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REPORT OF THE WORKING DESIGN GROUP

Chair: Stewart Johnson
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The engineerng study group in the LOUISA workshop was responsible for producing a preliminary general design for an optical synthetic aperture telescope on the Moon. This design is intended to be a test case for focusing continuing design studies. The scope of the design included consideration of the array geometry, individual telescopes, metrology, site attributes, and construction. However, no attempt was made to go into further depth in the design than to cover the essential characteristics of the instrument.

The starting point for the array design was the lunar optical array discussed by Burke (1985). His array geometry followed the design and correlation procedure of the 27-element Very Large Array (VLA) radio telescopes near Socorro, New Mexico

Assumptions

Agreeing on a common set of overall characteristics for the lunar synthetic aperture optical array was the first step taken by the design group. These were considered to be minimal assumptions to which the various possibilities of hardware implementation must adhere.

Spectral range: 0.1 to 1 micron
Largest array dimension: 10km
Operating modes: Snapshot and full synthesis

Other assumptions include a previously established lunar base, and unattended computer operation of the instrument. The pre-existence of a lunar base reduces the complexity of telescope construction. Knowledge acquired by lunar inhabitants during construction of the base will be appicable to construction of the observatory. Depending on the facilities located at the base, it may be possible to manufacture part of the instrument on the moon. Human interaction with the instrument is kept to a minimum by recommending only intermittent crew attendance. The maintenance crew can be technicians stationed at the base.

Proposed Array

The array configuration must support a considerable number of baselines to provide images of astronomical sources with minimal sidelobe levels, especially in a snapshot mode. The low rotation rate of the Moon, causing an extensive amount of time for full synthesis observations, makes the snapshot mode a very necessary requirement for the instrument. Hence, reasonable spatial frequency uv domain sampling must occur within an earth day.

Array Geometry

Two of the many possible geometries for the layout of the telescopes for the lunar array are a wye (Y) and a circle. Considerable experience has been gained with a wye by the VLA. In this configuration, an equal number of individual telescopes would be placed on each arm. Movement of portable telescopes can be done linearly along the arms. An advantage of the wye is the ease of extending the length of the baselines along each of three arms. In the VLA, control and data signals are communicated between each antenna and the central control building by way of millimeter wavelength guides buried along the arms. With the lunar telescope, this method of communciation is not feasible. Considerable complications arise in passing numerous free-space beams along the arms of the wye. As an alernative to this approach, we have chosen a circular geometry for the array configuration.

Placing optical telescopes in a circle simplifies communications between the telescopes and central control. This is especially important for metrology. The short wavelength of the optical signals places stringent requirements on the system for maintaining phase-stable paths between each telescope and central control. To measure a telescope position, three laser beams at three different wavelengths are beamed from control to the telescope. Mechanical aspects are simplified with the telescopes located circumferentially around the control center. Alternatively, beaming three lasers per telescope along the arm of a wye creates difficulties in reaching the outer telescopes without adding additional elements in the optical path to deviate the light around the inner telescope.

We recommend placing 33 telescopes on a so-called Cornwell reference circle 10 kilometers in diameter. The primary mirror of each telescope would be 1.5 m in diameter, giving a total array collecting area of 50 m^2. The Cornwell circle arrangement places the telescopes nonuniformly around a ring in such a way as to give relatively broad coverage of the UV plane. However, it doesn't give sufficient coverage for all astronomical objects. Additional coverage could be obtained by moving the 33 telescopes along radial paths to and from the central control building. But mechanical movement along radial paths involves an expensive transportation system, increases maintenance requirements, needs human interaction, and potentially raises a lot of lunar dust. Consequently, we rejected this approach. Instead, we would place the 33 telescopes on stationary pads and place another nine telescopes on stationary pads on an inner ring with a 500-m diameter. Besides eliminating tranportation problems, this approach offers another advantage. Infrared objects generally do not need the resolution of the full array. The inner nine telescopes, providing low resolution, would be constructed to operate efficiently throughout the entire wavelength range of 0.1 to 1 micron, while only a reduced set of the outer telescopes would operate efficiently at IR wavelengths. See Figure 1 in the Johnson and Wetzel paper at the end of Part IV of these proceedings for an artist's sketch of the proposed array configuration.

