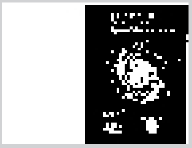

An International Discussion of Space Observatories: Report of a Conference Held at Williamsburg, Virginia, January 26-29, 1976

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An International Discussion of Space Observatories

Report of a Conference held at
Williamsburg, Virginia
January 26-29, 1976

Assembly of Mathematical and Physical Sciences
Space Science Board
National Research Council

NATIONAL ACADEMY of SCIENCES

EUROPEAN SCIENCE FOUNDATION

Notice by the National Academy of Sciences

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Notice by the European Science Foundation

Preparatory work for the conference in Williamsburg was started by the then provisional Space Science Advisory Board for Europe, set up by the Royal Society of London before October 1975, when this Board was formally transformed into the Space Science Committee of the European Science Foundation. After the conference, draft reports were considered by the ESF Space Science Committee and the ESF Astronomy Committee, and various remarks of these committees were taken into account. The publication of the report has been recommended by the chairmen of these two committees and by the President of the ESF.

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COVER: The spiral galaxy in *Canes Venatici*, Messier 51. (*Photo courtesy of Hale Observatories*)

PREFACE

This is a brief report of a discussion organized jointly by the Space Science Committee (SSC) of the European Science Foundation and the Space Science Board (SSB) of the National Academy of Sciences–National Research Council for the purpose of clarifying certain matters relating to permanent observatories in space, particularly the Large Space Telescope, that arise from international considerations.

The genesis of this discussion was a U.S. congressional suggestion that other nations (specifically the European Space Agency and European national space programs) should contribute to LST funding. In response, the National Aeronautics and Space Administration (NASA) instituted negotiations with the European Space Agency (ESA), the results of which have not yet been made public, but that probably involve both instrument construction and contributions to scientific operations.

This has been a government-to-government negotiation, and it has resulted in certain concerns among scientific communities on both sides of the Atlantic. We felt that the consultative structure established between the SSB and the SSC could be used to provide a foundation for coordinated advice from the science community to the several interested governments and agencies.

An example of a misunderstanding and its resolution through consultation is touched upon in the recommendation "Instruments for LST." ESA and NASA managements follow different traditions, including different approaches to instrument procurement. The associated scientific communities each understand their own systems but feel less comfortable with the other as a means of ensuring the best possible performance of the LST. The recommendation represents a compromise, avoiding unacceptable insistence on changes in management practices and yet affording alternative grounds for confidence that a good result will be achieved.

The U.S. and European astronomy communities are unequally prepared for a discussion of the LST, since the question of European involvement is of recent origin. The aim of our discussion was therefore modest: to establish a foundation of basic ideas upon which scientists could build, through NASA, ESA, and national governments.

The conference considered existing plans for the LST and its instruments as a basis for its judgments. It did not consider alternatives, partly because time did not permit and partly because the extensive work performed by NASA and its advisory groups appears to have been carried out well and responsibly. It also did not consider matters internal to U.S. or European space programs. There are, of course, many such matters, some of crucial importance to the future of space science, and they are frequently discussed in other publications of the Space Science Board.

The discussion addressed the following general considerations:

1. The extent to which the LST can be judged to be the most important advance presently in prospect for optical astronomy.
2. Access to space observatories by the best qualified individuals regardless of country of residence.
3. Questions stemming from multinational funding.
4. The logistics of the interface between the space observatory and the science community.
5. Preparedness of the community for new modes of operation associated with space observatories.

The Conclusions and Recommendations of this report record the conference views as to the general nature of the important questions and their solutions. The first item is a judgment of value fundamental to international cooperation at any level. Detailed work on the other items is already under way, principally under the aegis of a Space Science Board study of institutional arrangements for the LST to be carried out during the coming summer through a workshop chaired by Dr. Donald Hornig.

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Space Science Board
National Academy of Sciences

HARRIE MASSEY, *Chairman*
Space Science Committee
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1. INTRODUCTION

An international conference was held in Williamsburg, Virginia, January 26-29, 1976, under the auspices of the National Academy of Sciences (NAS) of the United States and the European Science Foundation (ESF) to discuss the scientific importance and use of planned space observatories. The meeting was organized jointly by the Space Science Board of the NAS and the Space Science and Astronomy Committees of the ESF and was conducted under the chairmanship of Sir Harrie Massey.

