Introduction to Orbital Science

At each landing site on the surface of the Moon, the astronauts' activities are limited to distances of a few miles. In comparison with the total area of the surface of the Moon, the regions explored by the astronauts on foot or with the Rover are miniscule. They are frequently referred to as "point" samples. The desirability of extending our observations to larger areas is obvious. Indeed, several things can be done *in orbit* about the Moon that will allow us to extrapolate from the data obtained on the surface to the rest of the Moon. One of these things is photography; many photographs have been obtained from the command module on each of the previous Apollo missions. Both the number and quality of photographs obtained from lunar orbit on Apollo 15 and 16, and scheduled to be obtained on 17, have been greatly increased over those of earlier missions.

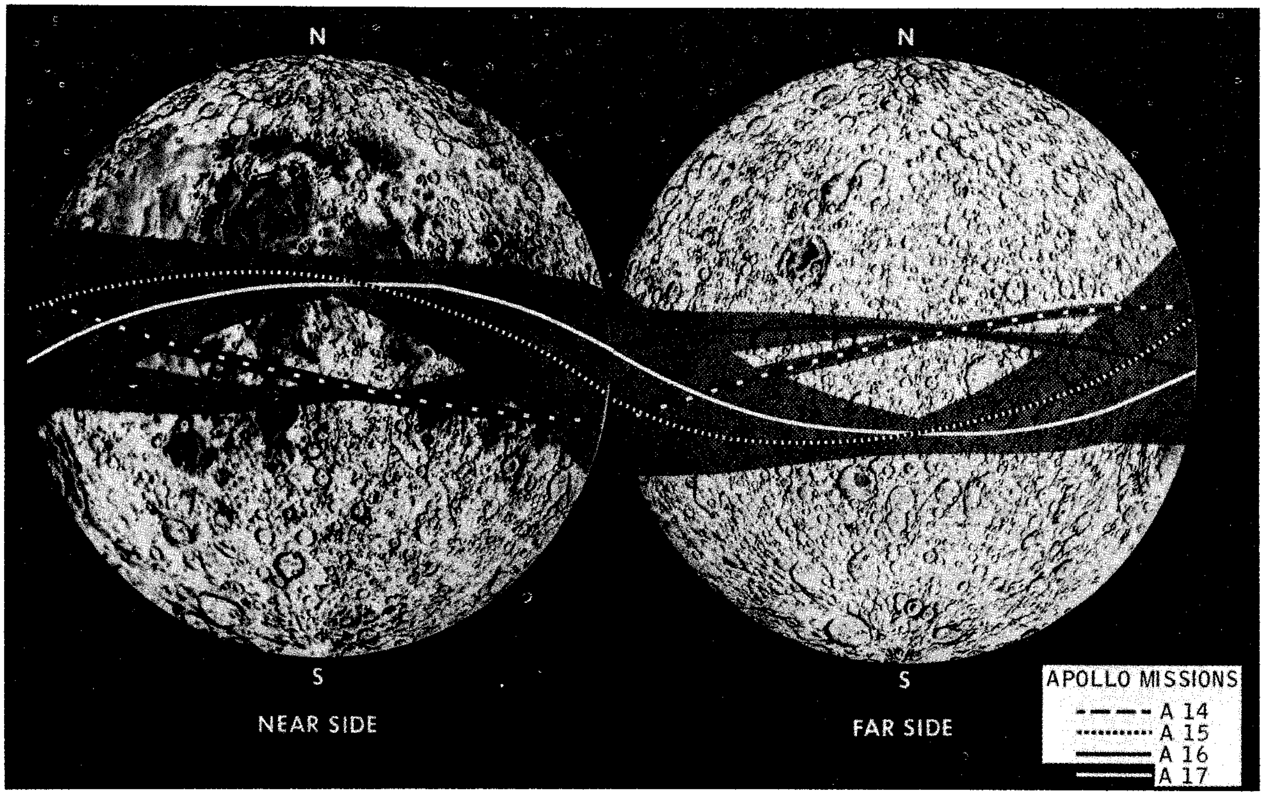

FIGURE 71A.—Orbital path coverage for Apollo 15 and 16. Because the landing site of Apollo 15 was located well away from the equator, the command module covered a rather large area of the Moon's surface. Data from the "chemical group" of experiments indicate the distribution of certain elements on the Moon's surface. The coverage of the farside of the Moon, never seen from Earth, is especially valuable. Almost 10,000 photos were obtained during Apollo 15. If the 8 × 10 prints were laid side by side, they would extend almost 2 miles. BASE MAP COURTESY OF NATIONAL GEOGRAPHIC SOCIETY.

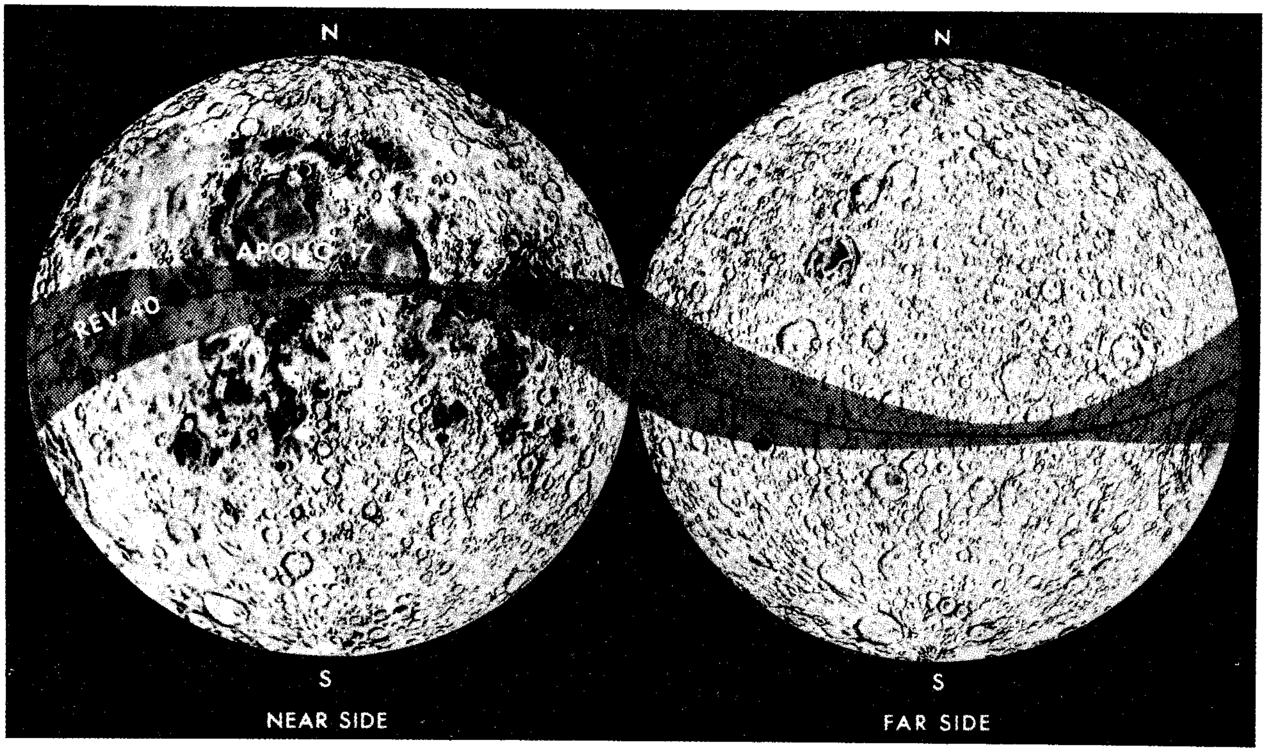

FIGURE 71B.—Orbital coverage for Apollo 17. See also caption for figure 71A. BASE MAP COURTESY OF NATIONAL GEOGRAPHIC SOCIETY.

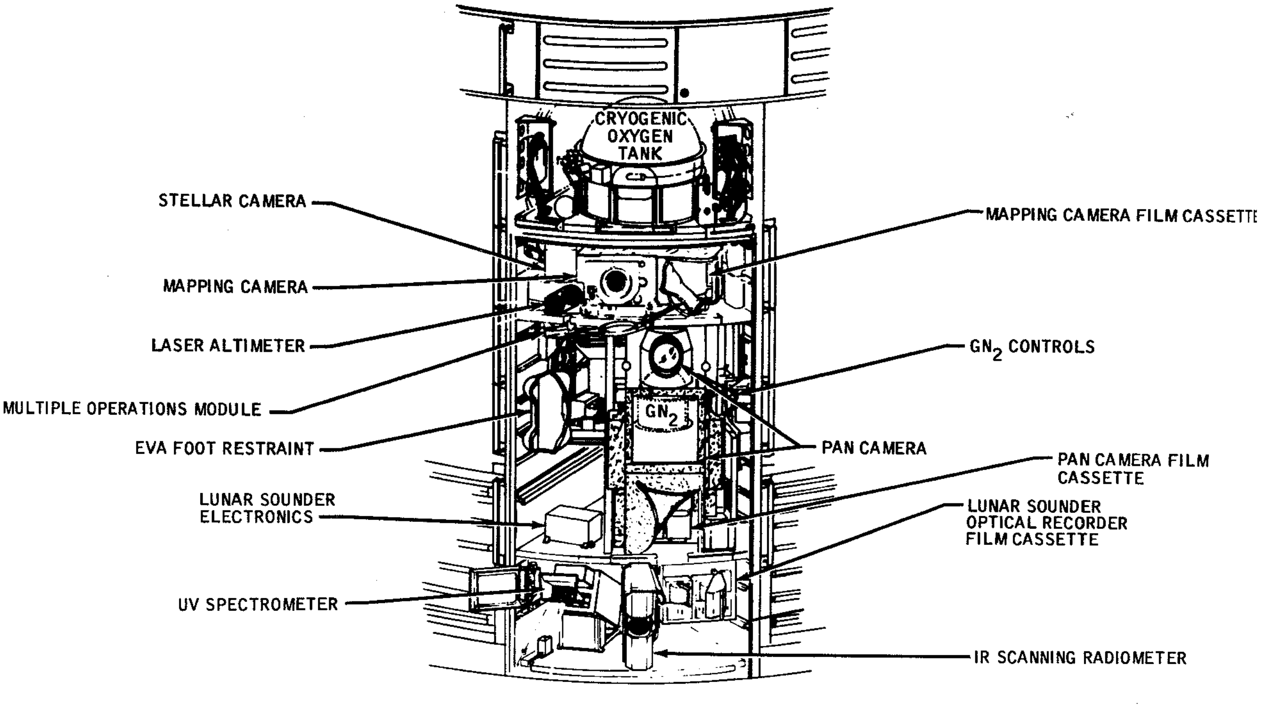

FIGURE 73.—SIM Bay. Shown here is the location within the scientific instrument module (SIM) of the equipment for each orbital experiment. Before the CM is separated from the SM the film cassettes must be retrieved.