Individual Telescopes

At this time few requirements are specified for the individual telescopes. Each telescope would have an azimuth/elevation or spherical mount with nearly full sky coverage, and would have an imaging mirror (as opposed to light-gathering ability only). Spherical mounts offer advantages in movement when combined with the metrology system using three laser beams per telescope (Labeyrie, this volume). Spherical mounts avoid the rotation required at alt-az mounts so optical paths are simplified.

Other signal paths between central control and the individual telescopes will be for control and monitoring signals to and from the telescopes and for astronomical signal paths from the telescopes. The control and monitoring signals can be sent via radio, infrared, or optical paths. Astronomical signal paths will be optical.

Array Optics

Optics for the array consist of path delays and a correlator system. Signals from each telescope but one must be delayed on their paths to central control to equalize the path lengths from the arriving wavefront from the celestial source to the correlator. These delays must be adjustable

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to account for the change in projected path length as the telescopes track the source while the Moon rotates. The slow rotation of the Moon will simplify the control system for movement of the delays.

The delay can be a movable mirror that doubles the free-space light path back upon itself, thereby lengthening the path. Future technology may allow the light from a telescope to propagate through a variable optical fiber delay on its way to central control. Fiber delays would presumably contain fewer mechanical parts than the movable mirrors operating with free-space paths. A hybrid delay system for one telescope would contain various length sections for optical fibers switched in and out of the light path to form the course delay system. Fine tuning of delays would be accomplished with a movable mirror. This system provides a continuous delay while minimizing physical movement of the mirror.

Central Optics

Upon arrival from the telescopes to central control, the light beams after a correlator system in which all possible pairs of signals from the telescopes are correlated together. The detected correlator outputs, representing the visibility function, constitute the data which is Fourier transformed to get the high resolution image. This "central optics" systems may be quite complex. Each signal must be correlated with every other signal. For an N-telescope system, each signal must be divided into N-1 parts so that each of these parts can be correlated with its counterpart from every other telescope. In this design study, no specifications were selected for the central optics except that it must be designed for interchangeability with alternate instrument systems. Methods of doing spectroscopy and polarimetry were also not considered.

Metrology

The metrology system, as mentioned earlier, consists of three beams at three different wavelengths for each telescope traveling between the telescope and central control. Three positional coordinates can be determined from this. The system must maintain short-term stability of the instrument, while for long-term stability, an astronomic reference source will be observed simultaneously with the program source. To achieve high accuracy, the system must be able to acquire white-light fringes.

Control Systems

Two control systems are necessary to operate the instrument. One system for pointing and tracking the telescope will be tied into the metrology system. All errors need not be eliminated from this control system since errors determined by the metrology system can be accounted for mathematically. Another control system will control the delays and correlator system. This will be tied into the metrology also, since telescope location must be known to calculate the appropriate delay lengths for correlation. Control signals can propagate over light beams from central control to the telescopes, and feedback signals from the telescopes can also propagate over light beams. It may be possible to use the metrology beams to carry control information.

Power System Requirements

Power needs for the lunar optical UV/IR synthesis array (LOUISA) will probably be furnished by a combination of power sources including solar, radioisotope thermoelectric generators (RTGs), and reusable fuel cells. The 33 telescope units on the outer 10-km-diameter circle will each have power needs of about 100 to 500 watts which could be satisfied with a combination of solar and reusable (rechargeable) fuel cells. Batteries would suffer a substantial weight penalty if designed to function through the long lunar night (two Earth weeks). The inner circle 500-m in diameter with nine telescopes and the central station at the system hub can be powered by a linked power distribution system of solar, rechargeable fuel cells, and RTGs. Power needs for the central station with its computer, control system, thermal control, and communications data relay will be of the order of 1000 watts. Shielded power conditioning and control will be required to meet tolerances and operational needs for the range of temperatures and radiation environments at the site.

