

THE SCIENTIFIC OBJECTIVES OF THE ABLE-5 PROGRAM

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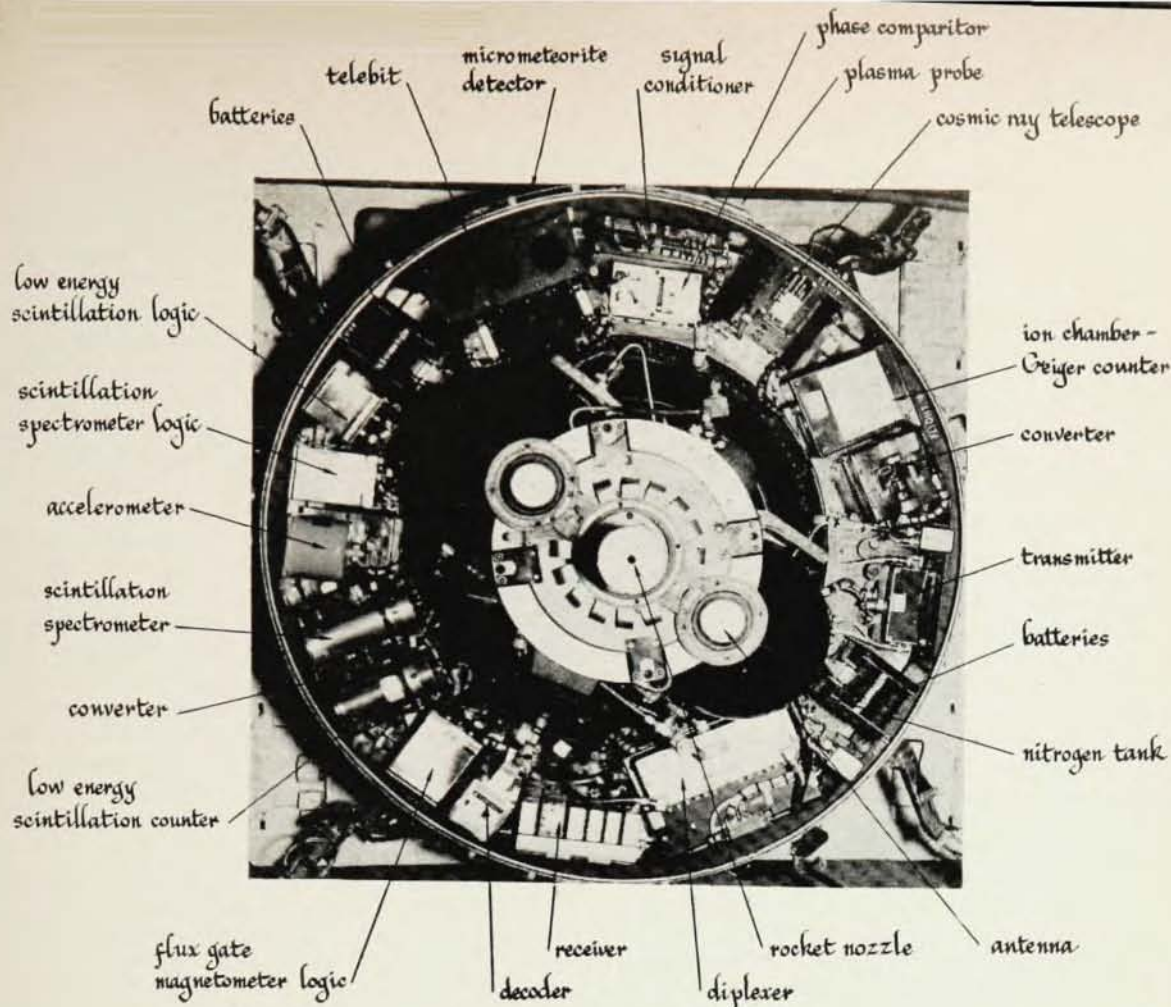
THE intent of the ABLE-5 program was to place a satellite into relatively close orbit around the Moon. The ABLE-5 satellite has been designed as a 390-lb scientific observatory to investigate some important aspects of the physics of space. It contains flux-gate and search-coil magnetometers, a set of radiation sensors (a plasma probe, scintillation counter, scintillation spectrometer, an ionization chamber and Geiger counter, cosmic-ray telescope, and a solid-state detector), and a micrometeorite counter. The general objective of these sensors is to acquire detailed information about the distribution of magnetic fields, the spectral density of charged particles, and meteoritic statistics.