Although the conference covered all space observatories, the participants paid particular attention to the projected Large Space Telescope (LST) because of its exceptional significance for the future of astronomy. In so doing, the participants were fully aware of the close relation of the LST to ground-based optical astronomy. Indeed, when the LST is in operation, there will be a new generation of ground-based telescopes; these will conduct observations that will be necessary for, and complementary to, those of the LST, whose mission will be in those areas in which it alone can operate.

The conference considered the LST and its mission and then discussed aspects of its scientific use, including institutional questions and problems posed by data handling and scientific manpower. The participants then reached conclusions on the role of the LST within the broader framework of optical astronomy and made recommendations aimed at ensuring full scientific exploitation of this unique instrument. This report describes the basic information on which their discussions were based and lists their conclusions and recommendations.

The participants would like to thank the conference observers for the many valuable contributions they made.

The Administrator of the National Aeronautics and Space Administration, Dr. James C. Fletcher, and the Director-General of the European Space Agency, Mr. Roy Gibson, participated in an informal discussion of the conclusions and recommendations of the conference.

2. SCIENCE WITH THE LARGE SPACE TELESCOPE

The LST will have two astronomical capabilities that are unique: ultraviolet study of faint objects and high-resolution, diffraction-limited imagery. In addition, infrared and submillimeter detectors can cover a further three decades of wavelength, from 1 μm to 1 mm. Enthusiasm for the LST is widespread among astronomers, who see how these unique capabilities can be utilized to solve a variety of problems at the frontier of astronomy.

Of special interest are the capabilities of the LST for study of the evolution of galaxies and the universe. Despite the great advances in understanding of the birth, evolution, and death of stars on both the observational and theoretical fronts since the early 1950s, there has been very little increase in our basic understanding of the physics and evolution of galaxies. This applies even to the understanding of our own galaxy–e.g., of its chemical evolution and of the nature and origin of the activity in its central region or nucleus. We still do not know precisely the ratio of abundances of the two most important elements, hydrogen and helium, in the oldest stars of our galaxy. If we can determine this ratio, we will have important information about the origin and early history of the universe.

It should be possible to achieve a thorough understanding of the ways in which stars have formed in our galaxy over its lifetime of 10^{10} years, as well as an understanding of the history of the enrichment of our galaxy in elements heavier than hydrogen that resulted as stars exploded and spewed newly formed elements into interstellar space. By the time the sun condensed 5×10^9 years ago, enough heavy elements had been formed to provide the solid material that constitutes the solar system, including planet Earth, with its potentiality for life. How is this, and the presumed formation of other similar planetary systems elsewhere, integrated in the evolution of our galaxy as a whole?

In the following sections we shall outline some ways in which the LST will advance our knowledge on this broad front. We shall first discuss the problems of determining the distance scale of the universe, from nearby objects in our galaxy, through similar objects in the nearest neighboring galaxies, to those distance indicators that the LST will enable us to study out to 10 times the distance attainable today. We then outline ways in which the imaging and UV capabilities of the LST can be applied to achieve understanding of the evolutionary history of our nearest extragalactic neighbors. In the next section we discuss the classical cosmological problem of the expansion of the universe, its history and future development, and its origin. We then turn to a discussion of the results obtainable from the imaging and spectroscopy of distant galaxies. Finally, we turn to those galaxies that have activity in their nuclear regions vastly exceeding the modest activity in our own, and to the tantalizing problem of the quasars. Here we discuss some problems of current interest—quasars, black holes, and intergalactic matter. In this last field the relationship of optical astronomy with radio astronomy and high-energy astrophysics, particularly x-ray astronomy, reaches its greatest importance. Throughout this brief discussion of exciting problems, the necessity of full-scale support and backup observations using ground-based telescopes will be obvious.

