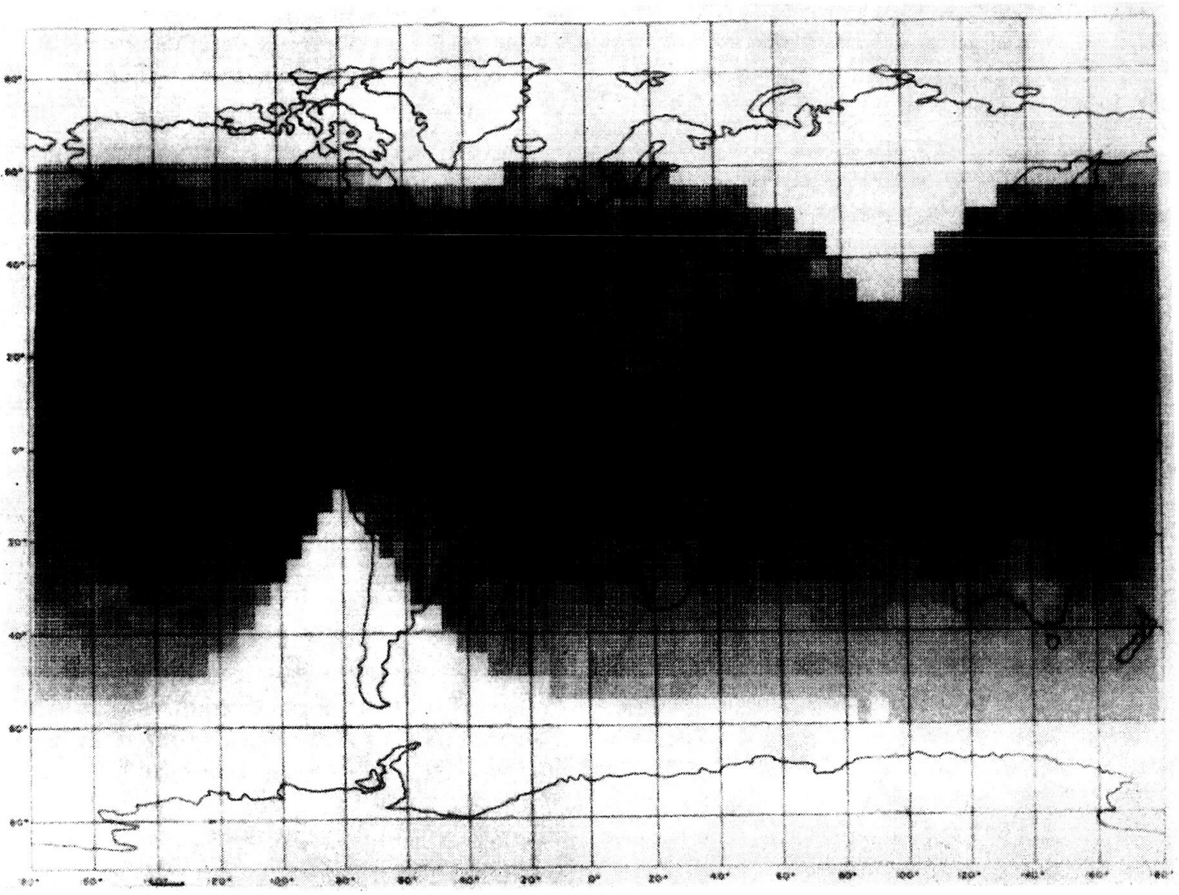

FIGURE 3.—Energy balance, spring of 1962. From Tiros IV.

obtained from satellites. In turn, this method may provide a better understanding of the role played by the energy balance of the atmosphere for long-range weather forecasting.

THE UPPER ATMOSPHERE

The physical processes which control the upper atmosphere are determined largely by the absorption of solar ultraviolet radiation by the atoms and molecules existing at great heights. Although the ultraviolet component of the solar radiation is only a small fraction of the total solar energy flux, the absorption of cross sections in the far ultraviolet are so large that these wavelengths are effectively removed from the incident spectrum by the time the incident flux has penetrated to a height of 100 km. The ultraviolet radiation is the principal source of heating of the thin upper air and the major determining factor in its structure.

At lower altitudes the air is composed of oxygen and nitrogen, and we can measure the proportions of these rather accurately. At the highest altitudes these gases have partially settled out of the air through diffusion. The lighter gases dominate the composition of the air at sufficiently high altitudes. Of these gases hydrogen is the lightest, and for this reason it was once believed to be the dominant constituent of the air above the oxygen-nitrogen layer. The hydrogen atmosphere was thought to emerge at an altitude of about 1,200 km. However, in July 1961, Marcel Nicolet of Belgium suggested on the basis of an initial examination of the density data of Echo II that between the oxygen-nitrogen atmsophere and the hydrogen atmosphere there should lie a layer of helium. The existence of the helium layer was confirmed experimentally at approximately the same time (fig. 4).