Experiments carried on previous satellites such as Explorer VI and Pioneer V have already provided data on such things as cosmic radiation, solar-flare particles, and geomagnetically trapped radiation. For several reasons ABLE-5 should add significantly to our understanding of these and other phenomena. Its radiation sensors cover a much larger range of energies (see Table I) than those of its predecessors, and they will be examining this radiation during a different part of the solar cycle than the earlier satellites. Furthermore, because ABLE-5's orbit is circumlunar, it will explore repetitively a new region of space. Finally, its duty cycle is expected to be nearly continuous. Thus fairly precise correlations between observations of changes

The Atlas-Able rocket which exploded shortly after being launched at Cape Canaveral on the 15th of last month was intended to place a compact space station into a circumlunar orbit. The following discussion of the proposed scientific program, a project of the National Aeronautics and Space Administration, was prepared by five members of the staff of Space Technology Laboratories of Los Angeles, the organization which was charged with over-all systems responsibility, including the development of the payload. Space Technology also designed some, although not all, of the experiments to be conducted.

Table I. Cosmic-Ray Spectral-Range Capability of ABLE-5 Circumlunar Satellite

Counter	Proton Energy Range	Electron Energy Range	Energy Resolution
Plasma Probe	200 ev $\leftrightarrow$ 20 kev	None	32 steps
Scintillation Counter	600 kev	50 kev	
Solid-State Detector	0.5 Mev $\leftrightarrow$ 9 Mev	None	
Scintillation Spectrometer	2 Mev $\leftrightarrow$ 10 Mev	200 kev $\leftrightarrow$ 10 Mev	8 steps
Ionization Chamber	> 20 Mev	> 1.2 Mev	
Geiger Counter	> 20 Mev	> 1.2 Mev	
Cosmic-Ray Telescope	> 75 Mev	> 13 Mev	



ABLE-5 payload (view looking aft).

in radiation intensity at the vehicle and at ground stations can be made, and relationships between satellite measurements and logs of solar activity examined. In the discussion which follows, we attempt to examine the purport which the full assemblage of data from this first lunar space station might have, and deal speculatively with some of the possible results.

The Solar Wind

BOTH the radiation sensors and the magnetometers aboard the ABL-5 satellite should provide us with new information about a central but little understood phenomenon, the solar wind. It is already well known that such things as terrestrial magnetic storms, auroras, and changes in the character of the ionosphere are profoundly related to solar activity. Cumulative observations in the form of geophysical time-series of ionospheric and auroral data, for example, point to an intimate connection between optical and radio solar activity and such terrestrial events. However, the collected data are mainly phenomenological, and are often not usefully subject to theoretical examination in convenient terms. Thus the exact nature of the link between the physics of the Sun and that of the Earth-Moon system is not understood. The existence of the

lower, photosensitive, insulating layers of our atmosphere complicates the problem, for they make it virtually impossible to discover the pertinent characteristics of the invisible solar matter merely by observing its terrestrial consequences. The net result is that while all plausible theories of such phenomena as magnetic storms and auroras are based on some form of transported solar corpuscular radiation, the quantitative description of geocoronal modification by a solar stream of known properties remains one of the most formidable problems of contemporary astrophysics. Since the ABL-5 satellite can make direct measurements upon the magnetic fields and cosmic-ray spectrum associated with solar activity, it should make significant additions to our quantitative understanding of this problem.

A primary question about the solar wind concerns the nature of the transport process. The velocity of the wind has been estimated by examining the dynamics of comet tails in the vicinity of the orbit of Mercury, and by measuring the delay times between the occurrence of a solar event and its terrestrial consequences. The resulting estimates fall within a range which extends from 3×10^7 cm/sec to 3×10^8 cm/sec. This velocity spectrum just corresponds to

the sensitivity of the ABLE-5's plasma probe, which measures soft proton flux in the energy range from 200 electron volts to 20 kilovolts for a 32-point spectrum. It is important to realize, however, that velocities inferred from solar-event-terrestrial-event delay times are inherently ambiguous until the transport process is understood. Part of the delay time, for example, may result from the storage of solar particles near the Sun, so that *apparent* transit times can be misleading unless the emission mechanism itself is known.

Since so little direct evidence in these matters exists as yet, it is perhaps desirable at this point to mention two welcome but divergent theories about the transport of the solar wind. According to the first,¹ the solar corona is not in hydrostatic equilibrium; rather, it is continually undergoing a simple hydrodynamic expansion. This produces a radial efflux of neutral plasma, the solar wind. Since the plasma is highly conductive, the magnetic field of the corona is carried outward by the gas, the lines of force being "frozen" into the medium. The hydrodynamic expansion of the corona thus produces a radial pattern of magnetic field lines whose form rotates with the Sun in much the same manner that water streams from a rotating hose—i.e., the stream lags behind the Sun's rotation.