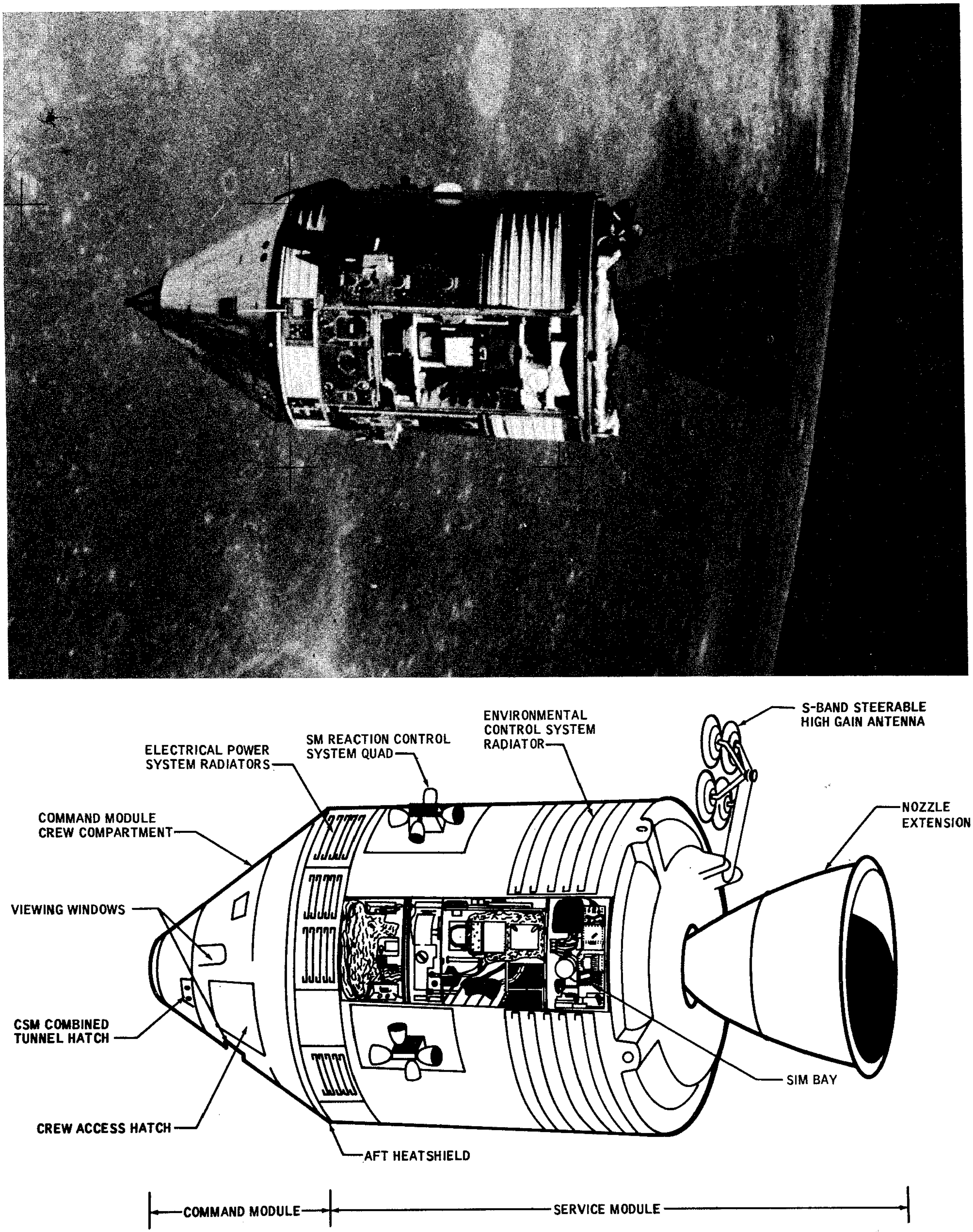

FIGURE 72.—Location of Scientific Instrument Module (SIM) in the Service Module. The Apollo 15 photo was taken from the LM with the Moon for background. NASA PHOTO AS15-88-11972. Sketch shows details and names.

Several things other than photography can be done from lunar orbit. In these next few sections I will describe them.

The region of the Moon that was examined with orbital experiments on Apollo 15 and 16 is shown in figure 71A. The coverage for the present mission, Apollo 17, is shown in figure 71B.

The total coverage for these three missions will exceed 20 percent of the Moon's surface for several of the orbital experiments and will exceed 5 percent for each of them.

Although some photographic tasks will be done in the CM, most of the experiments for the orbital science will be done with equipment located in the SM. The various orbital experiments include the following—Lunar Sounder, Infrared Scanning Radiometer, Far Ultraviolet Spectrometer, and S-Band Transponder. Only the S-Band Transponder has been flown before. The other three experiments are new. The equipment for the orbital science experiments are all housed in a section that is termed scientific instrument module (acronym SIM). The location of the SIM in the service module is shown in figure 72. The location of the equipment for the individual experiments in the SIM is shown in figure 73. The names and addresses of the principal investigators of each orbital experiment are given in Table 5.

Orbital Science Activities

The door that covers the scientific instrument module (SIM) will be jettisoned about 4½ hours before the spacecraft reaches lunar orbit. The door will continue past the Moon and be lost into space. By removing it *before* reaching lunar orbit, the astronauts keep the debris out of lunar orbit and remove the possibility of later contact with the door.

The initial lunar orbit is an ellipse with maximum distance from the Moon of 170 nautical miles and minimum distance 60 nautical miles. A nautical mile is 15 percent larger than a statute mile. A few hours later, a rocket burn places the spacecraft into a 60 x 14 nautical mile orbit from which the LM will descend to the Moon after another 18½ hours. During this 18½-hour period, the SIM experiments and cameras will scan the lunar surface. The S-Band Transponder experiment also will be performed.

Then shortly before the LM touchdown, another burn of the orbiting CSM's rocket engine will circularize the orbit at 60 nautical miles. During the next 3 days while the LM remains on the surface of the Moon, all of the orbital experiments will be performed. The CSM will change the plane of its orbit about 6 hours before the LM liftoff so that it will be in the proper place to rendezvous with LM.

After rendezvous, various items, including the lunar samples, photographic film, and the SEP tape recorder, will be transferred from the ascent stage to the command module. Then the LM, of no further use to the astronauts, separated from the CSM (i.e., undocked), will be crashed onto the Moon's surface at 20° N., 30° E., to provide a source of energy (i.e., an artificial moonquake) for the seismic experiments.

The total time in lunar orbit during which the SIM experiments and photography can be performed is about 6 days. None of the individual experiments will operate for the full time. The maximum time used by any experiment in lunar orbit is roughly 60 hours. Some experiments interfere with each other and so cannot operate simultaneously. For the cameras, the maximum operating time is set by the amount of film which can be stored in the supply cassettes.

LUNAR ORBITAL SCIENTIFIC EXPERIMENTS AND HARDWARE

In this section, I discuss each of the orbital experiments and the nature of the equipment. I hope to provide enough information so that you can understand the nature of each experiment. On the other hand, I do not intend to write a complete

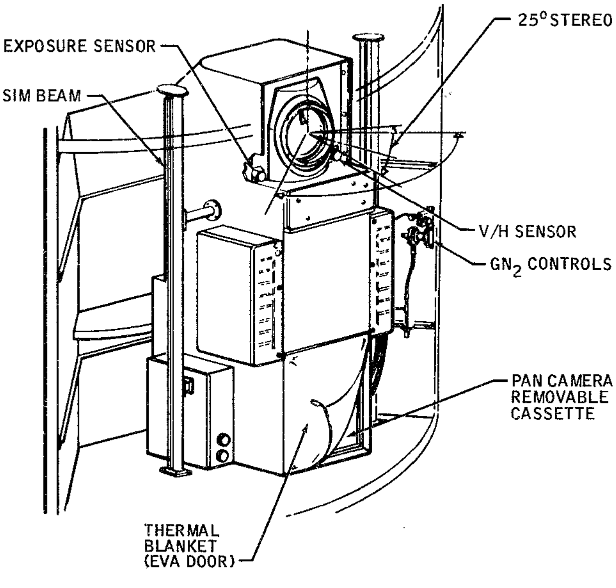

FIGURE 74.—24-inch panoramic camera. In operation, the camera lens rotates continuously and scans a total of 108° across the flight direction. The entire camera tilts 25° forward and backward along the track of the spacecraft to provide stereo coverage. The film cassette is retrieved by the CM pilot on EVA in space.

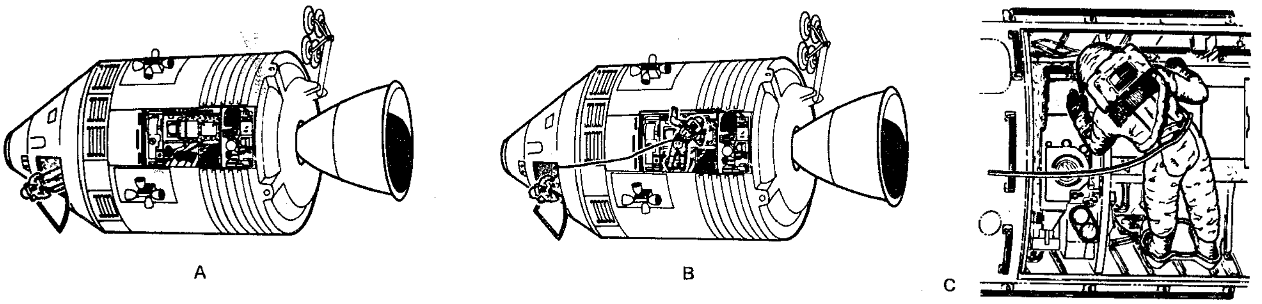

FIGURE 75.—Retrieving film from the SIM. In A, the astronaut is shown egressing through the CM hatch. All thre astronauts must wear spacesuits to protect themselves against the vacuum of space. In B, an astronaut has move to the vicinity of the SIM and is preparing to remove the film from the panoramic camera. He holds himself to th spacecraft by inserting his feet into special footholds, termed golden slippers because they were formerly gol colored. In C, he is removing the film cassette from the mapping camera. The other astronaut documents the procedure with photos and verbal descriptions. He also helps by passing the cassettes to the astronaut in the CM fo storage. NASA PHOTO S-72-16232.

textbook on the physics of lunar experiments. It is my hope that I can provide enough elementary information on each experiment for you to understand how it works. I hope then to show you a brief glimpse of the results that were obtained on the Apollo 15 and 16 missions. Undoubtedly there are many surprises yet to come from those data; results from Apollo 17 will surely be equally exciting.

Photographic Tasks and Equipment (PTE)

The purposes of the orbital photography are to obtain high resolution panoramic photographs of the Moon's surface, to obtain high quality metric photographs, and to obtain elevation of the surface of the Moon along the ground track. Two cameras and a laser altimeter, all mounted in the SIM, are used. The location of each of the cameras is shown in figure 73.

The 24-inch panoramic camera, figure 74, is used to obtain high resolution panoramic photographs with both stereoscopic and regular (technically termed monoscopic) coverage of the Moon's surface. Several automatic features have been incorporated into this camera. For example, the camera lens rotates continuously in a direction across the path of the orbiting spacecraft in order to provide the panoramic scanning (hence the name of the camera). The whole camera tilts forward and backward to provide stereo coverage. An exposure sensor, figure 74, measures the brightness of the Moon and adjusts the camera shutter automatically. And finally, the V/H sensor, figure 74, detects the ratio of the forward velocity to the height of the spacecraft above the Moon's surface and automatically corrects for it, thus removing the blu that would result from motion of the spacecraft All in all, I think that even the most avid camera enthusiast would agree that the 24-inch pan camera is a very fancy one. You might be interested in knowing that, from an orbital altitude of 60 miles, this camera will provide an image on the film of objects as small as 3 to 6 feet on the Moon's surface.