Our knowledge of atmospheric properties at altitudes of about 250 km is dependent on the measure-

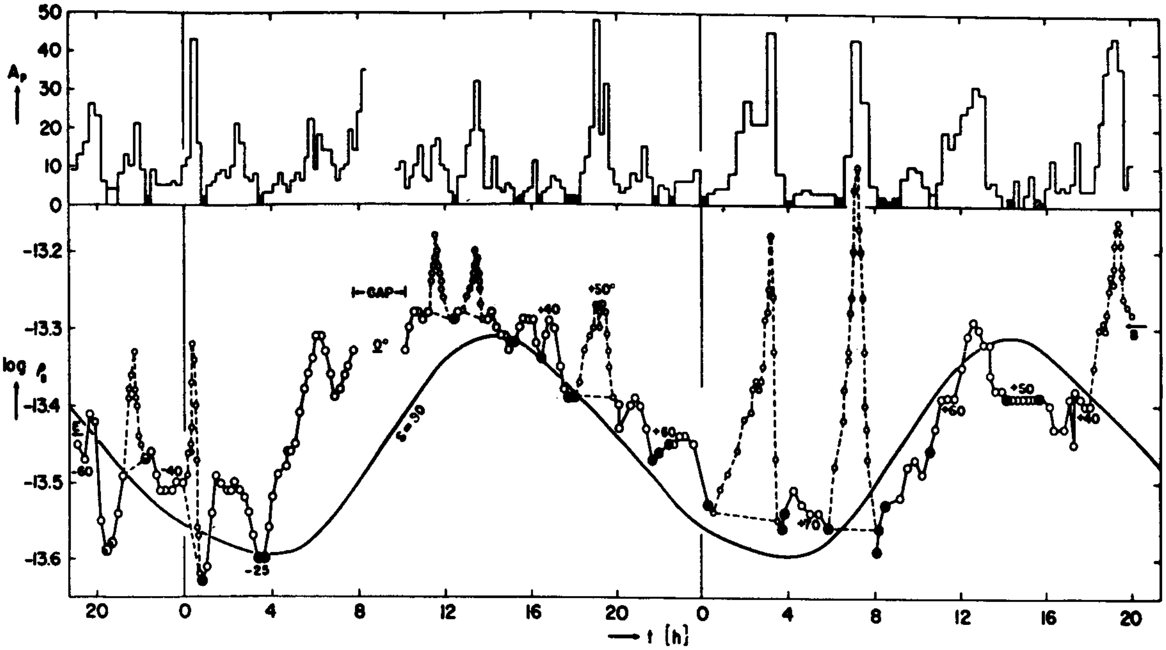

FIGURE 4.—Satellite drag.

ments of the atmospheric drag acting on satellites. The period of revolution of a satellite decreases steadily at a rate proportional to the drag force exerted by the atmosphere; and the coefficient of the observed rate of change of period therefore gives the value of the air density suitably averaged around the orbit.

The detailed study of satellite drag has in fact been a very valuable source of information on atmospheric properties. The most interesting result of investigations carried on by L. G. Jacchia of the Smithsonian Astrophysical Observatory was the discovery that the upper atmosphere is extremely responsive to solar control, undergoing excursions in density which were lately found to be as much as a factor of 100, and variations in temperature of hundreds of degrees, according the level of solar activity.

The significance of this correlation can be understood as follows: During the maximum of the sunspot cycle, the surface of the Sun is the scene of great activity, marked by sunspots and by hot, dense regions with temperatures of some millions of degrees, which are located in the solar corona above the sunspot areas. When such an active region faces the Earth in the course of the Sun's rotation, extreme ultraviolet radiation emitted from these active regions is absorbed in the upper atmosphere. The precise correlation between solar activity and density, discovered initially by Jacchia of the Smithsonian Astrophysical Observatory and W. Priester of the Institute for Space Studies, suggests that the amount of energy transferred to the Earth is sufficient to heat the atmosphere appreciably, causing an upward expansion and a large increase in the density of the exceedingly thin air at high altitudes. This discovery provided the first direct evidence regarding the effects of solar surface activity on fundamental atmospheric properties.

The continuing analysis of the correlation has given us a rather full picture of the degree of solar control over the upper atmosphere. It indicates that the atmosphere is appreciably heated by the ultraviolet emitted at times of general solar surface activity; analysis has also indicated that the atmosphere is further heated by interaction of the Earth with the solar plasma clouds, which are emitted from the Sun following solar surface eruptions. The arrival of the clouds of solar plasma at the Earth is signified by the onset of geomagnetic disturbances or "magnetic storms" (fig. 5). It is found that increases in the temperature of the atmosphere occur at just the time that the magnetic storms and, hence, the solar particles commence. Thus it appears that both ultraviolet radiation and corpuscular streams constitute sources of energy for the upper atmosphere. The question of

