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Observatories on the Moon

Hostile to life, the moon could be a haven for astronomy. Observatories on its surface could yield extraordinarily detailed views of the heavens and open new windows through which to study the universe

by Jack O. Burns, Nebojsa Duric, G. Jeffrey Taylor and Stewart W. Johnson

The harsh, lifeless surface of the moon may well be the best place in the inner solar system for human beings to study the universe around them. The near absence of an atmosphere, the seismic stability of its surface, the low levels of interference from light and radio waves (especially on the lunar far side) and the abundance of raw materials make the moon an ideal site for constructing advanced astronomical observatories.

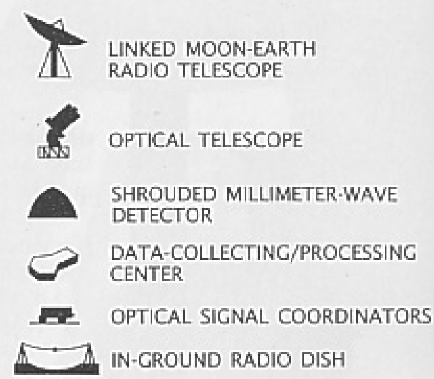
Observatories on the moon will exceed the resolving power of current ground-based optical instruments by an extraordinary amount, perhaps by a factor greater than 100,000. Such observatories will also open an entirely new window on the universe by permitting detection of very low radio frequencies; they may even help pioneer new branches of astronomy through the study of gravitational waves and the elusive neutral particles known as neutrinos.

In the U.S. there is a renewed interest in the moon as a science platform, as a resource base or as a steppingstone to Mars. In 1983 a National Academy of Sciences report, *Astronomy and Astrophysics for the 1980's,* advocated international planning for lunar-based astronomy. On July 20, 1989, President George Bush voiced his support for a permanently manned lunar base in his speech commemorating the 20th anniversary of the first Apollo landing. We and others in the scientific community have therefore begun serious efforts to plan for a permanent lunar base and for astronomical observatories that might be built on the moon in the 21st century.

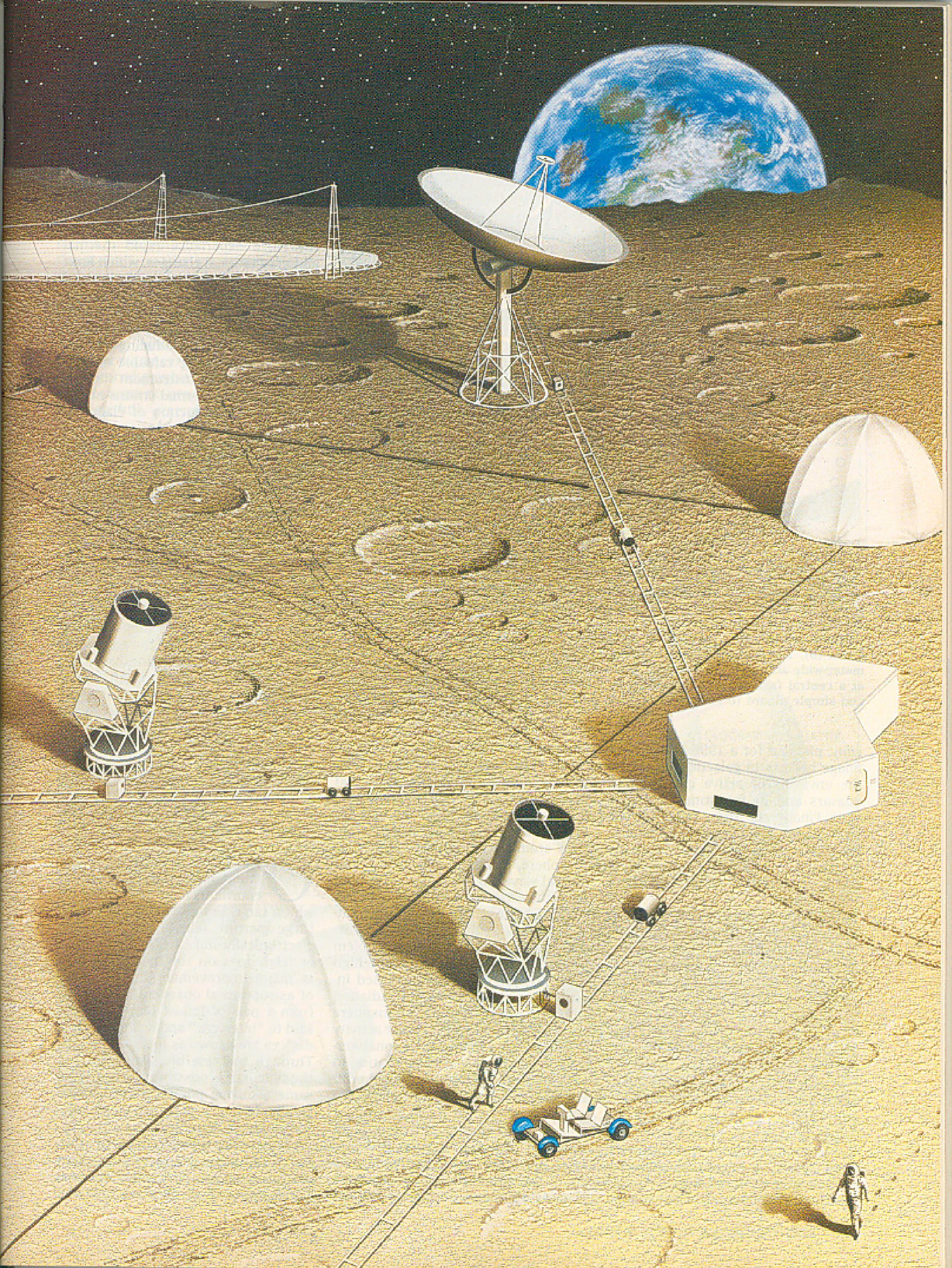
Until then, improved astronomical observations will come from satellites in earth orbit. Four major scientific satellites—the *Great Observatories*—are expected to be launched by the close of the century. These satellites will examine a large fraction of the electromagnetic spectrum, which includes light as well as radio waves, X rays and gamma rays. Virtually everything that astronomers know about the cosmos has been learned by studying electromagnetic emissions from celestial objects. Each section of the electromagnetic spectrum yields information about the specific physical processes that produce radiation of that particular energy, or frequency.