According to Sovie (private communication), four kinds of space power systems which are under development or in use are:

- Radioisotope thermoelectric generator (RTG)
- Photovoltaic (PV)
- Solar dynamic (SD)
- Nuclear space power systems (e.g., the SP-100)

The RTGs have operated in space in planetary exploration missions for up to 12 years. They generate about 4 watts per kilogram of mass and are usually limited to applications requiring no more than 500 watts but could be extended to 1 to 2 KWe with dynamic energy conversion. Photvoltaic power systems have flown extensively at power levels of a few KWe and below. When batteries are needed to store energy, as in LEO in times of darkness, specific power is 3 to 6 watts per kilogram of mass. SD power systems are still under development. They use a concentrator and a high temperature receiver to heat working fluid and also to heat a thermal energy storage material. The working fluid and the dynamic energy conservation system convert thermal energy to electricity with an efficiency of 20 to 30 percent. A radiator removes waste heat.

In the nuclear reactor space power systems (NRSPS), thermal energy from the reactor goes directly to a static or dynamic energy conversion system. A high temperature radiator removes waste heat. (See table 1.)

The NASA philosophy is that early lunar missions and initial outposts will be powered by advanced solar and/or RTG systems. Later the high capacity power at a lunar base will be provided by nuclear reactor power systems. The nuclear power plant will then run electrolysis units to provide liquid hydrogen and liquid oxygen for fuel cells. Surface transportation would be by vehicles powered by fuel cells. Vehicles powered in this manner will probably be used in constructing the LOUISA.

Photovoltaic solar power with NiH_2 battery energy storage is the state-of-the-art solar power system. Such a system would be prohibitive for use at an initial lunar base because of excessive weight for batteries for the long lunar night.

Advanced solar systems on the Moon will involve photovoltaic or dynamic solar power with reusable fuel cell (RFC) energy storage which reduces the weight penalty by a factor greater than four.

Table 1. Power Systems Characterization
(Specific Mass, kg/kWe)

Type	SOTA solar	Advanced solar	Nuclear					
Description	PV with NiH_2 battery energy storage	PV or dynamic with RFC energy storage	SP-100 with man-rated shield transported from Earth[1] and man-rated lunar surface materials[2] shield					
			Power level, kWe					
			100		500		2,000	
			Surface[2]	Earth[1]	Surface[2]	Earth[1]	Surface[2]	Earth[1]
*Lunar surface	33,000	740	40	119	24	41	12.5	18
*Mars surface	1,190	150	40	119	24	41	12.5	18

* - Specific Mass (kg/kWe)

LOUISA Engineering Test and Evaluation

The engineering test and evaluation of the entire LOUISA system will be a challenging task which must be preceded by technology development, tradeoff studies, component design, and prototype building. The 42 telescopes that compose the array are anticipated to be very similar in configuration to one another such that only about three prototype units will be built and tested as part of a verification system on Earth. Extensive tests of these three prototype units in thermal-vacuum chambers will be required to ascertain their capability to function and operate in vacuum and with variations of temperature comparable to lunar conditions. Tests will be required to ascertain ability to function through the long cold night and survive the high daytime thermal gradients from sunlight areas to shadowed zones.

Software validation and verification for the system will be an extremely important aspect of the development program for LOUISA. Checkout of software will be a very complex task with many different conditions and a complex hierarchy of possible responses in automatic, semiautomatic, and human-operated modes.