The astronauts must be careful to protect the camera's sensors from exposure to the Sun. Of course the "guards" against this happening are the people in Mission Control in Houston. Several of these sensors have no provisions to prevent damage if the Sun is viewed directly.

A low speed black and white aerial-type film is used. The cassette must be retrieved by one of the astronauts, normally the CM pilot, during an EVA. The sequence of operations is indicated schematically in figure 75. See also figure 76, a photograph from an earlier mission. Note the hose which is used to provide oxygen outside the CM The back pack here is the Oxygen Purge System (OPS), similar to the PLSS in providing oxygen it is used only in the (unlikely) event that the hose supply fails. The training for an EVA in space such as that needed to retrieve the film from the SIM cameras, is done in a very large water tank at MSC. See figure 77. A training mockup simulates the Command and Service Modules and the astronaut practices in a spacesuit.

Another camera in the SIM is the 3-inch mapping camera sketched in figure 78. It is really two cameras in a single assembly. Photographs of the

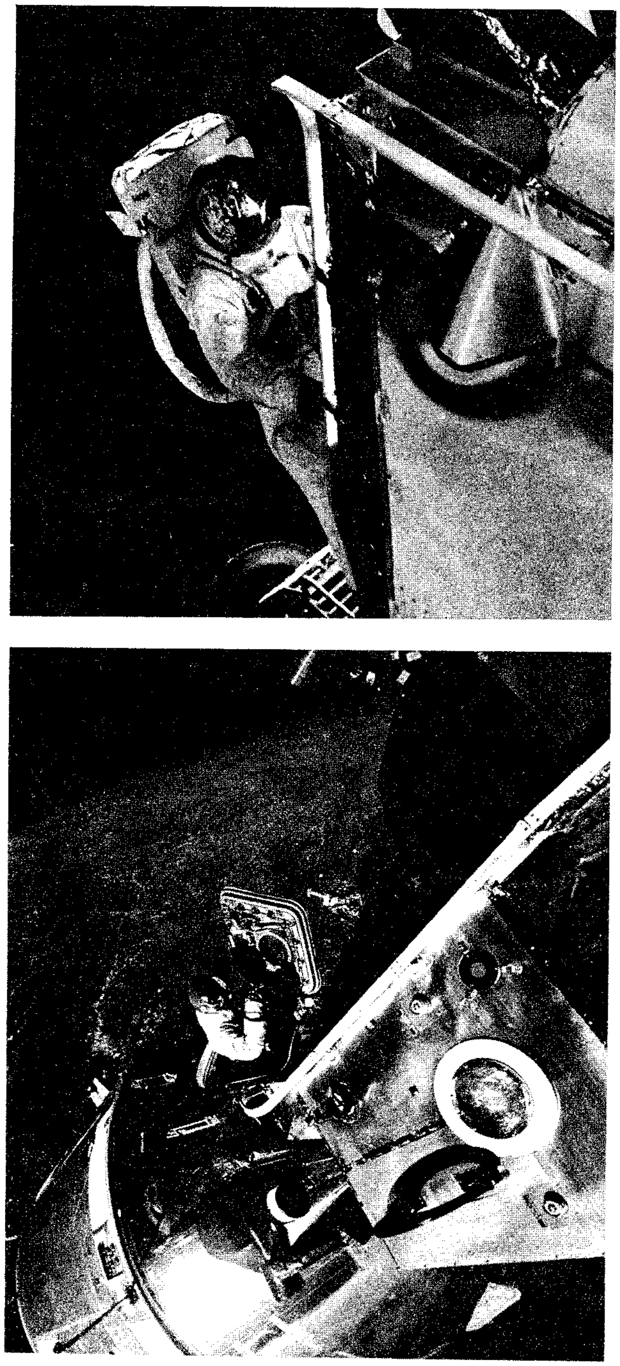

Figure 76.—EVA in space. Work in space when an astronaut is outside the protective shell of the spacecraft is always exciting. It is also dangerous and the astronaut must be extra careful. On Apollo 17, the film from the cameras in the SIM must be recovered in this way. Shown here is Astronaut Schweickert during an EVA on Apollo 9. The umbilical hose that connects him to the spacecraft furnishes oxygen and also prevents him from drifting away. Astronaut Dave Scott in the hatch is describing the activities of Schweickert and taking documentary photos. NASA PHOTOS AS9–19–2995 AND AS9–02–3064.

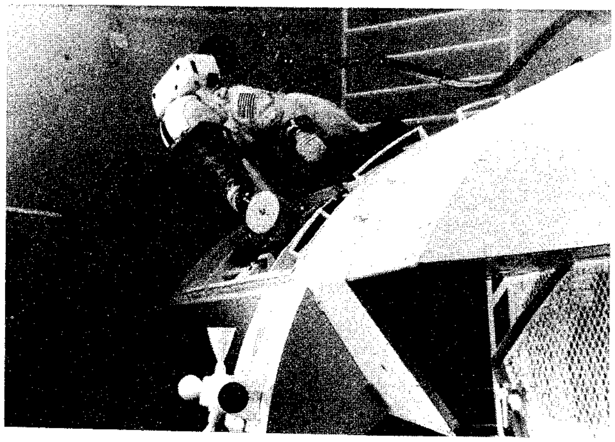

Figure 77.—Training for a space EVA. Shown here in the very large water tank is the mockup of a spacecraft. The CM Pilot practices in the reduced weight environment of the water. NASA PHOTO S–72–49971.

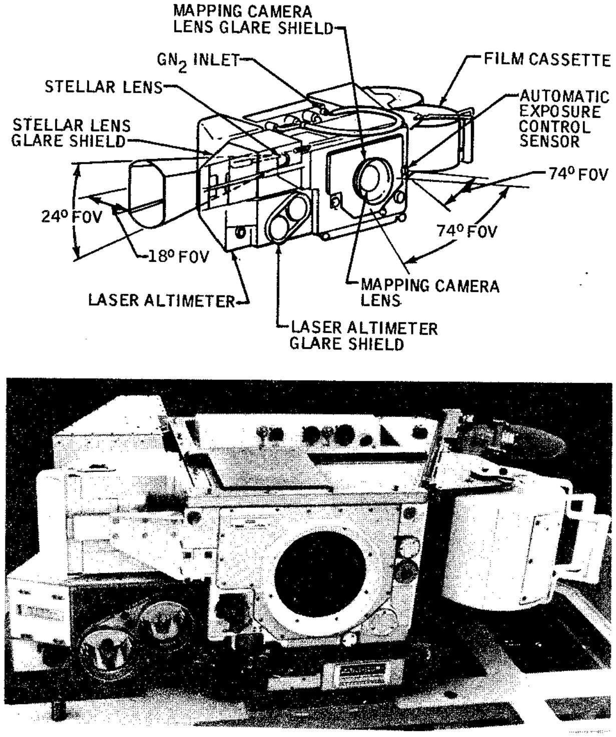

Figure 78.—Three-inch mapping camera and laser altimeter. This unit contains two complete cameras, one for photographing the Moon's surface, another for photographing the stars to obtain precise orientation of the camera in space at the time each photo is taken. The laser altimeter provides data on the altitude of the spacecraft with a precision of 1 meter (about 1 yard). The film cassette is retrieved by the CM pilot before the CM is separated from the SM. The location of this camera in the SIM bay is shown in figure 73. Above, we see a simple line drawing. Below, we see a photo of the camera. Gaseous nitrogen is used to maintain pressure in the camera.

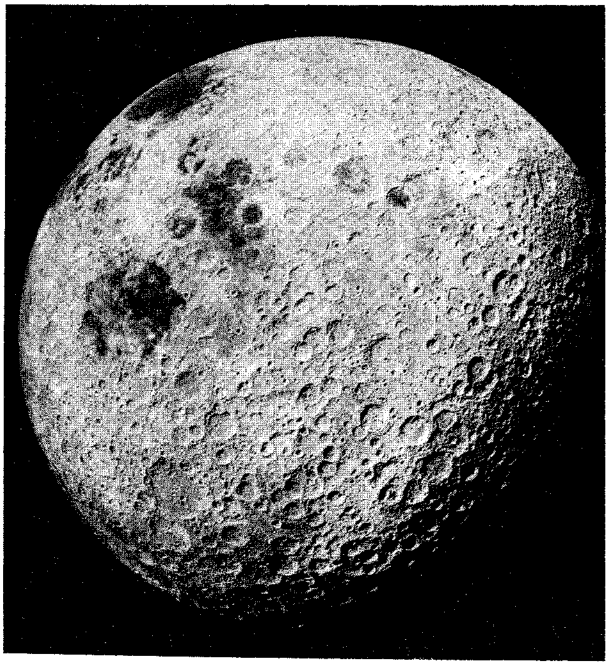

FIGURE 79.—Apollo 16 view of a near-full Moon. Thi view was photographed with the Apollo 16 Metric Mapping Camera shortly after the astronauts left luna orbit on their journey towards the Earth. This view cannot be seen from Earth. We are looking generally westerly towards the large, circular Mare Crisium on th horizon. The more circular mare area is Mare Smythii Most of the mare shown in this picture are on the sid of the Moon opposite the Earth. Note especially th many craters with flat bottoms and central peaks. Th central peaks are often 2 to 3 miles high. NASA PHOT FRAME NO. 3023, APOLLO 16 METRIC CAMERA.