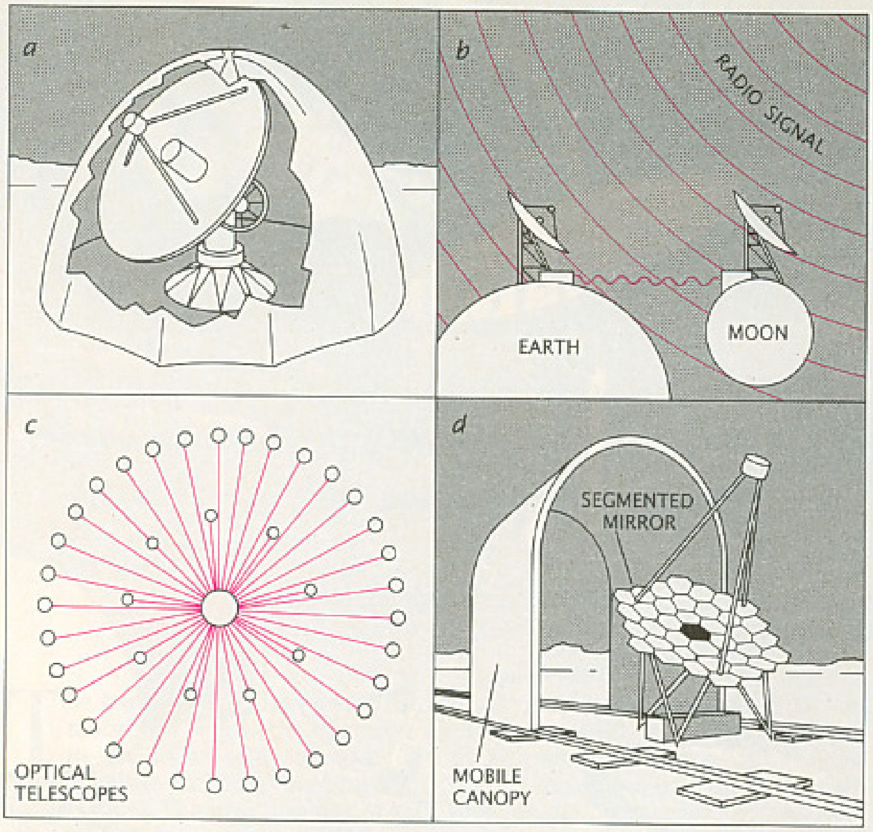
The *Hubble Space Telescope* will probe the universe at visible wavelengths with nearly 10 times the resolution of the largest ground-based telescopes when it is sent into space this year. The *Gamma Ray Observatory* is also slated for a 1990 launch; it will view radiation emitted by energetic processes that occur around dense, compact objects, such as neutron stars and black holes, with vastly improved sensitivity and resolution as compared with previous instruments. The *Advanced X-ray Astrophysics Fa-*

JACK O. BURNS, NEBOJSA DURIC, G. JEFFREY TAYLOR and STEWART W. JOHNSON share an interest in astronomy and exploring new frontiers. Burns is professor of astronomy and head of the astronomy department at New Mexico State University and has been designing and evaluating plans for lunar-based observatories for the past six years; he has a Ph.D. in astronomy from Indiana University. Duric is director of the Institute for Astrophysics and assistant professor of astronomy at the University of New Mexico. He received his Ph.D. in astronomy from the University of Toronto. Taylor is senior research scientist and assistant director of the Institute of Meteorics at the University of New Mexico and holds a Ph.D. in geology from Rice University. Johnson is adjunct professor of civil engineering at the University of New Mexico and is also principal engineer for advanced basing systems at BDM International. He earned a Ph.D. in civil engineering at the University of Illinois at Urbana-Champaign.



LUNAR OBSERVATORIES will greatly improve on existing facilities. Optical telescopes, unfettered by a distorting atmosphere, will be linked to a central facility to provide superior resolution. An array of detectors will map cosmic processes that emit millimeter-wavelength radio waves. Linking lunar radio telescopes with ones on the earth will permit high-resolution observations. Huge radio dishes built into craters will probe faint signals from deep-space structures.





TELESCOPES will be designed specifically for the lunar environment. Shrouds will protect delicate surfaces, such as the collecting dish of this millimeter-wave telescope, from meteoroid impacts (*a*). A radio telescope on the moon linked to one on the earth will have the resolving power of a single 400,000-kilometer-wide antenna (*b*). The authors envision linking 42 optical telescopes to form a 10-kilometer-wide array; signals received by the array would be collected and processed at a central facility (*c*). A proposed 16-meter telescope has a segmented mirror and simple mount to ease construction; a mobile canopy protects the optics (*d*).

cility, planned for a 1996 launch, will image hot gas in galactic clusters, in the environs of active galaxies and quasars and in the atmospheres of stars. Finally, the *Space Infrared Telescope Facility* will map cool interstellar gas clouds that are associated with the formation of stars and possibly planets; it is tentatively scheduled for a 1998 launch.