Distance Scale of the Universe

Knowledge of the distance scale of the universe is fundamental to the study of extragalactic evolution and cosmology. This distance determination depends upon, and is only as good as, its starting point, the distances to nearby standard stars found from the parallax induced by the Earth's motion about the sun. The luminosities of these nearby stars can then be calibrated for use in determining distances to farther objects via the inverse-square law. Step by step, the luminosities of rarer and more luminous objects, such as Cepheid variable stars, must be calibrated for use in deducing distances to other galaxies.

The high-resolution capability, pointing stability, and long lifetime (at least 10 yr) of the LST are expected to give a tenfold increase in the accuracy with which relative star positions and hence parallaxes (and proper motions) can be measured. With the LST, the distance to the Hyades star cluster, about which there is still controversy, can be measured accurately, and hence the luminosities of its unevolved (main-sequence) stars found. These will form the basis for estimates of the distances to Population I stars (metal-rich, young stars), including the Cepheid variables. Enough distances to local unevolved stars of Extreme Population II (metal-poor, old stars) can be obtained to set up an accurate Population II main sequence, to which main sequences of globular clusters (the oldest stellar aggregates in our galaxy) can be fitted. The faint limiting magnitude of the LST, based upon the high contrast with the night sky, will allow study of the highly luminous stars (Cepheids, entire globular clusters, and unstable stars with luminosities 400,000 times that of the sun) far beyond the present distance limits. For example, Cepheids will be observed in the Virgo cluster, and the most luminous stars may be studied out as far as the Coma cluster. Thus, the combination of precision astrometry and faint limiting magnitude will permit a decisive advance in the accurate determination of distance to other galaxies.

Evolution in Nearby Galaxies

The galaxies that are members of our local group provide the best opportunity for studying the evolution and history of star formation and chemical enrichment outside our galaxy. The tenfold increase in spatial resolution of the LST will enable these studies to be carried to much fainter stars in richer star fields than is possible from the ground. For example, study of main-sequence or unevolved stars in our nearest neighbors, the Magellanic Clouds, will be possible, allowing insight into the history of star formation there. Did this star formation occur in bursts, as has recently been suggested, rather than at a steady, continuous rate? If so, why? What has been the chemical evolution in the Magellanic Clouds, and how has it differed from that in our galaxy? What is the underlying stratum of the oldest stars like? How do they relate to the oldest stars in our galaxy? Detailed comparison will be possible between the globular clusters in the Magellanic Clouds and those in our galaxy. In our own globular clusters, we shall be able to observe the white dwarfs that should be present in very large numbers if current stellar evolution theory is correct.

In other nearby galaxies, such as the Draco system, we shall be able to study in some detail the highly evolved stars, as well as stars only just approaching the red giant stage after leaving the main sequence. The Andromeda Nebula (M31) has many similarities to our galaxy, but some important differences as well. It is important to understand the differences observed in integrated light between the globular clusters in M31 and the metal-poor ones in our galaxy. Normal stars of both Populations I and II will be observable in the spiral arms and disk of M31 and also in the spiral galaxy M33. The LST will enable us to tackle the history of star formation and chemical evolution in these galaxies.

Classical Cosmology

Extension of the absolute distance scale 10 times farther out than is presently attainable means that we shall be able to attack with new precision the classical cosmological problem, first set out by Hubble, of defining and tracking back in time the expansion of the universe. The high resolution of the LST will provide this extension to greater distances. We can address such questions as: How fast is the expansion decelerating? Is this deceleration uniform in space and time? What is the mean density of matter in the universe that produces this deceleration? How is the matter distributed? What will be the fate of the universe—expansion forever or an eventual collapse into another "primordial fireball" followed by rebirth and eternal recycling?

Or we may turn to unorthodox questions: Is the "universal expansion" isotropic on both small and large scale, or neither? Is our present view of the universe too simple-minded, limited as it is by the scope of our mathematical ability, vision, and imagination and, above all, by our limited ground-based view of those immensely distant galaxies that form the raw material for cosmology? The LST may throw new light on these questions.

Chemical Evolution and the Morphology of Distant Galaxies

Because the most abundant elements have resonance lines in the uv, the uv capability of the LST for faint-object spectroscopy will permit observations of the most abundant heavy elements over the whole range from nearby to extremely distant galaxies. We therefore hope to be able to trace the origin of the elements back through time as we reach out to ever more distant galaxies.