Data collected by the ABLE-5 satellite should provide some interesting tests for this theory. If the theory is correct, a field of one gauss in the solar corona (about 10^6 kilometers from the center of the Sun) will, when drawn out to the region of the Earth-Moon system, produce an estimated field of about 5×10^{-5} gauss. The ABLE-5 magnetometers are sufficiently sensitive to verify this. Soft proton flux measurements made by the satellite will also be revealing. If the solar corona is in fact undergoing a simple hydrodynamic expansion, the continuity equation should show a direct relationship between the soft proton flux measured at the satellite and the cometary proton flux density observed near the orbit of Mercury. Finally, the velocity at which the wind is traveling will be indicated by the measured "whip" angle of the magnetic field. Knowing the velocity and the flux, it is possible in principle to determine the local plasma density. If the hydrodynamic expansion theory obtains, the measured value of the plasma density in the solar corona, when expanded to the position of the satellite, should yield the value actually measured there.

A second theory,² which does not limit solar winds to the hydrodynamic expansion mechanism, holds that the radial flow pattern is often erased by the eruption of clouds of plasma from the surface of the Sun. During such eruptions, the highly ionized clouds which are ejected contain strong magnetic fields, of the order of 50 or 100 gauss. Thus a "tongue" of plasma with frozen magnetism whose lines are rooted in the source region expands into interplanetary space. High-energy particles can be trapped within this tongue. Its leading edge is a sharp wave front, interpreted as a shock wave

between the material ejected from the Sun and that which normally occupies the region between the Sun and the Earth. The theory thus furnishes an indirect, slow mechanism for transporting high-energy (MeV-range) trapped particles.

The direct observations on the solar corpuscular flux made by the ABLE-5 satellite should yield quantitative data with which to evaluate this theory. If a sharp wave front exists, it will be indicated by the magnetometer measurements. Additionally, the increased corpuscular flux of soft and high-energy radiation will be observed over the entire spectral capability of the ABLE-5 probe at the lunar station at the same time that cosmic-ray intensity is being monitored on the Earth. The time lag between the two will clarify the nature of the propagation mechanism. If the flow is radial and direct, the delay will be enormously smaller than it would be if the high-energy particles were magnetically trapped, and therefore constrained to move with the velocity of the expanding gas cloud.

Apart from resolving or redirecting thought about the transport processes discussed, the soft proton flux and magnetometer measurements may also provide information on the wake formed by the interaction between the solar wind and the Moon. Even if we assume a hydrodynamically expanding corona without a shock front, the velocity of an enhanced solar wind streaming past the Moon will be supersonic. It may therefore produce a shock wave, although this cannot readily be guaranteed. As yet, magnetohydrodynamic shock has not been clearly demonstrated in the laboratory, since the hot plasmas require all mean free paths to be excessive. A thin shock front, where irreversible processes occur, is thus of doubtful validity. The mean free paths of thermal protons and electrons in a hydrogen plasma are of the same order of magnitude, approximately 10^{11} cm for an ion concentration of $500/\text{cm}^3$ and a temperature of 10^5°K . This value for the mean free path is considerably greater than the size of the Moon (2×10^8 cm). Theoreticians have evolved a concept, yet to be tested, that a combination of small Larmor radii and charge separation can provide a small enough "effective" mean free path. In this same solar hydrogen plasma, the Larmor radii for electrons and protons are approximately 2×10^6 cm and 10^8 cm respectively, if the plasma contains trapped magnetism of only 10^{-5} gauss.

Shocks having fluctuations of 10^{-5} gauss or greater will be recorded by the satellite's magnetometers. If the existence of shock is experimentally verified by the lunar probe, it may be possible to interpret the combination of magnetic vector and plasma flux data in terms of this theory. However, since the theory is best represented by the nearly ideal plasma of interplanetary space, the absence of a shock front would cast serious doubt on its validity.

While the magnetometers measure locally, the various particle counters on the satellite are sensitive to the entire volume of space around the Moon in which

deformation of magnetic intensity occurs. Thus, if there is a sufficient intensity of electrons and protons in the portion of the primary cosmic-ray spectrum which could be deflected, some features of the solar-wind wake could conceivably be determined over the Moon as a whole. For example, if an increase in magnetic intensity of, say, 10^{-4} gauss should occur over a region comparable in extent to the lunar radius, the protons which could seriously modify the undisturbed primary spectrum are in the kilovolt energy range; the electron energy spectrum could be distorted in the Mev range. These estimates are conservative, since transported sunspot fields may provide magnetic intensities of the order of 10^{-3} gauss. It is therefore within the capability of the array of particle counters in the ABLE-5 satellite to register the over-all effect of a large-scale magnetic fluctuation, if the volumes of space involved subtend a sufficiently large solid angle at the vehicle to compete favorably with the background radiation.

It is possible that the primary background radiation is devoid of protons in the kilovolt energy range, or that if they are present their natural modulations might obscure the effects of the wake. However, suprathermal electrons and protons are likely to be present if the solar plasma originates from a flare. The existence of a magnetized wake might then manifest itself in a comparison of the radiation spectrum on the lunar night side with that obtained on the sunlit side.

