Institutional Arrangements for the Space Telescope

Report of a Study
at Woods Hole, Massachusetts
July 19-30, 1976

sponsored by the
Space Science Board
for the
Assembly of Mathematical and Physical Sciences
The National Research Council

NATIONAL ACADEMY OF SCIENCES
1976

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

PREFACE

Since the early days of the space program, it has been recognized that one of its major scientific contributions would come through telescopes placed in orbit outside of the degrading effects of the earth's atmosphere. In the succeeding years, NASA has carried through a number of highly successful programs, including the Orbiting Astronomical Observatories and the Small Astronomy Satellites, which have taken increasing advantage of the possibilities made available through space astronomy.

All of these programs, as well as the program of planetary observation and exploration, have posed the problem of achieving an interface between NASA, which is itself a complex organization involving close cooperation among headquarters, various centers and industrial contractors, and appropriate segments of the scientific community. Since the missions to date have had reasonably specific goals, to be achieved within limited periods of time, this interface has generally been achieved by *ad hoc* arrangements appropriate to the specific mission. By and large this has involved the designation of a principal investigator (PI) who is responsible for the scientific conduct of the mission and whose precise mode of operation is spelled out in a contract between NASA and the PI's institution. It is then the responsibility of the principal investigator to involve other scientists—through a guest investigator program, for example.

When the Space Telescope (ST) is considered, the questions involved in integrating the efforts of NASA with those of the worldwide astronomical community are much more complex. Within NASA the ST program involves the Marshall Space Flight Center, the Goddard Space Flight Center, NASA Headquarters, and the NASA worldwide communications and tracking network. The satellite will be a general-purpose facility, an observatory from which observations can be carried out simultaneously by at least four different investigators. It is hoped that the satellite will have a long life (10 to 20 years), so that its equipment can be upgraded from time to time and occasionally replaced by a new generation of instruments, utilizing the Space Shuttle either to effect the repairs or to bring the observatory back to earth for more extensive refurbishing. Moreover, it is expected that the investigations conducted on the ST will be at the frontier of astronomical research, with respect to both planetary and galactic astronomy, so that it will have an important part in shaping the evolution of astronomical knowledge.

Finally, the ST digital data will be returned at a higher rate than were the data from previous telescopes; ST observations will involve an intimate interaction between scientific investigators and the NASA control and communications organization.

Recognizing both the initial cost and the continuing operating costs of the ST, NASA is anxious to achieve the greatest possible scientific return. With this in mind, the Office of Space Science requested the National Academy of Sciences to undertake a study of possible institutional arrangements for the scientific use of the ST. The study was undertaken by the Space Science Board under the aegis of the Assembly of Mathematical and Physical Sciences. The charge given to the study group by the Assembly is presented as Appendix I. All of the items in the charge were considered by the study group, but with respect to some points no conclusions were reached.

The basic question posed concerned "the general principles applicable to those ground-based facilities that may be needed to provide the interface between large space observatories and the scientific user community internal to and external to NASA, including relevant communities outside the U.S." More specific questions related to the need for and functions of a Space Telescope Science Institute, the auspices under which the Institute should function and the structure of its policy-making mechanism, and the considerations that govern the location of the Institute.

The study group included astronomers who have previously been involved in space experiments and other astronomers who have done all of their work from ground-based observatories. Some of the group's members have been connected with national facilities in other fields of science, and others have extensive experience in the transmission and processing of digital data.

The work of the study group was carried out in two sessions. At a three-day meeting in Washington, including a full day at the Goddard Space Flight Center, the group was briefed regarding the plans for the ST program, the consideration of its organization by members of the NASA staff, experiences with related satellite missions, and considerations arising from the experience at existing scientific institutions.* Subsequently, the group met for two weeks of discussion at Woods Hole, Massachusetts. Despite the variety of backgrounds of the members, the group arrived at a consensus regarding the conclusions of this report. The report has been reviewed and concurred in as a whole by all members of the study group, but no effort has been made to secure unanimity regarding every detail of the presentation. For the details the Chairman assumes responsibility.

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CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are offered as a summary of this report; amplifying and supporting statements are contained in the main body of the report.

1. Because of the increase in resolving power, greater ability to detect faint objects, and ability to make observations in spectral regions in which the earth's atmosphere is opaque, the probability is high that the Space Telescope (ST) will lead to important discoveries.

2. The productive use of the ST depends upon the safe, reliable operation and maintenance of the spacecraft and its associated communications and data-processing systems, and upon the quality of the astronomical research which is conducted with it.

3. Whereas the operation of the ST and its associated systems is best carried out by NASA, optimum scientific use of the ST requires the participation of the astronomical community.

4. An institutional arrangement, which we call the Space Telescope Science Institute (STSI), is needed to provide the long-term guidance and support for the scientific effort, to provide a mechanism for engaging the participation of astronomers throughout the world, and to provide a means for the dissemination and utilization of the data derived from the ST.

5. We recommend that the STSI be operated by a broad-based consortium of universities and non-profit institutions. The consortium could be developed from an existing consortium or a combination of existing consortia, or a new one could be created for this purpose. The consortium would operate the Institute under a contract with NASA.

6. We recommend that the policies of the STSI be set by a policy board of about ten people representing the public interest, as well as the astronomical community and the broader scientific community. The quality and independence of the policy board is essential to the success of this enterprise.

7. The Institute should have a director and staff of the highest professional stature.

8. The Institute should be of sufficient size, in facilities and staff, to carry out its functions, but should not become so large as to absorb an inordinate fraction of the resources devoted to astronomical research. The Institute we

envision would be comparable in budget and manpower to other national astronomical facilities.

9. A productive institute requires suitable facilities and a first-rate central staff which, through its own involvement in research with the ST, will ensure the optimum use of the telescope by monitoring and improving the technical performance of the ST and by assisting visiting scientists in making observations and in processing data.

10. We believe the Institute should develop its own engineering and instrumentation facilities at a level which permits the staff to participate, along with NASA centers and others, in generating new capabilities for the ST. Unless it is thus involved in advancing the state of the art, it will be difficult for the Institute to recruit and keep a professional staff of the requisite quality.

11. By means of an extended staff and decentralization of some of its functions, the Institute should ensure broad, intimate, and responsible involvement of the astronomical community.

12. The Institute must be responsible for the scientific direction of the ST and should be involved in the provision of modified and second-generation instrumentation.

13. In order to make the best use of scarce and valuable observing time, the astronomical community should be involved through the Institute in the evaluation of experiments and the allocation of time on the telescope.

14. We suggest that initially a portion of the observing time on the ST be allocated to the Institute for two reasons: to assist in recruiting a Director and staff of the highest quality, and to permit the staff to become acquainted rapidly with the possibilities and limitations of the ST and its associated systems.

15. The Institute does not need to duplicate the full image-correction capability at the Goddard Space Flight Center (GSFC), which requires a very large computer, nor need it have access to a high-capacity land line.

16. For scientific interpretation of data, the Institute needs moderate-scale computational facilities which can be linked to remote minicomputers at perhaps ten centers in the country.

17. The Institute should coordinate the development of software that can be used at remote sites to reduce and interpret data derived from the ST.

18. We recommend that arrangements be made for close liaison with appropriate NASA organizations. In particular, we recommend that the principal responsibility for liaison with the NASA Project Manager rest with a senior staff member of the Institute and that representatives of the Institute be resident in the Mission Operations Center at GSFC.

19. We recommend that arrangements be made for international participation in the Institute, including its policy-making bodies.

20. It would be advantageous to the Institute if its basic funding could be

supplemented with private funds to provide discretionary resources. This might be achieved through an initiation fee and annual dues from members of the consortium. However, to provide long-term stability for the Institute, we believe it important eventually to raise an endowment from foundations and individuals.

21. We recommend that the Institute be favorably located for recruiting a high-caliber staff. We believe this requires proximity to a first-rate scientific center, availability of good schools and housing, and a stimulating environment.

22. We recommend that the Institute be located so that land, buildings, shops, and engineering facilities are available on a scale that will meet the initial needs of the Institute.

23. We recommend that the Institute be located where it has easy access to a major international airport.

24. We have not found any compelling data-handling, managerial, or cost reasons for locating the Institute at an existing NASA center.

25. Special arrangements should be developed to ensure ready access by the Institute to large, ground-based telescopes that may be needed to support the operation of the Space Telescope.

26. Although the model of an institute we have proposed may be applicable to other space-based astronomy projects, we have not addressed the question of their possible inclusion in the STSI.

27. The selection of a consortium and the search for a site should be initiated in the near future.

I INTRODUCTION

Much of the increase in astronomical knowledge in the twentieth century has come from a succession of large reflecting telescopes built at mountain-top sites chosen for their atmospheric clarity and steadiness. These telescopes will continue to provide essential data on a wide range of astronomical problems for decades to come. The optical performance of these telescopes, however, is limited by the blurring effect of the earth's atmosphere, and therefore falls short of the performance of which each instrument would be capable if the atmosphere were not a factor. Moreover, observations are limited to narrow spectral regions in which the atmosphere is transparent.

Since the beginning of the space program in 1958, it has been the desire of astronomers to place into earth orbit a large optical telescope to open up the inaccessible parts of the spectrum, to avoid the effects of atmospheric blurring, and to extend observations to fainter objects. Several smaller telescopes—up to about 1 meter in aperture—have been orbited by NASA and have achieved the improvements in performance that were expected.

The development of the Space Shuttle by NASA will make possible the deployment into orbit of a telescope of size comparable to that of the major present-day ground-based instruments. A specific proposal for an early (1983) Shuttle payload is the Space Telescope (ST), a 2.4-meter (94-inch) aperture instrument designed to be carried into orbit in the Space Shuttle bay, to be deployed by the Shuttle's manipulator system, escorted for a few days for checkout and test, and left in orbit for remote operation from the ground. The telescope can be maintained, and failed components can be replaced by periodic Shuttle visits as necessary. Major repair or refurbishment would be made possible by using the Shuttle to retrieve the telescope and return it to earth. The Space Telescope will be the first true astronomical observatory in space.