The LOUISA will require a substantial research and development effort to bring the elements to sufficient maturity of development for lunar applications. The optics, control systems, metrology, pointing and tracking, thermal control, and other subsystems, metrology, pointing and tracking, thermal control, and other subsystems of the LOUISA system must be integrated and proven to function without human intervention for long periods of time. This degree of autonomy for a complex LOUISA system probably can be achieved only through incorporation of advanced telepresence and artificial intelligence concepts.

Facilities

The lunar surface, with its temperature extremes (over 384°K to 100°K), vacuum, micrometeoroid impacts, and radiation environments, places constraints on the design of facilities for the LOUSIA.

The temperature variations day to night on the Moon dictate some aspects of engineering designs. Optical components and support structures should be of materials that have low coefficients of thermal expansion. Needed materials are becoming available with the development of graphite epoxies and metal matrix composite materials. These materials have high elastic moduli for desired stiffness and can be tailored for required low coefficients of thermal expansion.

The vacuum environment will lead to outgassing of organic materials, lubricants, and some coatings. Such outgassing and degradation must be anticipated and dealt with in material selection and engineering design. Outgassing can not only change the properties of outgassing materials in detrimental ways but can also lead to deposits that alter surface properties of sensitive optics and thermal control coatings.

Micrometeoroid impacts will cause pits to form and splatter ejected matter on exposed surfaces. Protection for optics to minimize damage will be required. For example, collimators can be used that restrict the number of degrees of sky to which the optics are exposed and reduce the probability of damage. The means to restore sensitive optics on the Moon should be developed to extend the life of the LOUISA system.

The radiation environments include ultraviolet, solar flare protons, and cosmic ray particles such as ion nuclei. Shielding for humans of the order of 2-2 1/2 m of regolith material will be required at the time of large solar flares. Electronics and computers will need shielding.

Lunar Surface Characteristics

The lunar surface layer is composed of fine-grained particles which, when disturbed, will travel in ballistic trajectories until they impact. The dust is not a problem unless it is disturbed by some mechanism such as vehicluar movement, rocket exhaust, or foot traffic. The dust tends to cling to any surface it impacts and thus can constitute a problem in altering surface reflectance.

Electrostatic charges on dust particles may cause particles to be displaced onto nearby objects. More needs to be learned of this phenomenology, particularly with respect to changes in charge as the terminator (boundary between day and night) passes. Vondrack (1974) has suggested the possibility of dust transport as a result of particle-charging which could lead to dust deposits on sensitive surfaces. This phenomenon could be investigated on precursor missions to the lunar surface. Evidence so far suggests that the dust problem is not severe and can be overcome with careful engineering and operations that restrict dust disturbances near the telescopes and other sensitive components. Elements will have to be protected while in transport.

At the Surveyor and Apollo sites, the lunar soil was noted to provide adequate bearing capacity and sheer strength for properly engineered observatory foundation elements (Mitchell 1974 and Carrier 1989). Apollo data show that the soil cohesion and angle of interval friction are 0.45 kPa and 40°, respectively, or greater (for 20 cm deep or greater by penetrometer tests). The upper few centimeters of soil are rather loose but at depth, the soil has a high relative density.

The lunar topography is characterized by large numbers of impact craters of sizes ranging to up to several kilometers in diameter and down to microcraters. Some leveling and surface preparation will be necessary for LOUISA to extend to its diameter of 10 km for the outer Cornwell circle and 500 m for the inner circle. Site selection can be made to reduce the amount of excavation, fill, and leveling required as better topographic information becomes available from lunar orbiting surface mappers. Sites favored are on the lunar far side just past the lunar limb so that earthshine is avoided at the telescope site. A site about 5° south of the lunar equator will facilitate observations of the Megallanic Clouds which are of interest to the community.

Soil sampling will be required to depth at the proposed LOUISA sites. In general, the soil relative density increases with depth and the soil tends to be less dense at the rims of relatively recent craters. A tradeoff study is desirable to determine the relative merit of performing more detailed soil engineering property investigations versus using a more robust foundation design suitable for the anticipated range of soil conditions. Soil conditions are the result of numerous and repeated meteoroid impacts which have "gardened" the soil to considerable depth and have made protuberances of competent bedrock highly unlikely. For the foundation design of each telescope of the array, it is anticipated that each of the 42 units of the array will have a mass of 500 km, including mirrors, mirror supports, and enclosures.

