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Space: Highlights of Recent Research

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Space science is the collection of scientific problems to which space vehicles can make some specific contributions not achievable by ground-based experiments. At present this field includes broad segments of the traditional disciplines of the earth sciences, physics, and astronomy. In future years the biological sciences will join this group in an important role, as our explorations of the moon and planets provide us with opportunities for studying the conditions under which physical life may have developed. This article reviews some highlights of recent space research in the physical sciences.

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 have a constant orientation in space.

Actually, the plane of a satellite's orbit rotates slowly in space, due to 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 for the flattening and the value expected on the basis of an assumption of hydrostatic equilibrium. It has been suggested by Munk and MacDonald that these results imply that the interior of the earth is not in hydrostatic equilibrium but has a mechanical strength sufficient to maintain the earth's shape in spite of the stresses at the base of the mantle.

There are other departures of the geoid from the shape expected in the case of hydrostatic equilibrium, in addition to the discrepancy in the flattening. These departures are of very great significance because they represent variations in gravity which depend on the entire distribution of mass within the planet, which are more significant for the gross structure of the planet than the simple topographical variations—for example, mountains—which represent the distribution of the mass at the surface alone.

Detailed analysis of these gravitational variations yields a figure of the earth having a positive anomaly, or a lump, in the region of the western Pacific, near Indonesia and the Philippines, a large depression or negative anomaly in the Indian Ocean, and a negative anomaly in the Antarctic (Fig. 1).

Although these depressions and elevations are relatively minute, they are exceedingly significant because they represent variations in the force of gravity, or in 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, relatively, so weak that the waters of the sea are not drawn together to the depth that one would expect 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 heat flow is anomalously low. On the average, the flow of heat outward through the crust of the earth is 60 erg cm^{-2} sec^{-1}. In the depression of the geoid near India, the flow of heat is substantially higher, 80 erg cm^{-2} sec^{-1}. At the elevation of the geoid in the western Pacific, the flow of heat is substantially lower, about 40 erg cm^{-2} sec^{-1}.

We expect this kind of correlation 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 the average. At the same time, the heat which the warm column transports upward would add to the normal release of radioactive heat throughout the mantle and crust, so that above the same upward-moving column there would be an exceptionally high 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

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gravitational force would be relatively great, and a bump would appear in the sea level there. This may be 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.

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 measuring the intensity of infrared radiation emitted from the earth-atmosphere system.

The cloud-cover photographs have already yielded results that are of great interest when correlated with ground observations, and they indicate that use of satellites may lead 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 present large parts of the globe are very poorly covered. These are regions in which weather activity can develop and grow without detection before moving out into the inhabited areas. They 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 it may be expected to have important consequences for the economies of this country and the world.

The cloud photographs may also be important for the basic objectives of long-range forecasting and the understanding of the causes of weather activity, because clouds have a strong influence on both the amount of solar energy admitted to the earth-atmosphere system and the amount of energy returned to space from the surface.

The energy balance of the earth-atmosphere system is the difference between the incoming solar radiation, mostly in the visible region of the spectrum, and the outgoing terrestrial radiation, in the infrared. The latitudinal variation of the energy balance shows an excess of incoming solar radiation over outgoing radiation near the equator, and a deficiency at the poles. It is this variation of the energy balance with latitude that drives the atmospheric heat engine.

That part of the visible radiation from the sun which is not reflected by clouds or scattered in the atmosphere reaches the surface of the earth and is absorbed, heating the ground to a temperature in the neighborhood of 235°K. 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 radiation from the ground by these molecules heats the lower atmosphere, which reradiates the absorbed energy, partly upward to outer space and partly downward, providing additional heating of the surface.

The additional heating of the surface by the return of infrared radiation from the atmosphere is analogous to the action of the glass panes of a greenhouse, and is called the "greenhouse effect." It is sufficient to raise the temperature