The ST will possess three unique advantages:

1) The absence of atmospheric blurring will make possible images ten times sharper than those obtainable from the ground under average conditions even at outstanding sites;

2) The diffuse light of the night sky, which interferes with astronomical

observations, will be reduced by a substantial factor because of the absence of atmospheric emission; and,

3) The absence of atmospheric absorption will make possible observations at wavelengths from 1000 Å (in the ultraviolet) to 1000 microns (in the infrared).

The sharper images produced by the ST will permit the study of extended objects such as emission nebulae at distances ten times the present limit, increasing 1000-fold the volume of space around our galaxy in which these objects can be observed. In association with the darker night sky available to ST, the sharper images of point-like objects such as stars will permit observation of such objects which are up to 100 times fainter and ten times more distant than can be seen from the ground under average conditions. Extension of observations into the ultraviolet region, where most of the chemical elements have their characteristic spectral signatures, will permit analysis of objects that are hotter than those studied from the ground at optical wavelengths. Similarly, extension into the infrared region, where most molecules have their signatures, will permit analysis of much cooler objects, such as planets and interstellar clouds.

The implications of these increased capabilities are important for the study of all astronomical objects, including quasars, pulsars, exploding galaxies and X-ray sources, as well as the better-understood objects such as planets, stars, and galaxies.

The problems of contemporary astronomy are currently under simultaneous attack by the methods of γ-ray, X-ray, ultraviolet, optical, infrared, and radio astronomy. The ST is an essential part of this concerted effort to understand the nature of the universe. In our view, the scientific objectives of the ST are among the most worthwhile undertakings of twentieth century civilization.

The Need for Special Institutional Arrangements

The ST will possess unique capabilities which can contribute greatly to the solution of frontier problems in astronomy. It is also unique because it is envisioned as an evolving orbiting observatory of indefinite lifetime.

The scientific goal of the ST is to obtain new knowledge and understanding of the nature of the universe. The scientific success of the ST project will be determined by the total new knowledge and understanding that flows from it, directly and indirectly.

The task addressed by this study is to find an institutional arrangement for the scientific operation of the ST that is most likely to permit the achievement of this goal with reasonable resources.

In order to achieve the goal, the study group believes that four conditions must hold:

1) Responsibility for the scientific component of the ST must be placed in a special, highly visible organization with a status commensurate with its importance to the productivity of the telescope.

2) There must be participation by the broad astronomical community in the use of the ST and in the analysis of the data it produces.

3) There must be a full-time staff of astronomers who make use of the ST in their own research.

4) There must be a strong and continuing interaction between the astronomical staff and the ST operating organization within NASA. These conditions are based upon the following considerations, which are amplified in this report.

The ultimate success of the ST depends equally upon the proper operation of the spacecraft and its associated systems over a long time, and on its optimal scientific utilization. Since a major share of the funds and people are devoted to the construction, maintenance, and operation of the spacecraft and related systems, most of the continuing attention of NASA at various levels can naturally be expected to be devoted to its operation, unless steps are taken to put the scientific component in a special, highly visible organization with a status commensurate with its importance to the productivity of the ST.

As we have said, the ST will open a new domain of spatial resolution and limiting brightness, extending the frontiers of research beyond the capabilities of ground-based telescopes. An instrument of such power and potential for providing new views of the universe should engage the efforts of some of the best astronomers in the country.

Complementarity and mutual support in instrumentation and research will exist between programs pursued with the ST and by ground-based observatories. A close coordination of the ST with ground-based astronomy is important because its efficient use will make heavy demands on the best ground-based astronomical facilities. Work on the ground will be needed to detect and pre-screen objects worthy of the limited amount of ST observing time. Correlative and theoretical interpretive studies of many of the objects are essential, as well as continuity in data analysis.

Because of its power and versatility, its long life (up to 20 years has been estimated), and its possibilities for refurbishment and periodic replacement of instrumentation, the ST goes far beyond its antecedents. No one can predict what new kinds of objects, what new concepts, what new enigmas it will yield, nor what particular combination of ground-based observations and ST observations may yield them. Astronomers not yet born may provide its crowning discoveries.

For all these reasons, we are led to the belief that the ST must not be used by only a few astronomers, or by some special segment of the astronomical community, but a large part of that community must be closely involved with the instrument over a long period of time.

It is the experience at ground-based observatories that a major telescope requires some permanent scientific staff dedicated to its use. Indeed, a permanent central staff has been found to be essential to the scientific productivity of complex facilities in all fields of science. The staff scientists, using the telescope regularly in pursuit of their individual projects, are highly motivated to see to it that the telescope and its auxiliary instruments are well maintained and properly operated, and that its focal-plane instruments, such as cameras and spectrographs, are as powerful and efficient as technology will allow. In the case of the national observatories, which are largely dedicated to use by guest investigators from other institutions, the same principle has been found to apply. A small, dedicated staff is required if the telescope is to be operated effectively for and by a large community of outside users. This same staff serves to help guest investigators utilize the observatory effectively. In the case of the ST, one can expect that almost all the astronomical groups in the country (and in the world) will wish to participate in its use; in this respect it will function like one of the national ground-based observatories. This is the basis of the need for a small, central staff which will use the ST for its own research, and which will assist the community as a whole in its use.

Considerations such as these lead us to the conviction that the goal of maximizing the flow of new knowledge from the ST will be better achieved if responsibility for the scientific use of the instrument is placed in an independent entity having a permanent scientific staff that interacts with the NASA operational organization. This report is devoted to examining the functions of and proposing a form for that entity, which we call the Space Telescope Science Institute.

General Objectives and Characteristics of the Space Telescope Science Institute

Some of the qualities that the STSI should have to help it attain the primary scientific goals include:

It should be able to attract the necessary complement of scientists needed to develop scientific priorities. It should provide a focal point for encouraging the participation of the astronomical community.

The staff and visiting scientists should work in an atmosphere as free as possible from organizational restrictions. Their activities should focus on the pursuit of scientific knowledge.

It should promote widespread familiarity with the nature and potentialities of the ST and the data it yields, and encourage collaborative efforts in using this resource.

It should possess a degree of stability that will permit it to undertake and complete organized programs of research over the long expected life of the ST.

Could the goals of the ST be reached without a special institute having these characteristics? One cannot, of course, prove that the answer is no. But such factors as the breadth and independence of the astronomical community, the wide range of applicability of ST data, the complexity of the telescope, and the digital form and large volume of ST output data which require special equipment for their reduction, make us believe that the ST would fall short of its potentials if the essential qualities given above were absent.

We gave serious consideration to the cost effectiveness of an institute compared with the cost of achieving the scientific goals of the ST program by means of an *ad hoc* arrangement within NASA. Our conclusions are based in part on the experience of national laboratories and national observatories where operation by an independent consortium of universities (or by a single university) provides a management structure that is representative of and responsive to a broad base within the scientific community. Although the cost effectiveness of the Institute will depend on many different factors, it is our judgment that the institute approach is the one most likely to provide an optimal scientific return for a given dollar investment in the ST program.

Relation of the Space Telescope Science Institute to the National Space Astronomy Program

Many important problems in astronomy require observations in all parts of the spectrum. For example, the nuclei of active galaxies contain concentrated sources of visible light, x-rays, γ-rays, infrared radiation, and radio waves. Progress in understanding the nature of the energy source in these nuclei requires more sensitive and precise observations at all wavelengths. Also, mysterious x-ray sources have been located apparently at the centers of compact globular clusters. These examples are only a few of many that illustrate the interdependence of all the subdisciplines of contemporary astronomy. It is clear, therefore, that the observing programs and the scientific results of the ST will have an important effect on other activities in astronomy, particularly on activities such as x-ray and certain infrared observations which can be conducted only from space.

When and if major x-ray and infrared observatories are placed in orbit, we anticipate increased interactions among the various components of space astronomy. However, in the time available to us, we have not been able to address the question of whether the STSI should include these other sub-disciplines. Institutional arrangements for the scientific direction of other major facilities for space astronomy should be considered in the near future. If the STSI proves useful in meeting the needs of the scientific community, it might serve as a model for future arrangements, or even include these additional activities. At present, we regard as premature any conclusions as to whether STSI should include the other subdisciplines.

II FUNCTIONS TO BE SERVED BY THE SPACE TELESCOPE SCIENCE INSTITUTE

Before considering such questions as how the STSI should be organized and managed, or where it should be located, we examined in some detail the functions to be served by the Institute and the relation of these functions to those carried out by appropriate elements of NASA. To this end we reviewed: the projected ST specifications, the organization of the ST Project within NASA and the various interactions which must take place efficiently, and the recent experiences in operations and data analysis of existing space astronomy projects.

We have identified the functions which we feel are the proper responsibilities of an effective space telescope institute and which, if well executed, will assure a high degree of scientific productivity.

1) The Institute should have the principal responsibility for planning the scientific program of the observatory and for specifying the control commands required to carry out the program.

2) The Institute, through the activities of scientists and engineers on its staff, should be informed about all developments in the ST project which may significantly change the scientific capabilities of the ST relative to the baseline specifications, and should participate to the greatest possible extent in tradeoff decisions and design modifications during the development of the ST and its subsequent refurbishment.

3) The Institute should receive all the preprocessed scientific and engineering data necessary for monitoring the ST performance and planning the operations. It should have the capability to process all such data.

4) The Institute should aim to achieve vigorous and scientifically productive participation by visiting scientists, and should aim to accomplish first-rate research by members of its own staff.

An institute based on these principles would be a strong one which could carry out the functions now performed by a single principal investigator and his group in smaller projects with guest observer programs, such as the Small Astronomy Satellites and Orbiting Astronomical Observatories. Indeed, the experience gained in these earlier successful space astronomy projects has provided a firm basis for identifying the functions of the STSI.

There are two classes of functions to be served: those relating to the scientific objectives, and those relating to the operational aspects of the ST.

A. SCIENTIFIC FUNCTIONS

1. Plan and Manage the Scientific Program

1.1 *Establish science policy governing STSI activities*

The Institute, in consultation with NASA, should be responsible for establishing the policies that govern the participation of the scientific community in the operation of the ST, and for the analysis and dissemination of data. It should advise NASA on the formation of policies governing the mission operations and the development and refurbishment of instruments.