Before we leave the question of the solar wind, a cautionary statement is in order. Our discussion has tacitly assumed that the wind is a magnetized, electrically neutral stream. Although widespread, this assumption is not without its problems. It fails to explain adequately, for example, how the ions are diverted to auroral altitudes. There are additional difficulties, as we have seen, in accounting for the transport of an ionized, electrically neutral stream through interplanetary space, which, far from being empty, is filled with a plasma of unknown density. Finally, it is of interest to note that Pioneer V failed to detect the radial magnetic field expected for an electrically neutral solar wind.

In the past, many features of auroral phenomena were explained on the supposition of a solar stream of particles of one sign. This explanation was widely rejected, however, for the reason that such a stream must disperse because of the mutual electrostatic repulsion of its particles. Yet the stream presumably is not traveling in a vacuum, but rather in an ambient mixture of charges of both signs. Under such conditions a single-sign stream might not disperse. For example, magnetic self-focusing of a proton stream could occur. Indeed, auroral phenomena have already been examined on the basis of such a theory.³

Perhaps both neutral and single-sign streams exist in space, each associated with a different solar ejection mechanism. Whatever the case may be, the character of the vector magnetic intensity data and particle radiation spectra will be profoundly different for an ion stream with a single polarity impinging upon the

Moon than for a magnetized, neutral corpuscular wind. The ABLE-5 sensors should thus be able to distinguish the two.

Finally, the ABLE-5's plasma-probe measurements in the vicinity of the Moon may tell us something about the lunar atmosphere. The subject of the density of the lunar atmosphere has been attended by much controversy. Although there is little doubt that the density is very low, it is still not known whether the lunar atmosphere is meteor-proof, or whether it would serve as an effective shield against cosmic rays for space travelers. The lowest estimate, made on the basis of radio occultation studies, places the density at 10^{-13} atmosphere, or about 2×10^6 particles per cm^3 . However, there are those who believe that occultations are not conclusive, and insist that the surface density of the lunar atmosphere is greater.

It is often assumed that only the heavy, chemically inert gases such as argon, xenon, and krypton exist on the Moon. If such indeed is the case, protons in the solar wind could interact most strongly with such gases by means of the charge exchange process. Here the protons in the $\frac{1}{2}$ -kilovolt to 10-kilovolt range will become neutralized by electron capture with a cross section of about $10^{-15}/\text{cm}^2$. Thus for a lunar atmospheric density of about 10^7 atoms/ cm^3 , the mean free path for the capture process is about 10^8 cm, or about one-third of the lunar diameter.

If the lunar atmosphere does neutralize solar protons, the ABLE-5 soft proton flux experiment will record a decrease in the proton flux each time the satellite's orbit makes it "see" the Sun through the lunar atmosphere. Knowing the decrease, we could then estimate the density of the lunar atmosphere.

The Cosmic-Ray Spectrum

A MAJOR objective of the ABLE-5 experiments is to make a coordinated study of the intensity and variations in both primary (galactic) and solar cosmic rays in a region free of geocentric influences. Apart from establishing a comparison between the geocentric and heliocentric influences on such rays, the probe can also investigate both highly active solar phenomena (which are relatively rare), and the properties of interplanetary space when it is "quite" or mildly active from the restricted viewpoint of a terrestrial observer.

If the Sun is quiet, the two-day transit period will establish the background primary cosmic-ray spectrum as well as the background interplanetary magnetic intensity vector. It will be of special interest to compare data from two portions of the transit trajectory with this background information. The first is that period during which the satellite gradually becomes free of the Earth's magnetic distortions and secondary emissions (albedo). The second occurs as the satellite becomes progressively exposed to any lunar influences. Observed fluctuations in the low-energy portion of the galactic spectrum during the two periods are especially revealing, for this portion

of the spectrum is not only related to interplanetary magnetic conditions but also indicative of magnetism associated with solar plasma or the Moon.

The background calibration of the sensors en route to the Moon is particularly important in preparation for the possible measurement of the Moon's radioactivity. There are two sources of radioactivity: (1) natural radioactivity; (2) the induced emission of gamma rays. The latter results from the transformation of the primary cosmic protons into soft neutrons which, upon nuclear capture, radiate gamma rays. Because of the spacing of the energy levels in nuclei, the most likely band of nuclear gamma radiation should fall in the range of $\frac{1}{2}$ to 6 Mev. This is in keeping with the design of the scintillation spectrometer. We consider only gamma radiation since at these energies the range of gamma rays in matter is greater than that of beta rays.