In spite of their considerable promise, we think the *Great Observatories* will likely be the last major astronomical instruments placed in low earth orbit. This is because at the low altitudes (500 to 600 kilometers above the earth) where most astronomical satellites orbit, telescopes encounter serious problems. First, the environment is dirty and the cloud of orbiting debris from space launches grows thicker each year. Much of the debris consists of high-velocity, micrometer-size objects that can seriously damage a telescope's sensitive optics and instrumentation.

Second, there is still a substantial amount of dust and gas at this altitude. The dust scatters light and creates an infrared background that masks emissions from the faintest celestial infrared sources. The high-velocity orbital motion of satellites excites atoms in the rarefied upper atmosphere, creating emission lines at optical wavelengths that can obscure or confuse astronomical observations.

Third, atmospheric drag causes satellites in low earth orbit to spiral slowly back toward the earth. The problem is exacerbated during times of high solar activity, when the increased intensity of solar ultraviolet radiation causes the earth's upper atmosphere to swell. Intense levels of solar activity have recently forced the National Aeronautics and Space Administration to reevaluate and raise the planned orbit for the *Hubble Space Telescope*.

Fourth, the earth itself is a major source of obscuring radiation. Light reflected off the earth can scatter into telescope optics and degrade the quality of the observations. Furthermore, the earth's magnetic field generates low-frequency radio noise that far exceeds the intensity of extraterrestrial sources. As a consequence, observatories in low orbit will have difficulty detecting and imaging low-frequency, kilometer-wavelength radio waves, the sole section of the electromagnetic spectrum that astronomers have not yet observed.

Finally, satellites orbiting close to the earth experience rapid thermal and gravitational changes, which limit the size, and hence the resolution and sensitivity, of telescopes that can be placed in such orbits. These changes deform mirrors and radio dishes, preventing them from producing optimal images and wasting valuable observing time while the instrument stabilizes. Eliminating thermal strains necessitates the construction of elaborate masks or sunshades.

Substantial improvements in the next generation of space observatories will require a better location from which observations can be made. One solution is to launch satellites into higher, geosynchronous orbits (where one orbit requires 24 hours), about 37,000 kilometers above the earth. Another is to place instruments on the surface of the moon (which orbits 384,000 kilometers from the earth).

Transportation costs increase with growing distance from the earth, but the *rate* of increase declines with distance: traveling from the earth to geosynchronous orbit requires 2.6 times the amount of fuel needed to travel from the earth to low earth orbit, but only an additional 50 percent is needed to reach the moon. More significantly, the environment for astronomy greatly improves with distance; the moon is an optimal location for astronomical observations.

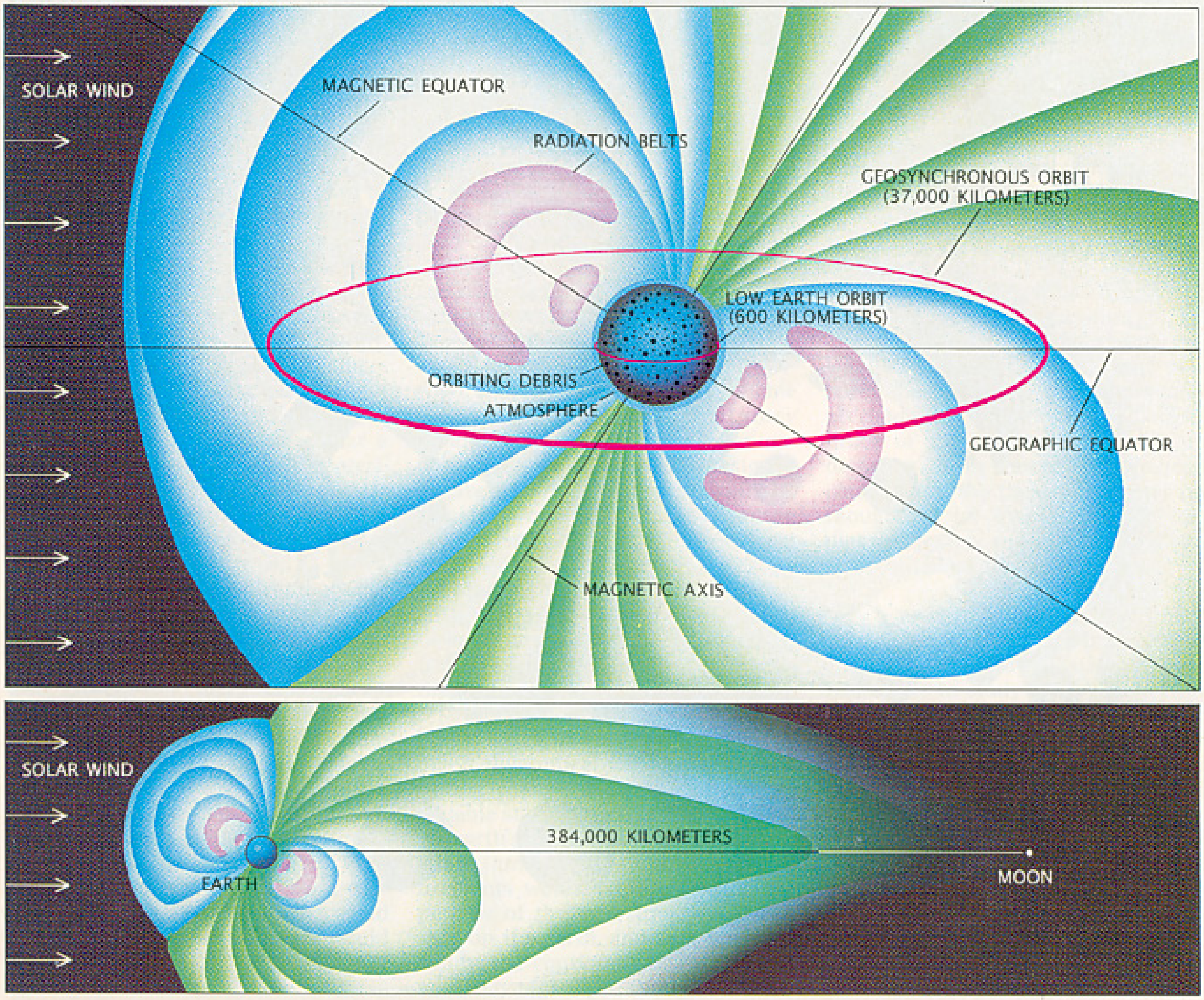
One major advantage of the moon is that it provides an enormous natural platform on which large structures can be built. Large-aperture telescopes and huge, electronically linked arrays of smaller telescopes on the moon will lead to major improvements in the detail of astronomical observations. Signals from a pair of linked telescopes are said to "interfere," and so such linked devices are known as interferometers. Through the careful combination of the signals, it is possible to achieve the same resolving power from a pair of small telescopes as from a single telescope whose diameter equals the distance between the pair. In earth orbit, interferometers would require giant platforms or complex and costly station-keeping of all the telescopic elements; on the moon, such instruments simply could be placed on the surface.