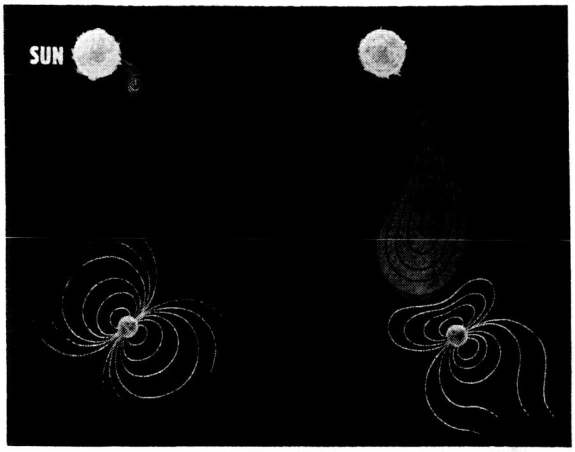

FIGURE 5.—Solar plasma cloud.

the energy sources for the upper atmosphere is the most important single problem for upper-atmosphere physics at this time and the continuing investigation of this matter, and in particular of the roles played by particle and radiation sources respectively, will be one of the main areas of experimental and theoretical effort in the next several years.

THE MAGNETOSPHERE

The evidence that has been cited suggests that corpuscular streams from the Sun transfer appreciable amounts of energy to the atmosphere. The question arises, How does the transfer of energy in the atmosphere occur?

The general answer seems to be connected with the properties of the outermost layer of the atmosphere. The density of the upper air merges into the density of the interplanetary gas at an altitude of about 100,000 km, marking the boundary of the atmosphere. Early in 1958, however, J. A. Van Allen of the State University of Iowa discovered, by analysis of Geiger counter data from Explorer I, that there was an additional layer of energetic charged particles in the upper atmosphere. These charged particles are trapped in the atmosphere by the Earth's magnetic field. The atmospheric layer which they constitute is called the magnetosphere, since it is the region dominated by the geomagnetic field.

During the last few years, three important developments have substantially changed our earlier impressions about the character of the magnetically trapped particles and their geophysical effects.

First, B. O'Brien, also of the State University of Iowa, using measurements from the Injun I satellite, discovered that the flux of charged particles coming down from the trapped region was so large that, if this flux consisted of previously trapped particles which had just been dislodged by solar disturbances, it would drain the whole magnetosphere in about an hour. He also found that when a solar disturbance occurred, both the flux of untrapped descending particles and the number of trapped particles increased. Thus, he concluded that the leakage of trapped particles from the Van Allen belts cannot be the principal source of the electrons which pass down through the atmosphere. He decided that while a few charged particles are trapped during or after a solar disturbance, most pass into the atmosphere directly without spending an appreciable amount of time in the trapped region. Apparently, the charged particles which are observed in auroral displays and other atmospheric phenomena are those which come directly down the lines of force into the atmosphere.

Secondly, a large population of low-energy protons, having a range from 100 Kev to several Mev, was discovered by A. H. Davis and J. M. Williamson of the Goddard Space Flight Center. The concentration of these protons peaks at 3.5 Earth radii. At that point their density is about 1 per cubic centimeter.

This value of the trapped-proton density has interesting implications. As a result of the magnetic-field gradient and curvature effects, the trapped protons drift westward in the magnetic field, with an associated electric current that produces magnetic effects. These have been calculated by S. Akasofu of the University of Alaska and S. Chapman of the University of Colorado and, in an unpublished work, by R. A. Hoffman of the Goddard Space Flight Center. They find that the changes in the intensities of these trapped protons produce magnetic perturbations large enough to explain most magnetic storms observed on the Earth, and also the very large perturbations of the geomagnetic field in space, in the neighborhood of the proton belt. The relation between the trapped-proton drift current and the geomagnetic storms was suggested by S. F. Singer of the University of Maryland in 1956.

The third development was the discovery of a substantial flux of electrons with very high energies, in the neighborhood of 1 million volts, at a distance of 3 or 4 Earth radii, presumably produced by beta decay of albedo neutrons resulting from cosmic-ray interactions in the atmosphere. These electrons penetrate the Geiger counters with high efficiency, and when allowance is made for their presence, the earlier estimate of the total flux of electrons is reduced from Van Allen's value of 10^{10} to the latest value of 10^8.

THE MAGNETOPAUSE

The connection between the magnetosphere and the transfer of corpuscular energy to the atmosphere is probably to be found in the properties of the magnetosphere near the magnetopause, a region which separates the interplanetary medium from the region around the Earth in which the geomagnetic field is dominant. Its sharply defined surface marks the termination of both the trapped-particle region and the geomagnetic field. Satellite measurements of the geomagnetic field by L. J. Cahill of NASA Headquarters in Washington show that the magnetopause has a thickness on the order of 100 km and occurs at a distance of 8 to 10 Earth radii on the sunlit side of the Earth (fig. 6).

Within the region of the geomagnetic field there are no substantial particle fluxes other than those of the magnetically trapped particles. Outside the geomagnetic field, experiments on Explorer X and Mariner II have shown that a substantial number of particles move outward in a radial direction from the Sun at velocities varying from 300 to 600 km/sec and at an average flux of 10^8/cm²/sec. Mariner II measured a higher kinetic energy in the directed solar plasma streams than in the random particle motions in the stream. The solar plasma cloud drags the lines of solar magnetic field with it, and its bulk motion is not affected by the presence of the field (fig. 7).