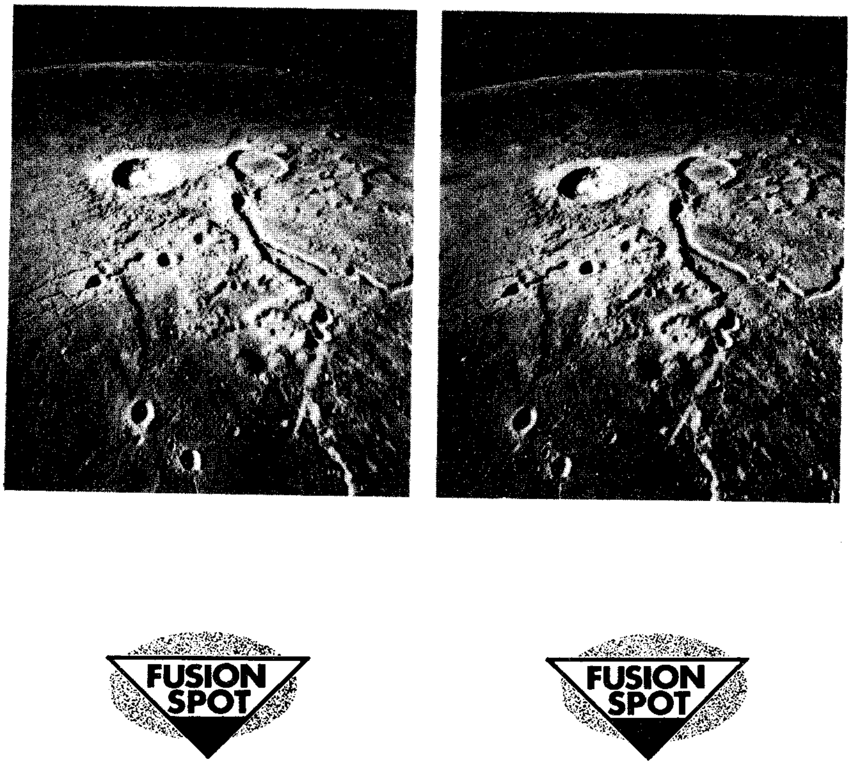

FIGURE 80.—Southward oblique view of Crater Aristarchus and Schroter's Valley. This stereo pair of photos was obtained on Apollo 15 with the mapping camera. See caption of figure 8 for instructions on stereo viewing. Arranged by Earl E. Krause. NASA PHOTO APOLLO 15 MAPPING CAMERA—FRAMES 2609 AND 2610.

lunar surface are obtained through the 3-inch cartographic lens and photographs of the starfield are taken through a different 3-inch lens pointed out to the side. From these stellar photographs, the exact orientation of the camera can be determined later. The mapping camera also has automatic exposure control, but forward motion compensation is manually controlled by the astronaut. Our purpose in using this camera is to locate very precisely the surface features of the Moon. The resolution is considerably poorer than that of the pan camera being only 60 feet. But the metric camera provides photographs with extremely small distortions and on which points can be located with very high precision. (A basic rule of camera design is that we cannot obtain in the same camera *both* the lowest distortion possible and also the maximum resolution possible! Hence we have used two cameras: one designed for high resolution, the other for high precision and minimum distortion.)

The film used in the 3-inch camera is an intermediate speed black and white film commonly used in aerial photography.

Shown in figure 79 is a photograph taken of a near-full Moon by the mapping camera on Apollo 16 shortly after the rocket burn that sent the spacecraft towards Earth. This view, which cannot be seen from Earth, is looking generally westerly. Another example of photography of the Moon with the mapping camera is shown in figure 80, a stereo photograph of the crater Aristarchus and Schroeter Valley.

The Laser Altimeter (LA)

The laser altimeter is used to obtain the elevation of the surface. It operates in much the same way that radar does. A pulse of light, produced by the laser, travels to the Moon's surface and is reflected back to a detector. The time of travel is measured. Since the speed of light is known (about 186,000 miles/second), we obtain the distance from the spacecraft to the Moon's surface. The orbit of the spacecraft is monitored continuously with tracking stations on Earth. The position of the spacecraft is known with rather high precision—say a few feet. The laser altimeter gives the distance between the spacecraft and the Moon's surface with a resolution of about 3 feet. Thus by substraction, we get the elevation of the lunar surface.

The results of the Apollo 15 laser altimeter for one revolution are shown in figure 81. They are very exciting. Analysis of those results shows that the center of mass of the Moon is displaced about 1½ miles from the center of volume in a direction that is approximately midway between Mare Serenitatis and Mare Crisium. We have known for about 2 years that these two maria are the sites of the two largest gravity anomalies on the front side of the Moon. (See the section "S-Band Transponder" for the discussion of gravity on the Moon.)

The two lowest elevations along the single revolution of Apollo 15, about 2½ miles, are in Mare Crisium and Mare Smythii. There were earlier indications (from the land mark tracking data) that Mare Smythii was topographically low. The Apollo 15 laser data showed clearly that the ringed Maria Serenitatis, Crisium, and Smythii are truly basins and are 1¼ to 2½ miles deep, Oceanus Procellarum is rather smooth and is depressed about ½ mile. The Apennines are rather high standing, about 1½ miles.

Apollo Lunar Sounder Experiment (ALSE)

The Apollo Lunar Sounder Experiment (ALSE) uses radar techniques to see into the Moon, possibly to a depth of 1½ km. Radio waves at one of three different frequencies (5, 15, and 150 Megahertz) are radiated from antennas mounted on the Service Module (SM) and shown schematically in figure 82. After a very short time, less than one-thousandth of a second, the transmitter is turned off and a radio receiver is turned on. The radio wave travels to the surface of the Moon where some of it is reflected and some enters the Moon. The portion that enters the Moon may be reflected by layers of rock within the Moon. The various reflected parts of the radio wave are detected by the antennas and delivered to the receiver where they are amplified and then recorded. The character of the reflected waves can tell us a great deal about the subsurface layers and the time needed for return tells us the depth of the layers.

After the radio signal has been amplified in the receiver, it is then converted to *light* signals and recorded optically on photographic film. Location of the optical recorder, as well as the other equipment for ALSE, is shown in figure 73. The film is

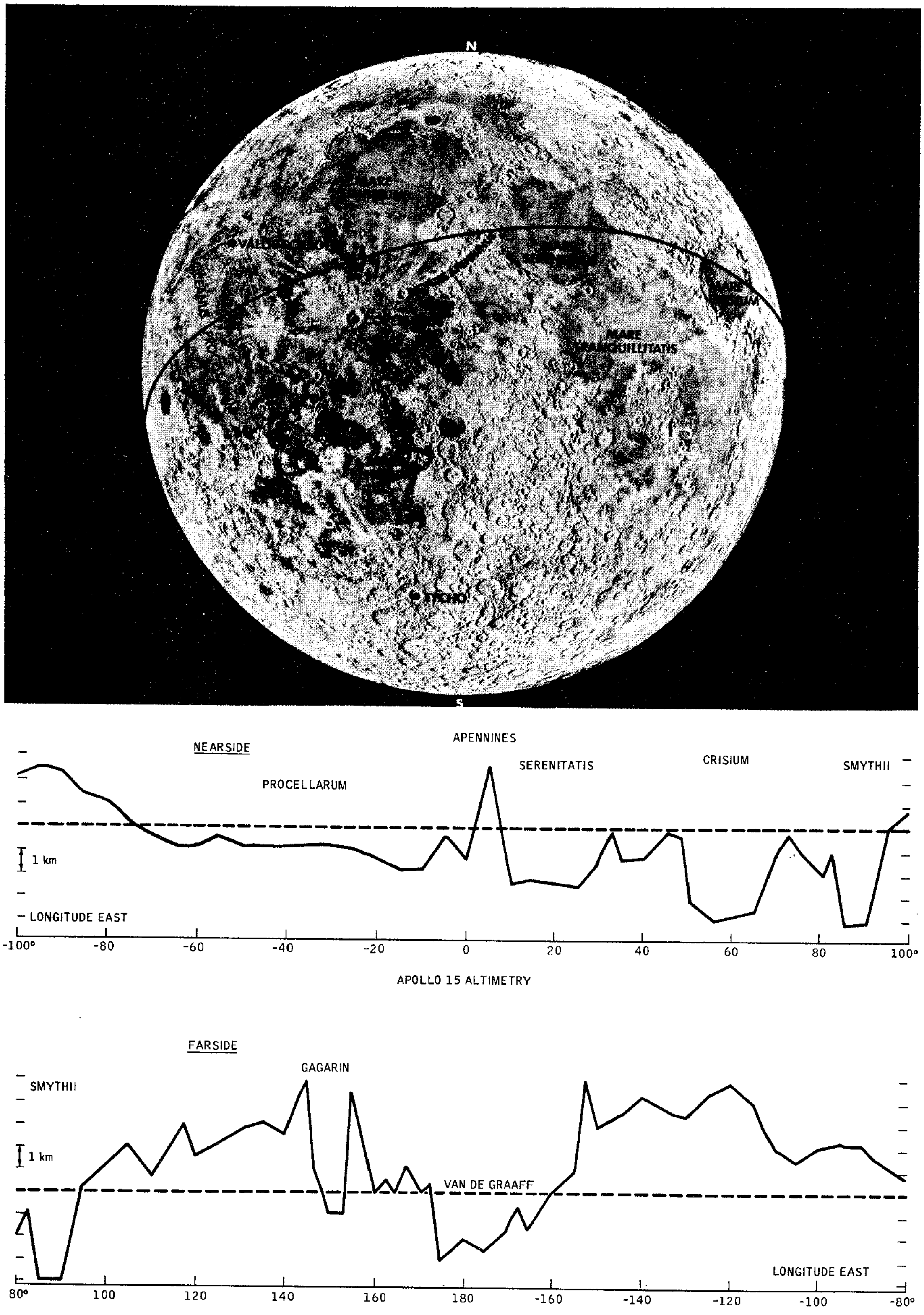

FIGURE 81.—Results of the Apollo 15 Laser Altimeter. Data are shown for one revolution only. The elevation of the surface of the Moon along that single ground track (above) is shown in diagram. The dashed line represents the elevation of a sphere with radius of 1737 km. Based on work of William Kaula in the Apollo 15 Preliminary Science Report. NASA PHOTOS S-72-16337 AND S-72-16322.

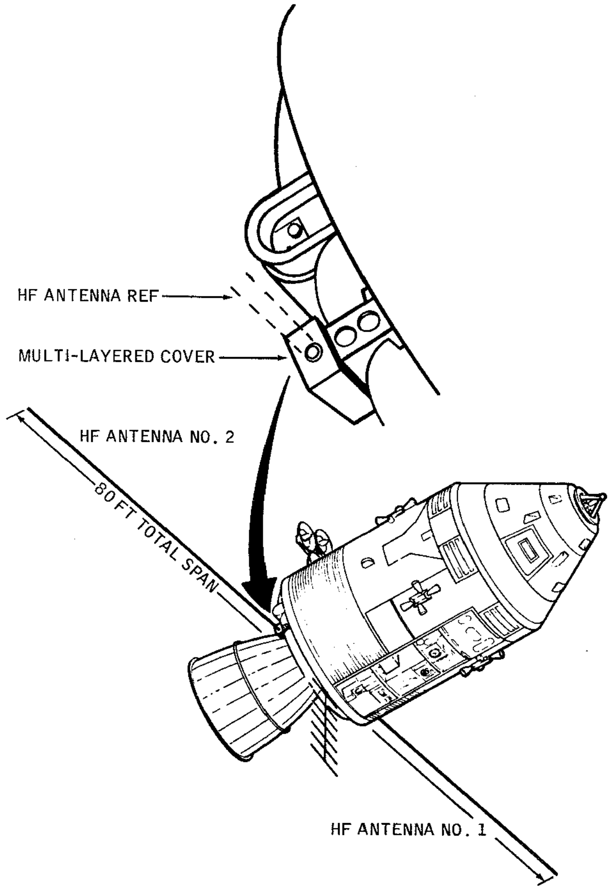

FIGURE 82.—Apollo Lunar Sounder Experiment. Two antennas are used, a dipole antenna with an 80 foot tip-to-tip length for use at 5 and 15 MHz and a Yagi for use at 150 MHz. During operation of the ALSE, the spacecraft orientation must be carefully controlled so that the Yagi points toward the ground track. NASA PHOTO S–72–49034.

retrieved by the CM pilot during an EVA in space and brought back to Earth for analysis. The job of building the optical recorder was not easy. In addition to the usual difficulties of building any equipment that must operate extremely reliably in the hostile environment of space, the equipment had to record very large quantities of data with high precision, very low noise, and high reliability. The external appearance of the optical recorder is seen in figure 83. The schematic diagram, showing how the recorder works, is shown in figure 84.