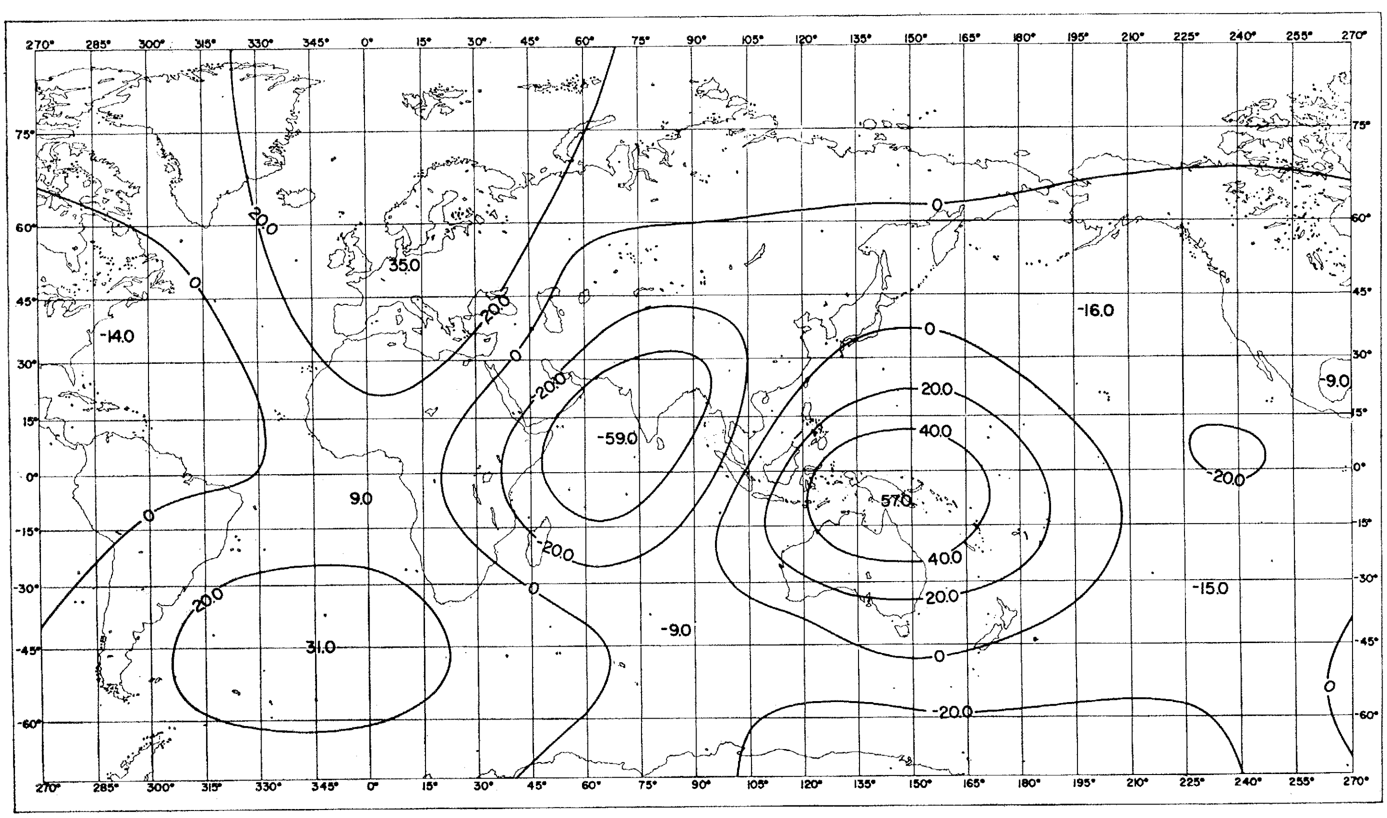


Fig. 1. Geoid heights (in meters) relative to an ellipsoid with a flattening of 1/298.3. The major features include a negative anomaly in the Indian Ocean and a positive anomaly centered near Indonesia and the Philippines. [From G. J. F. MacDonald, *Science* 143, 921 (1964)]

of the surface of the earth by about 55°K, so that the average temperature of the surface of our planet becomes 290°K.

Clouds are strong absorbers of infrared radiation and influence the infrared transmission and the local greenhouse effect. (This is in addition to the primary effect of clouds as reflectors of incident visible solar radiation.)

Thus, the cloud cover has an important effect on the deposition of energy in the atmosphere because it influences both the inflow and the outflow of energy through the atmosphere. Thus far the characteristics of clouds—amount, types, and approximate heights—have all been measured by ground-based observers. Satellite observation by television cameras introduces the possibility of obtaining extensive data on global cloud cover in relatively short periods.

A. Arking, of the Goddard Institute for Space Studies and New York University, has recently carried out the first statistical analysis of Tiros cloud-cover data, using a digitizing technique applied to Tiros III photographs. The Tiros III results are compared in Fig. 2 with a climatological mean cloudiness for the Northern Hemisphere that was compiled by K. Telegadas and J. London, then at New York University, from ground observations extending over a 50-year period. The Southern Hemisphere data of Fig. 2 were compiled by H. Landsberg of the U.S. Weather Bureau.

The results in Fig. 2 show that the cloud cover in middle latitudes is the same in the Northern and Southern hemispheres. However, in tropical latitudes there is an asymmetry, with a local maximum of the cloud cover in the tropics centered at 10°N. This is the average position of the "thermal equator" during the period 12 July to 30 September.

These results are preliminary, but the approach seems promising, and it is hoped that improved techniques will make it possible to detect fine-scale temporal and geographical variations in the distribution of the energy balance.

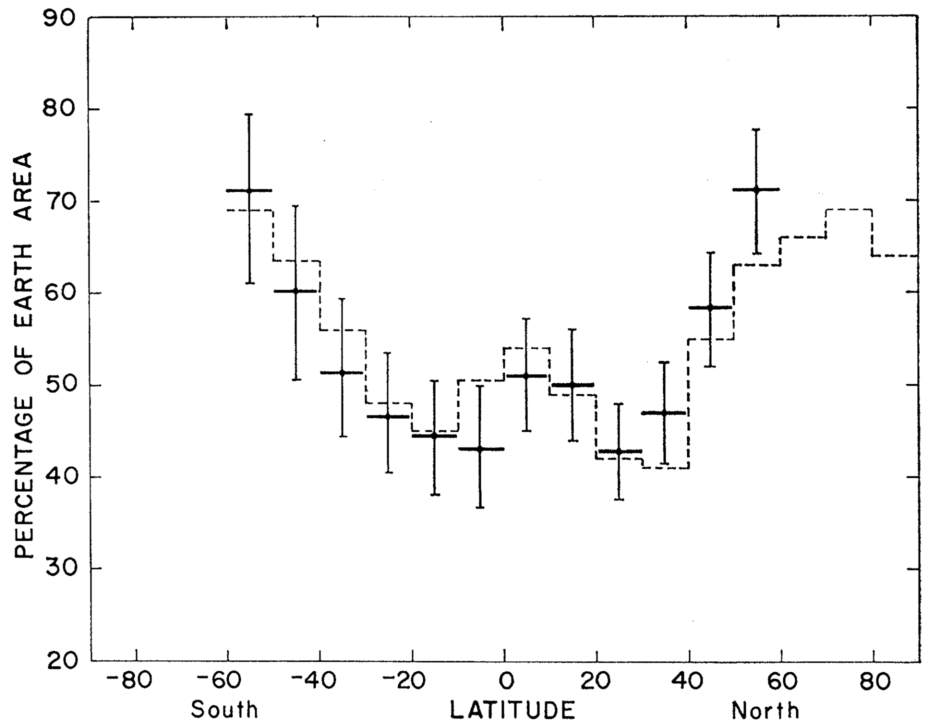


Fig. 2. The latitudinal distribution of cloud cover. (Solid horizontal bars) Results derived from Tiros III photographs taken from 12 July to 30 September 1961; (vertical lines) estimated uncertainty in the Tiros-derived data; (dashed histogram) climatological mean cloud cover derived from ground observations, as compiled by Telegadas and London for the Northern Hemisphere and by Landsberg for the Southern Hemisphere. The broad features of the latitudinal distribution are consistent with the known pattern of the general circulation. The air rising at the thermal equator produces a relative maximum in the cloud cover, while, on the average, there is downward motion of cool, dry air at latitudes 30° north and south of the thermal equator, which explains the relative minimum of cloudiness. [From A. Arking, *Science* **143**, 569 (1964)]

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 flux of solar energy, the absorption cross sections in the far ultraviolet are so large that radiation at these wavelengths has been effectively removed from the incident spectrum by the time the incident flux has penetrated to a height of 100 kilometers. 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 emergence of the hydrogen atmosphere was thought to come at an altitude of about 1200 kilometers. However, in July 1961, Marcel Nicolet of Belgium suggested, on the basis of an initial examination of the density data of Echo I, that between the oxygen-nitrogen atmosphere and the hydrogen atmosphere there lies a layer of helium. The helium layer was discovered experimentally a short time later by R. Bourdeau, of the NASA Goddard Space Flight Center, and the finding has since been confirmed in other experiments (Fig. 3).