Furthermore, the high-resolution capability of the LST will be essential for studying the forms of distant galaxies as they appeared long ago. Nearby galaxies include spirals like our own (containing stars and uncondensed matter arranged predominantly in spiral form, out of which new stars form), ellipticals (systems containing only stars, with no uncondensed material left) and irregulars (stars plus a considerable amount of uncondensed matter in irregular form). We cannot tell what forms the most distant detectable galaxies have, nor how these forms may evolve from one type to another. The high resolution of the LST will permit a hundred times as many picture elements in a galaxy image as can be obtained with a ground-based telescope, enabling spirals to be distinguished from ellipticals at great distances. The colors of the different types, including uv and infrared wavelengths, can then be related to the redshift and hence to the evolutionary state. By making such measurements on galaxies with redshifts as large as $z \approx 0.5$, at which point the ages are only half the present local value, and comparing these measurements with those of nearby galaxies, one may be able to see distinctive differences in color that would be decisive proof of the evolution of the universe and that would also give a quantitative handle on the rate of evolution of galaxies.

Active Nuclei of Galaxies and Quasars

In the past few years there has been an enormous increase in interest in the problem of the explosive activity in the nuclei of some galaxies. Much time on ground-based telescopes has been devoted to studying the quasars, those intriguing and puzzling objects whose large redshifts may make them the most distant objects in the universe. In spite of this attention, the nature of the quasars is still as mysterious as ever. They are faint and difficult to study in detail. Although plausible theories have been proposed for the source of their energy, including gravitational collapse into huge black holes, explosions of massive stars, and acceleration of particles by large numbers of pulsars, these theories are difficult to test because of current limitations of wavelength coverage and angular resolution.

The large redshifts of quasars have made it possible in many cases to study the far uv spectra from the ground: for quasars with $z \approx 2$, the Lyman α line appears at 3648 Å; for $z = 3$, the Lyman limit is easily visible. However, we are unable to put together the whole spectrum for any object, and we must do this to obtain a coherent picture of the similarities and differences between high- and low-redshift objects, possible differences in their chemical composition, and the like. The broad spectral coverage of the LST will make this possible. We would also be able to study with the LST the He I and He II resonance lines, and the He I ionization edge, in the highest-z quasars ($z = 3$ to 3.5), thus addressing the question of the origin of helium in the universe.

A particularly interesting problem concerns high-z quasars; they often have absorption lines in their spectra appearing at many different redshifts. These are probably produced by the ejection of blobs and filaments of gas from the central object at up to half the speed of light. Does this also happen in low-z objects? We shall know this only when we can look at the uv spectra of low-z objects from above the earth's atmosphere. How does this ejected matter interact with uncondensed intergalactic matter?

Or have the quasars themselves been ejected from galaxies, as some statistical studies suggest? What is the relationship between quasars and galaxies? Is there a real cutoff in redshifts of quasars, or do there exist large numbers of faint quasars that we could locate with the LST by uv and blue high-resolution imaging?

Study of the faint fuzz of light occasionally visible around quasars has been possible from the ground in two cases of low-redshift quasars, and it has been found that this light comes from hot gas. If we could observe in the uv, we could see whether these objects, like the high-redshift quasars, are ejecting gas at high speeds.

There is a definite similarity between the active nuclei of some galaxies, and the activity in quasars. The high-resolution spectroscopic capability of the LST will enable us to see what is happening, as regards both mass motions and the interaction between radiation and matter near the small active central nuclei of Seyfert and N-type galaxies.

In all these objects we are dealing with phenomena whose origin lies in the realm of high-energy astrophysics. At least one quasar is an x-ray source, as are the active nuclei of some galaxies, both quasars and active nuclei are radio sources, and often sources of a great deal of infrared energy. The ultimate energy source seems likely to be connected with gravitational energy release, and hence with pulsars and perhaps with black holes.

Conclusion

This outline of problems that one can presently envisage tackling with the LST is necessarily inadequate, because we cannot foresee what new turns astrophysics may take in the 8 years remaining before launch. Furthermore, we cannot foresee what new discoveries will be made when the first data are gathered with the LST. Astronomy and astrophysics have for several decades been the most challenging branch of physical science, just because discovery has outstripped theory. If this has happened with our limited, shuttered view of the universe from the cloud-bound earth's surface, what may happen when we first start using the LST? Perhaps our view of the universe will be drastically changed again.