Fabricating structures in the reduced-gravity environment of the moon will be easier than in the zero-gravity environment of earth orbit, as the Apollo and space-shuttle missions have revealed. Construction of observatories on the moon can be adapted from techniques developed on the earth, with the advantage that the moon's weaker gravitational pull makes it possible to build larger devices than are practical on the earth. Ferhat Akgul and Walter H. Gerstle of the University of New Mexico and one of us (Johnson) have drawn up plans for a lunar radio telescope made of advanced graphite-epoxy materials. They foresee no practical obstacles to building fully steerable radio-collecting dishes 500 meters across or 16-meter-wide mirrors for observing visible light and infrared radiation (which has somewhat longer wavelengths than visible light) on the moon.

The moon is a remarkably stable platform: the energy of a typical seismic event on the moon is 100 million times less than an average one on the earth, and moonquakes produce ground motions of only about one billionth of a meter. Such stability is a boon for optical interferometers, which require that the distance between telescopic elements in a linked system be known to within a fraction of a wavelength of light, or roughly one ten-millionth of a meter.

Another feature of the moon is that it offers a clear view of virtually all astronomically interesting radiations. The moon's atmosphere is essentially nonexistent: the mass of the entire lunar atmosphere is equal to that of the air inside a typical basketball stadium on the earth! As the moon orbits, one hemisphere always faces away from the earth. On the far side, the mass of the moon serves as a giant wall, blocking the natural and man-made sources of interference that make low-frequency radio observations impossible on the earth and difficult in earth orbit. Indeed, the far side of the moon is the only location within the inner solar system that is both large enough and sufficiently shielded to make it possible to study these frequencies.

There are other reasons why the lunar environment is ideal for astronomy. James D. Burke of the Jet Propul-