Our knowledge of properties of the atmosphere at altitudes above 200 kilometers is mainly derived from measurements of atmospheric drag on satellites. The period of revolution of a satellite decreases steadily at a rate proportional to the drag force exerted by the atmosphere, which is, in turn, proportional to air density; a measurement of the rate of change of period therefore gives the value of the air density suitably averaged around the orbit.

Data on satellite drag have been a very valuable source of information on atmospheric properties. L. G. Jacchia of the Smithsonian Astrophysical Observatory was the first to discover, by careful analysis of time variations in the drag, that the upper atmosphere is extremely responsive to solar control, deviating in density from the mean

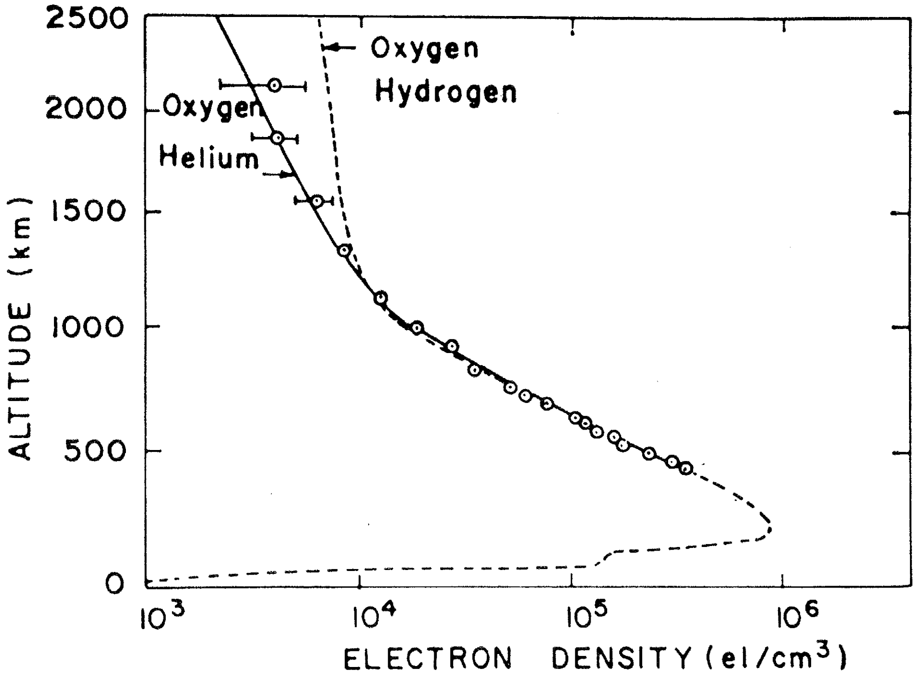


Fig. 3. Electron density profile measured by a Scout rocket, and providing evidence for a helium layer in the upper atmosphere. (Dotted line) Density distribution for a scale height derived from an oxygen-hydrogen mixture; (solid line) calculated density distribution for an oxygen-helium mixture. [From S. J. Bauer and J. E. Jackson, *J. Geophys. Res.* **67**, 1676 (1962)]

by as much as a factor of 100 and deviating in temperature by hundreds of degrees at times of solar activity.

The significance of the correlation between solar activity and the properties of the earth's upper atmosphere can be described as follows. The surface of the sun is the scene of great activity, especially during the maximum of the sunspot cycle, when it is 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 toward 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 was discovered by Jacchia and by W. Priester of Bonn University Observatory and the Goddard Institute for Space Studies. Their results suggest 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 of the influence of solar surface activity on atmospheric properties.

The continuing analysis of the correlation has given us a rather full picture of solar control over the upper atmosphere. It indicates that the atmosphere is appreciably heated by the ultraviolet radiation emitted at times of general solar surface activity, and is further heated by interaction of the earth with the clouds of solar particles which are emitted from the sun following solar surface eruptions. The arrival of the clouds of particles at the earth is signified by the onset of geomagnetic disturbances or "magnetic storms." It is found that increases in the temperature of the atmosphere occur shortly after the commencement of