These results, taken together, indicate that the Sun is the source of a solar particle stream which flows

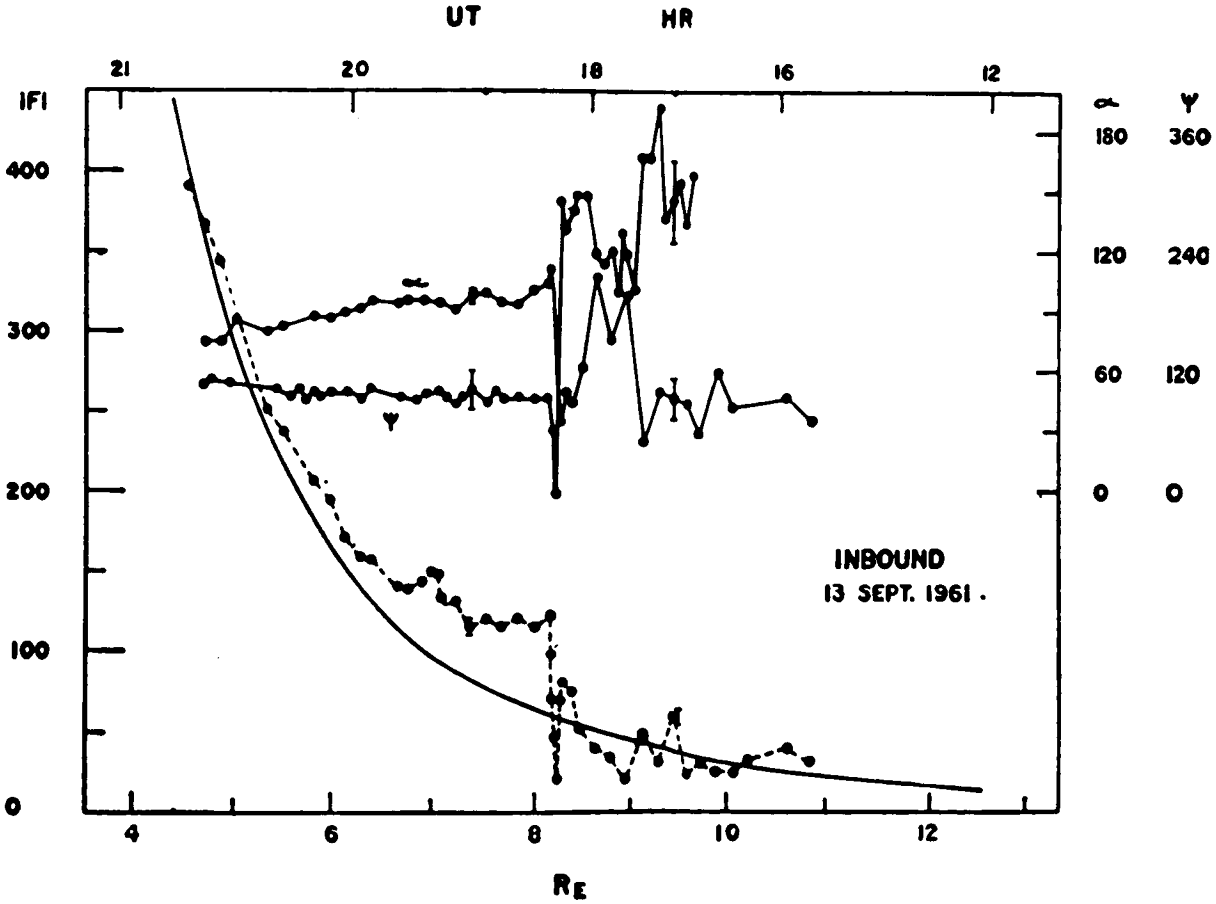

FIGURE 6.—Magnetopause.