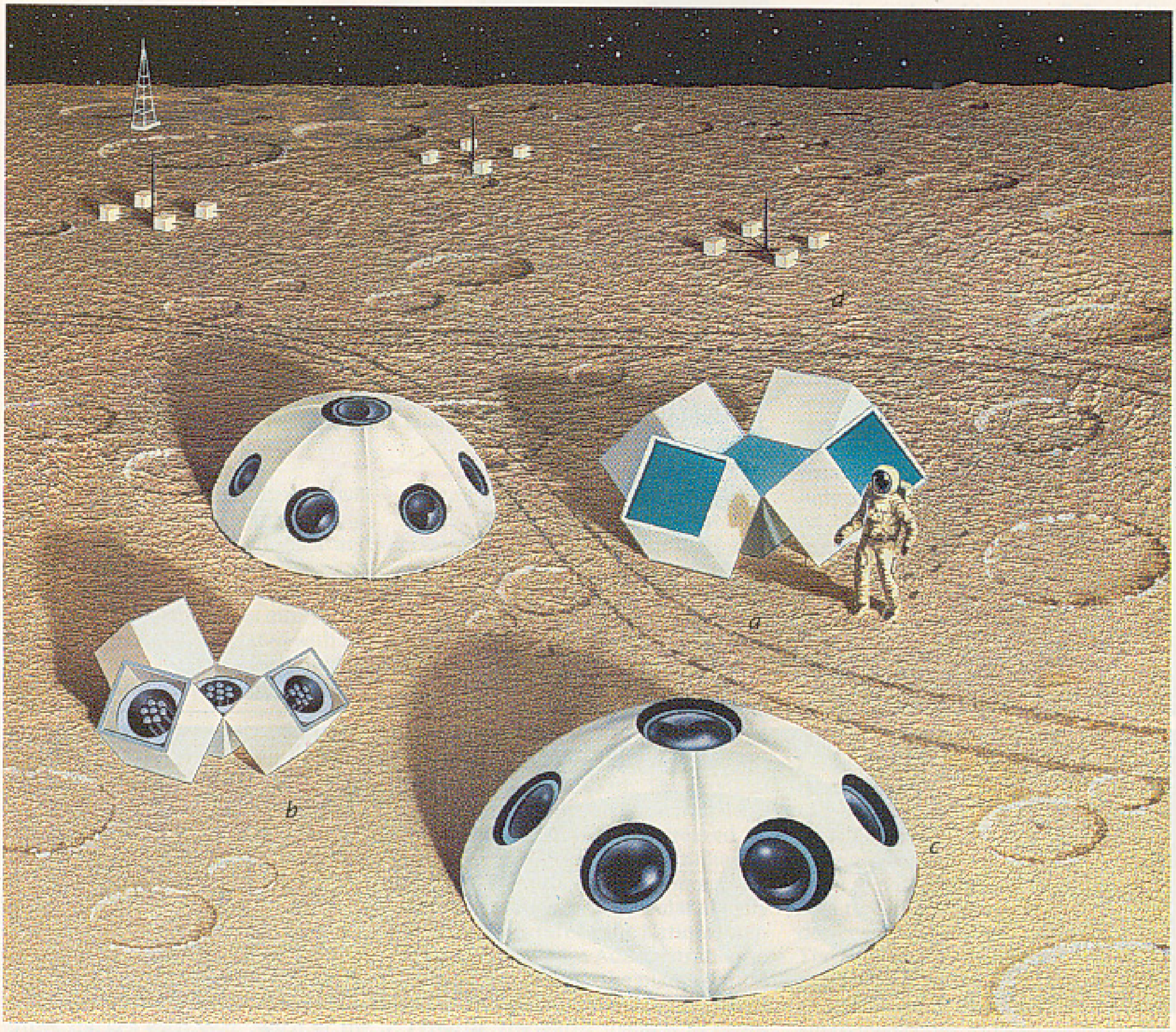
DIRT AND NOISE plague earth-orbiting astronomical satellites. Human-generated debris surrounding the earth threatens satellites with potentially devastating collisions. The thin upper atmosphere creates friction that generates unwanted light and causes satellites' orbits to decay. Even at higher altitudes, light from the earth degrades astronomical observations. The earth's radiation belts create radio noise and interfere with instrument operations. The prospects for astronomy are much brighter on the moon: it lies far from the troublesome environment surrounding the earth, and it is large enough to act as a shield, protecting observatories on its far side from natural and human-generated radiation emitted by the earth.

sion Laboratory in Pasadena, Calif., notes that some craters near the moon's poles appear to be constantly shadowed; the temperature in these locations is believed to be about 70 kelvins. Most astronomical detectors have to be cooled to or below this temperature to reduce the thermal noise that is always present in instrument electronics. Daniel F. Lester of the University of Texas at Austin suggests that the lunar poles may be ideal locations for infrared telescopes; the frigid environment would passively cool not only the electronics and infrared-sensitive detectors but also the telescope structures, which at higher temperatures are themselves major sources of infrared radiation.

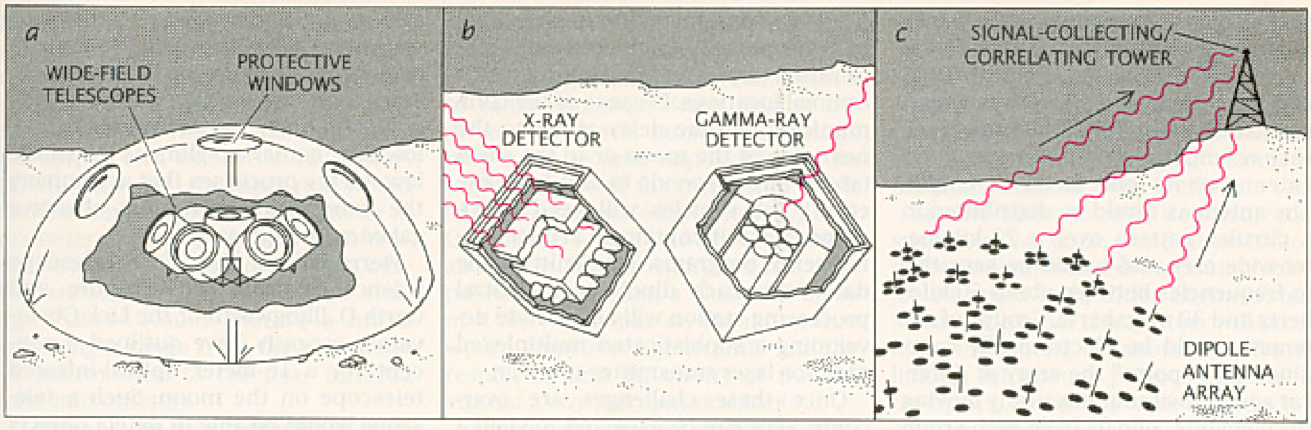
The moon has an abundance of raw materials that could be processed to yield aluminum, ceramics and superstrength glasses for the construction of telescopes. James D. Blacic of the Los Alamos National Laboratory notes that the extremely dry lunar environment will make it possible to produce glasses with tensile strengths comparable to that of steel and with low coefficients of thermal expansion. Such glasses could be used not only for optical mirrors but for the telescope structures as well. Mining, refining and processing on the moon could also serve commercial purposes and become an integral part of a permanently manned lunar base. By the middle of the 21st century, few components of astronomical telescopes may need to be brought from the earth.

There are, of course, difficulties associated with placing a base on the moon. The earth has a magnetic field that deflects charged cosmic-ray and solar-wind particles away from its surface and from near-earth space. There is no comparable field on the moon, and so precautions must be taken to protect human beings and sensitive electronics from hazardous radiation exposure.