The count rate above background in the spectrometer energy interval cannot be ascertained at the present time, although it is expected⁴ that the absolute count rate for the secondary gamma flux from the lunar surface should amount to at least one tenth of the primary flux. Because of the counter receiving area (about 10 cm²) and solid angle subtended by the Moon (approximately one-half steradian), the counting rate should therefore amount to roughly 30 counts per minute on the basis of 1 count per second per steradian in the primary cosmic-ray flux. Further calibration will occur periodically since during some parts of the orbit the sensitive axis of the counter (which is always perpendicular to the spin axis of the vehicle) will no longer be parallel to the lunar surface, but rather perpendicular, and thus fail to count the albedo. Consequently, a sinusoidal modulation is expected to be superimposed upon the inverse-square distance effect due to the variation in subtended solid angle during the course of the orbital motion.

Only the experiment can determine whether discrimination against primary radiation can be actually accomplished. However, the opportunity for revealing something of the composition of the Moon by means of its radioactivity is improved by the possibility of a high natural radioactivity. For example, if the radioactivity is like that of granite, the gamma-ray flux should be a hundredfold larger.⁴

There are several problems currently associated with the cosmic-ray spectrum. Measurements have shown a paucity of primary cosmic rays below 1 Bev, apparently a low-energy "cutoff". Another manifestation in need of clarification is the Forbush effect, the marked decrease of cosmic-ray intensity during the active phase of a magnetic storm. It is interesting and perplexing that storms can occur without a drop in cosmic-ray intensity. To explain the Forbush decrease, one theory postulates the existence of temporary currents circulating around the axis of the Earth. According to another, the decrease is produced by a geocentric magnetic "screen" which exists in space at a distance of several earth radii from the surface of the Earth. Serious doubt

has been cast on these theories by data from Explorer VI⁵ and Pioneer V,⁶ both of which recorded Forbush decreases at great distances from the Earth. The conclusion of the satellite measurements seems to be that the decrease does not depend on the Earth's electromagnetic system at all. The data are apparently consistent with a heliocentric modulation mechanism such as the one suggested by Gold.²

With regard to solar cosmic rays, very little data are available. The energies are apparently so low that the radiation is easily diverted, even for high-altitude observation at high latitudes. However, recent reports⁷ of great flare events have indicated large intensities of protons in the 30-Mev to 400-Mev range, the lower value being established by the Explorer VI satellite. No information is available for the more frequent smaller flares, which may also contain a high content of highly ionizing electrons and protons.

The problems we have described all point to the need for a comprehensive study of primary cosmic-ray spectral variation as a function of solar activity. The ABLE-5 lunar satellite instrumentation is ideally suited to gather relevant information. For example, comparisons of the satellite data with Forbush decreases monitored simultaneously on the Earth should help to clarify the nature of the Forbush effect. The modulations of the primary cosmic rays, which will show up with greatest amplitude for the primaries of low energy, are very sensitive to changes in the distribution of interplanetary magnetism. If we pursue the problem further, we see that interplanetary magnetic variations depend in turn upon the solar atmospheric magnetism. The latter fields presumably control many solar processes, such as flare formation, and they are undoubtedly responsible for the direction and acceleration of solar-particle emissions. Thus the important theoretical significance of the data simultaneously collected by the ABLE-5 radiation sensors and magnetometers should be emphasized, for such data may furnish new source material for a theoretical advance in the field of solar astronomy.

It will also be possible to separate the solar corpuscular spectrum from the variations in the galactic cosmic-ray spectrum whenever the satellite passes through the lunar shadow. During this interval (which can be greater than 100 minutes) the radiation spectrum is free of solar cosmic rays. Only primary cosmic rays will be recorded. This information can be compared with the quiet-time galactic spectrum. The differences, if any exist, are caused by changes in the state of interplanetary magnetism. The information gathered outside the shadow zone is a summation of galactic and solar-particle spectra. Hence solar-particle spectra are obtainable by subtracting the shadow-region spectrum.

Let us consider the moment at which the satellite emerges from the lunar shadow. If the satellite sensors indicate a discontinuous change in the spectra at this moment, the implication is that the solar particles were not deviated during their passage from the Sun to the

satellite. Conversely, the absence of an abrupt change, or a gradual change in some energy interval of the spectrum, would indicate that the solar particles in that energy band did not travel from the Sun in straight lines. In this case, the region between the Moon and the Sun must contain magnetic fields capable of deflecting the particles. From geometrical considerations and the measured data, it should be possible to deduce something about the strength and distribution of these interplanetary fields.

It is possible, of course, that the character of the spectrum over some energy range will be indifferent to whether or not the probe is in the shadow of the Moon. A circumstance of this kind could lend credence to Gold's conjecture² about the existence of magnetized "tongues" of solar plasma ejected from a flare. Such a configuration could trap solar particles, forming what Gold has referred to as a solar Van Allen belt.