1.2 *Perform long-term planning*

The Institute should define the broad scientific goals toward which the observing program will be directed, and specify the objectives for development and upgrading of the data system and instrumentation to carry out the long-term plan.

1.3 *Develop the observing program*

The Institute should solicit observing proposals from the scientific community, provide technical information and advice to potential users, and evaluate the scientific merits and engineering feasibility of the proposals, the former by an appropriate version of disinterested peer review. The Institute should establish a roster of accepted and priority-rated proposals that will be scheduled for telescope time, with due regard to seasonal, orbital, and other operational factors.

1.4 *Evaluate the scientific productivity of ST*

The Institute should maintain a current record of the status of research programs proposed for and conducted with the ST, and should carry out periodic assessments of the scientific merit and productivity of the ST science program as a basis for internal management decisions of the Institute and program reviews by NASA.

1.5 *Promote correlative research*

The Institute should develop effective working relations with ground-based and other space research activities to assure maximum scientific yield from correlative observations.

1.6 *Inform the public*

The publication of research results should be accomplished through the usual channels; however, the Institute should be a principal channel for disseminating information regarding the progress and operation of the ST and for communicating scientific knowledge derived from the ST to the public.

2. Participate in the Development of the ST

2.1 *Advise the Project Office*

The Institute should advise the NASA ST Project Office in all matters that affect the scientific performance of the ST. In order to perform this function, scientists and engineers of the Institute should acquire an intimate knowledge of all relevant technical aspects of the ST project.

2.2 *Develop the data system*

The Institute should be responsible for planning the hardware and software systems required to process and analyze the ST data emerging from the acquisition and preprocessing operations at GSFC. The Institute should develop, incorporate, or procure the required systems in a cost effective manner, employing existing capabilities where appropriate.

2.3 *Develop scientific control capability*

In preparation for performing its central function of planning and carrying out the scientific program of the ST, the Institute should develop the capability to determine the technical feasibility of proposed observations and to prepare the sequence of control commands to execute the observing program. To perform this function, the Institute should be aware of the engineering and operational considerations that significantly constrain the maneuvers of the ST and should have timely access to all the relevant data.

2.4 *Develop ST capabilities after launch*

Once the telescope is launched, the system is expected to undergo substantial change and evolution. Failures will have to be circumvented, safety requirements may be modified, and unexpected capabilities may be discovered. In order to accommodate to these unpredictable developments, the Institute should maintain close working relationships with the technical personnel responsible for the engineering performance and operation of the ST, and should develop in collaboration with them various contingency procedures that could facilitate rapid adjustment to such developments.

2.5 *Develop instrumentation for possible refurbishment missions*

In order to attract experimental scientists and engineers of the highest caliber to the Institute, it is our judgment that they should have the opportunity to spend a portion of their time in the development of advanced instrumentation relevant to space astronomy. The Institute should encourage such efforts and provide laboratory facilities of a size and quality comparable to those of active university groups.

3. Involve the Scientific Community

The Institute should involve the scientific community in a vigorous program in astrophysics and planetary sciences through the performance by the Institute of various service functions.

3.1 *Assist visiting observers*

The Institute should facilitate the use of the ST by visiting scientists, both at the Institute itself and at their home institutions. In particular, the Institute should assure ready access to all relevant information about the ST and about the data and control systems. Also, it should maintain library, catalogue, and data archive facilities, and provide visiting observers with appropriate reproduction services.

3.2 *Train users*

The Institute should train participating astronomers who are new to the ST project. Permanent staff members should set aside time to instruct newcomers in the use of instruments in the spacecraft and the use of software for the interpretation of data.

3.3 *Disseminate the data*

ST pictures resulting from the observing programs will contain a wealth of information, only a portion of which will be of direct interest to the original investigators. The remainder will form a growing reservoir of data which will be useful for other research programs. The Institute should catalogue and disseminate these data, and assist scientists outside the Institute in finding the material relevant to their studies.

3.4 *Coordinate computer hardware procurement and software development among users*

Compatibility of the data systems of the Institute and those of users is very important. This compatibility should be achieved by establishing and maintaining standard programming procedures and data formats that permit orderly growth of a common data system, and by incorporating new programs developed either in the Institute or by outside users.

3.5 *Facilitate international participation*

With respect to international participation, the Institute should be guided by the following observation of the Ramsey Report* of 1966: "Astronomy has traditionally been a field that excites the imagination and interest of a wide variety of inquiring minds, and one in which there is a long history of fruitful international cooperation. The nature of the orbiting observatory is such that participation in the scientific use and program observations could form an interesting and natural basis for international cooperation and for providing a powerful and constant reminder of the genuine interest of the United States in learning how to engage in helpful international cooperation."

International participation should be an essential part of the Institute's objectives. To this end, the Institute should be structured so as to ensure that access to data from the ST project is freely available to all qualified investigators. All Institute posts should be open to international recruitment to the extent permitted by U.S. law. The allocation of observing time should be made by a single observing-time assignment committee; where international

*NASA Ad Hoc Science Advisory Committee Report to the Administrator, 15 August 1966.

arrangements are made on an inter-governmental basis, the committee should include non-U.S. representation.

We note that discussions between NASA and the European Space Agency on an agreement covering participation in the ST project with cost-sharing are well advanced. We feel that this is a good development, but should not be regarded as limiting future increased participation.

4. Conduct Basic Research

In order to attract and hold a senior staff of the highest quality, the Institute should provide facilities and time for their individual research. Equal division of their time between the service functions of the Institute and their own research activities seems appropriate.

B. OPERATIONAL FUNCTIONS

We call operational those functions that are required to operate the ST, and to acquire and process the data. We identify five phases in the lifetime of the ST and describe the operational functions associated with each one.

1. Prelaunch: Support the Test and Calibration Activities

During the prelaunch phase, the STSI should develop the capability for carrying out the scientific program of the ST. It should verify the operational readiness of the data system and control procedures by simulation tests that culminate, well before the scheduled launch, in successful operational simulations. The initial instruments and the principal investigators who will supervise their construction and early use will have been selected before the Institute can be started. However, as soon as possible, staff members of the STSI should become thoroughly acquainted with the operation and performance of all the instruments through close association with the principal investigator groups and participation in the prelaunch tests and calibrations. The STSI should prepare manuals to assist observers in planning their observational programs, prepare tables of instrument parameters, and coordinate data system development between the STSI and the user community.

2. Launch: Support Ground Checkout

During the launch operation, while the ST is loaded aboard the Shuttle and is undergoing final tests, the STSI should verify the performance of the data system, supporting the principal investigators with the necessary data for evaluating their instruments' performance, and certify the scientific readiness of the ST for launch.

3. Shuttle Operation: Support Orbital Checkout

Once the Shuttle is in orbit, the ST will be readied for free-flight operation before it is released and the Shuttle returns to Earth. At this stage, the system will be tested by performing actual astronomical observations. In support of this phase, the STSI should specify the astronomical test program, evaluate the test results, recommend corrective action if needed, and certify release readiness.

4. Orbital Operation: Carry Out the Scientific Program

The decision as to what functions are to be performed by the STSI during the orbital operations is of fundamental importance to the scientific success and the cost effectiveness of the project. This decision is also a major determinant of the size and cost of the Institute. Since all operational functions must be performed somewhere, the exact location of the functional interface between the activities carried inside and outside of the Institute need not greatly affect the total effort required to accomplish them. On the other hand, some choices might require the installation of costly data links and excessive duplication of existing facilities.

With these considerations in mind we identified the functional requirements (shown in Figure 1), relevant data rates, and computational tasks. Data are acquired in the ST at the rate of about 10^9 bits per day and at appropriate times are sent to GSFC via relay satellites and high-capacity land lines. At GSFC, the image data receive standard preprocessing and correction, using highly specialized facilities, and is then recorded on high-density tape. Copies of all such tapes could be delivered to the Institute. The average bit rate of the ST data needed for monitoring the observations and controlling the telescope will be only of the order of 10^4 bps, and conventional telephone data lines are adequate to transmit them. Hence, we concluded that there are no compelling data-management and transmission-cost considerations involved in deciding exactly where, after the preprocessing function, the functional interface is placed. However, it is the output of this preprocessing function which marks the boundary between the conventional data manipulations that are common to all space experiments and the ones that will be essentially unique to the ST. Similarly, in the control functions, the input to the command message generator is the point of division between conventional and unique manipulations required for control of the spacecraft. Past experience in the OAO and SAS projects has demonstrated that the standard functions of control and data acquisition are performed with high reliability and efficiency by GSFC, but that timely and efficient development of software unique to a given project can be best assured if it is carried out under the direct supervision of the experimenters. Thus we conclude that all data handling after preprocessing could be carried out by the Institute or the users except for certain routine image-correction operations that may be accomplished more economically with the existing capabilities of GSFC. The Institute should also be responsible for all scientific control functions up to the point of generation of the command messages, although a substantial portion of these functions may actually be performed by Institute staff in residence at the Mission Operations Center at GSFC.

With the interfaces defined as above, the operational functions of the Institute during orbital observations may be summarized as follows:

4.1 *Plan observations*

a) Evaluate operational implications and requirements of observing proposals

The evaluation of the technical feasibility and operational requirements of each proposal can be accomplished best by the people who are responsible for detailed planning of the approved observations. These people should be members of the Institute and should have within the Institute the resources necessary to accomplish these tasks.

b) Plan and schedule approved observations

The roster of observations approved by the Program Committee must be planned in detail and scheduled with due regard to seasonal, orbital, and engineering constraints. The product of this function will be a continuous sequence of control commands. These will be transmitted to the Mission Operations Center (at GSFC) for verification and melding with the routine engineering commands that will be loaded by MOC into the ST delayed-command system.

c) Prepare finding charts and astrometric and other data to support the observations

The ST will have to be adjusted in real or near real time during the observations in order to acquire faint targets and optimize the instrument settings on the basis of quick-look data analysis. In some instances the necessary data on nearby guide stars, photometric sequences, etc. will not be available from previous observations. The Institute should be responsible for obtaining these data and providing them to the users. (See Appendix II.)

d) Plan coordinated ground-based and other satellite observations

Some ST research programs, particularly those concerned with objects that show rapid time variations in widely different parts of the spectrum, will be dependent for their success on obtaining simultaneous observations with ground-based infrared, optical, and radio telescopes, and satellite-borne x-ray and infrared telescopes. Recognizing the higher cost of ST observations relative to those of some other instruments, the Institute should encourage such correlative observations.