The moon is also constantly bombarded by small meteoroids. On the earth, these particles disintegrate in the upper atmosphere; on the airless moon, they rain down on the surface



NEW VIEWS OF THE UNIVERSE will result from lunar astronomy. X-ray variability monitors (*a*) and gamma-ray burst detectors (*b*) will scan the skies for mysterious, rapidly blinking sources of high-energy radiation. Wide-field optical and ultraviolet telescope arrays, seen here shrouded (*c*), may at last reveal the true nature of these sources. Dipole-antenna clusters (*d*) linked together will form the Very Low Frequency Array (VLFA), which will detect low-energy radio waves emitted by solar flares, supernova remnants and active galaxies. Such radio waves cannot be observed from the earth's surface.



ADVANCED TECHNOLOGIES will help exploit the potential of lunar-based astronomy. Full-sky monitoring arrays will be highly automated (*a*). Gamma- and X-ray monitors (*b*) will incorporate advanced detectors made of germanium and special masks to improve resolution. Self-guided robots will help place the VLFA's roughly 200 antennas on the moon's far side; each antenna will be linked to a central data-collecting facility via optical fibers or sophisticated radio transmitters (*c*).

at velocities ranging from 10 to several tens of kilometers per second. Analysis of data from the Apollo missions suggests that tiny craters from one micrometer to 10 micrometers wide will be common on exposed surfaces on the moon. Sensitive surfaces—optical mirrors, for example—will need to be protected with domes or tubes.

The moon's slow rotation (once every 27.3 days) and lack of an atmosphere create drastic and rapid temperature variations—from 100 kelvins at night to 385 kelvins during the day. Provisions must be made to minimize the thermal strains that would afflict lunar telescopes. Analyses by Akgul, Gerstle and Johnson suggest that a judicious choice of composite materials (such as graphite-epoxy) that resist expansion and contraction may prevent thermal changes from being a serious problem.

A vigorous base on the moon—involving mining, manufacturing and regular launch activities—could provide important resources but could also pollute the lunar atmosphere. Richard R. Vondrak of Lockheed has noted that, under extreme circumstances, mining activities could generate a long-lived lunar atmosphere opaque to ultraviolet radiation that would interfere with lunar astronomical activities.

Fortunately, analyses by Ilias Fernini of the University of New Mexico and us indicate that lunar pollution would be largely limited to the vicinities of mining or launch facilities. Atmospheric atoms quickly would be adsorbed by the lunar soil or swept away by the solar wind (the stream of particles from the sun). As a result, observatories more than 10 to 100 kilometers from mining operations should be largely unaffected by atmospheric pollutants.

The first lunar observatory will probably be modest in scope. Yet even a simple one-meter-diameter optical telescope on the moon could perform valuable studies; in the absence of a distorting atmosphere, such a telescope would have a resolution of about .1 arc second, better than the largest earth-based instruments.

Telescopes on the moon will have access to ultraviolet and infrared radiations (which have wavelengths somewhat shorter and longer than visible light, respectively) and so could study a wide range of astronomical phenomena. A lunar-based telescope designed to give a wide field of view would be ideal for producing a map of the entire sky that would show fainter objects and finer details than the Palomar Sky Survey, the current standard reference. Such a telescope also could be used to monitor solar activity and warn astronauts of impending solar cosmic-ray bursts.

Michael Zeilik of the University of New Mexico proposes dedicating a one-meter optical telescope to monitoring changes in the brightness of variable stars and quasars. Freed from the earth's bright and turbulent atmosphere, lunar-based brightness measurements would require less than 1 percent of the exposure time necessary on the earth, and they could be conducted continuously, without the short day-night cycles and the weather interruptions that hinder such observations on the earth.

Other fairly simple instruments well suited to the lunar environment include gamma-ray burst detectors and X-ray variability monitors. These devices could search the sky for the brief, enigmatic bursts of gamma-ray emission (lasting from .01 second to 80 seconds) that rise hundreds or thousands of times above the quiescent background. Little is known about gamma-ray bursters, primarily because astronomers have been unable to locate and identify optical counterparts to the bursts. Typical gamma-ray detectors can locate objects only to within a few degrees. A gamma-ray monitoring station on the moon, coupled with others scattered through the solar system, could pinpoint these sources with arc-second precision by comparing the arrival times of the bursts at the various detectors. X-ray variability monitors could study the flickering emissions thought to be associated with hot disks of matter surrounding neutron stars and black holes.