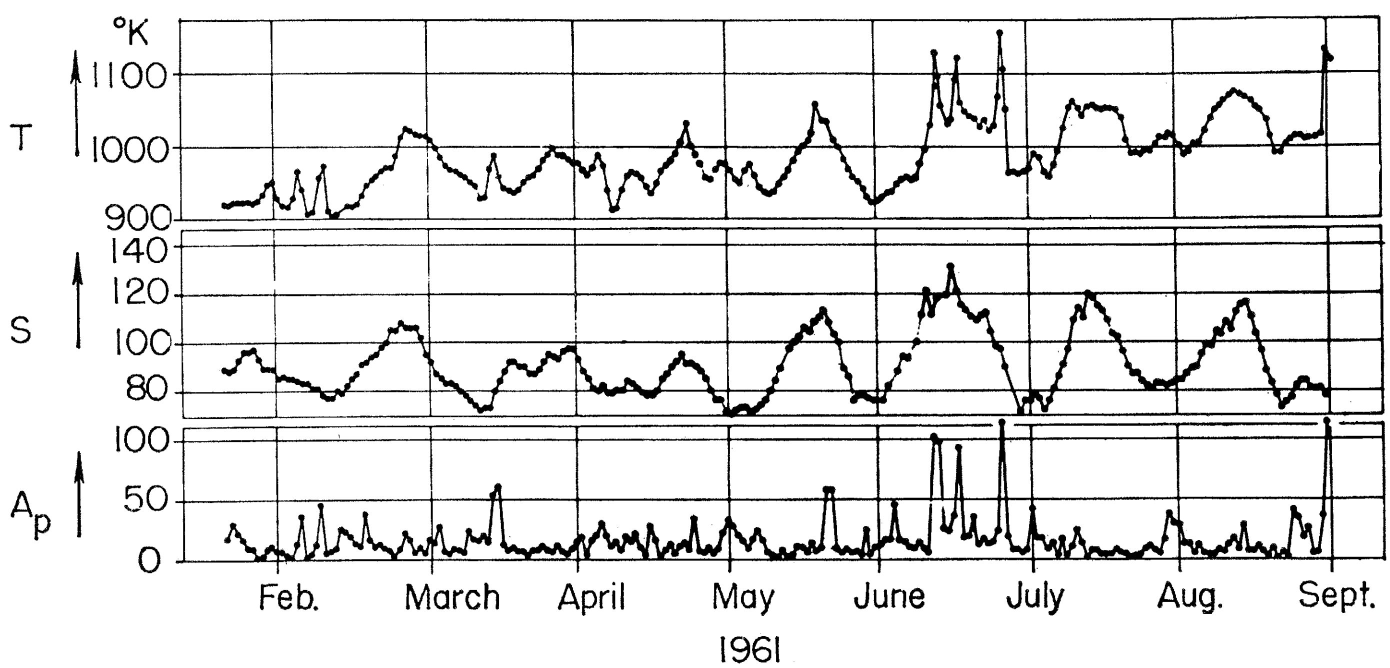


Fig. 4. Temperature variation correlated with solar radio emission and geomagnetic indices for the interval from February through September 1961. (Upper curve) Exospheric densities and temperatures, derived from Explorer IX drag measurements by L. G. Jacchia and J. Slowey (1962); (middle curve) flux of the solar radiation at 20-centimeter wavelengths, an indicator of solar activity, measured at the Heinrick Hertz Institut in Berlin; (lower curve) geomagnetic activity index (A_p). [The Explorer IX data are adapted from L. G. Jacchia and J. Slowey, *Smithsonian Astronomical Observatory Spec. Rept. No. 84* (1962); reproduced courtesy of W. Priester]

the magnetic storms. Thus, it appears that both ultraviolet radiation and corpuscular streams are sources of energy for the upper atmosphere (Figs. 4 and 5). The question of the energy sources for the upper atmosphere is the most important single problem for upper-atmosphere physics at this time. 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.

Magnetosphere

The evidence cited suggests that corpuscular streams from the sun transfer appreciable amounts of energy to the atmosphere. 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 kilometers, marking the boundary of the atmosphere. Early in 1958, however, J. A. Van Allen of the State University of Iowa discovered, by analyzing 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, and the atmospheric layer which they constitute is therefore called the magnetosphere.

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-particle 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 directly into the atmosphere without spending an appreciable amount of time in the trapped-particle 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.

Second, a large population of low-energy protons, having a range from 100,000 to several million electron volts, was discovered by A. H. Davis and J. M. Williamson of the Goddard Space Flight Center. The concentration of these protons reaches a maximum at a distance of 3.5 earth radii. At that distance their density is about one per cubic centimeter. This value for density of the trapped protons 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 effects have been calculated by S. Akasofu of the University of Alaska, S. Chapman of the universities of Colorado and Alaska, and (in unpublished work) R. A. Hoffman of the Goddard Space Flight Center. They find that the changes in the

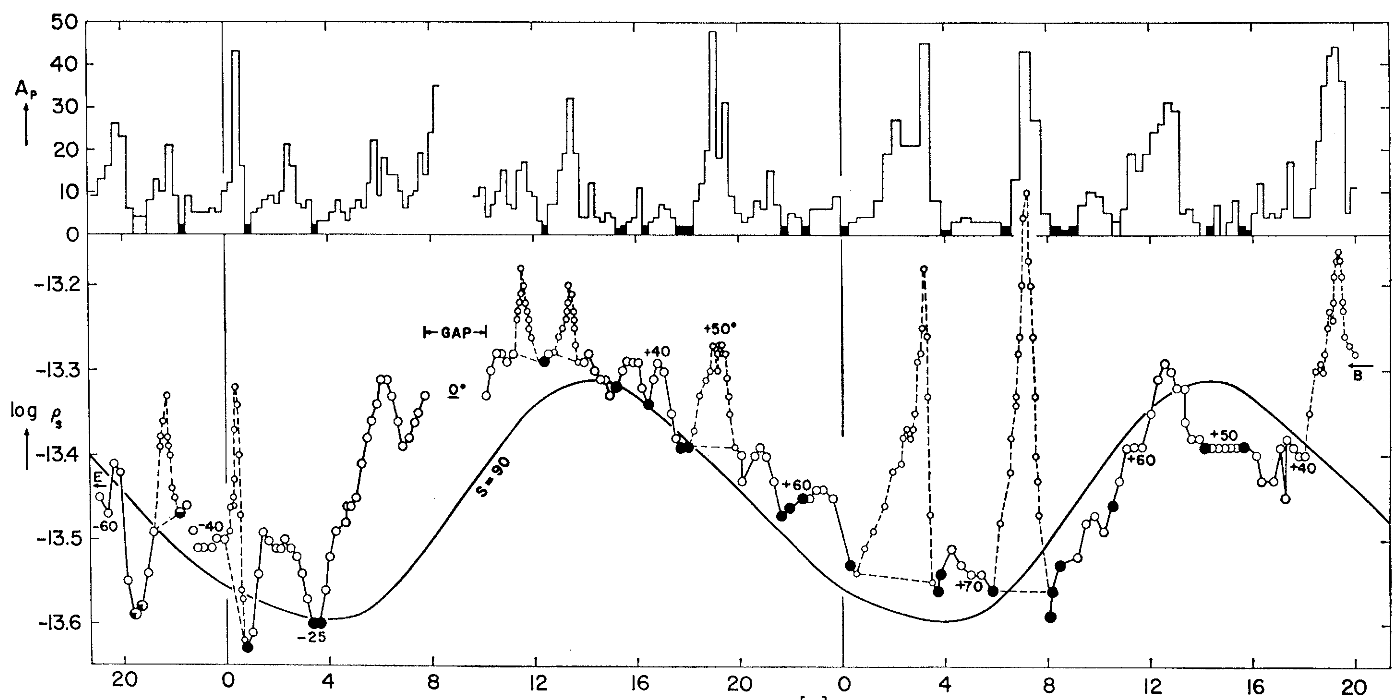


Fig. 5. Density variations at 250 kilometers above sea level as a function of local time t, determined by L. G. Jacchia and J. Slowey (1963) of the satellite Injun III from 15 December 1962 through 29 June 1963. During this time the geographic latitude of the perigee cover the range from +70° to −60°, as indicated by the numbers on the density curve. (Solid curve) The Harris-Priester model for the proper level of solar activity; (histogram at top) daily geomagnetic indices A_p; (open circles) densities during magnetic storms; (solid circles) densities during magnetically quiet days ($A_p < 2$). The response of the atmosphere to solar activity, as indicated by violent solar storms, is much greater within the auroral zone than outside it. [Adapted from L. G. Jacchia and J. Slowey, *J. Geophys. Res.* **69**, 905 (1964)]