4.2 *Perform observations*

a) Maintain constant working communication with MOC

The Institute should establish an office that maintains continuous communication with the MOC.

b) Monitor quick-look scientific and engineering indicators

Decisions on real-time control of ongoing observations will require knowl-

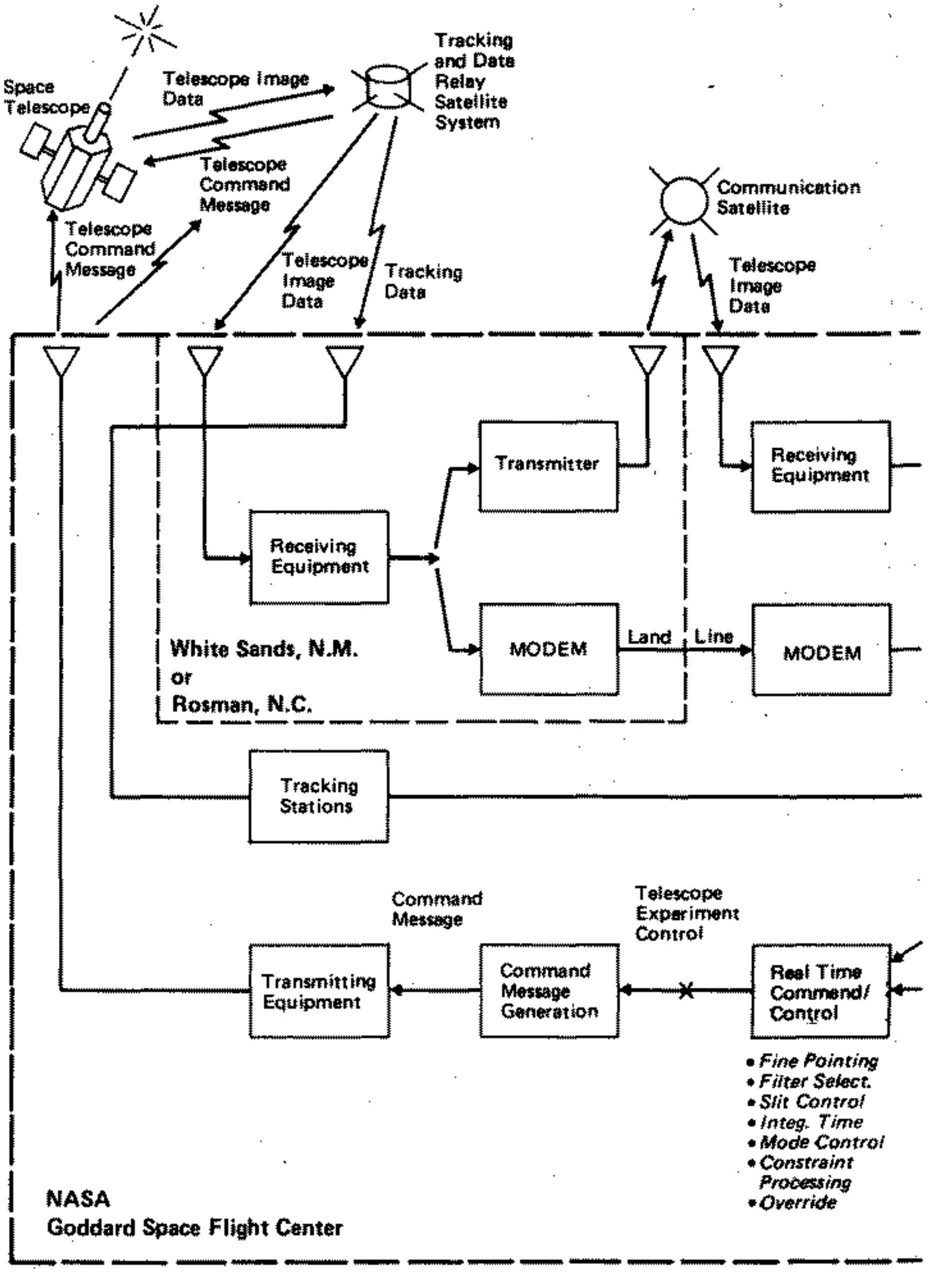
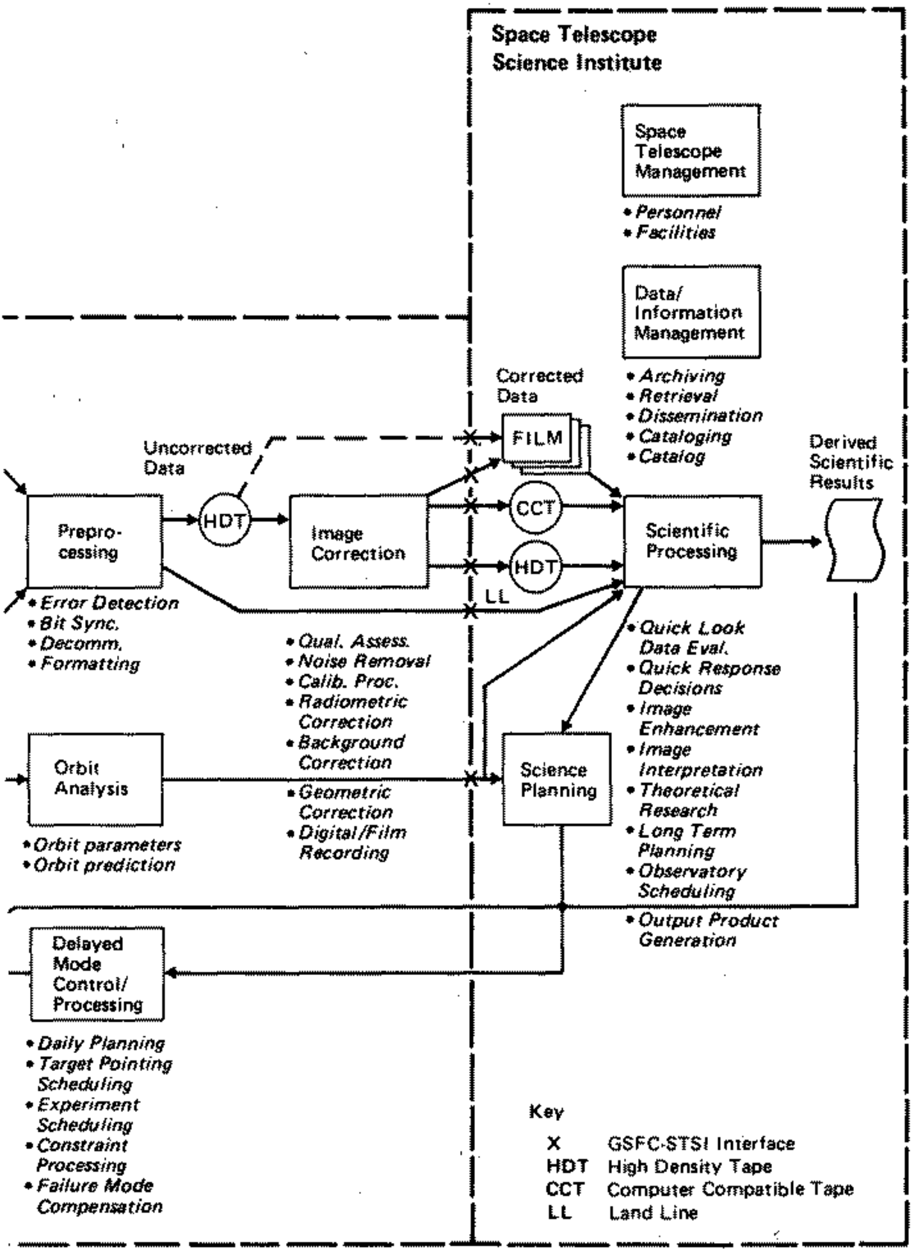


FIGURE 1 Space Telescope Functional Requirements and Allocations



Space Telescope
Science Institute
Space Telescope Management
• Personnel
• Facilities
Data/ Information Management
• Archiving
• Retrieval
• Dissemination
• Cataloging
• Catalog
Corrected Data
FILM
Uncorrected Data
HDT
CCT
Derived Scientific Results
Prepro-cessing
Image Correction
Scientific Processing
LL
• Error Detection
• Bit Sync.
• Decomm.
• Formatting
• Qual. Assess.
• Noise Removal
• Calib. Proc.
• Radiometric Correction
• Background Correction
• Geometric Correction
• Digital/Film Recording
• Quick Look Data Eval.
• Quick Response Decisions
• Image Enhancement
• Image Interpretation
• Theoretical Research
• Long Term Planning
• Observatory Scheduling
• Output Product Generation
Orbit Analysis
• Orbit parameters
• Orbit prediction
Science Planning
Delayed Mode Control/ Processing
• Daily Planning
• Target Pointing Scheduling
• Experiment Scheduling
• Constraint Processing
• Failure Mode Compensation
Key
X GSFC-STSI Interface
HDT High Density Tape
CCT Computer Compatible Tape
LL Land Line

edge of relevant engineering parameters. These data will be stripped out of the quick-look data stream and displayed for ready access by observers and operations controllers.

c) Modify observing plan as required

Unexpected results and discoveries will make it desirable to modify the observing plan in real time. For example, if a supernova is detected in an early stage in a distant galaxy, it may be desirable to interrupt the current observation and slue the ST to observe the supernova in order to measure its spectral distribution at peak luminosity. The Institute should develop a capability for quickly planning the modified observations and preparing the modified command sequence.

d) Coordinate with ground-based observatories

Communication should be maintained with ground-based observatories and other space projects to coordinate simultaneous correlative observations.