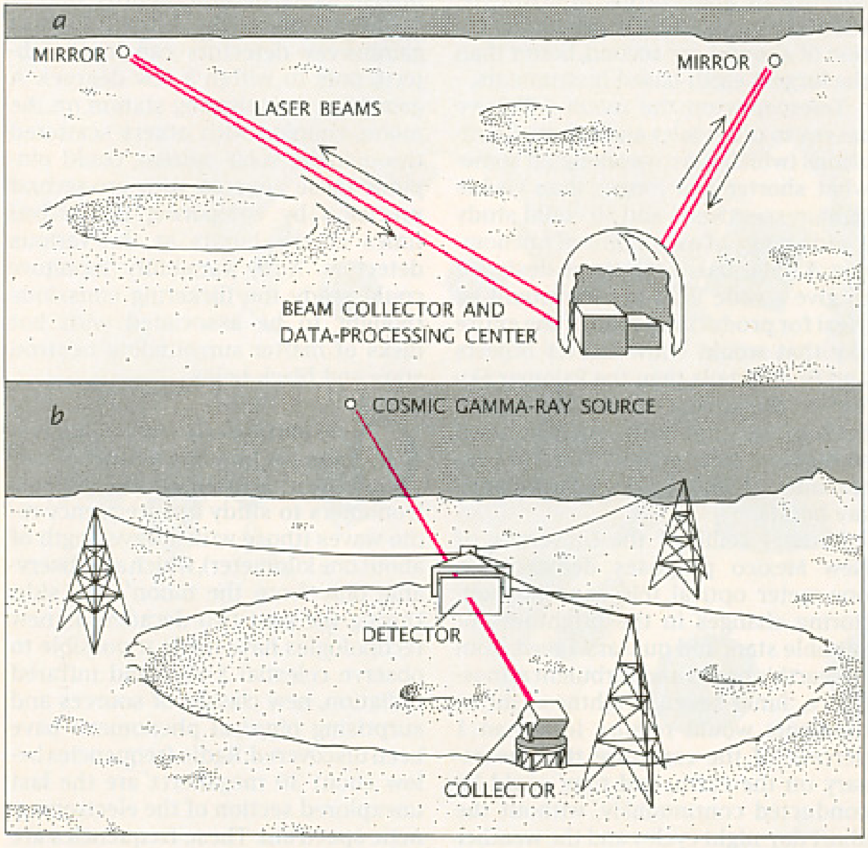
One particularly compelling reason for building a lunar observatory is that it would enable astronomers to study low-frequency radio waves (those with a wavelength of about one kilometer), which are observable only from the moon's far side. During the past two decades, as new technologies have made it possible to observe celestial X rays and infrared radiation, new classes of sources and surprising physical phenomena have been discovered. Radio frequencies below about 30 megahertz are the last unexplored section of the electromagnetic spectrum. These frequencies are inaccessible from the earth's surface because the upper atmosphere reflects the incoming radiation.

This tantalizing window on the cosmos could be opened by constructing the lunar Very Low Frequency Array

(VLFA), a concept proposed by James N. Douglas and Harlan J. Smith of the University of Texas at Austin in 1985 and developed by us. The VLFA would consist of about 200 dipole antennas, each resembling a television reception antenna about one meter in length. The antennas would be distributed in a circular pattern over a 20-kilometer-wide area and would be sensitive to frequencies between about 50 kilohertz and 30 megahertz. Groups of antennas would be electronically coordinated to "point" the array at different sources without physically moving the elements. Signals from each group would be relayed to a central location for correlation and calibration; the data could then be analyzed by computers on either the moon or the earth to reveal the surface brightness (and hence the structure) of the source producing the radiation.

Building the VLFA will pose several technological challenges. The array would be sited on the lunar far side, quite distant from any likely manned base, and so probably would be deployed remotely. Robotic vehicles will need to be designed; they must be able to traverse a 20-kilometer-wide area of varied terrain and place antennas at optimal locations. Because of the communications time delay either to the near side of the moon or to the earth (about three seconds to and from the earth), the vehicles will need to incorporate self-contained artificial-intelligence programs. Transmitting the data from each dipole to a central processing station will necessitate developing a sophisticated multiplexed radio or laser transmitter-receiver.

Once these challenges are overcome, VLFA can be expected to yield a scientific bonanza. Astronomers will be able to study the processes that accelerate high-energy particles in solar flares, making it possible to produce an early-warning system for energetic solar outbursts; this would complement the work of a one-meter optical solar monitor. Researchers will be able to study the flux of high-energy electrons in planetary magnetic fields, in supernova remnants, in pulsars and in extragalactic radio sources that are the sites of powerful but still poorly understood astrophysical processes. The VLFA will be able to probe the structure of the interplanetary and interstellar media. Finally, low-frequency observations will allow astronomers to glimpse the subtle low-energy processes that accompany the more visible behaviors of active galaxies and quasars.



ASTRONOMICAL FRONTIERS will be rolled back by lunar observatories. Gravity waves are thought to exist but have never been clearly detected. A laser distance-measuring facility (*a*) on the moon's highly stable surface will search for distortions that might arise from these elusive waves. Long-focal-length gamma-ray telescopes (*b*), possible on the airless moon, will view energetic processes in supernovas and distant galaxies with far greater sensitivity than existing instruments.

Pierre Bely of the Space Telescope Science Institute in Baltimore and Garth D. Illingworth of the Lick Observatory recently have outlined a concept for a 16-meter optical-infrared telescope on the moon. Such a telescope would be able to detect objects 40 times fainter than those accessible to the space telescope. The 16-meter-wide light-collecting mirror would be made up of several hexagonal segments, which would ease construction and assembly. The telescope would be supported by a simple, lightweight mount consisting of three pairs of legs; computer-controlled actuators in the legs would compensate for shifts in the telescope's foundation. J. Roger P. Angel of the University of Arizona has suggested that the telescope may be able to detect earthlike planets around other stars by searching for the characteristic emission signal of atmospheric ozone.

A far more ambitious project for optical astronomy would be to place a large optical interferometer on the moon. The eagerly anticipated *Hubble Space Telescope* will provide only a tenfold improvement in resolution as compared with ground-based telescopes. The telescope we propose, called the Lunar Optical-Ultraviolet-Infrared Synthesis Array (LOUISA) will improve on the resolution of the largest ground-based telescope by a factor of 100,000. Such an instrument could in principle resolve a dime on the earth from its vantage on the moon!