3. THE LST SCIENTIFIC CONFIGURATION

The LST is planned as a long-lived orbiting astronomical observatory containing a 2.4-m Ritchey-Chretien telescope with a focal ratio of f/24. The on-axis image is virtually diffraction-limited at 6328 Å, where the full width at half maximum intensity is a little larger than 0.05 arc sec.

The guidance sensing system is housed in three of four radial bays located close behind the primary mirror and off the optical axis. Two methods of compensating for the off-axis astigmatism in the guide stars have been proposed to provide a pointing stability of 0.007 arc sec rms.

The fourth radial bay houses the Focal Plane Camera, an instrument of the highest priority. An on-axis flat mirror directs a 3-arc-min-square portion of the f/24 image to this camera. The only detector expected to be available is the 50 × 50-mm SEC Vidicon, which has 2,000 × 2,000 picture elements (pixels), each 25 × 25 μm in size, corresponding to 0.09 arc sec square. The S-20 photocathode of the SEC Vidicon will allow imagery from 1200 Å to 6000 Å.

The Focal Plane Camera is designed to image the brighter parts of galaxies in one orbital night, i.e., in half an hour. A single exposure will reveal 26th-magnitude stars. Reaching the sky background will require the "stacking" of ten or more individual images by ground processing. A key feature of the Focal Plane Camera is its ability to image a portion of the sky at the same time any other scientific instrument on the LST is operating. This "serendipity mode" will produce a collection of high-resolution images that are expected to reveal very distant clusters of galaxies, as well as unsuspected objects in the ultraviolet.

The other scientific instruments are contained in four modular axial bays on the optical and geometric axis of the telescope. Foremost among these instruments are the Faint Object Spectrograph (FOS) and the Faint Object Camera (FOC). The FOS is characterized by resolving powers of $\lambda/\Delta\lambda = 10^2$ and 10^3 over the wavelength range 1200 Å to 8000 Å. In addition, the design can incorporate a higher resolution mode ($\lambda/\Delta\lambda = 10^4$). When coupled to a photon-counting detector, the FOS will be able to obtain the stigmatic spectrum of a 25th-magnitude star ($\lambda/\Delta\lambda = 10^2$) in a 10-hour exposure with a signal-to-noise ratio of about 10.

The FOC will have two modes of operation at focal ratios of f/48 and f/96.

Operated at f/96, it is designed to retain the full resolving power of the telescope. For a detector field of 500 × 500 pixels, the corresponding field of view is small (11 arc sec square). A 10-hour cumulative exposure with a photon-counting detector will yield 10 percent photometry on a 28th magnitude star in a 1000-Å band pass. The recommended photocathode response is S-20.

The other high-priority instruments being considered for the two remaining axial bays are the Planetary Camera and the IR Photometer. The latter covers the spectrum from 1 to 1000 μm with a resolving power of about $\lambda/\Delta\lambda = 10$, obtained by a series of filters. A Si:As or Si:P photoconductor covers the spectrum from 1 to 30 μm, while the longer wavelengths are reached by the use of a bolometer. Much of the IR Photometer is cooled to liquid helium temperatures by a dewar designed to last at least a year in orbit. The IR Photometer is diffraction-limited at all wavelengths.

The Planetary Camera is a 400 × 400 pixel unintensified analog camera with a silicon photometric response. When operated at f/96, its field of view is 9 arc sec square, which is adequate to obtain images of Uranus and Neptune with signal-to-noise ratios in excess of 100. When operated at f/24, the Planetary Camera is capable of imaging highly red-shifted galaxies ($z < 1$) in one orbital night.

Finally, astrometric observations can be readily performed using the fine guidance system.

4. EXPERIENCE WITH NATIONAL AND INTERNATIONAL OBSERVATORIES

The conference was concerned with the institutional arrangements that will be a key factor in ensuring the success of space observatories such as the LST. The concept of institutes or consortia, where research scientists provide an effective interface between large scientific facilities and the user community, has proven effective. Experience at ground-based observatories and in space activities has demonstrated the importance of involving users in the planning of observatories, the allocation of observing time, the planning of operations, and the reduction and distribution of data.