The antennas used in the ALSE are shown in figure 82. The short one is a Yagi. It is similar to the Yagi antennas that are so common on housetops and used for reception of television signals. The chief difference is that the ALSE Yagi is tuned for the frequency of 150 Megahertz. The other one, 80 feet tip to tip, is a dipole antenna, tuned to handle both 5 and 15 Megahertz signals. (Dipole antennas are discussed in the SEP section.)

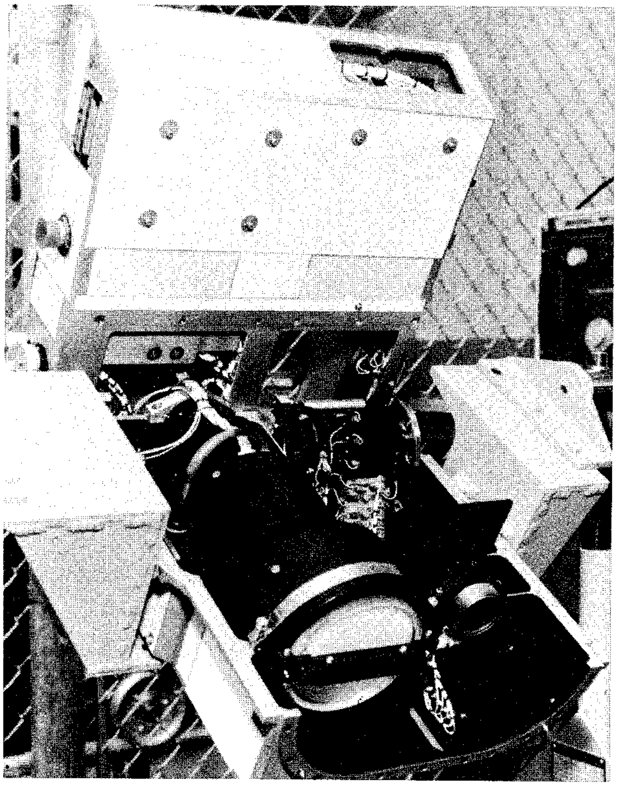

FIGURE 83.—ALSE optical recorder. The external appearance of the recorder is seen in this photo taken during a series of tests. The film in a cassette, not shown here, is removed by the CM pilot during an EVA in space and stowed in the CM for return to Earth. NASA PHOTO S–72–49482.

The ALSE will provide extremely valuable information obtained over a large area on the Moon with very good resolution. Data with which to "look" inside the Moon will be taken for a total time exceeding 10 hours. Any large changes in the electrical properties of the Moon—such as might be associated with a large deposit of iron (or other ores) would be seen easily. The thickness of the regolith will be measured over the total path around the Moon. Other layers, such as basalt flows, within the depth of 1½ km. will be detected and measured by ALSE. And of course, the presence of any water in the lunar subsurface (even less than 1 percent) would be seen easily.

One very exciting possibility for the team members of both ALSE and SEP is a combination experiment. During one revolution of the CSM, the

ALSE will not transmit radio waves but, instead, will listen only. During that revolution, the SEP transmitter will be sending radio waves at its normal frequencies, one of which can be received by ALSE. The basic idea is shown in figure 85. The ALSE *may* hear the SEP signals that have traveled through a part of the Moon and hence, will be received while the spacecraft is below the horizon. This part of our respective experiments is termed an occultation experiment.

One revolution around the Moon will be devoted by the ALSE to listening but with the SEP transmitter quiet. ALSE will listen to the various sources of noise in space. On the earthside of the Moon, there will likely be noise from the Earth. However on the backside of the Moon, the noise from Earth will probably be shielded by the Moon. We already know that electromagnetic noise sources exist in the Sun and other planets.

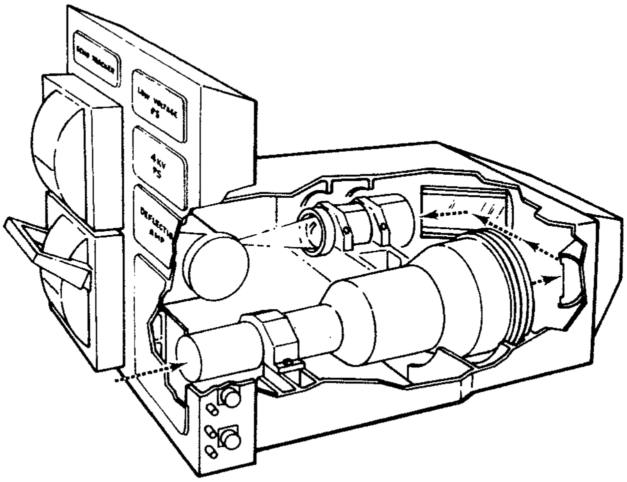

FIGURE 84.—Schematic diagram of the ALSE optical recorder. NASA PHOTO S-72-50317.

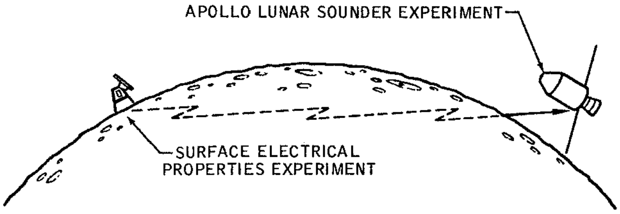

FIGURE 85.—Occultation experiment of SEP and ALSE. The surface electrical properties experiment will be used to transmit radiowaves. The Apollo lunar sounder experiment will listen. The radiowaves may propagate many kilometers through the Moon and be heard while the ALSE is below the lunar horizon. NASA PHOTO S-72-50316.

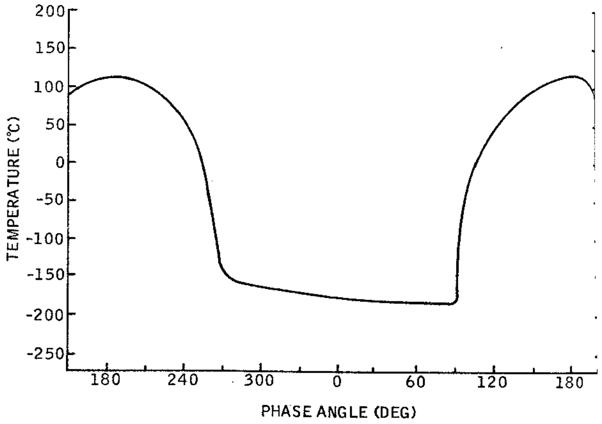

FIGURE 86A.—Temperature of the Moon. The average temperature of the Moon as a function of phase, or time, is shown here. The exact shape of the curve varies somewhat with geographical position on the Moon and is determined by the thermal properties at each position.

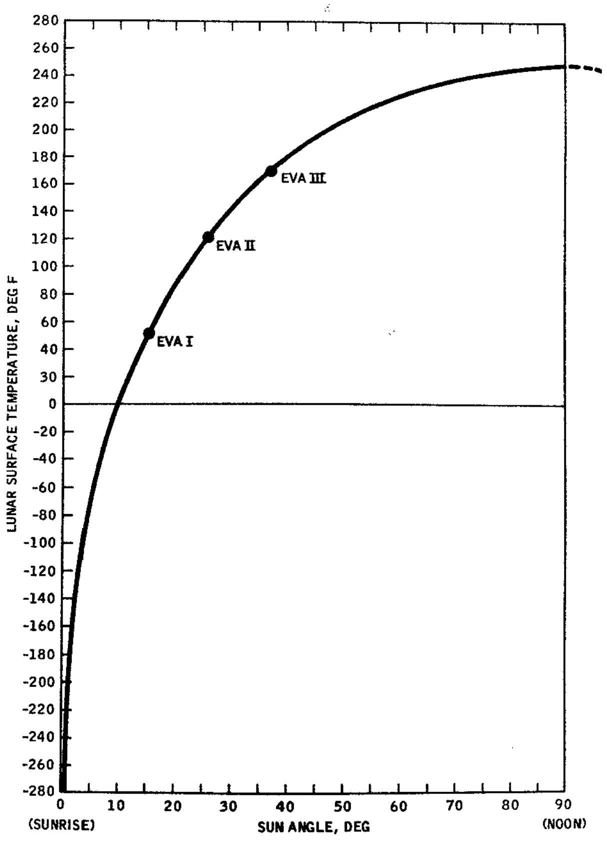

FIGURE 86B.—The temperature of the Taurus-Littrow site shown as a function of the Sun angle. Note that EVA 1 at +17° Sun angle should have +50° F, EVA 2 at +27° Sun angle should have +110° F, and EVA 3 at +37° Sun angle should have a temperature of +160° F.

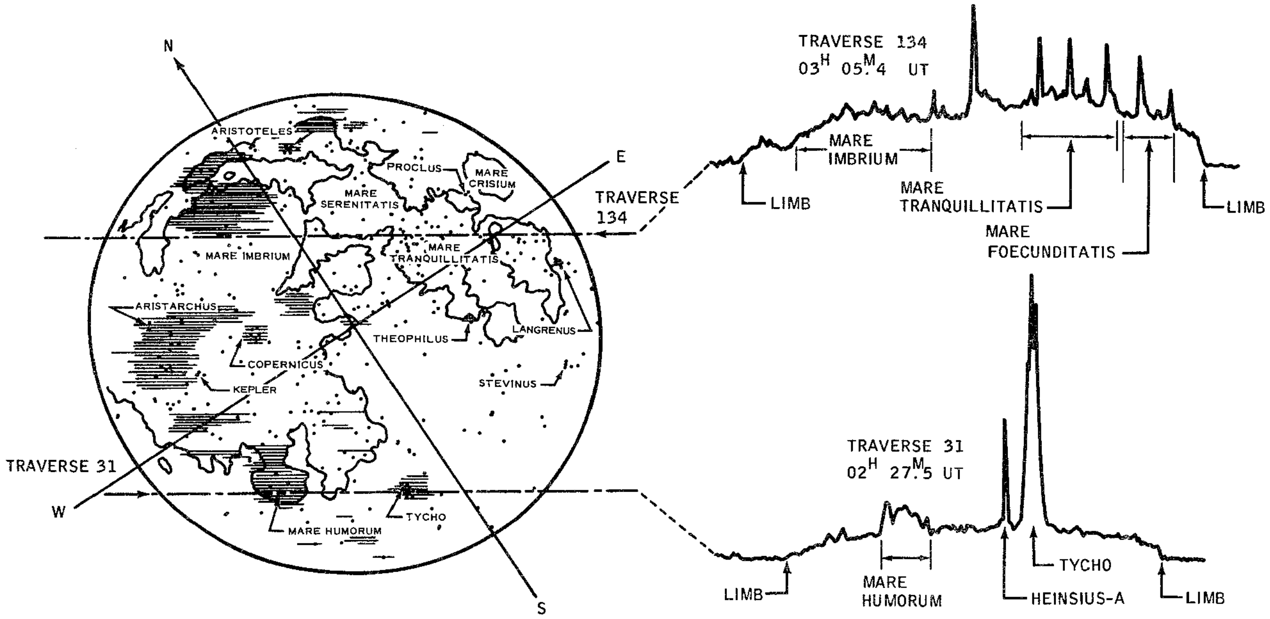

Figure 87.—Thermal Anomalies on the frontside of the Moon observed during an Eclipse. Saari and Shorthill used an automatically controlled telescope and high precision, fast-response circuits to measure the temperature of the Moon during an eclipse in 1966. Their resolution was about 15 km. Shown here is a map of the thermal anomalies (dots and lined regions on the map). Two selected scans are shown on the right side of the figure to indicate the sharp variation in temperature. Note especially the extreme thermal anomaly associated with the crater Tycho. FIGURE COURTESY OF RICHARD SHORTHILL.