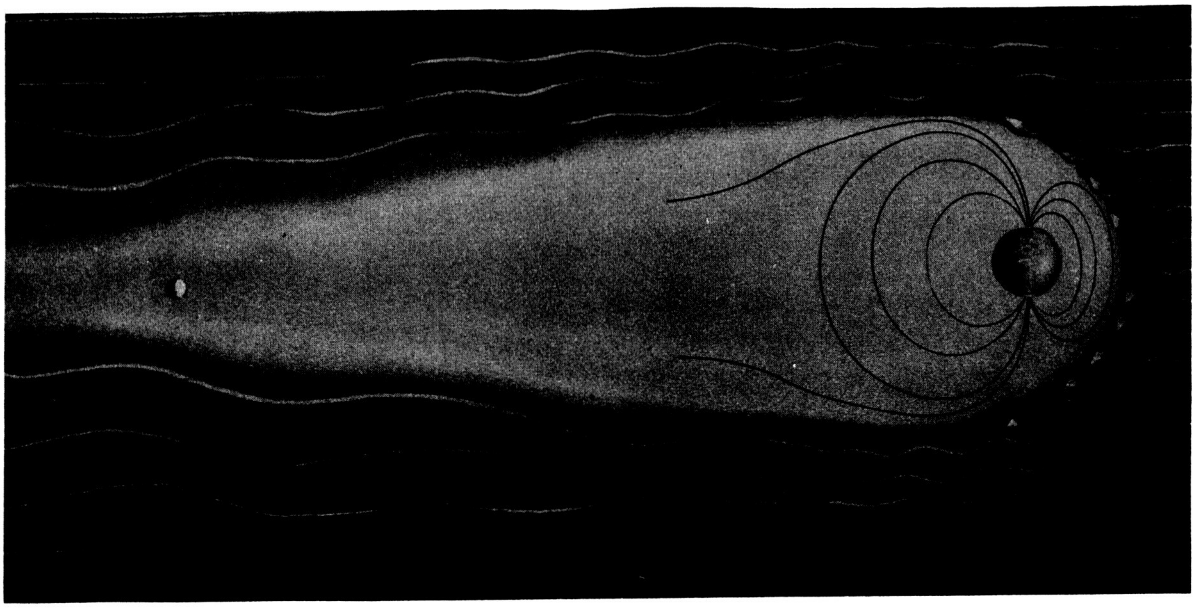

FIGURE 7.—Solar plasma (new concept).

all the time, although it varies in velocity and intensity. It cannot penetrate the magnetic field of the Earth, but divides and flows around the Earth as waters of a stream divide around a boulder. In fact, the closest distance of the solar wind to the Earth is about 10 Earth radii.

The shadow or cavity of the magnetic field of the Earth in this stream should, in principle, extend back indefinitely far into the solar system behind the Earth. However, because the particles of the stream have random transverse velocities, we expect these particles to diffuse together in the shadow of the Earth, thereby filling in the geomagnetic cavity at a distance of several times the diameter of the cavity, or roughly the distance of the Moon from the Earth.

The transfer of energy from the solar wind to the cavity is difficult to estimate. The variable magnetic fields in the solar plasma glue the particles together and give their motion the properties of fluid flow, in spite of the low density, with turbulence to be expected therefore at the solar impact point. The buffeting of the magnetosphere surface associated with this turbulent impact can generate hydromagnetic disturbances in the field lines located just within the magnetopause. These disturbances may propagate down or across the field lines into the atmosphere, where they may transfer energy which appears as atmospheric heating, ionization, auroral disturbances, and magnetic storms—that is, the whole complex of atmospheric disturbances associated with the high geomagnetic latitudes in times of solar activity.

Another aspect of the interaction of the solar plasma with the magnetosphere is the expectation that a "shock wave" will be formed some distance beyond the actual magnetopause. This arises from the supersonic flow of the plasma and the fact that such flow must become subsonic in the vicinity of the Earth. The transition requires a shock wave to be set up which stands off some distance from the magnetopause and has a thickness determined by the ability of the magnetic field to change the bulk motion of the plasma particles. The perturbed magnetic fields corresponding to the shock wave and the intervening transition region have been measured by N. F. Ness of the Goddard Space Flight Center using the IMP spacecraft.

THE ATMOSPHERE OF VENUS

Venus, the closest planet to the Earth, is the third brightest object in the sky next to the Sun and the Moon. It has been observed for centuries and yet, to this day, has remained an enigma to astronomers. The main reason for this lack of information is that the planet is permanently shrouded by a layer of clouds and no surface features have ever been observed.

Apart from reflecting solar radiation, which registers in the visible and near-infrared portions of the spectrum, a planet also emits its own radiation, which is confined to the far-infrared and microwave regions of the spectrum. Measurements of planetary radiation provide valuable information on the temperature structure of the atmosphere. Such a study of Venus has been hampered by the presence of clouds that are opaque to infrared. However, the small amount of radiation emitted by the planet in the centimeter wavelength region penetrates through the clouds without significant attenuation and can be usefully detected to determine the temperature of the surface of the planet.

First attemps to measure this radiation from Venus were made in 1956 with the radiotelescope of the Naval Research Laboratory. The temperature inferred from the measured radiation intensity was, however, unexpectedly high—of the order of 600° F, which is certainly too hot to support any imaginable form of life. Repeated measurements in the following years have forced a complete revision of our understanding of the surface conditions and the lower atmosphere of Venus.

One way of explaining such a high surface temperature is by assuming the presence of an extremely dense atmosphere composed of large quantities of carbon dioxide and water vapor. These molecules have strong absorption bands in the infrared region of the spectrum, but are relatively transparent to visible radiation. The major part of the sunlight which has not been reflected back by the planet will therefore penetrate through the atmosphere and heat the surface of the planet to a certain temperature.

Venus, whose reflectivity of visible radiation is very high (76 percent of the light received, as compared with some 40 percent for Earth), would be heated to only −40° F by the weak sunlight that filters through the clouds. Because of this cold surface temperature, Venus would emit radiation primarily in the far-infrared region, which would immediately be absorbed by the dense atmosphere. Reradiation from the atmosphere, according to this theory, then sends a major part of the radiation back to the ground, heating it to a very high temperature.