The telescope systems and other components that are to perform as a lunar optical ultraviolet infrared synthesis array must be capable of being set up and checked out on a terrestrial site. Such preflight testing is essential to aviod unwelcome surprises on the surface of the Moon.

At each lunar site, some dust stabilization will be desirable to facilitate deployment, calibration, checkout, and post-checkout maintenance. Dust stabilization may be by means of sintering using microwave processing. Foundation elements for the individual telescopes can be either shallow footings extended below the depth of diurnal thermal cycles (about 30 cm) or driven piles to greater depth. Tradeoff studies are needed to permit quanitification of the comparisons of these alternatives.

Technology Development

An extensive technology development program is required to make LOUISA a reality in the 21st Century. Tables 2-13 which follow present the significant technology development areas which need emphasis.

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TABLE 2. FACILITY/HARDWARE LIST

LUNAR FACILITY	33	1.5 M TELESCOPES - OUTER RING-VISIBLE/UV
	9	1.5 m TELESCOPES - INNER RING - UV/IR
	1	CENTRAL STATION
	1	50 M CALIBRATION TOWER
	2	SATELLITE COMMUNICATION SYSTEM
	2	LUNAR BASE COMMUNICATION SYSTEM
	2	LOCAL TRANSMITTING/COMMUNICATION SYSTEM
	1	SITE STORAGE FACILITY/WITH LANDING SITES
	1	MAN SAFE HAVEN
	41	DELAY-LINE SYSTEMS
	43	SOLAR ARRAY POWER STATIONS WITH BATTERIES (100 WATTS) (17-DAY CAPACITY)
LUNAR BASE	1	LTDRSS
	4	HABITAT/WORKSTATION
	4	LIFE SUPPORT SYSTEM
	AR	LOCAL SITE TRANSPORTATION - HUMAN/CARGO
	AR	TRANS EARTH TRANSPORTATION - HUMAN/CARGO
	2	LUNAR BASE COMMUNICATION SYSTEM
		TRANS EARTH COMMUNICATION SYSTEM
	1	EXCAVATION AND CONSTRUCTION SYSTEM
	1	TELEOPERATIONS CENTER
EARTH	2	PROOF OF CONCEPT TELESCOPE UNITS (IR/UV)
	1	PROOF OF CONCEPT CENTRAL STATION
	1	THERMAL/VACUUM FACILITY
LOUISA SCIENCE CENTER	1	TEST INSTRUMENTATION AND CONTROL HARDWARE/SOFTWARE
	1	IMAGE PROCESSING LAB
	1	DATA STORAGE/RETRIEVAL SYSTEM
	1	TRAINING FACILITY • OPERATIONAL MAINTENANCE • LUNAR ASSEMBLY
	1	EARTH-BASED COMMUNICATION CENTER
	1	EXCAVATION AND CONSTRUCTION DEVELOPMENT LAB
	1	MANUFACTURING DEVELOPMENT LAB

TABLE 3. TELESCOPE

SHELTER (HOUSING)
PRIMARY MIRROR SYSTEM
SECONDARY MIRROR SYSTEM
ACTIVE METROLOGY SYSTEM (LASER ALIGNMENT CONTROL)
ENVIRONMENTAL CONTROL SYSTEM
POINTING MEASUREMENT AND CONTROL SYSTEM
ALIGNMENT/SURVEY CONTROL SYSTEM
POWER DISTRIBUTION SYSTEM
ELECTRICAL POWER SYSTEM
CONTAMINATION CONTROL SYSTEM
TELESCOPE ASSEMBLY WITH BAFFLE
DATA MANAGEMENT SYSTEM
AUTONOMOUS/SELF-CONTAINED CHECK-OUT-HEALTH STATUS
TELESCOPE MOUNT/FOUNDATIONS/AUTO-LEVELING
COMMUNICATION SYSTEM
DELAY-LINE INTERFACE