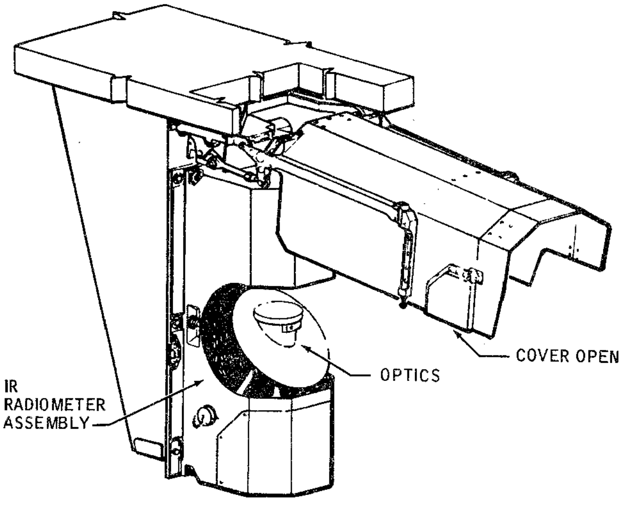

Figure 88.—External appearance of infrared scanning radiometer. This equipment is mounted in the SIM Bay.

Infrared Scanning Radiometer (ISR)

The exact temperature of the surface of the Moon has been of interest for many years. It was first measured in 1930 by Pettit and Nicholson. They used an electronic thermometer located at the focus of a telescope which was trained on the Moon. Data taken years later with the same technique but more refined equipment repeated their results but with higher precision and resolution. The temperatures actually measured on the surface of the Moon with thermometers onboard spacecraft have further confirmed the earth-based measurements. The temperature of the Moon is shown as a function of the phase of the Moon in figure 86. Notice that the coldest temperature is about −200 °C., the hottest about +100 °C.

The shape of the temperature curve, when measured over a small area on the Moon rather than the entire Moon, changes somewhat. Indeed, the *exact* shape depends critically upon the thermal properties of the Moon's surface. Much can be learned about the Moon from measurements of its thermal properties. One way to measure the thermal properties of Moon rocks on the Moon would be to suddenly turn off the Sun's radiation and to measure the surface temperature of the Moon. Nature helps us with just such an experiment by providing eclipses of the Moon by the Earth. During such an eclipse in 1966, Jack Saari and Richard Shorthill of the Boeing Co. obtained temperature scans of a large portion of the frontside of the Moon. The resolution on the surface of the Moon of their telescope (when pointed at the center of the Moon) was an area about 15 km. square. Some of their results are indicated in figure 87. More than 1,000 thermal anomalies—spots on the Moon that showed a temperature significantly in excess of the surrounding region—were discovered. Many of the thermal anomalies, or hot spots as many people prefer to call them, correlated well with known geographical features. Others, however, showed no correlations with visible features.

The chief purposes of the Apollo 17 Infrared Scanning Radiometer (ISR) Experiment are to determine the temperature with high precision and high ground resolution along the ground track of several orbits of the Apollo 17 Mission and to correlate the derived thermal properties with geographical features. But you ask, "How can the temperature of the surface of the Moon be measured from a spacecraft that is 60 nautical miles from the surface?" In much the same way that the temperatures of the Moon were measured by Pettit and Nicholson in 1930 at a distance of some 240,000 miles. A sensitive thermometer is mounted at the focus of a telescope. The external appearance of this equipment is shown in figure 88. The schematic is shown in figure 89.

Let's trace the light path through the telescope. Light enters the telescope from a mirror that is attached to a motor. The mirror oscillates back and forth in such a way that the spot on the Moon's surface, as seen by the telescope, moves across the ground track. The light passes through the various mirrors, baffles, and lens of the telescope, which is termed a Cassegrain folded telescope, to a detector. The detector is a thermistor, a very small solid state device—similar in some ways to the solid state devices used in your home TV sets—which changes the radiant energy into an electrical signal. The electrical signal is related to the temperature of the spot on the surface of the Moon which is viewed by the telescope. This system must be accurately calibrated before it is flown to the Moon. But in addition, it is calibrated at two temperatures many times during the mis-

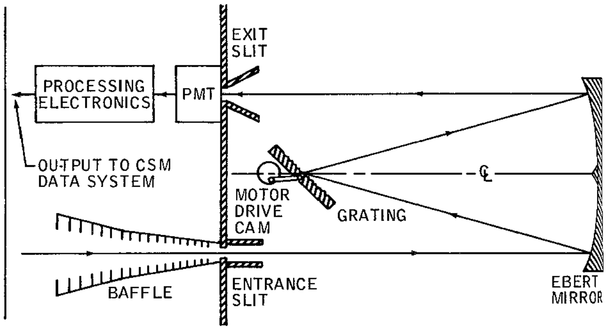

FIGURE 89.—Schematic of infrared scanning radiometer. A plane mirror rotates about the axis of the telescope to provide cross-track scanning.

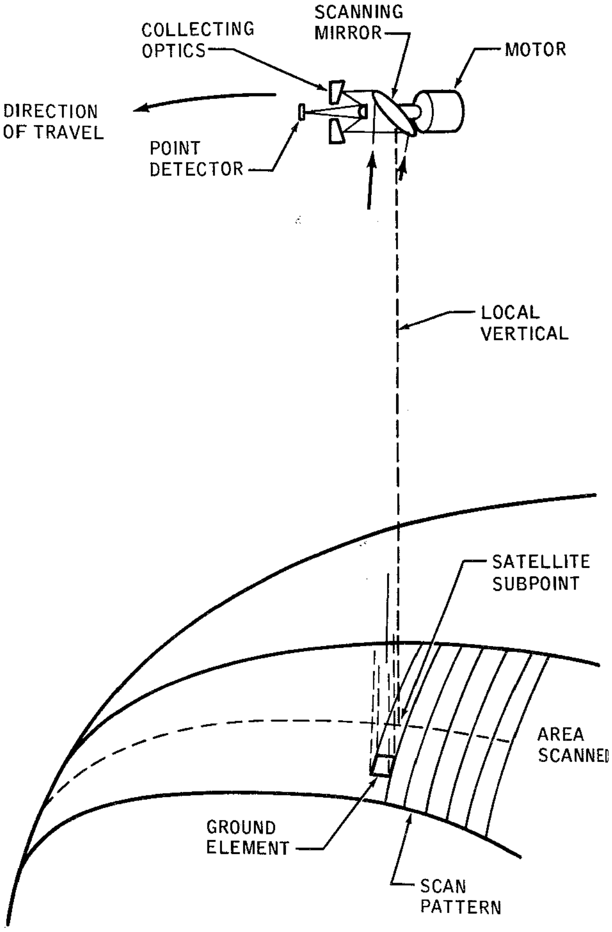

FIGURE 90.—Scanning relation for the IR scanning radiometer.

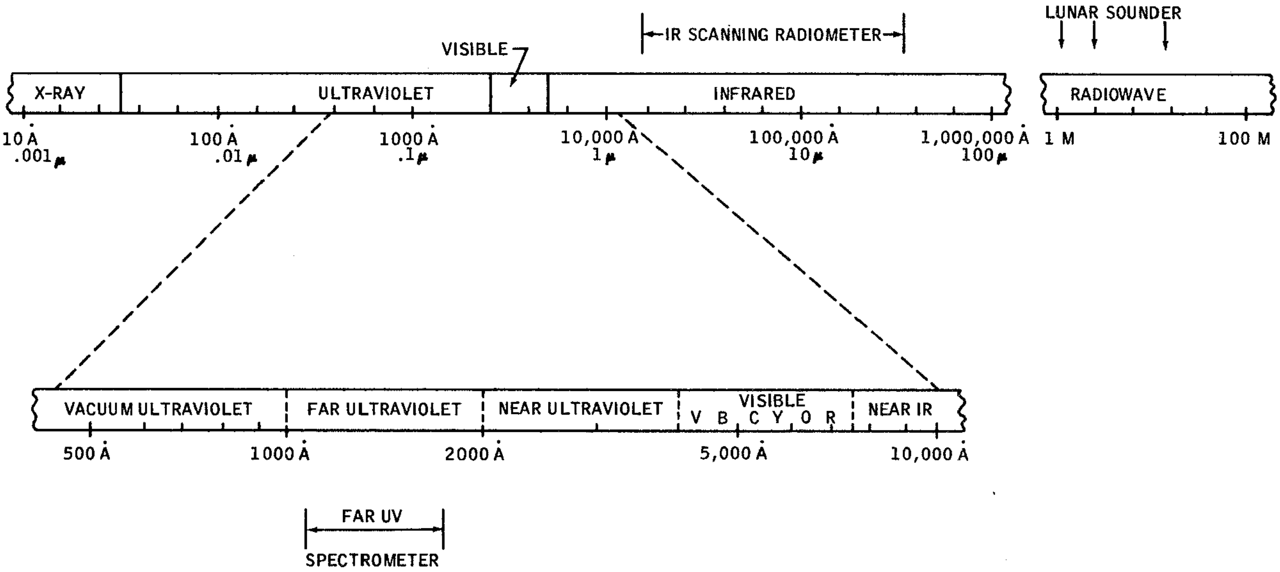

FIGURE 91.—A portion of the electromagnetic spectrum. Because the wavelength of the radiation changes so greatly over the spectrum, different units are most convenient for different portions of the spectrum. The Angstrom, Å, is 10^{-10} meters. The micron, μ, is 10^{-6} meters. The spectrum extends to still shorter, as well as longer, wavelengths. The FUS examines radiation over the spectrum from 1180 Å to 1680 Å. Shown also are the regions used by ISR and the Lunar Sounder.

sion. The mirror views briefly the inside of the equipment for one calibration temperature. It views deep space, which has a known effective temperature, for the second calibration point.

The relation of orbiting spacecraft to the area scanned by the ISR is shown in figure 90. Oscillation of the mirror causes the area "seen" on the Moon to move across the ground track of the spacecraft. The field of view of the telescope is such that the surface resolution is about 2 km. Temperatures can be recorded over the range of −213 °C. to +127 °C. The sensitivity is rather high, about 1 °C.

This experiment has many advantages over earth-based measurements. Most important are the greatly increased spatial resolution (2 km. versus 15 km.) and the ability to obtain data on the backside of the Moon.