The Lunar Magnetic Field

WE should perhaps emphasize the fact that the ABLE-5 will be the first satellite to measure the vector magnetic field.* To do so it carries a flux-gate magnetometer which measures the component of the field along the spin axis of the satellite, a search-coil magnetometer which measures the component perpendicular to the spin axis, and an aspect indicator which measures the angle between the sun vector and the field component perpendicular to the spin axis. From these, the magnitude and direction of the field can be calculated.

Data collected will provide valuable information on fields near the Earth and in interplanetary space, e.g., the ring current and geomagnetic boundary, the interplanetary field, and magnetic fields associated with both solar activity and solar quiescence. In addition, the satellite will record any magnetic field associated with the Moon. It is to the latter that we now turn our attention.

Heretofore, the only direct observation of a magnetic field near the Moon was recorded by the Russian impact vehicle, Lunik II. The threshold sensitivity of the magnetometer aboard this satellite placed an upper bound of 50 gamma (1 gamma = 10^{-5} gauss) on the field near the sunlit side of the Moon. The conjectured altitude of this observation was 1 kilometer. Extrapolation of the measurement of the lunar field to the ABLE-5 orbit yields a value of 1 gamma, which corresponds to the satellite's magnetometer threshold. Because of the sunspot fields transported by the solar wind, however, the noise level could be considerably higher than this value. Yet the continuous, long-term measurements of the vector magnetism during quiet and active solar periods, plus the data accumulated en route to the Moon, should establish any nonlunar contributions to the values actually measured.

* A previous space vehicle, Explorer VI, carried appropriate equipment for such measurements, but because the flux-gate magnetometer saturated, only the field component normal to the spin axis could be measured.

As was the case with the radiation sensors mentioned earlier, the transit orbit in effect serves to calibrate the satellite's magnetometer experiments.

Whether a perceptible lunar magnetic field exists is still considered an open question in many quarters. In the absence of directly measured evidence, the answer to this important question has ordinarily been deduced from theories about the magnetism of celestial bodies. These, in turn, are largely extensions of theories of terrestrial magnetism, since the Earth is the only planet for which extensive magnetic data are available. The mathematical physicist Gauss showed more than a century ago that the terrestrial magnetic field must have its origin within the Earth. Seismic evidence on the Earth's interior has since led to a general acceptance of the idea that the Earth has a fluid nickel-iron core. The source of the Earth's magnetic field and certain details of its behavior have accordingly been attributed by theoreticians to convection motions within the core. Such hydromagnetic assumptions have an interesting bearing on the question of lunar magnetism. The low density of the Moon and its rigid ellipsoidal figure make the presence of a liquid core seem quite unlikely. The hydromagnetic theory of magnetism thus leads to one of two conclusions: (1) the Moon has no appreciable magnetic field; (2) if the Moon has a strong magnetic field, the mechanism which produces it is different from that postulated for the terrestrial field.

The ABLE-5 magnetometers should yield extensive data about fields in the vicinity of the Moon. Furthermore, any appreciable lunar magnetic field will have a spectral analyzer action upon the particle counters aboard the satellite. We should thus have some quantitative data with which to evaluate speculations about lunar magnetism. For example, a weak lunar magnetic field could be construed as supportive evidence for the hydromagnetic theory, whereas a strong field would indicate that a fluid core is not a prerequisite for planetary magnetism. The latter eventuality would also suggest a careful review of the hydromagnetic model for terrestrial magnetism.

The presence of a permanent lunar magnetic field has other implications of considerable importance. The field would serve as a clue to the manner in which the Moon was formed, and thereby supply information pertinent to the history of the Earth-Moon system. During its early history the Moon was apparently considerably closer to the Earth than it now is. If the Moon cooled under the influence of the Earth's magnetic field, the lunar field would probably be a dipole aligned antiparallel to that of the Earth. Its magnitude would depend upon the composition of the Moon—that is, the content of ferromagnetic constituents. If, on the other hand, the Moon's magnetic moment is not aligned with that of the Earth, the possibility would suggest itself that large blobs of solar magnetism transported from sunspot emissions determined the magnetism of the cooling Moon.

It has been suggested⁸ that while the magnetic field

on the night side of the Moon might extend a considerable distance, the field on the sunlit side is confined to a region very close to the lunar surface because of the action of a ring current produced by the solar wind. If this is true, the field near certain portions of the lunar surface could be as high as 1000 gamma without contradicting the Lunik II data. The ABLE-5 orbit permits it to relay magnetic-field data obtained from both the sunlit and night side of the Moon at a variety of altitudes above the lunar surface. Thus, from the angular dependence of the field, it may be possible to discover the lunar magnetic poles, and to check the extent to which the alleged compression of the magnetic field by the solar wind occurs.