TABLE 4. TECHNOLOGY DEVELOPMENT PLAN

OPTICS
SENSORS
ELECTRONICS
MECHANICS
STRUCTURES
CONTROLS SYSTEMS
CALIBRATION
SYSTEMS

TABLE 5. TECHNOLOGY DEVELOPMENT PLAN:
OPTICS

- LUNAR FREQUENCY STABILIZED, LONG, LIFE
    - SOLID STATE SPACE HARDENED DIODE LASER
    - MULTIPLE WAVELENGTH
- OPTICS CONTAMINATION
    - REFURBISHMENT OF OPTICS
    - OPTICAL MATERIALS/COATINGS
    - SHIELDING
- LIGHTWEIGHT MIRROR FABRICATION
    - SUBSTRATE
    - TESTING
    - SURFACING
    - COATINGS
- POLARIZATION
    - COATINGS/MATERIALS
- UV COATINGS FOR LOW POLARIZATION, HI REFLECTIVITY, HARD
- SHIELDING AND BAFFLING STUDIES
- DISPERSIVE AND NONDISPERSIVE SPECTROMETERS
- AREA-SOLID ANGLE PRODUCT - TRANSMITTANCE
- DIFFRACTION ANALYSIS AND DEVELOPMENT OF SOFTWARE OPTIMZATION TOOLS
- THERMAL BACKGROUND AND BAFFLE ANALYSIS
- ADAPTIVE OPTICS
- NEW CONCEPT IN MIRROR MATERIALS
    - FOAM CERAMIC GLASS
    - COMPOSITE MIRROR SUBSTRATES
    - REGOLITH MIRRORS
    - GASEOUS MIRRORS
- METROLOGY SYSTEM
- WHITE-LIGHT BEAM-RECOMBINATION

TABLE 6. TECHNOLOGY DEVELOPMENT PLAN: SENSORS

- RADIATION SHIELDING
- LIFETIME
- PHOTON-COUNTING AVALANCE DIODE ARRAY DESIGNS, DEVELOPMENT, AND CHARACTERIZATION

TABLE 7. TECHNOLOGY DEVELOPMENT PLAN: ELECTRONICS

- RADIATION HARDENING
- THERMAL MANAGEMENT
- NEURAL NETWORKS FOR PATTERN-RECOGNITION OF STARFIELDS AND WHITE-LIGHT FRINGE FINDERS
- PREAMPLIFIERS
- CONTROL OF ELECTROSTATICS
- GROUNDING PLANE
- HIGH TE-SUPERCONDUCTIVITY
- CORRELATION

TABLE 8. TECHNOLOGY DEVELOPMENT PLAN: MECHANICAL

- THERMAL SHIELDING
- MATERIALS CHANGE OF PROPERTIES BY RADIATION
    - ALUMINUM
    - COMPOSITES
- BEARINGS AND FLEXIBLE JOINTS ACCURATE AT 10^{-6} RADIANS/SECOND
- PHASE DELAY LINE
- MAGNETIC LEVITATION BEARINGS, LOW POWER, RELIABLE
- MECHANICAL PARTS FABRICATED FROM LUNAR SURFACE MATERIAL