Far Ultraviolet Spectrometer (FUS)

Electromagnetic waves vary greatly in wavelength, extending from wavelengths shorter than X-rays to those longer than the familiar 60-cycle household power. The wavelength of X-rays is measured in Angstroms, 10^{-8} cm. The wavelength of 60-cycle power is 5,000 km., one-eighth the circumference of the Earth. A portion of the electromagnetic spectrum is shown in figure 91, where you can see that the wavelength of the ultraviolet is shorter than the wavelength of visible light. Incidentally, the black light that has become popular in recent years occurs in the near ultraviolet region.

The primary objective of the Far UV Spectrometer (FUS) is to determine the lunar atmospheric composition and its density. Other important objectives are these: to determine lunar surface characteristics in the ultraviolet region and their geographical variation over the surface of the Moon—to measure the fluorescence of the Moon on its dark side—to measure the contributions to the lunar atmosphere by the LM's engines—to measure the ultraviolet radiation of our galaxy—and to measure the far UV component of zodiacal light.

From data taken previously on the surface of the Moon, from orbiting vehicles, and from the Earth, we know that the Moon's atmosphere is extremely tenuous (when compared with the Earth's atmosphere). The way that the Moon's atmosphere bends radiowaves, which in free space always travel in

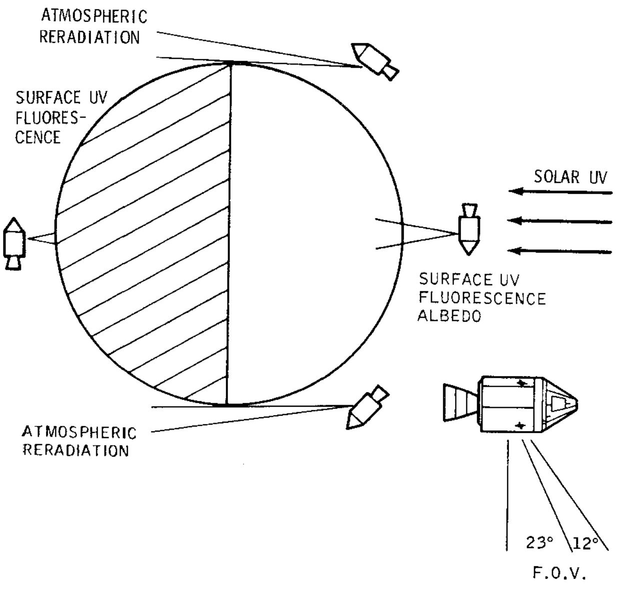

FIGURE 92.—Orientation of CSM during operation of Far UV Spectrometer. Near the terminator, the spacecraft is turned so that the field of view of the FUS is directed towards the Moon's dark side. This procedure minimizes the amount of direct radiation received from the Sun and maximizes that received from atmospheric reradiation. NASA PHOTO S–72–50285.

perfectly straight lines, indicated that the total pressure was less than 10^{-10} torr*. Actual measurements of the pressure by the cold cathode ionization gauge (a commonly used technique for measuring very low pressures in the laboratory) on Apollos 12, 14, and 15 showed that the total pressure was less than 10^{-11} torr. The CCIG equipment has also shown that there are sporadic increases in total pressure of 10 to 100 times the normal lunar atmospheric pressure and the large variations in pressure occur between lunar day and lunar night.

The Mass Spectrometers carried in the CSM on Apollos 15 and 16 showed clearly that a contamination cloud of gases surrounds the CSM in lunar orbit but does not accompany the CSM during its journey to and from the Moon. Furthermore, there is a large variation from day to night in lunar orbit. And finally, we have measured an upper limit for the abundance of neon-20, the major gaseous component in the Moon's thin atmosphere, at a height of 100 km. It is about 2,000 atoms per cubic cm. with a maximum density at the surface of the Moon of about 100,000 atoms per cubic cm. The maximum occurs at lunar night time.

You undoubtedly wonder how an instrument that measures electromagnetic radiation can determine composition. The principle is easy to understand and I think interesting. Let me explain it in some detail. An atom of any element can absorb energy of only certain wavelengths. In turn, the atom that has absorbed additional energy can release the energy by radiation only at the same wavelengths. This process is termed resonance reradiation. Thus an atom in the lunar atmosphere will receive energy from the Sun, absorb that energy, and then release the energy by reradiation. The reradiated energy—at its characteristic wavelength—is then detected and measured by the FUS equipment. So by measuring the wavelengths of the energy that is reradiated by the lunar atmosphere, we can determine which elements are present in the lunar atmosphere. The characteristic wavelengths of a few elements are:

Hydrogen	1216 Å
Carbon	1657 Å
Nitrogen	1200 Å
Oxygen	1304 Å
Krypton	1236 Å
Xenon	1470 Å

In this experiment, we wish obviously to minimize the amount of radiation that is received by the equipment directly from the Sun and to maximize the amount of energy that is received by reradiation from the lunar atmosphere. So on those orbits on which the FUS is operated, when the spacecraft is near the terminator (the separation between the sunlit and the dark regions of the Moon), it will turn so that the field of view of the FUS is looking directly away from the Sun as shown in figure 92.

While the spacecraft is on the dark side of the Moon, the FUS will measure fluorescence of the lunar surface as a function of geographic position. Those data will surely be interesting. But perhaps we will be fortunate enough to obtain UV data on one of the infrequent "transient events." In rare sightings, astronomers have reported seeing through Earth-based telescopes, short lived changes in the visible appearance of a few spots on the Moon. For example, such transient events

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*Torr is a unit of pressure commonly used for pressures less than atmospheric, i.e. vacuum. One torr is equal to the pressure exerted by a column of mercury that is 1 mm high and in the normal Earth's gravity field. From weather telecasts, you may know already that the Earth's atmospheric pressure is about 760 mm. Hg. (or equivalently 760 torr). The Moon's atmospheric pressure is therefore less than 10^{-13} times that of the Earth's atmopheric pressure!

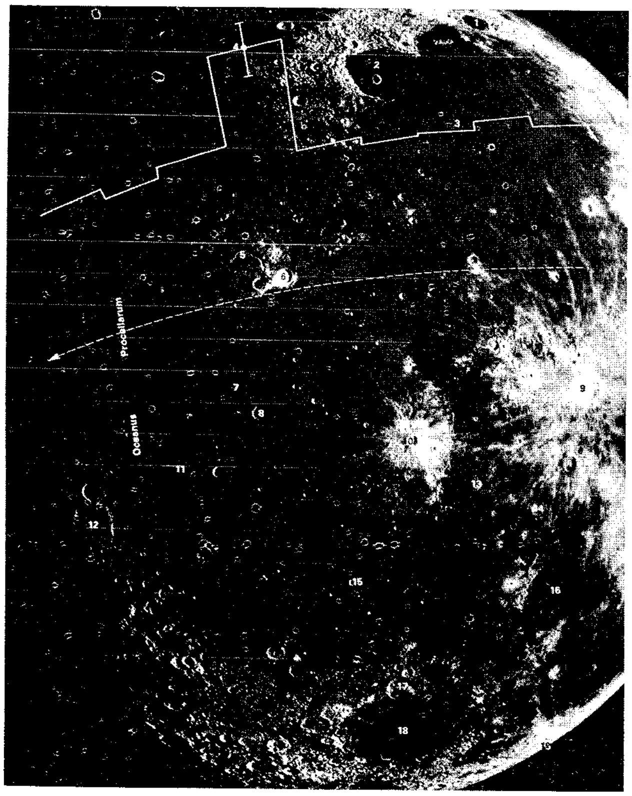

FIGURE 93.—Distribution of the count rate of Alpha particles from the decay of radon as a function of longitude. The solid line indicates the count rate, the dash line the ground track. The feature marked 6 on the figure is the crater, Aristarchus. COURTESY GORNSTEIN AND BJORKHOLM.

have been seen at the craters Aristarchus, Copernicus, and Kepler. These craters are all near the Apollo 17 ground track. So with luck, we just may obtain data with the FUS that will help us understand the cause of transient events.

Incidentally, the crater Aristarchus, shown in figure 80, is extremely interesting. It is one of the craters from which volcanic emissions—hot gases in this case and not liquid rock—have been observed. A Russian astronomer first measured about 15 years ago the spectra of the gases. Aristarchus also shows a significant thermal anomaly on the scans made by Saari and Shorthill. And even more recently one of the instruments carried in the Apollo 15 CSM, the Alpha-particle Spectrometer, detected the gas radon being emitted from the crater Aristarchus. In figure 93, reproduced from Gornstein and Bjorkholm, the correlation of the number of alpha particles from radon decay with the crater Aristarchus is unmistakable.

The FUS is carried in the SIM bay. Its location is shown in figure 73. Its sensitivity is very high. For example, it will detect reliably as few as 10 atoms of hydrogen per cubic cm. at the surface of the Moon, 100 for carbon, 200 for oxygen, 250 for xenon, and so on. The equipment is shown in an exploded view in figure 94 and in schematic form in figure 95. Let's trace the light path through the spectrometer, using figure 95. Radiation enters the spectrometer through the baffle which is really a telescope that limits the field of view to a few degrees. The webs in the baffle prevent scattered radiation from the surfaces of the baffle from entering the spectrometer. The radiation strikes the Ebert mirror and is reflected to the grating. An optical grating is a very flat surface on which many lines have been cut. The grating for the FUS is a mirror with 36,000 lines per cm. (about 90,000 lines per inch). The light is reflected from the grating back to the Ebert mirror where it is again reflected and finally travels through an

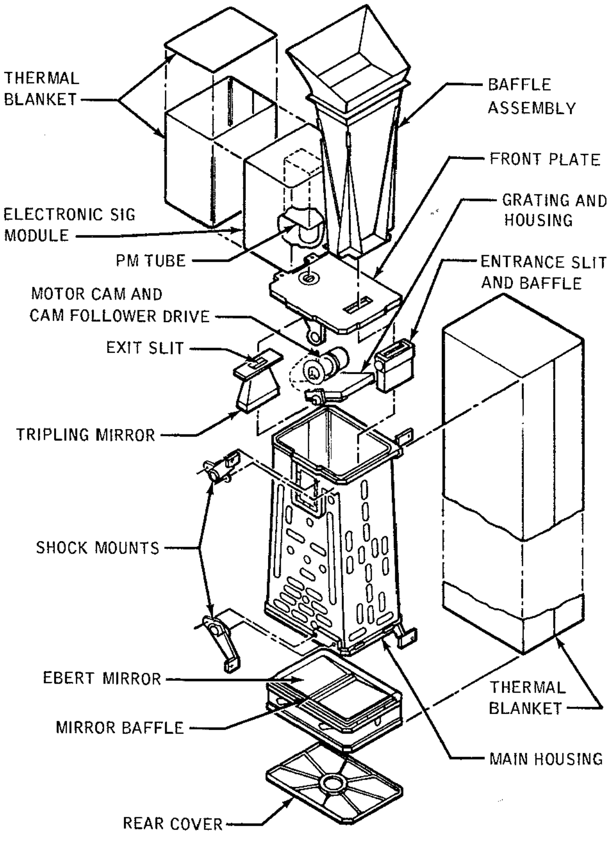

FIGURE 94.—Far ultra-violet spectrometer. Shown here is an exploded schematic view.