4.3 *Process data*

a) Perform analysis of data

All the preprocessed data and the output of the GSFC image-correction process should be sent via high-density tape to the STSI.

The Institute should carry out some additional processing of the data so as to produce rectified images of archival quality at an average rate at least as great as the rate of raw picture data accumulation.

b) Maintain status records of data processing

The magnitude and variety of the data-acquisition and data-processing tasks require a high degree of organization in data management if the program is to achieve the desired level of scientific productivity. The Institute should maintain adequate current-status records of the data processing in order to determine the proper allocation of resources and be in a position to inform observers about the status of their programs.

c) Archive and disseminate data

The Institute should establish and maintain a library of all preprocessed data and all output of standard production processing. In addition, results of individual research programs appropriate to archival storage should be catalogued and placed in the library for general access by the community.

d) Support analysis and dissemination of data

Most observations will require processing with specialized programs that can be run on the Institute or remote computers. The Institute should support these analyses through maintenance and updating of an ST software system, and by providing adequate facilities in the form of stand-alone or time-shared computers. The ultimate product of the ST is published results; the Institute should support the preparation of publications.

4.4 *Monitor engineering status and performance of the ST*

a) The Institute should maintain a current summary, based on quick-look data, of the engineering status and performance parameters of the ST for use by those concerned with planning and executing observations.

b) The Institute should work with the MOC and Project Office to establish and facilitate contingency procedures that can be quickly employed in cases of spacecraft emergencies or failures.

5. Refurbishment: Define Refurbishment Objectives

The Institute should evaluate the effectiveness of the ST instrumentation and monitor its performance with the aim of tracking its degradation and failure history. It should carry out periodic assessments of technologies pertinent to upgrading of ST performance. On the basis of this information, the Institute should prepare the objectives for possible refurbishment missions. At the same time, the Institute should bring the needs and possibilities for upgrading ST technology to the attention of NASA and industry, and encourage development of the relevant technologies.

III STRUCTURE OF AN INSTITUTION TO PERFORM THESE FUNCTIONS

In Section II we have described the functions that an Institute should carry out if a significant and productive program is to result from the Space Telescope. In our deliberations we considered several types of organizations that might carry out those functions. All these organizations had in common the need to recruit and enlist the cooperation of astronomers, on the one hand, and, on the other, the necessity of working intimately with the Missions Operation Center and various other elements of NASA. We have considered such possibilities as: a simple elaboration of the procedures which have been used with previous astronomical spacecraft, the establishment of an ST science organization at the Goddard Space Flight Center, possibly reporting directly to NASA headquarters, and various extra-NASA organizations with varying degrees of autonomy.

We conclude that a scientific program can be conducted successfully with a variety of institutional arrangements. However, experience with national laboratories and national observatories has shown that operation by an independent consortium of universities can offer a management structure that is efficient, cost effective, and responsive to the scientific community. We concluded that this type of organization could work in concert with NASA and would be more effective in maximizing the scientific return from the Space Telescope.

The following sections outline what we consider to be the more important features of a consortium-operated Space Telescope Science Institute.

A. CORPORATE STRUCTURE

1. The Consortium

The consortium is envisioned as a group of universities (and other nonprofit organizations, if appropriate) that would manage the Institute under a contract with NASA. Such a contract would provide the primary funding for the Institute; but we would encourage supplemental funding by other public agencies, such as the National Science Foundation, or by private means. Membership in the consortium should be open to institutions carrying on active research programs in astronomy and related sciences; it should not be limited to U.S. participants, since we expect substantial international participation in the development and use of the telescope. The consortium could be developed from an existing consortium, or from a combination of existing consortia, or it could be newly structured for the purpose at hand. Since the number of member institutions may be large, the policy-making and oversight responsibilities for the Institute should reside in a Board of Trustees of manageable size; in our view, approximately ten members would be suitable.

The stature and independence of the Board of Trustees will be a critical element in determining the success of the Institute. Board members should be chosen collectively by member institutions for their personal qualifications and not as representatives of those institutions or of groups of institutions. Board members should include astronomers, other scientists, administrators, and public members in order to provide a broad-based group competent to the task of oversight of the Institute. The Board may include non-U.S. members. While we are not able to specify the qualifications for membership in detail, experience with other organizations suggests that the success of the Institute and its ability to maintain reasonable autonomy will depend to a considerable extent on the degree to which the Board will command the respect of the member institutions, the sponsoring organizations, and the public, and will represent the Institute to its many constituencies.

Terms of service on the Board should be fixed at three to five years, once renewable, and staggered for uniformity of turnover. The Board should meet often enough to assure satisfactory guidance of and assistance to the Institute, and should report periodically to the consortium.

2. The Institute

The management structure of the Institute should be such as to facilitate the attainment of its goals and objectives, and to fulfill the essential functions described in Section II. Among the key elements in the managerial structure we identify the office of the Director, the scientific staff, and advisory committees to the Director.

2.1 *The Director*

The Board should designate, after consultation with NASA, a Director of the Institute. The nominee should be an outstanding scientist; the Director may influence the course of space astronomy for many years. The Director should serve at the pleasure of the Board. Among the Director's duties and functions are:

a) To propose to the Board appointments of the senior scientific staff, and inform the Board of the appointment of junior staff.

b) To recommend to the Board a continuing strategy of scientific priorities for space and related ground-based astronomy, including appropriate budgetary information.

c) To arrange for the establishment of committees, comprised of staff and community scientists, to perform various tasks required of or by the Institute. The major committees are identified below.

d) To identify, with NASA concurrence, a senior member of his staff (for example, a deputy director) whose chief responsibility is to provide the prime interface between the Institute and the ST Project at NASA.

e) To provide, perhaps by the appointment of associate directors for technical and administrative services, for necessary technical services such as engineering, shop and computer support to the scientists at the Institute, and administrative services such as personnel, budget, safety, property control, housing, and the like.

2.2 *Scientific Staff*

The resident scientific staff of the Institute should consist of about ten qualified persons of superior professional stature. The professional interests of the staff should encompass a broad range of current optical and infrared astronomical research, including theoretical studies. In the interest of assuring an excellent scientific program for the ST, the staff should strive to promote a feeling of common interest between the ST project and the astronomical community. This function can be carried out by emphasizing joint appointments, a program for visiting scientists, and an outreach program that involves outside scientists with Institute responsibilities while at their home bases.

The committee considered one possible means of accomplishing this goal, called the "extended staff." This should be considered, among others, for achieving the goal of maximum interaction with the astronomical community. The extended staff is discussed below.

Staff members, through their roles as principal investigators on experiments, as ST users, or as participants in related ground-based programs, would provide the scientific guidance, the NASA operational interface, and other essential functions of the Institute. At any given time, the scientific interface needed at the Mission Operations Center would be provided by staff members and their colleagues who are designated by the Director to serve in that role.

The extended staff would be a second component of staff members whose time and salary would be shared by the STSI and their home institutions. Members of the extended staff would have responsibilities assigned to them by the Director and would share in the privileges of resident staff. Extended-staff members could be located at any of the institutions which in some way use the ST or its data; these staff members, appointed by the Director on the basis of their capabilities and their potential for contributions to STSI, might serve for terms of one to five years.

This extended-staff function goes considerably beyond the traditional "visiting scientist" position and requires negotiations between the home institution of the member and the Institute to define details, for example, of relative responsibilities to the two institutions. The extended-staff concept involves a number of questions to which answers should evolve as experience is acquired. We suggest that the extended staff be inaugurated with about two appointments at an early date and grow gradually to about ten members over a period of five years. We feel that the extended staff would fulfill the following important needs:

a) An extended staff would increase the scientific breadth and capability of the Institute at relatively little proportionate cost.

b) It would spread out the "service function" obligations incumbent upon the staff and make these more easily fulfillable.

c) The extended staff, through its close association with ST experiments and operations, would carry to the astronomical community the information, data, and excitement of the Space Telescope, and stimulate from that community the correlative investigations needed to maximize the scientific output of the ST.

d) Among the duties of an extended-staff member would be that of interfacing with non-Institute staff at his own institution, e.g., in helping his colleagues learn to use ST data. This role will generate wider ST data use, encourage new ideas for ST observation, and lead to new ground-based research programs related to ST capabilities.

3. Advisory Committees

The identification of major scientific opportunities and the establishment of priorities for their realization are crucial functions of the Institute. The key to effective implementation of these functions is involvement of the members of the scientific community who will use ST facilities. Peer group review of proposals is the key to an observational program that will command the support and enthusiasm of the scientific community.

3.1 *Users Committee*

The user community should be encouraged to organize itself into a Users Group and should have direct access to the Director of the Institute. This access should be through a Steering Committee of the Users Group, elected by the users, which would advise the Director on matters of policy, procedure, and long-range facility planning.

3.2 *A Program Advisory Committee* is the key element in reviewing and evaluating proposals for observing programs. It might consist of about 12 members, with the Director acting as a non-voting chairman. At least 60 percent of the members should be chosen by the Director from nominations provided by the Users Steering Committee. The PAC should include one or more non-U.S. representatives and some astronomers who are not current users of the ST. The term of office should be three years.

3.3 *A Visiting Committee* should be composed of eminent members of the scientific community, and should provide to the Board and to NASA a yearly review of the scientific quality and productivity of the Institute.

4. Access to the LST

Access to the LST should be on the strength of written proposals, evaluated on the basis of the value and feasibility of the research program and the competence of the investigator. Proposals should be evaluated by the Program Advisory Committee.

We believe in the principle of selecting observing proposals and allocating time according to scientific merit. Therefore, at least after the initial phase, proposals for observing time from Institute members should follow the procedure outlined above. Since we regard a top-caliber staff as a primary requirement of the Institute, we suggest that a specific portion of the ST time be allocated to the resident staff during the initial two or three years of operation. During this period the Director should be responsible for allocating staff observing time.