TABLE 9. TECHNICAL DEVELOPMENT PLAN: STRUCTURES

- "OPTICAL" TRUSS
- REFERENCE TOWER

TABLE 10. TECHNICAL DEVELOPMENT PLAN: CONTROL SYSTEMS

- STAR AND FRINGE ACQUISITION SCENARIOS, POINTING AND TRACKING
- SYSTEM DRIFTS AND THEIR EFFECTS

TABLE 11. TECHNOLOGY DEVELOPMENT PLAN: CALIBRATION

- ANGLE ACCURACY - ASTROMETRY
- SURVEY-IN INSTRUMENT
- EARTH POINT-LASER
- UNRESOLVED STARS

TABLE 12. TECHNOLOGY DEVELOPMENT PLAN: SYSTEMS

STRAWMAN OPTO-MECHANICAL-ELECTRICAL DESIGN

- SEGMENTED OPTICS
- BASE LINE/APERTURE
- PHASE DELAY LINES/ FIBER OPTICS
- UV PLANE COVERAGE FOR INSTANT SHOT LATITUDE
- METROLOGY SYSTEM
- TELESCOPE MOUNT GEOMETRY
- POLARIZATION
- CALIBRATION AND VERIFICATION OF PERFORMANCE
- GRAVITATIONAL WAVES
- ASTROMETRIC REFERENCES
- BEAM RECOMBINATION
- OPTICS SPECTROMETERS DESIGN APPROACH
- AREA-SOLID ANGLE PRODUCT - TRANSMITTANCE
- THERMAL MANAGEMENT

PART VI

FINALE

Our workshop ended with a panel discussion and review of what we had learned and accomplished during the 3-day workshop. This section attempts to summarize the essence of the panel discussions and our general conclusions about LOUISA. H.J. Smith has provided astute comments on cost, cost-effectiveness, and the challenge of "selling" lunar observatories to our colleagues and the public. We then attempt to summarize the overall results of the workshop. Directions for future work are described in the final pages of these proceedings.

REMARKS AT CLOSING PANEL

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We've spent several days on technical questions concerning lunar interferometry. I'd now like to look at the topic in several broader contexts.

First is the question of cost. No matter how good the Moon is for astronomy of various kinds, it will be hard to justify the tens of billions of dollars needed for a substantial functioning Moon base solely or even primarily for astronomy. I suggest that we need to keep in mind and stress in our public statements that a number of factors support lunar base as the next step beyond Space Station. These include essential space experience, potential resources and commercial payoffs -- even tourism -- in addition to science. The decision to go for a Moon base will then lead to outstanding opportunities for astronomy, in particular for optical/IR interferometry.

Next is the problem of cost-effectiveness. Every astronomical facility considered for the Moon must also squarely face the competition from other possible sites or modes of operation. For interferometry, the possibilities include both ground- and space-based systems. Most of us appear to agree that, at least in the near future, orbiting systems have great promise for short baseline systems (up to tens, possibly someday hundreds, of meters). But we seriously question whether optical/IR baselines of kilometers and tens of kilometers will be very useful in space, primarily because of station-keeping and pointing problems, also the probably excessively high cost of the specialized free-flier elements of such a system. Ground-based optical/IR VLA's would seem to be ruled out almost prima facie because of atmospheric problems. However, when we recall that the real cost of a lunar optical/IR VLA is likely to be at least some billions of dollars, I suggest that a careful look be taken at what that amount of money could build on Earth, given a willingness to create substantial adaptive optics systems at the telescopes and tens of kilometers of vacuum tubes to interconnect them--a construction job vaguely on the scale of the Superconducting Supercollider. The Moon might well win on actual cost grounds, not to mention the sex appeal of the project and ability to go to UV wavelengths which will probably remain forever beyond the effective reach of ground-based systems, but the question should be examined.