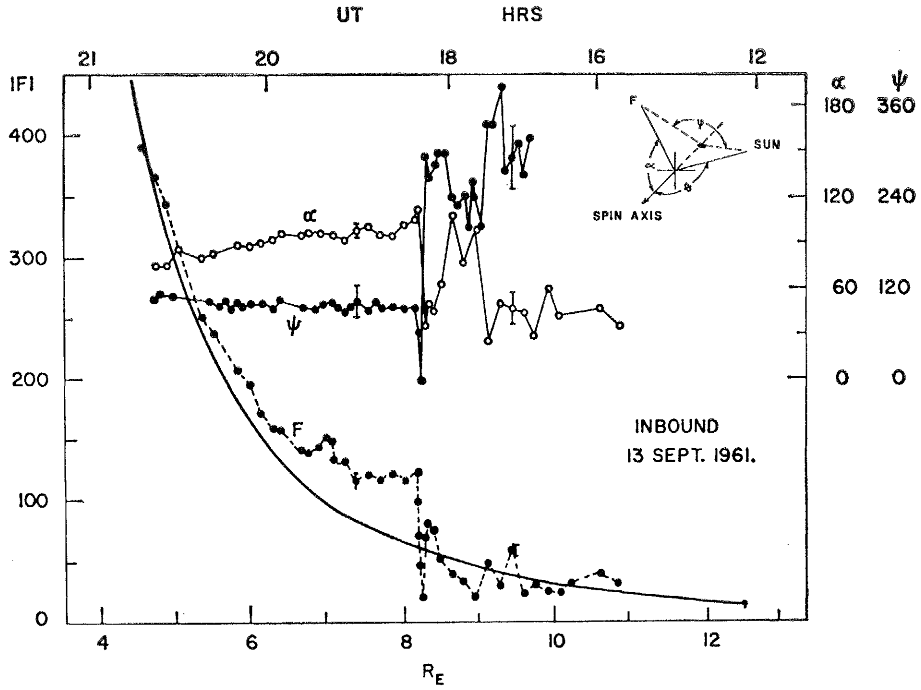


Fig. 6. Explorer XII measurements showing the abrupt termination of the geomagnetic field at the magnetopause. F is the magnitude of the magnetic field and α and ψ refer to its direction. Within the magnetosphere the field is closely described by the high-altitude extrapolation of the earth's approximately dipole field, shown as the solid curve. Outside the magnetopause, which occurred at 8.2 earth radii (R_E) during this flight, the field varies in magnitude and direction. [From L. J. Cahill and P. G. Amazeen, *J. Geophys. Res.* **68**, 1841 (1963)]

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 estimate of the total flux of electrons is reduced from the earlier estimated value of 10^{10} cm^{-2} sec^{-1} srad^{-1} to the currently accepted value of 10^{8} cm^{-2} sec^{-1} srad^{-1}.

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 atmosphere near the magnetopause, the boundary separating the interplanetary medium from the region around the earth, in which the geomagnetic field is dominent. The sharply defined surface of the magnetopause marks the termination of both the trapped-particle region and the geomagnetic field. Satellite measurements of the geomagnetic field by L. J. Cahill of the National Aeronautics and Space Administration and of the University of New Hampshire show that the magnetopause has a thickness on the order of 100 kilometers and occurs at a distance of 8 to 10 earth radii on the sunlit side of the earth.

The sharpness of the magnetospheric boundary is illustrated by Figs. 6 and 7. Figure 6 represents the magnetic-field measurements obtained by Cahill and P. G. Amazeen of the University of New Hampshire, using a three-component magnetometer flown on Explorer XII. At the magnetopause a sudden drop occurs, and outside the magnetosphere the magnetic field is highly variable in magnitude and direction. Figure 7 shows the counting rates of charged particle detectors flown on Explorer XIV by Van Allen, L. A. Frank, and E. Macagno of the State University of Iowa. The detector which accepts the particles of lowest energy is labeled 213A, and its counting rate reflects principally the flux of 50-kev electrons. At the magnetopause the counting rate of this detector drops, by a factor of approximately 20, to a value which is approximately independent of altitude and is produced by the cosmic ray background in space.

Within the magnetopause there are no substantial fluxes of energetic particles other than those of the magnetically trapped particles illustrated in Fig. 8. Detectors flown on Mariner II indicate that the sun is the source of a particle stream which flows through interplanetary space continually, although with variable velocity and intensity. The Mariner II detectors, and also the plasma probe flown on Explorer X by B. Rossi, H. S. Bridge, A. J. Lazarus, A. Bonetti, and F. Scherb of the Massachusetts Institute of Technology, have shown that these particles move radially outward from the sun at velocities varying from 300 to 600 kilometers per second and at an average flux of 10^{9} cm^{-2} sec^{-1} outside the magnetopause. The interplanetary stream of solar particles, called the solar wind, cannot penetrate the magnetic field of the earth but divides and flows around it as the waters of a stream divide around a boulder (Fig. 8). The closest distance of approach of the solar wind to the earth is about 10 earth radii.

The shadow or cavity carved by the magnetic field of the earth in the solar wind should, in principle, extend back indefinitely far into the solar system behind the earth. However, because the particles of the stream have appreciable transverse velocities associated with their thermal motions, we expect these particles to diffuse together eventually in the shadow of the earth. The ratio of mean transverse to radial velocities is about ¼, hence we expect the geomagnetic cavity to be filled in at a distance of 4 times the diameter of the cavity, or, roughly, the distance of the moon from the earth, as suggested in Fig. 8.

The amount of energy transferred from the solar wind to the atmosphere within the cavity is difficult to estimate. The variable magnetic fields in the solar plasma are believed to glue the particles together and give their motion the properties of fluid flow, in spite of the low density; thus turbulence would be expected at the region of impact of the solar wind on the magnetopause. The buffeting of the magnetospheric boundary associated with this turbulent impact may generate disturbances in the field just within the magnetopause. These disturbances propagate hydromagnetically down or across the field lines into the atmosphere, where they transfer energy which may appear as atmospheric heating, ionization, auroral disturbances, and magnetic storms—that is, the whole complex of disturbances produced in the atmosphere at high geomagnetic latitudes at times of solar activity.

The interaction of the solar plasma with the magnetosphere also leads to the expectation that a "shock wave" will be formed some distance beyond the actual magnetopause. This expectation arises from the fact that the flow of the plasma is supersonic and must become subsonic in the vicinity of the earth. Such a transition would set up a shock wave which would stand off some distance from the magnetopause and would have a thickness determined by the ability of the magnetic field to change the bulk motion of the plasma particles. Evidence of the perturbed magnetic fields corresponding to the shock wave and the intervening transition region has been detected by N. F. Ness of the Goddard Space Center with magnetometers flown on the Interplanetary Monitoring Platform (IMP) spacecraft launched on 27 November 1963.