Finally, we should note that terrestrial phenomena associated with magnetism, such as the trapping of charged particles and the formation of ring currents, may have their lunar parallels. If the Moon does have a substantial field, the ABLE-5 magnetometers will enable us to make a first approximation for such magnetically determined phenomena in the region around the Moon.

Micrometeorites

IN addition to magnetometers and radiation sensors, the ABLE-5 satellite also carries a micrometeorite momentum spectrometer. This experiment permits direct observation of low ($> \sim 5 \times 10^{-4}$ gm cm/sec) and high ($> \sim 5 \times 10^{-3}$ gm cm/sec) momentum micrometeorites, and their numerical distribution along the trajectory of the vehicle. To indicate some of the limitations inherent in the terrestrial observation of meteoritic material, and to make clear the kind of particles in which the ABLE-5 probe is chiefly interested, we shall begin our examination of the experiment with a brief historical discussion.

The existence in space of large particles of matter (with masses greater than a few milligrams) has long been known, principally as a result of the visual observations of meteor trails. Although the short duration of the light emitted from the ionized gas left in the trail of the meteors made precise observations extremely difficult, it was shown that the meteors in some of the well-known meteor showers are moving about the Sun in orbits identical to those of certain comets. The orbital properties of the nonperiodic meteors that continually enter the Earth's atmosphere—the sporadic meteors—are less well known. Nevertheless, recent developments in measurement techniques have established that the nonperiodic meteors also travel in elliptical orbits about the Sun, thus making very unlikely the possibility that meteoric material originates outside of the solar system.

Observational difficulties associated with visual studies of meteor trails were overcome to a considerable degree with the advent of the Super Schmidt camera and the development of the technique of scattering radio waves off the trail of ionized gas. Both methods, however, are limited to the study of particles sufficiently large (having masses of the order

of a microgram or greater) to produce an appreciable ionization in the atmosphere.

Meteoric material of smaller size (which we shall call micrometeorites) does one of two things: either it evaporates without ionizing the atmosphere sufficiently to permit optical or radio echo detection, or, if the particles are extremely small, it dissipates energy rapidly enough to prevent vaporization and drifts down through the atmosphere as a fine dust. The latter can be collected on the surface of the Earth and studied directly. Analysis shows that this material has a high-density composition which is similar to that of large meteorites which strike the Earth and also to the sporadic meteors. It is unlike that of the periodic meteors, which apparently consist of a very low-density material. The composition of micrometeoritic particles too large to remain intact in the atmosphere but too small to produce detectable ionization remains an enigma, however. It is with particles of this character that the ABLE-5 probe is especially concerned. The density of such micrometeorites, which range in size from approximately 1 to 100 microns, could conceivably lie anywhere between 7.8 gm/cm^3 and 0.1 gm/cm^3 . The first value is characteristic of iron, the latter associated with low-density cometary matter. It is certainly relevant to the design of future spacecraft to determine precisely where within these two orders of magnitude the actual micrometeorite density lies. Until the properties of such micrometeorites are better known, the expected damage to exposed surfaces of a space vehicle on a sustained interplanetary flight cannot be predicted with any certainty.

Not only are the physical properties of these micrometeorites uncertain, but so also (though perhaps to a lesser degree) is their number density and spatial distribution. Observations of the coronal and zodiacal light, and, in more recent years, more direct measurements of the cosmic dust by high-altitude rockets and satellites, have provided estimates of the space density of the particles in the order of 10^{-7} to less than $10^{-10}/\text{cm}^3$ in the neighborhood of the Earth. This relatively low particle density means that measurements must be made over extended periods of time if statistically significant results are to be obtained. In this respect the ABLE-5 experiment represents a decided improvement over earlier rocket and satellite experiments. Indeed, since the ABLE-5 payload will spend most of its lifetime in the vicinity of the Moon, it will explore repetitively a completely new environment. The results of the measurements are thus awaited with a correspondingly greater interest.

The micrometeorite experiment may also be relevant to some current speculations about the lunar surface. It has long been known that for all size ranges susceptible to measurement, the number of particles entering the Earth's atmosphere increases rapidly as the particle size decreases. This fact, plus other evidence on lunar temperatures during eclipses, and calculations on the disintegration of the lunar surface by hypervelocity meteoritic impact and high-energy solar

radiation, have led some observers to conclude that the surface of the Moon may be covered with a layer of fine dust. The contribution which interplanetary dust would make to such a layer depends, of course, on the flux of particles in the vicinity of the Moon. In considering this problem, it is important to realize that the particle flux near the Moon is not necessarily the same as that near the Earth, the difference depending on the velocity of the particles relative to the Earth-Moon system. If the velocity of the particles is very great, the amount of matter accumulated per unit area by either body would be the same. But if the relative velocity is small, the difference between the gravitational field of the Moon and that of the Earth becomes important. Given a small relative velocity, the difference in mass between the Moon and the Earth would imply a difference in the incidence of micrometeorites at each body. Furthermore, if the incidence is indeed field-dependent, the asymmetry of the lunar gravitational field should lead to a corresponding asymmetry in the flux of particles.