This phenomenon is called the "greenhouse effect" of the atmosphere, an allusion to the glass cover of a greenhouse that is transparent to the Sun's visible radiation but opaque to the infrared radiation emitted from the plants. Thus the infrared is trapped within the greenhouse and heats it up. If it were not for the greenhouse effect of the Earth's atmosphere, the average temperature of the Earth's surface would be a cold —20° F instead of a comfortable 60° F.

In the case of Venus, it is difficult to imagine a greenhouse effect so efficient as to raise the ground temperature to 600° F. This would require an atmosphere of extreme opacity in the infrared, and at the same time considerable transparency in the visible spectrum. Since such an atmosphere would be quite unique, this explanation of Venus' high surface temperature is very controversial.

It is possible that microwave emission from high densities of electrons in the ionosphere of Venus give rise to emission of microwave radiation which results in spuriously high values of the measured temperature. In order to measure the actual temperature, the United States launched the Mariner II Venus flyby, which passed 20,900 miles from the planet and made crucial measurements of the temperature across the disk. The spacecraft was equipped with two radiation experiments, one in the infrared and one in the microwave region.

The radiation emitted by the planet in the microwave region was measured at two discrete wavelengths —13.5 mm, where the radiation is strongly absorbed by water vapor, and 19 mm, which passed through the atmosphere unattenuated and, hence, provided a measure of the ground temperature.

The measurements at 19 mm tested the possibility that the high temperatures observed on Venus originate from a thick ionosphere rather than from the surface. If the ground has a high temperature, then measurements made of the edge or "limb" of the planet should show a slightly lower temperature or "darkening" due to the greater thickness of the intervening atmosphere. If the high temperatures are caused by a high-electron density in the ionosphere of Venus, then the readings at the limb should indicate a "brightening" because of the greater thickness of the ionosphere in the line of sight.

The wavelengths used to measure the infrared radiation of the planet were chosen to give information regarding the temperature at the cloud top and the amount of carbon dioxide above the clouds. Observations of Venus from Earth in the infrared region to date have indicated a temperature of —40° F. As clouds are opaque to infrared, it is believed that this temperature exists at the top of the clouds, similar to the temperature frequently observed at the top of terrestrial clouds.

The Mariner results indicate that the measured values of temperatures were actually correct. There is a limb darkening, indicating that the surface of Venus may actually be at a temperature of 600° K. The infrared radiometer confirmed the earlier temperature of —35° C at the cloud top. It also indicated that there were no breaks in the clouds of Venus during the time of measurement.

EXPLORATION OF THE MOON

The Moon is a uniquely important body in the study of the history of the solar system because its surface has preserved the record of its history remarkably well. The Moon has a negligible atmosphere and no oceans. It is, therefore, unchanged by the processes of erosion which erased the history of the Earth's surface in a relatively short period of time —between 10 and 30 million years.

This is evidenced, in part, by the tens of thousands of craters on the lunar surface, produced by the impact of meteorites which presumably have been colliding with the Moon since its formation. This is perhaps the only physical record which we have of events in the development of the solar system going back to that early time.

Because of this antiquity of the Moon's surface, another remarkable record has been preserved—a layer of cosmic dust which is believed to have rained on it from the solar system since its formation. This dust may be as much as a foot or more in depth and may contain organic molecules and the precursors of life on Earth, providing clues to the origin of physical life.

The most important measurements of lunar properties from spacecraft have resulted from the Russian flights of Lunik II and Lunik III. From the Lunik II magnetometer data Soviet scientists concluded that an upper limit of approximately 100 gammas could be placed on the Moon's magnetic field. In future flights, improvements on this limiting value of the Moon's magnetic field may provide information on the presence or absence of a liquid core within that body. On the Earth the magnetic field is supposed to be associated with currents in the liquid core of the planet. This in turn could have a bearing on our understanding of the formation of the Moon and similar bodies in the solar system.

Lunik III has provided us with the first pictures of the remote side of the Moon. In spite of some blurring, the photographs are still of great interest, for it is possible to distinguish a large number of features resembling the craters and maria on the front face. Perhaps the most interesting feature is the Soviet Mountain Range, a chain extending across the center of the Moon's hidden face. It resembles the great ranges on the Earth and is unlike the mountain formations characteristics of the Moon's front face which seem to be circular crater walls and deposits of debris formed by the impact of large meteorites on the lunar surface.

According to our present ideas, terrestrial mountains result from the combined effects of erosion and wrinkling of the Earth's crust, but these mountain-building forces are believed to have been much less effective on the Moon. The markings of the Soviet Mountain Range could have resulted from the running together of several obscured but independent markings. However, if they continue to appear as a single range in later, more detailed pictures, we may have to revise our theories of lunar structure.

SOLAR PHYSICS

One of the most interesting questions in solar physics is the manner in which energy is transported above the surface of the Sun to heat the chromosphere and corona.