Atmosphere of Venus

Venus is the third brightest object in the sky, the planet nearest the earth, and the planet most closely resembling the earth in size and mass. It has been studied with the telescope since Galileo's time, and yet it remains an enigma, because its surface is permanently shrouded by a layer of clouds. In this state of ignorance, hope has flourished that Venus offers a hospitable environment for the development of advanced forms of life.

Some information regarding the surface of the planet has been obtained in recent years through study of the microwave radiation emitted in the long-wave region of its thermal spectrum. This radiation, with wavelengths in the region of 1 to 10 centimeters, penetrates the clouds without significant attenuation; its intensity is proportional to the temperature of the emitting surface.

The first attempts to measure the microwave radiation from Venus were made in 1956 with the Naval Research Laboratory radio telescope. The temperature inferred from the measured radiation intensity was approximately 600°K (700°F)—certainly too high to permit any terrestrial forms of life. Repeated measurements have confirmed the Naval Research Laboratory results

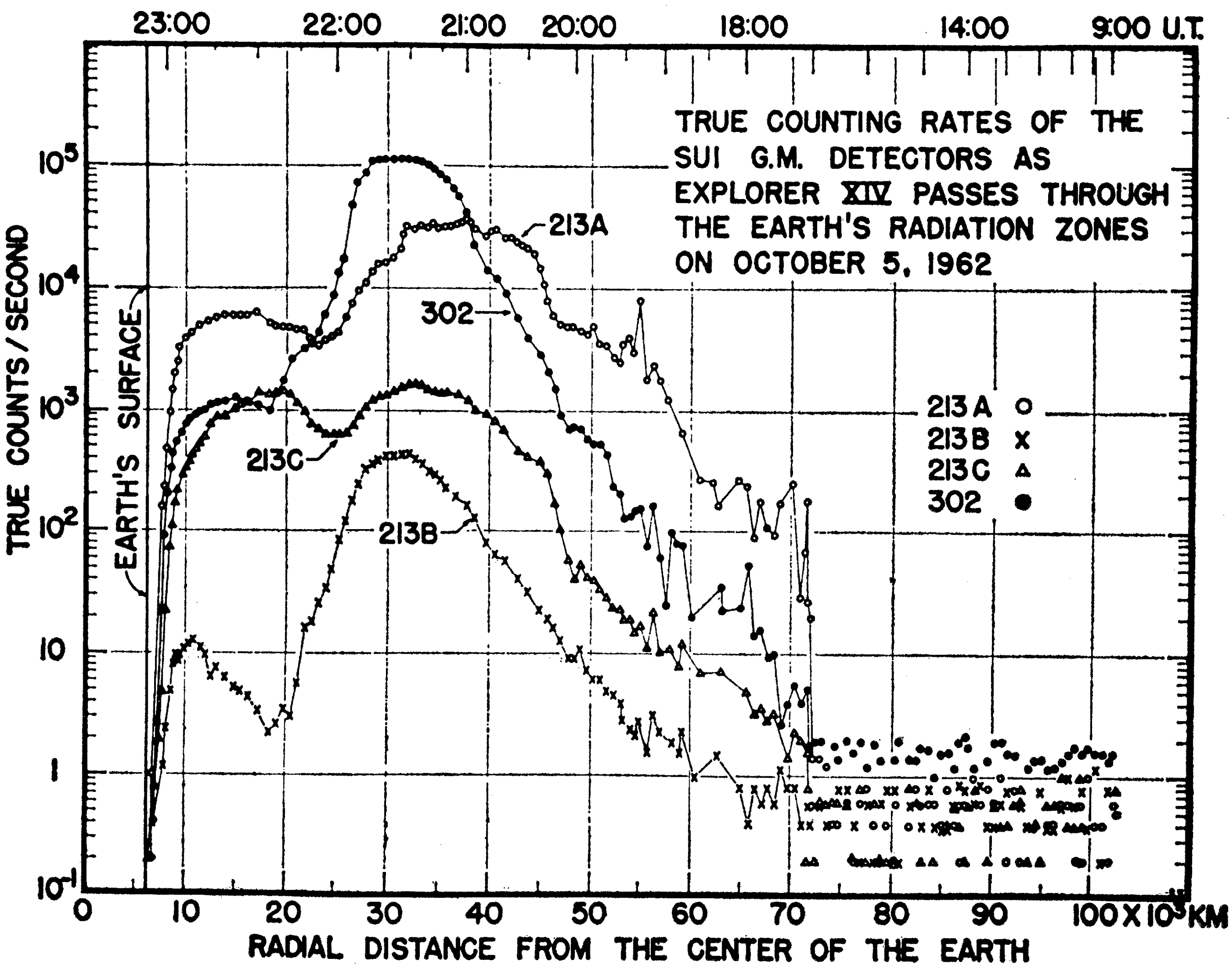
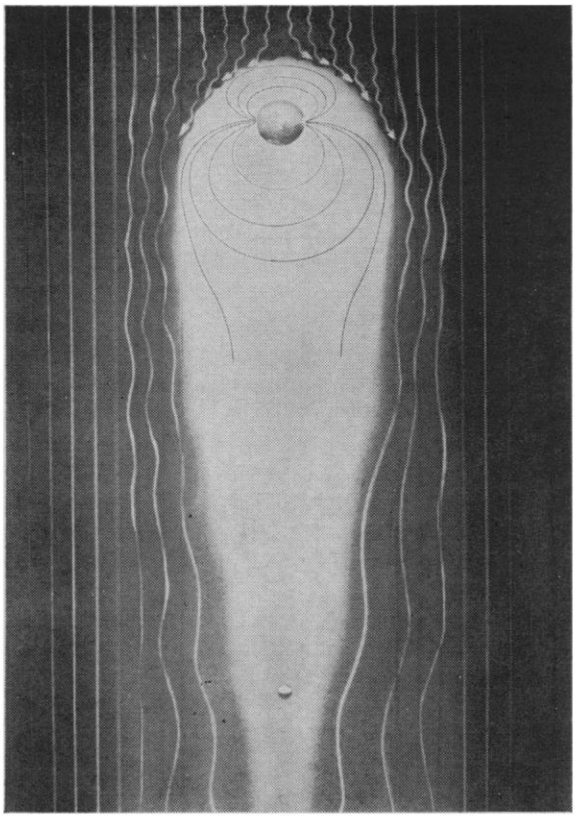