In addition to providing an opportunity to study the spatial variations of the interplanetary dust, the extended lifetime of the ABLE-5 satellite should also make possible the detection of temporal fluctuations in the particle flux. It has been hypothesized that such fluctuations may account for the sporadic ionization of the E-layer of our atmosphere.

Finally, it is not known whether the large meteor showers—consisting presumably of low-density cometary debris—contain particles of micrometeorite dimensions in addition to those which are detected by optical and radio means. The answer to this important question also lies within reach of the ABLE-5 satellite, since it will place a suitable micrometeorite detector in space during the characteristically heavy autumn and winter meteor showers.

Radio Scintillation *

THE lunar probe furnishes the opportunity for a major contribution to the understanding of the radio refractive irregularities of the terrestrial atmosphere as a whole. This phenomenon, analogous to the twinkling of ordinary stars, is caused by winds and complex motions in the ionosphere. Radio signals always exhibit scintillation; the form of the variations at times appears random, and at other times quasi-periodic.

Extensive studies of irregular fading have been carried out by observing radio stars. There is a pronounced diurnal variation of twinkling with a maximum near midnight, and a positive correlation with "spread" *F* echoes. The results indicate that the seat of the phenomena is in the *F*-region of the ionosphere. However, other observations show discrepancies and indicate that the sporadic *E* region may be the origin of the scintillation. The midnight maximum has not been ex-

plained. It may be associated in some way with the aurora, which is also a night-side phenomenon.

The irregularities impose phase and intensity fluctuation on radio signals. As a result, the tracking accuracy of space vehicles is inevitably limited. Heretofore, the statistical analyses of radio-star signals have been used in an effort to improve tracking accuracy. However, star signals are weak, so that a confident power spectrum cannot be extracted from their radio records. There is also little information as to the horizontal scale sizes of the ionospheric irregularities or their degree of isotropy.

The deficiencies in the data can be remedied in an unprecedented manner by simply tracking the beacon on the ABLE-5 satellite. Since the transmission power is 1.5 watts, the signal-to-noise ratio is adequate for obtaining confidence in the power spectrum of the scintillations, and firm zenith-dependent data is possible. For the first time, long-term correlations of interplanetary conditions and solar activity with ionospheric and tropospheric disturbances will be possible on a global scale.

Conclusion

THE foregoing discussion has involved several problems in the general area of astrophysics, rather than limiting itself to those specifically associated with the lunar environment. The reason for this lies in the nature of the ABLE-5 program, whose aim is to extract as much significance as possible from the data with which this first lunar space station will provide us. To meet this aim, the program is coordinated with sea-level observations and measurements in the vicinity of the Earth. The data from the satellite will thus be placed in a context of supplementary observations on solar flares, sunspots, coronal activity, and auroral and geomagnetic disturbances.

Hopefully, the terrestrial satellites which will follow the ABLE-5 program will enlarge this context and provide simultaneous data on ultraviolet and x-ray emission spectra, so important because of their influence on the ionosphere, and the activity of the trapped-particle radiation defined by the Van Allen belts. If so, a partition between electromagnetic and corpuscular influences upon the terrestrial atmosphere may be achieved for the first time.

In general, then, the ABLE-5 program represents a continuation of the attempt to discover, identify, characterize, and ultimately to order our knowledge of the physics of the solar system.

References

1. Parker, E., *J. Geo. Res.* **64**, 1675 (Nov. 1959).
2. Gold, T., *J. Geo. Res.* **64**, 1665 (Nov. 1959).
3. Bennett, W. H., and E. O. Hulbert, *Phys. Rev.* **95**, 315 (July 15, 1959).
4. International Series of Monographs on Aeronautical Science and Space Flight, Vol. II, 29, Pergamon Press, 1959.
5. Fan, C. Y., P. Meyer, and J. A. Simpson, *Phys. Rev. Lett.* **4**, 421 (Apr. 15, 1960).
6. Fan, C. Y., P. Meyer, and J. A. Simpson, *Phys. Rev. Lett.* **5**, 269 (Sept. 15, 1960).
7. *IGY Bulletin*, No. 35 (May 1960).
8. Neugebauer, M., *Phys. Rev. Lett.* **4**, 6 (Jan. 1, 1960).

* The instrumentation for the scintillation rate measurements is discussed in detail in "Scientific Objectives of the ABLE-3 Program," *IRE Transactions on Military Electronics*, MIL-3 No. 4, October 1959.