We know that near the center of the Sun, where the temperature is approximately 15 million degrees Kelvin, hydrogen is converted into helium by a variety of nuclear reactions. We also know that the Sun is a self-adjusting system which expands or contracts in order to maintain a precise balance between the energy generation at the center and the energy emission from the surface.

All regular mechanisms of energy transport can carry heat only from a region of high temperature to a region of low temperature. Therefore, in order to carry away from the center of the Sun the heat generated by nuclear reactions, it is necessary for the temperature to fall continuously from the center to the edge. This is in fact the case, the temperature falling from 15 million degrees at the center to 5,800° K at the visible edge of the Sun.

However, above the visible edge, which is called the photosphere, there lies a relatively tenuous region of gas which constitutes the atmosphere of the Sun. This region is divided into the chromosphere and, above that, the corona.

The puzzling fact about these circumstances is that the temperature of the Sun *rises* again from the photosphere, reaching a value of 1.5 to 2 million degrees in the corona. One of the paramount questions of solar physics is, What constitutes the source of the energy which produces the very high temperatures in the solar corona? Also, What is the mechanism of energy transport which can carry energy without appreciable losses through the dense gases of the photosphere and yet undergo strong losses in the tenuous regions of the corona?

A current belief is that a wave motion—either a sound wave, a hydromagnetic wave, or a gravity wave—carries energy upward from the photosphere and deposits it in the corona. When a sound wave propagates into a region of decreasing density, its amplitude increases and it will steepen into a shock wave. This is a mechanism in which considerable energy dissipation takes place. It appears that hydromagnetic waves are rapidly damped out below the photosphere, but if they can be generated in the region of the chromosphere, they will not tend to be dissipated until they have reached the corona. Magnetic disturbances above the photosphere may be particularly effective in generating these waves. Gravity waves consist of a kind of rolling motion similar to the waves on the surface of the ocean. These may, like sound waves, be generated by the motions of convecting material in the transition layer; they will have a vertical component of propagation and will be dissipated in the corona.

It may be that all three of these mechanisms are effective for the heating of the chromosphere and corona. If this is the case there may be a steady heating of the corona, upon which is superimposed a localized heating associated with magnetic activity. Thus, the heating of the corona is expected to depend upon the magnetic structure in the outer layers of the Sun. This is observed in many phenomena; in particular, in sunspot regions where the magnetic-field strengths are higher than is normal on the Sun's surface, both the chromosphere and the corona have a higher than normal temperature.

The behavior of the chromosphere and the corona is most easily observed by studying the ultraviolet emission from the Sun, since in the ultraviolet region the amount of light emitted from the photosphere greatly decreases, whereas the higher temperatures in the chromosphere and corona are responsible for the presence of large numbers of emission lines. The most important emission lines are due to hydrogen and helium. In order to understand solar surface physics in more detail, it is essential to obtain observations of the time variations of these emission lines as indicators of the time variations of behavior in the chromosphere and corona.

The first experiments in this direction were very successfully accomplished by the flight of the first Orbiting Solar Observatory, which was launched on March 7, 1962. It gave several months of data, continuously monitoring a number of different wavelength regions for emission from the Sun.

Particularly interesting are the data for the 11th through the 22d of March, 1962. At the beginning of this period the Sun was in an exceptionally quiet condition, but as the period progressed the Sun became more and more active, until on March 22 there was a flare of importance 3. Experiments revealed that the Lyman alpha line of He II at 304 Å increased by some 33 percent during the interval, and during the flare itself the line increased by an additional 14 percent. The lines of Fe XV at 284 Å and Fe XVI at 335 Å also increased in intensity by a factor of 4. At longer wavelengths, the Lyman alpha line of hydrogen was observed to increase in intensity by 6.8 percent during the flare.

Very interesting results were also obtained in the X-ray region, 1 to 10 Å. During the quiet period a flux was observed which was 360 times the theoretical background which would be obtained from a corona at a temperature of 1.8 million degrees Kelvin. This indicates that nonthermal processes are present and important in the corona under even the quietest solar conditions.

A continuing series of Orbiting Solar Observatories is planned in which these interesting phenomena can be monitored continuously during future years.

X-RAYS AND GAMMA RAYS

The space research program is not confined to the discovery of new facts about the solar system. It also represents an important opportunity for the astrophysicist to extend his knowledge of more distant parts of space through observations at wavelengths for which photons do not penetrate through the atmosphere. The principal regions involved are the X-ray and gamma-ray region, the ultraviolet, the infrared, and long-wave length radio waves. The early rocket and satellite measurements of X-rays and gamma rays have been particularly interesting to physicists because they suggest several possible new types of phenomena in space.