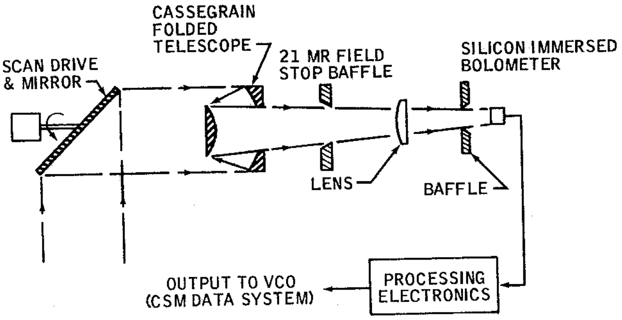

FIGURE 95.—Far ultra-violet spectrometer schematic. The individual components of the far UV spectrometer are shown here in schematic form. The path of the radiation through the equipment follows the line with arrows. See text for further discussion.

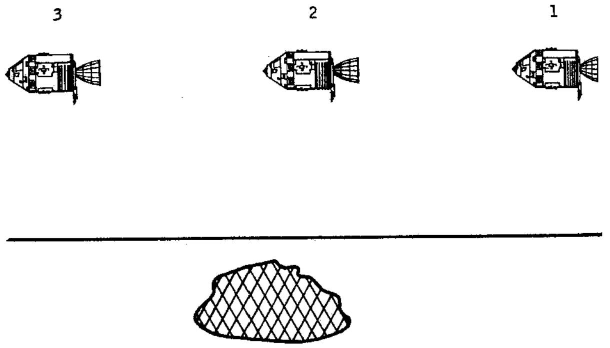

FIGURE 96.—Effect of density on spacecraft velocity. Suppose that a large chunk of material of high density is buried beneath the surface of the Moon. The spacecraft at position 1 will be pulled gently forward by it. At position 2, there will be only a net downward force and no horizontal force. At position 3, the high density material will pull gently backward on the spacecraft. Because of these forces the spacecraft speeds up slightly at 1 and slows slightly at 3. Of course these changes to the velocity of the spacecraft are really very small but can be easily measured with electrical means. See further discussion in text.

exit slit. It is then detected and measured by a light sensitive device termed a photomultiplier tube. The photomultiplier tube produces an electrical signal that is related to the intensity of the incident light. The electrical signal is processed through various electronic devices into a form that is suitable for transmission back to Earth.

A spectrometer measures the intensity of radiation as a function of the wavelength. In the FUS, the motor and drive cam cycle the grating through the wavelength range from 1180 A to 1680 A.

S–Band Transponder (SBT)

With the S-band transponder we measure very small *variations* in the Moon's gravity. I am sure that you know the Moon's gravity is only about one-sixth that of the Earth's. But did you know that the exact value changes significantly over the face of the Moon?

In order to see how the SBT works, think about the following situation. Suppose that the Moon is like a ball, perfectly round and homogeneous throughout. For a circular orbit around such an ideal Moon, there would be no variations in the velocity of the spacecraft. But suppose that we have at one spot buried just beneath the surface a very large chunk of material with very high density. Just for thinking purposes, let's suppose that this large chunk is 50 miles across and is twice as dense as the rest of the Moon. Consider figure 96. As the spacecraft approaches the dense chunk, at position 1, there is a gentle tug in the forward direction due to the gravitational attraction between the spacecraft and the dense chunk. That slight tug is enough to cause the CSM to speed up slightly. At position 2, all of the force is directed downward and there is no net increase, nor decrease in the horizontal velocity of the CSM. Finally in position 3, the spacecraft experiences a backwards pull on it and accordingly, the velocity decreases slightly. Now this change, even though it is very small, in the velocity of the orbiting CSM can be measured with extremely high precision.

These high precision measurements of the changes in velocity are obtained in the following way. From Earth, a radio wave of very stable frequency * of 2115 MHz is transmitted to the orbiting spacecraft. When the radio wave is received by the spacecraft, the frequency is multiplied by the constant 240/221 (for electronic reasons) and then retransmitted to Earth. The frequency of the signal when it arrives back on Earth, though, is usually slightly different from the original fre-

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* The unit megahertz is one million cycles per second. I am sure that you are already familiar with the concept of frequency; exactly the same concept is used for AM radio (frequency of .54 to 1.6 MHz), FM radio (frequency 88 to 108 MHz), VHF television (frequency 54 to 216 MHz), UHF television and so on. The frequency that we use for the S-band transponder experiment is somewhat higher than any of those, but the concept is exactly the same.

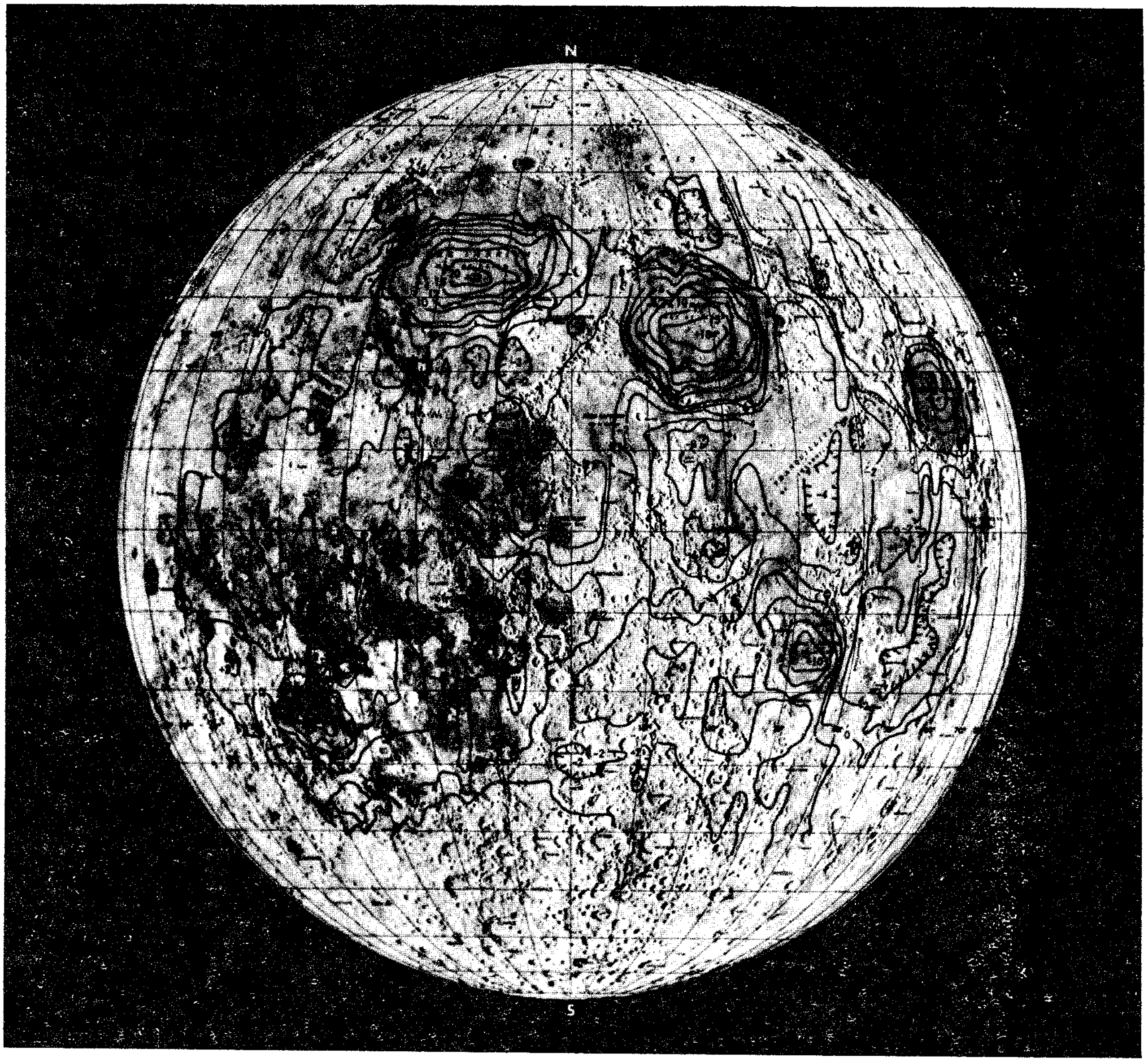

FIGURE 97.—Lunar gravity. These lines, called contour lines, show the departures from "normal" gravity on the front side of the Moon. The units are 10 milligals. The difference between adjacent lines, termed contour interval, is 20 milligals. To obtain total gravity, you must add the usual ⅙ of the Earth's gravitational field to these values. Muller and Sjogren, working at the Jet Propulsion Laboratory, first found these very large variations in the Moon's gravitational field by measuring the very small changes in the velocity of orbiting spacecraft. Notice the excellent correlation between the gravitational features and the surface features of the Moon. The discovery of these variations in the gravitational field surely ranks as one of the most important in Lunar Science. NASA PHOTO S-72-16340.

quency multiplied by 240/221. Let's see why. The radio waves sent by a moving source (the CSM) behave in exactly the same way as sound waves sent by a moving source. I am sure that most of us recall that a whistle on a train changes pitch considerably when the train passes us. The whistle is higher in pitch when the train is approaching than when it has already passed. The same phenomenon, termed Doppler shift, occurs when radio waves are transmitted from a moving source. In fact, the shifts that are observed are sometimes as large as several Hertz. We measure these shifts with a resolution of 0.01 Hertz. Thus we are able to measure very small changes in velocity of the spacecraft.

The basic data of the SBT experiment are the variations in velocity of the spacecraft along its path. From them, we deduce the changes in the Moon's gravitational field. This technique has been used on many of the spacecraft that have orbited the Moon. The earliest was done on the Lunar Orbiter series with the intriguing result shown in figure 97. Shown in that figure are the *variations* in gravity. The main part of the gravity field has been subtracted from these data and we are looking only at the *departures* from normal gravity. I personally think the discovery by Paul Muller and William Sjogren of the Jet Propulsion Laboratory of these variations of gravity over the face of the Moon ranks as one of the most important scientific discoveries about the Moon. On Apollo 17, the S-band transponder experiment will obtain data from both the orbiting CSM and the LM.

One big advantage of this experiment is that it allows us to "see" below the surface of the Moon. The differences in density of the rocks beneath the surface of the Moon produce the differences in the gravitational field which, in turn, affects the velocity of the spacecraft. Thus we have a tool with which to examine the distribution of the rocks beneath the surface of the Moon. It is a tool that we have found to be very effective in our exploration of the Earth's crust. We are especially anxious to see whether there are large variations in density beneath such topographic features of the Moon as the large craters.

Window Meteoroid Experiment (WME)

Many photographs and visual observations are taken *through* the Command Module windows. In order to prevent distortion of the photos and of the visual images by the windows, they are very carefully prepared of optical quality glass and the surfaces are polished to the same perfection as spectacle lenses. The outer surfaces of the windows are ideal detectors for micrometeroids. They are very carefully examined microscopically both before and after each mission. Particles as small as one-thousandth millimeter diameter (about 50 millionths of an inch) can be detected by the small pits produced on impact. A total of 10 possible meteoroid impacts have been found on the windows from previous missions—five on Apollo 7, one each on Apollo 8, 9, and 13, and two on Apollo 14.