5. Need for Multifaceted Interactions

The Institute structure should encourage participation by other elements of the astronomical community and should avoid unnecessary centralization. The Institute needs to be a focal point of planning, creative effort, data handling, and astronomical research. It should provide a strong interface between the astronomical community and NASA and its Centers. But it should not dominate future experiments on the ST or receive a disproportionate share of the observing time.

An early and close coordination of the STSI with ground-based astronomy is important because efficient use of the ST will make heavy demands on existing ground-based astronomical facilities. Work will be needed to detect and pre-screen objects worthy of the limited amount of ST observing time in addition to the astrometric support required for the selection of guide stars.

6. Concept of an Endowed Core for the Space Telescope Institute

In addressing the problems of the Institute in attracting first-rate staff and engaging the support of the scientific community, we have considered the concept of an endowed core to add stability and flexibility to the long-term funding of the Institute.

The operation of the Space Telescope should be funded primarily through NASA. In addition, NSF could fund various research projects as appropriate. However, a demonstration of a financial commitment by non-government sources would have a beneficial effect on the evolution of the Institute and might increase the willingness of capable scientists to commit their careers to it. We believe this concept represents a worthwhile goal for the consortium.

The consortium might consider a policy involving a financial commitment by the member institutions, which would consist of (1) a membership fee; such a contribution would demonstrate that the consortium members have a real interest in the success of the Institute, and (2) annual dues; recurring contributions would assure that the interest of the members is continuing.

In addition, since we believe that the ST and the STSI, if adopted, will be in operation for a long time, we recommend that efforts be made to seek endowment funds from individuals and foundations. The income from such an endowment would provide long-term stability for the Institute and its key staff members. Although efforts to interest prospective donors could begin immediately, the major effort, we believe, will have to come after the Institute is in existence, and the nature of the need can be set forth more explicitly. The funds resulting from these sources would increase long-term stability, assist in staff recruitment, and provide flexible operating funds and seed money.

B. INSTITUTE STAFF AND FACILITIES

1. Staff

During the limited time available for this study, we have attempted to identify the staff positions that are necessary to carry out the functions described in Section II above. A description of each staff position is contained in Appendix II. Our estimate of the total staff required, as a function of years before launch, presently anticipated in 1983, is shown in Table 1. For the staff at launch time, we have identified 89 specific positions, but the actual requirement may be somewhat greater.

The appointment policy should be such as to attract and retain a staff of the highest caliber. It should be competitive with the best practices of existing universities and other scientific organizations. If any consortium were to be considered as a manager, its policies should be examined on this point before selection.

2. Start-Up of the Space Telescope Science Institute

Technical plans and studies for the ST have been carried out over the last decade and the initial instruments have been identified. The principal investigators responsible for those instruments will have been selected by NASA before the STSI could be started. Nevertheless, the Institute should be started as soon as practicable and well before launch of the ST in order to provide scientific input to the telescope and instrument design, to provide input to the development of operational hardware and observing routines, to build systems for interpretive data analysis, and to provide the advisory structure by which the Institute can draw on the astronomical community at large. Early formation of the Consortium and the Board of Directors, and early selection of the Director, would ensure a firm and continuing input on behalf of the community throughout the design and development of both the telescope and instruments. Even though this proposal may not be realistic, given the currently anticipated schedule for the project, we recommend that the Director be appointed as early as possible.

The initial principal investigators, the project scientist, and the Institute Director and his staff could assume the role of the scientific working groups appointed by NASA which had the major scientific role in earlier phases of the project. In this way continuity of scientific input would be maintained.

During the first year of the Institute, the staff would be quite small, perhaps ten people, including the Director, his core scientific staff, and administrative assistants. We visualize expansion in two main directions: first, the Institute must be ready with suitable software and hardware to fulfill its responsibilities in telescope operations and in data processing by about one year prior to launch. This is to allow involvement of the Institute in the development of observing and data-handling techniques during the pre-

TABLE 1 Staff Build-Up to Launch Time

				Staff Increment by Year					
			No. at	Years Before Launch					
Category	Type	Qualification	Launch	6	5	4	3	2	1
Director	CS	Ph.D.	1	1	–	–	–	–	–
Principal Investigators	ES/CS	Ph.D.	6	6	–	–	–	–	–
Deputy Director	CS	Ph.D.	1	1	–	–	–	–	–
Core Staff	CS	Ph.D.	5	–	3	2	–	–	–
Extended Staff (in addition to PIs)	ES	Ph.D.	10	–	2	2	2	2	2
Telescope Operators									
Scheduler	SS	B.S.	1	–	–	–	–	–	1
Real Time Terminal Op.	SS	B.S.	4	–	–	–	–	–	4
Instrument Support Scientist	SS	B.S. or Ph.D.	6	–	2	2	2	–	–
Spacecraft Science Coordinator	SS	B.S. or Ph.D.	10	–	–	–	–	5	5
Technical Support									
Target Acquisition	SS	B.S.	2	–	–	–	–	–	2
Photo Specialist	SS	–	2	–	–	–	–	2	–
Computer Specialists									
Senior Specialists	SS	Ph.D.	2	–	2	–	–	–	–
Program Analysts	SS	Ph.D.	5	–	3	2	–	–	–
Research Assistants	SS	B.S.	3	–	–	–	3	–	–
Operators	SS	–	6	–	–	–	3	3	–
Sr. Engineers	SS	M.S. or Ph.D.	3	–	3	–	–	–	–
Jr. Engineers	SS	B.S.	6	–	3	3	–	–	–
Administration	SS	B.S.	16	4	3	3	3	3	–
TOTAL (Cumulative)			89	12	33	47	60	75	89

(ES = extended staff; CS = core staff; SS = support scientist) launch simulation phase and will require a buildup in the Institute's technical staff approximately three years before launch. The second follows from the requirement that the Institute should be ready to fulfill its role in determining scientific priorities in observing programs by the time of receipt of the first observer proposal.

3. Post-Launch Staff Requirements

We estimate that within a year or two following launch, a staff of about 120 will be required. The major staff increments after launch are anticipated to fall into these categories:

1) An increase in the number of extended staff to perhaps 15. This reflects the expected increase in scientific and data-analysis involvement by the community.

2) An increase in the engineering capabilities of STSI. We believe that an increment will be necessary to enable the STSI staff to compete effectively for some experiment space on ST when instrument refurbishment takes place.

3) A concomitant increase in the number of administrative personnel.

Allowing for needs that we have not foreseen, it seems reasonable to conclude that a staff of about 150 to 200 will represent the continuing staff requirements for the Institute.

4. Facilities

4.1 *Computers*

Three computer functions should be performed at STSI: an operations function for interaction with the Mission Operations Center, providing quick-look scientific data and pointing verification; a scientific function for the analysis and interpretation of scientific data by staff and visitors, and a software-development capability. None of these involve massive or unusual computer facilities.

The *NASA Operations Computer* could be used with suitable terminals at the Institute to provide telemetry and housekeeping information.

The *Scientific Computer* should be sufficiently large and fast to handle the scientific-computing requirements of the Institute staff and to service remote terminals located both within STSI and at other institutions around the country.

The *Terminals* are seen as having stand-alone mini-computers attached to them and as capable of processing and displaying ST images read from tapes or transmitted over telephone lines from the Institute's scientific computer. The terminals would have sufficient computing power to permit relatively simple algorithms to be used in processing image data, to correct the data if necessary, and to produce hard-copy records of the results.

The *Software Development Computer,* a computer with a picture-display terminal, should be provided in order to support the long-term software-development program of the staff. In the post-launch phase, we envision the scientific computer as dedicated primarily to the analysis of data received from the ST. Little time may be available for software developments involving new analytical techniques, given the expected load on the scientific computer. By providing an adequate software-development capability, we hope to allow for development of techniques for creative analysis of unexpected phenomena.

4.2 *Laboratory and Shop Equipment*

The Institute's shops should be large enough in the post-launch era to enable the scientific and engineering staff to participate in the design of new ST instrumentation.

Photographic equipment should be available to convert digital data arrays to film images, to copy plotting data, and to enable comparisons between ground-based and ST images.

4.3 *Ground-Based Telescope Support*

In addition to the many ground-based extensions of ST research, there is one area of ground-based observation that is crucial for support of the ST—namely, the determination of accurate positions for guide stars. The Palomar Observatory Sky Survey, and its southern counterpart the ESO-SRC Sky Atlas, will provide material for the determination of stellar positions to approximately the 20th magnitude. Auxiliary photographic material must be obtained for fainter objects, and in many cases even for the brighter stars. Observing time on northern and southern hemisphere 1.5 to 2.0 meter telescopes is necessary. Adequate measuring machines, microdensitometers, and reduction equipment are needed at the Institute to provide this service function (see Appendix III).

4.4 *Archives*

An archive for ST data should be provided, including machine accessible image data, relevant astronomical data, support information on telescope position and temperature, calibration data, and relevant engineering data. In addition, film and plate storage should be accommodated.

4.5 *Library*

Institute members should have ready access to a physics and astronomy library comparable to that available at a major university with an active astronomy department.

4.6 *Buildings*

To house the personnel and equipment of the Institute, buildings or a building will be required that includes space for offices, laboratories, shops, meeting rooms, a library, a telescope display-control room, rooms for seminars and conferences, and administrative and maintenance services.

C. INTERACTIONS WITH NASA

At the management and operational levels, the ST will involve complex interaction among several entities including the Science Institute, the astronomical community at universities and observatories, and a large, complex government agency (NASA) operating through several centers, headquarters, and a variety of industrial contractors. The differences in size, form, function, and work habits of these various elements requires that careful attention be given to the interaction among them. Because of the enormous complexity of the scientific and engineering problems involved, a close liaison must be maintained among the NASA Headquarters, NASA centers, engineering groups, contractors, and scientists in the Institute.

We show in Figure 2 a schematic representation of major interfaces between the proposed STSI and the principal elements of NASA. At the operational level, STSI would interact with MOC on the crucial data-transfer functions, and with the ST project on matters such as instrument development and data processing. The extended nature of the STSI operations is shown schematically by a series of remote stations (perhaps 10 to 15 eventually), one of which might, for example, be located at GSFC.