The European Southern Observatory (ESO) in Chile is operated by a consortium, sponsored by the governments of six European countries. The staff includes scientists who assist guest investigators in using the instruments and who also carry out their own research programs.

The Kitt Peak National Observatory (KPNO) and the Cerro Tololo Inter-American Observatory (CTIO) have been successfully managed by the Association of Universities for Research in Astronomy, Inc. (AURA), consisting of 12 universities under contract with the National Science Foundation. The professional staff of these observatories uses about 40 percent of the observing time, and a guest-investigator program, involving scientists from several countries, accounts for the remaining 60 percent of the observing time.

The Royal Greenwich Observatory has had considerable experience with the management problems of operating several instruments at different locations.

The National Radio Astronomy Observatory (NRAO) is funded by the National Science Foundation under a management contract with Associated Universities, Inc. (AUI), a consortium of 10 universities originally established to operate the Brookhaven National Laboratory. One of the oldest organizations for managing large scientific facilities, AUI has built up a great deal of experience in operational matters. The NRAO staff ensures the best possible use of the facilities both by visiting astronomers and by their own research. The observatory facilities are available to any qualified scientist or graduate student; visitors are assigned approximately 60 percent of the observing time. Similar experience of staff interactions with users and similar observing allocations were reported with the Bonn Radio Telescope in Germany and with the Westerbork Array in the Netherlands.

The Orbiting Astronomical Observatory (OAO) series of spacecraft has provided another example of an international guest investigator program. OAO-3 (Copernicus) has been used by 43 U.S. scientific groups and 19 foreign scientific groups. The principal investigators at Princeton University review proposals from guest investigators, instruct users on the instrumentation, and provide help with managing the data received at the Mission Control Center at Goddard Space Flight Center, as well as maintaining their own research program.

The International Ultraviolet Explorer (IUE) is an international observatory to be launched in late 1977. The construction of the spacecraft and instruments involves contributions from the U.S. and from Europe. Data will be received at two ground stations: Goddard Space Flight Center and a station near Madrid. There are no principal investigators: all observations will be made by guests, on a proposal basis.

The Lunar Science Institute, located near the Johnson Space Center in Houston, Texas, is operated by the Universities Space Research Association (USRA), a consortium of 45 North American universities, and serves as an interface between the academic community and the NASA center that is responsible for the lunar program and the data resulting from it. USRA also operates the Institute for Computer Applications in Science and Engineering (ICASE).

There is currently a proposal by a group of x-ray astronomers before NASA for the establishment of an x-ray science institute. This institute, responsible for the operation of x-ray observatories in space, could be associated with an existing consortium.

NASA is presently studying the creation of an institute to manage the LST. Although plans are not yet complete, a science institute (either an existing consortium or a new corporation), under contract to NASA, manned by private research scientists, that would involve users in the operation of the LST, has ample precedent. The institute would be responsible for the scientific planning, operations, and data reduction and distribution.

5. LST DATA HANDLING

The conference considered the magnitude of the LST data flow as presently estimated. While not large compared with that of current earth resources projects, it is large enough to require careful consideration of data handling and distribution procedures.

The conference was not able to consider in detail the ways in which the various LST instruments will generate data; such a consideration must be based on a detailed study of various typical missions. These conclusions are based, therefore, on quite elementary estimates of the data-generation rate.

Data Generation

In its first flight the LST will be able to generate data from five instruments, and there will be additional positional and housekeeping data. Of the five instruments, the data rate from the SEC Vidicon (if it is selected for use) of the Focal Plane Camera (FPC) will dominate and therefore is the only necessary consideration here.

The FPC pictures will be made up of 2000×2000 pixels, the intensity of each being digitized as a 12-bit number and read out twice to minimize errors. In each earth day some 20 pictures of 10^8 bits each will be transmitted, giving a total of 2×10^9 bits per day.