Fig. 7. Explorer XIV data showing the abrupt termination of the magnetically trapped particle belts at the magnetopause. The detector labeled *213A* accepts the particles of lowest energy; it records principally 50-kev electrons. Its counting rate drops sharply at a radius of 72,000 kilometers, or 12.5 R_E, which corresponds to the location of the magnetopause during this flight. [From L. A. Frank, J. A. Van Allen, E. Macagno, *J. Geophys. Res.* **68**, 3545 (1963)]



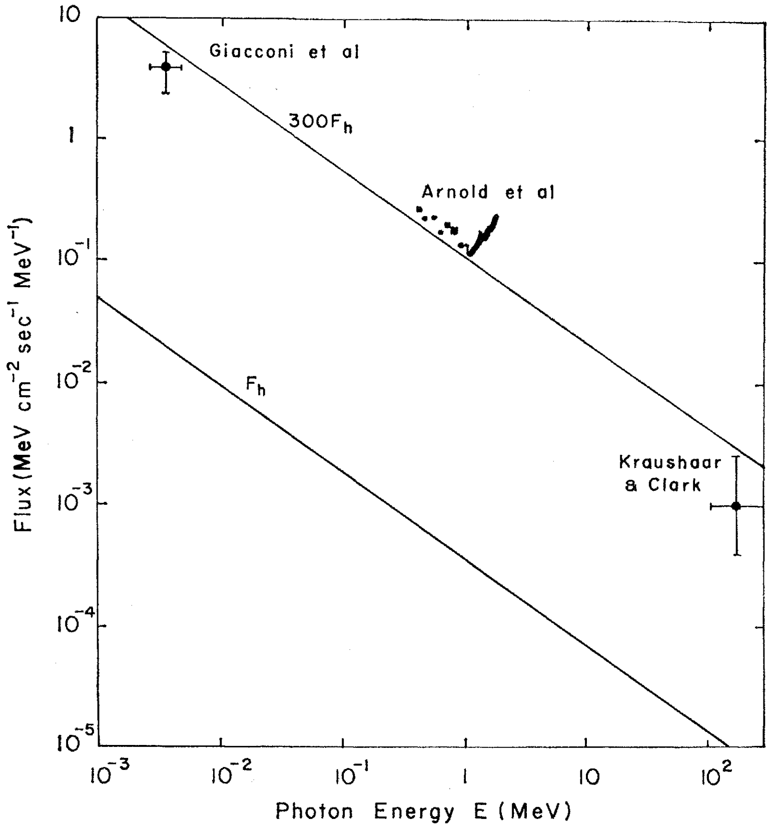


Fig. 8 (left). The geomagnetic cavity in the solar wind. Fig. 9 (right). Data on hard photon fluxes in space, compared with theoretical recoil spectra. The data points are as plotted by Felten and Morrison. F_h is the expected contribution from scattering in our galactic halo. The upper curve shows a flux 300 times greater, but still less by two orders of magnitude than the flux that would be obtained if the electrons in our galactic halo extended throughout intergalactic space. [From J. E. Felten and P. Morrison, *Phys. Rev. Letters* **10**, 455 (1963)]

and have forced a revision of our ideas regarding the surface and lower atmosphere of Venus.

It is difficult to understand why the temperature of Venus should be so much higher than that of the earth. The path to an explanation would seem to lie in the assumption of an extremely dense atmosphere which absorbs strongly in the infrared region of the spectrum but is transparent with respect to visible radiation. The part of the incident sunlight which is not reflected back by the clouds will therefore penetrate through the atmosphere and heat the surface of the planet. But when the surface layers reradiate this energy at infrared wavelengths, the radiation is absorbed by the atmosphere and returned in large measure to the surface, thus giving an additional flux of energy into the ground and raising its temperature. This atmospheric phenomenon is the greenhouse effect described earlier.

The clouds of Venus reflect three-quarters of the incident sunlight; the remaining quarter of the incident radiation would bring the surface of the planet to a temperature of 235°K if there were no atmospheric greenhouse effect. If the greenhouse effect is to raise the ground temperature to 600°K, the optical thickness of the atmosphere must be 50 mean free paths throughout the far-infrared region. In an atmosphere with this degree of opacity, only one photon in 10^{21} escapes directly, without absorption. This condition is so severe that alternative suggestions have been made, among them the hypothesis that the apparently high radio temperature of Venus is the result of microwave emission from its ionosphere rather than from the surface.

The Mariner II Venus flyby launched on 27 August 1962 included experiments designed to test this hypothesis. This spacecraft passed Venus at a distance of 33,440 kilometers (20,900 miles) on 14 December 1962, and made crucial measurements of the temperature across the disc. The spacecraft was equipped with two sets of radiation detectors, one in the infrared and one in the microwave region. Measurements of the radiation emitted by the planet in the microwave region included measurements of radiation of 19-millimeter wavelength, which passes through the atmosphere with little attenuation and hence provides a measure of the temperature at the ground, provided there is no additional emission from the ionosphere.

A modest degree of atmospheric attenuation is, however, to be expected, and in the scan of Mariner II across the disc of the planet this slight degree of attenuation should show up as a lower intensity of measured radiation at the edge or limb of Venus, where the thickness of the intervening atmosphere is greater. However, if the high microwave intensities and apparent temperatures result from emission by electrons in the inosphere of Venus, then the readings at the limb should indicate an enhancement or brightening because of the greater thickness of the ionosphere in the line of sight.

The Mariner II results showed a conclusive darkening of the limb of Venus at 19-millimeter wavelength, thus eliminating the possibility of ionospheric emission and confirming the supposition that the measured radio temperature of 600°K is associated with the surface of the planet.

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 erase the history of the earth's surface in a relatively short 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 the antiquity of the moon's surface, there is another remarkable record 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 30 centimeters or more in depth and may contain organic molecules and the precursors of life on earth.

The most important measurements of lunar properties from spacecraft have resulted from flights of the Russian 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, refinement of this limiting value for 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 of 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 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 characteristic 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 such mountain-building forces have been much less effective on the moon. In the photograph, the markings designated the Soviet Mountain Range could have resulted from the running together of several obscured but independent markings. However, if these features 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 concerns 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 for the heat generated by nuclear reactions to be carried away from the center of the sun, the temperature must fall continuously from the center to the edge. This is in fact the case; the temperature falls from 15 million degrees at the center of the sun to 5800 degrees at the visible edge.

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 is that the temperature of the sun *rises* again above the photosphere, reaching a value of 1.5 to 2 million degrees in the corona. One of the burning 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 by which energy can be carried without appreciable losses through the dense gases of the photosphere and yet undergo great 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 steepens into a shock wave. This is a mechanism in which considerable dissipation of energy takes place. It appears that hydromagnetic waves are rapidly damped out below the photosphere, but if they could be generated in the region of the chromosphere, then they would tend not to be dissipated until the waves had 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 would have a vertical component of propagation and would be dissipated in the corona.