Finally, there is the problem of getting the message to our colleagues and eventually to the necessary level of funding. Here I am reminded of the experience with Space Telescope (ST). The concept was an early one, floating around in conversations and stories. Lyman Spitzer began to give it reality in 1962 by forming an activist committee (supported, as I recall, by National Academy of Science funds) comprising seven of us, each from a different university. Over the next 3 or 4 years we held a number of meetings at different astronomical centers around the country to discuss and debate the issue, which was strongly questioned if not even attacked at first by some well respected but conservative astronomers. In time a sufficient consensus was built, and around 1967 the committee met to draft a small book which was published by the Academy and which presented the by-then well developed case for ST. All this activity was instrumental in giving the subject high prominence as the principal space initiative to be undertaken (funds permitting) in the definitive report Astronomy and Astrophysics for the 1970s (the Greenstein Report). Almost another decade was needed to get funding started, and more than a decade after that for flight, for a total of nearly 20 years after the first serious push was made. That same scale also feels about right for the lunar optical/IR VLA, in the sense that it may well take a decade or more for the idea to be developed and accepted, still another decade to develop enough lunar experience to be seriously able to design and contemplate building such an instrument there and, finally, another decade to construct it.

But what better time than the present to begin?

SUMMARY AND CONCLUSIONS

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A long baseline (1-100 km) Optical/UV/IR interferometer will produce the largest improvement in optical resolution since the original invention of the telescope. A 10-km baseline, for example, will have a resolution of 10 μarcsec in the middle of the optical band -->4,000 times better than the Hubble Space Telescope.

Short-baseline (<30-m) interferometers have resolutions modest enough that placement in low Earth orbit does not present insurmountable problems. However, for very long baseline arrays (kilometers), station-keeping of separate spacecraft is considered to be extremely difficult except possibly at L4/L5 or the surface of the Moon. If a permanent base in emplaced on the Moon, the lunar surface is the preferred location for such an interferometer. The Moon has a high degree of seismic stability and its orbital motion is precisely known. The Moon is also superior in terms of duration of total darkness (336 hrs), low level of debris, upgrade potential, and array maintenance.

LOUISA will allow astronomers to probe entirely new scales of structure in a variety of astronomical objects. For this reason, LOUISA may be the most scientifically exciting lunar telescope. For example, features on the surface of solar-type stars out to 1 kpc can be imaged, thus allowing the first detailed comparison with our Sun. With the resolving power of LOUISA, extra-solar planets, particularly Jupiter-class planets, can be resolved and mapped in nearby stellar systems. Accretion disks associated with compact objects could be viewed for the first time. Astronomers will be able to study the environmental factors that govern star and galaxy formation, particularly in the near-IR. Finally, LOUISA has the capability of placing strong constraints on the cosmological expansion of the universe.

The preliminary design for LOUISA consists of two concentric circular arrays. The outer array contains 33 telescopes distributed nonuniformly along a circle 10 km in diameter. The inner ring is made up of nine telescopes along a 0.5-km-diameter circle. Such a configuration produces a good instantaneous synthetic aperture (u-v coverage), and simplifies communication between elements, and does not require any movement of individual telescopes. Individual telescopes would be 1.5 m in diameter for a total collection area of 50 m^2, with possibly spherical mounts. Optics include delays and a correlator; the delay could consist of a movable mirror or variable-length optical fiber. Two central control systems are needed -- one for pointing and tracking, and the other for control of delays and the correlator.

Future Work

Further evaluation of space-based arrays for comparison with LOUISA is needed. In particular, studies of methods to steer long-baseline systems and control individual element positions are needed.

Substantial new technology development will be required for LOUISA. This is probably the most technically demanding of all the telescopes currently proposed for the lunar surface. In particular, detailed engineering studies of the optics, control systems, correlators, metrology (laser alignment control), pointing and tracking, thermal control, data management, and autonomous operation will be required.

Engineering tests and evaluation of components will be challenging. Individual telescopes will need to be evaluated in vacuum chambers to ascertain their functional capability in the lunar environment. Then, integration of the telescopes and correlators must be considered. This might best be accomplished on the lunar surface beginning with a simple two-element interferometer, then growing when technological barriers are overcome.

LOUISA must be capable of coping with the harsh lunar environment. The effects of dust, micrometeoroids, cosmic radiation, and structural degradation must be considered.

The power requirements are fairly substantial, about 25 kw of total electrical power will be needed during both lunar day and night. Generation and storage of this power at the LOUISA must be addressed.