X-rays and gamma rays can be produced by a variety of high-energy processes. These processes include collisions between high-energy nucleons which can create neutral pions, which in turn decay to give gamma rays exceeding 50 Mev in energy. Fast electrons can produce X-rays or bremsstrahlung when they pass close to a nucleus. Fast electrons can also collide with photons of visible starlight and increase the energy of the photons into the X-ray and gamma-ray region. If radioactive nuclei are produced and dispersed in space between the stars, some of them should emit characteristic gamma-ray energies which might be detected. If positrons are produced in dense regions of matter, such as stellar surfaces, then upon being slowed down and annihilated they will emit the characteristic gamma rays of 0.51 Mev energy. If neutrons are produced near stellar surfaces and are slowed down and captured by the overwhelmingly abundant hydrogen that is present, then these will provide characteristic capture gamma rays with an energy of 2.31 Mev. Finally, we may note that if objects should exist in space with surface temperatures of some millions of degrees Kelvin, then photons in the X-ray region will be emitted by thermal processes from their surfaces.

Preliminary measurements now exist of the fluxes of X-rays and gamma rays in a number of different energy intervals. A general background of X-rays of a few thousand electron volts energy was observed in a rocket flight by R. Giacconi, H. Gursky, F. R. Paolini, and B. B. Rossi. A general background radiation of gamma rays in the region near 1 Mev energy was measured in the Ranger 3 flight by J. R. Arnold, A. E. Metzger, E. C. Anderson, and M. A. Van Dilla. A small but still significant flux of gamma rays with energies exceeding 50 Mev was observed with the Explorer XI gamma-ray satellite by W. L. Kraushaar and G. W. Clark.

A number of attempts have been made to explain the presence of these background X-rays and gamma rays. Most mechanisms thus far examined appear quantitatively inadequate to explain the observed fluxes. One promising explanation is due to J. E. Felten and P. Morrison, who suggested the importance of the inverse Compton effect, in which the high-energy electrons present in the cosmic rays collide with photons with engeries of the order of 1 electron volt which are emitted from stars. Following such a collison, the photons can easily be raised to the observed range of X-ray and gamma-ray energies, depending upon the energies of the electrons with which they collide.

Calculations by Felten and Morrison were based on this effect. A flux will be emitted by the outer halo region of our galaxy if the observed flux of high-energy electrons at the position of the Earth exists throughout this large outer region of the galaxy. Electrons in the halo fail to account for the observed X-ray and gamma ray fluxes by some 2½ orders of magnitude. However, if it were to be assumed that the high-energy electrons are present throughout all of space with the same intensity with which they are observed near the Earth, then a background radiation of some 30,000 times that which would be produced within the galactic halo would be observed. Evidently, such high fluxes of electrons cannot exist throughout all of space. One percent of such a flux of electrons can be expected to give a backround of X-rays and gamma rays which fits the observations very nicely.

However, perhaps the most interesting questions concerning the celestial X-rays have been raised through the discovery of discrete sources by Rossi and his colleagues and by H. Friedman, S. Bowyer, T. A. Chubb, and E. T. Byram of the Naval Research Laboratory. Both groups have observed a strong X-ray source in Scorpius which is not coincident with any conspicuous object. Friedman has suggested that this object is a neutron star having a surface temperature of several million degrees, and that the X-rays are due to thermal emission from the surface layers. Rossi and his colleagues have determined from atmospheric absorption measurements that if the Scorpius source has a thermal spectrum its temperature is approximately 8 million degrees Kelvin. Friedman and his colleagues have also observed X-rays from the direction of the Crab Nebula, the remnant of the supernova explosion of 1054 A.D.

Neutron stars are hypothetical objects which form one class of degenerate stars, the other class being the degenerate white dwarf stars, which are observed. A typical density for matter in a white dwarf star is 10^6 gm/cm^3, and the electrons form a degenerate gas which exerts sufficient pressure to maintain the stars against further contraction. If mass were to be added to such a star, the central region would have to become denser in order to supply the additional pressure required to support the additional mass. There is a relativistic upper limit to the mass of white dwarf stars, but before this limit is reached the energies of the degenerate electrons have become so high that the nuclei are forced to undergo multiple electron capture reactions, and the nuclei dissolve mainly into neutrons, with only enough protons and electrons left to prevent the neutrons from undergoing their usual mode of decay into electrons and protons.

At 10^{15} gm/cm^3 or more, densities comparable to those in the atomic nucleus, this neutron-rich nuclear matter itself becomes degenerate, and it is expected that stable stars could be constructed of it. Such stars may be formed in the central regions of more massive stars when these stars undergo supernova explosions and blow off most of their mass. Recent work by D. Morton, E. E. Salpeter, H. Y. Chiu, S. Tsuruta, and A. G. W. Cameron indicates that the surface temperature of a neutron star is likely to lie between one and two orders of magnitude below its central temperature. Thus, if such stars are formed with central temperatures over 10^9 degrees Kelvin, as would be likely in a supernova explosion, then their surface temperatures are likely to be many millions of degrees for several thousand years.

If these speculations are correct, it is to be expected that several dozen neutron stars can be detected in our galaxy as X-ray astronomy improves its techniques. The neutron-star hypothesis predicts a specific thermal shape for the X-ray spectrum of the Scorpius source, with the possibility that the composition of the surface will be revealed by characteristic absorption edges. It should not be long before decisive tests of this hypothesis have been made.