In order to illustrate the variety of interfaces within NASA, a slightly more detailed but still schematic diagram (Figure 3) shows the lines of communication between NASA Headquarters, NASA Field Centers, the STSI, and the astronomical community as they might exist. The Office of Space Science (OSS) has overall responsibility for the ST and would provide the funding for the STSI. The Office of Tracking and Data Acquisition (OTDA) has management responsibility for NASA's tracking and data-acquisition activities, and provides support for the ST project. Marshall Space Flight Center has been assigned as the project-management center for the ST, while Goddard Space Flight Center is responsible for instrument-development and mission operations. As proposed here for the ST project, the interface between NASA and the astronomical community would be through the Institute.

In addition to this general description of NASA/STSI relationships, we identify four particular areas of strong interaction between the STSI and the NASA organization:

a) in the flow of ST science and supporting data from GSFC to the STSI and the reverse flow of operational instructions from STSI to GSFC;

b) in the development of hardware and software for the ST;

c) in the determination of scientific priorities; and

d) in STSI contract negotiations.

(a) The flow of data between the Mission Operations Center at GSFC and the STSI is central to the science objectives of the ST project and will involve extensive interaction between operating personnel in NASA and scientists and engineers in the Institute.

(b) In the development of hardware and software for the ST, the Institute will develop relationships with the Project Office elements of both MSFC and GSFC and, as necessary, with the Program Office in the Office of Space Science.

(c) The determination of scientific priorities involves a complex relationship with the NASA organization in which the STSI should play a central role. In essence, NASA should look to the Institute as its primary source of scientific information and advice on the ST.

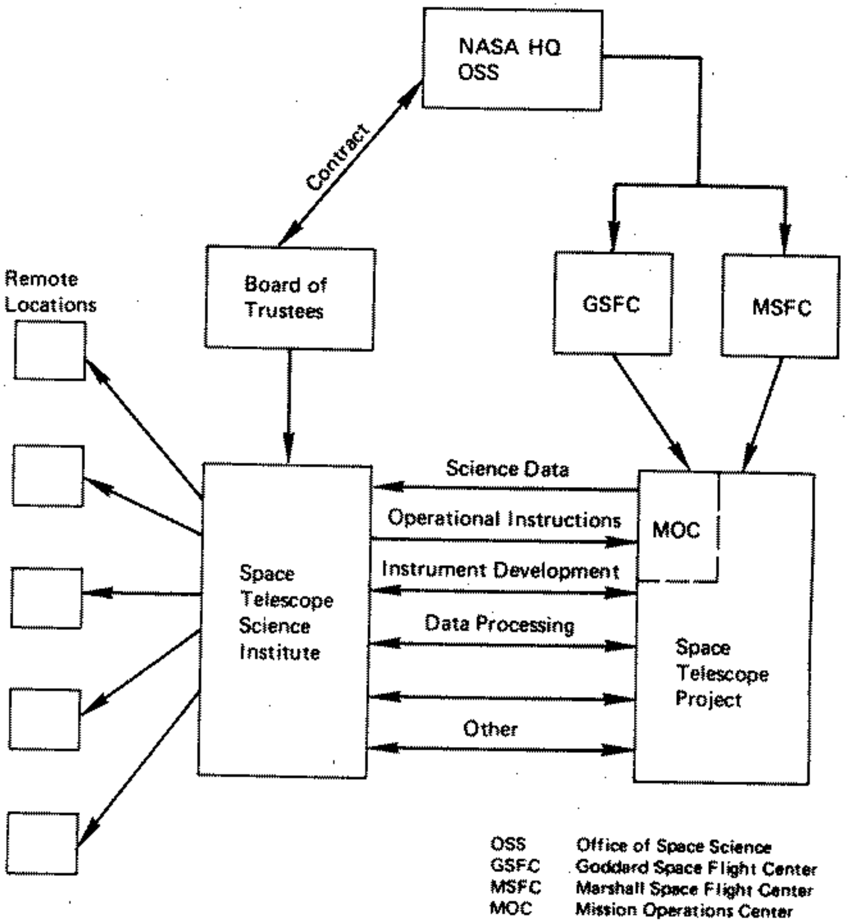


FIGURE 2 NASA-STSI Interfaces

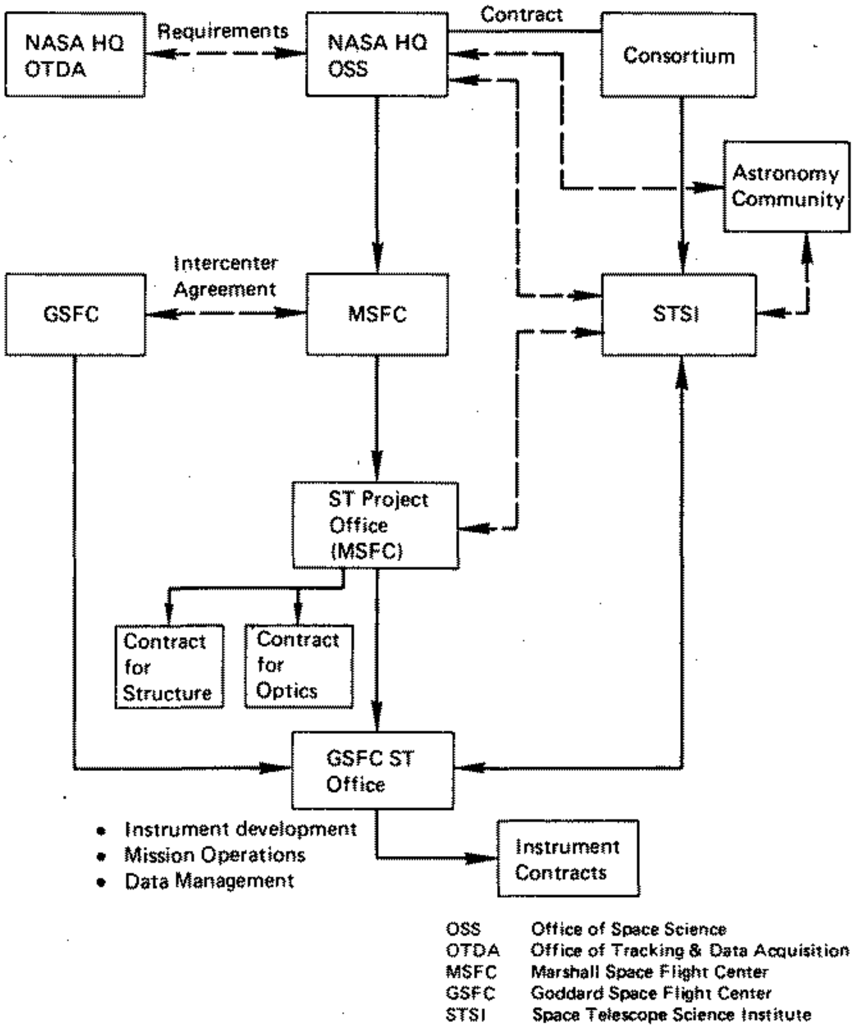


FIGURE 3 NASA Interfaces in Space Telescope Management

(d) Contract negotiations would be conducted between NASA and the Consortium, acting for the Institute, but the Institute Director should participate actively in these negotiations.

D. CRITERIA FOR THE LOCATION OF THE INSTITUTE

We considered the factors that should carry greatest weight in deciding upon the location of the STSI. These factors fall into several categories—those involving an environment conducive to innovative work, those relating to facilities to accomplish the goals of the Institute, and those often put forward as significant factors in site criteria but which we felt were less important.

Among the main social and environmental factors that we felt would attract scientists to the STSI are:

1) a stimulating intellectual and cultural atmosphere;

2) minimal constraints, consistent with adequate accountability for the expenditures of federal funds and an orderly operation;

3) proximity and accessibility to an active and diverse astronomical center of excellence;

4) insulation when required from the daily operational demands of the ST, and other routine duties;

5) a satisfactory environment for families, especially young families and families on leave from home institutions; and

6) the availability of family housing at an affordable price and good schools.

It was judged that the physical factors of primary importance contributing to the selection of a site are:

1) proximity to a major international airport;

2) easy access to a good astronomical library;

3) easy and direct access to technical and administrative support; and

4) availability of a building and land for initial housing of the STSI.

We consider the following factors as less important to site selection:

1) direct proximity to the Mission Operations Center; we envisioned the assignment of high-level Institute staff to interface with ST operations at GSFC;

2) co-location of STSI with either the Project Office at MSFC or the Instrument Program group at GSFC. The complex interactions with MSFC, GSFC, and other NASA activities will, of course, require careful attention. However, co-location of the entire staff was not regarded as essential; and

3) a large in-house computer for extensive theoretical or data-reduction calculations. It was assumed that access to a large computer can be arranged either by telephone link to a large multi-user computer network or by institutional arrangement with a nearby computer center.

We did not identify any compelling technical, managerial, or cost factors that would dictate location at any specific site. We believe that liaison with engineering and operations functions at GSFC can be implemented by co-location of Institute and GSFC specialists, and by appropriate interaction of the Institute staff as the situation requires. Previous experience with astronomy satellite operations has shown that the needs for personal contact between the investigators and the Mission Operations Center and Project Management Office can be met by frequent one-day visits. It would be a great convenience if the location of the Institute were such as to permit personnel to commute to GSFC within a single day, most of which can be spent at GSFC.

The location of the Institute within GSFC, but administered independently of NASA, was considered by the study group. We feel that the scientific productivity of the ST would be enhanced if the Institute were located elsewhere. Embedding the Institute in a very large organization whose goals are not primarily astronomical research might well result in distractions that would prevent the Institute from carrying out its tasks with maximum effectiveness. In our judgment the leading astronomers who would be candidates for the Institute staff would very likely be much easier to recruit were the Institute not located at GSFC.

APPENDIX I
TERMS OF REFERENCE

The study shall report on the general principles applicable to those ground-based facilities that may be needed to provide the interface between large space observatories and the scientific user community internal to and external to NASA, including relevant communities outside the United States. The study will be directed primarily toward consideration of the ST, but within a context that can accommodate other space observatories.