Data Transmission

No great difficulties should be encountered in returning data from the LST. Data rates of a few megabits per second will be easily handled by the proposed Tracking Data Relay Satellite System (TDRSS) or by the existing STADAN net.

Data Storage on the Ground

It seems probable that users will wish to store all their raw data for many months; therefore, considerable data-storage capacity on the ground will be necessary. One day's worth of SEC Vidicon data would require something like 10,000 ft of 9-track 1600 BPI tape. Undoubtedly, higher-density packing will be available in the mid-1980s, and the extent of increase in density will determine the physical storage requirements. In later stages of the LST project, users may find it possible to overlay successive pictures in the spacecraft or otherwise to reduce the data volume in orbit, further reducing the ground storage needs.

Data Manipulation

It is in this area that the need for detailed information is greatest. "Manipulation" includes everything from simple linearization, calibration, and overlaying of a few tens of pictures to the full treatment recent planetary pictures have received at the Jet Propulsion Laboratory.

A certain first requirement will be for quick-look pictures. At its simplest this might involve picture linearization, calibration, and distortion removal. It is not a difficult task, and an IBM 360-50 would not be overloaded in keeping up with the LST output.

Further analysis of data-handling procedures requires detailed study, but it is clear that a system for the transmission of data to experimenters over terminals will be required, so that the data can be analyzed further on a variety of devices.

Conclusions

- The data-transmission rates to be generated by the LST are already well within the capabilities of existing systems.
- The provision of quick-look pictures that have been linearized, calibrated, and freed from distortion will be well within the capability of a large computer.
- The storage of raw data in archives over months or years may require special provision, depending somewhat upon technical developments over the next few years.
- The magnitude of the full data-manipulation task requires detailed study to establish the level of manpower and equipment that will be required at an LST science institute and at the users' own institutions.

6. CONCLUSIONS AND RECOMMENDATIONS

The Role of the LST in Astronomy

The unique quality of the LST is its ability to concentrate light from a point source falling on a large aperture into an image approximately 0.1 arc sec across, together with the wide spectral range over which this can be achieved. This ability will lead to dramatic improvements in the limits of observation in many fields of astronomy, including planetary, galactic, and extragalactic studies, and particularly in studies of the faint objects of interest in cosmology and in the evolution of galaxies. These improvements are attainable only in telescopes operating outside the earth's atmosphere.

The capabilities of the LST therefore represent an improvement in astronomical technique, of a magnitude and importance that are unique in optical astronomy because the LST will operate beyond the atmosphere that imposes limitations on the sensitivity and resolution of ground-based telescopes.

Instruments for the LST

Every effort should be made to ensure that the focal-place equipment of the LST fully exploits the capabilities of the telescope. This requires wide-band and narrow-band instrumentation for the ultraviolet, optical, and infrared ranges. An advisory committee, appointed by NAS and ESF, should review, before final selection, the design of the focal-place instruments to ensure the choice of the best equipment.

To enable existing and future scientific teams to make the best use of the instrument complex, fully updated information and documentation of all instruments must be available through the European Space Agency and NASA at all times.

Institutional Arrangements for the LST

A scientific organization, one form of which could be a science institute, will be needed to carry out vital tasks in the operation of the LST. If international cost-sharing is involved, such an institute should have international participation at all levels. Its tasks would include planning and scheduling of observing programs in conjunction with an international program committee, interfacing between instrumentation and guest observers, and data reduction. The scientific staff would have two main tasks: first, helping guest investigators use the LST instruments; and second, carrying out their own astronomical research. The international character of the organization should also be relevant to its location.

Allocation of Observing Time

The prime consideration in the allocation of observing time on the various instruments of the LST must be the scientific merit of the proposals. We recognize that other considerations, such as the material contributions that may be made to the LST project by countries other than the United States, may affect the methods by which the allocations will be made.

Scientific Data and Manpower

The optimal use of the LST and other space observatories involves a large flow of data. The demands that this will place on the scientific community are not yet fully understood. Similar problems have arisen in the past, but they are not in themselves sufficient reason for failing to proceed with the LST; nevertheless, we recommend that a study be made of the problem of handling the flow of data from the various modes of operation, including the processes of data distribution and the requirements for manpower in data handling and scientific analysis.