It may be that all three of these mechanisms are operating in 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 dependence is observed in many phenomena. In particular, in sunspot regions where the strengths of the magnetic field 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 attributable 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 7 March 1962. It gave data over several months, continuously monitoring a number of different wavelength regions for emission from the sun.

Particularly interesting are the data for the interval 11 through 22 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 22 March there was a flare of intensity 3. Experiments revealed that the Lyman alpha line of helium II at 304 angstroms increased in intensity by some 33 percent during the interval, and during the flare itself the intensity of the line increased by an additional 14 percent. The lines of iron XV at 284 angstroms and iron XVI at 335 angstroms 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 angstroms. During the quiet period a flux was observed which was 360 times the theoretical background radiation which would be obtained from a corona at a temperature of 1.8×10^6 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 gives the astrophysicist an important opportunity 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-wavelength 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.

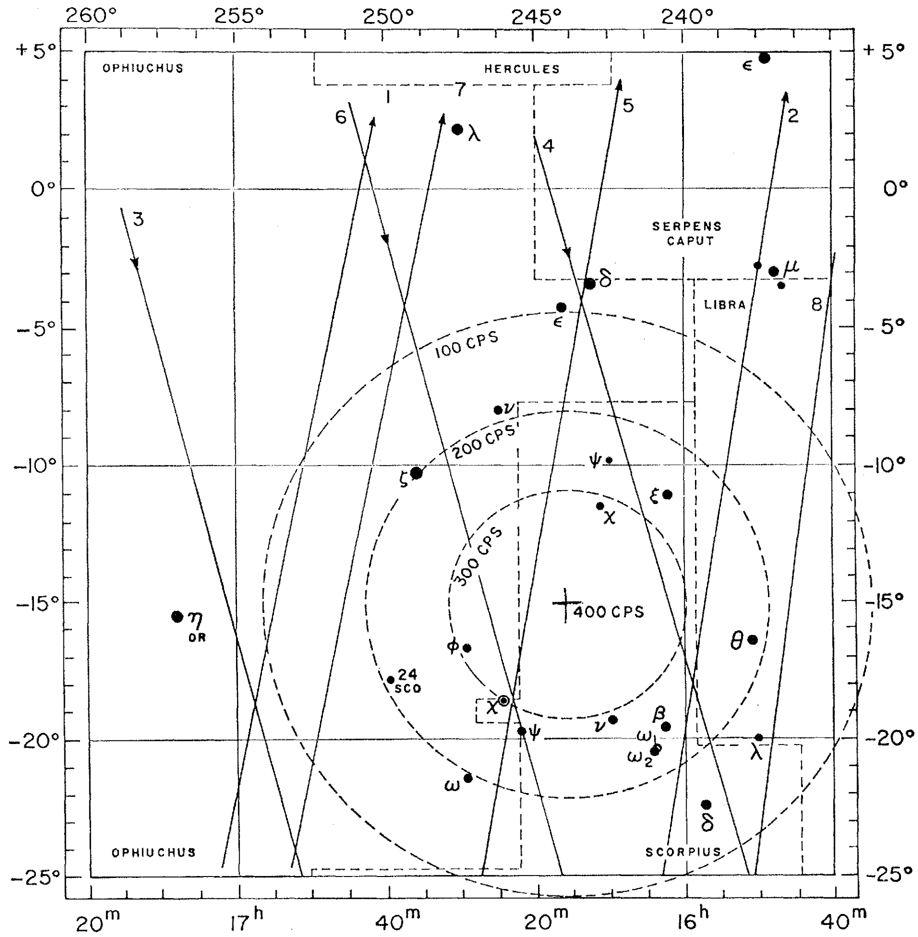


Fig. 10. Tracks of eight scans across the Scorpius region. The numbers along the tracks are counts per 0.09-second interval. The dashed circles are best fits to equal-intensity contours and indicate a central intensity peak of 400 count/sec at $\alpha = 16$ hours 15 miutes, $\delta = -15°$. [From S. Bowyer, E. T. Byram, T. A. Chubb, H. Friedman, *Nature* **201**, 1307 (1964)]

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 of 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 up to the x-ray and gamma ray regions. If radioactive nuclei are produced and dispersed in space between the stars, then 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 annihiliated, 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, if objects should exist in space with surface temperatures of some millions of degrees Kelvin, then photons in the x-ray region would 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 energy of a few thousand electron volts was observed in a rocket flight by R. Giacconi, H. Gursky, and F. R. Paolini, of American Science and Engineering, Inc., and by B. B. Rossi of the Massachusetts Institute of Technology. A general background radiation of gamma rays in the region near 1-Mev energy was measured in the Ranger III flight by J. R. Arnold of the

University of California (La Jolla), A. E. Metzger, of the California Institute of Technology, and E. C. Anderson and M. A. Van Dilla, of Los Alamos. A small but still significant flux of gamma rays with energies exceeding 50 Mev was observed with the Explorer XI satellite by W. L. Kraushaar and G. W. Clark of the Massachusetts Institute of Technology.

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 was proposed by J. E. Felten and P. Morrison of Cornell University, who suggested the importance of the inverse Compton effect in which the high-energy electrons present in the cosmic rays collide with photons with energies of the order of 1 electron volt which are emitted from stars. Following such a collision, the energies of the photons can easily be raised to the observed x-ray or gamma ray energies, depending upon the energies of the electrons with which they collide. Calculations by Felten and Morrison were based on this effect (Fig. 9). A flux will be emitted by the outer halo region of our galaxy if the observed flux of high-energy electrons at 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 the flux of high-energy electrons is the same throughout space as near the earth, then a background radiation 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 space. One percent of such a flux of electrons can be expected to give a background of x-rays and gamma rays which fits the observations very nicely.

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 8×10^6 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 A.D. 1054 (Fig. 10).

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 g/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} g/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 of Princeton, E. E. Salpeter of Cornell, and H. Y. Chiu, S. Tsuruta, and A. G. W. Cameron of the Goddard Institute for Space Studies indicates that the surface temperature of a neutron star is likely to lie below its central temperature by between one and two orders of magnitude. Thus, if such stars are formed with central temperatures over 10^9 degrees Kelvin, such as would probably be produced in a supernova explosion, then their surface temperatures are likely to be many millions of degrees for several thousand years.

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