The detailed description of the ST program will be required from NASA to form the basic reference material for the study. This should include: the design of the ST and its instruments, the plan for scientific management during the construction phase, the approach to the construction of instruments (i.e., principal investigator vs. consortium), the operational plan for the first five years, if available.

The study should review:

1) Plans for the ST and its instrumentation.

2) The operation of space observatories already flown, about to be flown, or planned.

3) Relevant features of the operation of ground-based telescope facilities KPNO, CTIO, NRAO, ESO, Hale, etc.

4) Questions of international participation.

5) Transmission and handling of data in ground-based radio observatories, Atmospheric Explorers and planetary missions as relevant to the ST.

6) NASA documentation relevant to the ST institute.

7) Practices for data storage and retrieval.

The study should consider the following points:

1) The need for an ST institute.

2) The scientific policy and management of a proposed institute.

3) The appropriate structure under whose auspices an institute will operate.

4) The composition, size, and responsibilities of a policy board, if appropriate, of prominent scientists, drawn from a wide spectrum of interest in astronomy, space science, and space policy, which will be responsible for

ensuring that the Institute's performance is directed in the interests of its scientific mission.

5) The relationship of a policy board to NASA and other federal funding agencies.

6) The assignment of responsibility for future instrument research, design, and development.

7) The point at which the participation and/or financial responsibility of NASA in the ST project should cease: After raw data have been gathered? After preliminary reduction of data? After final reduction of the data? When the research is completed?

8) Implications of the above considerations with respect to the size of the institution, facilities and the number of personnel at the scientific interface as a function of time. The study should consider both minimum and desirable levels in each category.

9) The duties of the scientific staff. Should the scientific staff have a service function only or should they also participate in scientific research? What should be the service functions and what considerations should determine the fraction of the staff scientist's time to be allocated to these functions?

10) Considerations that govern the location of the ST institute. The study shall examine existing NASA centers among other possibilities.

11) Considerations that govern the corporate management of the ST Institute.

12) Access to the ST by the astronomical community. Consideration should be given to methods by which priority is assigned to various experiments and by which the needs of the user community are communicated to the ST management.

13) Data storage, organization, and dissemination.

14) In-house facilities necessary to support the ST program.

15) The extent to which the corporate structure would facilitate international scientific participation in the use of the ST and would function under conditions of either national or international financing.

16) The questions that may arise from projected ST lifetimes of five, 10, 15 and 20 years, including the relationship of ST to the national astronomy program.

APPENDIX II
STAFF DUTIES

In Section IIIB we outlined our estimate of the staff required to carry out the functions of the Institute. A brief description of staff positions follows:

Director. The Director should be a scientist of international standing in the community. He is directly responsible to the Board of Trustees for the scientific health of the Institute. He works with NASA officials and represents to NASA the views of the astronomical community regarding ST. He is responsible for recruiting all staff and recommending to the Board the appointment of scientific staff. He encourages the involvement of the astronomical community in the ST activities. He devises appropriate mechanisms for seeking the advice of the scientific community and for ensuring an open, democratic operation of STSI. He is responsible for operating the Institute within an approved budget and for preparing proposals for future funding.

Deputy Director. The Deputy Director (or another senior staff member) would be appointed by the Director after consultation with NASA to assume the important role of coordination between the Institute and the NASA Project Offices at both Marshall and Goddard Space Flight Centers, and to perform other duties as specified by the Director.

Core Scientific Staff. The core scientific staff would be research scientists in residence at the STSI, some of whom, after open competition, would be selected to carry out their own research with the ST. Also, they would assume typical STSI duties such as: development of new instruments, guidance of software development for reduction and analyses of the ST data, guidance of the outside (user) community in operation of the ST, coordination with ground-based observatories, and pursuit of theoretical research related to ST programs.

Extended Staff. The extended staff would be research scientists associated with universities or other research institutions and not always in residence at STSI. They would be appointed by the Director for specified terms and part of their salary would be paid by STSI. Extended-staff members would carry out their own research with the ST and would perform definite service functions for STSI and the astronomical community similar to those performed by the core staff.

Principal Investigators. The current development of the ST project envisages early selection of teams headed by principal investigators to develop the initial instrument packages for the ST. The principal investigator group should be intimately involved with STSI operations in the pre-launch and immediately post-launch period. We expect that some members of the principal investigator teams would be extended staff members of the Institute.

Telescope Operator-Scheduler. From scientific priorities developed by the Program Advisory Committee, the scheduler would develop a long-term schedule, melding these priorities with spacecraft operational requirements. He would submit a long-term operating schedule to the PAC for review; upon approval he would then forward the schedule to STSI representatives at MOC for integration into the daily planning.

Real-Time Terminal Operators. They would operate remote viewing consoles at STSI so that astronomers may identify targets and adjust instrumentation on a real-time basis.

Instrument-Support Scientists. These specialists would be fully aware of the capabilities and possibilities of each instrument package on the ST. They would work with the core staff and with the outside user community to devise optimum operational modes for instrument use. Some of these individuals might be recruited from the principal investigator groups as the mission profile changes from a development to an operations phase.

Spacecraft Science Coordinators. These would be representatives of STSI at the MOC. They would be responsible for daily mission planning.

Target-Acquisition Specialists. Their duties would be to provide accurate coordinate measurements from photographic plates and ST data for target acquisition.

Photo Specialists. These would be technical support people hired to operate photolab and measuring equipment.

Senior Computer Specialists. One of these specialists would act to coordinate software development at STSI, among the extended staff, and at GSFC. The other senior specialist would be specifically responsible for interfacing STSI software with GSFC computers and operations; he should be based initially at GSFC. These specialists should be conscious of the need for wide dissemination of software developments among the community of users and the desirability of promoting the evolution of standard computing languages, formats, and basic reduction procedures.

Program Analysts. They would develop data-analysis techniques and picture-processing algorithms with a view toward developing a package of standard reduction program modules that would form the basis for extension to more specialized data-reduction programs.

Computer Research Assistants. They would work with senior computer specialists to facilitate coordination with the user community and GSFC. They would also work with ST users visiting STSI to introduce them to the computer software available at STSI. They would also be responsible for program documentation.

Computer Operators. These operators would assist in operation of the scientific computer and in preparation of hard-copy output.

Senior Engineers—Optical, Electronic, and Mechanical. They would form the nucleus of an engineering staff which, in the post-launch era, will build up to a strength suitable for the design of one or more ST instrument packages to replace the initial instruments. In the pre-launch phase, these engineers would provide in-house engineering expertise to permit the STSI staff to have expert input to the priority decisions during the telescope and instrument design phase. They would work with the Deputy Director to develop STSI engineering input to the ST project.

Junior Engineers. This category would be divided among optical, electronic, and mechanical engineers who would assist senior engineers in the performance of their functions.

Administrative Services. These positions include the Senior Administrator and staffing for the budget, accounting, and personnel offices, the library and building support services, and a public information office.

APPENDIX III
GROUND-BASED OBSERVATIONS REQUIRED FOR ST OPERATION

The need for ground-based observations to complement the ST arises from two sources: the technical aspects of the ST pointing and acquisition system, and the variety of scientific problems that the ST will assist in addressing.

Position Determinations

As currently defined, the ST can point within a reference frame defined by bright guide stars to an accuracy of ± 0.3 arc sec rms. Although this accuracy is adequate for many types of observations, numerous problems of spectroscopy and photometry demand the use of entrance "slits" comparable in size (0.2 arc sec) to the stellar images; here the nominal pointing accuracy is insufficient.

While there are methods for acquiring and holding a stellar image to the required accuracy, the positions of faint objects will have to be known with respect to a reasonably bright nearby object to a precision of ± 0.1 arc sec.

Guide star coordinates for the telescope will be obtained by measuring the positions of the object and suitable guide stars on the Palomar Observatory Sky Survey (POSS) and its Southern Hemisphere counterpart with respect to a star catalogue such as the SAO catalogue. For objects too faint to be visible on the sky surveys, photographs must be taken (if they do not already exist) on a large ground-based telescope (for magnitudes brighter than 23) or on the ST f/24 camera (for magnitudes fainter than 23). Astrometric measurements are then made to relate the coordinates on the new plate to the sky survey and subsequently to the SAO positions. If a positional accuracy of greater than ± 0.3 arc sec is required, then special-purpose astrometric photographs must be obtained and the object's coordinates measured relative to the guide stars or a nearby bright star.

Complementary Observations

In addition to the need to provide ground-based observations to determine accurate positions of objects for study with the ST, valuable complementarity can be expected between activities of the space telescope and those of ground-based telescopes. Therefore, the scientific impact of the ST will be greatly enhanced by the establishment of operational links with ground-based observatories.

We can expect that discoveries on the ground will lead to major changes in the scientific priorities governing the operation of ST. For example, the accidental discovery of a near-by nova will probably lead to frenetic activity on the ST. The reverse will also be the case: discoveries with the ST could lead to many observing programs on the ground that will be aimed at extending the wavelength range and time scale of the observation and the spectral resolution. Special-purpose instrumentation or instrumentation too complex to incorporate in the ST may be employed. Surveys for special types of objects that might be discovered by ST will be conducted with wide-field instruments on the ground in order to increase the sample of such objects so that well-known methods of astronomical statistics can be introduced. Refurbishment of ST instrumentation will benefit from the application of new detectors and instruments to large ground-based telescopes prior to use in the ST.

Several examples exist that demonstrate the utility of a firm link between a spacecraft mission and ground-based telescopes. The 107-inch telescope at the University of Texas and the Arecibo radar facility have provided information fundamental to the execution of Mariner missions to Mars and Venus. The construction of a NASA infrared telescope on Mauna Kea, Hawaii, is partially justified by its potential in complementing the scientific return from the Mariner-Jupiter/Saturn mission. The McGraw-Hill Observatory of the University of Michigan was established at Kitt Peak, in part, to provide correlative observations of x-ray sources discovered by spacecraft. Therefore, it is our opinion that the Space Telescope Science Institute should be responsible for developing firm links with ground-based observatories and should establish operational agreements for the use of their facilities.