Bernard F. Burke of the Massachusetts Institute of Technology first proposed building an instrument of this kind; we envision LOUISA as a series of electronically linked optical telescopes placed in a circular array 10 kilometers wide. An optical interferometer of this kind cannot be built on the earth because of atmospheric turbulence and seismic motions of the earth's crust. In low earth orbit, the gravitational gradients over a 10-kilometer baseline would necessitate constant, highly sophisticated and expensive repositioning of each of the telescope elements.

In February, 1989, some 50 of the leading researchers in the field of optical interferometry gathered at a workshop at the University of New

Mexico and settled on a preliminary design for LOUISA. The array would consist of two concentric rings of telescopes with 1.5-meter-diameter mirrors. The outer ring would contain 33 telescopes and would be 10 kilometers in diameter; the inner ring would contain nine and be half a kilometer in diameter. Light collected by each telescope would be transmitted to a central station for processing and storage. LOUISA would observe a broad wavelength range from the ultraviolet (.1 micrometer) to the near infrared (one micrometer).

LOUISA is the most technically challenging of the telescopes being considered for construction on the lunar surface, but it potentially has the largest scientific payoff. With a resolution of about one hundred-thousandth of an arc second, LOUISA will open entirely new classes of problems for study. LOUISA will be capable of detecting possible earthlike planets orbiting nearby stars (and perhaps determining their atmospheric composition); this is the first step in ascertaining the feasibility of life elsewhere in our galaxy. In our own solar system, LOUISA could provide images of planets and asteroids with a level of detail exceeding even the views provided by the Voyager spacecraft. The surface features of stars could be viewed directly, thereby revealing the connection between activity on the sun and on other stars and making it possible to study subtle motions of stellar surfaces; these motions yield information about the stars' internal structures and provide clues to their evolution. Astronomers will be able to explore the dynamics of galactic nuclei, view disks of matter spiraling into black holes and neutron stars and probe the structures of disrupted galaxies. In the area of cosmology, LOUISA will measure the proper motion of quasars and reveal any unevenness in the expansion of the universe.

Other lunar telescopes that would offer vast improvements over current instruments have also been proposed. A moon-earth radio interferometer would extend the technique of interferometry to a baseline stretching from the earth to the moon, essentially creating a 384,000-kilometer-wide radio telescope. Such a device would have a resolution of about one hundred-thousandth of an arc second, at a frequency of 10 gigahertz.

Frank D. Drake of the University of California at Santa Cruz has proposed constructing a giant radio-dish antenna, perhaps 1,500 meters wide, in a lunar crater. An antenna this large could conduct high-sensitivity observations of radio emissions from neutral hydrogen in space; such observations may soon become impossible on the earth because of the increasing levels of human-generated interference. Paul Gorenstein of the Harvard-Smithsonian Center for Astrophysics has proposed constructing a clustered array of X-ray telescopes on the moon that would improve significantly on the resolution and sensitivity of the *Advanced X-ray Astrophysics Facility.*

The construction of an observatory on the moon also may help expand astronomy into the largely unexplored realms of gravity waves and neutrinos. Gravity waves are predicted by Einstein's theory of general relativity; the detection of gravity waves would provide important tests of his theory as well as of models of galaxy formation.

Gravity waves are believed to be generated by the collapse of the stellar core that occurs during a supernova explosion and possibly by exotic high-energy processes relating to so-called cosmic strings that may have formed in the early universe. The predicted intensity of these waves is so low that sensing them will likely require highly stable detectors more than 1,000 kilometers long. The moon's seismic steadiness and its large surface area make it an attractive location for a gravity-wave detector.

Neutrinos are extremely abundant and may in fact be the dominant form of matter in the universe. They may also hold the key to understanding the thermonuclear reactions in the sun, which do not seem to behave as predicted. Neutrinos are difficult to detect because they interact extremely weakly with matter. On the earth, observing neutrinos from astronomical sources is further complicated by the constant showers of high-energy particles (including neutrinos) that form when cosmic rays crash into the atmosphere. Michael Cherry and Kenneth Lande of the University of Pennsylvania have noted that the neutrino background on the moon is less than one thousandth that on the earth, making the moon a superior location for a neutrino detector.

Two recent reports, *Pioneering the Space Frontier* and *Leadership and America's Future in Space* (often referred to as the Sally Ride report), advocate the establishment of a permanent lunar base as one of several desirable goals for the U.S. space program. The reports recognize the great scientific and resource potential of the moon. Learning to live and work on an alien world relatively close to the earth is also an important prerequisite to embarking on more ambitious and challenging manned missions, such as those to Mars.

Sizable lunar construction projects such as VLFA, LOUISA and large radio dishes will undoubtedly stimulate major advances in facilities engineering. Moreover, a lunar observatory will promote integrated, collaborative efforts linking astronomy, physics and electro-optics, as well as various branches of engineering.

As the level of East-West tension eases, the U.S. will presumably spend a declining fraction of its gross national product on defense; yet the U.S. must maintain its technological readiness. Lunar astronomical facilities could help the U.S. create a clearly stated, coordinated long-range plan for technology development and application. A lunar base would also provide a prime opportunity for international cooperation.

Political and economic considerations offer solid reasons for the U.S. to choose a return to the moon as a high-priority goal for the 21st century. Even if a lunar base is established primarily for nonscientific reasons, its existence will make construction of lunar observatories relatively simple and inexpensive. By analogy, the Apollo missions may have been spurred by political motivations, but they nevertheless returned a wealth of scientific data. It is time to take advantage of the staggering astronomical potential that could result from a permanent return to the moon in the 21st century.

For ages humans have looked up at the moon and dreamed of reaching it. Soon we may find ourselves gazing up from the moon itself in order to explore the universe as never before.

FURTHER READING

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